A discussion on indicators and criteria for sustainable urban infrastructure development

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Summary

Infrastructure systems are at the core of urban sustainability issues. As population growth in urban centres continues to increase, infrastructure requires both development and rehabilitation. Unsurprisingly, this challenge is more evident in urban centres across the world and Portugal is not exception. To address this issue, the technical proposal of the Portuguese Program of the Policies for Land-Use Planning (PNPOT), and according to the Council of Ministers Resolution of April 27, 2006, considers that in order for Portugal to become an equitable territory in terms of development and well-being, the territorial model and corresponding policies-program should encompass strategic options that amongst other things, define the urban system as the guiding criterion for infrastructure network and public facilities design. The European Council released the Renewed EU Sustainable Development Strategy (EU SDS) in June 2006, calling for sustainability research efforts that promote and are carried out via inter- and transdisciplinary approaches, with the purpose of bridging the gap between science, policy-making and implementation. As spatial distribution and structure of human activities change, so does the call for increased urbanization and associated negative environmental impacts. Therefore and predictably, 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. Life-cycle and threshold analysis are potentially applicable tools. However, measuring the sustainable development level of a given region remains the result of a careful process of selecting and defining sustainability indicators/criteria. Though several have been proposed for a plethora of case studies, the fact remains that each case requires a specific set of indicators/criteria. Some of these indicators will be presented and explored in the paper presented herein for a case-study area of Portugal, the sub-region of Trás-Os-Montes, a mountainous, sparsely populated and deprived area.

1 - Introduction

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, p.54) 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 promise of improved services, more opportunities of employment and the prospects of 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 are promoters of 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.

As the world embraced the sustainability paradigm, a new perspective was offered 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).

2 - Sustainable development policies

The European Union expressed its sustainable development strategy during the 2001 Gothenburg European Council. However and up until 2005, its implementation remained a problem as unsustainable trends continued to worsen. In June 2006, the European Council adopted a revised strategy, and released the Renewed EU Sustainable Development Strategy (EU SDS). The renewed strategy calls for "cross cutting policies" as means of 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" (EU, 2006). Additionally, sustainability research efforts must promote and be carried out via inter- and transdisciplinary approaches, that ideally will 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 address 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. Furthermore, the technical proposal of the Portuguese Program of the Policies for Land-Use Planning (PNPOT), according to the Council of Ministers Resolution of April 27, 2006, considers that in order for Portugal to become an equitable territory in terms of development and well-being, the territorial model and corresponding policies-program should encompass the following strategic options:

- "Defining the urban system as the guiding criterion for infrastructure network and public facilities design, thus ensuring adequate national coverage.
- Promoting city networks and local polycentric urban subsystems, for the qualification of services to the population and economic activities from a complementarity and specialization standpoint.
- (…)
- Acknowledging and promoting territorial diversity, guaranteeing access to knowledge

and public services, good mobility and good communication conditions throughout the country, favouring the preference for different spaces and lifestyles."

Sustainable development planning and management ideals 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. As population growth in urban centres continues to increase, infrastructure requires both development and rehabilitation (Sahely *et al.*, 2005). Unsurprisingly, this challenge is more evident in urban centres worldwide and Portugal is not exception. As spatial distribution and structure of human activities change, so does the call for increased urbanization and associated negative environmental impacts. Therefore and predictably, 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).

3 - Sustainability assessment models – an overview

According to Basiago (1999), there is a close link between the key elements of sustainability. 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). Additionally, sustainable development is about achieving social, economic and environmental equilibrium over spatial and dynamic horizons (Hellström *et al.*, 2000), often spanning decades (Sahely *et al.*, 2005) and taking in to account the nature and utilization of resources – renewable and non-renewable - that are utilized (Lomborg, 2001).

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) and 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 a decision-support model suitable 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.

Given the diverse nature and origin of the input data, it requires normalization and conversion into a common unit so that it can be compared (Stokes and Horvath, 2006). However, the normalization and reduction of data to a common unit is not without fault, as it may warp the uniqueness of each parameter (Barton, 2004). To validate this point, Barton (2004) compares high quality urban design with safety from flood. While data can be converted into comparable terms, it does not pertain to equivalent parameters. Recognizing that some parameters could mean a “make or break” type of decision when taken in extreme, Barton (2004) and then Mitchell (2005) 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).

That said, the definition of thresholds or limits is case-specific. In an urban development context, they may as well be the factors that allow for or hinder sustainable progress. Lourenço (2003), 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 - 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.

4 - Methodology for sustainability assessment

Assessing sustainability is the first logical step before any sustainability-enhancement planning is carried out, in a sort of “does boiling water really need additional heating?” type of approach. For the sake of time and resource consumption efficiency, each case should undergo a preliminary analysis to have its sustainability status evaluated before embarking on to more involved and complex levels of data-gathering, analysis and problem-solving stages typical of any planning practice. The completion of these should result in further but more efficient resource-consuming implementation efforts towards a timely and successful conclusion of the whole process.

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 implies a degree of generalization that at the very least, could compromise the validity of the final result, mirroring Barton’s concerns (2004). Sustainability is evaluated via the analysis of a selected group 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. Therefore, enduring generalizations are difficult to establish. While some can and should be considered for the sake of efficiency, the fact is that no two cases are exactly alike. This explains and justifies the need for defining series of case-specific infrastructure sustainability criteria and indicators. However, the issue does not preclude general guidelines on how to design and apply sustainability assessment models.

Having already mentioned a few, 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; O’Regan *et al.*, 2002; Weng and Yang, 2003). They vary in degrees of integration and also in scale, ranging from global level down to single components, such as housing and infrastructure (Daniell *et al.*, 2005). Furthermore, some studies have dwelled on the intricacies of the difficult task of defining sustainability criteria for urban infrastructure systems (Quental *et al.*, 2004; Sahely *et al.*, 2005). While discussing the challenges of measuring sustainability, they have proposed several generic criteria, as well as possible system-specific indicators. Extensive lists of selected indicators and criteria have been proposed by a number authors (Daniel *et al.*, 2005; Kashem and Hafiz, 2006; O'Regan *et al.*, 2002; Sahely et. al, 2005; Stokes and Horvath, 2006; Weng and Yang, 2003), taking into consideration the environmental, economic, engineering and social aspects of the particular system under study.

5- Sustainability indicators and criteria for urban water-wastewater systems

The distinction between indicator and criterion must be emphasized, 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 by 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 and from its social, environmental, engineering and economic angles. As for any sustainable system, there has to be 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. Sustainability is ideally the establishing of a balanced and dynamic trade-off relationship between all the intervening components and/or parts, for the duration of the life-cycle of the system. Predictably, the successful operationalization of such an ideal balance remains elusive. However, it is possible to infer on the state of the system by "taking a snapshot" at a few parameters that best describe its condition. Thus, deciding which parameters are the system's best descriptors is a largely challenging task.

There are many approaches on how to go about selecting, from a long list of possible indicators, those that are deemed most useful. In other words, it is not about gathering all the existing information, but rather selectively analyse the one which is more fundamental in essence and more likely to produce the most accurate information. Weng and Yang's approach (2003) 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. Moreover, selected indicators must relate to the system in a fundamental way, reflecting its social, economic and environmental/engineering aspects. Per Weng and Yang (2003), a system of indicators should encompass a hierarchical distribution of parameters, consisting of tiered indicators. Data is collected only for the lowest tier indicators. How each level fares is a direct consequence of the results obtained for the precedent level. Additionally, this approach allows for very visual, organized and easy to read relationships between the parameters.

An indisputable advantage of this approach is that it relies on a hierarchical method of setting up parameters, thus assisting the whole process of setting apart fundamental/essential from non-essential parameters - much like Lourenço's approach (2003) to critical and determinant factors on urban expansion. Similar 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. Nevertheless, they all point out towards the need for partitioning the system under study into components (sub-systems) and then treat each component in an isolated manner. Whether these sub-systems are treated hierarchically or not, it depends on the system and/or the approach adopted by the authors. However, the tier or hierarchical approach to indicator characterization is not without fault. As thoroughly described by Mitchell (2004), issues like number of indicators, double-counting, controversial inclusions and/or omissions must be addressed on a case-by- case basis. Table 1 presents a possible list of indicators that can be used for assessing urban water systems' sustainability status.

Table 1: Examples of indicators for assessing sustainability of urban water systems

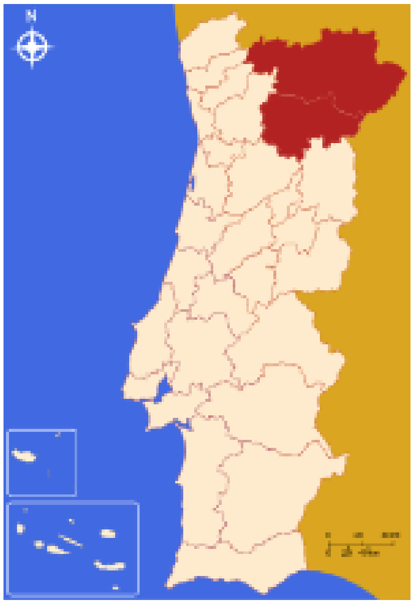
Overall Parameters			
Environmental	Economic	Engineering	Social
Specific Indicators			
- Use of: chemicals electricity water - Discharge of : BOD N P DO - Sludge to landfill - Energy from biomass - Nutrients to farming land	- O&M costs - Reserve funds - R&D investments - User fees	- Service interruptions - Water losses - Leakage - Ratio of treated wastewater	- Water and sewer connections - Incidence of waterborne diseases - Flood risk - Groundwater vulnerability

Source: aggregated from Barton (2004), Sahely *et al*. (2005) and Weng and Yang (2003).

Given the sheer complexity and specificity of each urban system and subsystems under scrutiny, the innovative aspect of this proposed piece of transdisciplinary research lies on the use of existing empirical evidence regarding urban form and its relation with infrastructure development. The advancement of knowledge in this topic, particularly in the northeast region of Portugal, known for its continued struggle with alternating conditions of flooding and severe drought-related issues, is critical in societal problems improvement. The sub-regions Trás-Os-Montes will be taken as case-study.

6 - Case-Study: Trás-Os-Montes

The region formerly known as Trás-Os-Montes includes the statistical units (NUT III) currently designated as Alto Trás-Os-Montes and Douro sub-regions. It is located in the interior north-eastern part of Portugal, encircled by Spain from the northern and eastern sides (see Figure 1).



Source: Wikipedia (2007)

Figure 1: The Trás-Os-Montes region

The region is included within the rivers Cávado and Douro watersheds, characterized by a great diversity of morphological, ecological and weather conditions. Consequently, there is a great natural and cultural heritage variety and the population distribution is heterogeneous (INAG, 1999). The main topographical features of the region consist of its mountainous, plateau and valley elements. These characteristics hinder the mobility and the development of better accessibility conditions, the results of which are highlighted below.

As will be seen in the following sections, Douro differs from Alto Trás-Os-Montes in the sense that it is age-segregated, having lost population in the active population group (25 to 64 years old). Douro is also suffering from lack of accessibility at the boundary areas.

6.1 - Social context

The Alto Trás-Os-Montes and Douro sub-regions are home, respectively, to 219 200 and 215 500 inhabitants, totalizing 434 700 inhabitants and approximately 4% of the country's population (CCDRN, 2007). Encompassing a combined area of approximately 12 280 km^2, the sub-regions yield an overall weighed average population density of 43 inhabitants per km^2, a number well below the national value of 115 inhabitants per km^2 (CCDRN, 2007; INE, 2006), thus qualifying for the designation of sparsely populated area. Following a trend observed throughout the national territory, people tend to move away towards the coastal areas or abroad, in search of better job and life opportunities. As a result, the overall population projections for 2010 and 2020 are 429 000 and 407 400, respectively, further highlighting the decreasing trend that has been observed for this part of the country.

Demographics for the sub-regions are further highlighted in Table 2.

Table 2: Selected demographic data for Alto Trás-Os-Montes and Douro

	Alto Trás-Os-Montes	Douro	Country
Age distribution (%)[1]			
25-64	51.5	13.4	55.1
>=65	23.7	52.5	17.1
Aging Index[1]	198.0	142.8	110.1
Unemployment rate (%)[2]	8.6	8.2	6.8

Source: [1] CCDRN (2007); [2] INE (2006).

The unemployment rates for the sub-regions are among the top five in the country, though closer to the average than to the highest rate of 11.5% (INE, 2006). According to the CCDRN (2007), globalization is directly related to the employment and unemployment trends that have been observed in recent years in the region. However, it still occupies a favourable position when compared to the European average and the region is expected to comply with the goals set forth in the European Strategy for Employment for global employment rates of 70% by 2010 (CCDRN, 2007).

The health sector has seen some significant improvements, with newer and better equipped facilities and better-qualified human resources. However, accessibility is still a problem so some areas remain relatively isolated and thus are not as well-served as others. This imbalance between municipalities is due to the fact that they are crossed by many routes but have not yet been reached by the larger and more recent highways.

6.2 - Economic context

The region remains one of the poorest in the country, despite strong partaking in global trading and exports. The gross domestic product (GDP) per capita is approximately two-thirds of the national GDP, amounting to 8.9 thousand euros for each sub-region. In terms of gross value added (GVA), the sub-regions make a combined contribution of 1.33% to the national GVA. However, this figure may not give an accurate picture of the reality, since exports are still accounted mostly from Oporto or multinational companies. Table 3 presents more detailed information as well additional data on economic activities per sector.

Table 3: Economic data for Alto Trás-Os-Montes and Douro

	Alto Trás-Os-Montes	Douro	Country
GVA, 10^6 €	1420	1580	112 521
% of GVA, per sector			
primary	7.8	19.1	3.7
secondary	25.2	19.9	25.9
tertiary	67.0	61.0	70.4

Source: CCDRN (2007)

Agriculture has seen a decrease in activity since the 1990s, despite an increase in land productivity (CCDRN, 2007). Generally speaking, the extent of arable land has diminished, whereas the non-cultivated and forestry areas have increased. Furthermore, the increase in animal-farming and dairy productivity has not been able to offset the decay in the agricultural sector. A weakening of the human occupation of the territory has been considered one of the main causes for the phenomenon. As a result, several organizations have come together to form a network for the management and promotion of forest property, an effective albeit uncommon structural transformation for rural land in recent years (CCDRN, 2007).

Tourism activities are some of the main contributors to the wealth of the region, specifically because of the existing and enduring diversity of tourism resources. Home to three natural parks and including part of the country's only national park – Peneda-Gerês – the sub-regions of Alto-Trás-Os-Montes and Douro are prime targets for the so-called nature, culture and adventure tourism. More importantly, its particular soil and climate conditions are fundamental for the production of the world-famous Port wine, produced in Douro, at the world's oldest demarcated wine region. Other tourism resources are also important, such as historical sites, archaeological parks, natural spas and a diverse and rich gastronomy (CCDRN, 2007)

6.3 - Infrastructure and environmental issues

According to the CCDRN (2007), the supply of transportation to areas of low population density is increasingly disappearing outside of the urban areas, hindering the mobility and circulation of people and goods. This causes a reduced ability for competing with areas not so negatively affected by lack of transportation infrastructure. This disproportion is not only territorial but also seasonal, varying throughout the year. The lack of continuity and consistency in mobility particularly affects rural and urban fringe areas that are not provided with adequate, sufficient and specific transportation alternatives.

In terms of water distribution infrastructure, there have been significant improvements in recent years, resulting from funding by the World Bank in the 1980s and subsequent funding from the European Union upon Portugal's admission to the then-designated European Economic Community (EEC), in 1986. Those incentives, along with the local trend for urban densification, have helped placing the sub-regions above the national average (97.5% of the population served regionally versus 92.4% served nationally). The same is true for wastewater collection (82.7% versus 74.6%). As for percent of population served by wastewater treatment plants (WWTP), the numbers are almost identical, 61.3% for the Alto Trás-Os-Montes sub-region and 61.7% for the country. The Douro sub-region presents a slightly lower percentage, at 53.3% (CCDRN, 2007).

7 - Indicators for selected municipalities – a preliminary discussion

The sub-regions of Alto Trás-Os-Montes and Douro include 14 and 19 municipalities (*concelhos*), respectively. Eight of them have been selected due to their central location, being a transition area between the coastal and the interior areas. The discussion that ensues, concerns the list of urban water and wastewater infrastructure parameters presented in Table 4. The selection of indicators was carried out based on the state of the art and information available. Furthermore, criteria corresponding to the indicators under analysis are not presented, as this work is still a first approach of a preliminary nature. However, they will be discussed from a theoretical standpoint, as tangible information is not yet available.

A brief and comparative discussion on how each municipality fares will be offered and supported by the information presented in Tables 5 and 6, which was obtained by applying a multi-criteria evaluation method approach. It ought to be pointed out that though data were available for most of the selected indicators, there were instances where that was not the case. As a result, some of the indicators had to be dropped prior to the comparative analysis step.

Table 4: Urban water and wastewater indicators for selected municipalities belonging to the Alto Trás-Os-Montes and Douro sub-regions.

I	Indicator \ Municipality	Alijó	Mesão Frio	Murça	Peso da Régua	Sabrosa	Sta. Marta de Penaguião	Vila Pouca de Aguiar	Vila Real
1	**Social**								
11	Population density (inhabitants/km^2)	46.8	174.6	34.2	189.6	43.6	121.2	34.5	133.3
12	Population served by water supply systems (%)	90.0	100.0	90.0	85.0	99	99.0	100.0	99.0
13	Population served by wastewater collection systems (%)	87.7	70.0	60.0	80.0	94	88.4	65.0	70.0
14	Population served by wastewater treatment plants (%)	20.0	30.0	n.a.	77.0	45	18.0	35.0	1.0
2	**Environmental/Engineering**								
21	Water intake by municipal services (10^3 m^3)	3 776	459	680	1 617	366	552	970	3 514
22	Total water intake (includes other services) (10^3 m^3)	3 776	459	680	1 617	366	552	970	3 786
23	Water treated by municipal services (10^3 m^3)	3 776	459	480	1 590	366	531	485	3 514
24	Total water treated (includes non-municipal services) (10^3 m^3)	3 776	459	480	1 590	366	531	485	3 786
25	Public water consumption, total (10^3 m^3)	376	153	252	777	281	303	467	2 737
26	Wastewater produced (10^3 m^3)	262	76	125	547	200	214	245	2 146
27	Wastewater treatment rate (%)	38.9	47.4	n.a.	49.4	52.5	25.2	50.6	2.1
28	Wastewater treatment in WWTP and municipal septic tanks (10^3 m^3)	102	36	n.a.	270	105	54	124	46
3	**Economic**								
31	Expenditure per 1 000 inhabitants on wastewater management (€)	16 071	14 030	38 433	35 425	41526	51 287	35 583	17 601
32	Expenditure by municipality, on wastewater management (10^3 €)	225	67	253	647	287	434	535	883
33	Revenue by municipality, from wastewater management (10^3 €)	80	35	61	272	30	30	146	822
34	Public expenditure on environmental protection, local (10^3 €)	n.a.	n.a.	n.a.	7	81	21	55	7
35	Public revenue on environmental protection, local (10^3 €)	n.a.	n.a.	n.a.	3	48	n.a.	n.a.	n.a.

Source: [1] INE (2006). Legend: I - Indicator; n.a. - not available.

The remaining parameters were evaluated as to whether an increase in the corresponding value would constituted a benefit (B) or a cost (C). The presented data were normalized according to expression (1) if they were a benefit and expression (2) if they were a cost,

$$b_i = \frac{d_i - d_{min}}{d_{max} - d_{min}} \quad (1)$$

$$c_i = 1 - b_i \quad (2)$$

where b_i: normalized benefit;
c_i: normalized cost;
d_i: datum;
d_{max}: maximum datum, and
d_{min}, minimum datum.

Knowing that there are several forms of data normalization (Silva *et. al*, 2004), the examples presented here merely serve the purpose of illustrating the process of multi-criteria comparison and are not the subject of this piece of research. Nonetheless, ongoing work will consider alternate methods of normalization.

Table 5: Multi-criteria evaluation data

I	I type	Alijó	Mesão Frio	Murça	Peso da Régua	Sabrosa	Sta. Marta de Penaguião	Vila Pouca de Aguiar	Vila Real
1									
11	B	0.08	0.90	0.00	1.00	0.06	0.56	0.00	0.64
12	B	0.33	1.00	0.33	0.00	0.93	0.93	1.00	0.93
13	B	0.98	0.35	0.00	0.70	1.00	1.00	0.18	0.35
2									
21	C	0.00	1.00	0.93	0.65	1.00	0.97	0.85	0.08
22	C	0.00	1.00	0.93	0.65	1.00	0.97	0.85	0.00
23	B	1.00	0.00	0.01	0.34	0.00	0.02	0.01	0.92
24	B	1.00	0.00	0.01	0.34	0.00	0.02	0.01	1.00
25	C	0.91	1.00	0.96	0.76	0.95	0.94	0.88	0.00
26	C	0.91	1.00	0.98	0.77	0.94	0.93	0.92	0.00
3									
31	C	0.95	1.00	0.35	0.43	0.26	0.00	0.42	0.90
32	C	0.81	1.00	0.77	0.29	0.73	0.55	0.43	0.00
33	B	0.06	0.01	0.04	0.31	0.00	0.00	0.15	1.00

Legend: I - Indicator.

7.1 - Criteria and thresholds

It is important to explain the rationale behind the classification of each indicator as a benefit or a cost. Assessing the type of indicator for the purposes of a multi-criteria comparison approach implies establishing a series of criteria that will assist in deciding whether a given indicator is a benefit or a cost. It also implies the understanding that some parameters may be seen as either, depending on a threshold that is pre-defined and/or imposed. As explained before, criteria will not be presented at this time. Conversely, some considerations will be made where pertinent.

Regarding population density (indicator 11), given the particular topographical and resulting accessibility difficulties, it is believed that population will be better served assuming densification rather than scattering scenarios. Therefore, an increase in population density is seen as a benefit. However, this increase means that more people will require more service connections, begging the "how many is too many?" question. Also, will the water and wastewater systems be able to accompany the rate of population increase? Vice versa, if the population decreases, what will happen to the existing infrastructure? This indicates the call for local threshold analysis and evaluation of growth and other demographic trends.

In terms of percentage of population served by water distribution and wastewater collection (indicators 12 and 13), the benefit is self-explanatory, since having 100% of the population served is undoubtedly a success. However, there are some concerns. What should be the minimum community size for a full-blown water and wastewater system to be put in place? Again, a threshold analysis would be valuable in determining the best criteria for the type of infrastructuring this indicator points to.

As for the environmental/engineering factors, there are several considerations to be made. From a water intake standpoint (indicators 21 and 22), and following the current water-saving policies that are taking place not just locally but at a global level as well, an increase in water intake is seen as a cost. On the other hand, is "sufficient enough"? Are the water needs being met? How is the water being used? How much is it being wasted? How much does it cost to transfer it from the intake reservoir to the corresponding – not always the closest - treatment facility?

Conversely, an increase in water treatment (indicators 23 and 24) is seen as a benefit. Assuming that human consumption is the end-use of the raw water that is removed from the natural (surface and/or groundwater) reservoirs, then all water requires treatment. Please note that the processes of treatment and distribution are not being considered at this point, nor are the levels of treatment that are required and/or sufficient. In principle, water for irrigation or for street cleaning should not have to meet the same stringent quality parameters as potable water, for instance. Therefore, the degree of treatment is a threshold by definition and so should be the volumes allocated per end-use (industrial, residential, etc).

As for public water consumption (indicator 25), it follows the same logic as the water intake issue and thus it is classified a cost. So is the volume of wastewater produced (indicator 26), because it requires collection, treatment and disposal, along with all of the secondary processes (disposal of bio-solids, energy consumption, emissions, etc.) that must be carried out in order to comply with the applicable regulations.

The classification assigned to economic factors (indicators 31, 32 and 33) are also very easy to understand, since expenditures are, by definition, costs, whereas revenues are clearly benefits. Nonetheless, how much of the local budget is being spent on water and wastewater infrastructure? Does it matter that the revenues are below the expenditure, thus generating a deficit? Since providing water and sanitation is a matter of wellbeing of the community, financial aspects are not typically considered, though they should be incorporated in the analysis. However, is there anything that can be done to reverse the trend?

7.2 - Scores

Scores were calculated based on the weights assigned to each set of indicators rather than having one weight per indicator. Though ideal it may be, it was not done at this time, for sake of simplicity and given the preliminary nature of the analysis. Four hypotheses were tested – W1, W2, W3 and W4 – as seen in Table 6.

Table 6: Scores for different weight distributions

			Alijó	Mesão Frio	Murça	Peso da Régua	Sabrosa	Sta. Marta de Penaguião	Vila Pouca de Aguiar	Vila Real
			Scores							
W1	**1**	0.333	7.03	**8.26**	5.31	6.24	6.88	6.91	5.68	5.83
	2	0.333								
	3	0.333								
W2	**1**	0.25	2.71	**3.07**	2.28	2.44	2.69	2.69	2.30	1.96
	2	0.50								
	3	0.25								
W3	**1**	0.125	2.77	**3.03**	2.38	2.35	2.57	2.45	2.27	1.95
	2	0.50								
	3	0.375								
W4	**1**	0.375	2.66	**3.10**	2.18	2.52	2.82	2.94	2.32	1.96
	2	0.5								
	3	0.125								

As observed in Table 6, an equal weight distribution (hypothesis W1) yields somewhat different results from the ones obtained via the remaining hypotheses, ranking Mesão Frio as the "best" municipality whereas Murça is deemed the "worst". However, when assigning the greatest weight to the environmental/engineering category, regardless of how the social and economic categories are comparatively treated, Mesão Frio remains as the number one municipality, with Vila Real ranking the lowest of the group on all three possible variations.

7.3 - Final considerations

An underlying assumption was that population density would have caused a greater impact that it appears to have had. In fact, population density does not appear to be a deal-breaker, as highest and lowest scores do not differ by more than 24% in terms of population density (relatively speaking, the greatest difference is approximately 82%, between Murça and Peso da Régua, both of them staying on the bottom half of the ranking on all accounts). Nevertheless, it is very important to recognize that population density calculations are based on the entire municipal area, not considering the existing diversity of land uses. For the sake of accuracy and for the purposes of this discussion, population density values should be calculated based on actual urban land use and not the municipal boundary. Therefore, any consideration pertaining to the impact of population density on the availability of urban water and wastewater system should not be regarded as anything beyond speculation at this point in the research. A deeper and certainly more accurate understanding is unquestionably to be gained if applying the current line of research to the *freguesia* level (a territorial organization unit hierarchically placed below municipality, comparable to the British parish) and combining that knowledge with that available for land uses.

Another point that deserves some attention is that the target municipalities are clustered in the central-western part of the combined sub-regions, making up a transition area between the more populated coastal sub-regions and the interior municipalities. In terms of accessibility, the selected municipalities cannot be considered as impaired as the interior-most ones, a factor that can leads to urban sprawling issues.

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