Universidade do Minho
Escola de Engenharia

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Sustainable Infrastructure Development – Definition of Criteria and Quantification of Indicators for Water and Wastewater Systems in Douro and Trás-os-Montes

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Dissertação de Mestrado em Engenharia Civil
Área de Especialização Engenharia Municipal

Trabalho efectuado sob a orientação da
Professora Doutora Júlia Maria Brandão Barbosa Lourenço

Junho de 2008

DEDICATION

I dedicate this dissertation to my husband, Doctor Anthony “T” Steven Danko. Thank you for your genuine love, support and understanding. Thank you for sharing your own dissertation-writing experiences and commiserating with me. Thank you for allowing me to skip dinner, sleep and for picking up the slack when I wasn’t around to do it. And above all, thank you, thank you, thank you for making me laugh hard every day since we first met...

“I have seen the top of the mountain. And it is good.”

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the support and encouragement of Professor Júlia Maria Brandão Barbosa Lourenço, under whose insightful suggestions and enthusiastic supervision I had the pleasure of working.

I would also like to thank the following individuals, whose assistance was much appreciated:

Professor Rui António Rodrigues Ramos, for literature suggestions and reading orientation,

Mr. Ricardo Bento, doctoral candidate at the University of Trás-os-Montes e Alto Douro, for sharing data,

Mr. Nuno Quental, doctoral candidate at the Instituto Superior Técnico, whose time, suggestions and assistance were instrumental for the completion of this work, and

Miss Carina Picas, senior student at University of Minho, for double-checking and formatting references and abbreviations.

Also to Nuno and Carina, I would like to express my sincerest gratitude for their camaraderie, bouts of laughter and free ice-cream.

This dissertation was partially funded by *Fundação para a Ciência e Tecnologia* (Foundation for Science and Technology), under Project POCTI/ECM/49495/2002.

ABSTRACT

The work presented herein describes the process and results of the application of a methodology based on multi-criteria analysis techniques designed to evaluate and rank a series of municipalities in terms of their urban water and wastewater systems and addressing the issue of sustainable infrastructure development.

The selected area comprising eight neighbouring municipalities within Douro and Alto Trás-os-Montes is characterised by complex morphological and climate conditions that have historically hindered the region's development by past absence of adequate accessibilities. Despite recent and significant investment and ensuing infrastructure improvements, the area continues to struggle with declining population dynamics, aging, moderate to high unemployment rates, and an overall more reticent economical development, particularly when compared to that of the more affluent coastal areas. The land is occupied mainly by rural and forestry uses, hence urbanised areas are few and scattered. Since the land is sparsely populated, it is difficult to reach by comprehensive systems of urban water and wastewater service, and thus, accessibility to minimum service levels is not homogeneous throughout the area.

A multi-criteria evaluation procedure was developed using a series of case-defined indicators and applying available analytical methodologies for data processing. Two analytical scenarios were proposed and two data normalisation methods were used. Sets of scores were calculated for each analytical option, revealing that the top and bottom scorers were consistently the same, regardless of initial assumption scenario or data normalisation model. A sensitivity analysis was conducted to verify the robustness of the ranking order, while testing some variations to the sustainable development model. The consistency of the results suggests that the series of selected indicators was well-designed and robust.

Though based on existing approaches focused on similar subjects, the methodology developed herein was original and involved the definition of case-specific indicators and decisions regarding analytical options that can be potentially applied to similar case studies.

Keywords: Multicriteria Analysis; Water and Wastewater infrastructure; Douro; Alto Trás-os-Montes.

RESUMO

A dissertação apresentada a descreve o processo e resultados obtidos no âmbito da aplicação de uma metodologia baseada em técnicas de análise multi-critério, concebida para avaliar e ordenar um conjunto de concelhos quanto aos seus sistemas de água e saneamento, tendo em conta a problemática da infra-estruturação sustentável.

A área seleccionada inclui uma área do Douro e Alto Trás-os-Montes englobando oito concelhos. É caracterizada por uma morfologia complexa e condições climáticas que têm vindo, historicamente, a dificultar o desenvolvimento da região pela carência de acessibilidades adequadas. Apesar das melhorias infra-estruturais derivadas de investimentos recentes e significativos, a área continua a debater-se com populações em progressivo declínio, envelhecimento, taxas de desemprego moderadas a altas e um desenvolvimento económico ainda incipiente, sobretudo quando comparado com as áreas costeiras, tipicamente mais desenvolvidas. O solo encontra-se ocupado maioritariamente por usos rurais e florestais, pelo que as áreas urbanizadas são de pequena dimensão. A distância entre os aglomerados populacionais dificulta, assim, a implementação de sistemas de água e saneamento abrangentes e portanto, os níveis mínimos de serviço não são uniformes ao longo da área em estudo.

O procedimento de avaliação multi-critério foi desenvolvido através da utilização de indicadores específicos e da aplicação de alguns métodos de processamento dos dados. Dois cenários de avaliação foram propostos, bem como dois métodos de normalização de dados. Para cada opção analítica calculou-se uma série de *scores*, revelando que tanto os valores mais elevados como os mais reduzidos eram consistentemente obtidos para dois concelhos, Vila Real e Peso da Régua, independentemente da hipótese inicial ou método de normalização. Uma análise de sensibilidade foi levada a cabo com o intuito de verificar a robustez do *ranking*, através do teste de algumas variações ao modelo geral de desenvolvimento sustentável. O grau de semelhança entre os resultados sugere que a lista de indicadores é adequada.

Apesar de baseada em abordagens existentes para objectos semelhantes, a metodologia desenvolvida no contexto desta dissertação é original, decorrendo da definição de indicadores específicos e da tomada de decisões quanto aos métodos a adoptar, podendo vir a ser aplicada a outros casos semelhantes.

Palavras-Chave: Análise Multi-Critério, Infra-estrutura de Água e Saneamento, Douro, Alto Trás-os-Montes.

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

Abbreviations and Acronyms

AHP: Analytic Hierarchy Process

ALJ: Alijó

ATMAD: Águas de Trás-os-Montes e Alto Douro (Waters of Trás-os-Montes and Alto Douro)

B: Benefit

BL: Balanced

BOD_5: 5-day Biochemical Oxygen Demand

C: Cost

CCDRN: Comissão de Coordenação e Desenvolvimento Regional do Norte (Regional Coordination and Development Commission of Norte)

CI: Consistency Index

CM: Câmara Municipal (City Hall)

CNPGB: Comissão Nacional Portuguesa das Grandes Barragens (Portuguese National Comission on Large Dams)

COD: Chemical Oxygen Demand

CR: Consistency Ratio

CST: Colective Septic System

DGEG: Direcção Geral de Energia e Geologia (General Department of Energy and Geology)

DL: Decreto Lei (Law Decree)

DO: Dissolved Oxygen

EC: European Commission

ECo: European Council

ECON: Economic

EEA: European Environmental Agency (Agência Europeia do Ambiente)

EEC: European Economic Community (Comunidade Económica Europeia)

EIO: Economic Input-Output

EMARVR: Empresa Municipal de Água e Resíduos de Vila Real, E.M. (Water and Waste Municipal Entreprise of Vila Real)

ENDS 2015: Estratégia Nacional de Desenvolvimento Sustentável (National Strategy for Sustainable Development)

ENV: Environmental

EU SDS: European Union Sustainable Development Strategy

EU: European Union

GDP: Gross Domestic Product

GVA: Gross Value Added

GWP: Global-Warming Potential

ID: Identification

IEFP: Instituto do Emprego e Formação Profissional (Employment and Professional Training Institute)

IGEO: Instituto Geográfico Português (Portuguese Geographic Institute)

INAG: Instituto da Água (Water Institute)

INE: Instituto Nacional de Estatística (Statistics Portugal[1])

Inhab.: inhabitant

INSAAR: Inventário Nacional de Sistemas de Abastecimento de Água e de Águas Residuais (Water Supply and Wastewater Systems National Inventory)

IP: Itinerário Principal (Main Itinerary)

IRAAR: Instituto Regulador de Águas e Resíduos (Regulating Institute for Water and Waste)

IRAR: Instituto Regulador de Águas e Resíduos (Regulating Institute of Waters and Wastes)

LCA: Life-Cycle Assessment

LST: Linear Scale Transformations

MAOTDR: Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional (Ministry of the Environment, Territory Planning and Regional Development)

MAS: Multi-Agent Simulation

MCA: Multi-Criteria Analysis

MF: Mesão Frio

MU: Murça

n.a.: Not available

NCE: Non-compliance event

No.: Number

NUT: Nomenclatura de Unidade Territorial (Nomenclature of Territorial Unit)

NUTS: Nomenclature of Territorial Units for Statistics

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[1] Official designation

OWA: Ordered Weighted Average

PDM: Plano Director Municipal (Municipal Land-Use Plan)

PDR: Peso da Régua

PEAASAR 2007-2013: Plano Estratégico de Abastecimento de Água e de Saneamento de Águas Residuais (Strategic Plan for Water Supply and Wastewater Collection and Treatment)

PIENDS: Plano de Implementação da ENDS (Implementation Plan of ENDS)

PM: Particulate Material

PMOT: Planos Municipais do Ordenamento do Território (Municipal Spatial and Land-Use Plans)

PNPG: Parque Nacional da Peneda-Gerês (Peneda-Gerês National Park)

PNPOT: Programa Nacional da Política de Ordenamento do Território

PRN: Plano Rodoviário Nacional (Nacional Road Plan)

PROT-N: Plano Regional do Ordenamento do Território (Regional Plan of Territorial Management)

QCA: Quadro Comunitário de Apoio (Community Support Framework)

RCM: Resolução de Conselho de Ministros (Council of Ministers' Resolution)

RI: Random Index

S: Social

SAB: Sabrosa

SMP: Santa Marta de Penaguião

SNIRH: Sistema Nacional de Informação dos Recursos Hídricos (National Information System on Water Resources)

SR: Score Range

TSP: Total Suspended Particulate matter

TSS: Total Suspended Solids

UDTC: (EU Council of Ministers for) Urban Development and Territorial Cohesion

UF: Utility Functions

UKEA: United Kingdom's Environment Agency

UN: United Nations

VF: Value Functions

VOC: Volatile Organic Compounds

VPA: Vila Pouca de Aguiar

VR: Vila Real

WCED: World Commission on Environmental and Development

WEST: Water-Energy Sustainability Tool

WHO: World Health Organization

WTP: Water Treatment Plant

WWTP: Wastewater Treatment Plant

LIST OF SYMBOLS

Cd: Cadmium

CO_2: Carbon dioxide

Cu: Copper

H: Hydrogen

Hg: Mercury

NOx: Nitrogen oxides

O_2: Oxygen

Pb: Lead

SO_2: Sulphur dioxide

SOx: Sulphur oxides

1. INTRODUCTION

For the past two years, Europe and Portugal have been equally prolific in their endorsement, adoption and implementation of several strategic plans and programmes concerning environmental protection, social equity and cohesion, economic prosperity, and meeting of international responsibilities, having issued a series of key guidelines for sustainable development.

The work focuses on a particular geographical region characterized by a combination of harsh topographic and weather features that have historically hindered mobility and development of better accessibility conditions, thus rendering the region one of the poorest in Portugal and in Europe. Notwithstanding the impact of decreasing population densities, aging population, high unemployment rates and increasingly shifting climate conditions, this is an area that has seen significant improvements in some fundamental sectors – water and wastewater infrastructure, agricultural productivity, health services, tourism – as a result of specific local planning and regional management programmes.

1.1. Sustainable development within the European Union

In 2001, the European Council (EC) in Götenburg endorsed the first European Union Sustainable Development Strategy (EU SDS). In preparation for the Johannesburg 2002 World Summit on Sustainable Development, the EC in Barcelona addressed external dimensions to integrate global aspects of the SDS, while taking stock of issues such as the seemingly vagueness of concepts regarding sustainable development and intrinsic problems of implementation, that combined with an increasing focus on economic competitiveness and globalisation, had decreased the EU leaders' interest on the issue (EURACTIV, 2005). Up until 2005, implementation of the EU SDS remained a problem as unsustainable trends continued to worsen regarding a variety of contexts such as climate change, energy use, public health, poverty, social and demographic issues, management of natural resources and biodiversity, land use and transportation. In June 2006, the European Council adopted a revised strategy, and released the renewed EU Sustainable Development Strategy. The renewed EU SDS focuses on four sets of key objectives, namely (1) environmental protection; (2) social equity and cohesion; (3) economic prosperity, and (4) meeting of international responsibilities. It calls for “cross-cutting policies contributing to the knowledge society”, under which “research into sustainable development must include short-term decision support projects and long-term visionary concepts and has to tackle problems of a global and regional nature". Additionally, research is to be promoted and carried out via inter- and transdisciplinary approaches that ideally combine social and natural sciences and thus bridge the gap between science, policy-making and implementation. The EU SDS also calls for further development of smart growth-related technologies and addresses the strong need for the intensification of research in the interplay between social, economic and ecological systems, methodologies and instruments for risk analysis and back- and forecasting prevention systems (EU, 2006).

The particular case of sustainable urban policies has been the subject of the 2007 Leipzig Charter on Sustainable European Cities (UDTC, 2007a and 2007b). On its way to redefine the concept of the European City, it incites Member States to pursue common strategies for integrated urban development and to take action against social exclusion. Amongst the Charter's many recommendations, the coordination between local and city-regional levels and the involvement of citizens and other stakeholders are seen as essential implementation-oriented tools towards the drawing up of urban development programmes. Furthermore, these programmes should be supported by assessments of strengths and weaknesses of each city and/or neighbourhood, aiming towards an early coordination of housing, economic, infrastructure and services. The modernization of technical infrastructure networks, particularly those for water supply and wastewater collection and treatment is urged along with early-stage improvements adapted to changing requirements to meet future needs at a high quality level (UDTC, 2007b).

1.2. Sustainable development within Portugal

The Portuguese National Strategy for Sustainable Development for 2015 (ENDS 2015, *Estratégia Nacional de Desenvolvimento Sustentável*) was approved in August 20, 2007 by Resolução de Conselho de Ministros no. 109/2007, along with its corresponding Plan of Implementation (PIENDS, *Plano de Implementação da ENDS 2015*). The strategy focuses on steering the country's development processes according to sustainability guidelines, integrated with existing and/or soon to be available instruments, plans and programmes, including those that concern European funding up until 2013, while vying for the participation of citizens and a variety of economic and social agents (RCM, 2007).

The ENDS 2015 stems from a series of initiatives that began with the 1992 Earth Summit's Agenda 21, calling for all nations to adopt national strategies for sustainable development. Subsequent world meetings held in 1997 – the *United Nations Earth Summit +5* –, in 2002 – the *Johannesburg World Summit* – and in 2005 – the *2005 World Summit* – reinforced the fundamental roles played by national growth policies and strategies towards sustainability, thus confirming the world's intent on committing to sustainable development ideals.

Akin to the EU SDS in objectives and form, the ENDS 2015 aims towards a sustainable growth path capable of turning Portugal into one of the most competitive and attractive countries in the EU, through high levels of economic, social and environmental development and responsibility. Seven fundamental purposes are established, supported by the three traditional pillar-concepts of sustainable development: social cohesion, environmental protection and valorisation and economic development (RCM, 2007). Consequently, the ENDS 2015 is complemented by a series of other strategies, programmes and plans, including the Portuguese Programme of the Policies for Land-Use Planning (PNPOT, *Programa Nacional da Política de Ordenamento do Território*), approved in September 4, 2007, by Law no. 58/2007. This particular programme establishes a series of objectives regarding strategic options encompassing all dimensions of sustainable development, including that of territorial equity in terms of the endowment of infrastructures, namely for water supply and wastewater collection and treatment, and their management from a social co-responsibility standpoint.

Specifically, the PNPOT stipulates the implementation of the Strategic Plan for Water Supply and Wastewater Collection and Treatment (PEAASAR 2007-2013, *Plano Estratégico de Abastecimento de Água e de Saneamento de Águas Residuais*), so that water supply and urban wastewater collection and treatment goals are fulfilled for the generality of the population, at high quality levels, reasonable prices and by way of necessary funding and investment. The PEAASAR 2007-2013 was approved by Despacho n° 2339/2007, of February 14, 2007, following in the steps of its predecessor plan, the PEAASAR 2000-2006, which focused on the structuring of the water supply and the urban wastewater collection and treatment sectors from a social, environmental and economic sustainability standpoint. Having successfully accomplished most of the previous objectives, the 2007-2013 version of the strategy updates the former and focuses on management optimisation and the role of private entrepreneurship. It seeks to minimise systems' inefficiency from a cost rationale perspective, while establishing financing models and guidelines for proficient rate and regulation policies. Three main strategic objectives are defined, namely (1) universal access to, continuity and quality of the services rendered; (2) sustainability of the water and wastewater sector, and (3) environmental protection. The completion of these goals is intrinsically linked to operational objectives, thus defined[1]:

a) To provide approximately 95% of the total Country's population with public systems of water supply;
b) To provide approximately 90% of the total Country's population with public systems of urban wastewater collection and treatment, covering at least 70% of the population for integrated systems;
c) To guarantee the integral recuperation of service costs;
d) To promote the private national and local entrepreneurship; and
e) To fulfil the objectives from national and European regulations for environmental and public health protection.

The Regulating Institute of Waters and Wastes (IRAR, *Instituto Regulador de Águas e Resíduos*) was created by Decreto-Lei n° 230/97, of August 30, 1997, becoming the Country's regulating institute for water quality and sanitation services (including wastewater and solid waste collection and treatment/disposal) as provided by municipal and multimunicipal entities. Its job is to enforce existing and applicable water and sanitation regulations, while striving for reasonable and adequate efficiency/quality/cost relationships in services rendered to consumers (IRAR, 2007). Its mission is clearly guided by sustainability principles, matching the strategic objectives of the PEAASAR 2007-2013.

1.3. Goal and objectives

The work presented herein describes the process and results of the application of a methodology designed to evaluate and rank a series of eight municipalities in terms of their urban water and wastewater systems and addressing the issue of sustainable infrastructure development.

Studying the sustainability level of urban systems is not, by any means, a novel idea. However, it continues to command interest and renewed understanding on the suitability of the analytical options available.

The main goal of this research was to describe how selected locations in northeastern Portugal are faring in terms of their water and wastewater infrastructure systems, in light of a few

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[1] Translated and adapted from Despacho n° 2339/2007 by the author.

sustainable development concepts. Therefore, the assessment of the sustainability status of existing systems took on a central role. It was carried out following a multi-criteria evaluation procedure using a series of case-defined indicators and applying available analytical methodologies for data processing and interpretation. Pursuant to the goal, a list of objectives was developed and is listed below:

a) To review different sustainability assessment approaches and outline primary research challenges;
b) To identify, define, select and quantify a series of case-appropriate indicators and criteria;
c) To carry out a comparative analysis of the target-locations in terms of indicators and criteria and obtain location-specific score; and
d) To rank target-locations in terms of their relative scores.

The selected area comprising eight municipalities within Douro and Alto Trás-os-Montes is characterised by complex morphological and climate conditions that have historically hindered the region's development by past absence of adequate accessibilities. Despite recent and significant investment and ensuing infrastructure improvements, the area continues to struggle with declining population dynamics, aging, moderate to high unemployment rates, and an overall more incipient economical development, particularly when compared to that of the more affluent coastal areas. The land is occupied mainly by rural and forestry uses, hence urbanised areas are few and scattered. Since the land is sparsely populated, it is difficult to reach by comprehensive systems of urban water and wastewater service, and thus, accessibility to minimum service levels is not homogeneous throughout the area.

1.4. Outline

This dissertation is organised in seven chapters, beginning with Chapter 1 – **Introduction** and followed by Chapter 2 – **Sustainability Assessment Models**, offering a general overview of fundamental sustainability concepts and assessment approaches. Chapter 3 – **Strategies for Multi-Criteria Analysis**, is presented next, where specific methodology alternatives are described in terms of concepts and options regarding indicator and criteria selection, data processing and results interpretation. The analytical steps carried out within the context of this work are described in Chapter 4 – **Methodology**, which is followed by Chapter 5 – **Case Study: Selected Municipalities from Douro and Alto Trás-os-Montes**, where the selected target-locations are described according to pertinent characteristics. Results are presented, critically reviewed and discussed in Chapter 6 – **Results and Discussion**. Finally, Chapter 7 – **Conclusions**, outlines and summarises the main points of discussion, presenting a few recommendations for future work. The remaining segments of the work consist of the **References** and **Appendices** sections.

2. SUSTAINABILITY ASSESSMENT MODELS

The concept of sustainability was first introduced in the World Commission on Environment and Development (WCED) *Our Common Future* report (later referred to as the Brundtland Report) in 1987 (Lomborg, 2001). Sustainable development was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987) and moreover, a worldwide purpose and commitment to ensure that the generations to come enjoy levels of affluence and development comparable to those of nowadays (Lomborg, 2001). Achieving sustainable development and ensuring environmental sustainability are key goals for the international community, as a means to ensure human well-being. This requires that the established interrelationships between population, resources, the environment and progress be fully recognized and appropriately managed.

In May 1996, the United Nations Population fund predicted that half the world's population would be living in urban areas by 2006 (Basiago, 1999) and later evidence supported these estimates (UN, 2004). The prospect of improved services, more employment opportunities and better social and economic interactions (Daniell *et al.*, 2005) are indisputable factors of attraction. However, as population density increases, access to services and other factors that promote quality-of-life become threatened by increasing social conflict, unacceptable environmental degradation and the collapse of basic services (Basiago, 1999). As urban areas adapt to accommodate an ever growing number of inhabitants, it is of paramount importance that they do so in an integrated manner that best serves the economic, social and environmental imperatives of each developing community. This "trio" of fundamental imperatives is the conceptual basis upon which sustainability models are founded.

The embracing of the sustainability paradigm offered a new perspective on how to address advancing economic development while protecting environmental systems and enriching the quality of life for this and future generations (WCED, 1987). However, a major difficulty remains: the transformation of the conceptual principles of sustainable development into operational models (Sahely *et al.*, 2005). Sustainability refers to the establishing of balanced and dynamic trade-off relationships between all the intervening components and/or parts of a system, for the duration of its life-cycle. Predictably, the successful operationalisation of such equilibrium remains elusive. According to Basiago (1999), there is a close link between the key elements of sustainability (Figure 2.1).

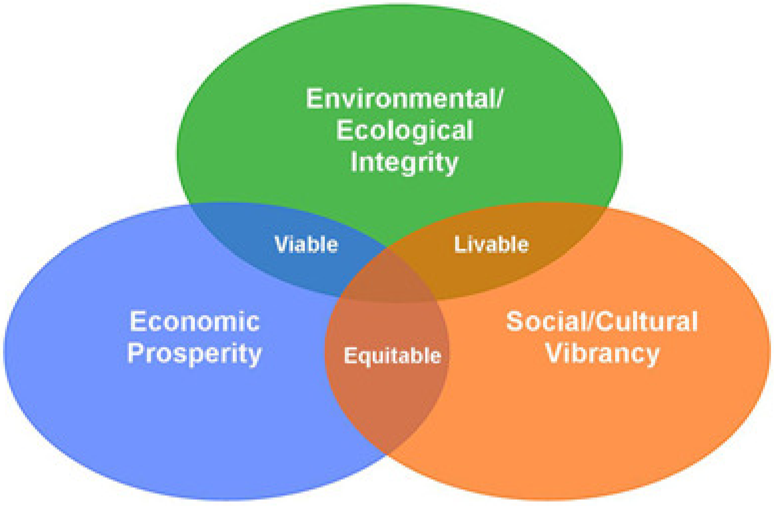

Figure 2.1 – The sustainable development model (Dubuque, 2008)

Social and environmental interaction leads to a liveable development, rendered viable by establishing the appropriate connections between environmental and economic elements. Finally, an equitable society is one where social and economic needs are balanced. The implementation of measures for sustainable social and environmental conditions results in economic sustainability as well. Therefore, planning, management and policy-making should be conducted in such a way as to ensure healthy economic growth, citizen satisfaction and adequate maintenance, development and redevelopment of infrastructure (Daniell *et al.*, 2005).

Sustainable urban development planning and management can be more effective when supported by adequate knowledge of the urban system and its subsystems (Quental *et al.*, 2006). Studying the interactions between them (Fernandes *et al.*, 2006; Lourenço, 2003; Lourenço *et al.*, 2005) provides for a better grasp on how specific planning decisions might impact sustainability issues (Daniell *et al.*, 2005). Infrastructure systems are at the very core of urban sustainability issues. Growing populations require infrastructure that is either developed or rehabilitated (Sahely *et al.*, 2005) to accommodate ever increasing demands, a challenge that prevails in urban centres worldwide and Portugal is no exception. As long as spatial distribution and structure of human activities change and continue to migrate towards urban areas, negative environmental impacts will intensify if the call for urbanization is not carried out according to ideals of sustainability. Therefore and predictably so, a major challenge is the development of practical tools to measure and enhance urban sustainability, particularly those that concern design and management of sustainable infrastructure (Matos *et al.*, 2004; Sahely *et al.*, 2005). Several models that address one or many aspects in the sustainability development spectrum have been put forth. The following section briefly highlights those that have been found most influential and pertinent.

2.1. Sustainability assessment models – an overview

Sustainable development aims at achieving social, economic and environmental equilibrium over spatial and dynamic horizons (Hellström *et al.*, 2000), often spanning decades (Sahely *et al.*, 2005) and taking into account the nature and utilization of renewable and non-renewable resources (Lomborg, 2001). The complexity of the interactions between the three main domains (environmental, social and economic) associated with the myriad of variables and corresponding interactions that characterize them drives the existence of numerous approaches towards modelling of sustainability.

Sustainability is typically seen as a problem of multi-objective optimisation, where several goals are to be attained simultaneously, but no result is supposedly optimal for any of the parameters subject to optimisation. Therefore, trade-offs are required as some objectives may be conflicting (Sahely *et al.*, 2005). Ideally, there would be a simple model for preliminary sustainability assessments that would be applicable to all types of cases and would be easily applied by all. However, that would require a degree of generalisation that at the very least, would compromise the validity of the final result, mirroring Barton's concerns (2004). Consequently, generalisations must be carried out with caution, as each approach can be too case-specific and may not correlate reliably with other situations.

In any case, practical tools for measuring sustainability provide valuable information that is used to assist in decision-making processes. Just as in any other context, decisions regarding urban water and wastewater infrastructure are the result of a combination of factors with varying degrees of importance. There are many tools for appraising sustainability both at local and global scale. These can be classified according to the particular object and/or context of analysis (Ridder, 2005, as cited in Kashem and Hafiz, 2006):

- Physical assessment tools for physical parameters, including life-cycle assessments;
- Monetary assessment tools for financial/economic parameters, including cost-benefit and cost-efficiency analysis;
- Models that use computer modelling, including land use change models;
- Scenario analysis for forecasting potential outcomes;
- Multi-criteria analysis for the comparative analysis of diverse criteria;

- Sustainability appraisal tools that prescribe how it could/should be carried out, including sustainability impact assessment;
- Stakeholder analysis tools that involve public participation, including multi-agent simulation modelling, and
- Tools that support transition management.

Naturally, each category is applied pursuant to particular and specific methodologies and techniques, data requirements and mode of decision-making process (Kashem and Hafiz, 2006).

Several models and integrated assessment techniques have been published and are available for use (Berger *et al.*, 2007; Deakin and Curwell, 2004; Kashem and Halfiz, 2006; Weng and Yang, 2003). They vary in degrees of integration and also in scale, ranging from global level down to regional level (O'Regan *et al.*, 2002) down to single components, such as housing and infrastructure (Daniell *et al.*, 2005). A very brief description of those deemed more significant is presented in the following sections.

2.2. The BEQUEST Framework

The BEQUEST is an international network founded by the European Commission focused on identifying issues concerning sustainable urban development and structuring them in order to provide a framework for analysis (Deakin and Curwell, 2004). The framework is based on the PICABUE model of sustainable urban development that includes four analytical dimensions: (1) ecological integrity or quality of the environment; (2) equity of access to resources; (3) public participation or the ability to influence decisions, and (4) futurity or the future implications of decisions made in the present. Albeit simplified, the model allows for the representation of the breadth and complexities associated with building consensus from a collaborative platform, particularly in matters of integrating common understanding and contributions from a wide variety of stakeholders. The framework also calls for protocols aimed at integrating sustainable urban development elements such as planning, property development, design, construction and operational components, granting decision makers the opportunity to select the mode of assessment capable of better evaluating the level of sustainability of urban development.

Knowing whether urban interventions made today will lead or support more sustainable communities in the future is not the output the model is able to provide, as such an answer is undoubtedly case-specific (Deakin and Curwell, 2004). However, BEQUEST does lay out a frame of reference that can be used by decision-makers to understand the context in which they are working: urban development activities, sustainability issues, spatial level and timescale (Figure 2.2).

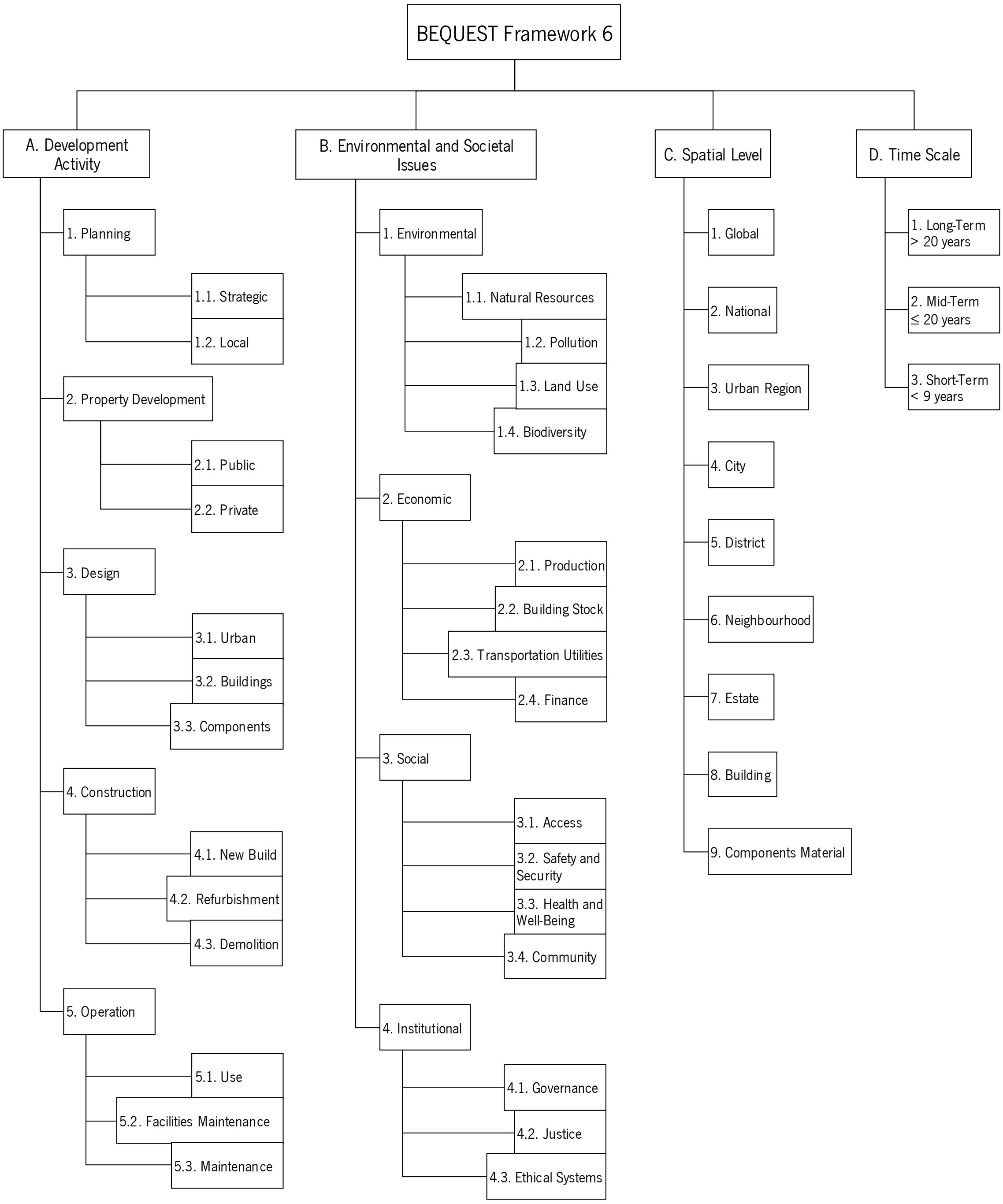

Figure 2.2 – The BEQUEST Framework (Deakin and Curwell, 2004)

This approach enables the representation of urban development as a life-cycle of inter-related activities, where the urban process must agree with sustainable development issues and be framed within spatial and temporal boundaries of analysis.

2.3. Multi-Agent Simulation Modelling

Berger *et al.* (2007) have analysed water uses and users within sub-basins, while trying to simulate the outcome of technological innovation and policy change. A case study from Chile provided the backdrop for demonstrating the potential of the proposed framework, a multi-agent simulation (MAS) model in a multi-stakeholder context. The complexity of the model is derived not only from the different allocations for water resources – and consequently, the variety of water uses – but also from the inherent complexity of addressing the different types of water users. Since the MAS approach can represent social and institutional relations among water users, it brings the phenomenon of collective action[1] into the sphere of the analysis. Therefore, the model can be construed as an important planning tool for the evaluation of different policy scenarios and their implications for different groups of users, before they are even implemented. The model couples aspects of water use as diverse as run-off, crop growth, economic decision and network interaction models at the water user level. It consists of two components, a cellular model that connects biophysical process sub-models contained in a grid-cell structure and an agent-based component that combines socio-economic decision and market models (Figure 2.3).

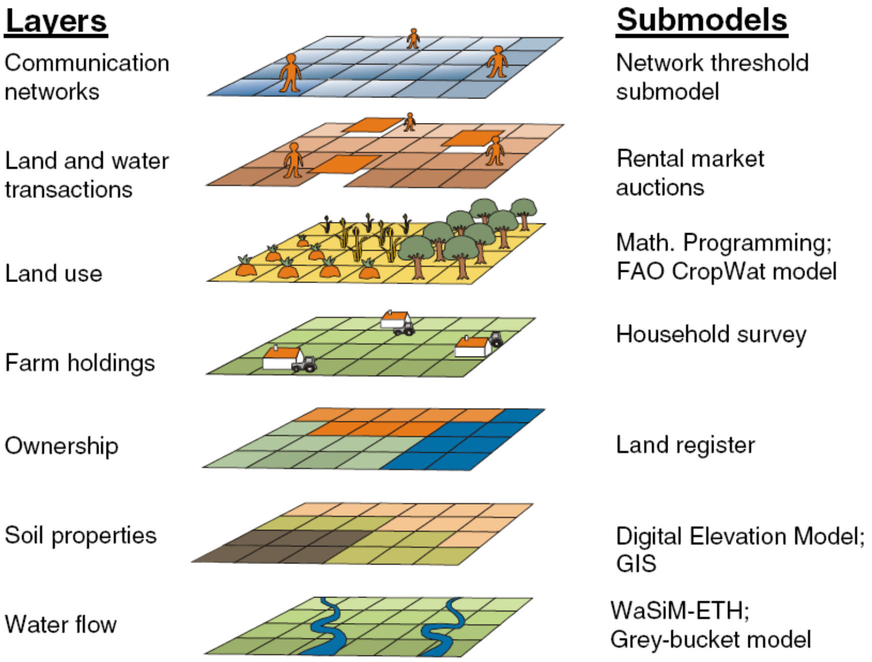

Figure 2.3 – Multi-Agent Simulation model layout (Berger *et al.*, 2007)

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[1] Collective action can be defined as voluntary action taken by a group to achieve common interests. Members can act directly on their own or through an organization (Meinzen-Dick and Di Gregorio, 2004). Collective action is the pursuit of a goal or set of goals by more than one person. In economic theory, collective action is concerned with the provision of public goods and other collective consumption via the collaboration of two or more individuals, and the impact of externalities on group behaviour.

The latter one constitutes the main challenge of this approach, since the biophysical and technical characterization of water uses are already well analysed and studied. The model generates information that can then be condensed in payoff matrices and analysed applying game theory analysis of strategic interactions between agents. The combination of MAS and game theory enables the modelling of the behaviour of the actors intervening in water resources management and their complex interrelations. Several behavioural assumptions are tested and outcomes evaluated using payoff matrices, which provide valuable understanding regarding distribution of incentives and dynamics of collective action problems. Consequently, there is an added opportunity to test how cooperative outcomes may be encouraged by policy instruments. Naturally, this leads to the evaluation of trade-offs between different policies scenarios and hence, the possibility of making better informed decisions.

2.4. Life-Cycle Assessment

The utilization of resources can be analysed from a life-cycle standpoint. Traditionally, life-cycle assessment (LCA) tools have been used to evaluate the environmental impacts related to a product, process or activity, given the inputs used (energy, materials) and outputs released (wastes, emissions) into the manufacturing and carrying out of aforementioned product, process or activity (Gloria, 2006). It is a systematic, quantitative “cradle-to-grave” approach to the environmental implications of design, planning, material extraction and production, manufacturing or construction, use, maintenance stages and end-of-life fate of products (if applicable) (Curran, 1996, cited in Stokes and Horvath, 2006). This systematic analysis can potentially be applied to urban infrastructure development issues, particularly for urban water systems (Lundim *et al.*, 2000), using a combination of economic input-output (EIO) and process-based LCA approaches as defined and developed by Stokes and Horvath (2006). As explained, EIO-LCA is as a matrix-based approach that combines economic input and output data with resource consumption and wastage data, in a methodical effort to characterize product and service supply chains. Process-based LCA includes four main stages: (1) goal and scope definition; (2) inventory analysis; (3) impact analysis, and (4) improvement analysis. Stokes and Horvath (2006) combined both approaches to yield WEST (Water-Energy Sustainability Tool), a decision-support model suitable and deemed necessary for analysing water supply systems, based on input data for parameters concerning the many types of processes/activities relevant to obtaining and supplying water under alternative scenarios. See Figure 2.4.

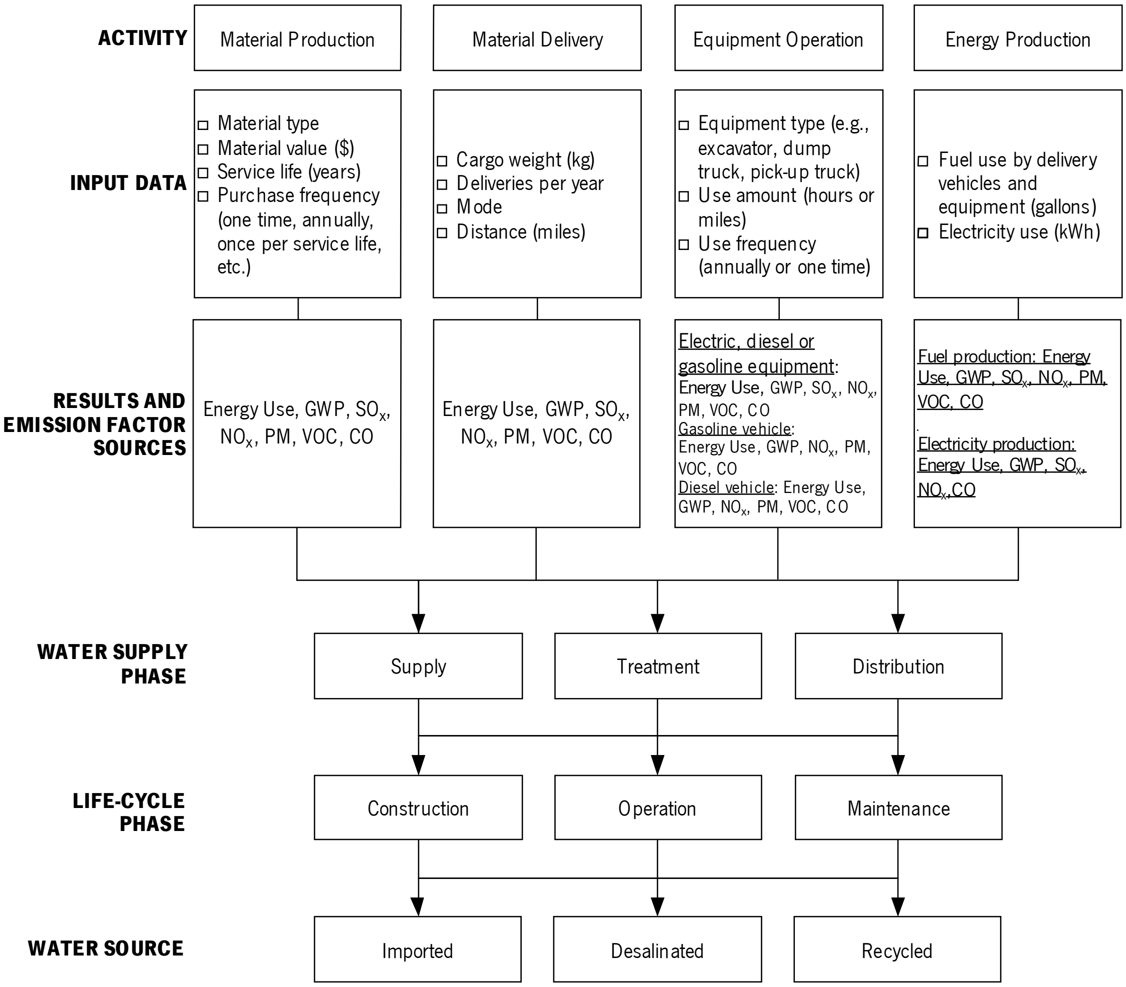

Figure 2.4 – The structure of WEST (adapted from Stokes and Horvath, 2006)[2].

In more general terms, Sahely *et al.* (2005) define four components for LCA: (1) goal and scope definition, where boundaries and functional units are defined for the study; (2) inventory analysis, where raw materials and energy use and discharge over the entire life-cycle are accounted for; (3) impact analysis, where results from the previous stage are categorized according to the environmental impact produced, and (4) improvement analysis, where a systematic evaluation of needs and opportunities to reduce the environmental impact is carried out. A great advantage of this approach is the fact that it has been widely used and thus, it is well-established and uses an already standardized methodology. However, it is complex and time-consuming, requiring large sets of data and boundary definition. Where it is limited solely to environmental aspects, it becomes cumbersome to include economic and social factors and

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[2] GWP: global-warming potential; SOx: sulphur oxides; NOx: nitrogen oxides; PM: particulate material; VOC: volatile organic compounds; CO: carbon monoxide.

therefore, this approach may not be the most adequate for an integrated and overall assessment of sustainability (Sahely *et al.*, 2005).

2.5. Sustainability threshold analysis

Recognizing that some parameters could mean a make-or-break decision when taken literally, a few authors have identified the need for a threshold analysis approach to sustainability assessment issues. Essentially, each indicator would be evaluated against a criterion, which in turn would be given on a scale up and/or down to a certain quantity or quality that is considered the threshold (limit).

Threshold analysis has been successfully applied to sustainability assessment in a series of projects by the United Kingdom's Environment Agency (UKEA) (Barton, 2004; Mitchell, 2005). Briefly, the concept behind this approach is one of carrying capacity of a given system for a given set of disturbances (Barton, 2004; Hughes and Kozlowski, 1968). From an urban water system sustainability standpoint, it may as well be the level of acceptable impact on the ecosystem per technical or economic level of improvement to the urban system. Conversely, to what extent can one promote environmental protection before jeopardising the desired 100% access to water service? What are the degrees of acceptability? Sustainability threshold analysis attempts to combine these topics not in an antagonistic but rather in an integrated manner (Barton, 2004). It can be represented by a matrix that combines a series of indicators and an acceptability scale designed to appreciate the degree of compliance or non-compliance with criteria (Table 2.1).

Table 2.1 – Example of a threshold analysis matrix (Barton, 2004 and Mitchell, 2005)

Potential for development	Sub-system	
	Infrastructure Capacity	Water
Impossible	-	Areas liable flood every 30 years or more
Problematic	Major threshold breached; shift in investment priorities required	Marginal flood areas: high groundwater vulnerability
Conditional	Contribution needed to school, sewage treatment, roads, station, etc	Areas of medium groundwater vulnerability
OK	No particular thresholds are breached	Supply, treatment, drainage, OK; no flood risk
Priority	Spare capacity in local schools, road systems, sewage treatment	-

In the example above, the potential for development of two sub- systems is assessed and described in terms of colour-coded thresholds of acceptability (Table 2.2).

Table 2.2 – Sustainability threshold analysis application (Barton, 2004)

Code	Meaning	Example application - Water
Red	Unacceptable	Construction in flood plain area
Orange	Highly problematic: compliance not possible without major reassessment and change in basic assumptions	Development in water shortage area without demand management
Yellow	Negotiable: significant areas of unsustainably that can be overcome by practical means	Absence of strategy for drainage
Green	Good sustainability: best practice levels are satisfied	Demand management, rain water collection, grey water recycling
Blue	Excellent sustainability: full satisfaction of criteria	Autonomy of supply and treatment, *in situ* drainage and flood management

Threshold analysis can also be applied to Multi-Criteria Analysis (MCA), but however visual and easy to grasp conceptually, this practical application is a complex matter as threshold definition may result in incorrect assignment of weigh to indicators (factors) with less demanding thresholds. Additionally, it is assumed that any sub-system behaviour falling beyond the established threshold is unacceptable, regardless of how well other sub-systems fare. This denies opportunities for trading-off, central to the sustainability paradigm (Mitchell, 2005). Nevertheless, MCA tools have built-in procedures, such as fuzzy sets, that enable the model to address threshold issues.

2.6. Multi-Criteria Analysis

Multi-Criteria Analysis (MCA) is a decision-making tool developed for complex multi-variable problems that combines quantitative and/or qualitative characteristics of a given problem, requiring the standardisation of data and thus enabling a comparative and weighted analysis that results in an unique outcome for given a set of hypotheses or alternatives. This approach appears to be particularly adequate for sustainability analysis, given the many elements that characterize the sustainability paradigm. Furthermore, it is readily applicable at different levels of decision. The MCA approach has been widely used, with some degree of variations, depending on the nature and context of the problem at hand. There are several types of MCA models, depending on extent of data available, software requirements and decision context. The most commonly used are the Linear Additive Model, Direct Analysis of Performance Matrix, Multi-Attribute Utility Theory, Analytical Hierarchy Process, Outranking Methods and Fuzzy Set Methods.

As an example, Kashem and Hafiz (2006) have applied the Linear Additive Model due to its flexibility, easy interpretation capability and minimum data requirement for appraising sustainability in the urban fringe in Dhaka City, Bangladesh, whereas Weng and Yang (2003) have looked into the sustainability of the urban ecosystem in Guangzhou, China, using a Fuzzy Set Method approach. In both cases, the Analytic Hierarchy Process (AHP) was used as the method to assign a weight to each sustainability criterion.

3. STRATEGIES FOR MULTI-CRITERIA ANALYSIS

Sustainability assessment requires, regardless of the selected approach, the analysis of particular groups of parameters or indicators, using existing or case-tailored models capable of producing reliable, reproducible and defensible solutions, given a certain set of input data and a series of case-specific constraints. As mentioned in the previous chapter, enduring generalisations are difficult to establish. Nevertheless, general guidelines on how to design and apply sustainability assessment models are not precluded.

First and foremost, the distinction between indicator and criterion must be stressed, as these terms are sometimes used interchangeably and incorrectly. As explained by McClaren and Simonovic (1999) (cited in Sahely *et al.*, 2005) an indicator is a measure of the state of a particular system given in the form of a number or set of characteristics, while the criterion is the standard against which the indicator is measured and compared. They can be expressed in qualitative or quantitative terms and naturally, both indicator and criterion need to be expressed using the same units or type of qualifier.

In general terms, indicators and criteria must be selected according to the purpose of the assessment. Consider the meaning of infrastructure sustainability when applied to urban water and wastewater systems from its social, environmental, engineering and economic angles. Just as for any sustainable system, there needs to be a dynamic equilibrium between inputs and outputs, the revenues generated must cover the costs of operation and maintenance and the system must function with minimum impact and maximum efficiency, to the greatest possible extent. To infer on the state of such a system is to “get a snapshot” of its state of equilibrium, by analysing the parameters that best describe its condition in a particular moment in time.

3.1. Selection of sustainability indicators

The selection of case-appropriate sustainability indicators is no trivial matter. Since they loose their usefulness if considered in isolation (Sahely *et al.*, 2005), the goal is to somehow correlate changes in indicators that will then serve as surrogate measures of the state of the system and thus, the selection process is limited by such a requirement. Another requirement is the number of indicators or parameters under evaluation. Given the multitude of topics involved, it is relatively easy to assemble an extensive list of applicable indicators. However, it is best to focus on a few key indicators only, lest the analysis is rendered too lengthy, too complex and ultimately not worth the effort.

3.1.1. Evaluation themes

A first task is defining which main themes to evaluate. Although sustainability is paradigmatically seen as the result of the symbiotic three-dimensional interaction between social, environmental and economic issues, it is common, if not essential, to consider other main themes of assessment. The selection of these themes can be more or less generic, though always tailored to the case under scrutiny. However, the inclusion of additional main themes does not rule out the need for restriction for comprehensiveness. It simply brings an increased sense of thoroughness to the analysis while tending to the requirement of keeping it to a low number of fundamental parameters. To better illustrate this point, a few examples will be presented and discussed.

As part of a national research programme to evaluate the sustainability of urban water management systems in Sweden, Hellström *et al.* (2000) have devised five groups of evaluation themes, reflecting the multidimensional nature of sustainability. They are (a) health and hygiene; (b) social and culture; (c) environmental; (d) economic, and (e) functional and technical.

This implies any sustainable urban infrastructure should aim for a series of goals focused mainly on the need to move towards a less toxic environment, concerns of health, hygiene, the need to save and preserve human, natural and financial resources. More specifically, systems should be functional, robust and flexible, be adapted to local conditions and, encourage users to adopt responsible behaviours.

Each theme selected for the analysis includes sets of topics and each topic can be described by a series of indicators, where applicable, as exemplified in Table 3.1 presented next. In this case, five themes were selected and assigned a series of topics for investigating. Each topic would then be described by series of specific indicators, ranging from one to eight parameters per topic. A combination of objective and subjective parameters was deemed necessary and appropriate for the goal at hand.

In the example displayed below, a few of the indicators are not listed since the corresponding topic was not conducive to the definition of specific indicators. Such is the case for “easy to understand”, “work demand” and “acceptance”. These topics, however, were included to illustrate the complexity inherent to this multi-dimensional framework, taking into consideration that it was the authors concern to include all possible aspects of sustainability. Environmental indicators were selected based on the relative environmental impact exceeding 10% of the anthropogenic impacts.

Table 3.1 - Sustainability indicators: an example of a tiered approach (Hellström *et al.*, 2000)

Evaluation Theme	Topic	Indicators
Health and Hygiene	Availability of clean water	Acceptable quality; Accessibility
	Risk of infection	No. of waterborne disease outbreaks; No. of affected persons
	Exposure to toxic compounds	Drinking water quality
	Working environment	Number of accidents
Social and Cultural	Ease of understanding	-
	Work demand	-
	Acceptance	-
	Availability	Violation; Omission; Ignorance
Environmental	Groundwater preservation	Groundwater level
	Eutrophication	Nitrogen and phosphorus to water; Oxygen consumption potential
	Contribution to acidification	H^+ - equivalent
	Contribution to global warming	CO_2 – equivalent
	Toxic contamination of water	Cd, Hg, Cu, Pb
	Toxic contamination of soil	Cd, Hg, Cu, Pb
	Use of natural resources	Utilization of: available land, electricity and fossil fuels, fresh water, chemicals, construction materials; Total energy consumption; Potential recycling of phosphorus;
Economic	Total cost	Capital costs; Operation and maintenance costs
Functional and technical criteria	Robustness	Overflow; Sewer stoppages; Flooding;
	Performance	Out-leakage; In-leakage
	Flexibility	-

Data collection in fulfilment of the framework presented above is expected to be time consuming and expensive. Consequently, a reduced and more manageable list of priority indicators was defined.

3.1.2. Hierarchic organisation of themes, sub-themes and specific indicators

Comparable approaches have been described by other authors (Barton, 2004; Daniell *et al.*, 2005; Kashem and Hafiz, 2006; Mitchell, 2005; O'Regan *et al.*, 2002; Sahely *et al.*, 2005), placing more or less emphasis on generating sub-themes (tiers) of indicators for an easier-to-read data evaluation procedure. Not surprisingly, the greater the number of main themes included in the analysis, the greater the potential for larger numbers of indicators and therefore, the greater the complexity of the evaluation process. Predictably, all authors stress the need for partitioning the system under study into components (sub-systems) and then treat each component in a somewhat isolated manner. This partitioned approach to indicators allows for very visual, organized and easy-to-read relationships between the parameters.

Weng and Yang (2003)'s evaluation system to assess the level of sustainability of the Guangzhou's urban ecosystem is represented in Figure 3.1. It can be observed, in this particular case, that the authors opted for following the conventional sustainability model as seen in the Tier C structure, that includes the economic (C1), social (C2), and natural (C3) subsystems.

According to the authors, a sustainability evaluation system should rely on a hierarchical distribution of parameters, consisting of tiered indicators where hard data are collected only for the lowest tier indicators (Tier F). How each level fares is a direct consequence of the results obtained for the precedent level. This means that if the results are not good for the lowest level of analysis then there is no need to carry the evaluation on to higher levels. Conversely, if all criteria are met for the lowest level of indicators, the analysis can carry on to the following and higher tiers.

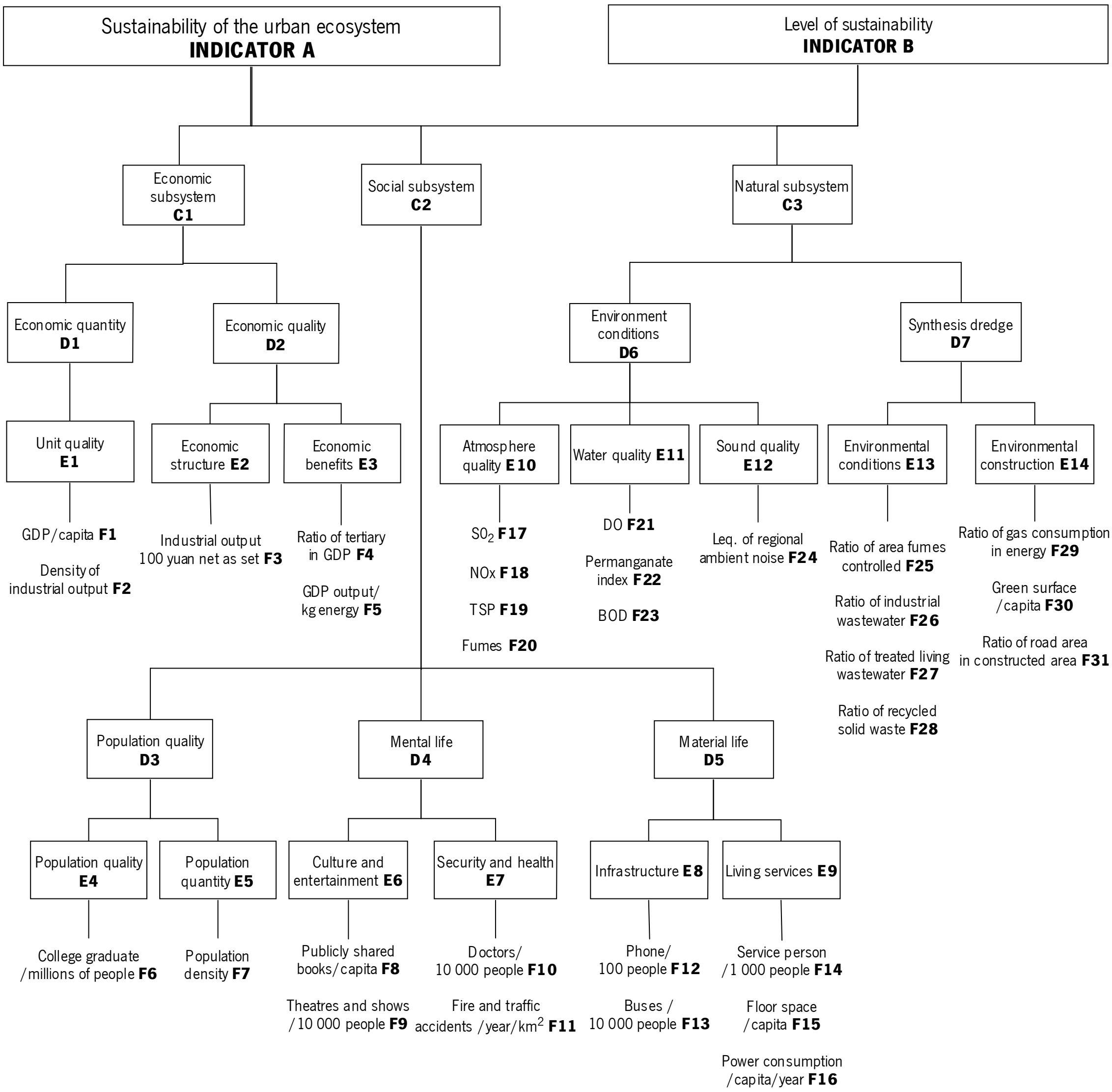

Figure 3.1 - An example of a hierarchical evaluation of sustainability indicators (Weng and Yang, 2003)

As observed, parameters such as F2 (density of industrial output) and F3 (industrial output/100 Yuan net asset) would not be adequate for application in a Portuguese case, since it is a country that operates in context of a service economy, unlike China, from where the example was drawn.

3.1.3. Guidelines for selecting indicators

Specific guidelines have been described by several authors. Foxon *et al.* (2002) (cited in Sahely *et al.*, 2005) have defined five guiding principles for selecting indicators adequate to the assessment of urban water systems: (a) comprehensiveness; (b) applicability; (c) tractability; (d) transparency, and (e) practicability. This list was developed with the purpose of incorporating sustainability aspects in decision-making processes and was developed based partly on results derived from focus groups involving stakeholders and surveys of water service providers.

Vieira and Baptista (2007) have also listed guidelines for selecting individual and groups of indicators, respectively. These orientations were developed for a study on the performance of water and sanitation utilities conducted by the Portuguese Regulating Institute for Water and Waste (IRAR, *Instituto Regulador de Águas e Resíduos*, IRAR, 2007b). The study focused on how well specific utilities throughout the country addressed customers needs. A series of twenty indicators was selected according the guidelines summarized below.

Individual indicators must be: (a) rigorously defined, with concise meaning and unequivocal interpretation; (b) able to be calculated by any of the target entities without significant additional effort; (c) verifiable; (d) simple and easy to interpret, and (e) able to be quantifiably measured, in an objective and impartial manner. Conversely, definition of groups of indicators must abide by the following rules: (a) adequate representation of major relevant aspects; (b) non repetition of meaning or objectives amongst indicators; (c) reference to the same time period; (d) reference to the same geographical area, that should be well-delineated, and (e) applicability to entities with diverse characteristics and levels of development.

An approach worthy of comment is the SOLUTIONS sustainability assessment model presented by Barton (2004) and discussed by Mitchell (2005). The SOLUTIONS project was designed to characterise the sustainability of alternative urban land use and transport plans and includes a diverse set of parameters. Albeit similar to the Hellström (2000) model, SOLUTIONS offers yet another dimension to the issue of hierarchic organization of indicators, an approach recognized both for its effectiveness and limitations, including definition of number of indicators, double-counting, controversial inclusions and/or omissions, which are occurrences to be addressed on a case-by- case basis. The model was designed to incorporate the concept of scale-specific indicators. According to the authors, sustainability assessment, more than a matter of hierarchy, it is a matter of scale (Table 3.2).

Table 3.2 – Sustainability appraisal indicators in the SOLUTIONS project (Mitchell, 2005)

Theme	Sub-Theme	Indicators	
		City/Strategic Scale	Neighbourhood/Local Scale
Economy	(not defined)	Net economic benefit (includes accessibility and externality costs)	(not required)
		Feasibility (infrastructure economic efficiency)	Feasibility (practicality, acceptability, marketability)
Resources	Materials	Need for new construction	(not required)
	Energy	Energy use in transport	Mean distance to local amenities
		Energy use in building stock	Energy use in building stock
	Land	Undeveloped land developed	Undeveloped land developed
Environment	Impact	Surface impermeability	Surface impermeability Properties in flood zone
		Green space fragmentation	Designated wildlife sites
		Greenhouse emissions	
		Acid gas emission (NOx, SO_2)	
		VOC emission	
	Quality	Quality of open space	Conservation areas and other valued landscape features
			Designated built heritage
Social	Opportunities	Vitality	Vitality of local retail services
		(not required)	Mean trip distance to local schools and shops
		(not required)	Accessibility to local public transport services
		(not required)	Accessibility to open spaces
	Equity	Social distribution of economic benefit	(not required)
		Social distribution of environmental quality	(not required)
		Social segregation	(not required)
	Health	Exposure to noise	(not required)
		Exposure to poor air	(not required)
		Traffic accidents	(not required)
		(not required)	Trips by walk or cycle

The rationale behind this approach is that sub-themes are better assessed when using scale-specific indicators. This implies that indicators need not be identical from one scale to the other, even if there are sub-themes that are relevant to both city/strategic and neighbourhood/local scales. As seen, the example does not list specific indicators for all sub-themes nor does it repeat indicators that could have been included in more than one sub-theme.

3.1.4. Critical versus determinant indicators

An indisputable advantage of the hierarchical approach is that it relies on a methodical and logical setting-up of parameters, intrinsically assisting the process of distinguishing between fundamental/essential and non-essential parameters. This particular procedure has been widely applied to broad set of fields, namely urban expansion. An example is Lourenço (2003)'s approach to critical and determinant factors behind urban expansion. In her life-cycle analysis of urban development and inherent land infrastructuring – concerning a 70-year period that included planning, action (implementation) and actual living experience for a number of cities and towns. The author found persistence of goals and perception of innovation to be critical factors while others of a physical, technical and cultural nature (e.g. existing land use, technical and economic feasibility and public participation, respectively) are seen as determinant factors.

Similarly, Hellström *et al.* (2003) have selected, from within their original set of topics those deemed more important and that should be addressed first. Additionally, the authors recommend one or more evaluation methods for each of the priority topics (Table 3.3).

Table 3.3 – Priority topics and evaluation methods (Hellström *et al.*, 2000)

Priority topic	Evaluation Method
Health and Hygiene Risk for infection	Microbial risk assessment
Social and Cultural Acceptance	Action research and assessment scales
Environmental Eutrophication Spreading of toxic compounds to water Spreading of toxic compounds to arable soil Use of natural resources	Life-cycle assessment, computer-based modelling, material-flow and exergy analysis
Economic Total costs	Cost-benefit analysis
Functional and technical Robustness	Functional risk analysis

As observed, the number of topics under evaluation and analysis has been drastically reduced from 19 initial to 8 critical, in order to save resources and lower the potential complexity of the system by reducing the number of variables.

There are many approaches on how to select, from a long list of possible indicators, those that are deemed most useful. In other words, it is not about gathering all the existing data, but rather selectively analyse those which appear more fundamental in essence and more likely to produce the most accurate information. Weng and Yang (2003)'s approach to defining an indicator system mirrors the ideas of Warren (1997) (cited in Weng and Yang, 2003), claiming that selected indicators "must be simple, quantifiable, sensitive to change across space or within groups, and to time, predictive [...]". Also, corresponding data must be relatively easy to collect, resulting in a practical and operational use of the sustainability concept (Hellström *et al.*, 2000). Moreover, selected indicators must relate to the system in a fundamental way, reflecting its social, economic and environmental/engineering aspects.

3.2. Definition of criteria

As mentioned before, a criterion is the standard against which the measurement obtained for one or more indicators is compared and evaluated. Hence, the definition of adequate criteria is no less important than the selection of adequate indicators. In fact, while the existence of criteria may support or even motivate the selection of a given indicator, their lacking could disqualify the use of certain parameters. Adequate criteria definition is paramount when resorting to MCA tools as a means to comparatively assess levels of sustainability for more than one target system. Although there are several manners of carrying out this type of comparative analysis, methods of rating and ranking typically rely on the indicator measurement/criteria relative comparison method.

3.2.1. Sources of criteria

Criteria can be strictly case-defined or obtained from existing studies, regulations and/or other pertinent and applicable sources, as long as their inclusion as such is supported by intrinsic quality of robustness and capability of enduring predictable scrutiny. For example, when assessing urban water systems, one commonly used indicator is accessibility to service, typically measured in terms of percentage of population or of households served by the system. Ideally, the criteria (standard) would be 100%, but there are instances where the law sets a minimum acceptable threshold that may be less than the ideal goal.

In general, criteria obtained from regulatory documents appear to be the most commonly used. The concept of comparing measured data against regulatory standards is universal and widely applied and thus, does not warrant lengthy explanations on its logic. For instance, Weng and Yang (2003) resorted to using guidelines from the Chinese National Standard Level One and compared how each indicator fared based on whether measurements complied or not with standard requirements. Logically, complying with a set standard meant tipping the balance towards a higher degree of sustainability and *vice versa*.

In choosing this approach and taking the context of this analysis in consideration, one assumes that regulatory standards and guidelines are defined with sustainability in mind. The argument can be made that this is indeed the case. However, there may be instances where that assumption is not exactly clear. Using the example above, 100% accessibility to the urban water system may be a sustainability goal from a social standpoint, but is it sustainable from an environmental or even technical/engineering point of view? While desired from a quality of life angle, it may not be completely acceptable from a natural resources/technical perspective (Barton, 2004). Whereas these considerations may be disregarded for the sake of simplicity, a less reductive approach (cost-oriented) is not only possible but recommended.

3.3. Weight assignment

The relative importance of the evaluation indicators should be defined. Critical and determinant indicators do not contribute equally to the decision process. For instance, in water treatment, it is critical that the minimum levels of treatment are provided in order to comply with the minimum quality standards defined by regulatory law. When treatment takes on more sophisticated approaches that might be non-essential though are certainly desirable, this is a condition that should be deemed determinant but not critical. More sophisticated levels of treatment determine higher quality, which is certainly a beneficial contribution, but cannot be considered critical unless they are absolutely indispensable. In other words, all essential factors are critical, while additional factors may only be determinant. Naturally, some factors (indicators) may not be consistently critical and/or determinant, depending on the system's circumstances, driven by external factors. To use the same example as above, the level of water treatment required is determined by the quantity available and quality of the raw water that, in turn, depends on a series of natural and even anthropogenic factors – climate patterns, hydrogeological conditions, baseline quality, and existence of hydroelectric power dams and other water resource-dependent structures and activities, etc. The effects imparted may even vary throughout more or less defined temporal intervals, such as the seasonal variation of weather conditions, for instance. Since MCA provides a snapshot picture of the system for a given set of conditions for a given moment in time, it is not surprising that establishing the relative weight amongst indicators is another essential stage in the process of setting up the analysis.

There are many methods available (Malczewski, 1999; Saaty and Vargas, 1991; Silva *et al.*, 2004). These are particularly useful when the nature of the indicator is not immediately definable. Also, some of these methods compare factors of apparent equivalent importance and determine whether they should be equally considered or not. A few of the most used methods are briefly described below.

3.3.1. Ranking

The method consists of ranking the indicators according to their relative importance and then calculating the corresponding weight. This is the simplest method and depends on the analyst's preference, who can decide on following either straight or inverse ranking approaches (decreasing and increasing importance of factors, respectively). After ranking is complete, numerical weights are calculated via three possible methods: rank sum, rank reciprocal and rank exponent. See Equations 3.1-3.3 in Table 3.4.

Table 3.4 - Weight assignment by ranking

<table>
<tr><td colspan="6">1: Ranking</td></tr>
<tr><td colspan="3">Straight ranking

1 - Most important
↑↑↑↑↑
n - Least important</td><td colspan="3">Inverse ranking

1 - Least important
↓↓↓↓
n - Most important</td></tr>
<tr><td colspan="6">2: Calculating numerical weights</td></tr>
<tr><td colspan="2">Rank Sum
$$\omega_i = \frac{n - r_i + 1}{\sum_k (n - r_k + 1)} \quad (3.1)$$</td><td colspan="2">Rank Reciprocal
$$\omega_i = \frac{\frac{1}{r_i}}{\sum_k \frac{1}{r_k}} \quad (3.2)$$</td><td colspan="2">Rank Exponent
$$\omega_i = \frac{(n - r_i + 1)^p}{\sum_k (n - r_k + 1)^p} \quad (3.3)$$</td></tr>
<tr><td colspan="6">Where, ω_i is the normalised weight of indicator i, r_i is the ranking order of indicator i, n is the number of indicators, and p is an unknown variable for which the equation is solved, following a preliminary definition of an initial weight ω_i.</td></tr>
</table>

These are popular methods due to their simplicity, being particularly adequate for a small number of indicators (Malczewski, 1999; Silva *et al.*, 2004).

3.3.2. Rating on a seven-point scale

Another frequently used weight definition method is the direct rating of each indicator on a seven-point scale (Figure 3.2), using the principle of differential semantics (Osgood *et al.*, 1957, cited in Silva *et al.*, 2004) and keeping in mind that n-point scales can also be used (Canter and Knox, 1986; Mendes *et al.*, 2004). Once all indicators have been rated, the corresponding weights are calculated by normalising the numerical values assigned.

Insignificant	1	2	3	4	5	6	7	Important

Figure 3.2 – Seven-point scale (Silva *et al.*, 2004)

This method is limited by the central tendency error, which is the tendency to avoid extreme ratings (high and low) and to systematically use mid-range values. Typically, this occurs when there is reluctance in explaining the reasoning behind very low or very high ratings. However, avoiding such ratings is a way to hinder the significance of the evaluation process and thus, high and low values should be selected when appropriated and should be adequately justified.

3.3.3. Point allocation

This is another commonly used rating method. Each indicator is assigned a certain number of points on a previously defined scale. On a scale of 0 to 100, an indicator rated 0 would be ignored in the subsequent analysis (0% importance) while the remaining indicators would be considered in terms of their relative value (Malczewski, 1999; Silva *et al.*, 2004).

3.3.4. Ratio estimation

A variation on the previous method, it starts by assigning the maximum number of points to the most important indicator, identified beforehand using a ranking method. Fewer points are proportionally assigned to lower-ranking indicators until the least important indicator is rated. Then, ratios are calculated based on the least number of points assigned. A final normalisation step calculates normalised ratios or final weights based on the total sum of the originally estimated ratios (Silva *et al.*, 2004).

3.3.5. Pairwise comparison

The following description references the work described also by Canter and Knox (1986), Malczewski (1999), Silva *et al.* (2004), and also by Saaty and Vargas, (1991) who have developed this procedure in the context of Analytical Hierarchy Process (AHP). The procedural steps are presented in Table 3.5 (Equations 3.4–3.9).

Table 3.5 – Pairwise comparison methodology (Saaty and Vargas, 1991)

Step	Procedure
1: Build the pairwise comparison matrix $A=[a_{i,j}]$, where i is the row indicator, j is the column indicator, and $a_{i,j}$ is the matrix element corresponding to row i and column j.	Use Saaty and Vargas (1991) scale for pairwise comparison; $a_{i,j} = \frac{1}{a_{j,i}}; a_{i,i} = 1$
2: Calculate the main eigenvector[1], ω	$A_{\omega} = \lambda_{max} \times \omega$ (3.4) $\omega_i = \frac{\left(\prod_{j=1}^{n} a_{i,j}\right)^{\frac{1}{n}}}{\sum_{k=1}^{n}\left(\prod_{j=1}^{n} a_{k,j}\right)^{\frac{1}{n}}}$ (3.5)
3: Calculate the maximum eigenvalue[2], λ_{max}	$\omega' = A \times \omega$ (3.6) $\lambda_{max} = \frac{1}{n} \times \left(\frac{\omega'_1}{\omega_1} + \frac{\omega'_2}{\omega_2} + \ldots + \frac{\omega'_n}{\omega_n}\right)$ (3.7)
4: Calculate the Consistency Index, CI	$CI = \frac{\lambda_{max} - n}{n - 1}$ (3.8)
5: Determine the Random Index, RI	Use Saaty and Vargas (1991) estimations;
6: Calculate the Consistency Ratio, CR	$CR = \frac{CI}{RI}$ (3.9)
7: Re-evaluate the matrix	If CR > 0.1, the initial pairwise comparison needs to be repeated;

A square n indicators × n indicators ratio matrix is created by comparing all indicators two at a time, until all possible pair combinations have been evaluated in terms of their relative importance and according to a rating scale purposely defined for this application. Final weights are obtained by normalising the eigenvector associated to the maximum eigenvalue of the reciprocal ratio matrix. It should be noted that for all practical purposes, the normalised weights are obtained upon completion of step 2. However, carrying out the subsequent steps is deemed good practice as they encompass a procedure that verifies the robustness of the solution.

3.3.6. Trade-off analysis

In this method, the weight assignment decision is based on the analyst's direct assessment of the trade-offs he or she is willing to make between pairs of alternatives. Each trade-off decision defines a unique set of weights to apply to equally preferred alternatives in the trade-off analysis

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[1] An *eigenvector* is the solution-vector associated with a matrix forming linear sets of equations (equation matrix); can also be designated as *characteristic vector*, *proper vector*, or *latent vector* (Stephenson, 1973; p. 314-315).

[2] An *eigenvalue* is a root or solution of the equation matrix (Stephenson, 1973; p. 314-315).

to get the same overall value. The underlying assumption is that the trade-off decision between two indicators does not depend on the other indicator.

Weights assigned are obtained from on a comparison between two alternatives based on sets of two indicators at a time. The analyst is required to decide which alternative is preferred or indifferent. The procedure is repeated until all alternatives are assessed in terms of all available indicators. More detailed explanations and examples are presented in Canter and Knox (1986) and Malczewski (1999).

3.4. Data processing and evaluation of results

Data processing stands out as one of the most critical aspects of the work. Given the number of possible vectors for analysis, it is essential that data are handled and transformed in a consistent manner throughout the study. This implies taking certain precaution as to ensure that results obtained from data thus processed are reliable, indisputable and reproducible.

Given the diverse nature and origin of the input data, conversion into a common unit and/or normalisation – to allow the comparison between data and criteria – are required (Stokes and Horvath, 2006). In fact, any combination of data for analytical purposes requires that they are commensurate, i.e., expressed in the same units, thereby avoiding scale problems (Malczewski, 1999). However, normalisation and reduction of data to a common unit may present some problems, as it may warp the uniqueness of each parameter. To validate this point, Mitchell (2005) compares high quality urban design with safety from flood. Both apply to construction but while data can be converted into comparable terms, they do not pertain to equivalent parameters. The former focuses mainly on aesthetical concerns while the latter is concerned primarily with safety. That said, the definition of thresholds or limits is case-specific. In an urban development context and more specifically, in an urban water context, they may as well be the factors that allow for or hinder sustainable progress.

3.4.1. Data normalisation

Data must be commensurate in order to be combined and/or compared. The type of normalisation depends on the nature of the information available. In general, data can be classified as deterministic – certain, single value data -, probabilistic or fuzzy – both uncertain. Each case requires specific normalisation procedures. Deterministic or single value data can be normalised using linear scale transformations or value functions. Probabilistic data are normalised using utility functions and probabilistic approaches. Fuzzy membership functions can be used to generate commensurate data from fuzzy datasets (Malczewski, 1999).

3.4.1.1. Deterministic Data

Linear Scale Transformations (LST)

Two procedures are most frequently used, maximum score and score range. Both require each indicator –attribute- to be classified as either a benefit or a cost, *i.e.*, whether an increase in score is desirable or undesirable. Thus, the normalisation method vies for either maximisation of the benefit or minimisation of the cost.

Maximum Score

The goal is to obtain the maximum score possible for either of the approaches as explained below. The normalisation procedure for maximisation of benefit is represented in Equation 3.10.

$$s_i = \frac{d_i}{d_{max}} \tag{3.10}$$

Where

s_i is the normalised, standardised score for attribute/indicator i;

d_i is the datum value for attribute/indicator i; and

d_{max} is the maximum datum value.

In this case, an increase in score translates into a positive contribution. Conversely, when a greater normalised score is construed as a cost, the goal is to minimise that cost and hence, the calculation procedure is as follows (Equation 3.11):

$$s_i = 1 - \frac{d_i}{d_{max}} \tag{3.11}$$

It should be noted that in situations where both benefit and cost data are present, Equations 3.10 and 3.11 should not be used simultaneously. Instead, the reciprocal of the datum should be used. Equation 3.12 is an adaptation of Equation 3.10 for cost data (Malczewski, 1999).

$$s_i = \frac{\frac{1}{d_i}}{\max\left(\frac{1}{d_i}\right)} = \frac{d_{min}}{d_i} \tag{3.12}$$

Where

d_{min} is the minimum datum value.

The maximum score procedure allows for the linear (proportional) transformation of raw data. Also, the relative order of magnitude of standardised score remains unchanged. A disadvantage is that the lowest standardised score is not necessarily zero (=0).

Score Range

The score range procedure is another LST method that has the advantage of having the measurement scale varying precisely between zero and one (0 and 1) for each indicator. The calculation is represented in Equations 3.13 and 3.14, for benefit and cost indicators, respectively.

$$s_i = \frac{d_i - d_{min}}{d_{max} - d_{min}} \tag{3.13}$$

$$s_i = \frac{d_{max} - d_i}{d_{max} - d_{min}} \tag{3.14}$$

A disadvantage is that standardised data do not retain the absolute order of magnitude.

Value Functions

Normalisation using value functions is performed by attaching a number to a given level of indicator (attribute) data. It is a function that relates worth, on a scale of 0 to 1, to the indicator of concern. The function is represented by an expression that yields a standardised value scale for each value of a range of attribute data. In other words, each numerical datum is assigned a value that results from applying a particular value function to the dataset. Of the many techniques available for deriving a value function, the midvalue method is the one used most frequently (Malczewski, 1999).

Midvalue Method

1. Determine the range over which the value function is to be assessed: find the upper and lower bounds of the dataset and respectively assign the values of 0.0 and 1.0.
2. Find the midvalue point between these two bounds and assign a value of 0.5 to that point.
3. Find the midvalue point between 0.0 and 0.5 and assign the value of 0.25 to that point. Repeat for interval 0.5 and 1.0 and assign value of 0.75 to the midvalue point.

4. Repeat until at least the values of 0.125, 0.375, 0,625 and 0,875 are assigned and so on, until a sufficient number of values has been defined as needed to construct the Value Function curve. Also, the greater the number of points, the greater the accuracy level of the curve.
5. Draw the curve Value = F(Datum) and find the analytical model that fits the point distribution.
6. Apply the function thus defined to the dataset and transform each datum into a value score between 0.0 and 1.0.

Utility functions can also be used in a context of certainty (deterministic data). In fact, value functions are but utility functions operating under the assumption that the level of uncertainty is a known or negligible, and value scores are obtained. However, though utility functions can sometimes be value functions, the opposite is not true (Malczewski, 1999).

3.4.1.2. Probabilistic Data

Utility Functions

As mentioned above, utility functions can be applied to both deterministic and probabilistic data. Utility scores can be defined for both types of data whereas value scores can only be defined for deterministic data. When the level of uncertainty is not negligible or unknown, the attitude towards risk is important and therefore, normalisation procedures produce utility scores.

Indifference Technique

The indifference technique (the "50-50 lottery method") can be used to derive utility curves and is analogous to the midvalue method in what concerns major methodological steps (Malczewski, 1999). However, instead of defining a sequence of midvalues, the indifference technique focuses on finding midpreferences (or utility levels) limited by higher or lower outcomes with probabilities p and 1-p, respectively. In essence, it is the assessment of an outcome that renders any decision indifferent when faced with this particular outcome and one resulting from a 50-50 gamble of two other outcomes. The method asks the question: for attribute (indicator) j, what is the outcome x_j that is equally desirable at the highest outcome with a probability p and the lowest outcome with a probability 1-p? For the utility function u_j associated to attribute j (Equation 3.15):

$$u_j\left(x_j = ?\right) = p\left[u_j\left(x_j\right)\right] + \left(1 - p\right)u_j\left(x_j\right) = p \tag{3.15}$$

Where

$u_j(x_{j+}) = 1$ represents the best outcome; and

$u_j(x_{j-}) = 0$ represents the worst outcome.

The utility curve can be constructed by varying p in fixed increments until sufficient discrete points have been defined or otherwise, an outcome x_j can be specified for a range of values, for which p is calculated based on x_j being as desirable as $p[u_j(x_{j+})] + (1-p)u_j(x_{j-})$. See Figure 3.3.

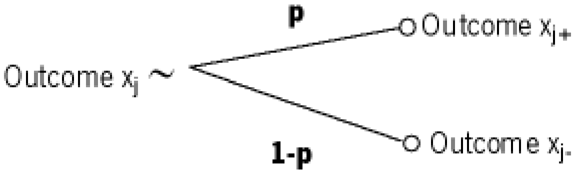


Figure 3.3 - A graphical representation of the indifference technique for building utility curves (Malczewski, 1999)

When operating in a context of uncertainty, there are concerns about whether decisions are stable over spatial ranges and/or time and thus, utility levels may not be the same throughout different locations and moments in time. Once the utility curve is defined, it is applied to the dataset and used to generate normalised values.

Probability Approaches

Another method for generating commensurate data is based on probability theory that states that a single observation will produce a particular outcome that depends on chance and consequently, cannot be predicted precisely ahead of time. Nevertheless, repeated observations provide statistical regularity and allow the representation of the relative frequency at which a specific outcome is produced. The likelihood of it occurring may be assessed by a number of ways, including objective probability and subjective probability (Malczewski, 1999).

Objective Probability

This approach indicates the relative frequency with which a certain outcome is likely to occur in the long run, based on past observations of similar or equal events under similar or equal conditions.

Subjective Probability

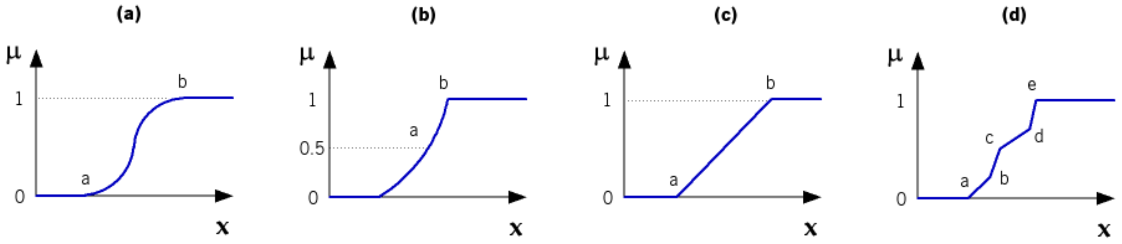
Contrary to the previous approach, this one provides an assessment of the likelihood of an event to occur based on a subjective perception of that likelihood. In this particular case, the analyst brings his or her personal experience, judgement and intuition to the decision process -on whether the outcome is bound to occur or not– influenced by his or her nature, prejudices, level of optimism in the future, etc. Therefore, probability is expressed as a degree of belief. In the absence of quantitative data, relying on subjective probability decision may not necessarily be detrimental, as long as the decision-maker acts accordingly with his or her decision. The key is ensuring consistency between a stated belief expressed in terms of subjective probability and actions derived from it (Malczewski, 1999).

3.4.1.3. Fuzzy Datasets

Fuzzy sets are classes of elements that do not have well-defined boundaries between what belongs in that class and what does not, whereas data belong partly to multiple sets. Concepts such as these are useful for dealing with the oftentimes ambiguity of entities in the "real world", where belonging to a particular class is a matter of degree (Malczewski, 1999). This brings to mind the concept of threshold analysis, where pass, fail and in-between grades would be assigned to an indicator whether it met, somewhat met or failed to meet all or some particular conditions defined per level of requirement (threshold). Fuzzy logic applies the same reasoning to data, allowing the formulation of mathematical models capable of describing intermediate states, resulting in the assignment of numerical values for those intermediate states. In other words, fuzzy logic focuses on the values amid the "yes/no" boundaries and assesses the several degrees of "maybes" in-between.

Fuzzy Set Membership Function

The normalisation of fuzzy sets or fuzzification requires the translation of the value scale into a normalised scale between 0.0 and 1.0. Fuzzy set membership functions are models that are used to determine the variation between a minimum set point, where the contribution from the score to the decision begins to take shape, and a maximum set point, where there is not additional contribution. A few models are discussed by Silva *et al.* (2004) and are illustrated in Figure 3.4.



$$\mu = \sin^2 \alpha \qquad (3.16)$$

$$\alpha = \frac{x - x_a}{x_b - x_a} \times \frac{\pi}{2} \qquad (3.17)$$

$$\begin{cases} x > x_b \Rightarrow \mu = 1 \\ x < x_a \Rightarrow \mu = 0 \end{cases}$$

$$\mu = \frac{1}{\left(1 + \frac{x - x_b}{(x_b - x_a)^2}\right)} \qquad (3.18)$$

$$x > x_b \Rightarrow \mu = 1$$

$$\mu = \frac{x - x_a}{x_b - x_a} \qquad (3.19)$$

$$\begin{cases} x > x_b \Rightarrow \mu = 1 \\ x < x_a \Rightarrow \mu = 0 \end{cases}$$

The fuzzy function membership can be interpolated between any two points.

Figure 3.4 – Examples of fuzzy set membership functions (Silva *et al.*, 2004)

All models are represented showing their upward trend, meaning that both normalised and original scores vary (increase) concurrently. On the contrary, if normalised and original scores exhibit opposite variation trends, the equations will have to be adjusted accordingly and the model will take on a downward variation aspect. Bearing in mind that the selection of a fuzzy function should be adequate to the target indicator, the sigmoid curve is the most commonly used.

Fuzzy restrictions or control points (a, b, ...) are presented for each case. The selection of these fuzzy restrictions is one of the most critical steps in the fuzzification process since it calibrates the model, setting boundaries for its application. Both Silva *et al.* (2004) and Malczewski (1999) explain the fuzzification process using slope gradient examples (Table 3.6).

In the first example, the goal is to determine whether a certain location is suitable for construction, by evaluating the type of slope and grading it on a scale ranging from “suitable” to “not suitable”. This linguistic value scale is translated into a numerical scale, defined by a set of control points or fuzzy restrictions, which delineate the boundaries to the slope gradients thus defined.

Table 3.6 - The fuzzification concept applied to land slopes

Adapted from Silva *et al.* (2004)	Linguistic Value	Suitable	Variable	Unsuitable
	Fuzzy Restrictions	2% ≤ slope < 8%	8% < slope < 20%	slope ≥ 20%
	Fuzzy Numbers	0.0	∈] 0.0, 1.0 [	1.0
	What it means	Land suitable for construction	Suitability for construction is variable	Land unsuitable for construction
Malczewski (1999)	Linguistic Value	Shallow	Moderate	Steep
	Fuzzy Restrictions	0% ≤ slope < 5%	5% < slope < 10%	slope ≥ 10%
	Fuzzy Numbers	∈ {0.0, 0.0, 0.4, 0.6}	∈ {0.2, 0.5, 0.5, 0.8}	∈ {0.6, 0.8, 1.0, 1.0}
	What it means	Any land whose slope falls within the given gradient is classified as “shallow”	Any land whose slope falls within the given gradient is classified as “moderate”	Any land whose slope is greater than the maximum set point is classified as “steep”

This fundamental conversion from a qualitative “sense” into a quantitative “amount” is what allows MCA to successfully combine contributions from both types of evaluation parameters and produce true multi-criteria-based decisions. Nonetheless, other methods for accomplishing this conversion are discussed below.

Once a numerical scale is successfully defined, it is then manipulated using arithmetic and algebraic expressions and producing normalised fuzzy numbers. Malczewski (1999)’s example is supported by the detailed description of the specific steps leading to the values presented above. The procedure can be more easily understood by using graphical illustrations such as the ones presented in Figure 3.5.

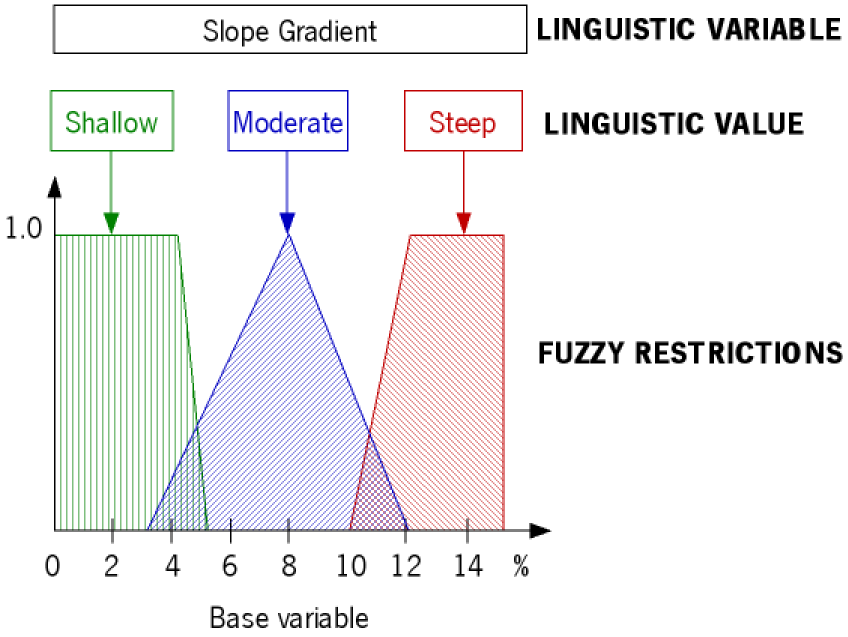


Figure 3.5 – Numerical representation of linguistic values (Malczweski, 1999)

The procedure relies on defining intermediate linguistic values and thus, intermediate fuzzy restrictions, generating a greater number of points. The graphical representation of this concept is presented in Figure 3.6.

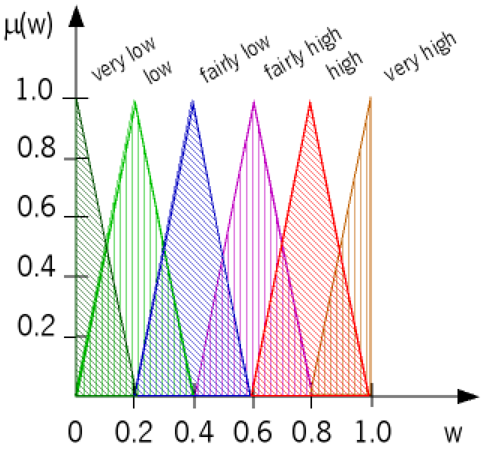


Figure 3.6 – Converting linguistic values to fuzzy numbers (Malczweski, 1999)

As mentioned above, setting gradient boundaries is the most critical step. Just as in threshold analysis, guidance for defining such limits should be derived from existing criteria and other sources, *i.e.*, guidelines, applicable standards, similar cases found in the literature and/or in their absence, the judgement of the analyst[3].

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[3] And the same concerns expressed for subjective probability apply.

3.4.2. Combining data

After normalisation, data for each alternative are ready for combination into a single value or final score, according to the individual weight assigned to each indicator under evaluation. Its calculation can be carried out via a number of possible methods. The two most typically used are the Weighted Linear Combination (WLC) and the Ordered Weighted Average (OWA) (Malczewski, 1999; Silva *et al.*, 2004).

3.4.2.1. Weighted Linear Combination

This method requires the calculation of a weighted average –final score S- of the normalised data, which is given in the same scale and units as the normalised values. The main advantage of this approach is that it allows trading-off between indicators. The calculation procedure is presented in Equation 3.20.

$$S = \sum_i \left(\omega_i \times s_i \right) \tag{3.20}$$

However, when exclusions occur, S is calculated according to Equation 3.21:

$$S = \sum_i \left(\omega_i \times s_i \right) \times \prod_j c_j \tag{3.21}$$

Where

c_j is the exclusion score, expressed in a binary scale (0/1>).

3.4.2.2. Ordered Weighted Average

The OWA method considers not only ω_i (normalised weight of indicator i) but also another set of weights –order weights O_i- that are related to the order in which each alternative is placed after being assigned a weighted score S. The method starts out with the application of the WLC procedure. Once the scores S are obtained, they are organised by ascending order. The alternative i with the lowest S is assigned the first order weight O_i, the second lowest S gets the second order O_i and so forth. This way, the alternatives are judged based on their order scores, independently of the indicators under analysis. In doing so, three decision contexts are generated: (a) a pessimistic or low risk context, where the lowest score S is assigned the greatest weight; (b) an optimistic or high risk context, where the highest score S is assigned the greatest weight, and (c) a medium risk context, where all scores S are assigned equal weights[4].

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[4] In this case, the method becomes the WLC.

Trade-off is absent from the first two situations, since only the extreme scores (lowest and highest) are used, in an all-or-nothing approach. However, medium risk situations are, by definition, based on the total trade-off between benefits and costs associated to the factors (indicators) under analysis, *i.e.*, bad scores are offset by good ones. Nonetheless, it should be noted that this levelling of scores is global and not specific to a particular indicator or factor. In other words, an indicator showing poor performance will remain so whilst its corresponding score is balanced by a good performance by another indicator.

The risk spectrum generated can be graphically represented for a better understanding of how the decision can be carried out under greater or lower risk circumstances (Figure 3.7).

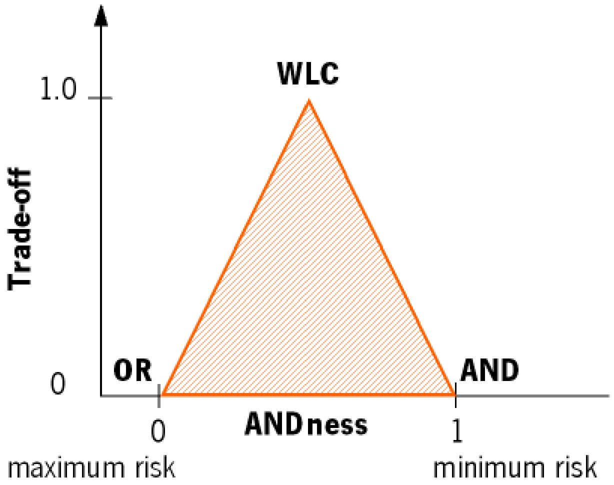

Figure 3.7 – Risk spectrum for decision-making (Silva *et al.*, 2004)

Risk is defined by the variable ANDness (Malczewski, 1999; Silva et al, 2004) and calculated using Equation 3.22.

$$\text{ANDness} = \frac{1}{N-1} \times \sum_i \left[(N-1) \times O_i \right] \tag{3.22}$$

Where

N is the number of alternatives; and

O_i is the order weight for alternative i.

Trade-off is calculated using Equation 3.23.

$$\text{Trade-off} = 1 - \sqrt{\frac{N \times \sum_i \left(O_i - \frac{1}{N} \right)^2}{N-1}} \tag{3.23}$$

This graphical representation allows the analyst to visualise the effects of the decision in terms of trading-off, should he or she favour conditions of greater or lower risk.

4. METHODOLOGY

This chapter describes the methodological steps followed through the completion of the study. In order to better demonstrate the relevance of each working stage and explain the sequence of inherent tasks, a process flow diagram was produced and is presented in Figure 4.1.

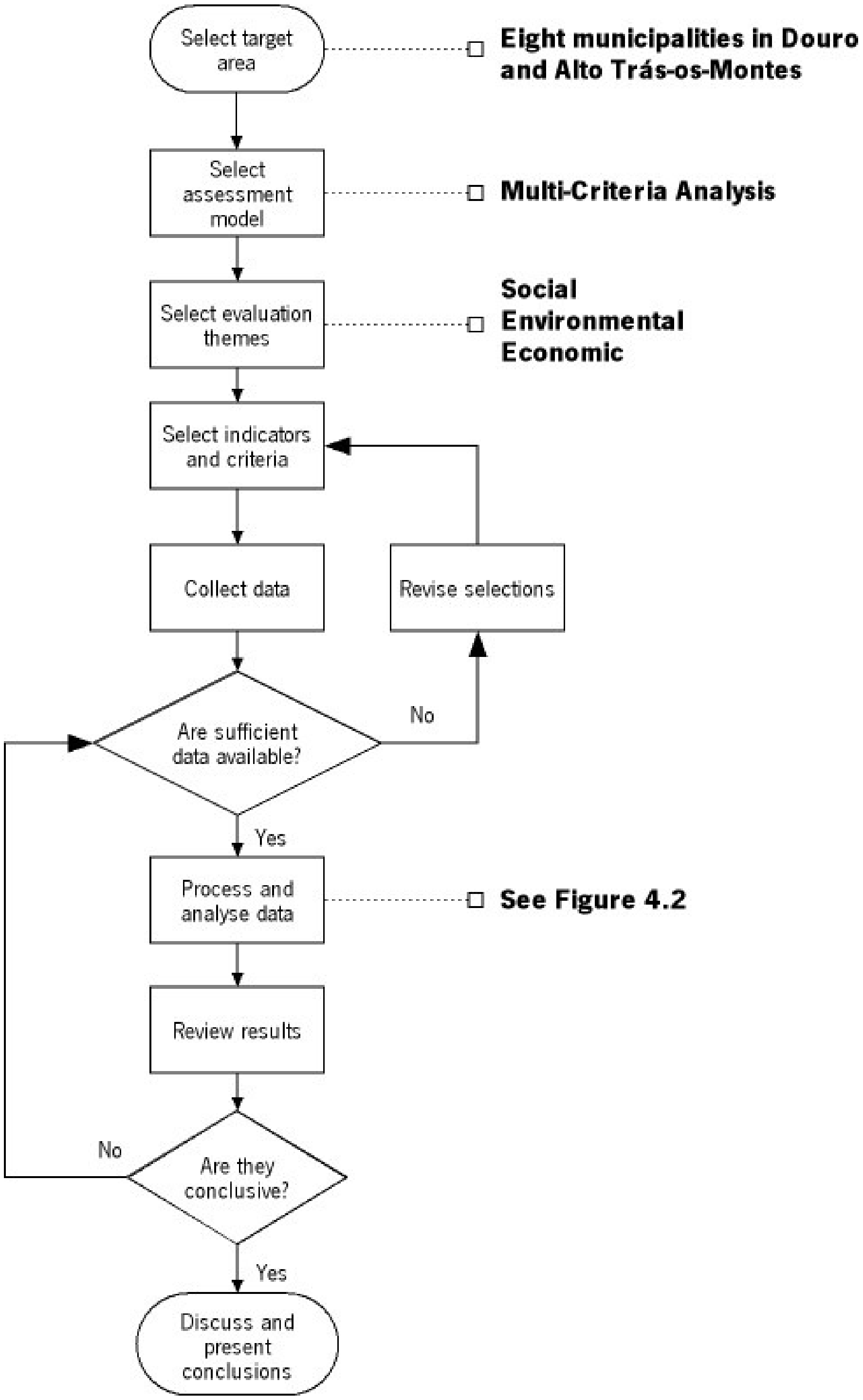

Figure 4.1 – General methodology

After identifying the study area, a multi-criteria analysis (MCA) model was selected and a number of indicators and criteria was defined. The decisions involving indicators and criteria selection resulted from an iterative process, involving a preliminary look at the nature, quality and quantity of the data available for analysis.

Data processing and analysis were designed to accommodate the set of alternatives (municipalities) under evaluation, evaluation parameters (indicators) and scenarios. A schematic representation of the intended analytical steps is illustrated in Figure 4.2.

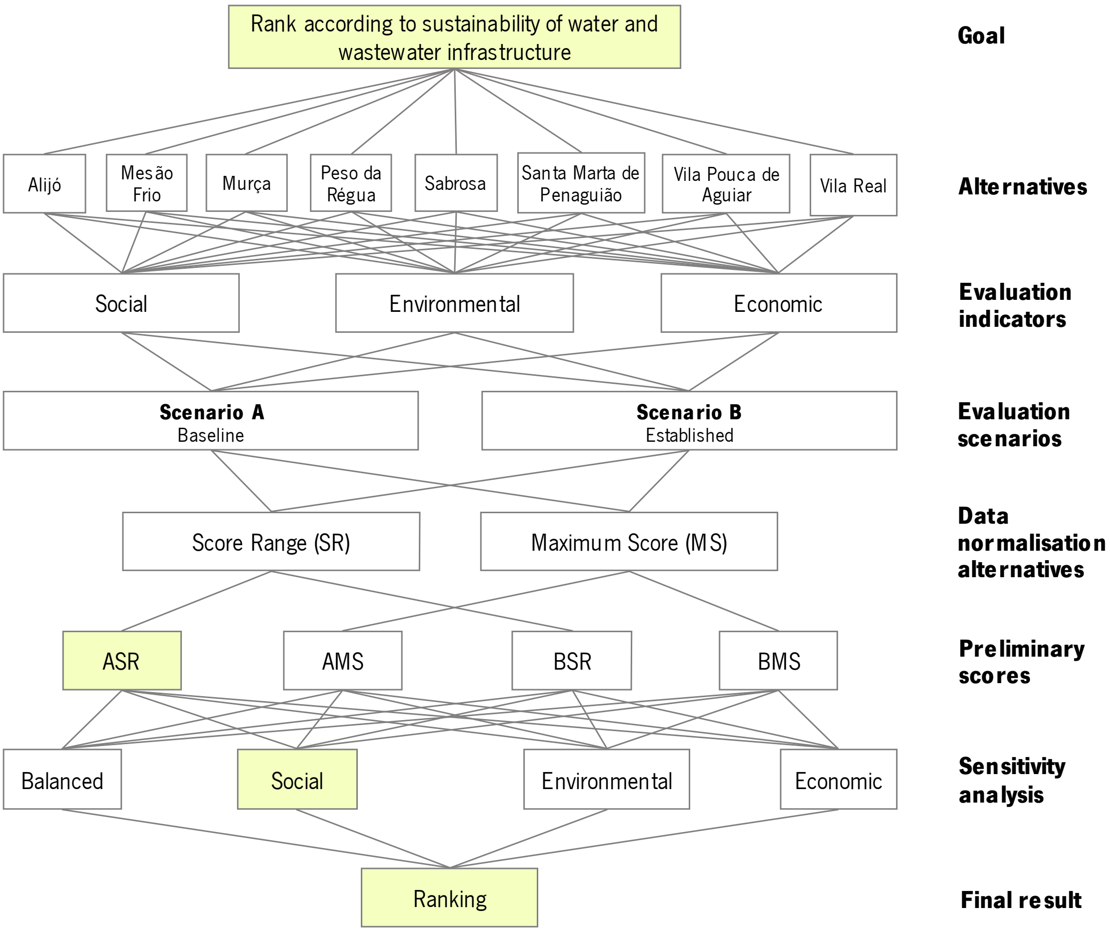

Figure 4.2 – Analytical methodology

Having defined the analytical goal, eight municipalities were evaluated in terms of a list of social, environmental and economic indicators. After an initial review of the available data and nature of indicators, it became necessary to define two analytical approaches: (a) first one (scenario A) which assumed that the data correspond to a baseline state, *e.g.*, critical mass not yet attained to justify full-scale infrastructure system; and (b) a second approach (scenario B) that assumed those conditions have already been established. Thus, sustainability evaluation was analysed from two different angles. Two data normalisation methods were used to test the robustness of the assessment methodology, under the assumption that if both methods produced the same ranking order, then the methodology was adequately applied. A series of adjustments were required as the analysis progressed and preliminary results were obtained and reviewed. The final set of scores that ultimately led to the fulfilment of the analytical goal was the result of those adjustments and considerations.

Detailed descriptions and explanations regarding each methodological step and decision are presented in the following sections.

4.1. Selection of target area

Geographical consistency is one of the requirements for defining and/or selecting adequate sets of indicators and criteria. Thus, it became paramount that any area under study was well-delineated and identified. The broad area of interest concerned Northeastern Portugal. Background knowledge on the region regarding its demographics, topography, climate and water resource characteristics rendered it an interesting subject for studying local urban water and wastewater system sustainability. Here is an area that displays conflicting circumstances, characterised by declining and aging population, dry climate and difficult topography, and that nonetheless exhibits an elevated level of water and wastewater infrastructuring. These paradoxical conditions may question, in the long term, the sustainability of the systems.

A cluster of eight municipalities – Alijó, Mesão Frio, Murça, Peso da Régua, Sabrosa, Santa Marta de Penaguião, Vila Pouca de Aguiar and Vila Real – was selected after reviewing existing information and relevant literature (see Figure 4.3).

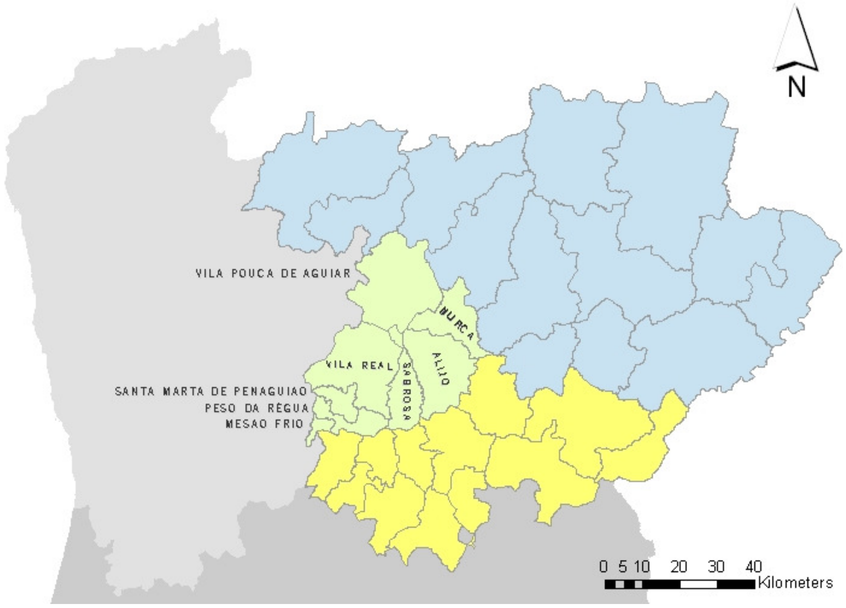

Figure 4.3 – Target area selected

4.2. Selection of model

After reviewing existing models designed to comparatively assess sustainability of urban water systems (or similar), the MCA approach was selected. Its adequacy was briefly described in Chapter 2 while some of the constraints to its application, namely the selection of case appropriate indicators, criteria and data processing issues, were addressed in Chapter 3.

4.3. Selection of evaluation themes and indicators

Having decided to use the MCA approach, it became necessary to define the analytical boundaries regarding its application. Initially, a set of four evaluation themes were proposed: (a) social; (b) engineering; (c) environmental, and (d) economic. Each of these themes was assigned specific sets of indicators, taking into account the discussion and examples presented in the state of the art (Chapters 2 and 3). Following a preliminary stage of data collection and analysis, it was clear that the four-evaluation theme approach was not adequate and thus, the three-theme model emerged excluded engineering parameters. After a number of iterations, a final list of indicators was established. The list presented in Tables 4.1 corresponds to the final version designed in terms of adequacy and data availability for each parameter, and in view of the ultimate goal under analysis, which was the ranking of municipalities according to their respective sustainability score for water and wastewater infrastructure. The combination of indicators presented herein is original, even though it is based on similar lists and/or recommendations found in the literature, where and as noted. Two sets of parameters that were not found in the reviewed literature are sub-groups 2.3 and 3.5 As explained in section 4.3.2, knowing the percentage of wastewater treated in what type of facilities was deemed an important term for comparison in the context of this sustainability evaluation. The reasons for choosing to evaluate the ratio between revenues and expenditure are described in section 4.3.3.

A few indicators were discarded from the original selection due to the lack of data for the set time and spatial frame. These parameters included "construction material–pipe length per inhabitant" for which there were data for some but not all municipalities and "regulation compliance–number of non-compliance events" for which data were not available for the period of interest[1]. Nonetheless, their exclusion at this point should not preclude future efforts towards obtaining the necessary data as they become available. Another parameter that would have been useful and interesting to analyse would be the number of reported waterborne diseases per

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[1] The period of interest was 2005, as will be explained ahead. Non-compliance event data were mainly available for 2006-2007.

municipality. However, these are not yet available to the public and therefore, this particular indicator was not considered at this point.

Table 4.1 – Selected evaluation themes and indicators

Theme	Topic	Indicator (unit)
1.Social	1.1.General Characterization [1]	1.1.1.Total Population (no. of inhabitants) 1.1.2.Population density (no. of inhabitants/km^2) 1.1.3.Old-age dependency ratio (%)
	1.2.Accessibility [2]	1.2.1.Population served by water services (%) 1.2.2.Population served by wastewater services (%) 1.2.3Population served by wastewater treatment plants (%)
2.Environmental	2.1.Water [2] [3]	2.1.1.Consumption/Intake (%) 2.1.2.Treatment/Intake (%) 2.1.3.Consumption/Treatment (%)
	2.2.Wastewater [1] [2]	2.2.1.Wastewater collection/Water consumption (%) 2.2.2.Wastewater treatment/Wastewater collection (%)
	2.3.Wastewater – treatment facilities	2.3.1.Wastewater treated in WWTP (%) 2.3.2.Wastewater treated in collective septic tanks (CST) (%)
	2.4.Solid waste [2]	2.4.1.Total urban solid waste collected (kg/inhabitant) 2.4.2.Total urban solid waste recycled (kg/inhabitant) 2.4.3.Total recycled/Total collected (%)
	2.5 Electrical energy use – per capita [1] [3] [4]	2.5.1.Total (kWh/inhabitant) 2.5.2.Household (kWh/inhabitant) 2.5.3.Agriculture (kWh/inhabitant) 2.5.4.Industry (kWh/inhabitant)
3.Economic	3.1.Expenditure ratios [3] [4]	3.1.1.Environmental expenditure/Total expenditure (%) 3.1.2.Wastewater management expenditure/Environmental expenditure (%) 3.1.3.Remaining environmental protection activities expenditure/Environmental expenditure (%)[2]
	3.2.Expenditure per capita [3] [4]	3.2.1.Environmental expenditure (€/inhabitant) 3.2.2.Wastewater management expenditure (€/inhabitant) 3.2.3.Remaining environmental protection activities expenditure (€/inhabitant)
	3.3.Revenue Ratios [3] [4]	3.3.1.Environmental revenue/Total revenue (%) 3.3.2.Wastewater management revenue/Environmental revenue (%) 3.3.3.Remaining environmental protection activities revenue/Environmental revenue (%)
	3.4. Revenue per capita [3] [4]	3.4.1.Environmental revenue (€/inhabitant) 3.4.2.Wastewater management revenue (€/inhabitant) 3.4.3.Remaining environmental protection activities revenue (€/inhabitant)
	3.5. Revenue over expenditure	3.5.1.Environmental revenue/Environmental expenditure (%) 3.5.2.Wastewater management revenue/Wastewater management expenditure (%)

Based on:
[1] Weng and Yang (2003)
[2] Vieira and Baptista (2007)
[3] Sahely *et al.* (2005)
[4] Hellström (2000)

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[2] Remaining environmental protection activities include: (1) protection and remediation of soil, groundwater and surface water; (2) protection of ambient air and climate; (3) waste management; (4) noise and vibration abatement; (5) protection of biodiversity and landscape; (6) protection against radiation; (7) research and development, and (8) other environmental protection activities (INE, 2008).

4.3.1. Social indicators

The social component addresses two main topics: general characterization (1.1) of the population and accessibility (1.2) to water and wastewater services. The goal was to provide a snapshot description of the type of communities served by the water and wastewater system from the standpoint of type of customer and level of service rendered.

Total population (1.1.1) was deemed important as a measure of the demographic size of the municipality. This parameter bears a direct relationship to the water and wastewater infrastructure subject, as larger populations require larger systems. The contention is that the larger the system, the more difficult it becomes to manage and operate in a sustainable fashion. Intuitively, smaller systems (*i.e.*, smaller populations) appear to be more sustainable.

Population density (1.1.2) measures the distribution of people per unit of surface area. While it does not directly measure the level of population dispersion within the municipality – population is not distributed in a homogeneous manner throughout the territory – it can be used as a comparative measure for how compacted the populations are from one municipality to another. Therefore and in an indirect way, population density does become a surrogate measure for population dispersion. Its bearing on the analysis is that more compact systems are easier to implement, operate and manage, rendering compact communities more desirable that scattered ones.

Old-age dependency ratio (1.1.3) provides a measure of "how old" the community is. Its importance to the analysis stems from the fact that older individuals are naturally more susceptible to public health issues and thus, perhaps more dependent on reliable water and wastewater systems. Older populations imply increased stress on systems and therefore, this indicator is relevant. Naturally, good quality and reliable infrastructure and service are rightfully expected and demanded by all age strata of the population. But it is also true that not every person has the same ability to handle unexpected events such as service interruption, contamination incidents, etc. Individuals with compromised health systems are less able to cope with infrastructure performance that is both undesired and/or not up to minimum standards. It is also a fact that compromised health systems are not particular of a specific age group, namely older people. Nevertheless, health decay is more prevalent amongst the more aged layers of the population, and thus, a measure of population aging such as the one provided can in fact, point to the need for particularly sustainable systems.

The accessibility to services – water (1.2.1), wastewater (1.2.2) and wastewater treatment plants (1.2.3) – was considered an important measure of sustainability. The issue of sustainable infrastructure lies beyond environmental concerns to become primarily a matter of public health. Therefore, more than any other parameter, levels of service coverage are instrumental in defining how well the systems are performing, as their main purpose is to ensure that communities are provided with access to clean water and reliable sanitation.

4.3.2. Environmental indicators

Six sub-sets of indicators were defined under the Environmental group: water (2.1), wastewater (2.2), wastewater - treatment facilities (2.3), solid waste (2.4), electrical energy use – per capita (2.5), and electrical energy use – ratios (2.6).

Water indicators were selected to provide some measure of loss and/or waste along intake, treatment and the distribution stages of the system. It was assumed that a sustainable system is one for which losses, accidental or not, are kept to a minimum and are preferably non-existent. Water consumption over intake (2.1.1) was used as an intended measurement of water loss. Ideally, all of the water removed from a source (underground well, surface intake, etc.) is to be consumed, lest the wastage of a natural resource. The ratio between consumption and intake was taken as a surrogate measure of how much water is being wasted. A similar indication is provided by the ratio between the treated volume and intake volume (2.1.2). Once again and ideally, all water that has been removed from a source reservoir is destined for consumption and thus, it should be treated accordingly. However, and depending on the water source, agricultural and industrial uses may not require the level of treatment that is mandatory for human consumption (if any at all) and so, this particular indicator cannot be considered as reliable as the previous one for inferring on the level of water losses/waste. Finally, water consumption over treatment (2.1.3) provides a measure of how much of the treated water is actually being consumed. The closest these values are, the more sustainable the system.

Selected wastewater parameters take into account the ratio of wastewater collection (as a matter of production) over water consumed (2.2.1). As the designation itself indicates, wastewater is water that has been “transformed” into waste via its many different uses and that, for the sake of public health and environmental compliance, requires adequate collection, treatment and disposal options. A more sustainable system is one that minimizes the waste and so, the ratio should be as low as possible[3]. Conversely, the ratio between collected and treated wastewater (2.2.2) should be as close to the unity as possible. Given the threat to public health and environmental integrity, all of the wastewater that is collected should be adequately treated and disposed.

Wastewater can be treated in either wastewater treatment plants (WWTP) (2.3.1) or collective septic tanks (CST) (2.3.2). The first approach is the most desirable alternative, since WWTP can provide levels of treatment that CST cannot. Therefore, a more sustainable system is one for which treatment in WWTP is maximised. Conversely, the percentage of wastewater directed to CST should be kept to a minimum. These parameters were selected to comparatively assess the supply of treatment options in each municipality.

Solid waster parameters were selected to provide some information on the municipalities' population behaviour towards other environmentally-sensitive issues such as solid waste separation. The goal was to assess the population's potential for sustainable conduct and to possibly extrapolate for other sensitive-areas such as water and wastewater management. Per capita values of total urban solid waste collected (2.4.1) and recycled (2.4.2) were analysed, assuming the underlying concept that increased solid waste collection is a sign of a more wasteful society. On the other hand, a higher amount of recycled solid waste is seen as positive. In fact, the same is true for the ratio between recycled and collected solid waste (2.4.3). An environmentally-sound community is one that minimises the percentage of solid waste that goes untreated and/or is simply shipped over to a landfill. Yet, these are concepts derived from speculative reasoning, since there is no information on the quantities of uncollected solid waste and so, there is no actual measure of the environmental mindfulness of the communities.

The electrical energy use parameters were selected to complement the information derived from the previous indicators. Once again, the goal is to obtain some level of measure on the communities' behaviour towards the issue of wasting resources, electrical energy, for instance. Per capita consumptions were compared for total (2.5.1), household (2.5.2), agriculture (2.5.3) and industry (2.5.4) uses. These particular parameters were selected to allow the identification of the dominant energy users and infer on the potential for energy wastage. One hypothesis is that more wasteful energy consumption comes from household users. If that is the case, then the

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[3] This comparison between collected wastewater and consumed water cannot provide a very accurate measure of how much of the wastewater is not being collected. Also, leakages, inflows and stormwater are not being considered.

potential for energy waste increases with the per capita household share, thus dropping the community's sustainability rating.

4.3.3. Economic indicators

Economic indicators were sub-grouped into expenditure (3.1), revenue (3.2) and revenue over expenditure (3.3) and focused on four main budgets: municipality total, environmental, wastewater management and remaining environmental protection activities. Expenditure and revenue ratios were calculated to assess the relative weight of each one of the parameters over the group they belong to. For example, indicator 3.1.1 (environmental expenditure over total municipal expenditure) tries to assess how much of the total budget is assigned to environmental expenses. Likewise, indicator 3.1.2 (wastewater management over environmental) provides some information at how much of the environmental budget is spent solely on wastewater management activities. Expenditure and revenue parameters were also examined from a per capita perspective. The goal was to infer on the amount spent or gained per inhabitant of each municipality. Finally, revenues over expenditures were evaluated to find out and compare whether municipalities were able to balance the budget regarding environmental protection activities.

This selection of economic indicators is simplistic in its approach, as there is no differentiation of spending and revenue categories – operation and maintenance costs, reserve funds, etc. – and related short-term and long-term expenditures, for instance and as suggested by Sahely *et al.* (2005). These levels were not considered for lack of available data.

4.4. Weight assignment

From among the available options, the pairwise comparison weight definition per Saaty and Vargas (1991) described in Table 3.6 was selected for establishing the weight of each indicator, sub-groups and groups, following the AHP logic. Although other approaches such as ranking or point allocation for instance, could have been simpler and easier to implement, they rely on the researcher's intuition, which is more subjective than the selected method. The procedure stood out as the most dependable option for carrying out a consistent weight distribution, particularly since it included a control step designed to assess the quality of the weight assignment technique and revise it, if necessary.

Each individual indicator was compared to the others within the same sub-group and weights were assigned accordingly. Each tier was subjected to the procedure, starting out with the lowest level (tier 3, individual indicators). The following level (tier 2) was processed only after completion of tier 3, up to the highest level possible (tier 1). The results are presented in Tables 4.2–4.4. Individual weight assignment tables are presented in Appendix I.

Table 4.2 – Assigned weights – Social components

ID	1.1.1	1.1.2	1.1.3	1.2.1	1.2.2	1.2.3
ω_i	0.627	0.280	0.094	0.327	0.413	0.260
ID	1.1			1.2		
ω_i	0.167			0.833		
ID	1					
ω_i	0.333, 0.714, 0.143*					

Table 4.3 – Assigned weights – Environmental components

ID	2.1.1	2.1.2	2.1.3	2.2.1	2.2.2	2.3.1	2.3.2	2.4.1	2.4.2	2.4.3	2.5.1	2.5.2	2.5.3	2.5.4
ω_i	0.745	0.099	0.156	0.250	0.750	0.833	0.167	0.089	0.352	0.559	0.167	0.500	0.167	0.167
ID	2.1			2.2		2.3		2.4			2.5			
ω_i	0.293			0.293		0.293		0.073			0.047			
ID	2													
ω_i	0.333, 0.714, 0.143*													

Table 4.4 – Assigned weights – Economic components

ID	3.1.1	3.1.2	3.1.3	3.2.1	3.2.2	3.2.3	3.3.1	3.3.2	3.3.3	3.4.1	3.4.2	3.4.3	3.5.1	3.5.2
ω_i	0.528	0.333	0.140	0.200	0.600	0.200	0.528	0.333	0.140	0.200	0.600	0.200	0.250	0.750
ID	3.1			3.2			3.3			3.4			3.5	
ω_i	0.203			0.124			0.063			0.038			0.572	
ID	3													
ω_i	0.333, 0.714, 0.143*													

*Different weights assigned for sensitivity analysis

Expenditure indicators were consistently assigned greater weights than revenue indicators. This is due to the fact that, theoretically, expenditures carry with them negative impacts whereas revenues do not. Therefore, from a sustainable equilibrium standpoint, expenditures take on more significance than revenues do. In any case, one of the main deciding factors according to the weight model proposed is precisely sub-group 3.5. It was designed to translate the importance of operating in a scenario where revenues and expenditures are balanced. As will be seen later, this is not the case for any of the target municipalities. Nevertheless, this is a desired condition and, as such, was rated accordingly.

In tier 2, sub-groups that included indicators directly related to water and wastewater infrastructure sustainability were assigned higher weights than the remaining sub-groups. This is the case for sub-groups 1.2, 2.1, 2.2, 2.3, 3.1 and 3.5. Sub-groups of indicators designed to provide some sort of indication as to the overall behaviour of the each municipality's population towards environmentally-sensitive areas consistently obtained much lower weights.

Since sustainability is typically defined by the equilibrium between three major groups of factors, each one of the tier 1 divisions was initially assigned equal importance, or one third of the total weight each. As the results were obtained, it was decided to carry out a sensitivity analysis step in which each group was assigned a greater weight than its counterparts. This was done in order to verify whether the ranking order would be sustained under these varying conditions and establish which municipality would be stronger or weaker in terms of what evaluation component, social, environmental and/or economic. The assigned weights (by pairwise comparison) are indicated in Tables 4.2–4.4. Whenever a group was assigned a weight of 0.714, the two other groups were assigned an equal weight of 0.143. Naturally, more combinations would have been possible, including those resulting from assigning a different weight to all of the groups as long as one would clearly stand out. However, it was decided not too carry this sensitivity analysis to the extreme and thus the exercise was left to the conditions described.

4.5. Criteria definition

Criteria definition was mainly left to conceptual considerations given the unavailability of published standard and/or boundary values that would enable a more precise definition. Criteria were defined based on the hypotheses put forward during the rationale for selecting the final round of indicators. For example, when looking at population densities, it was assumed that a population that is more compact requires smaller, more manageable and thus, more sustainable systems. In this case, the criteria would be: the smaller the better, down to a critical point (critical mass). It was not possible to find out, for this particular parameter, the critical population density for which it would no longer be feasible or recommended that whole infrastructure systems be designed and built. Therefore, a decision was made to uphold the original hypothesis and regard smaller systems as the more sustainable option. Therefore and in this case, the criterion was "smaller", meaning a municipality with a denser population would get a better score than one that was more sparsely populated. A similar exercise was conducted for the remaining indicators.

The case for service coverage (accessibility, sub-group 1.2) emerged as the exception that, nonetheless, allowed for no more than an academic exercise in setting a rating scale based on a series of boundary values. In this particular case, a very simple threshold scale was developed as presented in Table 4.5, using standard minimum coverage values published in the PEAASAR 2007-2013, previously presented and discussed in Chapter 1.

Table 4.5 – Threshold scale for 1.2 indicators

Thresholds	Rating
Below standard	0
At standard	1
Above standard	2

A similar exercise was conducted for data included in sub-group 3.5, in which revenues over expenditures were evaluated. As mentioned earlier, these indicators served the purpose of inferring whether municipalities were able to balance the environmental budget by producing revenue to expenditure ratios of one. Ratios below the unity would be considered as having a less positive impact but not as negative as ratios above the unity. Therefore, a scale was developed accordingly (Table 4.6).

Table 4.6 – Threshold scale for 3.5 indicators

Thresholds	Rating
Above unity	0
Below unity	1
At unity	2

Ratings were assigned as follows: higher (2 points) rating to situations where revenues and are balanced, intermediate (1 point) to situations on their way to become balanced and lower (zero points) to situations past the balance.

The remaining indicators were subject to more theoretical, if not speculative, reflections involving their nature and potential contribution to the overall sustainability score. In fact, criteria were essentially assigned on the basis of each indicator being either a contribution to or detraction from the final desired goal, *i.e.*, sustainability of the system, according to the rationale that led to the inclusion in the final list. This carried direct implications onto the data normalisation step, that required each indicator to be categorized as either a benefit (B) or a cost (C), depending on how an increase in each relative value is taken as either a desired (beneficial) or undesired (costly) development. Therefore, a rating scale was not defined for any of the remaining indicators *per se*, only a statement of whether an increase or decrease in relative score would result in an advantageous or disadvantageous change. The criteria then became "high" or "low", depending on the category assigned to the corresponding indicator.

4.6. Analytical approaches

Early on, there was an attempt to infer on the baseline of each municipality with regards to population size and infrastructure availability. Since there was no certain information on this subject, the reasoning with respect to these issues is largely one of a deductive nature derived from observations on available data. Initially, it was thought that the systems already in place, were due to the fact that critical mass had been attained in the past, thus justifying their existence.

A problem with this logic is that water and wastewater infrastructure systems are not dimensioned according to population sizes but rather according to their per capita flows of consumed water and produced wastewater. In fact, the number of inhabitants parameter becomes rather secondary when compared to these new variables, since locations may differ in their economical make-up. Depending on the number and type of dominant economical activities, per capita flows may differ. Locations that are sparsely populated but where industrial activities dominate may produce similar of even higher equivalent per capita wastewater flows when compared to areas that are mainly residential. That being the case, population sizes do not actually matter as much as the relative units of resources consumed and waste produced.

In terms of sizing wastewater infrastructure, typical design values range from 230 to 420 litres per capita per day overall, and more specifically for domestic outputs, between 270 to 380 litres per capita per day (ASCE, 1998). The data available allowed a quick estimation of what the per capita wastewater flows might have been in 2005 of each of the municipalities under study. The results are presented in Table 4.7.

Table 4.7 – Wastewater flows per capita

Municipality	Wastewater flows based on wastewater data L/(inhab.day)	Wastewater flows based on water data L/(inhab.day)
Alijó	2	5
Mesão Frio	7	21
Murça	37	37
Peso da Régua	319	320
Sabrosa	93	82
Santa Marta de Penaguião	30	34
Vila Pouca de Aguiar	13	19
Vila Real	614	765

Values were also calculated based on water consumption figures, assuming that the volume of wastewater produced is approximately 70% of the volume of water consumed. This approximation was based on typical range from 60 to 90%, where the lowest value is typically used for semi-arid locations (ASCE, 1998). In either case, Peso da Régua is the only municipality that meets the typical design criteria. Except for Vila Real, all other municipalities report values well below the typical range. The very low magnitude of the values obtained suggests one of three possible explanations: (1) wastewater production is indeed extremely low; (2) wastewater is not being captured and is bypassing the existing collection, treatment and disposal system; and/or (3) the reported values are inaccurate.

The lowest per capita daily flow ascribed per residential sources is typically 40 litres per inhabitant per day (ASCE, 1998). None of the municipalities above meets this value and as will be seen, these are not strictly residential municipalities. Therefore, the first explanation is not valid.

The second hypothesis is more pertinent. Given the percentage of wastewater that is collected and treated using CST, it is not unreasonable to think that in some instances, these are being rejected in favour of direct discharges into waterways or land-application. In these situations, the volumes are not accounted for, which might justify the low values reported above. A third option is that data may not be as accurate as desired and flows are underreported. In this case, data cannot be relied upon and should not be used for further analysis.

In short, there are no conclusive data to allow further considerations on the matter as is. The underlying assumption regarding per capita flow production cannot be proved or disproved based on the existing information and therefore, it was decided to go back to the original contention of using population size as a surrogate measure of whether a system should be implemented or not. In order to circumvent the lack of unambiguous information (*i.e.*, how many people are sufficient people?) two approaches for analysis were defined: a first one where population sizes were considered to be below critical numbers, and a second one, where the opposite condition was assumed.

These distinct approaches interfere with the original categorisation of this indicator as either a cost or a benefit –per data normalisation method- in the sense that in the first scenario, a population increase would logically be a benefit as it would bring its size closer to the desired number. Naturally, the second scenario defined an increase in population as a cost, assuming the systems were not designed to handle larger population and thus, would be exposed to increased stresses.

A similar reasoning was carried for the economic indicators group. Since no reference values regarding desirable expenditures and revenues were found, two analysis scenarios were also assumed: one in which current expenditures do not guarantee the sustainability of the systems and thus, require additional spending (a benefit, thus), and another in which expenditures are already at a sustainable level and further spending would be regarded as a nuisance (cost). On the other hand and in theory, revenues from environmental protection activities would be desirable for promoting the system's economic sustainability. However, that may not be the case, particularly when the systems depend on more than local funding to be implemented, operated and maintained.

One line of thinking determines that the greater the revenue from a particular activity the lower the chances for getting additional subsidies from the central government and therefore, an increase in local revenues would not necessarily be regarded as a desirable affair. Conversely, full-scale urban water and wastewater systems become necessary for many reasons, including public health, environmental protection, development and convenience. Once these needs are established, implementing such systems is a matter of providing an essential public service and typically, economic imbalances between expenditures and revenues are not deterrents. In fact, the majority of public services and projects are implemented and carried out even when there are no expectations of generating any profit from them (their estimated net present value is negative), because they are designed to meet a public need and that is seen as the main motivator and promoting factor for these types of projects. Conversely, private businesses typically do not move forward with projects or activities unless there is a fairly certain chance that they are to generate profit and at least some level of self-sustainability. Some of these ideas have been gradually adapted by municipal managing groups and the onset of municipal companies with similar financial managerial styles is proof of a renewed concern with the economic sustainability of systems.

In short, two scenarios were established: (1) scenario A or "Baseline", that considers population sizes to be below a threshold dimension, and expenditures and revenues to be below a desired level; and (b) scenario B or "Established", under which population sizes are at or above critical mass, and expenditure and revenues are at or above desired levels. The analytical approaches are summarised in Figure 4.4.

Scenario A – Baseline

Lack of critical mass for implementing infrastructure

Expenditure below desired level

Revenue below desired level

Scenario B – Established

Critical mass attained

Expenditure at or above desired level

Revenue at or above desired level

Figure 4.4 – Analytical scenarios

One additional remark concerns the issue of determining whether sub-group 3.5 indicators - ratio of revenues over expenditures for both total environmental and wastewater management activities– depend on the analytical approach thus defined or not. For the purposes of this analysis, a sustainable system is one where revenues and expenditures are balanced and thus, their ratio is one.

Scenario A assumes that expenditures are below a value that would be desired and therefore, an increase would be desirable. As for revenues, they would be required to increase only up to where they would match the expenditures (optimal point) and no more than that. A ratio below the unity implies that this condition is has not been met and thus, an increase in ratio would be desirable and consequently, deemed a benefit. Alternatively, an increase in a ratio that is already at or past the optimal point implies the deviation in excess from the ultimate goal and therefore, both situations are classified as costs. Under scenario B, it is assumed that expenditures are already at a desired level. Once again, the increase in revenue over expenditure ratio up to the unity is a benefit. And likewise for scenario A, the increase in ratio beyond the desired set point of one represents an unwanted situation and thus the parameter is deemed a cost. Consequently, how these indicators are classified is independently of the established scenario.

The remaining indicators (sub-groups 1.2, 2.1, 2.2, 2.3, 2.4, 2.5) were considered to be scenario-independent as well.

4.7. Categorisation as cost or benefit

Indicator categorisation as either a cost or a benefit bears a direct influence on what data normalisation equation to adopt. Table 4.8 presents the list classification assigned to each indicator and where pertinent, according to analytical scenario.

Table 4.8 – Classification of indicators and governing criteria

ID	C/B?		ID	C/B?		ID	C/B?	
	Scenario A	Scenario B		Scenario A	Scenario B		Scenario A	Scenario B
1.1.1	B	C	2.3.1	B		3.2.1	B	C
1.1.2	B	B	2.3.2	C		3.2.2	B	C
1.1.3	C	C				3.2.3	B	C
1.2.1	B		2.4.1	C		3.3.1	B	C
1.2.2	B		2.4.2	B		3.3.2	B	C
1.2.3	B		2.4.3	B		3.3.3	B	C
2.1.1	B		2.5.1	C		3.4.1	B	C
2.1.2	B		2.5.2	C		3.4.2	B	C
2.1.3	B		2.5.3	C		3.4.3	B	C
			2.5.4	C				
2.2.1	C		3.1.1	B	C	3.5.1	B	
2.2.2	B		3.1.2	B	C	3.5.2	B	
			3.1.3	B	C			

As explained earlier, total population (1.1.1) was considered a benefit or cost depending on analytical scenario. Population density (1.1.2) was considered a benefit. Assuming that population density is a reliable measure of dispersion, then an increase in density translates into an increase of the systems' ability to meet the population needs, *ergo*, a potential increase in sustainability. Old-age dependency ratio (1.1.3) was deemed a cost. The older the population, the greater the dependency on reliable, sustainable infrastructure. Therefore, the older the population, the less sustainable the system might be.

Population served by water systems (1.2.1), wastewater systems (1.2.2) and wastewater treatment plants (1.2.3) were all classified as benefits, because the greater the coverage, the better the chance to meet or exceed minimum regulated criteria and thus, the greater the possibility for increased sustainability.

The water indicators – consumption/intake (2.1.1), treatment/intake (2.1.2) and consumption/treatment (2.1.3) – were all considered as benefits. These indicators were selected based on the assumption that they would serve as surrogate measurements of the tendency for water waste and/or losses. According to that line of reasoning, a greater the ratio implies a lower waste and/or loss of water and an increased potential for sustainability.

Wastewater collection/water consumption (2.2.1) was classified as a cost. The implications are two-fold: as seen in section 4.5, an increased volume of wastewater versus what would be expected by extrapolating over historical water consumptions might mean an increase in the quantity of wasted volume. On the other hand, if the wastewater collection system includes stormwater collection and/or is disturbance by leakages and/or inflow, then variations in collected volume cannot be solely correlated to water consumption. In any case, the greater the volume of wastewater collected, the greater the stress on the system and its sustainability. Conversely, wastewater treatment/wastewater collection (2.2.2) was deemed a benefit. Ideally, all of the collected wastewater should be treated. Hence, the greater the ratio, the smaller the volume of untreated wastewater, which in itself is an obvious benefit from an environmental and public health sustainability point of view.

As for wastewater treatment facilities, treatment in WWTP (2.3.1) was considered a benefit, since plants can provide treatment options that are both qualitative and quantitatively superior to those available from collective septic tanks. Therefore, an increase in the percentage of the total collected wastewater that gets sent to WWTP implies an increase in the system's sustainability. In contrast, treatment in CST (2.3.2) is comparatively disadvantageous. Thus, the greater the volume of wastewater treated by CST, the less sustainable the system might be. Nevertheless, these considerations should not be misconstrued as a disregard for CST technology when in fact, it has proven its worth and it has enjoyed a continuous applicability status, particularly in locations where a more involved treatment infrastructure has not yet been feasible. When no other wastewater collection and treatment options are available, CST are viable technology alternative despite their operational simplicity and long-standing design.

With regards to solid waste, total urban solid waste collected (2.4.1) expressed in terms of mass per capita was deemed a cost. Keeping in mind the purpose behind the selection of this parameter, it was assumed that the greater the mass of solid waste produced per capita the greater the impact on the environment and thus, the lower the potential for sustainable behaviour exhibited by the population. On the other hand, the per capita total urban solid waste recycled (2.4.2.) indicator was considered a benefit. As recycled waste constitutes a fraction of the total waste produced, recycling not only reduces the amount destined for discarding into a landfill, it also affords a means for a getting some worth out of solid waste and thus, the greater the amount of recycled waste per capita, the more sustainable the community. Similarly, the greater the percentage of recycled over total collected waste (2.4.3), the smaller the portion that remains untreated and sent to a landfill. Note that other solid waste management approaches are possible, such as composting and use of solid waste as raw material for energy production. These are documented and recorded as part of the solid waste handling and treatment processes existing in the country. However, as of 2005, no data was reported for the target municipalities.

Electrical energy uses were included for the same reason as solid waste data. Per capita uses (2.5.1, 2.5.2 and 2.5.3) were all classified as costs. Depending on the source, energy consumption may heavily tax natural resources, whether by depleting them (source material) or by polluting the environment (*i.e.*, the case of industrial emissions derived from fossil fuel use for energy production). The region is amongst the better served by renewable energy sources when compared to others throughout the country (DGEG, 2007). However, it was not possible to obtain sufficient data to estimate how much of the recorded uses derive from the renewable production. Therefore, and to take on a more conservative stance, it was assumed that greater the use of energy, the greater the drain on natural resources and thus, the greater the cost to sustainability.

Economic indicators were divided in expenditures and revenues. Expenditures (3.1.1, 3.1.2, 3.1.3, 3.2.1, 3.2.2 and 3.2.3) were all considered benefits or costs depending on the analytical approach. Both revenue over expenditure indicators (3.5.1 and 3.5.2) were deemed beneficial in terms of the rating scale presented in section 4.5. How these ratios were considered did not depend on the approach scenario but rather on how they fared against a desired optimal value.

4.8. Data collection

Quantitative data collection was carried out for each indicator, taking advantage of readily available digital databases published by Statistics Portugal (INE), Waters of Trás-os-Montes and Alto Douro (ATMAD, *Águas de Trás-os-Montes e Alto Douro*) and Water Supply and Wastewater Systems National Inventory (INSAAR, *Inventário Nacional de Sistemas de Abastecimento de Água e de Águas Residuais*) and other sources, where noted.

4.8.1. Temporal issues

One the main concerns regarding comparative analyses is that a consistent and identical frame of reference be established and/or available for each of the alternatives under scrutiny. In other words, spatial and temporal frames should be set at the same scale and naturally, that implies that data are available for any and both of these frames of reference. It was also mentioned that MCA tends to be a snapshot-type of analysis since it focuses on a particular point in time, as opposed to a dynamic analysis that is able to process and examine data progression for any number of indicators. This does not mean that MCA cannot be used to evaluate data progression over time or space, only that each MCA round can only look at a point at a time. A series of MCA rounds each looking at distinct time periods can, in fact, be combined to provide a dynamic view of how the system is evolving. To put it differently, each set of alternatives would be subjected to an MCA round and each round would correspond to a different year. Hence, there could be a “year 1-MCA”, “year 2-MCA”, “year 3-MCA” and so forth, each yielding a corresponding set of scores and alternative rating. These could then be compared and possibly interpreted in terms of trend forecasting and such. Conversely, data could be processed in terms of trend coefficients and these could replace the simpler form of indicators. In that case, a single MCA exercise would suffice to score and rate the alternatives in terms of trends exhibit for the study period (a five or ten-year period, for instance).

Regarding the work presented herein and despite the vast numbers of data collected, 2005 was the only year for which it was possible to address all of the selected indicators (Table 4.9).

Table 4.9 – Periods of data availability

ID	Period for which data are available	ID	Period for which data are available	ID	Period for which data are available
1.1.1 1.1.2 1.1.3	2000 – 2006	2.4.1 2.4.2 2.4.3	2002-2006	3.2.1 3.2.2 3.2.3	2004-2005
1.2.1 1.2.2 1.2.3	2001-2006	2.5.1 2.5.2 2.5.3 2.5.4	2000-2005	3.3.1 3.3.2 3.3.3	2004-2005
2.1.1 2.1.2 2.1.3	2005	2.6.1 2.6.2 2.6.3	1994-2005	3.4.1 3.4.2 3.4.3	2004-2005
2.2.1 2.2.2	2005	3.1.1 3.1.2 3.1.3	2004-2005	3.5.1 3.5.2	2004-2005
2.3.1 2.3.2	2005				

Unfortunately, though data were available for many of the indicators for periods up to 5 years or more, these were mainly partial sets that could not be used for a more “dynamic” analysis. Therefore, the methodology was applied to 2005 data only. However, observed trends and additional data were used to characterize, understand and explain the observed results.

4.8.2. Data processing and score calculation

All data available for analysis were deterministic and thus, methods such as utility functions and probability approaches –for probabilistic data– and those available for fuzzy data were not applicable. Instead, the two linear scale transformation (LST) methods –score range (SR) and maximum score (MS)- .were used as explained in Chapter 3 and described by equations 3.10 through 3.14 according to whether the target indicator was classified as a benefit or a cost. Also, the categorisation of an indicator as either bears directly on the definition of the governing criterion, as mentioned earlier in this chapter. Two data normalisation methods were used to test the robustness of the assessment methodology.

4.8.2.1. Score calculation

Scores were obtained by resorting to the weighted linear combination (WLC) approach described in Chapter 3. Using the weights previously assigned to each indicator, a series of partial scores were calculated first for tier 3. Then, the results were once again subject to the WLC method using the weights assigned to tier 2 and so forth, until a final set of global scores was obtained for the eight target municipalities. Since the ordered weight average (OWA) procedure was not used, the results obtained represent an obvious trade-off scenario, where the effects of detrimental scores were offset by better ones.

4.9. Complementary work

Complementary work was carried out to establish the history of non-compliance events (NCE) with regards to treated wastewater quality standards for the WWTP identified in each municipality. As mentioned before, this is a parameter that could not be included in the final indicators list due to the lack of sufficient data for the selected period of analysis. However, it was deemed important and worthy of further consideration. The work performed on this parameter and preliminary results are presented and discussed in full in Appendix II. Data for this preliminary analysis were obtained only for WWTP managed and operated by ATMAD.

5. CASE STUDY: SELECTED MUNICIPALITIES FROM DOURO AND ALTO TRÁS-OS-MONTES

Northeastern Portugal encompasses the general area selected for studying the implications of the methodology presented earlier. Occupying approximately 12 280 km^2 (INE, 2008), the area includes the currently designated NUT[1] III sub-regions of Douro and Alto Trás-os-Montes[2] (INE, 2006). See Figure 5.1.

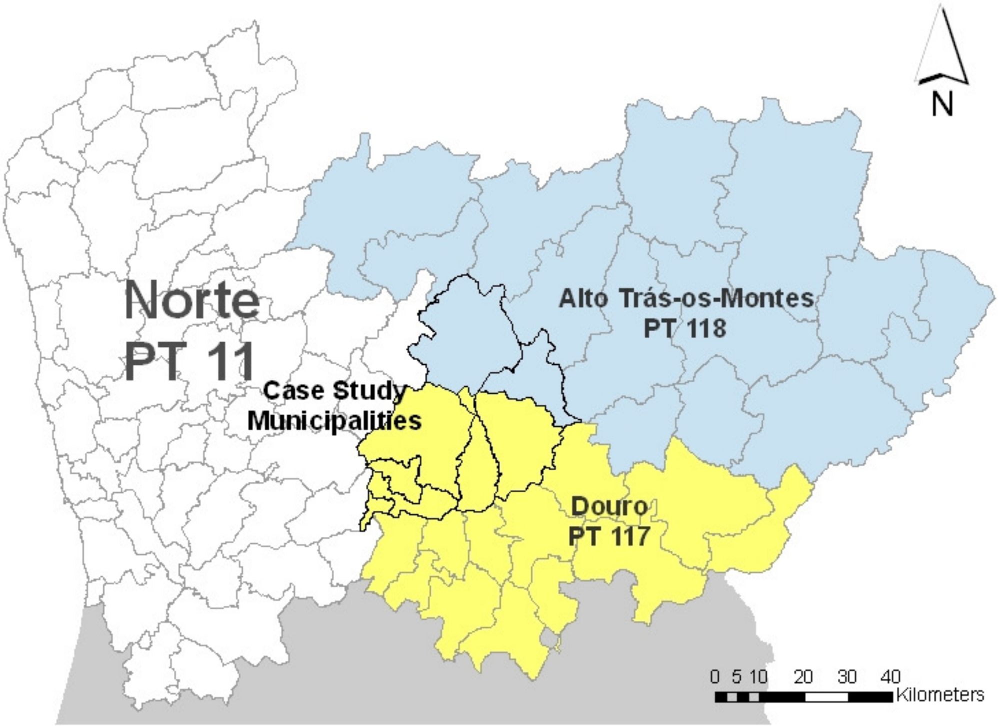

Figure 5.1 – Case study area

The sub-regions are included in NUT II Norte, in terms of the Portuguese revision of its previous statistical partitions according to the European Nomenclature of Territorial Units for Statistics (NUTS) guidelines (EC, 2005; EC, 2007). Douro and Alto Trás-os-Montes are further divided into 33 municipalities (*concelhos*), as listed in Table 5.1. Of these, a cluster of eight municipalities was selected as case study.

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[1] Nomenclatura de Unidade Territorial (INE, 2006).

[2] Not to be confused with "Trás-os-Montes and Alto Douro", a designation belonging to the province system of 1936–1976 and that remains, to this day, as the most popular term for referring to the region.

Table 5.1 – Municipalities in the sub-regions

NUT III: Douro (PT 117)		NUT III: Alto Trás-os-Montes (PT 118)	
Alijó Armamar Carrazeda de Ansiães Freixo de Espada à Cinta Lamego **Mesão Frio** Moimenta da Beira Penedono **Peso da Régua** **Sabrosa** **Santa Marta de Penaguião**	São João da Pesqueira Sernancelhe Tabuaço Tarouca Torre de Moncorvo Vila Flor Vila Nova de Foz Côa **Vila Real**	Alfândega da Fé Boticas Bragança Chaves Macedo de Cavaleiros Miranda do Douro Mirandela	Mogadouro Montalegre **Murça** Valpaços **Vila Pouca de Aguiar** Vimioso Vinhais

The following text provides a general overview of the target area, presenting the reasons for its selection. A more detailed description of the some of the region's features is presented afterwards.

5.1. General overview

The sub-regions display a series of characteristics including climate, mountainous morphology and historical population dynamics – decreasing population densities, aging population, high unemployment rates – that have historically contributed to hinder mobility and decrease development. Consequently, the sub-regions remain some of the poorest in Portugal and Europe. The access to comprehensive infrastructure networks (namely for water and wastewater service) has also been limited in the past, though the level of infrastructuring is now elevated. As mentioned in Chapter 4, this type of conflicting situations may bring into question the long-term sustainability of the many systems that support Douro and Alto Trás-os-Montes.

The eight municipalities in bold (Table 5.1) – Alijó, Mesão Frio, Peso da Régua, Sabrosa, Santa Marta de Penaguião and Vila Real from Douro, and Murça and Vila Pouca de Aguiar from Alto Trás-os-Montes – were selected for a variety of reasons, including their transitional location between coastal areas and the interior. Also, they were considered to be adequate representatives of the general characteristics of the sub-regions.

The area is typically dry and prone to severe drought episodes. Such examples include the 1993 and the more recent 2004-2005 droughts, which affected many municipalities in the region, including Vila Real and Vila Pouca de Aguiar that were classified as critical areas. These events are not as severe for the municipalities in the Douro river banks, such as Mesão Frio, Peso da Régua, Sabrosa and Alijó, that benefit from the microclimate effect imparted by the vicinity to the Douro river.

The typically dry character of the sub-regions does not preclude the occurrence of floods that, although not as critical as droughts, also result in severe impacts to the affected areas. Peso da Régua is usually critically affected and more so than its counterparts, since the western side of the sub-regions typically receives increased precipitation rates.

The complex morphology of the terrain is also varied and responsible for some of the differences between municipalities that are, nonetheless, located in such close proximity. These affect the manner in which water and wastewater infrastructure can be implemented. For example, Peso da Régua's shape and morphology is complex in a way that is not very favourable and therefore, more difficult for water systems infrastructuring, whereas wastewater infrastructure implementation might be better at negotiating the complexities of the terrain (via gravity lines).

Not unlike other municipalities in Northeastern Portugal, land uses for the area essentially relate to agricultural and forestry uses, consequence of an overall decrease of natural areas brought by the increase in low density urban uses and mixed agriculture occupation. However and despite their influence, urban uses continue to have little expression in the study area. Population clusters are not limited to areas indicated as urban uses, so their small dimension and scattered nature carries some significant consequences in terms of service coverage, particularly with regards to comprehensive water and wastewater systems.

Notwithstanding the impact of increasingly shifting climate conditions, harsh topography and population dynamics, this is an area that has seen significant improvements in some fundamental sectors such as water, wastewater and transportation infrastructure, agricultural productivity, health services and tourism, as a result of specific local planning and management programmes, complemented by a series of strategic plans and programmes that have recently been released and are now in the initial stages of implementation, suggesting the continued improvement of the region.

5.1.1. Topography and natural features

The sub-regions feature diverse topographic elements consisting of mountain ranges, plateaux and deep valleys (Appendix III). The rich natural and environmental features led to the implementation of several Natural Parks, such as the International Douro, Alvão, Azibo and Montesinho, for the protection and promotion of their great biodiversity and high-quality natural characteristics. The country's only national park, the Peneda-Gerês National Park (PNPG), is partially included within the Alto Trás-os-Montes territory, located northwest of the study area (Figure 5.2). Regional development is taking into account the many aspects related to protect and promote its natural heritage. Over 40% of the Norte areas are covered by natural protection programmes such as the National Ecological Reserve (REN, *Reserva Ecológica Nacional*), Natura 2000 Network, (*Rede Natura* 2000) (CCDRN, 2007).

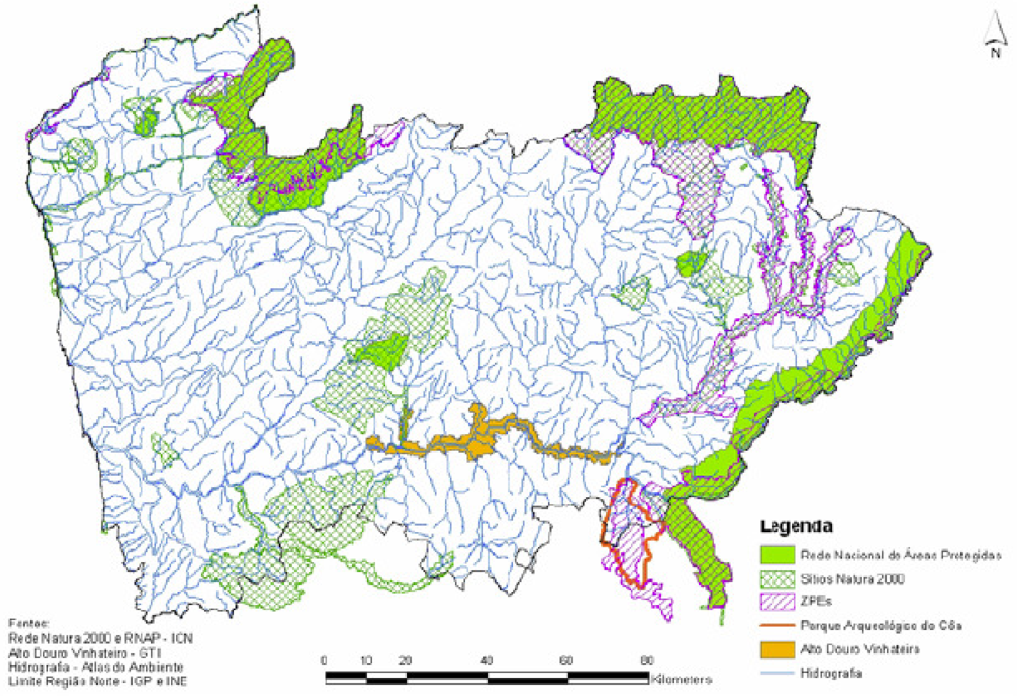

Figure 5.2 – Classified areas in Norte (CCDRN, 2007)

The landscape has remained predominantly natural, safe for the man-made terraces devoted to wine-farming in the Douro river banks and closer tributaries, and other region-specific land uses. Furthermore, the Douro sub-region exhibits a large diversity of morphological, ecological and climate conditions, displaying great natural and cultural heritage variety with a humanized, evolving landscape derived from the work by successive generations. These have secured the Douro Valley area the classification of World Heritage by UNESCO in 2001, joining the pre-historic rock art carvings in the Côa Valley, that were themselves likewise classified in 1998.

The sub-regions' energetic potential was also taken into account. Recognizing wind as a strategic natural resource of national dimension, several facilities have been constructed over the past decade. There are approximately 244.9 MW of total installed capacity from wind farms scattered across the region (Rodrigues, 2007). Projected installations include an additional capacity up to 600 MW, namely in the vicinity of Bragança (Agência Lusa, 2007). Dams for hydroelectric production can also be found throughout the entire region (see sub-section 5.1.3 ahead).

5.1.2. Climate

The northern part of the sub-regional area is locally designated as *Terra Fria* (*i.e.*, cold land) due to typically harsh winters of very low temperatures frequently below zero degrees centigrade and frequent precipitation. Conversely, summers are very hot and comparatively dry and the area has been traditionally described by residents as one of "nine months of winter and three months of hell". Milder climate conditions are found at lower latitudes, particularly in the upper Douro areas (*Terra Quente* or hot land), where the climate displays typical Mediterranean characteristics.

The heterogeneous topography of the area is responsible for the rather severe variations in climate conditions throughout the year. Spatial climate variations can be quite extreme as well, leading to microclimate areas originated by differences in sun exposure and wind direction caused by the distinct morphological features of the terrain. Temperature varies accordingly, with higher altitude areas exhibiting average annual temperatures between 8.1 and 12.0 degrees centigrade. A range of 12.1 to 15 degrees centigrade is observed for lower altitude areas. Average annual precipitation also varies throughout the study area, where the western locations receive between 1 201 to 2 800 mm versus the 501 to 1 200 mm measured for the eastern parts of the sides of the area (INAG, 1999). Temperature and precipitation charts are presented in Appendix IV.

5.1.3. Hydrological characteristics

The Douro and Alto Trás-os-Montes sub-regions are mainly included within the Douro river basin, occupying a comparatively much smaller area within the Cávado river basin. The Douro river basin includes a total of 17 sub-basins corresponding to tributary rivers, either completed or partially located within the case study region. As observed in Appendix V, there are a total of 43 large and small dams located within the sub-regions within the area. These structures account for an equal number of artificial lakes and reservoirs designed to fulfil a number of different purposes (Figure 5.3).

The built-in water storage capacity is devoted mostly to the generation of hydroelectric power (66.43%) and water transfer between reservoirs (diversion, 15.66%). A total installed capacity of 1 685 MW generates approximately 6 310 GWh per year (CNPGB, 2007).

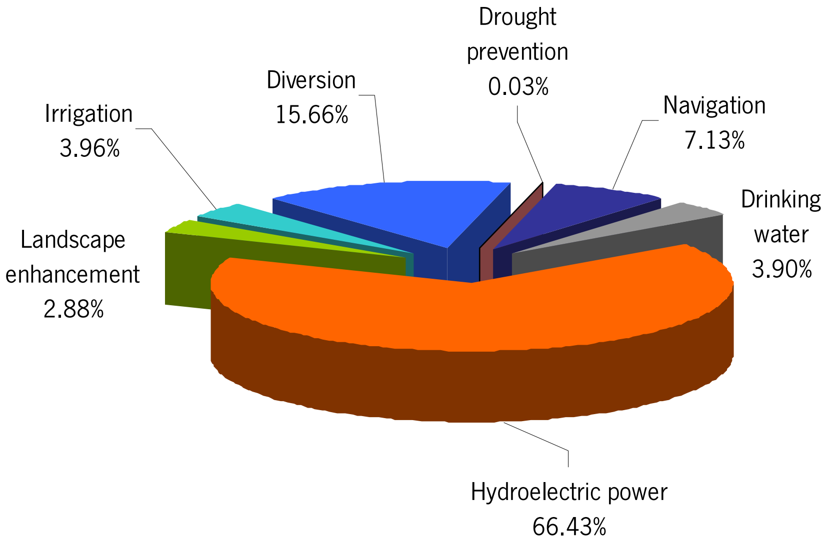

Figure 5.3 – Purpose of basins and reservoirs in Douro and Alto Trás-os-Montes

Nevertheless, given the region's history of severe hydrological situations such as droughts and floods, this network of storage reservoirs serves also the purpose of partially counteracting the effects of such extreme episodes, though that purpose was reported only for the Mirandela Dam in Rio Tua.

Droughts[3] occur more frequently during the period of April through September (3rd and 4th trimesters of the hydrological year). Regardless of the severity, they are more frequent in the Tâmega, Paiva, Varosa and Torto rivers sub-basins. Conversely, the Sabor, Côa, Tua, Arda are the least frequently affected. Droughts are particularly harsh for Bragança and Vila Real, and within the Côa, Sabor and Tua rivers sub-basins, affecting Macedo de Cavaleiros, Miranda do Douro and Alfândega da Fé. During the 1993 drought, these municipalities and Vila Flor, Mogadouro, Torre de Moncorvo, Vila Real and Vila Pouca de Aguiar were deemed critical areas, affecting over 50% of the population (INAG, 1999). More recently, the exceptionally severe drought of 2004-2005 was the worst of the past 65 years (MAOTDR, 2006).

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[3] Understood as the meteorological phenomenon where the measured precipitation for a given period is below the average precipitation on record for that period (INAG, 1999).

Flooding is another extreme hydrological situation that has been observed for the region,, albeit less critical due to historical monitoring by public entities and populations. Peso da Régua Alijó and Sabrosa are located within dam-rupture segments. Also, one of the few flood critical points that have been identified located in Peso da Régua.(INAG, 1999; SNIRH, 2003). See Figure 5.4.

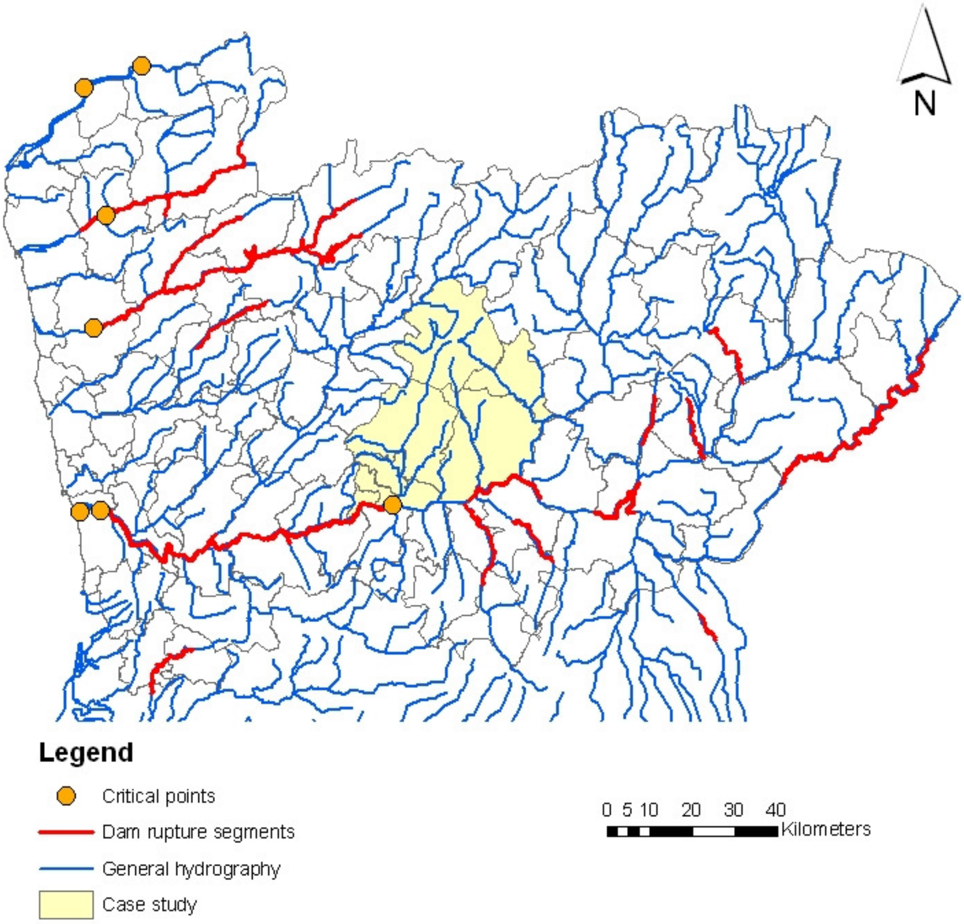

Figure 5.4 – Flood-risk areas in the Norte region

Areas affected by potential dam rupture include Carrazeda de Ansiães, S. João da Pesqueira, Tabuaço, Torre de Moncorvo, Alfâdega da Fé and Macedo de Cavaleiros. Areas affected by 100-year floods are Mirandela (Tua river) and Torre de Moncorvo (Ribeira da Vilariça). Flood spots on record include most of the Alto Trás-os-Montes and Douro sub-regions but appear to be more prevalent on the western side of the study area, because of the higher precipitation rates observed and discharges from dams.

5.2. Land uses

As mentioned previously, the region is home to a vast array of natural and landscape elements comprising a natural heritage that is intimately linked to the agro-forestry uses of the land. With regards to rural development, three main trends have been observed: (1) the complementarity and interchangeability between agricultural, forestry and tourism uses; (2) the global regression of the agro-forestry uses, and (3) the expansion of barren land. In regional terms though not in a homogeneous manner, agricultural uses have decreased while forested and barren land areas have increased. Between 1990 and 2000, there was an increase in the areas devoted to urban uses, vineyards, eucalyptus forests and areas lost to forest fires, particularly around the urban cluster of Alto Trás-os-Montes (CCDRN, 2007; Lourenço *et al.*, 2008). The Corine Land Cover 2000 presented in Appendix VI provides additional information about the specific land uses in the region.

5.3. Social features

According to the latest estimate update (INE, 2008), population in Douro and Alto Trás-os-Montes totalled 214 045 and 217 882 inhabitants[4], respectively, or approximately 4.1% of the country's total population (Table 5.2).

Table 5.2 – General population and territory statistics for 2005 (INE, 2008)

Location	No. of inhabitants	Surface area (km^2)	Population density (inhabitants/km^2)
Portugal	10 569 592	92 090	115
Norte	3 737 791	21 286	176
Douro	215 527	4 108	52
Alto Trás-os-Montes	219 240	8 172	27

In terms of population density, these are considered sparsely populated areas, yielding a mere 43 inhabitants per km^2 (weighed average), a value that is significantly below the national average of 115 inhabitants per km^2. Historically, population numbers have been gradually declining for the entire region, a trend that is projected to continue (INE, 2008). Alto Trás-os-Montes has seen a more drastic reduction, as opposed to Douro, which has seen a steady, albeit smoother, decrease. The sub-regional population decline is not observed at a regional level. In fact, Norte has seen its population increase, which is expected to endure for at least a few more years. This phenomenon matches the trends observed at a national level, for which growth rates, though positive, have been decreasing over time, showing that the overall population growth has entered a deceleration or stagnation phase (INE, 2005). Figure 5.5 below presents the base level

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[4] Figures for 2006 (INE, 2008).

evolution predicted for population growth and/or decline at a national, regional and sub-regional level. A slight population increase is expected up until around 2010 for both Portugal and the Norte region, while Douro and Alto Trás-os-Montes are expected to retain their full declining mode.

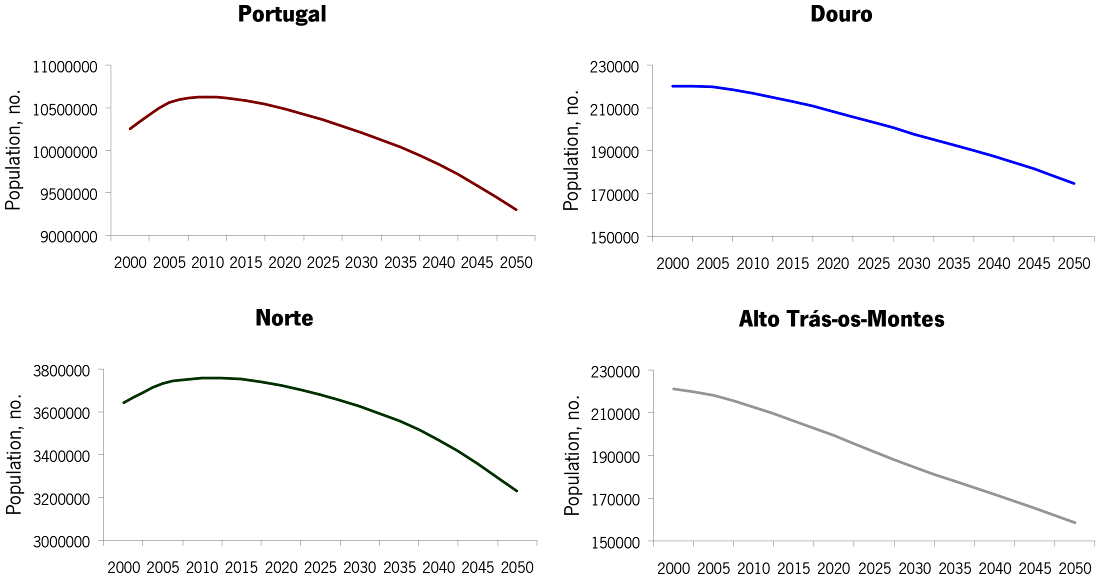

Figure 5.5 – National, regional and sub-regional population projections for 2000-2050 (INE, 2005)

This population decline is related to several local factors, including migration in search of better employment opportunities towards the more developed coastal areas or even abroad.

Local employment and unemployment trends are directly related to the effects of globalisation, as observed in recent years across the region (CCDRN, 2007). Unemployment rates[5] for Douro and Alto Trás-os-Montes are high to moderate, at 5.16% and 3.84%, respectively, compared to the national average of approximately 4.03% (IEFP, 2008; INE, 2008). Nevertheless, when compared against European averages, all are favourable rates well on their way towards meeting the European Strategy for Employment recommendation of global employment rates of 70% by the year 2010 (CCDRN, 2007).

5.4. Economic overview

The sub-regions remain amongst the poorest in the Country. Their contribution to the national gross domestic product (GDP) has consistently been approximately 3% combined (INE,

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[5] Values for 2006 (IEFP, 2008; INE, 2008).

2008). Figure 5.6 illustrates the relative share of the GDP[6] for 2004[7], attending to the fact that the values remained essentially unchanged throughout the 2000-2005 period.

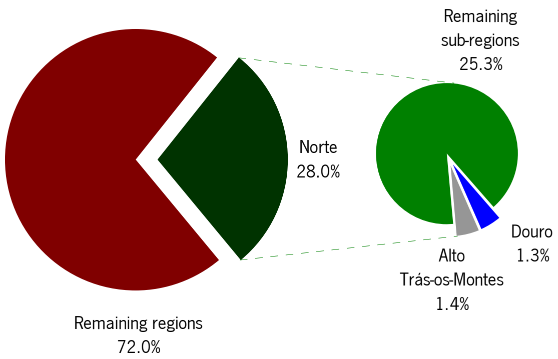

Figure 5.6 – Regional and sub-regional contribution to the national GDP in 2004 (INE, 2008)

With a share of 28% or 40 421 million Euros, the Norte region was the Country's second largest contributor to the national GDP (CCDRN, 2007).

In terms of per capita GDP, there was a steady increase from 2000 through 2005 (Table 5.3), at a rate of approximately 417 and 445 Euros per capita per year for Douro and Alto Trás-os-Montes, respectively, in agreement with the national rate of 419 Euros per capita per year (Appendix VII)

Table 5.3 – Variation of per capita GDP from 2000 through 2005 (INE, 2008)

Location	Per capita GDP at current prices, (B.1*g) (Base 2000-€), thousands €					
	2000	2001	2002	2003	2004	2005
Portugal	11.9	12.5	13.0	13.2	13.7	14.1
Norte	9.7	10.3	10.5	10.5	10.8	11.2
Douro	7.1	8.0	8.2	8.5	8.8	9.4
Alto Trás-os-Montes	7.4	7.8	8.0	8.4	9.1	9.6

Given the population distribution over the same period, it is reasonable to assume that sub-regional increases in per capita GDP could have been caused by the decrease in population observed for Douro and Alto Trás-os-Montes, while regional and national increases could have resulted from a general strengthening of the economy.

In terms of international trade, almost half of the total national exports originated from the Norte region, while imports accounted for less than a fifth of the national total (Figure 5.7).

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[6] GDP calculated at current prices (B.1*g) (Base 2000-€), millions € (INE, 2008).

[7] Last year for which this type of data is available (INE, 2008).

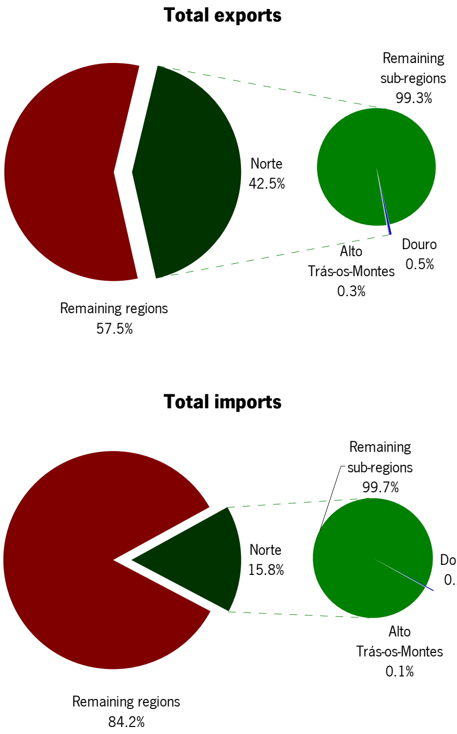

Figure 5.7 – Regional and sub-regional contribution to total exports and imports in 2006 (INE, 2008)

Exports from the Norte region concerned mainly those of industrial origin, corresponding to the strong presence of the secondary sector in the region (CCDRN, 2007). The coastal/interior imbalance could have not been plainer. The more rural and agricultural Douro and Alto Trás-os-Montes contributed comparatively very little at 24 284 and 5 597 million Euros towards the total exports and imports, respectively. Such low significance from Douro does not agree with its reputation of strong partaking in global trading and exports. Actually, many of the foreign companies devoted to producing and trading Douro's exports (*e.g.*, Port wine) have their headquarters on the coastal cities of Vila Nova de Gaia and Porto. Ultimately, any financial transactions concerning these trades are reported based on these locations and not on the production sites. Therefore, transactions and trading in Douro for these particular products amount to no more than a few local sales at the farms where they are produced and thus, have very little or no expression in terms of global results.

In 2004, the combined sub-regional contribution towards the total national gross value added (GVA) was of approximately 2.7% or 3 392 million Euros[8] (Figure 5.8).

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[8] The only year for which this type of data is available (INE, 2007).

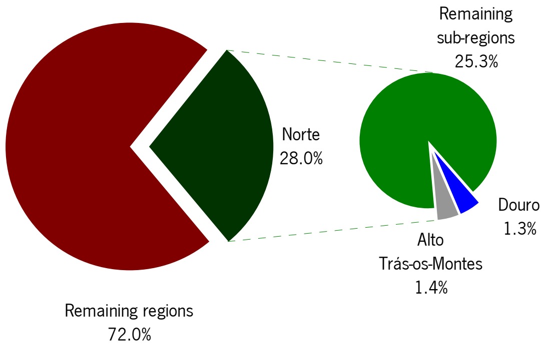

Figure 5.8 – Regional and sub-regional contribution to the national GVA in 2004 (INE, 2007)

In spite of a regional contribution of over a quarter of the national total, most of the GVA from Norte was produced by sub-regions other than Douro and Alto Trás-os-Montes. Nonetheless, the sectoral allocation of the GVA was slightly more favourable, particularly for the primary sector (Figure 5.9), that includes agricultural, hunting and forestry, fishing and operation of fish hatcheries, and fish farming activities (INE, 2007).

Primary activities were and continue to be amongst the main sub-regional contributors to the national GVA. The region is of great relevance for the Portuguese agricultural sector regarding the production of high quality products, including wine, olive oil, dried fruits and fresh fruits. This is an essentially rural area where agricultural activities, more than just a means for supplying food demands, are also important agents of geographical occupation, affecting the dynamics of other sectoral activities such as tourism, handcrafts, gastronomy and agro-related industry. Landscape, agro-ecosystems and environmental features are also significantly impacted by agriculture (Lima, 2000). However and since the 1990s, agricultural land uses have steadily decreased despite an increase in land productivity, accompanied by an overall reduction of arable land and increase in forestry and non-cultivated uses (Lourenço *et al.*, 2008). The simultaneous increase in animal-farming and dairy productivity has not been able to offset the decay of the primary sector. Factors such as decline of human occupation and farmer aging have been pointed out as possible causes for the phenomenon. These may be factors that prevent further investment, potentially jeopardising productive systems themselves (Lima, 2000). Consequently, several organizations have come together in setting up networks focused on managing and promoting forest property, which has been dubbed an effective albeit uncommon structural transformation for rural land in recent years (CCDRN, 2007). Exceptionally, vineyard land uses have seen an increase in Douro of approximately 2 230 ha (Lourenço *et al.*, 2008) that can be related to the world-reputable Port wine.

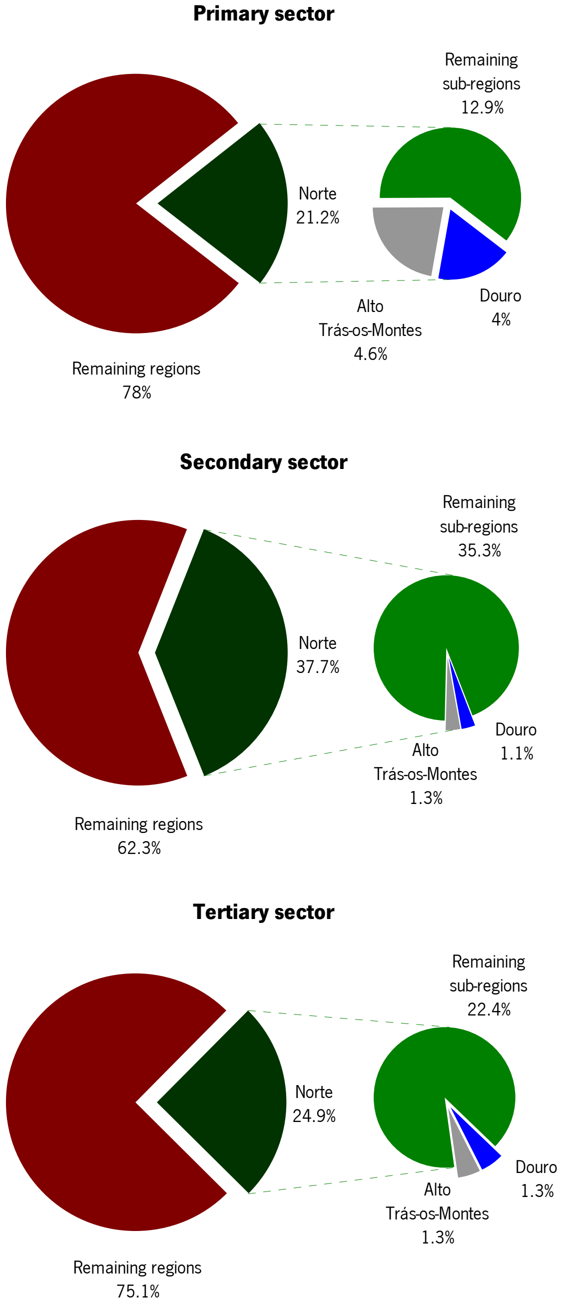

Figure 5.9 – Regional and sub-regional sectoral contribution to the national GVA in 2004 (INE, 2008)

The enduring diversity of the local natural resources allows tourism activities to be some of the main contributors to the region's wealth. Amongst the several natural parks mentioned earlier, the Country's only national park is partially located in the Alto Trás-os-Montes sub-region, which is, of its own right, a prime destination for the so-called nature and adventure tourism. Other important tourism resources include historical sites, archaeological parks, natural spas and a diverse and rich gastronomy (CCDRN, 2007). Tourism activities have been expanding in the Douro Valley as well, taking advantage of the transportation of people and commodities up the river, an activity that has been developing progressively by navigating the 300 km river stretch from its base level in Porto up to the Spanish border near Barca d'Alva.

5.5. Mobility, accessibility and transportation

The supply of transportation to areas of low population density is increasingly disappearing outside of the main urban areas, hindering mobility and circulation of people and goods. Areas affected by lack of adequate mobility solutions exhibit a reduced ability for competing with other areas where the transportation infrastructure is not as lacking. These are disparities not only of a territorial but also of a seasonal nature. Throughout the year, there are significant variations in mobility patterns that particularly affect rural and urban fringe areas. They result in discontinuity and inconsistency in mobility behaviour because the affected areas are not adequately supplied with sufficient and specific transportation alternatives (CCDRN, 2007).

Since the region is considered one of the most open to the exterior in the Country, investing in transportation infrastructure and networking with neighbouring Spain, thus establishing a connection with Central Europe, namely through to the Spanish Galicia and Castilla-León regions, takes on a decisive role with regards to defining national priorities. National consolidation includes improvements to and expansion of the existing road infrastructure towards the centre of the Country (CDDRN, 2007).

The main accessibility network has been the target of significant investment since the start of the Community Support Framework I (QCA, *Quadro Comunitário de Apoio*). According to CCDRN (2007), it is expected that after the current National Road Plan (PRN, *Plano Rodoviário Nacional*) is concluded, over 80% of the municipality seats in Norte will be less than 30 minutes away from a Main Itinerary (IP, *Itinerário Principal*). If this is accomplished, there will be new functional connections, interdependencies and centralities in terms of traffic, which will lead to the redefinition of network hierarchy, a favourable factor in terms of territorial competitiveness and cohesion (CCDRN, 2007). Figure 5.10 illustrates the highway road infrastructure in Douro and Alto Trás-os-Montes.

Figure 5.10 – Road network in Norte (Fernandes, 2007)

As observed, the IP cross the entire Norte region. In Douro, three IP intersect or converge towards the vicinity of Vila Real, IP3, IP4 and IP9, further accentuating the importance of this municipality. A similar observation can be made for Bragança and Chaves in Alto Trás-os-Montes, that are served by IP4 and IP2, and IP3, respectively, and Régua and Lamego in Douro, both served by IP3 and IP4.

5.6. Urban water and wastewater service coverage

Sub-regional water and wastewater systems benefitted from financial support by the World Bank in the 1980s. Additional funding was provided upon Portugal's admission into the then-designated European Economic Community (EEC) in 1986. These incentives and a continued concern with expanding, upgrading and renovating the existing networks have resulted in significant improvements to the infrastructure that, along with urban densification, has placed the sub-regions at or above the national average for service coverage (Table 5.4).

Table 5.4 – National, regional and sub-regional water and wastewater service coverage (INE, 2008)

Location Parameter	Portugal	Norte	Douro	Alto Trás-os-Montes
Population served by public water supply services, %	92	84	97	98
Population served by public sewerage systems, %	76	64	81	86
Population served by wastewater treatment plants, %	64	55	55	64
Proportion of wastewater treated, %	86	88	80	89
Water consumption per inhabitant, m^3/inhabitant	63	42	49	52
Consumption of water distributed by public water systems, 10^3 m^3	659 359	157 579	10 628	11 395

By 2005, service coverage in Douro and Alto Trás-os-Montes by water systems exceeded the minimum 95% requirement stipulated in the PEASAAR 2007-2013, whereas in Norte it did not. In terms of wastewater service, sub-regional coverage topped the national average of 76%, while Norte lagged behind once again, at 64%. None of the levels met the requirement of 90% population coverage (MAOTDR, 2006). Overall, Alto Trás-os-Montes fared better than its counterparts on all counts, including water consumption per inhabitant.

5.7. Selected Municipalities

The municipalities under study (Figure 5.11) are included in an area where accessibilities have improved particularly over the past 1990-2000 decade, though followed by urban development that intensified the disproportion between interior and the significantly more developed coastal areas, a west-east disparity despite the many types of development plans and programmes providing extensive coverage for the region.

Figure 5.11 – Selected municipalities

Yet, Northeastern Portugal continues to struggle with large areas of dispersed population and few higher-density urban clusters. These are conditions that have hampered urban growth and development that could potentially enable competitiveness with the coastal west.

5.7.1. General socio-economic features

Each municipality is partitioned into a number of *freguesias*, which are local administrative units based on the local religious parishes, in a process comparable to the genesis of "civil" parishes in England around the end of the 19th century (Oliveira, 2005). The number of *freguesias* is more or less dependent on the number of inhabitants, hence varying from municipality to municipality (Table 5.5).

Table 5.5 – Population and territory statistics for selected municipalities for 2005 (INE, 2008)

Location	*Freguesia* (no.)	Total population (no. of inhabitants)	Surface area (km^2)	Population density (inhab./km^2)
Portugal	4 260	10 569 592	92 090	115
Norte	2 028	3 737 791	21 286	176
Douro	3 01	215 527	4 108	52
Alijó	19	13 822	297.6	46
Mesão Frio	7	4 580	26.7	172
Peso da Régua	12	17 737	94.9	187
Sabrosa	15	6 768	156.9	43
Santa Marta de Penaguião	10	8 321	69.3	120
Vila Real	30	50 473	378.8	133
Alto Trás-os-Montes	398	21 9240	8 172	27
Murça	9	6 411	189.4	34
Vila Pouca de Aguiar	18	15 095	437.1	35

Population density distribution was very much as expected and the highest values were observed for locations provided with better accessibilities, such as Mesão Frio, Peso da Régua, Santa Marta de Penaguião and Vila Real (Figures 5.21 and 5.13).

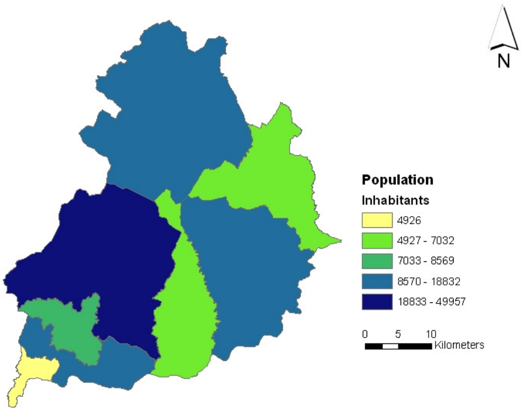

Figure 5.12 – Population distribution in study area

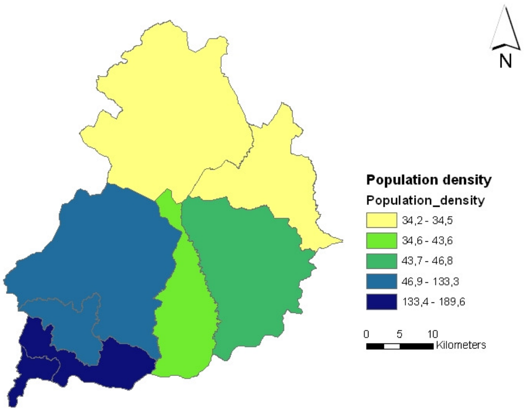

Figure 5.13 – Population density in study area

Historically, population numbers have been decreasing gradually for the selected area (INE, 2008). Vila Real presented itself as the exception, exhibiting an average yearly population growth of 0.56% up until 2004, when a declining trend began at a rate of 0.07%, thus resulting in a net growth rate of 0.49% for the 2000-2006 period. Of the selected municipalities, Vila Real was the only one that exhibited population growth dynamics similar to the ones observed at a regional and even national level. See Appendix VIII. Table 5.6 presents data concerning age parameters for the target populations.

Table 5.6 – Selected age indicators (INE, 2008)

Location	Aging ratio	Old-age dependency ratio
Portugal	111.7	25.6
Norte	93.3	21.9
Douro	146.2	30.4
Alijó	196.4	35.2
Mesão Frio	114.7	26.3
Peso da Régua	109.6	23.6
Sabrosa	177.4	35.1
Santa Marta de Penaguião	164.1	31.9
Vila Real	103.7	22.9
Alto Trás-os-Montes	203.5	37.0
Murça	180.2	35.3
Vila Pouca de Aguiar	172.8	32.8

With regards to the aging ratio distribution, most of the municipalities fared above the national average of 111.7. This indicator is defined by dividing the number of individuals aged 65 and over – generally considered economically inactive – by the number of individuals aged from 0 to 14 (INE, 2008). The aging ratio thus defined provides some information on the prevalence of the oldest inactive over the youngest inactive individuals. Alternatively, the old-age dependency ratio is obtained by dividing the number individuals aged 65 and over by the number of persons of working age (from 15 to 64), indicating the level of dependence of old individuals over younger economically active ones. Data show that all but Peso da Régua and Vila Real were below the national average, a fact tat mirrors the previous trend observed for the aging ratio parameter. In short, the lower the aging and old-age dependency ratios, the fewer the number of older individuals and the younger the population. An interesting fact was the occurrence of younger populations in the same municipalities identified before as having better accessibilities and higher urban population densities.

In what concerns unemployment rates, the number of unemployed individuals from 2004 through 2007 has remained essentially stable, as shown in Table 5.7.

Table 5.7 – Unemployment rates from 2004–2006 (IEFP, 2008; INE, 2007; INE, 2008)

Location	Unemployment rate (%)			Population on unemployment benefits (%)
	2004	2005	2006	2006
Portugal	3.46	3.99	4.03	4.78
Norte	5.37	5.74	5.56	5.55
Douro	4.69	4.99	5.16	3.90
Alijó	3.64	3.92	4.00	2.51
Mesão Frio	9.51	9.84	9.03	4.27
Peso da Régua	4.73	5.01	5.37	4.25
Sabrosa	4.69	4.87	4.45	3.78
Santa Marta de Penaguião	5.00	4.88	5.32	3.60
Vila Real	5.03	5.18	5.29	4.78
Alto Trás-os-Montes	3.86	3.94	3.84	3.18
Murça	4.54	5.04	5.86	4.53
Vila Pouca de Aguiar	3.35	3.43	3.38	3.90

Data were derived from monthly unemployment tables from *Instituto do Emprego e Formação Profissional* (IEFP, Employment and Professional Training Institute). Although total unemployed population values were available for 2007 as well, the rates expressed as number of unemployed individuals per 100 inhabitants could only be presented up to 2006 since population estimates for 2007 were not available at the time of the analysis. As seen above, unemployment has remained stable with slight positive or negative variations. These variations could not be correlated to the degree of accessibility exhibited by each municipality. Actually, of the previous four municipalities, only Mesão Frio demonstrated a slight rate decrease which is, however, insignificant since it still held the highest rate. Nevertheless, the type of data presented is not sufficient to explain whether the decrease in unemployment was due to an increase in the number of available jobs or decrease in the number of residents. By 2006, an average of 3.89% of the resident population within the selected municipalities took advantage of unemployment benefits (INE, 2007).

Sectoral activity distribution is illustrated in Figure 5.14. As for the active population, 2005 data based on the number of employed population working for others (INE, 2007) provided an approximate sectoral distribution. The tertiary sector dominated, taking up to 77.6% of total in Mesão Frio and 74.8% in Vila Real.

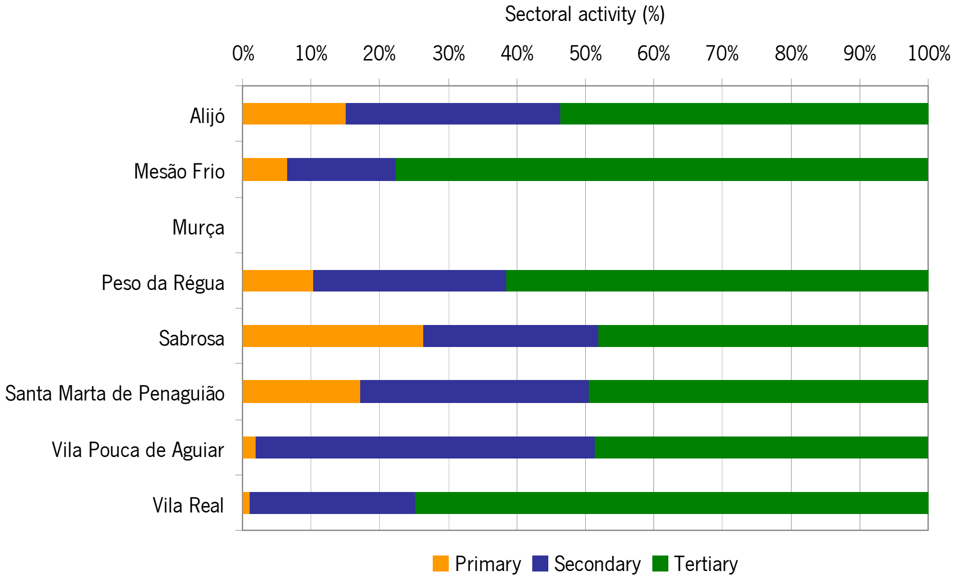

Figure 5.14 – Sectoral activity distribution (INE, 2007) (Data not reported for Murça)

These data did not include statistics related to self-employed individuals and were biased this way. For this reason, it would be imprudent to impart more than a speculative reliability to any conclusion drawn from the information just presented. With regards to purchasing power, 2005 data demonstrated the overall rating below the national standard (set at 100%) for the entire region and sub-regions, including the selected set of municipalities (Table 5.8).

Table 5.8 – Purchasing power (INE, 2008)

Location	Purchasing power (%)
Portugal	100.00
Norte	85.45
Douro	67.52
Alijó	50.96
Mesão Frio	56.19
Peso da Régua	73.80
Sabrosa	52.13
Santa Marta de Penaguião	51.90
Vila Real	96.09
Alto Trás-os-Montes	69.05
Murça	54.05
Vila Pouca de Aguiar	54.80

Six out of the eight municipalities exhibited purchasing power capabilities at approximately half of the Country's standard. Peso da Régua and Vila Real stood out as the two exceptional cases where their respective purchasing powers reached about 75 and 96 percent of the national benchmark.

With regards to municipal expenditures and revenues, relative per capita amounts are illustrated in Figure 5.15.

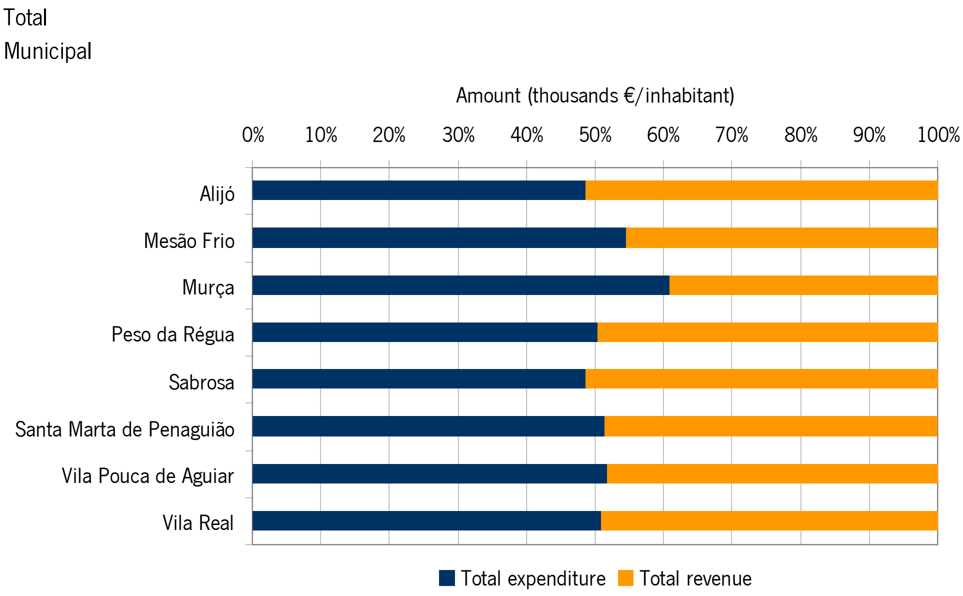

Figure 5.15 – Total municipal expenditure and revenue for 2005 (INE, 2007)

As observed, expenditure and revenues were rather evenly balanced, except for Murça and to some extent, Mesão Frio that showed a clear albeit not too significant dominance of expenditures over revenues.

Environmental revenues over expenditures are depicted in Figure 5.16.

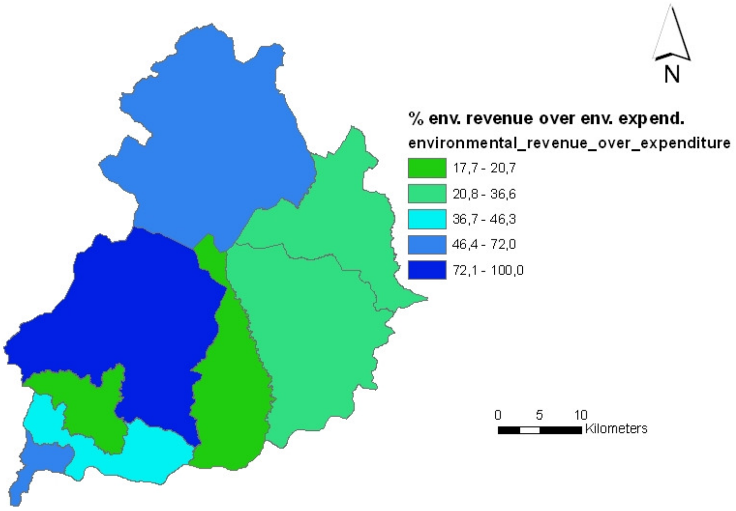

Figure 5.16 – Environmental revenues over expenditures for 2005 (INE, 2007)

Vila Real was the municipality displaying a greater balance between environmental expenditures and revenues, followed by Vila Pouca de Aguiar. Conversely, Santa Marta de Penaguião and Sabrosa were the most uneven of the group.

Environmental protection activities include: (1) wastewater management; (2) protection and remediation of soil, groundwater and surface water; (3) protection of ambient air and climate; (4) waste management; (5) noise and vibration abatement; (6) protection of biodiversity and landscape; (7) protection against radiation; (8) research and development, and (9) other environmental protection activities. For the purposes of the analysis carried out in this study, wastewater management activities were considered separately while the remaining eight were considered as a whole. Wastewater management per capita expenditures and revenues were compared and are presented below (Figure 5.17).

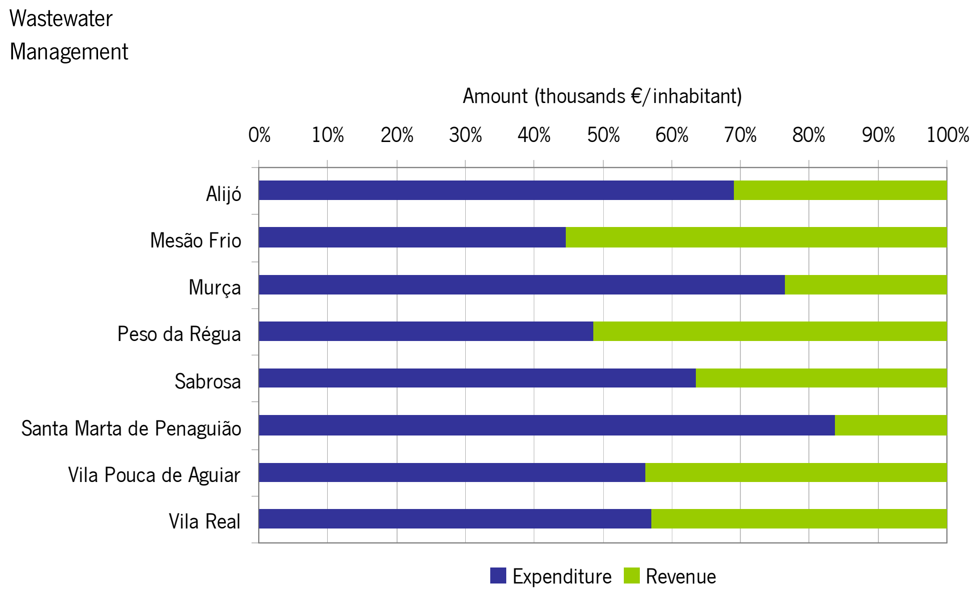

Figure 5.17 – Expenditure and revenue from wastewater management activities for 2005 (INE, 2007)

Unlike the previous case, the balance between wastewater management expenditures and revenues was rather uneven from municipality to municipality. All except for Mesão Frio and Peso da Régua reported more expenditure than revenue per inhabitant. Of those, account imbalances ranged from differences of 22% (Vila Pouca de Aguiar) to 81% (Santa Marta de Penaguião) in favouring expenditures over revenues. As for the remaining environmental protection activities, their corresponding expenditure and revenue figures are shown next (Figure 5.18).

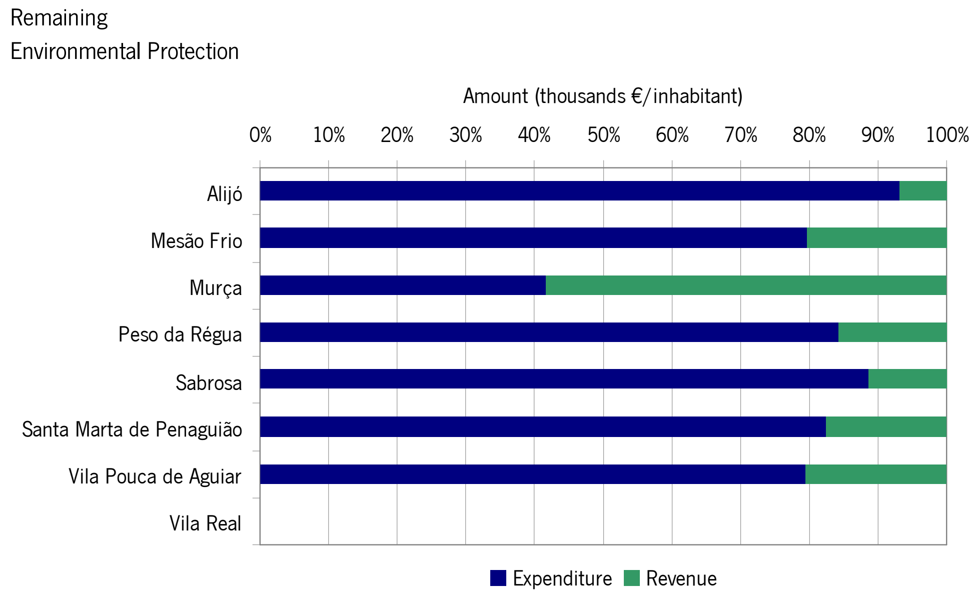

Figure 5.18 – Expenditure and revenue from remaining environmental protection activities (INE, 2007) (No data reported for Vila Real)

Murça stood out as the only municipality exhibiting more revenues than expenditure in an excess of approximately 40%. The remaining municipalities fared rather worse, with expenditures surpassing revenues from 74% (Vila Pouca de Aguiar) to 93% (Alijó).

5.7.2. Plan coverage and land uses

Not unlike the other municipalities included in the Douro and the Alto Trás-os-Montes sub-regions, land is essentially occupied by agricultural and forestry uses (Figure 5.19). The map illustrates the observed uses in 2000, consequence of an overall decrease of natural areas brought by the increase in low density urban uses and mixed agriculture occupation. Despite their influence, urban uses continued to have little expression in the overall area under study. Also, population clusters were not limited to them. There were several other clusters throughout any of the selected municipalities but given their small dimensions, these could not be accurately indentified and represented. Their small dimension and scattered nature carries significant consequences in terms of service by infrastructure networks, namely for water, wastewater and transportation. Though data were not shown for Vila Pouca de Aguiar, land uses and concerns are very similar for this municipality.

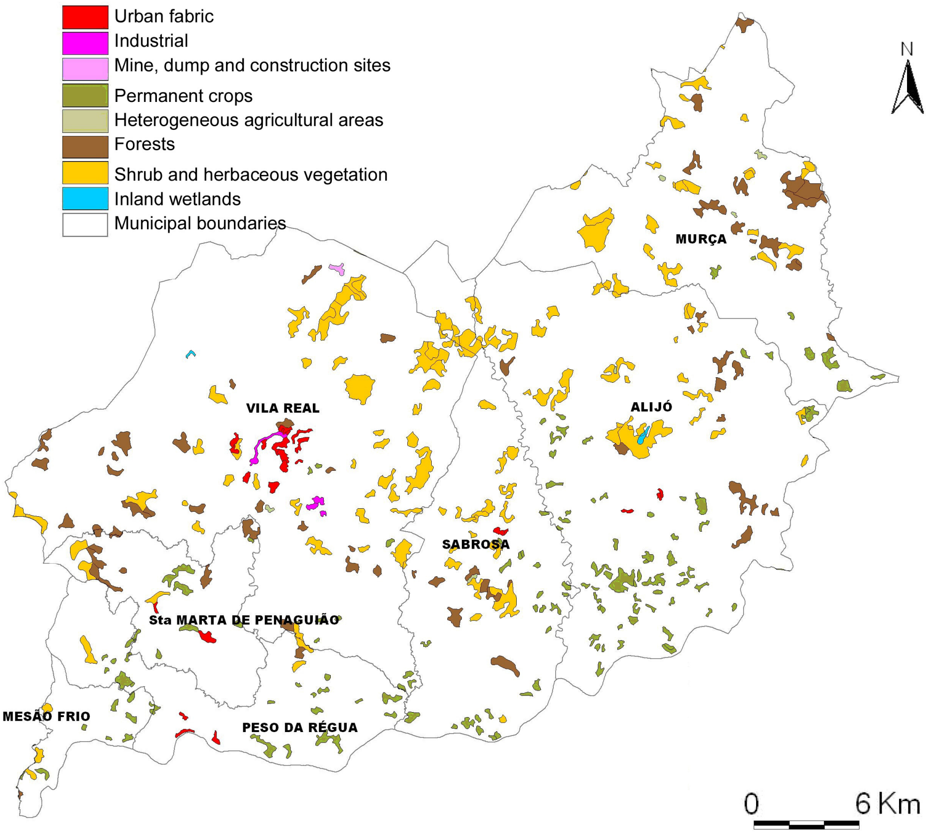

Figure 5.19 – Land uses for the selected municipalities (Lourenco *et al.*, 2008)
(Data not available for Vila Pouca de Aguiar)

Land occupation defined under Municipal Spatial and Land-Use Plans (PMOT, *Planos Municipais do Ordenamento do Território*), are represented in Figure 5.20. These unitary development plans, also known as Municipal Land-Use Plans (PDM, *Plano Director Municipal*), concern a comparatively much smaller area of the municipalities addressed. The plans have been published between 1993 and 1995 and most of them are undergoing or have completed the mandatory revision process to adapt and accommodate land use changes and strategic policies established in the meantime. It should be noted that, according to DL no. 380/99, PDM should be revised and updated with a minimum frequency of 10 years between revisions and/or updates.

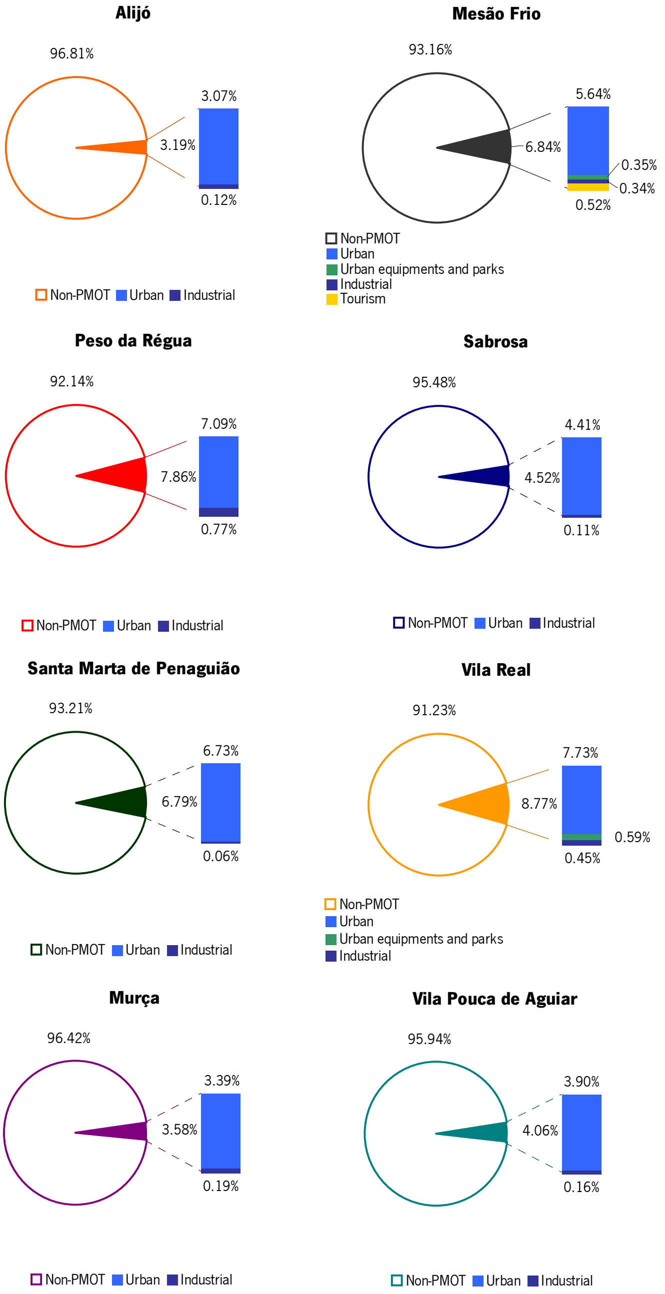

Figure 5.20 – Land use distribution according to the PMOT (INE, 2007)

In general terms, all PDM identify areas for urban and industrial development. Mesão Frio and Vila Real's PDM also discriminate areas for urban equipment and parks and tourism (Mesão Frio, only). The rest of the territory is subject to other directives such as the RAN, REN Natura 2000 Network, Regional Plan of Territorial Management of the Area Surrounding Douro, (PROZED, *Plano Regional de Ordenamento da Zona Envolvente do Douro*) and the regionally-encompassing Regional Plan of Territorial Management–Norte (PROT-N, *Plano Regional do Ordenamento do Território– Norte*) that, at the date of this work, has not yet been approved (CCDRN, 2008).

5.7.3. Water and wastewater systems

Water and wastewater service coverage were not equally available in 2005 (INE, 2008). See Figures 5.21 and 5.22.

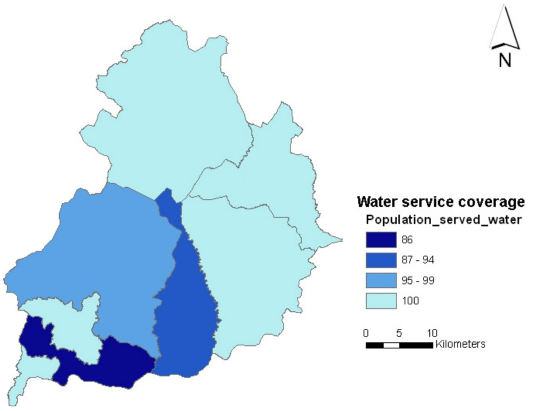

Figure 5.21 – Water service coverage in 2005

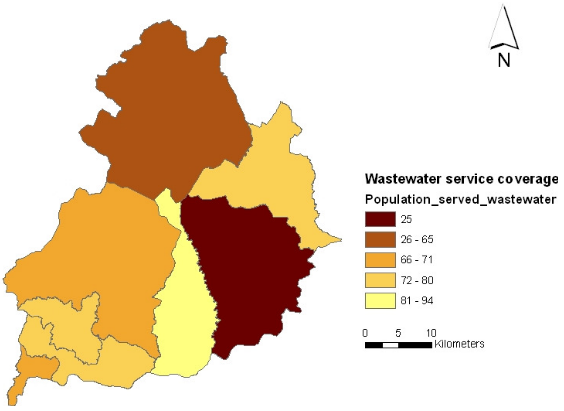

Figure 5.22 – Wastewater service coverage in 2005

Water service coverage in Peso da Régua was the lowest of the group, which is not surprising attending to the topography within the municipal boundaries. Alternatively, the terrain morphology favours wastewater infrastructure (mostly gravity lines) and hence, this municipality fared considerably better than its counterparts. On the other hand, Alijó fared the best in terms of water and the worst in terms of wastewater, followed by Vila Pouca de Aguiar, which also reported 100% water service coverage, as did Murça.

According to data from the INE (2008)[9], Peso da Régua and Sabrosa did not meet the regulated standard for water service coverage of 95% (MAOTDR, 2006). Also, Sabrosa was the only municipality meeting the required 90% coverage for wastewater systems. In terms of wastewater treatment facilities, the regulations are not as explicit. However, minimum service

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[9] Data for municipal services, only.

coverage of 70% is required for each integrated system. Assuming the same standard applies, only Peso da Régua was able to meet the requirement (Figure 5.23).

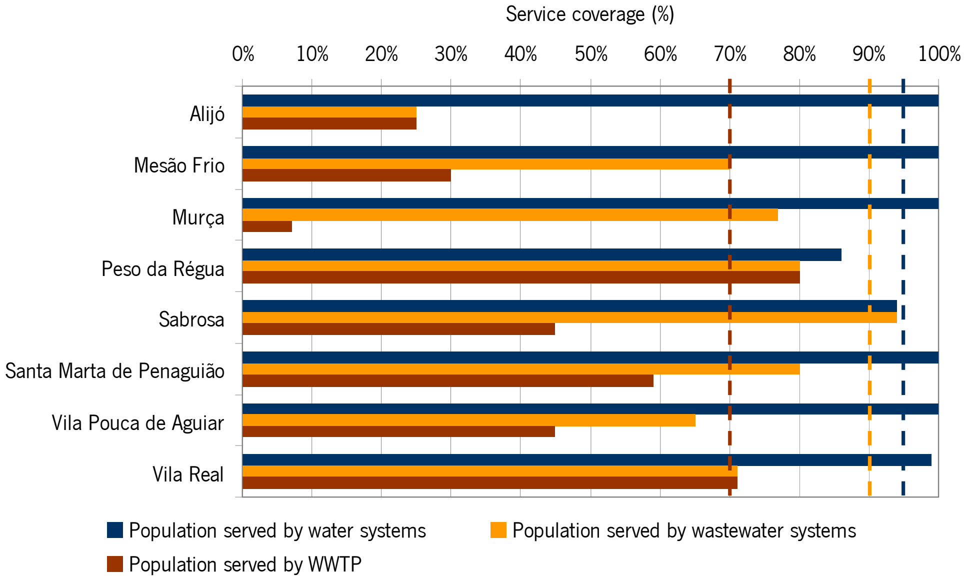


Figure 5.23 – Water and wastewater service coverage in 2005 (INE, 2008)

The dashed lines above indicate the standard requirement for each of the parameters. As seen, service coverage is not uniform across the selected municipalities.

The volumes of water intake, treatment and consumption are illustrated in Figure 5.24. Water treatment data were reported as “zero” Murça and Sabrosa.

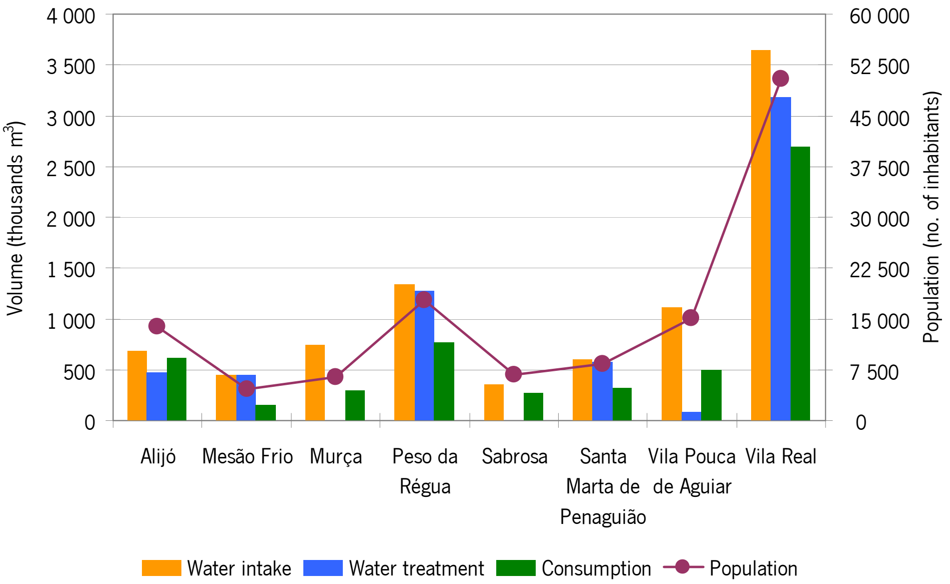


Figure 5.24 – Water parameters and population for 2005 (INE, 2007; INE, 2008)

Population size correlated well with intake, treatment and consumption values. Larger populations required larger volumes of water and *vice versa*.

According to the Water Supply and Wastewater Systems National Inventory (INSAAR, *Inventário Nacional dos Sistemas de Abastecimento de Água e Águas Residuais*), water intake was secured by a total of 483 points throughout the cluster of selected municipalities in 2005. Of these, only 10 concerned surface intakes (one in Alijó and Mesão Frio, two in Murça, four in Peso da Régua, and two more in Vila Real). The remaining intakes were directed at groundwater uptake, using a variety of sources and intake designs, where springs, mines, wells and boreholes were the most commonly observed.

Assuming that all intake volume removed from a water source was to be consumed and hence treated beforehand, there were clear differences between these three parameters. Reported consumption included not only household, but also industrial and other uses such as fire flows, street cleaning and irrigation (INE, 2007). However, reports were not clear on whether irrigation included agricultural uses or if it was only related to public garden upkeep and similar uses. Supposing they are not included, the differences between intake and treatment volumes could be explained more easily, assuming that agricultural irrigation water requires no treatment whatsoever. Nevertheless, there are no data available to determine one way or the other. In instances where consumption surpassed treatment, population were either drinking non-treated water or they were getting their treated water from sources external to the municipality. That would explain the data for Murça and Sabrosa, as well. In fact, by 2005, none of these municipalities included conventional water treatment plants (WTP) or chlorination facilities and resorted to drinking water treated neighbouring facilities. That also appeared to be case for Peso da Régua and Santa Marta de Penaguião, served by the WTP from Vila Real, which is planned to serve part of the Mesão Frio and Peso da Régua municipalities in the future as well (INSAAR, 2005; ATMAD, 2008). The lack of conventional treatment facilities did not imply the inexistence of intake points within municipal boundaries (Table 5.9).

Table 5.9 – Water treatment facilities (INSAAR, 2005)

Location	Type	Name
Alijó	WTP	Vilar de Maçada
Mesão Frio	WTP	São Nicolau
	Chlorination points	Donsumil, Granjão, São Gonçalo, Tojais, Valemoreira, Valpentieiro, Ventuzelas
Vila Pouca de Aguiar	WTP	Pedras Salgadas, Valugas
Vila Real	WTP	Borbela, Sôrdo

By 2005, there were six conventional WTP within the boundaries of the target area. These facilities were complemented by seven chlorination points located throughout the distribution system.

Wastewater collection, treatment and discharge was guaranteed by a system that included a total of 150 sampling points, 23 wastewater treatment plants (WWTP) and 126 urban collective septic tanks (CST). See Table 5.10.

Table 5.10 – Wastewater treatment facilities (INSAAR, 2005)

Location	Number of WWTP	Number of CST
Alijó	2	46
Mesão Frio	1	9
Murça	2	17
Peso da Régua	1	18
Sabrosa	7	19
Santa Marta de Penaguião	5	12
Vila Pouca de Aguiar	2	5
Vila Real	3	0

According to data from the INSAAR (2005), CST not only were the primary destination for wastewater treatment, they also accounted for the majority of the treated volume (Figure 5.25).

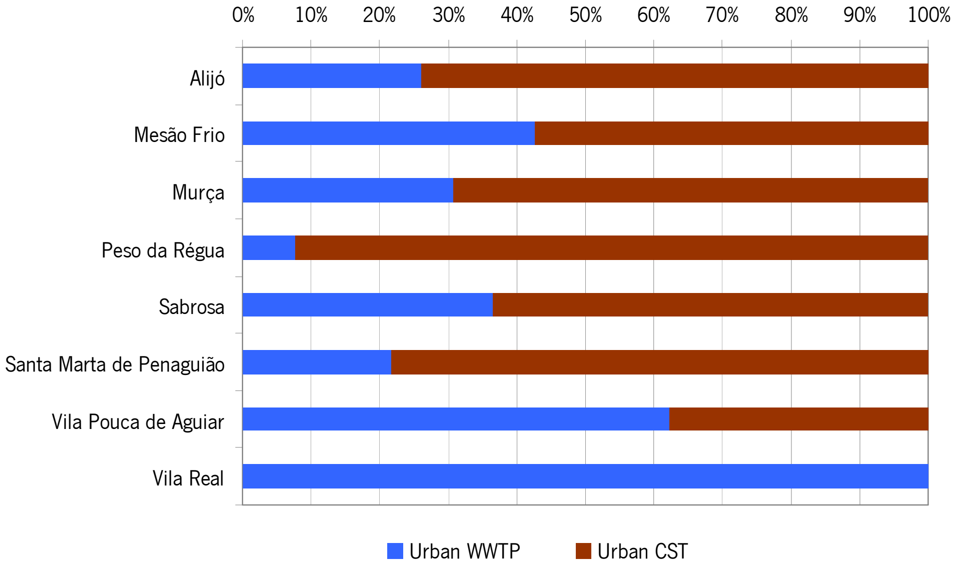


Figure 5.25 – Wastewater treatment facilities in 2005 (INSAAR, 2005)

Vila Real was the sole exception, where the untreated wastewater was directed to conventional WWTP. In general terms, WWTP can provide a wider range of treatment levels – usually primary and secondary, and tertiary as well, though not as frequently – and better final quality. Although not necessarily comparable to WWTP in terms of treatment levels – primary level only – septic tanks offer the possibility of some level of treatment in locations where there are no WWTP or access to one is unfeasible. In these situations, CST simple design and operation are often the best and/or only solution available, short of having none whatsoever. As seen earlier, urban areas tend to be scattered and thus, difficult to reach by comprehensive networks of water and wastewater infrastructure. The dispersed nature of the urban clusters in combination in the complexities of the terrain renders this area a difficult target for systems that are more inclusive, hence the practicality of CST.

Wastewater production (*i.e.*, collection) and treatment is represented in Figure 5.26. Note the situation for Sabrosa, Santa Marta de Penaguião and Vila Pouca de Aguiar.

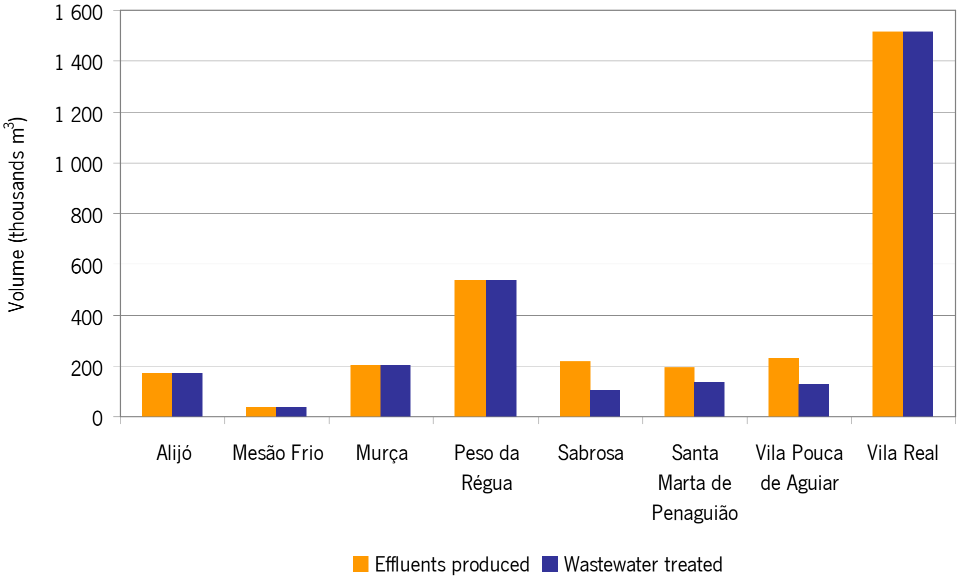


Figure 5.26 - Wastewater parameters for 2005 (INE, 2007)

Treated volumes did not match produced/collected volumes, implying that a portion of the total wastewater did not receive the necessary treatment. Of the 173 discharge points across the target area, seven concerned untreated wastewater or direct discharges onto the receiving medium, were it a waterway or land (Table 5.11).

Table 5.11 – Treated and untreated wastewater discharges (INSAAR, 2005)

Location	Treated		Untreated	
	Waterway	Land	Waterway	Land
Alijó	2	47	0	1
Mesão Frio	10	0	4	0
Murça	25	0	0	0
Peso da Régua	19	0	0	0
Sabrosa	29	0	0	0
Santa Marta de Penaguião	22	0	0	0
Vila Pouca de Aguiar	9	0	2	0
Vila Real	3	0	0	0

Untreated wastewater accounted for approximately 4.1% of the total discharges. While much less significant, they, nonetheless, carried potentially serious health hazards. The discharge of untreated wastewater is, obviously, an undesired occurrence. Untreated discharges are responsible for water contamination events that may pose severe risk to public health. For instance, land-application of untreated wastewater (*e.g.*, for irrigation) may lead to *Escherichia coli* outbreaks from food contamination. Alternatively and depending on many factors, water contamination episodes vary in degrees of severity, namely the type of contamination and typical use assigned to the waterway. Fecal contamination episodes are fairly typical examples. These and other events may lead to waterborne disease outbreaks of an assorted nature, bringing more or less dramatic consequences to the populations subjected to the ordeal. Infections can be of several natures: protozoan, parasitic, bacterial, viral and even allergic Symptoms may range from short-term gastro-intestinal disturbances to more extended and even chronic implications, and in more severe cases, death (WHO, 2004).

At this point, there are no publicly-accessible data to identify the past occurrence of such events within the boundaries of the target area. Since 2003, the Portuguese Health Department (*Direcção-Geral da Saúde*, DGS) has been using the SisAgua database to record not only data on several water quality parameters but also data on series of indicators concerning waterborne disease outbreaks. According to the DGS (2008), information is periodically released to the many regional and local health centres throughout the country, and also to public laboratories. One of the goals is to determine whether there are correlations between water quality and disease outbreak. Unfortunately, such data were not available to the public and consequently, could not be obtained for the purposes of this study.

Additional information is presented in Appendix IX.

5.7.4. Other urban environmental concerns

Urban solid waste collection included selective and non-selective approaches, where the latter clearly dominated (INE, 2008). Non-selective collection accounted for almost all of the solid waste produced, with selective collection for recycling having but a minimal contribution (Figure 5.27). As seen below, the solid waste collection distribution was very consistent from one municipality to another.

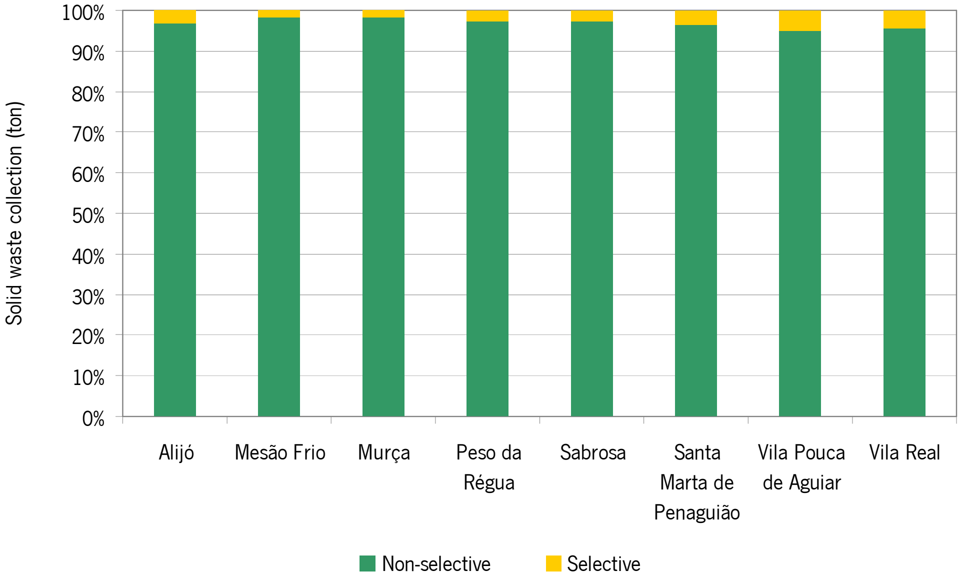


Figure 5.27 – Urban solid waste collection in 2005 (INE, 2008)

By 2005, these were municipalities not in habit of separating between the different types of solid waste, be it by lack of processing facilities or general reluctance of the population. According to INE (2008), landfills were the sole destination for all non-selective collection waste. Other fates such as energy production and composting were not available options for these municipalities.

Per capita solid waste collection was not as evenly distributed. Given the distinct population sizes, these differences were expected. However and as shown, solid waste collection data do not correlate to population size (Figure 5.28).

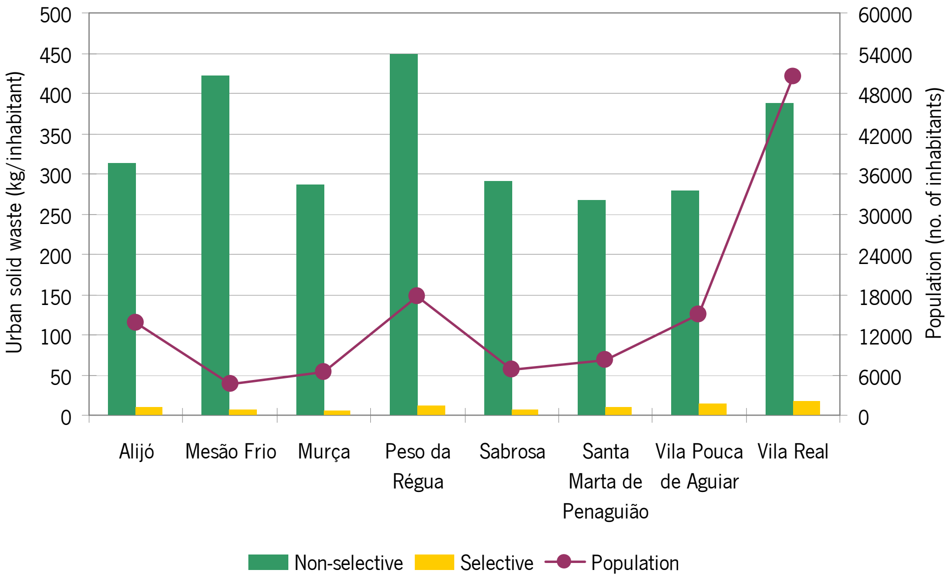


Figure 5.28 – Per capita urban solid waste collection in 2005 (INE, 2008)

Mesão Frio and Sabrosa displayed proportionally higher per capita solid waste collected than the remaining municipalities. Theoretically, larger populations would result in proportionally larger quantities of collected solid waste than smaller populations, assuming two hypotheses: same solid waste collection efficiency and equivalent per capita wastage rates. These assumptions could not be tested since there were no data regarding the efficiency rate of solid waste collection, that is, how much of the produced waste was actually collected. Additionally, since there was no information regarding solid waste production, it was not possible to establish whether per capita wastage rates were the same or otherwise. Hence, there are two possible scenarios that might explain the data correlations illustrated above. First, if the collection efficiency was the same, then smaller populations were wasting more. Conversely, if the per capita wastage rates were the same, then the collection efficiency was better for municipalities with smaller populations. Given the former or the latter assumptions, Mesão Frio and Sabrosa stand out, respectively, as either the bottom or the top two municipalities.

Per capita electrical energy consumption patterns are presented in Figure 5.29. Target categories included household, agricultural, industrial, non-household, electric traction and public lighting (INE, 2007). As observed, household consumption was not only one of the main uses across the set of municipalities, but also the major consumption use except for Vila Pouca de Aguiar and Vila Real where, respectively, industrial and non-household uses were higher.

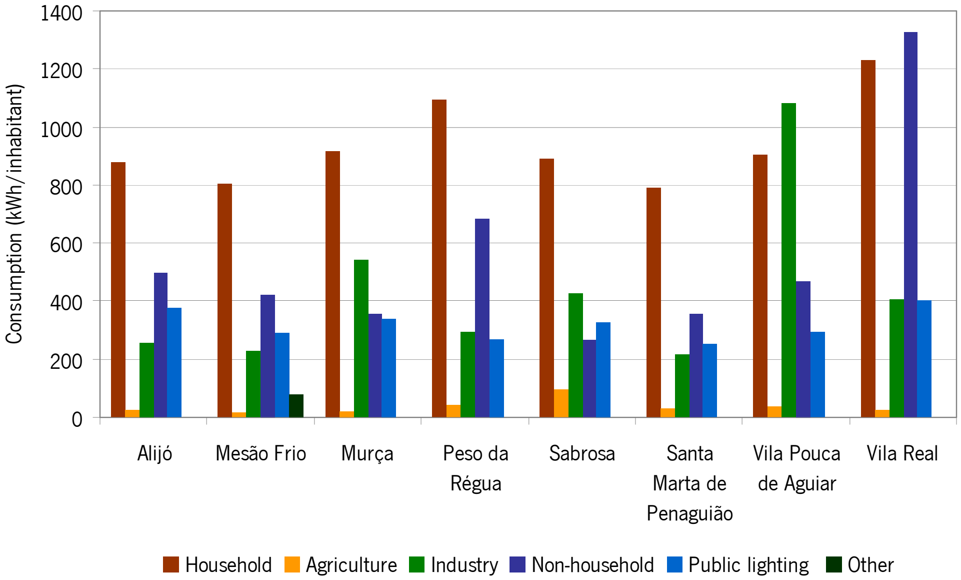


Figure 5.29 – Per capita electrical energy consumption in 2005 (INE, 2007)

Agricultural uses were comparatively very low. Industrial consumption had some significance throughout the area, mostly around between 200 and 600 kWh per inhabitant, with the exception of Vila Pouca de Aguiar, displaying higher per capita consumptions above 1 000 kWh. Other non-specified uses had some minor significance in Mesão Frio. Public lighting includes state and public utility buildings and public ways. As shown, per capita uses are balanced throughout the cluster of municipalities, with Vila Real exhibiting the highest consumption at approximately 400 KWh per inhabitant.

6. RESULTS AND DISSCUSSION

Aiming to rank the eight municipalities according to a series of indicators selected to evaluate and compare the sustainability of their water and wastewater systems, and attending to the nature of the data available, two analytical scenarios were proposed. A scenario A or "Baseline", in which the populations were considered to be below a critical size for warranting a full-scale system, including also expenditures and revenues, that were considered to be below a sustainable level. Scenario B or "Established" assumed that any of the above conditions had been already met and thus, considered the opposite.

For each alternative, scores were calculated based on two different data normalisation methods and results were compared. The results are discussed in terms of normalisation outcomes, partial (group) scores and overall scores. The final ranking order is presented and discussed as well. Additional work included a brief round of sensitivity analyses conducted to determine and discuss what group(s) of indicators (social, environmental and/or economic) were the most likely to have contributed to the final ranking order.

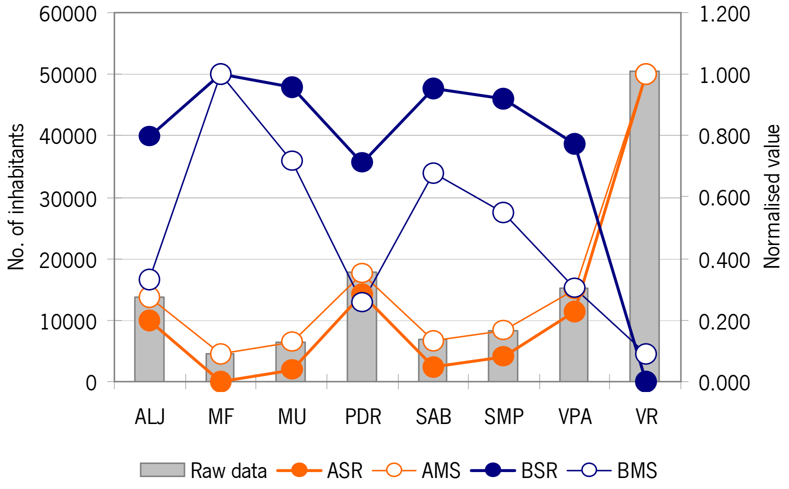
6.1. Group Results

Using the hierarchical approach described in Chapter 2 and illustrated in Chapter 4, a series of partial scores (social, environmental and economic) were calculated for each municipality. Indicator-specific charts were produced and are presented and discussed throughout the text. Raw and normalised data tables are presented in Appendix X.

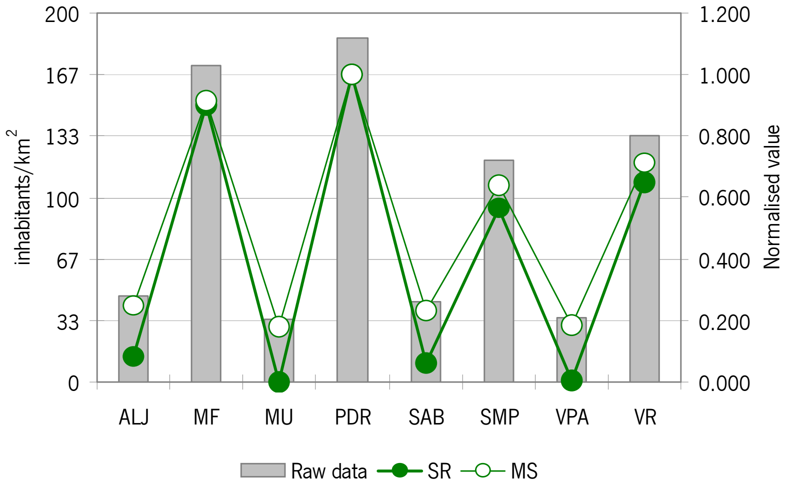
6.1.1. Social scores

The results for the general characterization indicators sub-group (1.1) are depicted in Figure 6.1. Raw data are represented by the light gray columns and each line represents the data obtained per evaluation alternative. As indicated on each graph, the lighter lines correspond to scenario A and the darker lines to B, with the filled dots matching data that were normalised using the score range (SR) method, while the non-filled dots represent normalised data obtained through the maximum score (MS) method.

1.1.1 - Total population



1.1.2 - Population density



1.1.3 - Old-age dependency ratio

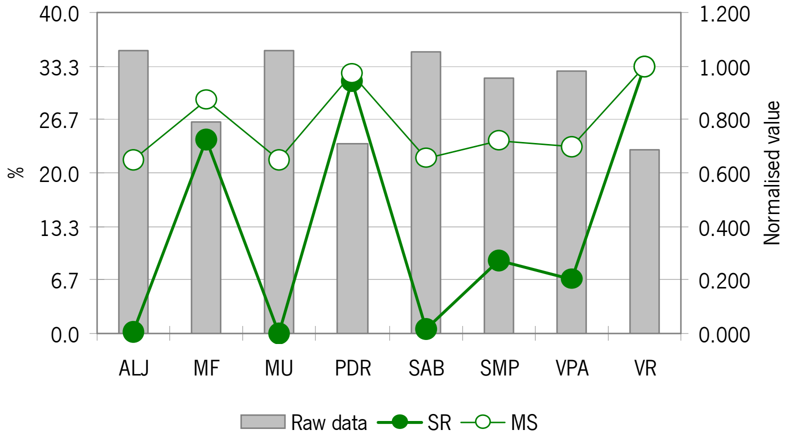


Figure 6.1 – Social indicators: general characterization data

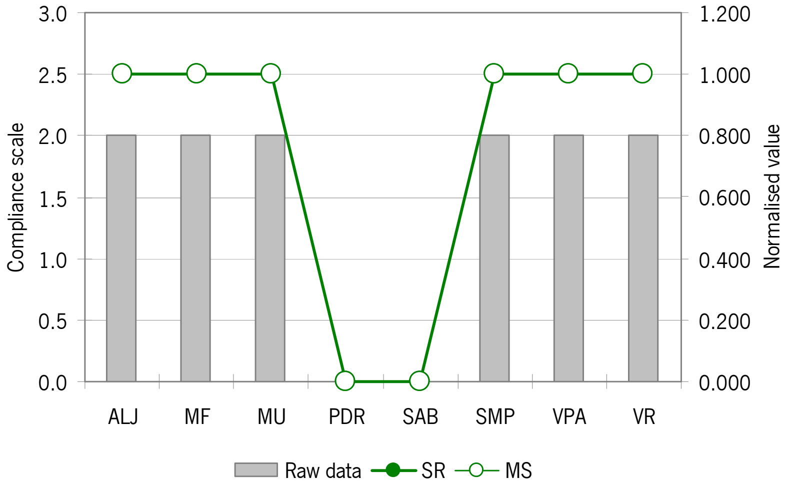
In the case of indicator 1.1.1 (total population), alternate scenarios generated alternate results. Significant differences were observed for Mesão Frio, Murça, Sabrosa, Santa Marta de Penaguião and Vila Real. For these municipalities, both scenarios were clearly expressed, since under scenario A, larger populations produced higher normalised values and *vice versa*. Alijó, Peso da Régua and Vila Pouca de Aguiar exhibited similar values regardless of the scenario. This is explained by the fact that in these municipalities the populations were intermediate in size and similar overall, whereas the previous populations were either on the lower or upper ends of the population size range.

Vila Real's largest population produced extreme results, either the highest or the lowest normalised value, depending on the evaluation scenario. In both options, Vila Real was followed by Peso da Régua and Alijó (second best/worst and third best/worst municipalities). The remaining municipalities yielded similar values, particularly under scenario A. In scenario B, these similarities were not as visible, particularly for data normalised using the MS method. The normalised data obtained under this method were more distinct from one municipality to the other. This is explained by the method itself, which caused the relative order of magnitude of data to remain unchanged. In other words, normalised data variation was proportional to raw data's. On the other hand, the SR method dampened the original variation tendency of raw data, because it limited the range of normalised data variability to an interval between 0 and 1. Consequently, the SR-curve is smoother than the MS-curve.

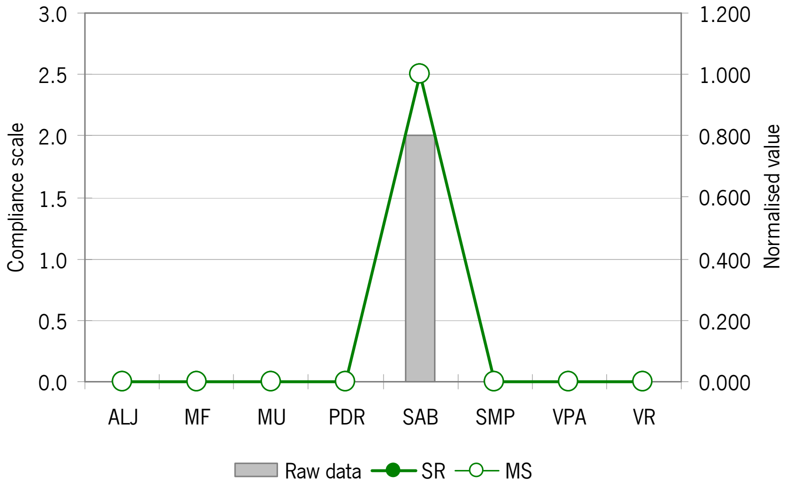
In terms of population density (1.1.2) and old-age dependency ratio (1.1.3), the results were the same for both alternatives since these parameters were deemed independent of scenario. Once again, the MS method produced normalised data that followed raw data's behaviour more closely, unlike the SR approach that disregarded the variability of the original data set. In this case and because of the nature of the raw data, normalised values did not vary as dramatically as SR-normalised values. An interesting fact is the occurrence of younger populations in the same municipalities identified higher population densities.

Accessibility values are depicted in Figure 6.2. All three indicators were considered independent of scenario and calculated values show that they were also independent of normalisation procedure. The normalised values were the same for both SR and MS methods. This happened because the minimum datum was "zero", which essentially converted the normalisation model in Equation 3.13 into Equation 3.10's model.

1.2.1 - Population served by water systems



1.2.2 - Population served by wastewater systems



1.2.3 - Population served by WWTP

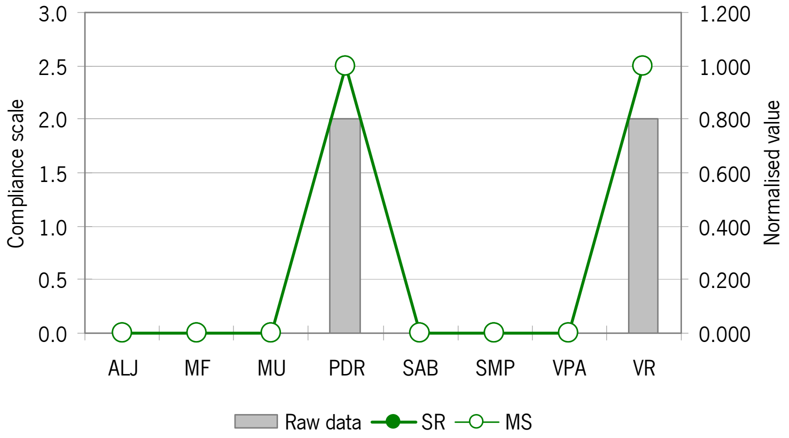


Figure 6.2 - Social indicators: accessibility data

Accessibility to water and wastewater systems was either below or above the regulated standard. None of the municipalities complied with all three requirements simultaneously but all of them met the recommended values for at least one system. Sabrosa was the only municipality in compliance with minimum recommended wastewater system coverage (exceeding it, actually) though it did not meet the desired minimum water service coverage. Vila Real also met two requirements, water and WWTP service coverage. Peso da Régua complied with the WWTP standard but not with the water one. All remaining municipalities complied only with the water service requirement. The scale used accurately translated the situation described in Chapter 4. The impacts of using two different evaluation scenarios and data normalisation methods are visible in the sub-group score distribution presented in Figures 6.3 and 6.4.

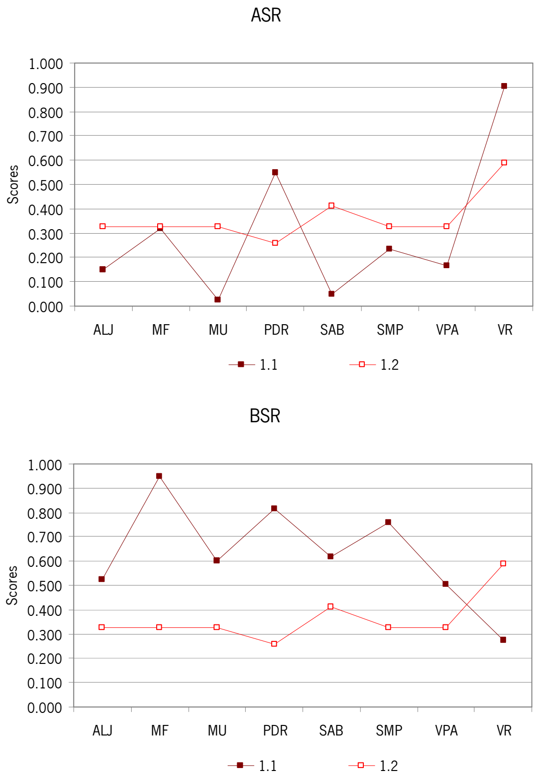


Figure 6.3 – Social sub-group score variation (SR)

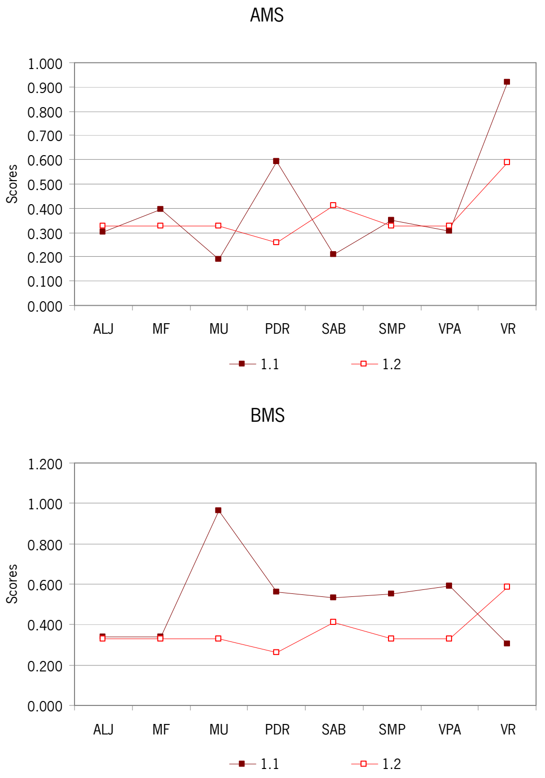


Figure 6.4 - Social sub-group score variation (SR)

Score variation within scenario A (Baseline) was very similar, with Vila Real and Peso da Régua faring the best in both data normalisation methods. Differences were more pronounced in scenario B (Established). Considering that the individual weights assigned to each indicator remained unchanged, the differences in the results were due to the distinct assumptions behind each scenario and to the normalisation method. Also, since greater weights were assigned to the parameter that was affected by the alternate scenarios (1.1.1), the variation in scores was greater. This is particularly visible for Vila Real, which was the municipality that exhibited the largest population size. In this case, the final score clearly benefited in scenario A and, for both normalisation methods, the scores were the highest and the best. Conversely, the results for scenario B were the lowest. Since Mesão Frio was the municipality with the lowest population, it obtained the highest score using either normalised method.

Scores for sub-group 1.2 (accessibility) remained unchanged since there was no scenario variation nor normalisation effect, accurately representing the access to water and wastewater services across the cluster of selected municipalities.

As the analysis progressed from tier 3 (sub-groups) to tier 2 (groups), the differences in scores were carried along as well. Nevertheless, score variability was significantly lower for tier 2 scores. The overall scores for the social indicators group are presented in Figure 6.5.

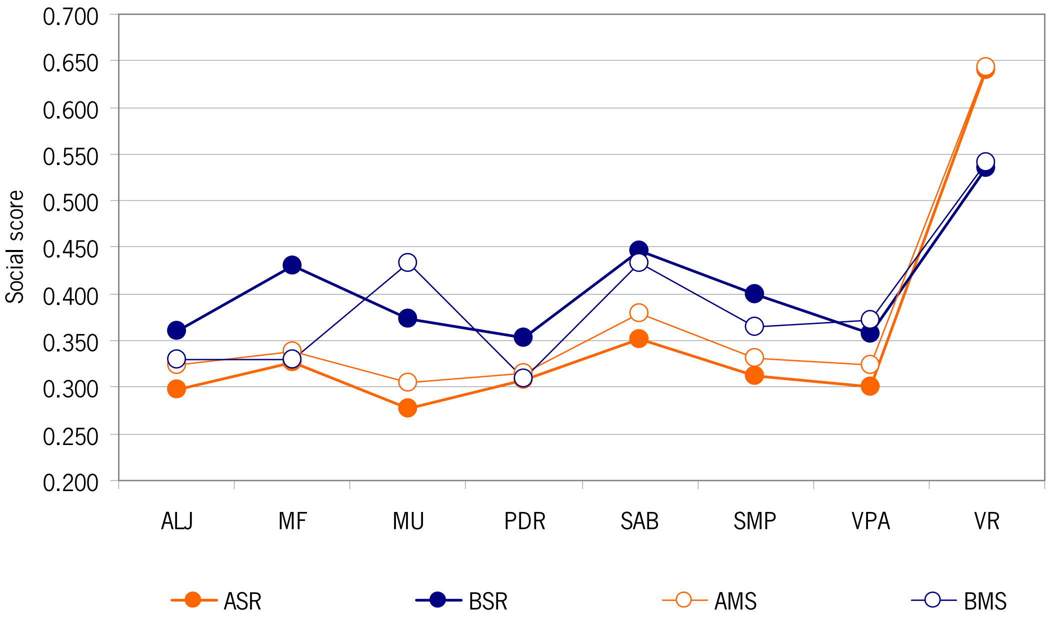


Figure 6.5 – Social scores according to analytical scenario and data normalisation method

Overall, the relative municipality order remained fairly unchanged regardless of scenario and normalisation method. The largest score variation of 0.157 was observed for Murça. Incidentally, the largest and lowest scores under tier 3 also belonged to this municipality (0.965 and 0.025, respectively), further highlighting its results. Vila Real obtained the highest scores in all counts. Its performance was not hindered by the lowest individual score for total population under scenario B is because sub-group 1.1 was assigned a much lower weight (0.167) than sub-group 1.2 (0.833). This weight difference was sufficient to balance out the score differences. Assigning a greater importance to the accessibility sub-group has reduced the magnitude of variations originated by the distinctive analytical scenarios.

In general, scores were higher under scenario B, except for Vila Real. Considering an increase in total population as a cost rather than a benefit was advantageous, allowing municipalities to obtain a larger partial social score. Scenario A yielded comparatively lower scores, but as explained above, those differences were not too significant.

Results from the two data normalisation procedures have also yielded some differences. Under scenario A, both SR and MS methods produced similar values, though the latter were consistently higher. Under scenario B, results were variable and only for Murça, Vila Pouca de Aguiar and Vila Real, were the MS scores slightly higher than the SR scores.

In order to infer on the statistical similarities between the scores obtained for all municipalities, a series of statistical parameters was calculated and evaluated. The results are presented in Table 6.1.

Table 6.1 – Social scores: statistical features

Municipality	Standard deviation	Mean	99% Confidence interval		Score range	
			Min	Max	Min	Max
ALJ	0.026	0.328	0.295	0.361	0.298	0.360
MF	0.050	0.356	0.292	0.420	0.326	0.431
MU	0.070	0.347	0.256	0.438	0.277	0.434
PDR	0.021	0.321	0.294	0.348	0.308	0.352
SAB	0.045	0.402	0.345	0.460	0.352	0.446
SMP	0.038	0.352	0.302	0.401	0.312	0.399
VPA	0.032	0.338	0.297	0.380	0.300	0.372
VR	0.060	0.590	0.513	0.667	0.535	0.643

Except for Mesão Frio and Peso da Régua, scores were within the 99% confidence interval. This happened because BSR scores for these municipalities functioned as outliers while the remaining ASR, AMS and BSR scores were almost identical.

This first part of the analysis translates the initial assumptions well, given the weight assignments decisions previously made. As shown, accessibility factors dominated the final scoring and compensated for impact from the general characterization indicators, namely total population. Accordingly, Vila Real, Sabrosa and Mesão Frio were the top three scorers in terms of social sustainability.

6.1.2. Environmental scores

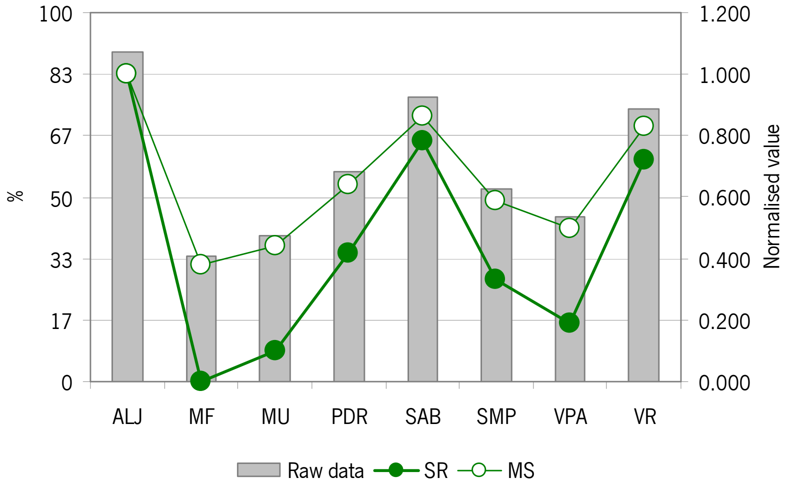
The group of environmental indicators (tier 2) was divided into five sub-groups (tier 3). As mentioned in Chapter 4, environmental parameters were found to be scenario-independent.

Consequently, the graphs depicted next only show the results derived from using the two distinct data normalisation methods.

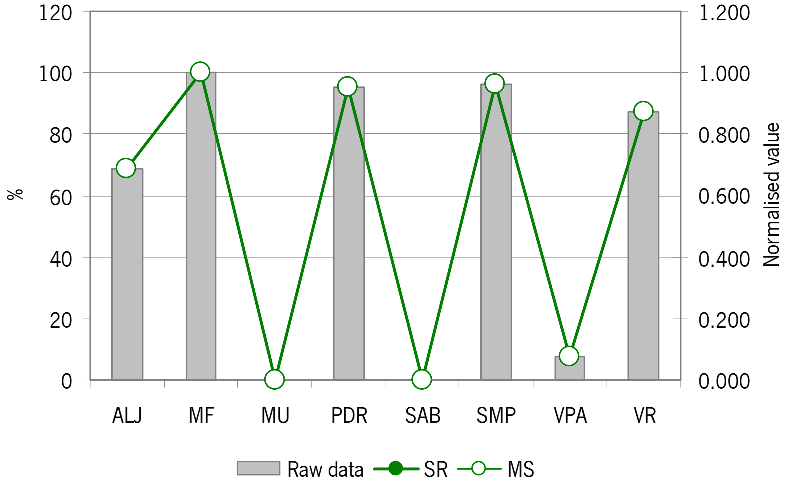
As previously noted, the MS method reproduces the proportional variation indexed to the maximum datum between raw data points while the SR translates that variation within a 0 to 1 range. For indicator 2.1.1 (Figure 6.6), the result was a smoother curve for MS data and, conversely, a sharper curve for SR normalised values. In any case, both methods accurately translated the variability in water consumption over intake for the group of selected municipalities. Alijó, Sabrosa, and Vila Real were the top water users per volume of intake, with Mesão Frio and Murça placing last in the group.

Normalised values for indicator 2.1.2 matched regardless of the method employed since at least one of the data values was zero (Murça), causing the normalisation models to become one and the same. According to the data sets in Appendix X, water treatment over intake was approximately 100% for Mesão Frio, Peso da Régua and Santa Marta de Penaguião, followed closely by Vila Real. Murça reported no values for water treatment and thus the resulting normalisation is also zero. This does not mean that Murça did not have its water treated prior to consumption. It simply means only that it may have gotten its water for consumption from outside its boundaries and/or did not report how much. Additionally, Murça did not report having any conventional WTP or chlorination points within its borders and neither did Peso da Régua, Sabrosa nor Santa Marta de Penaguião, yet having reported figures for water treatment. It is important to mention that data from the INE refer only to water handling and management by municipal services and entities and does not include private or other services. Therefore, data available may not have accurately described the actual situation.

2.1.1 - Water consumption/intake



2.1.2 - Water treatment/intake



2.1.3 - Water consumption/treatment

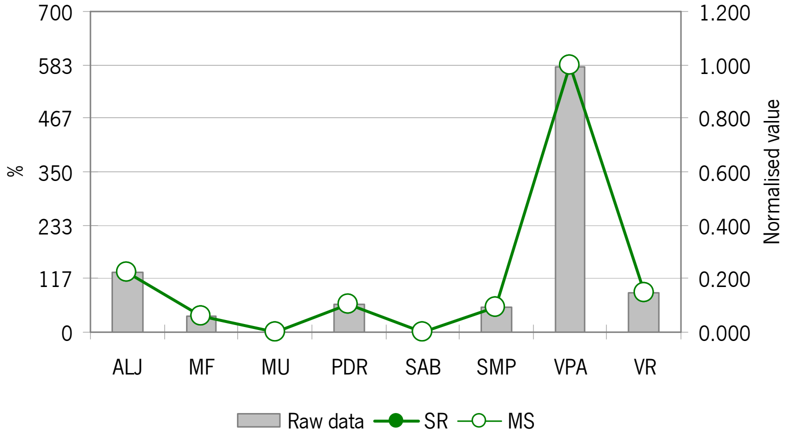


Figure 6.6 – Environmental indicators: water data

The same reasoning can be applied to Vila Pouca de Aguiar, since it reported a very low percentage of treated water over intake. In terms of water consumption over treatment, it would not be possible to observe percentages over 100 unless the municipality was obtaining treated water for consumption from external sources. This is the case for Alijó and Vila Pouca de Aguiar, where water consumptions rates exceed those of water treatment. Murça and Sabrosa do not report water treatment but they do report water consumption. Since data for indicator 2.1.3 could no be calculated for these municipalities, they were given a value of zero, thus being penalised as shown by the normalised data results in the graph.

Wastewater indicators data (2.2) are represented in Figure 6.7.

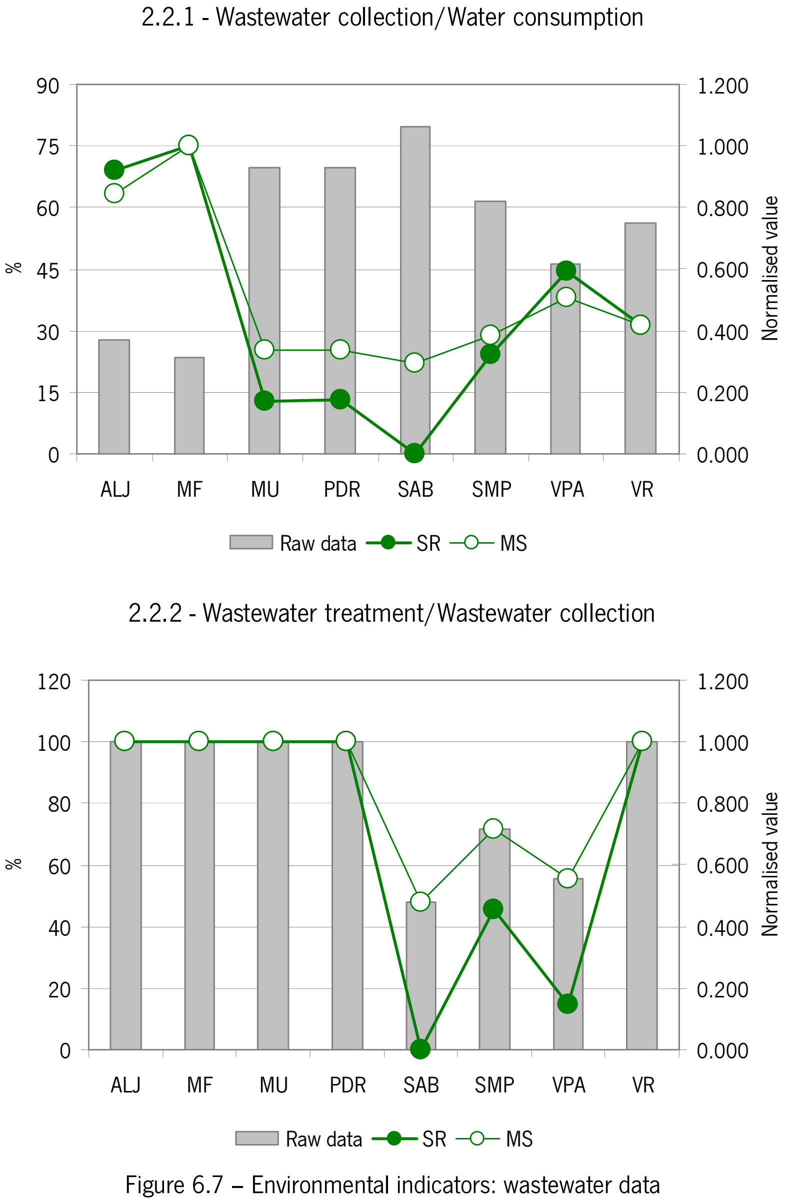


Figure 6.7 – Environmental indicators: wastewater data

Wastewater collection over water consumption percentages (2.2.1) were the highest for Sabrosa and closely followed by Murça, Peso da Régua, and Santa Marta de Penaguião. As explained in the methodology, this indicator was calculated to infer on the percentage of water being lost as wastewater. The reasoning was that the highest the ratio the greatest the waste. The normalised data results agree with that assumption. Both normalisation procedures yielded similar results and consistently benefitted municipalities that exhibited the lowest wastewater to water percentages, such as Alijó and Mesão Frio. There was little variability between normalised data under SR and MS. This was also apparent for indicator 2.2.2. For Sabrosa, Santa Marta de Penaguião and Vila Pouca de Aguiar, only up to approximately 72% down to 48% of the collected wastewater was treated. These results were somewhat surprising considering the accessibility to wastewater treatment services in these three municipalities. In fact, Sabrosa was the only one exhibiting above-minimum standard service coverage and yet, showed the lowest treatment to collection percentage at 47.7%. Furthermore and according to the INSAAR database, there were no reports of untreated discharges for this municipality. This suggests that either records on collection and/or treatment were incomplete, or there could be infrastructure issues affecting the reliability of flow quantification, such as pipe leakage, for instance. The remaining five municipalities treated all of their reported collected wastewater, hence the 100% results.

Wastewater treatment can either be carried out in WWTP or more simply in collective septic tanks (CST). Figure 6.8 illustrates the data obtained for indicators 2.3.1 and 2.3.2. The majority of the collected wastewater was handled by CST except for Vila Real, where 100% of the treated wastewater was handled by the municipality's WWTP. Because of that, this municipality produced the highest normalised datum. Conversely, Murça rated the worst, since over 90% of its wastewater was handled using CST.

The large variability in data allowed both normalisation methods to produce similar results. Moreover, the single zero datum point (Vila Real) for indicator 2.3.2 penalised the normalised values for the remaining municipalities through the use of equation 3.12[1].

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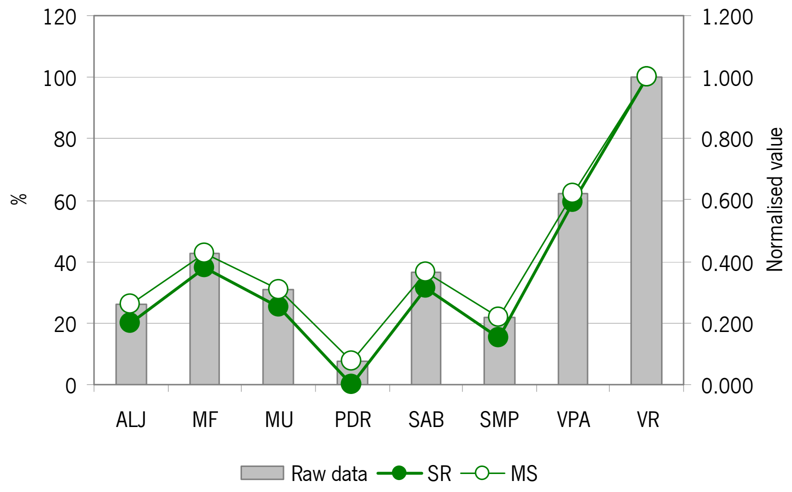
[1] Concerning this issue, a small remark is required. Since it would have been a mathematical impossibility to apply the equation to the zero datum, it was written as 0.0000001 and used instead, thus enabling a normalised datum of 1 for Vila Real. The selection of this number was arbitrary; needing only to be sufficiently low.

2.3.1 - Wastewater treated in WWTP



2.3.2 - Wastewater treated in CST

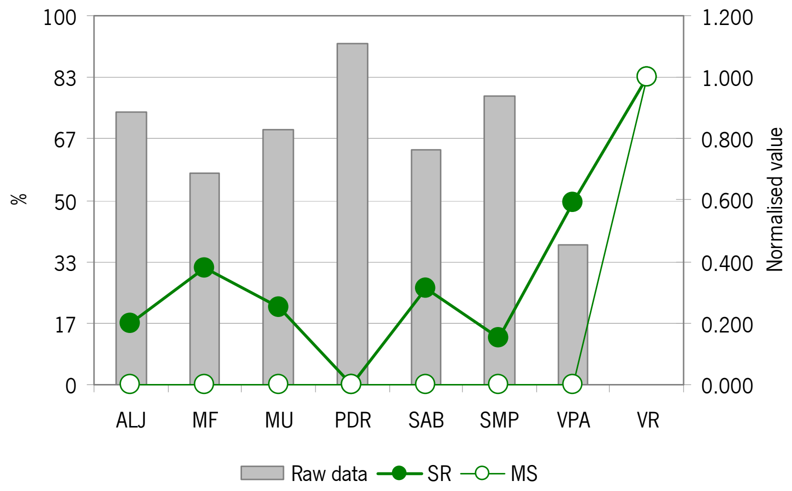
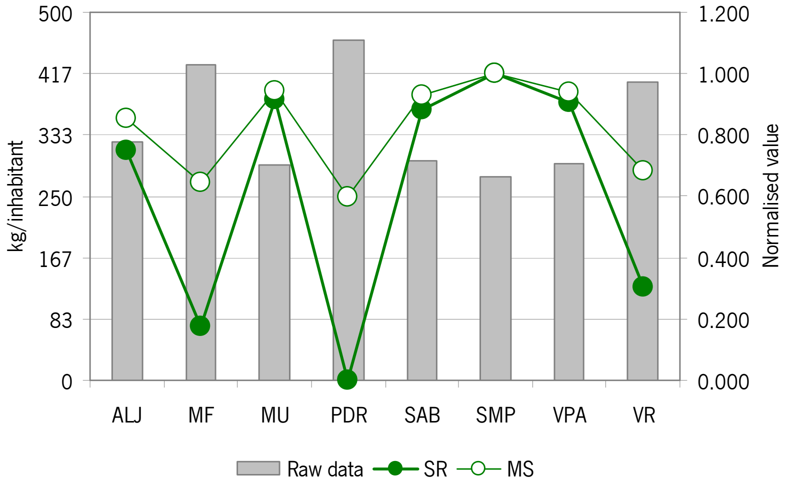


Figure 6.8 – Environmental indicators: wastewater treatment facilities data

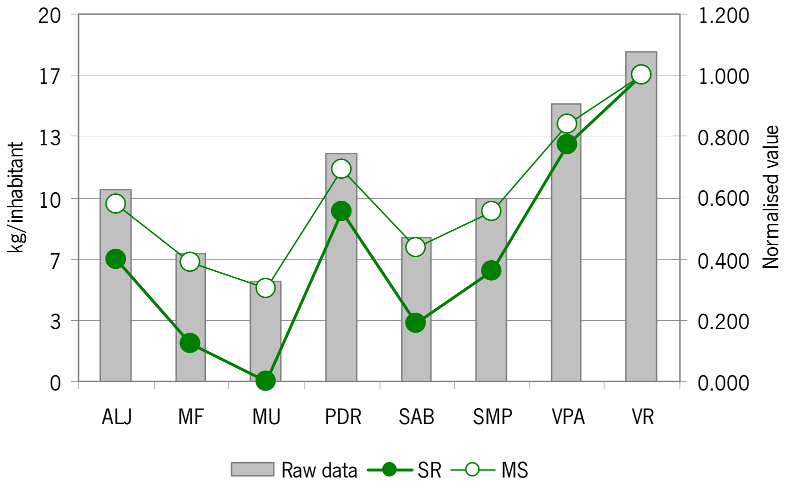
Two additional sets of environmental parameters (2.4 and 2.5) were selected and analysed. Though not directly related to water and wastewater systems, they were deemed useful as potential surrogate indicators of the sustainability status of each municipality.

Information on solid waste collection and recycling is presented in Figure 6.9. Per capita collection rates (2.4.1) were significant throughout the selected municipalities, and more so for Mesão Frio and Peso da Régua (with 429 and 462 kg/inhabitant, respectively), which obtained the lowest normalised data values under both methods, since increases in solid waste collection were deemed a cost.

2.4.1 - Total urban solid waste collected per capita



2.4.2 - Total urban solid waste recycled per capita



2.4.3 - Total recycled/total collected

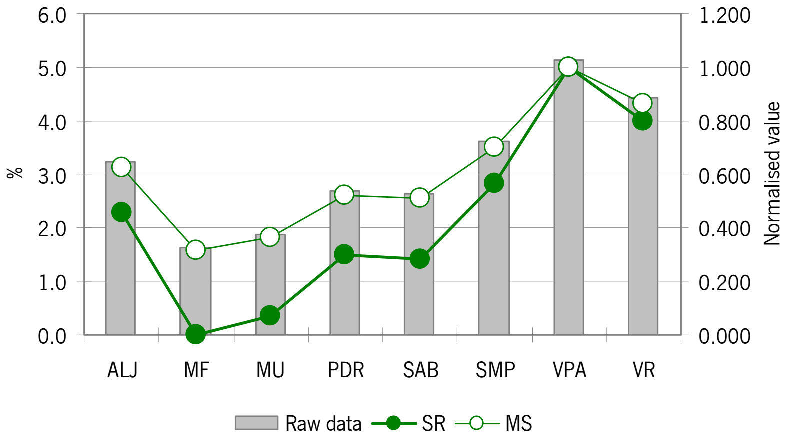


Figure 6.9 – Environmental indicators: solid waste data

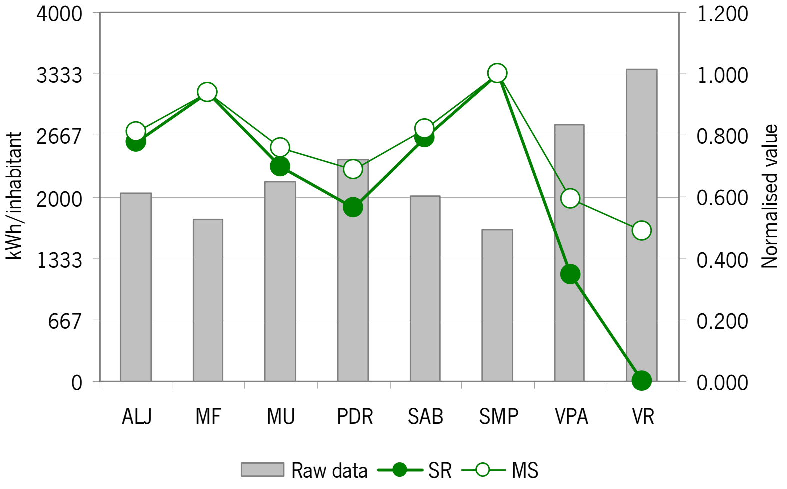
Alternatively, Santa Marta de Penaguião was better than its counterparts producing 277 kg of total urban solid waste collected per inhabitant, receiving the highest normalised value of the set in both normalisation methods. In terms of recycled solid waste (2.4.2), the best per capita contribution was observed for Vila Real and Vila Pouca de Aguiar. In fact, their percentages of recycled waste over total collected waste (2.4.3) were the best results at 4.43% and 5.14%, respectively.

Overall, the results for sub-group 2.4 derived from the application of the two normalisation methods show that these have translated the variation in raw data points according to the approach for which they were designed. Also, the SR-produced data sets revealed a more dramatic variation because the method forces them to vary between 0 and 1.

The raw and normalised data for total and household per capita electrical energy consumption are shown in Figure 6.10, though not all electrical energy consumption uses were considered. The original data source (INE, 2007) also included also non-household, heating, public lighting and other categories. These were nonetheless included in the “total electrical energy consumption” category.

As expected, lower per capita consumptions yielded the highest normalised data. This was the case for Mesão Frio and Santa Marta de Penaguião in terms of total consumption. Vila Real and Vila Pouca de Aguiar were the municipalities in which per capita consumptions were higher, thus receiving the lowest normalised values under either normalisation methods. The same trends can be observed for household consumptions. The variation in electrical energy usage from one municipality to another followed a similar distribution to that for total consumption, with the same municipalities rating best and worst. Yet again, the normalisation methods produced similar results.

2.5.1 - Total electrical energy use per capita



2.5.2 - Household electrical energy use per capita

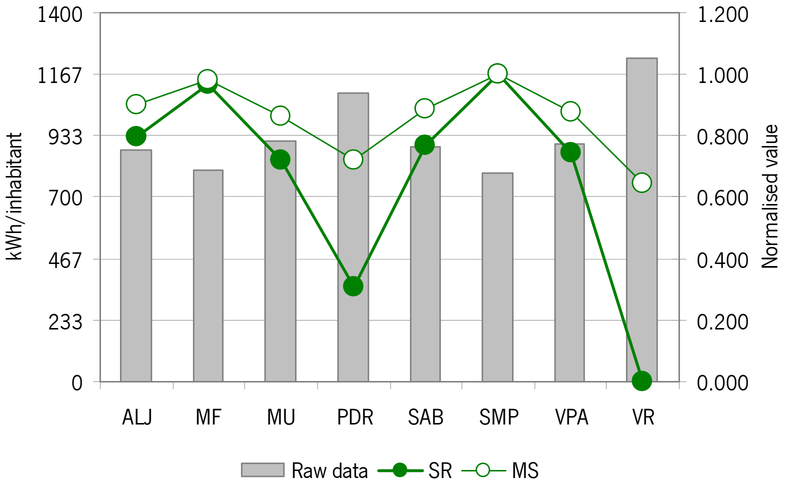
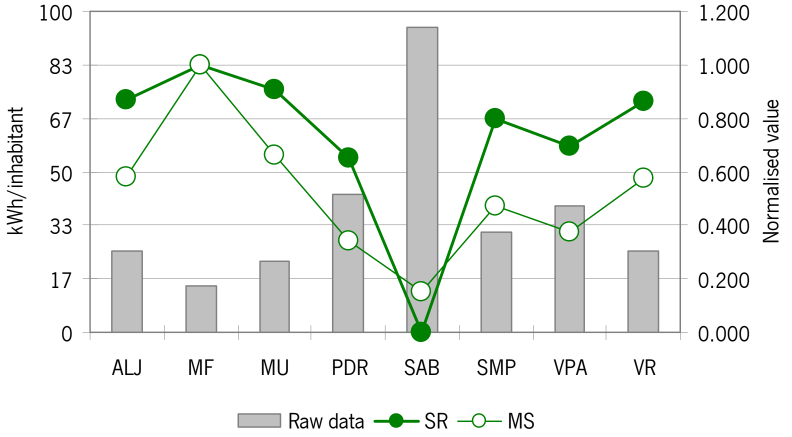


Figure 6.10 – Environmental indicators: total and household electrical energy consumption

Agricultural and industrial per capita electric energy consumptions are illustrated in Figure 6.11. Agricultural energy uses were clearly more significant in Sabrosa (95 kWh/inhabitant) than in any other municipality, with Peso da Régua occupying a distant second place (approximately 43 kWh/inhabitant). According to the sectoral activity distribution described in Chapter 5, Sabrosa showed the highest dominance of primary sector activities as opposed to the remaining municipalities, which explains the highest per capita figure. On the other hand, primary sector activity was the least representative in Vila Pouca de Aguiar, which nonetheless, produced relatively high consumption rates. This is due to the fact that not all agricultural uses are identical in their requirements of electrical energy and efficiency of use. The remaining municipalities' consumptions were comparatively lower, a fact that has been adequately translated by both data normalisation methods applied. Mesão Frio showed the least per capita consumption and thus, generated the highest normalised value.


2.5.3 - Agricultural electrical energy use per capita

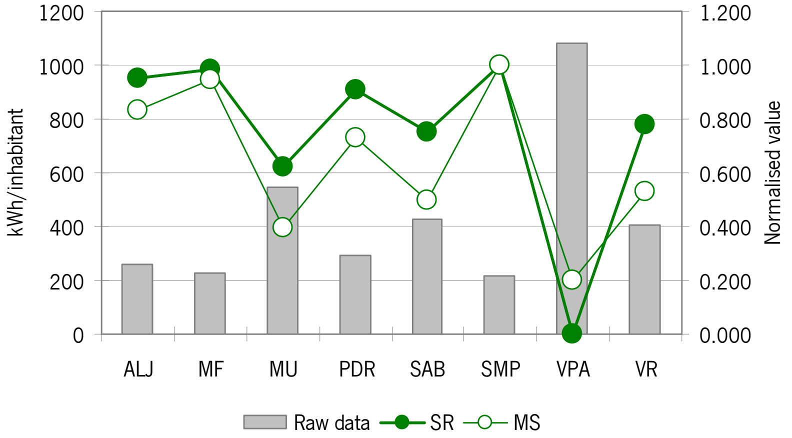

2.5.4 - Industrial electrical energy use per capita

Figure 6.11 – Environmental indicators: agriculture and industrial electric energy consumption

Industrial per capita uses were the highest for Vila Pouca de Aguiar at approximately 1080 kWh per capita, followed by Murça at about 543 kWh per capita. Vila Pouca de Aguiar was the municipality that exhibited the greatest dominance of the industrial activity sector (see Chapter 5). As seen in the graph above, these municipalities received the lowest normalised data values, whereas municipalities in which consumptions were lower produced higher normalised values, such as Santa Marta de Penaguião. In all cases, data normalisation methods resulted in energy consumption trends across the cluster of selected municipalities that were in accordance with the assumed hypothesis that an increase in electrical energy consumption would be an undesirable event and consequently seen as a cost.

The scores for the sub-groups of indicators are presented in Figure 6.12.

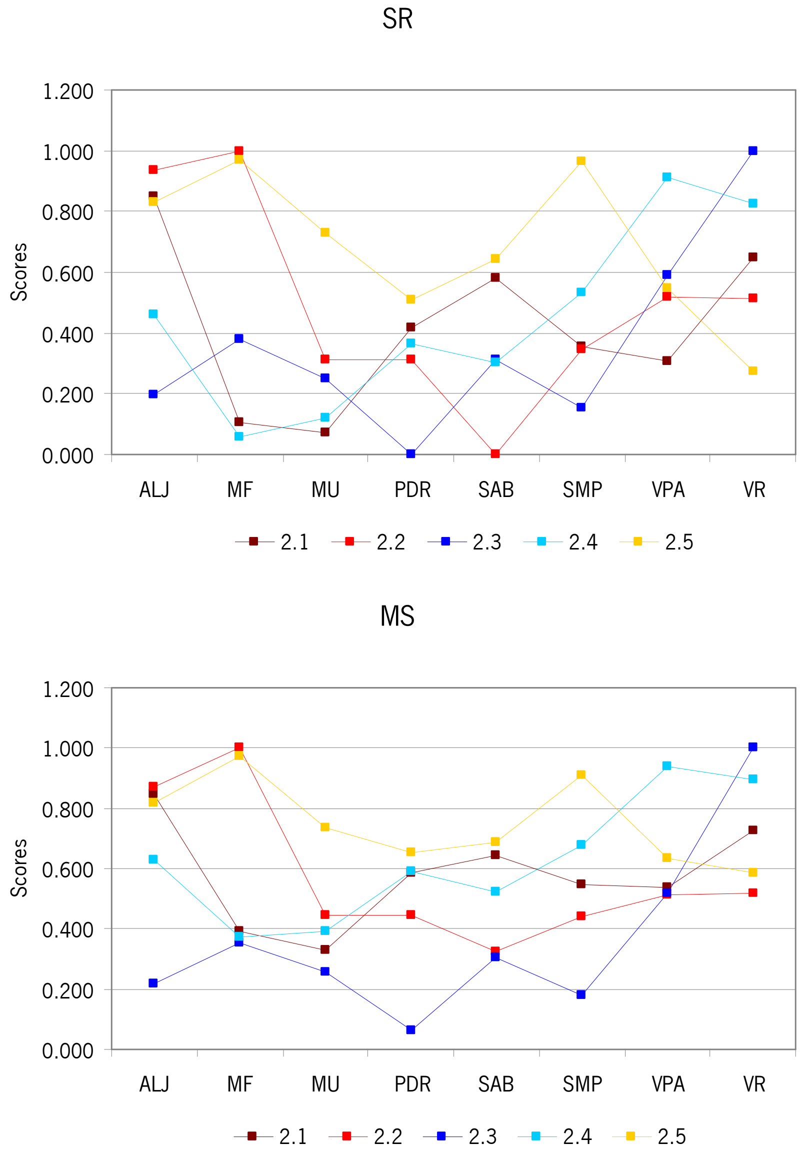


Figure 6.12 – Environmental sub-group score variation

After combining the normalised data sets using the WLC technique, the result was an identical order distribution of scores for both normalisation procedures. Despite generating slightly different values upon which to calculate the scores, the order by which municipalities were organised for each indicator did not change from one method to the other.

In terms of water parameters (2.1), Alijó scored the highest, implying the lowest water losses in these to municipalities. Wastewater (2.2) scores were highest for Mesão Frio, while Alijó took a close second position. Conversely, Sabrosa obtained the lowest score and could be considered the largest water waster of the group, attending to the initial assumptions that led to the inclusion of this indicator in the final list. Vila Real was the best municipality in terms of wastewater facilities (2.3) since it did not report any treatment using CST. Peso da Régua was the worst amongst the eight.

Vila Pouca de Aguiar obtained the highest marks for solid waste data (2.4), given its high rates of recycling rate, though Vila Real was the top per capita recycler. The latter municipality scored second to the former in this indicator.

Santa Marta de Penaguião and Mesão Frio were the top electrical energy consumers, scoring almost the highest score possible (1.000). Alternatively, Vila Real was the municipality that obtained the lowest score, given its high per capita total and household consumptions.

As described earlier, environmental indicators were considered scenario-independent and therefore, the analytical steps focused only on how the partial scores would be affected by the application of two data normalisation methods. The overall scores for the environmental group are depicted in Figure 6.13.

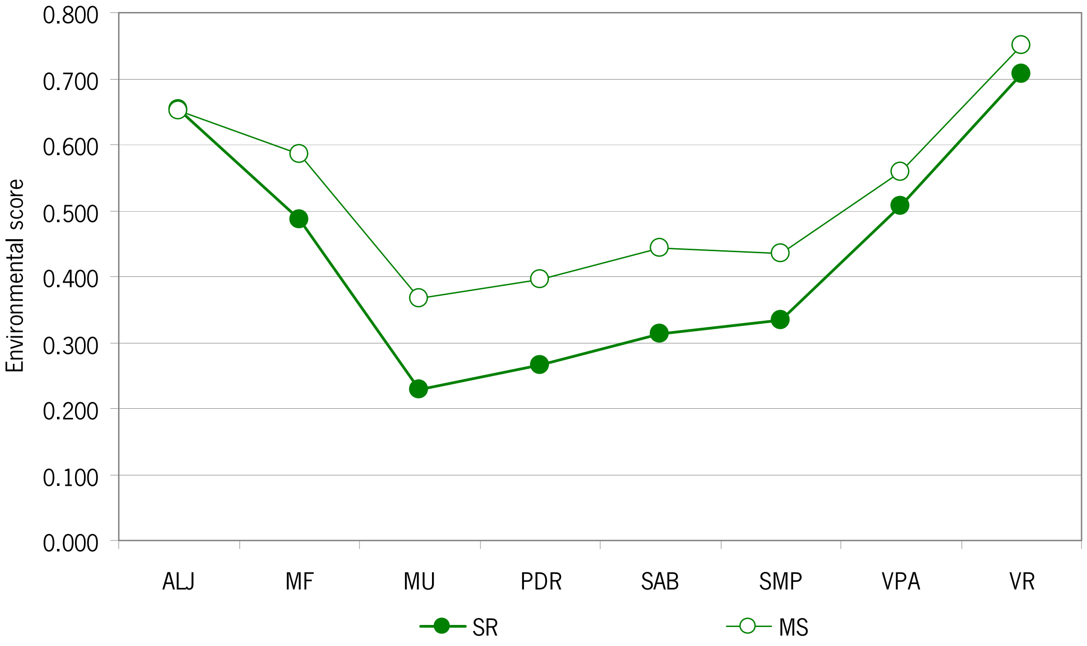


Figure 6.13 – Environmental scores according to data normalisation method

The absolute differences between SR and MS scores was expected and already explained by the fundamental differences between them. The relative municipality order remained almost identical were it not for the case of Sabrosa and Santa Marta de Penaguião. In the SR method, Santa Marta de Penaguião scores slightly higher (0.334) that Sabrosa (0.314), while in the MS procedure, Santa Marta de Penaguião scored lower than Sabrosa by 0.010 (0.434 against

0.444). Of the eight target municipalities, Vila Real fared better that its counterparts, followed by Alijó. Murça was clearly the lowest scoring municipality in environmental terms.

In order to determine whether the scores obtained would be considered significantly different, a few descriptive statistics were calculated and are presented in Table 6.2.

Table 6.2 - Environmental scores: statistical features

Municipality	Standard deviation	Mean	99% Confidence interval		Score range	
			Min	Max	Min	Max
ALJ	0.001	0.653	0.651	0.656	0.652	0.654
MF	0.070	0.536	0.408	0.664	0.486	0.585
MU	0.097	0.298	0.121	0.475	0.229	0.366
PDR	0.092	0.330	0.162	0.499	0.265	0.396
SAB	0.092	0.379	0.212	0.546	0.314	0.444
SMP	0.071	0.384	0.256	0.513	0.334	0.434
VPA	0.036	0.533	0.467	0.599	0.507	0.559
VR	0.031	0.729	0.673	0.784	0.707	0.750

The partial scores for all municipalities fit within the 99% confidence interval calculated and therefore, it is correct to assume the calculated mean as a representative value (within ±1%) of the set of scores calculated for in each case under separate data normalisation methods.

The weights assigned to each indicator (tier 3) and afterwards to each sub-group (tier 2), allowed the compensation between worse and better performances, benefitting more the municipalities that scored best in those indicators for which the corresponding weight was higher (2.1, 2.2 and 2.3). Equally, municipalities that scored poorly saw their partial scores negatively impacted by the relative significance assigned to these indicators as opposed to others for which they might have scored better. Such was the case for Murça. Its better score for sub-group 2.5 was not sufficiently high to compensate for the mediocre performance for the remaining sub-groups and hence, this municipality ranked the lowest under both data normalisation methods.

In general, the municipalities that started out with better raw data for water and wastewater systems obtained a better classification. This is the case for Alijó, whose consistently high scores for sub-groups 2.1 and 2.2 enabled this municipality to secure the second position. Likewise, Vila Real's highest score for sub-group was sub-group 2.3 was critical to award it the first position, implying an obvious trade-off between higher and lower scores, which were nonetheless consistently moderate to high for all indicators, scenarios and normalisation methods. Consequently, score consistency may be preferred over compensation between extreme values, since a high mark may not always cancel out a low one because of the difference in weights assigned to each indicator, or in this case, sub-group of indicators.

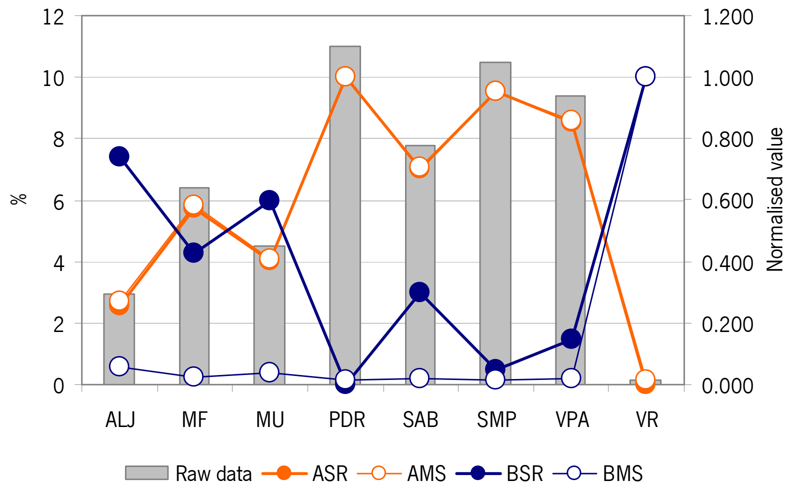
6.1.3. Economic scores

The economic component for the case study was evaluated using expenditure and revenue data for each of the municipalities, using the categories of total and environmental protection activities, including wastewater management and others. Given the scenario definition explained in the methodology (Chapter 4), sub-groups 3.1, 3.2, 3.3 and 3.4 were found to be scenario-dependent, whereas sub-group 3.5 was not.

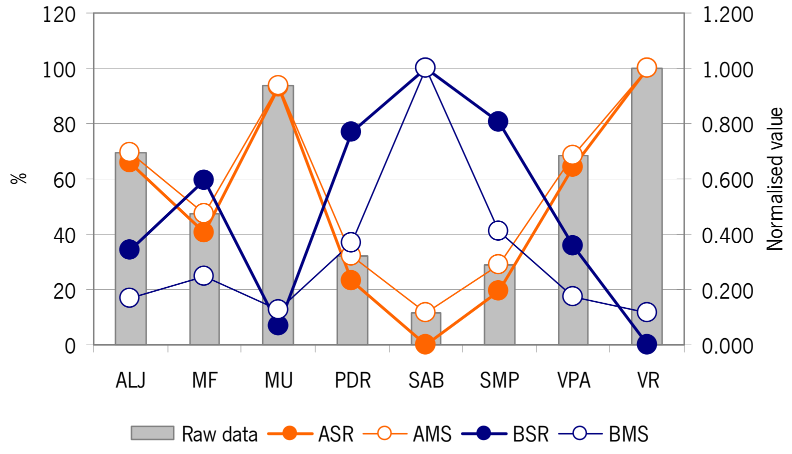
Raw data were normalised using both SR and MS normalisation methods under both scenarios where pertinent. The results are presented and discussed below.

Expenditures were evaluated in terms of what percentage of the total municipal expenditure was dedicated to environmental protection activities and more specifically, what percentage was devoted to wastewater management and remaining environmental protection activities, including water resource protection. There was no specific class for water management and therefore, only wastewater management was analysed separately. Results are shown in Figure 6.14. As expected, different scenarios produce different results, since the indicators were either considered a benefit (scenario A - Baseline) or a cost (scenario B – Established).

3.1.1 - Environmental expenditure/Total expenditure



3.1.2 - WW management expenditure/Environmental expenditure



3.1.3 - Remaining environmental protection activities expenditure/Environmental expenditure

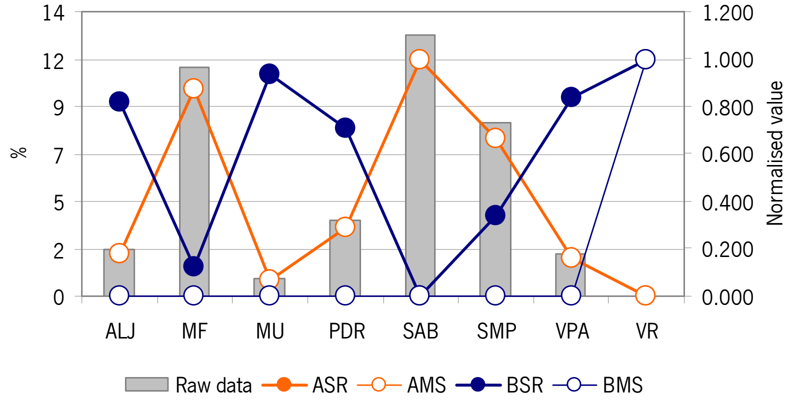


Figure 6.14 – Economic indicators: expenditure ratios

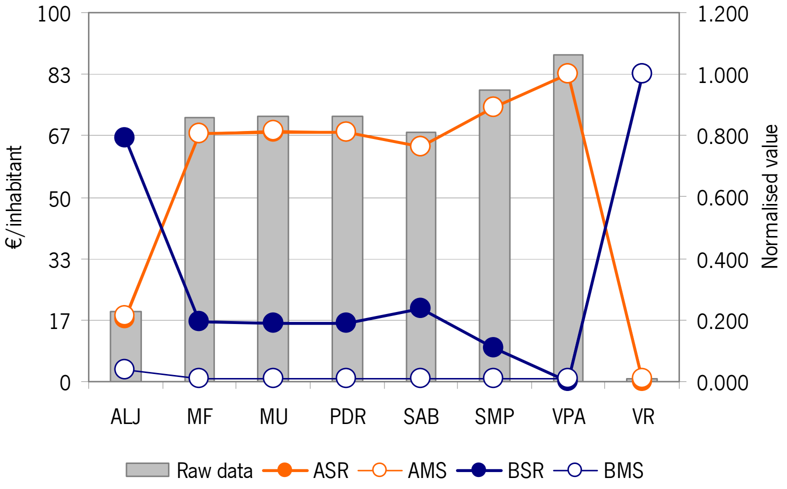
Peso da Régua and Santa Marta de Penaguião were the municipalities that spent, in 2005, more of their total municipal expenditure in environmental protection activities (3.1.1), at approximately 11 %, respectively. On the other hand, Vila Real spent the least (about 0.2%) of the selected municipalities. For these reasons, the first two municipalities got top marks and Vila Real rated the worst under scenario A. In scenario B, the results were reversed. Since an increase in environmental expenditures was assumed to be an undesirable occurrence, Vila Real obtained the highest value and the remaining municipalities received lower normalised values. Additionally, the normalised value distribution tracked well the variations between raw data points. Nevertheless, because the raw datum for Vila Real was comparatively much lower, it affected the results of the MS normalisation in scenario B.

Indicator 3.1.2 concerned the percentage of the environmental expenditures that was devoted to wastewater management. As seen, that percentage was higher for Vila Real (100%) and Murça (approximately 94%), leaving Sabrosa (about 12%) for last. In Vila Real and according to data from the INE (2007), all of the environmental spending was solely related to wastewater management. Accordingly, and under scenario A, this municipality obtained the highest normalised value, since an increase in spending was deemed a benefit. Conversely, such an increase was undesirable in scenario B and thus, both normalisation methods produced the lowest normalised value for Vila Real.

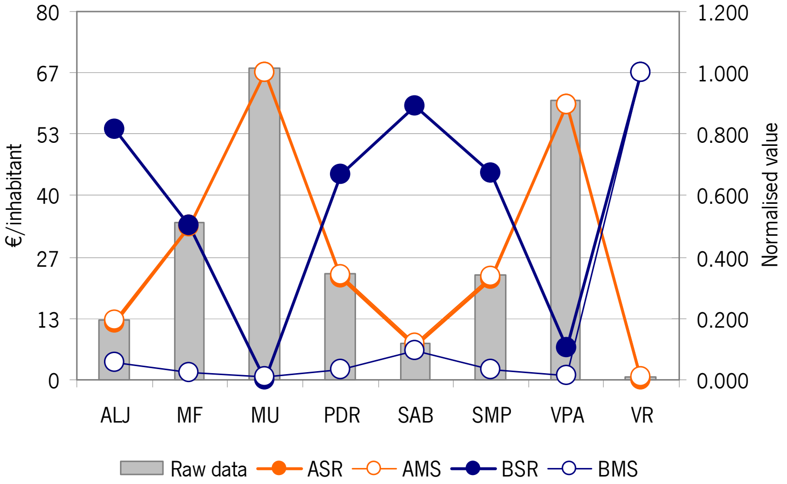
Remaining environmental protection activities (3.1.3) include a variety of other activities, as described in Chapter 5. Sabrosa and Mesão Frio dedicated a larger percentage of their environmental budget (approximately 12.9 and 11.3%, respectively) while Vila Real recorded zero, as anticipated. Murça was a very close low performer at 0.9%. The behaviour in each scenario was as expected, with the higher-spending municipalities taking advantage of higher normalised values in scenario B and *vice versa*. As noted previously in this discussion, a raw datum value of zero affects the normalisation method in the way it reproduces the relative variation between raw data points. This was evidenced by the performance of the MS values under scenario B. Because of the zero value for Vila Real, the remaining municipalities obtained a normalised value of zero, which ultimately did not retain any of the raw data original variability.

Per capita expenditures were also analysed and are presented in Figure 6.15. Environmental spending (3.2.1) was lower in Alijó and Vila Real than in the remaining municipalities.

3.2.1 - Environmental expenditure per capita



3.2.2 - WW management expenditure per capita



3.2.3 - Remaining environmental protection activities expenditure per capita

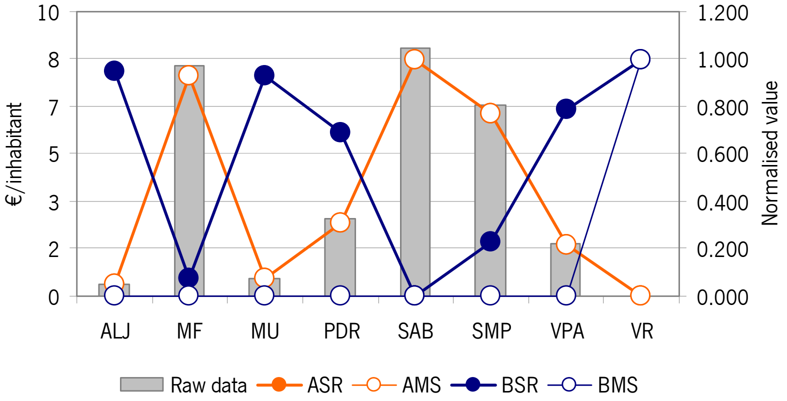


Figure 6.15 – Economic indicators: expenditure per capita

Alijó reported approximately 19 Euros per inhabitant while Vila Real stayed at 75 Euro-cents per capita. The highest value was reported by Vila Pouca de Aguiar, with an expenditure of 89 Euros per capita. The normalised results were once again affected by the significantly lower value for Vila Real, which caused the MS values to be almost zero. This did not allow for a better representation of the raw data variability under this normalisation procedure. This effect was not observed for the SR method that, nonetheless, produced values almost identical to those originated by the MS method. Values of zero or close rendered the normalisation equations 3.10 and 3.13 identical and therefore, the results were the same.

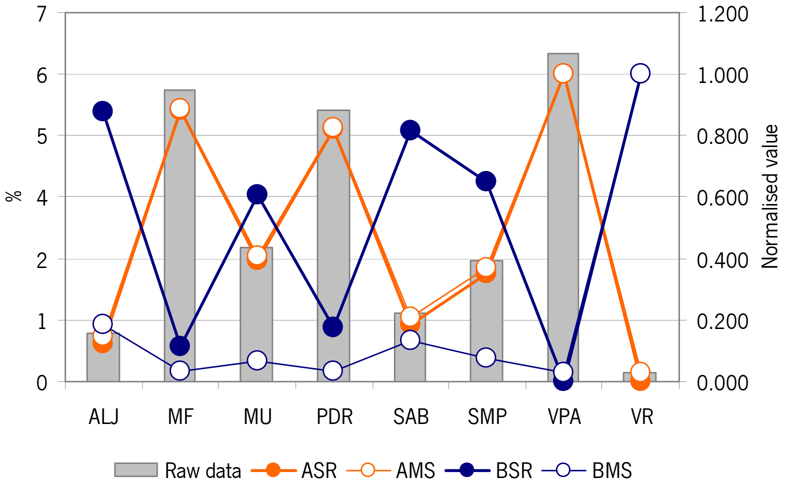
Wastewater management per capita expenditure (3.2.2) varied from municipality to municipality. Murça and Vila Pouca de Aguiar spent the most (approximately 68 and 61 Euros per inhabitant, respectively) while Vila Real continued to occupy the last position, with 75 Euro-cents per capita. Sabrosa also showed comparatively low spending, at about 8 Euros per inhabitant. Consequently, it obtained the second lowest value in under scenario A, with Vila Real received the lowest of the eight. Logically, these municipalities were benefited in scenario B, for which high expenditures per capita were undesired. Yet again, the impact of having a very low value in the raw data set produced similar results to those observed earlier and for other indicators. Under scenario A, the results were almost identical and for scenario B, they were distinguished by the fact that the MS values are almost all zero and thus, differed significantly for the SR values.

This effect was also observed for indicator 3.2.3, remaining environmental protection activities expenditure per capita. In this case, however, since the raw datum for Vila Real was actually zero, so were the MS-normalised values for the remaining municipalities analysed under scenario B. This is obviously not the case for SR values nor for scenario A results, that are identical regardless of normalisation procedure, as explained before. Sabrosa was the municipality that spent the most in 2005, with a little less than 9 Euros per capita, followed closely by Mesão Frio, at 8 Euros per inhabitant.

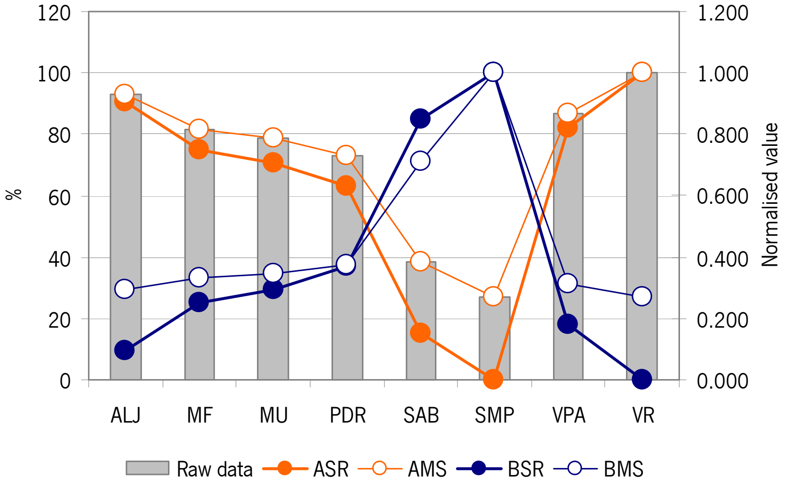
Revenues were analysed for the same categories as above, following the same scenario and normalisation method approaches as before. The results are illustrated in Figure 6.16 and discussed below.

Generally speaking, municipalities that showed larger expenditure percentages for indicator 3.1.1 typically exhibited larger revenues for indicator 3.3.1, with few exceptions.

3.3.1 - Environmental revenue/Total revenue



3.3.2 - WW management revenue/Environmental revenue



3.3.3 - Remaining environmental protection activities revenue/Environmental revenue

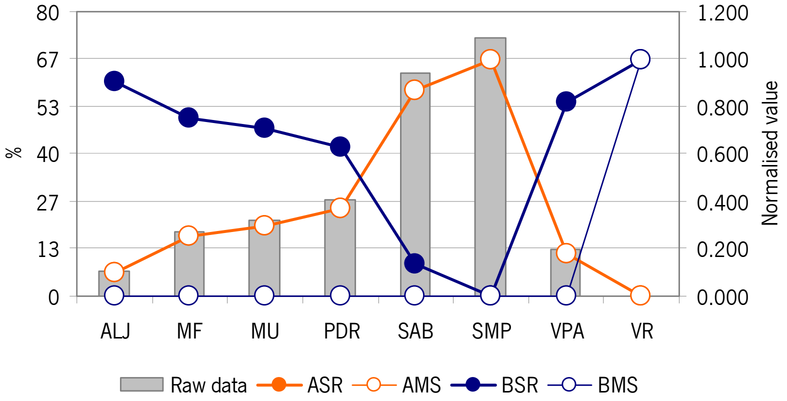


Figure 6.16 – Economic indicators: revenue ratios

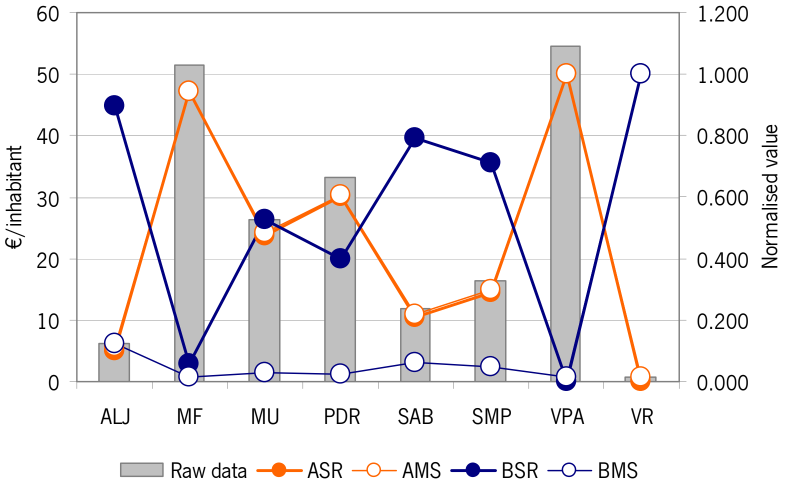
Sabrosa, Murça and Santa Marta de Penaguião were such examples. While their expenditures were kept fairly high, their revenues were not. Having contributed with the highest expenditure percentage of environmental over total, Vila Pouca de Aguiar also exhibited the highest percentage for the corresponding revenues. Alternatively, Alijó and Vila Real continued to show the lowest percentages also for revenues, as seen in the graph. The normalisation methods translated the variability of the raw data in a satisfactory manner, safe for the influence of the *quasi*-zero value for Vila Real that, one more time, affected the MS-normalised data in scenario B. Under scenario A, the values were practically identical for both SR and MS methods.

The percentage of wastewater management revenue included in the environmental revenue total (3.3.2) was also variable from municipality to municipality, though slightly more uniform than in the expenditure case (3.1.2). Vila Real and Alijó showed the highest percentages (100 and about 93%, respectively), while Santa Marta de Penaguião and Sabrosa exhibited the lowest (27 and 38%). Since the raw data were close in magnitude (*i.e.*, no datum was close to zero or significantly lower than the remaining data), both normalisation methods translated well the variability of the raw data into the normalised values. Because the MS method did not force normalised data to vary precisely between 0 and 1, the resulting curves were smoother than their SR counterparts. Also, there were some scenario-dependent variations. As expected, higher ratios produced higher normalised data in scenario A and lower in scenario B. Also, normalised data were closer under both scenarios for intermediate raw data values, as observed for Peso da Régua.

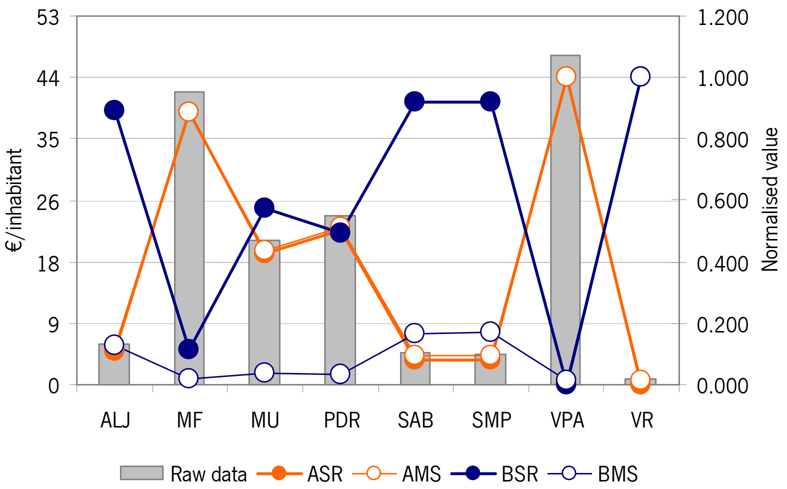
With regards to indicator 3.3.3, the municipalities exhibiting lower percentages earlier were the ones displaying the highest remaining environmental protection activities to environmental revenues percentages. Sabrosa and Santa Marta de Penaguião topped the group of selected municipalities at 63% and 73%, respectively. Vila Real showed zero revenue and thus obtained a zero-valued ratio, affecting the outcome of the MS-normalised data under scenario B. For that very same reason, normalisation under scenario A produced identical values.

Revenues per capita were also analysed, following the approach presented earlier. Figure 6.17 shows the raw data and normalised data distribution per municipality and scenario under analysis.

3.4.1 - Environmental revenue per capita



3.4.2 - WW management revenue per capita



3.4.3 - Remaining environmental protection activities revenue per capita

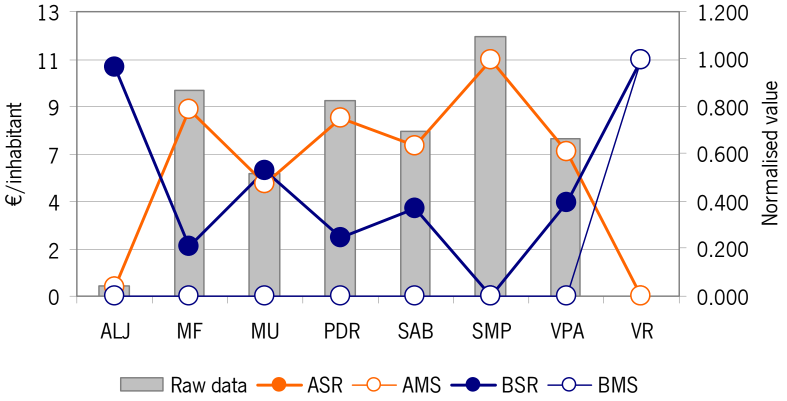


Figure 6.17 – Economic indicators: revenuer per capita

Unlike expenditures, environmental per capita revenues (3.4.1) exhibited more variability and comparatively lower absolute values. Vila Pouca de Aguiar was the highest contributor, at approximately 55 Euros per capita. Once again, Vila Real was the municipality presenting the lowest raw datum, at 75 Euro-cents. These disparities were accurately matched by the corresponding normalised data under either scenario. The much lower value for Vila Real impacted MS-normalised values in scenario A, by turning almost identical values for SR and MS normalised data, and also in scenario B, by producing MS-normalised data that were almost zero for all municipalities.

The situation was repeated for indicator 3.4.2. As seen in the graph, the low value of Vila Real produced the same effect upon the normalised data, depending on scenario. In this case, it was not as pronounced since the raw data were closer in magnitude than in the previous situations. Once more, Vila Pouca de Aguiar presented the highest absolute and normalised data and was followed by Murça. Alijó was the second lowest contributor in terms of per capita wastewater management revenue.

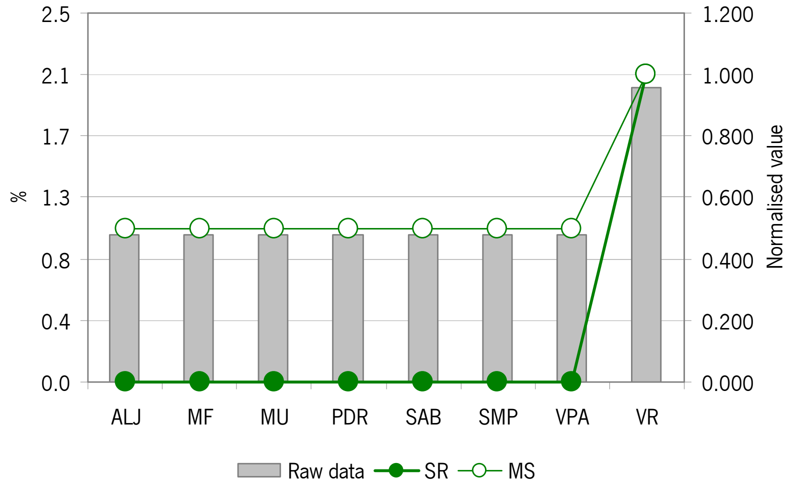
The remaining environmental protection activities revenues per capita were zero for Vila Real and 43 Euros-cents for Alijó. The other municipalities exhibited values that were significantly higher but still low, ranging from approximately 6 Euros (Murça) to 12 Euros (Santa Marta de Penaguião). As shown, raw data variability was again well reproduced by both normalisation methods and for each scenario, obeying the original assumptions of considering the indicator either as a benefit (scenario A) or as a cost (scenario B).

Municipalities exhibited similar behaviours in terms of magnitude of expenditure and revenues. Ratios between revenue and expenditure for the environmental and wastewater management categories (expressed as percentages) were evaluated and are discussed below (Figure 6.18).

As explained in the methodology (Chapter 4), indicators belonging to sub-group 3.5 were considered independent of scenario and were analysed based on a rating scale that classified each municipality based on whether they were at, above or below the unity. For indicator 3.5.1, all municipalities exhibited ratios below 1, except for Vila Real, which was already at the unity, and thus received the highest rating. The normalisation methods accurately reproduced the raw data trends, as seen in the graph.

Indicator 3.5.2 presents an almost identical case, were it not for the cases of Mesão Frio and Peso da Régua, that obtained the lowest rating on the scale (zero) for showing ratios above the unity, that is, revenues that were greater than the corresponding expenditures. As explained earlier, ratios above 1 were considered undesirable and therefore were assigned the lowest rating. Once again, the zero-rated values affected the normalisation methods in that the values produced were identical.

3.5.1 - Environmental revenue/Environmental expenditure



3.5.2 - WW management revenue/WW management expenditure

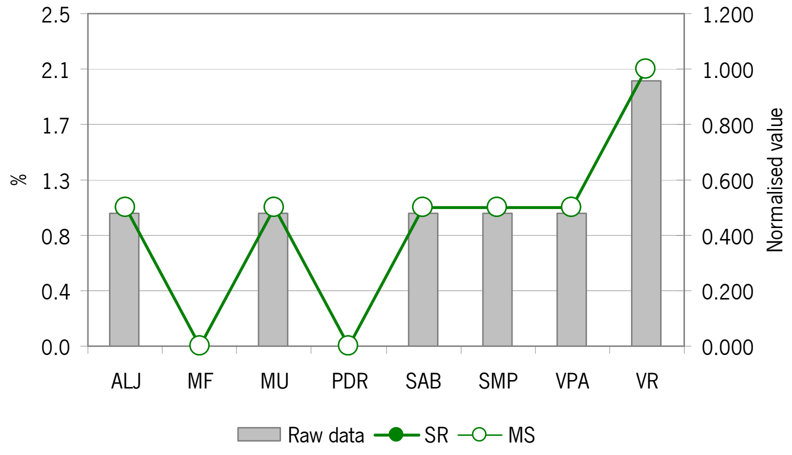


Figure 6.18 – Economic indicators: revenue over expenditure ratios

The scores for the sub-groups of economic indicators are presented in Figures 6.19 and 6.20 below. In general terms, the relative order of municipalities was maintained from one normalisation method to the other (ASR to AMS, and BSR to BMS). Under scenario A (ASR and AMS), Alijó and Sabrosa scored lower than the remaining municipalities for sub-groups 3.1 through 3.4. Conversely, Mesão Frio and Vila Pouca de Aguiar were the top scorers, with Vila Real receiving variable scores according to whether these refer to expenditure (3.1 and 3.3, mid-range scores), revenue (3.2 and 3.4, low scores) or revenue over expenditure percentages (3.5, top score). In general, this variability in scores was also apparent for the other municipalities, though the range of variation was not as wide as it is for Vila Real. The exception lay with the behaviour of score 3.5. The values obtained behaved as outliers, because group 3.5 indicators were considered and treated independently of scenario.

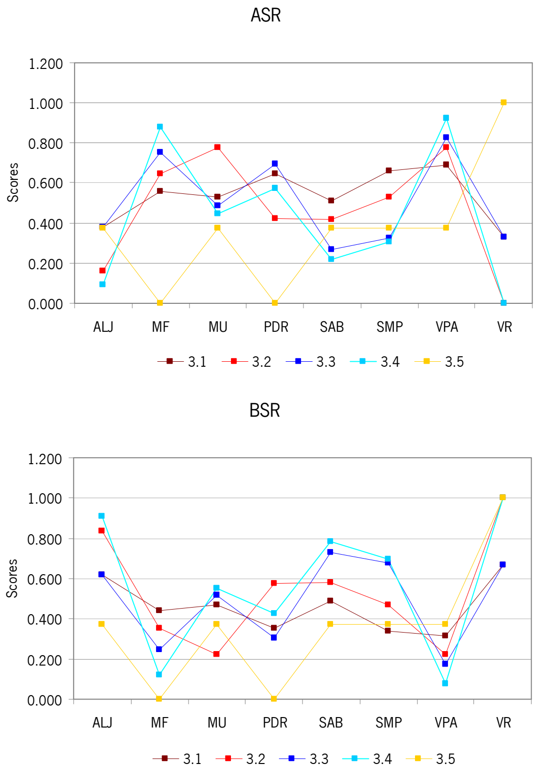


Figure 6.19 - Economic indicators sub-groups scores (SR)

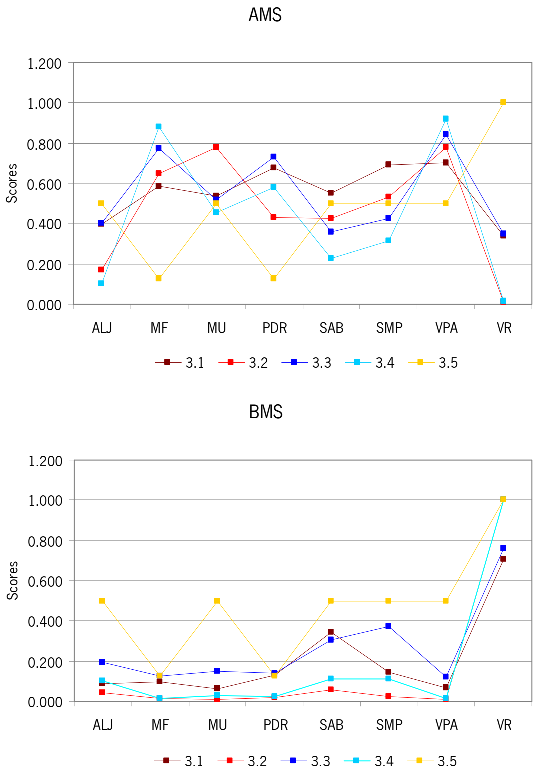


Figure 6.20 - Economic indicators sub-groups scores (MS)

Under scenario B, the order of the municipalities was reversed, with Alijó and Sabrosa producing the best scores and Mesão Frio and Peso da Régua scoring lower. Vila Real continued to display a wide spreading of scores, though exhibiting a tendency for higher values than in scenario A, for both normalisation methods. Vila Real was also a top scorer in scenario B.

About sub-group 3.5, the variation in scores was almost identical to the variation of the normalisation values for indicator 3.5.2, which was assigned a much greater weight than indicator 3.5.1 (0.750 and 0.250, respectively). The slight difference between 3.5 scores from one data normalisation method to another was related to the specifics of each one of them. Since the MS approach did not force data to vary between 0 and 1 like the SR method, the scores resulting from MS-normalised data simply reproduced the original variability in data, and thus, generated values that were slightly higher than their SR-normalised counterparts.

The overall partial scores for the economic group of indicators are illustrated in Figure 6.21 below.

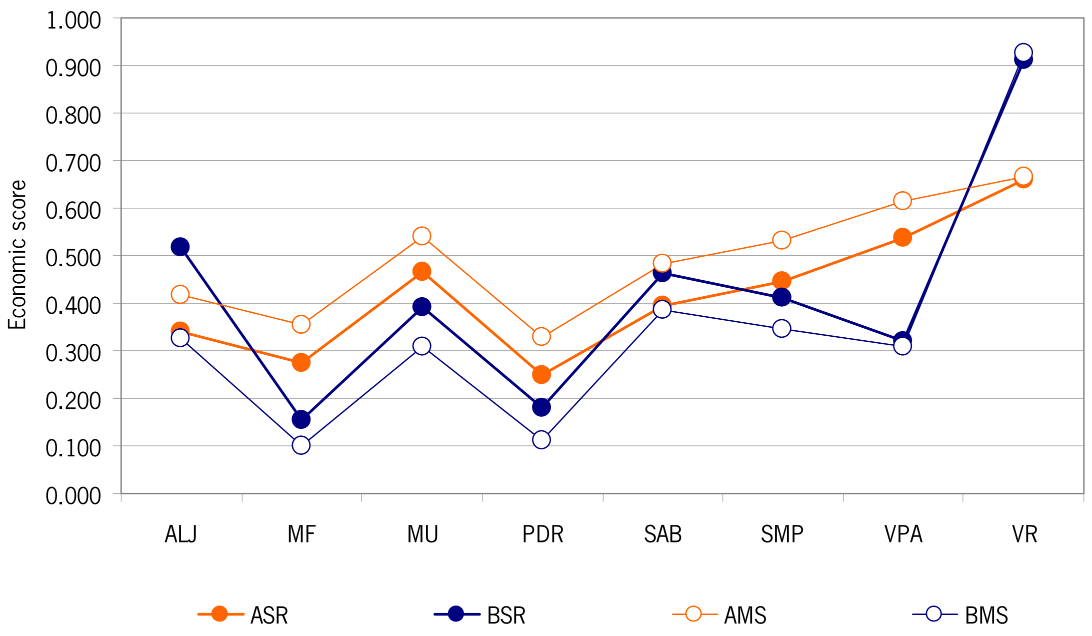


Figure 6.21 - Economic scores according to data normalisation method

In general, scores obtained under scenario A (baseline conditions) were higher than those obtained in scenario B (established conditions), except for Vila Real (B-scores were higher) and Sabrosa (A and B-scores were practically identical).

The municipality order according to the partial scores remained essentially unchanged, except for Santa Marta de Penaguião and Vila Pouca de Aguiar. The results obtained for these two municipalities followed opposing trends in terms of scenario that originated them. This means that there was less compensation between better and worse scores and thus, the rating of these municipalities is scenario-dependent. This was a direct result of two phenomena: nature of the raw data, and limitations of the MS normalisation method. Particularly for Vila Pouca de Aguiar, the lowest assigned scores were derived from lowest data normalisation results in scenario B, corresponding to high raw data values. As mentioned before, extreme values (highest or lowest) were more difficult to compensate, and thus the trade-off benefit was reduced in these situations. The effects of this reduced ability for levelling-off the scores are seen in curve BSR.

With regards to curve BMS, and as explained earlier, whenever the raw data presented at least one zero data point, any normalisation would yield zero for all of the normalised values, given the form of equation 3.12. Hence, as described and discussed above, there were many instances in which this effect was visible, namely for indicators 3.1.3, 3.2.3, 3.3.3 and 3.1.3

(parameters for which Vila Real reported datum was zero). Furthermore, a similar effect was verified for situations where the lowest raw datum was close to zero or at least, much lower than the remaining data (indicators 3.1.1, 3.2.1 and 3.2.2). This effect was observed more clearly for Santa Marta de Penaguião and Vila Pouca de Aguiar because they were both awarded a zero value in situations where they would be expected to receive a higher normalised value. That was not the case for the remaining municipalities. Regardless of assumed scenario, their resulting scores kept essentially the same order. Just as for the social scores, there has clearly been a compensation between benefit and cost-oriented scores. More importantly, it means that the same relative ranking was obtained for opposing initial assumptions.

A few descriptive statistics are presented in Table 6.3.

Table 6.3 – Economic scores: statistical features

Municipality	Standard deviation	Mean	99% Confidence interval		Score range	
			Min	Max	Min	Max
ALJ	0.089	0.400	0.285	0.514	0.325	0.518
MF	0.115	0.221	0.073	0.368	0.101	0.354
MU	0.099	0.427	0.299	0.555	0.310	0.541
PDR	0.094	0.217	0.096	0.338	0.110	0.330
SAB	0.048	0.431	0.370	0.493	0.387	0.482
SMP	0.077	0.434	0.334	0.533	0.346	0.531
VPA	0.154	0.445	0.246	0.644	0.309	0.614
VR	0.148	0.790	0.600	0.981	0.660	0.925

Generally, all scores except for Alijó's BSR score fit within the 99% confidence interval. This is a situation similar to that observed for the social scores, for which outliers were identified. As seen in Figure 6.21 above, the BSR-score for Alijó does appear to be an outlier, since the remaining three data points are clustered closely to one another. If the outlier were ignored, the mean score for Alijó would be 0.360 and the 99% confidence interval would be 0.286 to 0.434, which would include the score range obtained for this municipality.

Overall, Vila Real stands out as the municipality that was able to surpass its counterparts under any evaluation scenario and regardless of data normalisation approach. Considering the normalised data opposing behaviour for each of the indicators under either evaluation scenarios, the scores were consistently distributed, apart from the exceptions already discussed.

6.2. Overall scores

After obtaining the partial scores for each of the groups (tier 2), a final round of WLC allowed the calculation of the overall scores for each municipality. This was carried out in the context of a sensitivity analysis, to find out which group of indicators was the most influential within the selected municipalities. Also, the goal was to determine whether the ranking order would be sustained from one condition to the other. As explained in the methodology (section 4.4) the procedure started out by assigning an equal weight to each group, translating the theoretically equal importance that social, environmental and economic components have in terms of the sustainability model. On the other hand, this is often not the case. Although it is desired that all the components of the model are equally weighed and addressed, in reality, one will be favoured over the other two and *vice versa*, an imbalance that is driven by circumstances that are many times external to the issue at hand (*e.g.*, political). Therefore, three additional models were tested and for each of them, one of the components was favoured in detriment of the others, having established beforehand that these would be equally weighted. The weights were assigned using the pairwise comparison model as follows: (1) social – 0.714; (2) environmental – 0.143, and (3) economic – 0.143. The results are displayed in Figure 6.22.

In the Balanced model, Vila Real was the top scorer and Peso da Régua was the lowest ranked municipality. These results were repeated for all and any of the models tested, for any scenario and data normalisation method. The relative order of the remaining municipalities varied, if slightly, with scenario and data normalisation method. The Balanced model was taken as reference for comparison with the results from the other sustainability modelling approaches.

The Social model generally favoured Peso da Régua, the only exception being for the AMS scores. Alijó, Vila Pouca de Aguiar and Vila Real were hindered in this approach. Mixed results were observed for Mesão Frio, Murça, Sabrosa and Santa Marta de Penaguião, depending on scenario and data normalisation method. Municipalities benefitted more under the Environmental model. Alijó, Mesão Frio, Vila Pouca de Aguiar and Vila Real obtained higher score under the assumption that environmental matters were more important than social and economic ones. Conversely, Murça displayed lower scores for any condition tested under this model. Mixed results were obtained for the remaining municipalities. Overall, no municipalities benefitted from the Economic model. Mixed results were obtained for all but Peso da Régua, for which the scores were worse under this model that under the reference Balanced model.

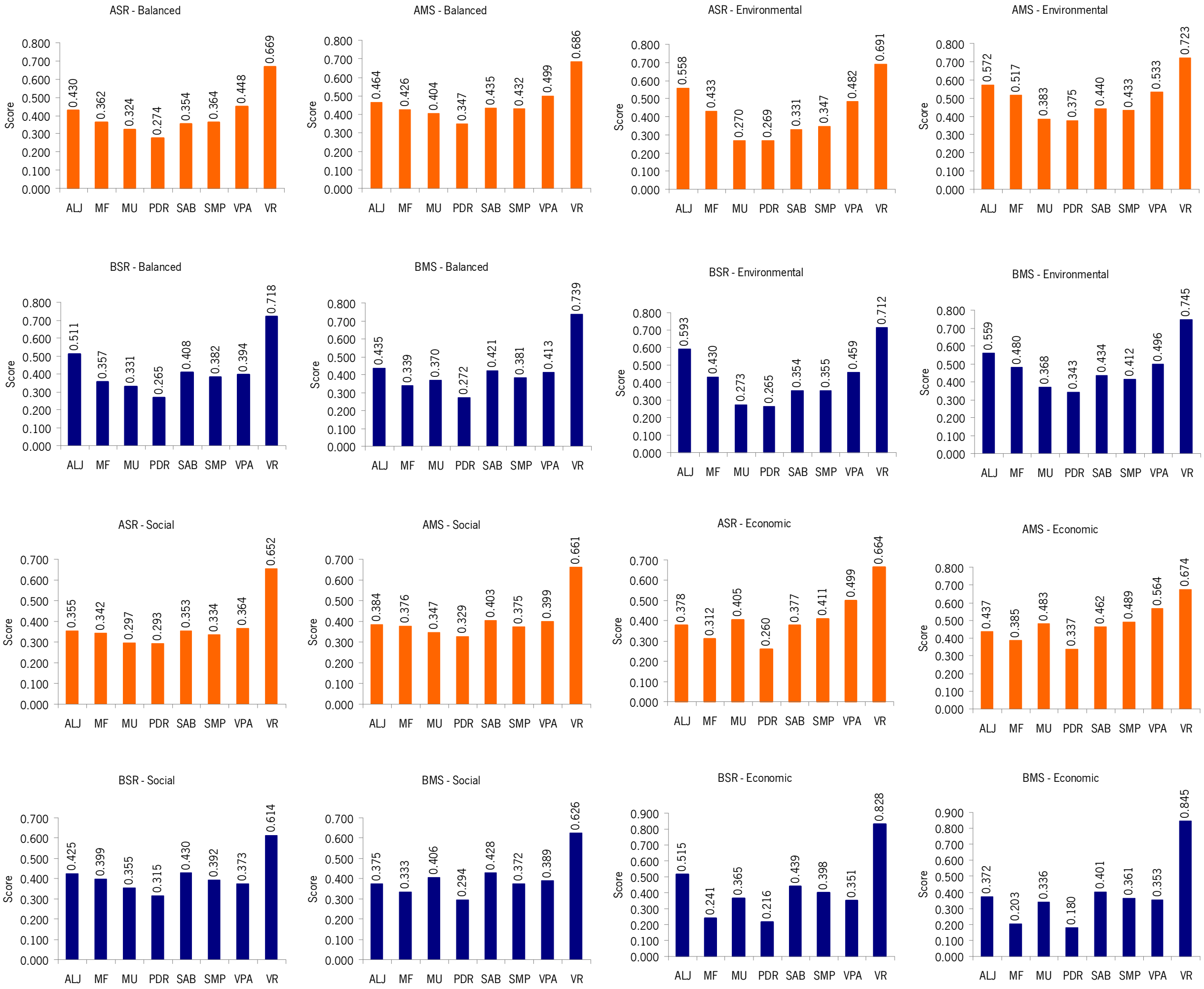


Figure 6.22 - Overall scores for Balanced, Social, Environmental and Economic models

The shape of each graph was mainly consistent and similar, safe for some slight variations in the relative order of some mid-range municipalities that have scored similarly throughout the MCA process. For each sustainability model tested, the shape of the curve is not independent of scenario, though the score distribution is similar. Consequently, the ranking is not the same. Variations observed also concern matters of data normalisation. Since the intermediate scores exhibited more variability, the problem lay in selecting the most appropriate set of data for establishing a ranking order for all the municipalities and not so much finding out which ones were the top and/or lowest ranking, since those were already indentified.

6.3. Ranking

Establishing a ranking order of the municipalities based on their respective scores required that a set was selected from amongst the options presented above. A decision was made on whether to use a single set of scores (*i.e.*, select a scenario, data normalisation method, sustainability model and use the corresponding scores) or define a way in which to combine the different results obtained for each municipality (*i.e.*, using an averaging model). The former approach was favoured over the latter.

As seen, overall trends were not independent of scenario, and so, the slight differences in municipality order were not solely due to differences generated by different normalisation approaches. A conservative approach would select scenario A, since it established a baseline condition that, for all purposes, implied that municipalities were still on their way to generate the necessary conditions for attaining sustainability. On the contrary, scenario B assumed that those conditions were already in place and sustainability would not be more than a matter of upholding them. Given the uncertainty with regards to the quality of the data collected for the analysis conducted herein (as discussed in the sections preceding this one) a conservative approach seemed the most appropriate path and therefore, scenario A was selected over scenario B.

After reviewing the results and performance of both data normalisation approaches, the SR (score range) method was considered the more reliable of the two. One of the reasons for this preference is that, unlike the MS method, the SR was better equipped to handle the particular nature of the raw data, which included a few zero data points. By design, the SR normalisation models (equations 3.13 and 3.14) include two very important characteristics that render it virtually “invulnerable” to problem values, at least from the standpoint of the data used in this work. First, the model does not normalise the datum *per se*. Instead, it normalises the relative differences between data, bounded by maximum and minimum values in the data set, which lead to the second important feature, which is “forcing” normalised values to fall within a 0 to 1 range. A subsequent limitation is that normalised data variations are not proportional to the variations of raw data (a hallmark of the MS method). As seen before, when raw data variability was weak, the normalised curve showed dramatic variability. Conversely, when differences between data points were well marked, the normalised curve was smoother, all thanks to the 0 to 1 range rule. In the context of data combination indexed to a particular set of weights, these differences in variations were nuanced upon calculation of the scores (via the WLC model) and thus, were considered non-critical. Bearing in mind these particular strengths of the SR normalisation method, only SR-derived scores were considered for the final step of the analysis.

Regarding the choice of sustainability model, it was reasonable to assume that the social component would realistically be favoured over the other two for water and wastewater infrastructure. As mentioned earlier, matters of meeting social needs often overcome matters of economic feasibility and environmental concerns. Therefore, it would be expected for the social component to carry additional importance and hence, should not be weighted as a mere third of the overall model. The typical sustainability model does call for the integration of the three, but does not necessarily establish how this integration is supposed to be carried out. In the context of this work, the Social approach was deemed the most fitting to the reality of the situation of urban water and wastewater infrastructure in the target area.

Having decided about what set of scores to use, the spatial distributions of scores were illustrated in Figures 6.23 to 6.26 below.

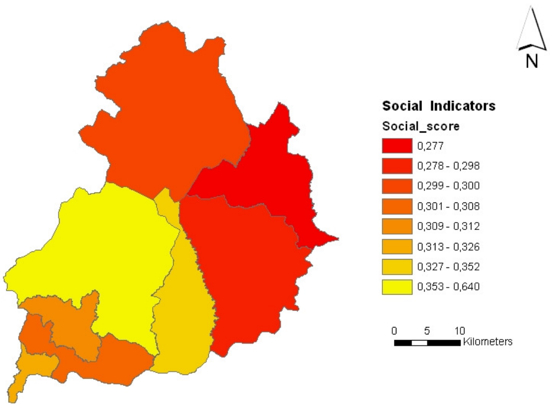


Figure 6.23 – Spatial distribution of Social ASR scores

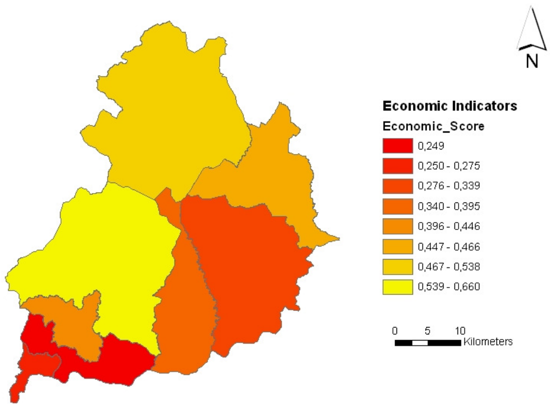


Figure 6.25 - Spatial distribution of Economic ASR scores

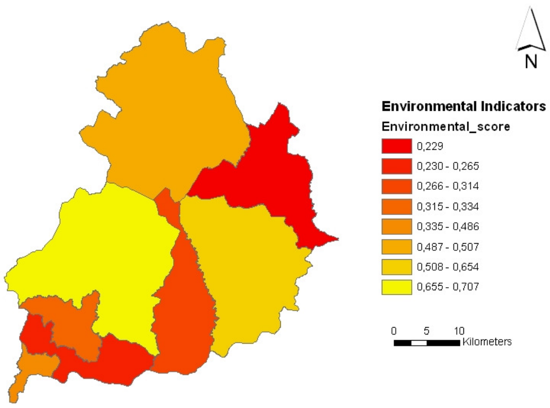


Figure 6.24 – Spatial distribution of Environmental ASR scores

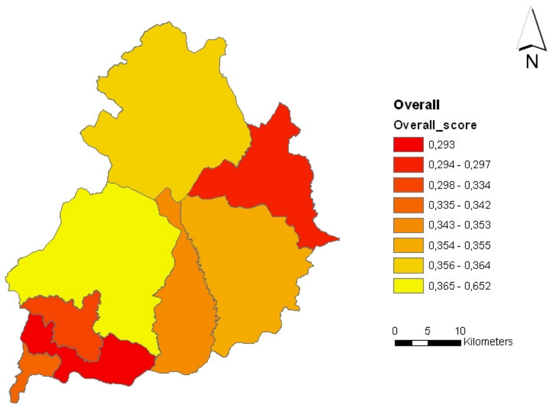


Figure 6.26 - Spatial distribution of Overall ASR scores

Considering the list of evaluation parameters, Vila Real was the most sustainable municipality in 2005 from amongst the target group. It consistently outranked its counterparts, obtaining the leading position in the overall ranking. It also scored the highest marks for all of the indicator groups (social, environmental and economic). See Table 6.4. Peso da Régua and Murça were the least sustainable municipalities.

Table 6.4 – Overall and partial ranking results (Social model)

Ranking	Overall		Social		Environmental		Economic	
1st	VR	0.652	VR	0.640	VR	0.707	VR	0.660
2nd	VPA	0.364	SAB	0.352	ALJ	0.654	VPA	0.538
3rd	ALJ	0.355	MF	0.326	VPA	0.507	MU	0.466
4th	SAB	0.353	SMP	0.312	MF	0.486	SMP	0.446
5th	MF	0.342	PDR	0.308	SMP	0.334	SAB	0.395
6th	SMP	0.334	VPA	0.300	SAB	0.314	ALJ	0.339
7th	MU	0.297	ALJ	0.298	PDR	0.265	MF	0.275
8th	PDR	0.293	MU	0.277	MU	0.229	PDR	0.249

Considering the list of evaluation parameters, Vila Real was the most sustainable municipality in 2005 from amongst the target group. It consistently outranked its counterparts, obtaining the leading position in the overall ranking. It also scored the highest marks for all of the indicator groups (social, environmental and economic).

There was a great deal of score variability amongst the partial sets. Given the much greater weight assigned to the social component, municipalities that did not fare as well in this group were able to use the partial score as much as possible. Vila Pouca de Aguiar had fared well in the environmental and economic groups but not so much in the social. However, it managed to take the second slot in the ranking, although its corresponding score is a little over half (56%) of the highest score obtained by Vila Real. In contrast, the difference between second and eighth scores is approximately 24%. Alijó underwent a similar situation, but did not score as high because of its lower economic score and despite faring better than Vila Pouca de Aguiar in the environmental group. Sabrosa scored high in the social group but did not do very well in the remaining partial scores, thus obtaining a fourth placement in the overall ranking, less than 1% away from Alijó. Mesão Frio took fifth place, despite its third placement in the social group. The municipality's low contribution from the environmental and, most of all, economic groups produced the low overall value. Murça and Peso da Régua were the lowest-faring municipalities, in spite of the reasonable scoring obtained by Murça in the economic group. Peso da Régua's moderate social score was not sufficient to counteract the effects of the poor rating obtained for the environmental and economic groups. As observed, lower scores were compensated by higher scores and *vice versa*, a trading-off conducted in the moulds allowed by the weight assigned to each group of indicators.

Vila Real was the most developed of the considered group, characterized by high total population numbers and densities and the only municipality that, by 2005, displayed population growth dynamics similar to the ones observed at a regional and even national level, including a net growth rate of 0.49% for the 2000-2006 period, as described in Chapter 5. Also, the municipality is better served in terms of transportation infrastructure as well.

Vila Real shows less urban population spread that the others that, as mentioned, are characterised by scattered population clusters that are difficult to reach by comprehensive networks of water and wastewater infrastructure. The dispersed nature of the urban clusters in combination with the complexities of the terrain renders this area a difficult target for systems that are more inclusive. Also, Vila Real is located in a more forgiving terrain, thus benefitting from comparatively better access to urban water and wastewater infrastructure.

7. CONCLUSIONS

The work focused on reviewing different sustainability assessment models and methodologies and defining a procedure for carrying out a comparative analysis between eight municipalities located in Northeastern Portugal. The results were used to evaluate the sustainability status of the target-locations and used to establish a ranking order. A multi-criteria analysis was conducted based on a set of case-specific indicators, considering two analytical approaches and different data processing methods. A sensitivity analysis was conducted and revealed trends that were, to some extent, independent of analytical scenario. The municipalities were ranked according to the results obtained. The following text lists the conclusions drawn from the work developed and presented in this dissertation, along with a few recommendations for future work.

Though based on existing approaches focused on similar subjects, the methodology developed herein was original and involved the definition of case-specific indicators and decisions regarding analytical options. The conclusions are as follows:

- The methodology was adequately implemented and can be applied to similar case studies, despite data limitations in terms of availability and reliability.
- The consistency of the results suggests that the series of selected indicators was well-designed and robust, thus strengthening the overall methodology.
- The two data normalisation procedures tested demonstrated to have different levels of applicability. The Score Range method proved to be more adequate than the Maximum Score method in dealing with problem-data.

The work was framed by a few limiting conditions, namely those concerning data availability and reliability, that hindered the inclusion of additional evaluation parameters. Such limitations are addressed below:

- Data for a series of potentially useful indicators were not available, thus preventing their inclusion in the final selection used for the analysis.
- A dynamic study of scores was prevented by the lack of data for equivalent temporal ranges. The results are based on data strictly from 2005, producing no more than a snap-shot view of the possible sustainability status of each municipality.
- Data did not appear to be very reliable in a few instances. Nevertheless, they were used for the lack of other data sources.

  - Complementary data were not available to provide a better understanding of the complexity of the systems under analysis. Therefore, the analysis is preliminary in nature and requires improvement.

The results obtained from applying the methodology in view of the limitations listed above were consistent with initial assumptions. Furthermore, different analytical approaches yielded similarities that point out to the robustness of the methodology and validity of the analytical decisions made. The following concluding remarks are offered:

- The 1st and 8th ranking orders were independent of analytical scenario, data normalisation method and sustainability model. Vila Real and Peso da Régua consistently received top and bottom scores, respectively. These are municipalities that differ in their overall features, namely topography and susceptibility for experiencing extreme weather events.
- Rankings for the remaining municipalities were not independent of analytical approach, but they were, nonetheless, based upon scores that differed only slightly between them.
- Four distinct levels of sustainability were identified. The top and bottom scorers were separated by 2 groups of intermediate-high and intermediate-low scorers, whose order was not independent of scenario, or data normalisation approach.

The region's mountainous morphology and climate features define the type of land uses and human occupation of the territory and limit the distribution of water and wastewater system infrastructure. Not unlike other municipalities in Northeastern Portugal, land uses for the target area are essentially related to agricultural and forestry uses, consequence of an overall decrease of natural areas brought by the increase in low density urban uses and mixed agriculture occupation. However and despite their influence, urban uses continue to have little expression in the study area. Additionally, population clusters are not limited to areas indicated as urban uses. Their small dimension and scattered nature carries some significant consequences in terms of service by water and wastewater infrastructure networks. Since Vila Real comprises the largest of the urban areas in the target municipalities, this scattering of population does not represent a major problem for this municipality. The results obtained show this with clear evidence. Vila Real scored significantly higher than its counterparts, not only overall but also in terms of social, environmental and economic partial scores.

Harsh natural factors combined with observed population regression represent major hindrances to the implementation of improved levels of service, though these are not felt homogeneously throughout the study area. The overall performance of the remaining municipalities support the original decision to use them as case studies for the methodology developed.

Taking into consideration the results and limitations described above, it is advisable to provide a few suggestions and recommendations for future work. These are believed to be worthy of consideration, as they will complement and refine the work developed in the context of this dissertation. These recommendations are:

- The temporal analysis on WWTP performance in terms of non-compliance events was deemed important and worthy of continuation. Therefore, the work developed in this dissertation should continue. Additional data would allow for the adjustment of the methodology developed herein and the improvement of the analytical accuracy.
- Provided sufficient and reliable data are available, additional indicators are needed for refining and strengthening the analysis, particularly those that can provide complementary and more problem-oriented information about the systems under study.
- Qualitative indicators were not included at this point. However, population surveys regarding perception of service coverage, quality and performance are deemed worthy of consideration. Furthermore and depending on how these surveys are designed, a series of new data types would be available for testing other data processing methods (*i.e.*: fuzzy data sets).
- Weight assignment techniques could also be revised, and/or another method be tested.
- Analytical scenarios could be revised and redefined, provided new parameters and corresponding data are available.
- The sensitivity analysis stage could be revised to include other sustainability models based on different relative weight assignments.

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APPENDIX I: PAIRWISE COMPARISON RESULTS

Individual indicators

n = 3	1.1.1	1.1.2	1.1.3	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
1.1.1	1	3	5	15.000	2.466	**0.627**	1.934	3.086		
1.1.2	1/3	1	4	1.333	1.101	**0.280**	0.863	3.086	0.0429	0.0739
1.1.3	1/5	1/4	1	0.050	0.368	**0.094**	0.289	3.086		
				Σ	3.935	1.000	λ_{max}	3.086		

n = 3	1.2.1	1.2.2	1.2.3	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
1.2.1	1	1	1	1.000	1.000	**0.327**	1.000	3.054		
1.2.2	1	1	2	2.000	1.260	**0.413**	1.260	3.054	0.0268	0.0462
1.2.3	1	1/2	1	0.500	0.794	**0.260**	0.794	3.054		
				Σ	3.054	1.000	λ_{max}	3.054		

n = 3	2.1.1	2.1.2	2.1.3	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
2.1.1	1	6	6	36.000	3.302	**0.745**	2.275	3.054		
2.1.2	1/6	1	1/2	0.083	0.437	**0.099**	0.301	3.054	0.0268	0.0462
2.1.3	1/6	2	1	0.333	0.693	**0.156**	0.478	3.054		
				Σ	4.432	1.000	λ_{max}	3.054		

n = 2	2.2.1	2.2.2	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
2.2.1	1	1/3	0.333	0.577	**0.250**	0.500	2.000	0.0000	0.0000
2.2.2	3	1	3.000	1.732	**0.750**	1.500	2.000		
			Σ	2.309	1.000	λ_{max}	2.000		

n = 2	2.3.1	2.3.2	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
2.3.1	1	5	5.000	2.236	**0.833**	1.667	2.000	0.0000	0.0000
2.3.2	1/5	1	0.200	0.447	**0.167**	0.333	2.000		
			Σ	2.683	1.000	λ_{max}	2.000		

n = 3	2.4.1	2.4.2	2.4.3	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
2.4.1	1	1/5	1/5	0.040	0.342	**0.089**	0.271	3.054		
2.4.2	5	1	1/2	2.500	1.357	**0.352**	1.075	3.054	0.0268	0.0462
2.4.3	5	2	1	10.000	2.154	**0.559**	1.707	3.054		
				Σ	3.854	1.000	λ_{max}	3.054		

n =4	2.5.1	2.5.2	2.5.3	2.5.4	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
2.5.1	1	1/3	1	1	0.333	0.760	**0.167**	0.667	4.000	-0.3333	-0.370
2.5.2	3	1	3	3	27.000	2.280	**0.500**	2.000	4.000		
2.5.3	1	1/3	1	1	0.333	0.760	**0.167**	0.667	4.000		
2.5.4	1	1/3	1	1	0.333	0.760	**0.167**	0.667	4.000		
					Σ	4.559	1.000	λ_{max}	3.000		

n = 3	3.1.1	3.1.2	3.1.3	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
3.1.1	1	2	3	6.000	1.817	**0.528**	1.612	3.054		
3.1.2	1/2	1	3	1.500	1.145	**0.333**	1.015	3.054	0.0268	0.0462
3.1.3	1/3	1/3	1	0.111	0.481	**0.140**	0.426	3.054		
				Σ	3.443	1.000	λ_{max}	3.054		

n = 3	3.2.1	3.2.2	3.2.3	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
3.2.1	1	1/3	1	0.333	0.693	**0.200**	0.600	3.000		
3.2.2	3	1	3	9.000	2.080	**0.600**	1.800	3.000	0.0000	0.0000
3.2.3	1	1/3	1	0.333	0.693	**0.200**	0.600	3.000		
				Σ	3.467	1.000	λ_{max}	3.000		

n = 3	3.3.1	3.3.2	3.3.3	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
3.3.1	1	2	3	6.000	1.817	**0.528**	1.612	3.054		
3.3.2	1/2	1	3	1.500	1.145	**0.333**	1.015	3.054	0.0268	0.0462
3.3.3	1/3	1/3	1	0.111	0.481	**0.140**	0.426	3.054		
				Σ	3.443	1.000	λ_{max}	3.054		

n = 3	3.4.1	3.4.2	3.4.3	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
3.4.1	1	1/3	1	0.333	0.693	**0.200**	0.600	3.000		
3.4.2	3	1	3	9.000	2.080	**0.600**	1.800	3.000	0.0000	0.0000
3.4.3	1	1/3	1	0.333	0.693	**0.200**	0.600	3.000		
				Σ	3.467	1.000	λ_{max}	3.000		

n = 2	3.5.1	3.5.2	Π	$\Pi^{1/n}$	ω_i	$\omega i'$	$\omega i'/\omega i$	CI	CI/RI
3.5.1	1	1/3	0.333	0.577	**0.250**	0.500	2.000	0.0000	0.0000
3.5.2	3	1	3.000	1.732	**0.750**	1.500	2.000		
			Σ	2.309	1.000	λ_{max}	2.000		

Sub-groups

n = 2	1.1.1	1.1.2	Π	$\Pi^{1/n}$	ω_i	ω_i'	ω_i'/ω_i	CI	CI/RI
1.1	1	1/5	0.200	0.447	**0.167**	0.333	2.000	0.000	0.000
1.2	5	1	5.000	2.236	**0.833**	1.667	2.000		
			Σ	2.683	1.000	λ_{max}	2.000		

n = 5	2.1	2.2	2.3	2.4	2.5	Π	$\Pi^{1/n}$	ω_i	ω_i'	ω_i'/ω_i	CI	CI/RI
2.1	1	1	1	5	5	25.000	1.904	**0.293**	1.481	5.048		
2.2	1	1	1	5	5	25.000	1.904	**0.293**	1.481	5.048		
2.3	1	1	1	5	5	25.000	1.904	**0.293**	1.481	5.048	0.0371	0.033
2.4	1/5	1/5	1/5	1	3	0.024	0.474	**0.073**	0.390	5.341		
2.5	1/5	1/5	1/5	1/3	1	0.003	0.306	**0.047**	0.247	5.254		
						Σ	6.491	1.000	λ_{max}	5.148		

n = 5	3.1	3.2	3.3	3.4	3.5	Π	$\Pi^{1/n}$	ω_i	ω_i'	ω_i'/ω_i	CI	CI/RI
3.1	1	2	5	6	1/6	10.000	1.585	**0.203**	1.091	5.366		
3.2	1/2	1	2	5	1/6	0.833	0.964	**0.124**	0.638	5.161		
3.3	1/5	1/2	1	2	1/7	0.029	0.491	**0.063**	0.324	5.141	0.0911	0.0813
3.4	1/6	1/5	1/2	1	1/7	0.002	0.299	**0.038**	0.210	5.484		
3.5	6	6	7	7	1	1764.000	4.460	**0.572**	3.242	5.669		
						Σ	7.799	1.000	λ_{max}	5.364		

Groups

n = 3	1	2	3	Π	$\Pi^{1/n}$	ω_i	ω_i'	ω_i'/ω_i	CI	CI/RI
1	1	1/3	1	1.000	1.000	**0.333**	1.000	3.000		
2	3	1	3	1.000	1.000	**0.333**	1.000	3.000	0.0000	0.0000
3	1	1/3	1	1.000	1.000	**0.333**	1.000	3.000		
				Σ	3.000	1.000	λ_{max}	3.000		

n = 3	1	2	3	Π	$\Pi^{1/n}$	ω_i	ω_i'	ω_i'/ω_i	CI	CI/RI
1	1	5	5	25.000	2.924	**0.714**	2.143	3.000		
2	1/5	1	1	0.200	0.585	**0.143**	0.429	3.000	0.0000	0.0000
3	1/5	1	1	0.200	0.585	**0.143**	0.429	3.000		
				Σ	4.094	1.000	λ_{max}	3.000		

n = 3	1	2	3	Π	$\Pi^{1/n}$	ω_i	ω_i'	ω_i'/ω_i	CI	CI/RI
1	1	1/5	1	0.200	0.585	**0.143**	0.429	3.000		
2	5	1	5	25.000	2.924	**0.714**	2.143	3.000	0.0000	0.0000
3	1	1/5	1	0.200	0.585	**0.143**	0.429	3.000		
				Σ	4.094	1.000	λ_{max}	3.000		

n = 3	1	2	3	Π	$\Pi^{1/n}$	ω_i	ωi'	ωi'/ωi	CI	CI/RI
1	1	1	1/5	0.200	0.585	**0.143**	0.429	3.000		
2	1	1	1/5	0.200	0.585	**0.143**	0.429	3.000	0.0000	0.0000
3	5	5	1	25.000	2.924	**0.714**	2.143	3.000		
				Σ	4.094	1.000	λ_{max}	3.000		

APPENDIX II: COMPLEMENTARY WORK

Complementary work was carried out to establish the history of non-compliance events (NCE) with regards to treated wastewater quality standards. This was a parameter that could not be included due to the lack of sufficient data for the selected analysis period. Also, data were obtained only for WWTP managed and operated by ATMAD.

In an effort to quantify the number of NCE occurred in each of the WWTP, all of the quality reports published up to December have been analysed and examined for violations of the minimum quality standards established per regulations as to provide some idea of how the facilities are operating. The target quality parameters were BOD_5[1] (5-day Biological Oxygen Demand), COD[2] (Chemical Oxygen Demand), and TSS[3] (Total Suspended Solids). Standard limits are listed in Table II.1.

Table II.1 – Standard treated wastewater regulations

Parameter	Maximum monthly average	Minimum % reduction
BOD_5 (mg/l O_2)	25	70
COD (mg/l O_2)	125	75
TSS* (mg/l TSS)	35; 60	90

*The maximum standard TSS concentration depends on the equivalent population at the time of the sampling and analysis (DL 152/1997).

It was not possible to obtain an equal number of quality reports for all of the WWTP for the same time period, hence the database is, at this point, quite incomplete. However and as new reports are published, more data can be added to the analysis, thus rendering it stronger and more consistent.

To facilitate the analysis and allow for comparison between performances, data were collected, normalised and compared against standards set in the corresponding regulations. A threshold rating scale was developed to allow the ranking of the facilities in accordance to the number of violations demonstrated. The data tables (II.2–II.15) are presented next.

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[1] In Portuguese: *CBO, Carência Bioquímica de Oxigénio.*

[2] In Portuguese: *CQO, Carência Química de Oxigénio.*

[3] In Portuguese: *SST, Sólidos Suspensos Totais.*

Table II.2 – ALJ (Alijó-Favaios)

Month	BOD_5		COD		TSS	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Ago-05	5.0	98.0	20.0	97.0	12.0	93.0
Set-05	7.0	99.0	46.0	97.0	2.0	100.0
Out-05	80.0	79.0	150.0	72.0	74.0	78.0
Nov-05	5.0	97.0	43.0	88.0	18.0	87.0
Dez-05	5.0	97.7	10.0	98.2	5.0	98.4
Jan-06	4.4	99.2	39.9	95.9	11.9	95.3
Fev-06	6.0	99.4	24.0	98.6	12.0	98.6
Mar-06	6.0	97.5	30.0	95.8	14.0	92.4
Abr-06	6.0	97.9	34.0	93.4	11.0	50.0
Mai-06	4.9	99.7	9.9	99.5	4.0	99.1
Jun-06	16.0	95.4	34.0	96.9	8.0	96.0
Jul-06	12.0	97.7	23.0	96.6	5.0	97.6
Ago-06	10.0	97.4	35.0	94.2	5.0	97.4
Set-06	20.0	97.1	83.0	91.2	30.0	85.0
Out-06	4.9	96.9	9.9	95.4	11.0	89.5
Nov-06	4.9	80.4	13.0	77.6	11.0	78.0
Dez-06	4.9	n.a.	9.9	n.a.	3.0	n.a.
Jan-07	<5	100.0	13.0	88.5	6.0	84.2
Fev-07	<5	100.0	<10	100.0	2.0	99.1
Mar-07	5.0	96.0	12.0	92.9	4.0	93.8
Abr-07	<5	100.0	<10	100.0	4.0	96.9
Mai-07	<5	100.0	10.0	98.9	4.0	98.9
Jun-07	6.0	97.3	20.0	97.2	3.0	98.9
Jul-07	8.0	97.8	21.0	95.8	3.0	98.2
Ago-07	20.0	92.9	34.0	92.7	6.0	97.1
Set-07	<5	100.0	<10	100.0	4.0	98.4
Out-07	14.0	97.6	27.0	97.1	26.0	96.0
Nov-07	9.0	97.5	20.0	96.9	5.0	97.8
Dez-07	16.0	96.7	8.0	96.5	2.0	99.1

Table II.3 – ALJ (Sanfins do Douro)

Month	BOD_5		COD		TSS	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Ago-05	16.0	96.0	43.0	95.0	16.0	85.0
Set-05	10.0	98.0	54.0	95.0	17.0	95.0
Out-05	7.0	99.0	31.0	97.0	9.0	99.0
Nov-05	5.0	95.0	40.0	88.0	7.0	95.0
Dez-05	5.0	98.0	18.0	97.1	3.0	98.8
Jan-06	6.7	99.2	28.9	97.6	12.7	98.9
Fev-06	8.0	96.4	34.0	93.8	1.0	98.7
Mar-06	10.0	97.9	26.0	96.1	4.0	95.9
Abr-06	6.0	99.8	39.0	99.7	13.0	99.8
Mai-06	4.9	99.2	9.9	99.3	4.0	98.9
Jun-06	25.0	93.2	91.0	89.8	3.0	99.4
Jul-06	14.0	98.1	53.0	94.6	3.0	98.8
Ago-06	35.0	89.1	53.0	93.5	10.0	96.2
Set-06	5.0	99.1	9.9	98.8	1.0	99.6
Out-06	4.9	95.9	9.9	94.1	13.0	87.3
Nov-06	4.9	95.1	9.9	92.6	3.0	95.4
Dez-06	11.0	89.5	26.0	86.7	1.0	98.4
Jan-07	<10	100.0	<5	100.0	<2	100.0
Fev-07	8.0	88.6	18.0	93.8	<2	100.0
Mar-07	10.0	99.4	51.0	97.8	57.0	98.9
Abr-07	6.0	98.7	16.0	97.8	4.0	99.4
Mai-07	<10	100.0	<5	100.0	2.0	99.4
Jun-07	5.0	99.2	23.0	97.4	3.0	99.0
Jul-07	10.0	98.6	22.0	98.3	<2	100.0
Ago-07	22.0	96.8	37.0	96.8	35.0	90.3
Set-07	16.0	98.4	34.0	97.9	5.0	99.2
Out-07	24.0	94.0	39.0	93.8	2.0	98.4
Nov-07	12.0	98.5	23.0	98.2	13.0	96.8
Dez-07	12.0	94.6	32.0	93.2	<2	100.0

Table II.4 – MF (Mesão Frio)

Month	BOD_5		COD		TSS	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Mai-04	16.0	96.0	92.0	93.0	22.0	82.0
Jun-04	13.0	93.0	74.0	85.0	18.0	82.0
Jul-04	50.0	94.0	181.0	82.0	31.0	62.0
Ago-04	55.0	91.0	197.0	77.0	38.0	62.0
Set-04	35.0	96.0	100.0	91.0	32.0	64.0
Out-04	40.0	90.0	130.0	83.0	28.0	70.0
Nov-04	45.0	90.0	163.0	83.0	38.0	44.0
Dez-04	80.0	89.0	190.0	83.0	38.0	54.0
Jan-05	138.0	85.0	297.0	78.0	90.0	66.0
Fev-05	87.0	85.0	232.0	71.0	62.0	77.0
Mar-05	66.0	97.0	226.0	95.0	44.0	99.0
Abr-05	58.0	95.0	181.0	90.4	29.0	96.3
Mai-05	34.0	97.8	122.0	95.3	20.0	96.0
Jun-05	57.0	95.7	186.0	91.3	43.0	95.1
Jul-05	29.0	97.6	161.0	91.0	66.0	93.8
Ago-05	71.0	93.7	183.0	89.4	55.0	89.3
Set-05	436.0	81.1	666.0	79.3	71.0	87.3
Out-05	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Nov-05	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Dez-05	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Jan-06	100.0	95.8	305.0	91.5	78.0	73.1
Fev-06	36.0	96.0	127.0	93.1	10.0	99.0
Mar-06	22.0	98.5	109.0	n.a.	n.a.	n.a.
Abr-06	32.0	94.3	97.0	94.6	18.0	97.8
Mai-06	120.0	78.4	168.0	87.2	27.0	96.7
Jun-06	45.0	96.3	145.0	85.7	45.0	87.9
Jul-06	n.a.	n.a.	n.a.	95.9	38.0	98.6
Ago-06	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Set-06	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Out-06	12.0	96.0	64.0	89.1	14.0	95.3
Nov-06	10.0	98.8	56.0	95.8	18.0	97.2
Dez-06	21.0	97.5	46.0	95.9	33.0	93.6
Jan-07	14.0	98.5	76.0	95.3	23.0	96.2
Fev-07	12.0	95.6	75.0	85.1	7.0	97.2
Mar-07	14.0	98.7	69.0	97.2	20.0	99.3
Abr-07	19.0	99.2	38.0	98.8	29.0	97.5
Mai-07	20.0	98.0	58.0	95.5	11.0	97.4
Jun-07	12.0	92.9	39.0	89.5	6.0	97.7
Jul-07	10.0	99.6	19.0	99.6	14.0	99.5
Ago-07	25.0	98.1	63.0	97.1	12.0	98.4
Set-07	22.0	95.9	73.0	91.4	19.0	97.8

Out-07	100.0	96.0	149.0	96.2	33.0	98.3
Nov-07	80.0	94.3	133.0	93.9	33.0	96.1
Dez-07	60.0	90.0	138.0	85.5	43.0	90.1

Table II.5 – MU (Murça)

Month	BOD_5		COD		TSS	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Set-05	6.0	98.0	29.0	95.0	10.0	95.0
Out-05	44.0	92.4	104.0	89.4	78.7	85.4
Nov-05	5.0	97.0	33.0	95.0	7.0	73.0
Dez-05	5.0	95.1	10.0	96.9	4.0	97.1
Jan-06	5.6	98.5	37.2	94.7	7.4	97.4
Fev-06	4.0	99.1	20.0	98.1	6.0	96.8
Mar-06	18.0	96.8	66.0	92.1	16.0	85.2
Abr-06	6.0	99.0	29.0	96.8	7.0	96.9
Mai-06	4.9	99.0	9.9	99.0	3.0	98.0
Jun-06	20.0	95.8	27.0	96.6	6.0	98.3
Jul-06	20.0	95.2	30.0	95.2	4.0	97.9
Ago-06	5.0	98.5	9.9	98.4	2.0	99.3
Set-06	10.0	98.6	18.0	98.0	3.0	99.2
Out-06	6.0	98.0	9.9	97.6	22.0	78.6
Nov-06	4.9	97.4	9.9	96.8	5.0	96.3
Dez-06	12.0	n.a.	26.0	n.a.	17.0	n.a.
Jan-07	8.0	99.6	26.0	98.9	4.0	99.2
Fev-07	<5	100.0	11.0	99.7	<2	100.0
Mar-07	<5	100.0	<10	100.0	5.0	98.2
Abr-07	8.0	94.7	33.0	95.3	5.0	98.5
Mai-07	14.0	96.8	45.0	92.2	2.0	99.7
Jun-07	<5	100.0	<10	100.0	2.0	98.8
Jul-07	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ago-07	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Set-07	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Out-07	10.0	99.1	23.0	98.6	8.0	98.0
Nov-07	12.0	97.6	20.0	97.5	6.0	97.8
Dez-07	8.0	96.2	26.0	96.2	6.0	97.5

Table II.6 – PDR (Régua)

Month	BOD$_5$		COD		TSS	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Fev-07	8.0	98.8	25.0	97.2	4.0	98.4
Mar-07	<5	100.0	<10	100.0	10.0	96.4
Abr-07	<5	100.0	11.0	97.9	3.0	99.1
Mai-07	<5	100.0	<10	100.0	3.0	99.3
Jun-07	8.0	93.3	34.0	94.6	2.0	98.8
Jul-07	18.0	96.4	49.0	93.2	3.0	99.3
Ago-07	8.0	98.5	14.0	98.3	3.0	99.3
Set-07	8.0	97.4	21.0	97.4	2.0	99.2
Out-07	7.0	98.3	15.0	97.7	2.0	99.6
Nov-07	14.0	97.7	21.0	97.9	14.0	98.9
Dez-07	8.0	98.8	15.0	98.6	6.0	99.0

Table II.7 – PDR (Vilarinhos dos Freires - Poiares)

Month	BOD$_5$		COD		TSS	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Set-06	6	98.4	42	94.1	5	98
Out-06	4.9	99	9.9	98.4	10	97.1
Nov-06	6	96.3	23	92.6	19	93.8
Dez-06	5	99.4	9.9	99.2	14	98.2
Jan-07	17	91.8	35	88.1	9	98.24
Fev-07	6	75	15	92.6	5	94.2
Mar-07	<5	100	<10	100	2	99.7
Abr-07	<5	100	<10	100	6	94.8
Mai-07	<5	100	<10	100	3	96.5
Jun-07	8	96.2	18	96.4	7	95.3
Jul-07	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ago-07	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Set-07	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Out-07	8	97.6	13	97.5	5	97.3
Nov-07	10	98.3	21	97.37	11	96.7
Dez-07	9	98.7	26	98.1	5	98.8

Table II.8 – SAB (Sabrosa)

Month	BOD$_5$		COD		BOD$_5$	
	mg/L O$_2$	% reduction	mg/L O$_2$	% reduction	mg/L TSS	% reduction
Ago-05	12.0	99.0	27.0	99.0	22.0	98.0
Set-05	10.0	100.0	70.0	97.0	22.0	99.0
Out-05	50.0	96.0	161.0	95.0	8.0	99.0
Nov-05	5.0	99.0	10.0	99.0	7.0	100.0
Dez-05	4.9	99.6	33.0	98.1	2.0	99.7
Jan-06	117.1	92.1	304.3	87.7	116.6	91.4
Fev-06	4.0	99.6	38.0	97.3	4.0	98.8
Mar-06	16.0	99.1	66.0	97.7	9.0	99.2
Abr-06	8.0	98.5	40.0	97.0	8.0	97.4
Mai-06	16.0	98.5	48.0	97.1	17.0	96.7
Jun-06	6.0	98.8	19.0	97.4	4.0	97.5
Jul-06	13.0	97.5	27.0	96.1	7.0	94.4
Ago-06	16.0	95.4	24.0	96.5	7.0	97.8
Set-06	65.0	91.9	85.0	92.2	20.0	91.2
Out-06	16.0	98.0	54.0	95.6	14.0	91.1
Nov-06	4.9	92.9	9.9	94.0	6.0	91.8
Dez-06	4.9	89.1	9.9	93.9	2.0	97.3
Jan-07	20.0	96.7	95.0	87.8	35.0	90.5
Fev-07	34.0	95.1	62.0	96.6	17.0	98.2
Mar-07	8.0	98.5	43.0	96.6	10.0	98.2
Abr-07	12.0	99.0	33.0	97.8	6.0	99.8
Mai-07	8.0	98.4	31.0	95.5	8.0	99.4
Jun-07	8.0	99.5	26.0	99.0	5.0	99.7
Jul-07	5.0	99.8	37.0	99.0	6.0	99.9
Ago-07	51.0	96.0	85.0	96.0	15.0	99.4
Set-07	12.0	99.9	28.0	99.9	2.0	100.0
Out-07	25.0	98.8	54.0	98.4	14.0	97.9
Nov-07	15.0	98.0	29.0	97.5	7.0	99.4
Dez-07	50.0	94.9	176.0	91.5	49.0	92.9

Table II.9 – SMP (Cumieira)

Month	BOD_5		COD		BOD_5	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Dez-05	79.0	89.5	178.0	74.7	64.1	85.8
Jan-06	28.0	98.0	228.0	89.4	60.0	91.2
Fev-06	20.0	97.3	155.0	85.4	55.0	77.1
Mar-06	12.0	98.4	104.0	91.7	35.0	90.8
Abr-06	19.0	96.5	120.0	86.7	56.0	84.2
Mai-06	11.0	98.4	91.0	92.7	30.0	90.6
Jun-06	18.0	98.3	66.0	96.2	24.0	94.5
Jul-06	10.0	98.7	48.0	96.3	18.0	95.4
Ago-06	7.0	99.0	39.0	96.7	3.0	99.4
Set-06	16.0	95.0	32.0	96.8	12.0	96.6
Out-06	6.0	98.5	9.9	98.3	10.0	95.7
Nov-06	5.0	98.4	27.0	94.2	27.0	90.9
Dez-06	9.0	98.3	42.0	95.3	14.0	94.2
Jan-07	12.0	98.7	30.0	97.4	10.0	99.8
Fev-07	<5	100.0	45.0	91.0	12.0	91.8
Mar-07	<5	100.0	<10	100.0	27.0	91.7
Abr-07	<5	100.0	<10	100.0	2.0	98.0
Mai-07	6.0	99.2	26.0	97.3	12.0	97.9
Jun-07	<5	100.0	10.0	98.6	4.0	98.5
Jul-07	6.0	98.3	11.0	99.0	21.0	95.6
Ago-07	25.0	94.6	59.0	92.4	8.0	97.5
Set-07	6.0	99.7	24.0	99.2	8.0	99.4
Out-07	16.0	98.4	37.0	97.6	2.0	99.4
Nov-07	10.0	98.2	20.0	97.6	18.0	95.4
Dez-07	25.0	97.7	47.0	97.3	25.0	93.9

Table II.10 – SMP (Fornelos-Tuisendes)

Month	BOD_5		COD		TSS	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Dez-05						
Jan-06	64.0	98.6	254.0	95.8	105.0	97.0
Fev-06	48.0	95.2	190.0	91.6	85.0	91.7
Mar-06	36.0	89.7	84.0	83.0	25.0	80.8
Abr-06	28.0	96.7	105.0	93.0	40.0	89.6
Mai-06	25.0	94.4	110.0	88.4	58.0	79.6
Jun-06	18.0	96.0	100.0	89.1	70.0	90.0
Jul-06	11.0	98.6	73.0	95.2	28.0	96.4
Ago-06	24.0	98.7	89.0	96.6	12.0	99.4
Set-06	24.0	97.7	103.0	93.6	52.0	91.0
Out-06	10.0	99.5	33.0	98.9	13.0	99.4
Nov-06	4.9	99.3	9.9	99.2	9.0	98.6
Dez-06	4.9	93.9	9.9	95.5	15.0	94.4
Jan-07	<5	100.0	54.0	94.6	19.0	95.7
Fev-07	7.0	96.5	37.0	86.3	3.0	96.4
Mar-07	9.0	97.8	61.0	88.8	9.0	94.7
Abr-07	8.0	98.1	13.0	97.6	21.0	91.4
Mai-07	6.0	99.3	47.0	97.0	8.0	98.7
Jun-07	6.0	88.5	18.0	91.2	5.0	95.8
Jul-07	9.0	98.5	13.0	98.4	13.0	96.8
Ago-07	30.0	92.2	64.0	90.0	21.0	99.7
Set-07	14.0	99.5	31.0	99.4	7.0	99.6
Out-07	25.0	90.4	53.0	87.1	14.0	95.9
Nov-07	18.0	95.3	31.0	94.6	6.0	94.9
Dez-07	24.0	99.1	52.0	98.8	20.0	98.9

Table II.11 – SMP (S. João de Lobrigos)

Month	BOD_5		COD		BOD_5	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Dez-05	14.0	96.1	84.0	86.0	50.0	76.0
Jan-06	360.0	90.4	1600.0	86.1	150.0	66.7
Fev-06	45.0	96.5	388.0	79.7	90.0	78.6
Mar-06	20.0	99.2	75.0	98.3	38.0	92.9
Abr-06	20.0	94.3	78.0	92.7	18.0	94.4
Mai-06	5.0	99.1	38.0	95.7	10.0	97.1
Jun-06	6.0	99.0	33.0	96.9	14.0	96.0
Jul-06	7.0	99.2	22.0	98.5	12.0	97.4
Ago-06	4.9	98.5	9.9	98.3	5.0	98.1
Set-06	42.0	93.0	68.0	92.1	34.0	89.6
Out-06	8.0	96.8	21.0	95.0	5.0	95.5
Nov-06	4.9	95.4	9.9	96.3	4.0	97.3
Dez-06	5.0	n.a.	10.0	n.a.	10.0	n.a.
Jan-07	<5	100.0	446.0	92.3	7.0	97.9
Fev-07	38.0	96.8	212.0	91.3	15.0	97.1
Mar-07	<5	100.0	36.0	94.4	10.0	98.4
Abr-07	5.0	99.6	15.0	99.2	9.0	99.6
Mai-07	18.0	94.0	30.0	96.4	9.0	98.0
Jun-07	8.0	98.3	34.0	97.5	9.0	99.2
Jul-07	<5	100.0	<10	100.0	<2	100.0
Ago-07	18.0	96.7	33.0	95.2	4.0	98.6
Set-07	12.0	96.5	48.0	91.1	6.0	96.9
Out-07	30.0	96.9	65.0	95.7	16.0	98.8
Nov-07	40.0	97.1	89.0	95.8	26.0	96.0
Dez-07	38.0	93.7	88.0	90.7	19.0	94.4

Table II.12 – SMP (S. Miguel de Lobrigos)

Month	BOD_5		COD		BOD_5	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Dez-05	11.0	99.7	65.0	98.4	45.0	85.0
Jan-06	13.0	99.2	77.0	96.7	50.0	85.3
Fev-06	14.0	99.4	50.0	98.8	35.0	97.1
Mar-06	13.0	99.3	84.0	96.9	60.0	80.6
Abr-06	10.0	98.9	48.0	99.1	28.0	94.5
Mai-06	11.0	99.2	49.0	97.2	28.0	84.4
Jun-06	7.0	99.1	28.0	97.5	16.0	93.5
Jul-06	12.0	99.5	54.0	98.7	22.0	93.4
Ago-06	6.0	99.4	9.9	99.3	22.0	89.4
Set-06	20.0	98.6	30.0	98.7	19.0	96.2
Out-06	10.0	98.4	69.0	92.1	34.0	74.4
Nov-06	5.0	99.7	53.0	97.7	15.0	97.0
Dez-06	4.9	99.6	9.9	99.4	13.0	96.4
Jan-07	<5	100.0	<10	100.0	13.0	94.9
Fev-07	22.0	97.6	103.0	94.8	42.0	96.8
Mar-07	<5	100.0	28.0	97.4	10.0	97.3
Abr-07	<5	100.0	<10	100.0	7.0	97.6
Mai-07	18.0	99.0	48.0	98.0	8.0	97.0
Jun-07	<5	100.0	<10	100.0	9.0	97.2
Jul-07	12.0	97.6	17.0	98.6	8.0	98.7
Ago-07	15.0	98.4	32.0	97.9	7.0	99.2
Set-07	8.0	98.8	26.0	97.4	10.0	97.6
Out-07	80.0	95.3	131.0	95.0	64.0	94.2
Nov-07	18.0	98.6	38.0	98.0	18.0	98.8
Dez-07	155.0	93.3	328.0	90.9	54.0	93.1

Table II.13 – SMP (Sever-Fontes)

Month	BOD_5		COD		TSS	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Set-07	25.0	93.2	60.0	89.3	53.0	66.0
Out-07	8.0	98.5	23.0	97.3	5.0	96.9
Nov-07	8.0	97.7	13.0	97.5	5.0	98.1
Dez-07	13.0	96.9	33.0	96.2	10.0	98.4

Table II.14 – VPA (Vila Pouca de Aguiar)

Month	BOD_5		COD		TSS	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Out-07	25.0	92.2	57.0	88.2	2.0	98.4
Nov-07	8.0	97.1	15.0	96.5	6.0	96.4
Dez-07	8.0	98.6	17.0	98.1	13.0	97.4

Table II.15 – VR (Vila Real)

Month	BOD_5		COD		TSS	
	mg/L O_2	% reduction	mg/L O_2	% reduction	mg/L TSS	% reduction
Jan-05	275.0	39.0	345.0	55.0	254.0	22.0
Fev-05	119.0	70.0	127.0	83.0	99.0	61.0
Mar-05	25.0	93.0	113.0	82.0	65.0	69.0
Abr-05	62.0	76.6	215.0	64.6	130.8	43.4
Mai-05	22.0	94.3	78.0	89.2	18.8	93.8
Jun-05	121.0	73.3	253.0	68.9	153.0	46.3
Jul-05	<20	94.2	115.0	86.2	61.0	86.0
Ago-05	54.0	89.3	103.0	88.3	27.6	96.4
Set-05	190.0	69.4	312.0	66.5	212.0	49.9
Out-05	44.0	92.4	104.0	92.4	78.7	85.4
Nov-05	41.0	88.5	216.0	83.9	100.0	69.3
Dez-05	41.0	88.8	123.0	79.8	67.0	78.0
Jan-06	40.0	92.6	137.0	80.0	34.0	89.2
Fev-06	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Mar-06	90.0	77.5	304.0	65.1	52.0	49.0
Abr-06	10.0	98.1	71.0	90.9	11.0	94.6
Mai-06	5.0	98.9	43.0	88.0	14.0	94.8
Jun-06	39.0	86.8	88.0	89.0	31.0	91.7
Jul-06	10	92.4	67	90.9	12.0	93.9
Ago-06	26.0	96.4	67.0	92.8	20.0	95.3
Set-06	80.0	90.0	187.0	83.9	112.0	58.2
Out-06	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Nov-06	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Dez-06	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Jan-07	14.0	97.1	100.0	87.1	34.0	84.1
Fev-07	6.0	97.3	52.0	83.0	8.0	94.3
Mar-07	22.0	93.7	73.0	84.6	21.0	87.5
Abr-07	24.0	73.3	70.0	87.5	26.0	87.4
Mai-07	22.0	91.5	118.0	82.9	57.0	79.5
Jun-07	14.0	98.4	85.0	94.0	15.0	97.5
Jul-07	11.0	98.5	21.0	98.0	8.0	98.2
Ago-07	14.0	95.9	60.0	90.8	15.0	93.4
Set-07	25.0	95.7	59.0	93.5	26.0	84.2
Out-07	32.0	94.5	80.0	91.3	11.0	95.1
Nov-07	40.0	90.7	81.0	88.2	19.0	92.0
Dez-07	30.0	94.6	124.0	89.0	47.0	87.2

A WWTP is said to be non-compliant whenever the monthly average for any of the required parameters, reported as final concentration and percent removal, does not meet the standard limit required by law. The purpose of this exercise was to examine the number of violations reported per WWTP. The analysis began by collecting the WWTP monthly quality reports published and available to the public (ATMAD, 2008). An immediately identifiable problem was that not all municipalities had the same number of WWTP nor did the available water quality reports cover the same time period. It was clear that a comparison between WWTP performances could not be resumed to a plain comparison regarding the total number of non-compliance events (NCE) on record. Therefore, a rating method was developed to allow for WWTP performance comparability.

Data was compiled into a number of spreadsheets using Microsoft® Office Excel 2003. The number of violations per parameter was determined resorting to the conditional counting function included in the software. See example expressions below.

Single parameter: NCE = CONTAR.SE(RANGE;">STANDARD")

RANGE means the range of values to scan and STANDARD means the regulations standard against which the values within the range are compared. Note that the software is configured for Portuguese users. The instruction CONTAR.SE is equivalent to the COUNTIF function in English-configured versions of the program.

In the case of TSS, since there were two standards to comply with depending on the time of the year and/or equivalent population, the expression used required a simple modification:

NCE_{TSS} = CONTAR.SE(RANGE;">35") + CONTAR.SE(RANGE;">60")

After the total number of NCE was quantified, it was divided by the total number of monthly measurements and converted to number of NCE per year. This value was used to compute the corresponding score based on a rating model.

The rating model was defined by setting a maximum number of twelve monthly measurements per year, corresponding to the required number of monthly quality reports. The scale identified a number of violation scenarios expressed in a crescent rate of non-compliance events (NCE). If no NCE were reported, the WWTP was assigned a maximum score of 5 points. Otherwise, the number of points assigned decreased in proportion to the average number of NCE per year (Table II.16 and Figure II.1).

Table II.16 – Rating scale

NCE/Year	Score
0	100
3	90
6	80
9	70
12	60
15	50
18	40
21	30
24	20
27	10
≥30	0

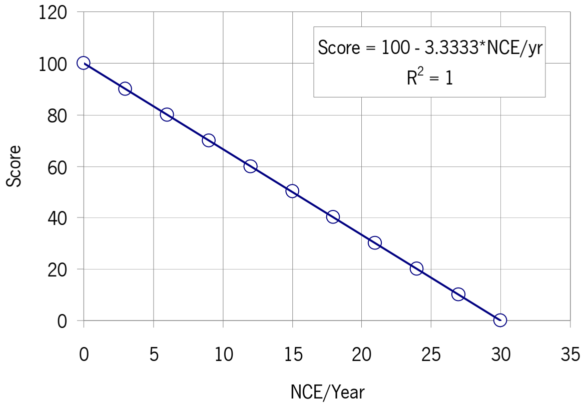

Figure II.1 – Rating model for NCE

Taking Mesão Frio as an example, there were 24 NCE events with regards to meeting maximum monthly average concentrations of BOD_5 and none regarding its minimum percent reduction. For COD, there were 20 maximum concentration and 1 minimum percent reduction violations. Finally, there were 6 and 15 concentration and reduction NCE for TSS. For a total of 39 measurements corresponding to 39 months on record, the rate of monthly non-compliance was approximately 0.62 and 0.0 for BOD_5, 0.51 and 0.03 for COD, and 0.15 and 0.38 for TSS. These values corresponded to yearly non-compliance rates of 7.38 and 0.0 for BOD_5, 6.15 and 0.31 for COD, and 1.85 and 4.62 for TSS. A total of 20.3 NCE per year was calculated, resulting in a score of 32.3 for this WWTP. For municipalities that included more than one WWTP, a separate score was determined for each one of the facilities. The final municipality score was obtained by calculating the weighted average of the individual scores. The results are presented in Table II.7.

Table II.17 – Scores per NCE

Municipality	WWTP	NCE/Yr	Score	Final Score
Alijó	Alijó	4.67	84.4	90.0
	Sanfins do Douro	1.24	95.9	
Mesão Frio	Mesão Frio	20.31	32.3	32.3
Murça	Murça	2.77	90.8	90.8
Peso da Régua	Régua	0.00	100.0	100.0
	Vilarinho dos Freires - Poiares	0.00	100.0	
Sabrosa	Sabrosa	4.55	84.8	84.8
Santa Marta de Penaguião	Cumieira	4.32	85.6	81.4
	Fornelos - Tuisendes	5.97	80.1	
	S. João de Lobrigos	7.59	74.7	
	S. Miguel de Lobrigos	5.40	82.0	
	Sever-Fontes	4.40	85.3	
Vila Pouca de Aguiar	Vila Pouca de Aguiar	0.00	100.0	100.0
Vila Real	Vila Real	24.75	17.5	17.5

Peso da Régua and Vila Pouca de Aguiar show top marks since neither of the corresponding WWTP reported non-compliance events. Conversely, Mesão Frio and Vila Real were assigned the lowest score, since their respective WWTP reported approximately 2 discharge quality violations per month. The remaining municipalities scored high and close to the top classifications. The relative standing of each municipality is illustrated in Figure II.2.

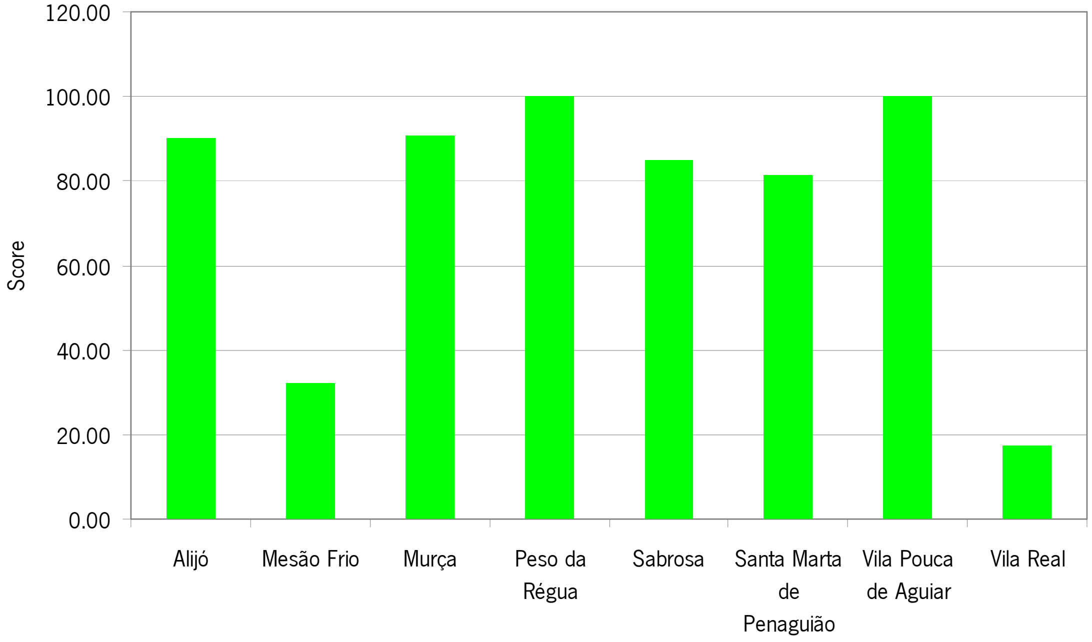

Figure II.2 – Scores according to the number of NCE per year

The work developed thus far has been no more than preliminary in nature. Several issues need addressing, such as the insufficiency of data for a matching temporal range. Also, the scoring scale should reflect the frequency nature of the many types of NCE, as they refer to different parameters and different WWTP. As observed, NCE per year between 1 and 10 clearly corresponded to the majority of the reported cases. Violation events of more than 10 per year were rare, as were the instances of zero violations. The scoring scale as it stands, did not take into account these distinct clusters of data and was established by a linear correlation between expected NCE per year and a rather arbitrary set of points. For increased accuracy, more points should have been given to the cases reporting zero NCE as they are apparently more difficult to come by. On the other hand, WWTP exhibiting violation numbers worse than the observed mean should have been more heavily penalised. Upon the availability of additional data, the scale could therefore be adequately adjusted, aiming for a more precise analysis of the facilities' compliance history.

Finally, there is no information regarding the base operational level of each WWTP to explain the reasons for the type, persistence and occurrence of NCE. Knowledge about the typical performance level of each WWTP would allow the identification and understanding of the underlying causes for each NCE and sort between operation error and out of the ordinary situations. These may include unexpected toxic loads (e.g., unlawful toxic discharges into the wastewater collection system), heavy rains, peak organic loads, process equipment shutting down, etc. Operational mishaps may include equipment and process breakdown, and operator error. Start-up periods are also typically hampered by discharge quality violations, as the treatment processes climb to a continuous, balanced operation mode. In fact, violations are common during start-up periods, particularly for new WWTP and should not be included in the data range for analysis. Having additional data and more importantly, information regarding the events that originated the faulty event would be instrumental in establishing outliers, in order to refine the analysis and ultimately, obtain more reliable results.

APPENDIX III: HYPSOMETRIC INFORMATION

Figure III.1 – Portuguese hypsometric chart (IGEO, 2008)

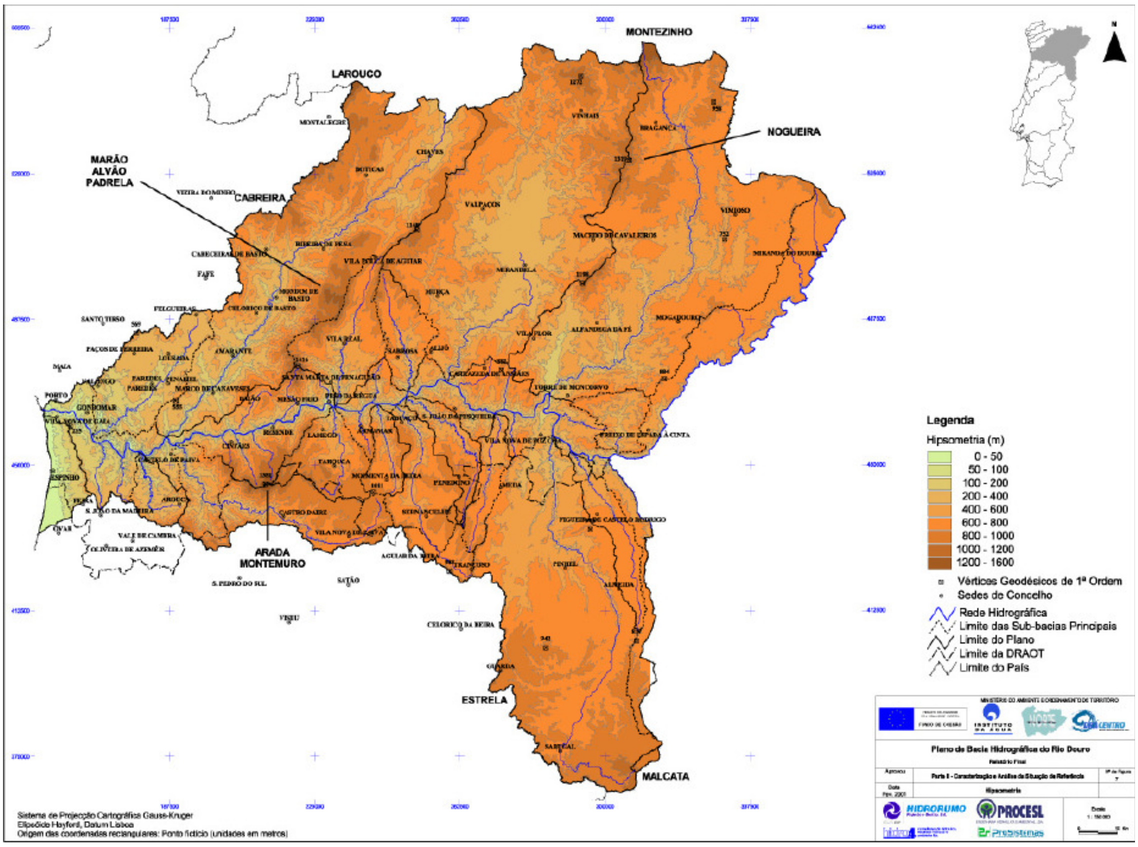

Figure III.2 –Douro river basin hypsometry (INAG, 1999)

APPENDIX IV: TEMPERATURE AND PRECIPITATION MAPS

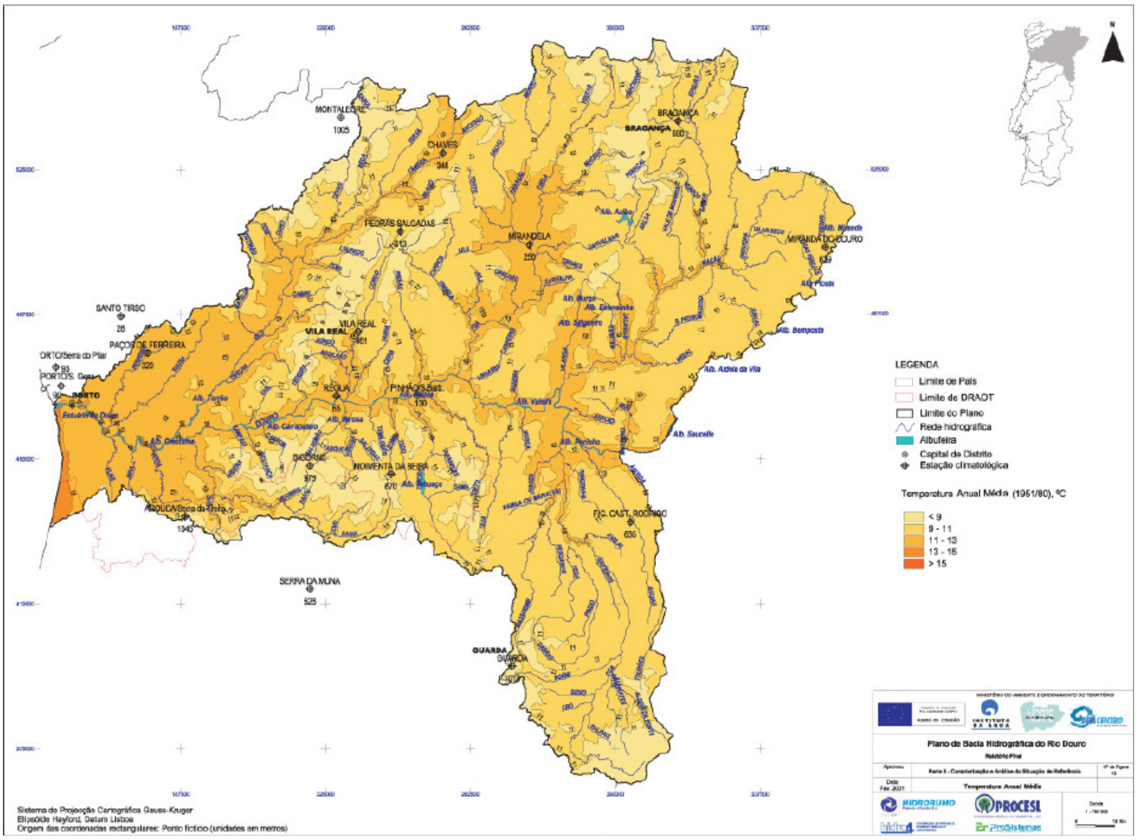

Figure IV.1 – Average annual temperatures throughout the Douro river basin (INAG, 1999)

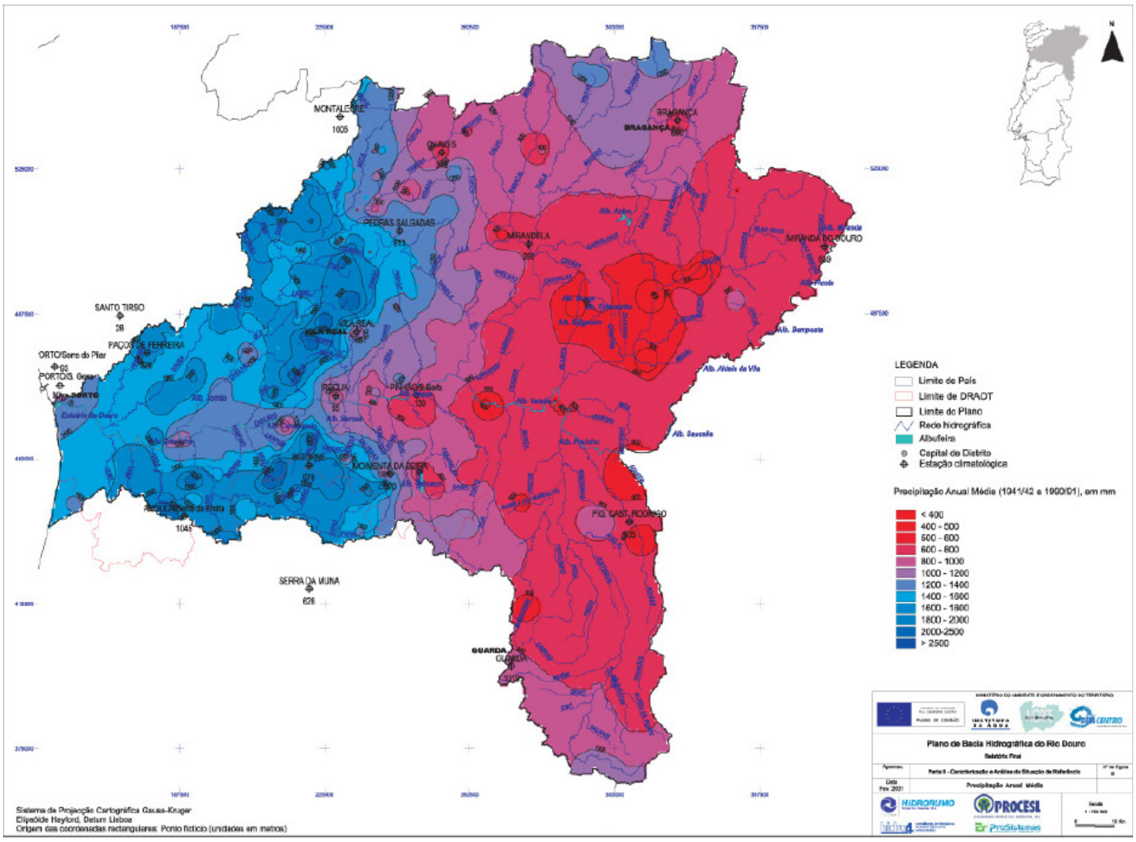

Figure IV.2 – Average annual precipitation throughout the Douro river basin

APPENDIX V: HYDROLOGICAL INFORMATION

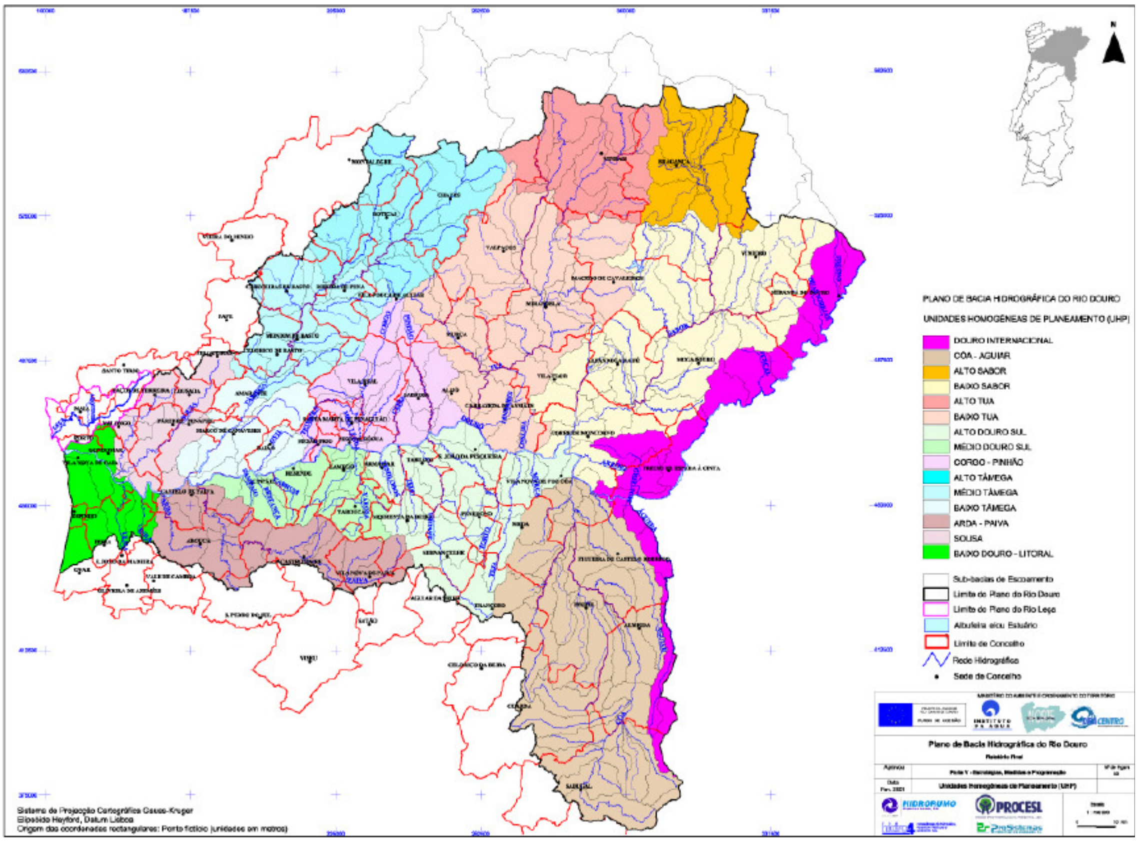

Figure V.1 - The Douro river basin

Table V.1- Main Douro river sub-basins in study area (INAG, 1999)

Major river sub-basins	Area in Portugal (km^2)	Average flow (hm^3/year)
Águeda[1]	249	45
Aguiar	273	44
Côa[2]	2 521	6092
Corgo	469	361
Douro Internacional[1]	645	127
Mosteiro	205	35
Paiva[2]	795	697
Pinhão	277	132
Sabor[1]	3 313	744
Tâmega[1]	2 649	1906
Távora	532	165
Tedo	172	70
Teja	202	51
Torto	218	57
Tua[1]	3 123	988
Vale do Douro	1 927	932
Varosa	332	260

[1]: Data for Portuguese side of the basin;

[2]: Data for whole sub-basin, though only partially included within the study area;

Figure V.2 – Dams in Northern Portugal

Table V.2 – Dams in Douro and Alto Trás-os Montes (CNPGB, 2007) (continues)

Waterway	Dam	Flooded area (km^2)	Useful capacity (hm^3)	Installed power (MW)	Average yearly production (GWh)	Purpose	Municipality
Ribeira do Alambiques	Alfândega da Fé	0.22	1.3	-	-	Drinking water, irrigation	Alfândega da Fé
Ribeira da Chã	Alijó	0.18	1.59	-	-	Drinking water	Alijó
Rio Cávado	Alto Cávado	0.5	2	n.a.	n.a	Hydroelectric power, diversion	Montalegre
Rio Rabagão	Alto Rabagão	22.12	557.92	68	97	Hydroelectric power	Montalegre
Ribeira de Arcossó	Arcossó	0.412	4.876*	-	-	Drinking water	Chaves
Ribeira de Temilobos	Armamar	0.32	2.8	-	-	Irrigation	Armamar
Ribeira do Azibo	Azibo	4.1	46.67	-	-	Drinking water, irrigation, landscape enhancement	Macedo de Cavaleiros
Ribeira de Bastelos	Bastelos	0.176	1.2	-	-	Drinking water	Mogadouro
Rio Douro	Bemposta	4.05	20	210	1086	Hydroelectric power	Mogadouro
Rio Rabaçal	Bouçoais-Sonim	0.0153	1.365*	10	30	Hydroelectric power	Mirandela Valpaços
Ribeira da Burga	Burga	0.161	1.383	-	-	Irrigation	Alfândega da Fé
-	Cachão	-	-	-	-	-	-
Ribeira de Camba	Camba	0.095	1.08	-	-	Drinking water, irrigation	Alfândega da Fé
Ribeira de Vale de Ferreiros	Carviçais	N/A	0.992	-	-	Drinking water	Torre de Moncorvo
Rio Teja	Catapereiro	0.435	4	4	n.a.	Hydroelectric power	Vila Nova de Foz Côa
-	Cimeira	-	-	-	-	-	-

Table V.3 – Dams in Douro and Alto Trás-os Montes (CNPGB, 2007) (continues)

Waterway	Dam	Flooded area (km^2)	Useful capacity (hm^3)	Installed power (MW)	Average yearly production (GWh)	Purpose	Municipality
-	Curalha	0.177	0.74	-	-	Irrigation	Chaves
Ribeira de Gostei	Gostei	0.149	1.374	-		Irrigation	Bragança
Ribeira das Aveleiras	Mairos	0.067	0.359 700	-		Irrigation	Chaves
Rio Douro	Miranda	1.22	6.66	390	1036.3	Hydroelectric power	Miranda do Douro
Rio Tua	Mirandela	0.138	0.515*	n.a.	n.a.	Drinking water, hydroelectric power, irrigation, landscape enhancement, drought prevention	Mirandela
Rio Tuela	Nunes	N/A	0.098	9.9	41.56	Hydroelectric power	Vinhais
-	Palameiro	-	-	-	-	-	-
Rio Cávado	Paradela	3.8	159	n.a.	253	Hydroelectric power, diversion	Montalegre
Ribeira do Arco	Peneireiro	0.14	0.67	-	-	Drinking water	Vila Flor
Rio Douro	Picote	2.44	13.43	180	1038	Hydroelectric power	Miranda do Douro
Rio Douro	Pocinho	8.29	12.24	186	534	Hydroelectric power, navigation	Vila Nova de Foz Côa
Ribeira da Vidoeira	Prada	0.046	0.233	-	-	Irrigation	Vinhais
Rio Rabaçal	Rebordelo	0.46	3.130*	8.75	24	Hydroelectric power	Vinhais
Ribeiro do Milho	Rego do Milho	0.184	1.880*	-		Irrigation	Chaves
Rio Douro	Régua	8.5	95.000*	156	738	Hydroelectric power, navigation	Peso da Régua
Ribeira do Salgueiro	Salgueiro	0.22	1.65	-	-	Irrigation	Alfândega da Fé

Table V.4 – Dams in Douro and Alto Trás-os Montes (CNPGB, 2007) (continued)

Waterway	Dam	Flooded area (km^2)	Useful capacity (hm^3)	Installed power (MW)	Average yearly production (GWh)	Purpose	Municipality
Ribeira de Santa Justa	Santa Justa	0.28	3.476*	-	-	Irrigation	Alfândega da Fé
Ribeira das Andorinhas	Serra Serrada	0.2674	1.5	3.4	8.71	Drinking water, hydroelectric power, navigation	Bragança
Rio Sordo	Sordo	0.084	0.85	10	25	Drinking water, hydroelectric power	Vila Real
-	Vale Côvo	-	-	-	-	-	-
Ribeira de Mourel	Vale Madeiro	0.183	1.335	-	-	Irrigation	Mirandela
Rio Douro	Valeira	7.95	8	216	801	Hydroelectric power, navigation	São João da Pesqueira
Rio Varosa	Varosa	0.7	12.937	24.7	60	Hydroelectric power	Lamego
Rio Rabagão	Venda Nova	4	93	144	389	Hydroelectric power	Montalegre
Rio Távora	Vilar	6.7	95.27	64	148	Hydroelectric power, diversion	Tabuaço
n.a.: not available			Σ	1685	6310		

* total capacity, since no useful capacity figures were available.

APPENDIX VI: CORINE LAND COVER 2000

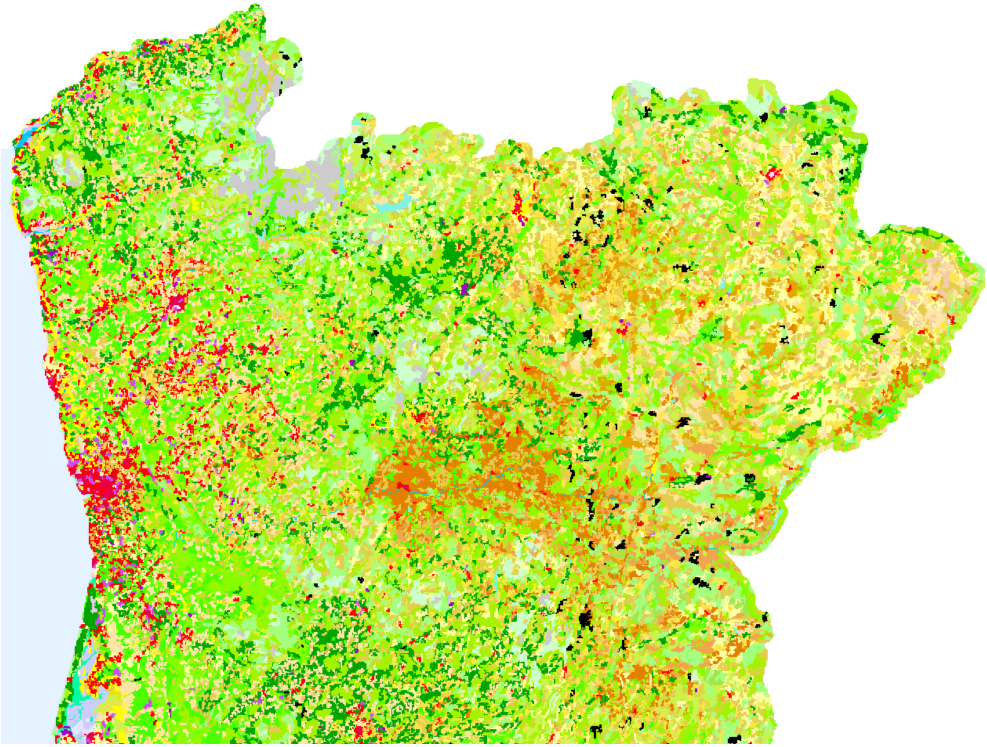

Figure VI.1 – Corine Land Cover 2000 (©EEA, Copenhagen, 2004)

Corine land cover classes

1. Artificial surfaces

1.1 Urban fabric

- ■ 1.1.1. Continuous urban fabric
- ■ 1.1.2. Discontinuous urban fabric

1.2 Industrial, commercial and transport units

- ■ 1.2.1. Industrial or commercial units
- ■ 1.2.2. Road and rail networks and associated land
- ■ 1.2.3. Port areas
- ■ 1.2.4. Airports

1.3 Mine, dump and construction sites

- ■ 1.3.1. Mineral extraction sites
- ■ 1.3.2. Dump sites
- ■ 1.3.3. Construction sites

1.4 Artificial, non-agricultural vegetated areas

- ■ 1.4.1. Green urban areas
- ■ 1.4.2. Sport and leisure facilities

2. Agricultural areas

2.1 Arable land

- ■ 2.1.1. Non-irrigated arable land
- ■ 2.1.2. Permanently irrigated land
- ■ 2.1.3. Rice fields

2.2 Permanent crops

- ■ 2.2.1. Vineyards
- ■ 2.2.2. Fruit trees and berry plantations
- ■ 2.2.3. Olive groves

2.3 Pastures

- ■ 2.3.1. Pastures

2.4 Heterogeneous agricultural areas

- ■ 2.4.1. Annual crops associated with permanent crops
- ■ 2.4.2. Complex cultivation patterns
- ■ 2.4.3. Land principally occupied by agriculture
- ■ 2.4.4. Agro-forestry areas

3. Forests and semi-natural areas

3.1 Forests

- ■ 3.1.1. Broad-leaved forest
- ■ 3.1.2. Coniferous forest
- ■ 3.1.3. Mixed forest

3.2 Shrub and/or herbaceous vegetation associations

- ■ 3.2.1. Natural grassland
- ■ 3.2.2. Moors and heathland
- ■ 3.2.3. Sclerophyllous vegetation
- ■ 3.2.4. Transitional woodland shrub

3.3 Open spaces with little or no vegetation

- ■ 3.3.1. Beaches, dunes, and sand plains
- ■ 3.3.2. Bare rock
- ■ 3.3.3. Sparsely vegetated areas
- ■ 3.3.4. Burnt areas
- ■ 3.3.5. Glaciers and perpetual snow

4. Wetlands

4.1 Inland wetlands

- ■ 4.1.1. Inland marshes
- ■ 4.1.2. Peatbogs

4.2 Coastal wetlands

- ■ 4.2.1. Salt marshes
- ■ 4.2.2. Salines
- ■ 4.2.3. Intertidal flats

5. Water bodies

5.1 Inland waters

- ■ 5.1.1. Water courses
- ■ 5.1.2. Water bodies

5.2 Marine waters

- ■ 5.2.1. Coastal lagoons
- ■ 5.2.2. Estuaries
- ■ 5.2.3. Sea and ocean

Figure VI.2 – Corine Land Cover 2000 legend (©EEA, Copenhagen, 2004)

APPENDIX VII: PER CAPITA GDP VARIATION

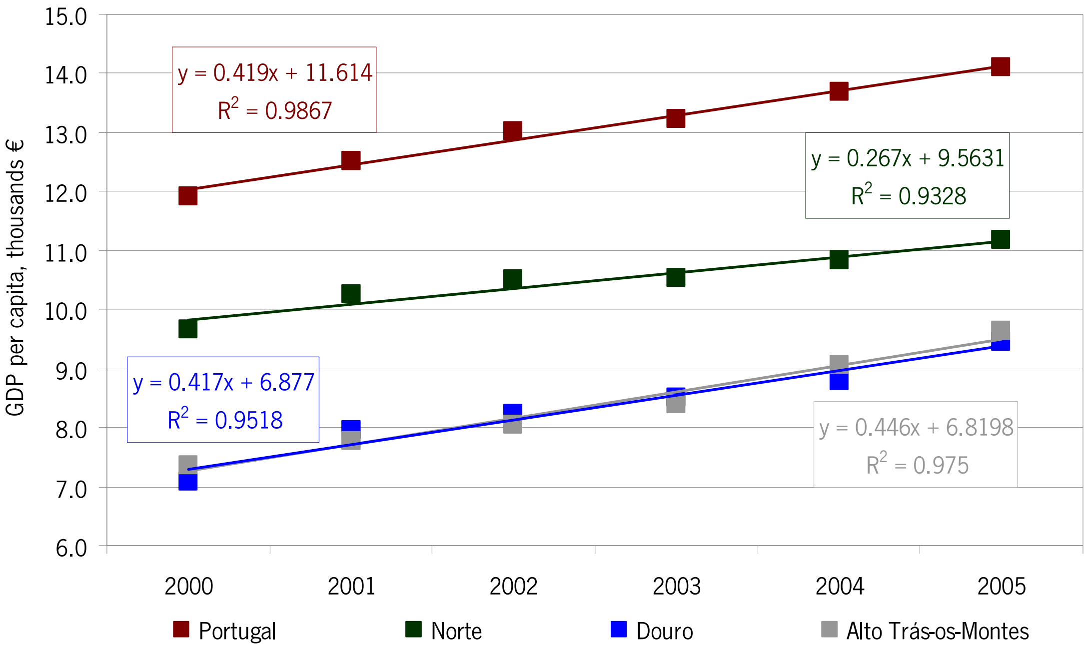

Figure VII.1– National, regional and sub-regional per capita GDP variation in 2000-2005 (INE, 2008)

APPENDIX VIII: SOCIO-ECONOMIC FEATURES OF THE CASE STUDY AREA

Table VIII.1 - Resident population (no.) and variation (%) by geographical location (INE, 2008)

Location	Portugal	Norte	Douro	Alijó	Mesão Frio	Peso da Régua	Sabrosa	Santa Marta de Penaguião	Vila Real	Alto Trás-os-Montes	Murça	Vila Pouca de Aguiar
2000	10 256 658	3 643 795	220 054	14 239	4 893	18 753	6 965	8 527	49 339	221 177	6 705	14 903
variation	0.71%	0.65%	-0.46%	-1.01%	-1.37%	-1.37%	-0.19%	-0.73%	0.83%	-0.20%	-1.22%	-0.20%
2001	10 329 340	3 667 529	219 048	14 095	4 826	18 496	6 952	8 465	49 748	220 738	6 623	14 873
variation	0.76%	0.67%	-0.21%	-0.28%	-1.41%	-0.87%	-0.46%	0.17%	0.59%	0.04%	-0.33%	0.81%
2002	10 407 465	3 691 922	218 591	14 056	4 758	18 335	6 920	8 479	50 042	220 819	6 601	14 994
variation	0.65%	0.54%	-0.28%	-0.36%	-0.78%	-0.77%	-0.59%	-0.46%	0.51%	-0.04%	-0.80%	0.43%
2003	10 474 685	3 711 797	217 982	14 005	4 721	18 194	6 879	8 440	50 297	220 735	6 548	15 058
variation	0.52%	0.42%	-0.42%	-0.45%	-1.46%	-1.14%	-0.64%	-0.47%	0.40%	-0.20%	-1.10%	0.28%
2004	10 529 255	3 727 310	217 067	13 942	4 652	17 987	6 835	8 400	50 499	220 289	6 476	15 100
variation	0.38%	0.28%	-0.71%	-0.86%	-1.55%	-1.39%	-0.98%	-0.94%	-0.05%	-0.48%	-1.00%	-0.03%
2005	10 569 592	3 737 791	215 527	13 822	4 580	17 737	6 768	8 321	50 473	219 240	6 411	15 095
variation	0.28%	0.18%	-0.69%	-0.72%	-1.22%	-1.38%	-0.84%	-0.83%	-0.10%	-0.62%	-1.53%	-0.34%
2006	10 599 095	3 744 341	214 045	13 722	4 524	17 492	6 711	8 252	50 423	217 882	6 313	15 043
Growth	0.52%	0.41%	0.00%	0.00%	0.00%	0.00%	0.00%	0.17%	0.56%	0.04%	0.00%	0.46%
Decrease	0.00%	0.00%	0.42%	0.55%	1.27%	1.12%	0.55%	0.66%	0.07%	0.21%	0.91%	0.13%
Net	0.52%	0.41%	-0.42%	-0.55%	-1.27%	-1.12%	-0.55%	-0.49%	0.49%	-0.18%	-0.91%	0.33%

Table VIII.2 – Employees per sector of activity for 2005 (INE, 2007)

Location	Number per sector				Percentage per sector		
	Total	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary
Portugal	2 173 144	38 238	828 379	1 306 527	1.76%	38.12%	60.12%
Norte	741 827	6 609	374 312	360 906	0.89%	50.46%	48.65%
Douro	....	...	....	17 309	...	...	...
Alto Trás-os-Montes	23 232	371	7 571	15 290	1.60%	32.59%	65.81%
Alijó	1 207	181	378	648	15.00%	31.32%	53.69%
Mesão Frio	585	38	93	454	6.50%	15.90%	77.61%
Murça	....	...	186	322	...	...	...
Peso da Régua	2 595	267	732	1 596	10.29%	28.21%	61.50%
Sabrosa	616	163	157	296	26.46%	25.49%	48.05%
Santa Marta de Penaguião	525	90	175	260	17.14%	33.33%	49.52%
Vila Pouca de Aguiar	1 377	27	681	669	1.96%	49.46%	48.58%
Vila Real	9 623	107	2 322	7 194	1.11%	24.13%	74.76%

APPENDIX IX: ADDITIONAL INFORMATION ON THE STUDY AREA

The existing WWTP within the target area are managed and operated by several entities: ATMAD (*Águas de Trás-os-Montes e Alto Douro*), EMARVR (*Empresa Municipal de Água e Resíduos de Vila Real, E.M.*) or each municipality's City Hall utilities services (CM, *Câmara Municipal*).

Table IX.1 – WWTP within the selected municipal boundaries

Municipality	WWTP	Managing entity
Alijó	Alijó - Favaios Sanfins do Douro	ATMAD
Mesão Frio	Mesão Frio	ATMAD
Murça	Murça Jou	ATMAD Murça CM
Peso da Régua	Régua Vilarinho dos Freires – Poiares Loureiro	ATMAD ATMAD Peso da Régua CM
Sabrosa	Sabrosa Arcã Covas do Douro Gouvães Pinhãocele São Martinho de Antas Vale de Gatas	ATMAD Sabrosa CM Sabrosa CM Sabrosa CM Sabrosa CM Sabrosa CM Sabrosa CM
Santa Marta de Penaguião	Cumieira Fornelos – Tuisendes S. João de Lobrigos S. Miguel de Lobrigos Sever-Fontes Romarigo	ATMAD ATMAD ATMAD ATMAD ATMAD Santa Marta de Penaguião CM
Vila Pouca de Aguiar	Vila Pouca de Aguiar Bornes de Aguiar Nozedo/Cidadelhe	ATMAD Vila Pouca de Aguiar CM Vila Pouca de Aguiar CM
Vila Real	Vila Real Lameirões Ponte da Pesqueira	ATMAD EMARVR EMARVR

- - - - - - - - - - - - - - -

Vila Real is currently under a contract-programme for wastewaters, which is an instrument of technical and financial support granted to municipalities and municipality groups through the coordination of the Water Institute (INAG, *Instituto da Água*) and the Northern Regional Coordination and Development Commission (CCDRN, *Comissão de Coordenação e Desenvolvimento Regional - Norte*). These types of programmes are aimed at supporting studies, projects and work designed to meet the needs of the municipality in terms of new or existing wastewater treatment systems.