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Sustainability as the key to prioritize investments in public infrastructures

Francesc Pardo-Bosch & Antonio Aguado

Infrastructure construction, one of the biggest driving forces of the economy nowadays, requires a huge analysis and clear transparency to decide what projects have to be executed with the few resources available. With the aim to provide the public administrations a tool with which they can make their decisions easier, the Sustainability Index of Infrastructure Projects (SIIP) has been defined, with a multi-criteria decision system called MIVES, in order to classify non-uniform investments. This index evaluates, in two inseparable stages, the contribution to the sustainable development of each infrastructure project, analyzing its social, environmental and economic impact. The result of the SIIP allows to decide the order with which projects will be prioritized. The case of study developed proves the adaptability and utility of this tool for the ordinary budget management.

Keywords: decision-making; infrastructure management; MIVES; public investments; sustainability.

SIIP = *Sustainability Index of Infrastructure Projects*
NIf = *Need for Infrastructure*
CRB = *Contribution to Regional Balance*
ZID = *Zone Inversion Deficit*
IPI = *Public Investments in Infrastructures*
Pop = *Population*
Ext = *Extension*
GDP = *Gross Domestic Product*
LAS = *Level of Actual Services*
ASt = *Alternative State*
ASa = *Alternative Saturation*
SSP = *Scope of the Solved Problem*
PoS = *Population Served*
SeI = *Service Important*
RNA = *Risk Not Act*
IV_x = *Indicator Value*
AUC = *Annual Unitary Cost*
InI = *Initial Investments*
LT = *Life Time*
ReC = *Recurring Cost*
MaC = *Maintenance Cost*
OpC = *Operating Cost*
IRe = *Investment Return*
ImR = *Impact Rank*
QuC = *Quality Change*
ImF_x = *Improvement Field*
CpC = *Capacity Change*
CpV = *Capacity Variation*
CrJ = *Creation of Jobs*
JCo = *Jobs Construction*
JOp = *Jobs Operation*
CoA = *Community Acceptance*
CV = *Coefficient of Variation*

1. Introduction

Making decisions is not an easy job. Doing it ethically means finding what is right and good for people at the same time (Donaldson and Werhane, 2007). Sometimes, unfortunately, the construction and operation of public infrastructures has gone together with unethical behavior from those who had the responsibility and the power of governing. Estache and Trujillo (2009) point out, for instance, that all over the world fraud, embezzlement, favoritism, cronyism have been very common. These behaviors together with populism and the lack of technical criteria have created an unsustainable development. Sustainability, according the World Commission on Environment and Development (1987), is the capacity to meet the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits - not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources.

Many infrastructures around the world have cost huge amounts of money and have later been qualified as unsustainable, in the most general meaning of the term, which has caused the social rejection of some of these projects. As an example, certain of those can be mentioned: *Zentrum für Operative Medizin II* (Düsseldorf, Germany), *Aeropuerto de Castellón* (Castellón, Spain), *Viaduto Estaiado* (Curitiba, Brasil), conference center *Nuvola* (Rome, Italy) or the *High Speed 2* (United Kingdom). The big magnitude of the projects and the existing oligopoly in this sector do not contribute to good results. This helps increase the hostility to the political class which, in general terms, is going through a notable prestige crisis. This perception has been amplified by the economic crisis that most of the developed countries are going through or have gone through, because times of difficulty is when most benefit is to be obtained from projects funded with public money.

Bebbington *et al.* (2008) or Lee (2008) claim that the results obtained from these big investments could improve as long as the public sector becomes transparent to civil society. The governments have realized this problem and are setting this mentioned transparency as one of their priorities (Mol, 2013). A good way of making it a reality is through sustainability studies, just as shown in works from Gray *et al.* (2009), Guthrie *et al.* (2010), García-Sánchez *et al.* (2013) or Alcaraz-Quiles *et al.* (2014). In addition, they agree that there is still a long way to go in this matter, because, as Lee & Hung (2007) point out, sustainable development from the perspective of both the resource management and government aspects will become increasingly important in the future.

In this context, this paper presents a model to assess beforehand the sustainability of any kind of infrastructure project through the Sustainability Index of Infrastructure Projects (SIIP): a multi-criteria decision-making system, based on MIVES, which sorts non-uniform investments. The final goal is to compare *n* projects with non-common characteristics (that is to say: buildings, hydraulic constructions, transportation systems… located in different areas, with different, costs or territorial impacts) that have to be financed by one institution and with only one budget, in order to choose and to build the ones with best global results to deliver the most benefit to all citizens.

2. Background

2.1. Decision-making in the field of infrastructure management

In public infrastructure construction, a systematic framework that includes the engineering judgement and expert opinion should be used to make decisions with maximum rigor and strictness. The Multi-criteria decision-making (MCDM) are a group of tools that provide this framework through a detailed and repetitive analysis including multiple criteria. In this matter, the benefits and drawbacks of each project can be evaluated, according to Huang *et al.* (2011), using several concepts that can be very different. Therefore, making sure that, as Hajkowicz and Collins (2007) point out, a complete and transparent audit is done on each one of them.

Some models have formulated a multi-criteria decision-making system to help in the management of certain kinds of infrastructures. Kabirb *et al.* (2013) present an interesting revision of 300 different methodologies that have been developed in the last twenty years. The work identifies seven fields to classify these methodologies (the number of applications are in parenthesis): hydrological resources systems (68), potable and waste water (54), transportation (56), bridges (58), buildings (33), underground infrastructures (11) and urban systems (21). All these only work if the assessment is to be done with very specific kinds of infrastructures, thus they can be very useful for an administration that manages a specific type of infrastructure. The results obtained with these methodologies cannot be compared because they have different implications, so they are not useful tools to make strategic decisions.

There are two papers, Ziara *et al.* (2002) and Lambert *et al.* (2012), which have not been considered in that revision, but they are very interesting because they present an index to prioritize infrastructure. Although, they are used as theoretical references in this paper, both of them present some conceptual differences with SIIP.

Ziara *et al.* (2002) present a methodology to prioritize urban infrastructures in Pakistan, where all resources were and are limited and where, in addition to the political uncertainty, business suffer from confusing commercial legislation. This model, which was developed to select the most sustainable projects (without taking into account the environmental impact), uses only six indicators to assess the investments. These indicators are *Project importance, Sector importance, Finance suitability, Execution suitability, Operation suitability, Reliability* and *Consequence of failure*, and all of them are measured by qualitative variables. An important particularity of the model of Ziara *et al.* (2002) is that it uses the analytic hierarchy process (AHP), developed by Saaty (1980), to evaluate the set of projects. Its means that the model realizes a comparison by pairs of the set of projects. So, using AHP, if the decision-makers want to add a project, it will be necessary to evaluated all the projects again. The authors present a case study where they evaluate 10 projects. The main conclusion of their analysis is that the model is not discriminant (CV=0.20), a result that is lower than the 0.25 value that Morales (2008) considers the limit to have a discriminant classification.

Lambert *et al.* (2012), meanwhile, presents a model to prioritize only major civil infrastructures in Afghanistan, a country that needs important infrastructures investments to be rebuilt after very hard years of war. Fourteen indicators composed the model, which are *Create employment*, *Reduce poverty*, *Improve connectivity and Accessibility*, *Increase industrial/agricultural capacity*, *Improve public services and utilities*, *Reduce corruption/improve governance*, *Increase private investment*, *Improve education and Health*, *Improve emergency preparedness*, *Improve refugee management*, *Preserve religious and cultural heritage, Improve media and information technology, Increase women's participation* and *Improve environmental and natural resource management*. All of them are evaluated only with one qualitative variable. In that case, the indicators do not have any kind of relationship with the sustainable development, at least explicitly. It is interesting that this model does not take into account the cost of the project because it could be one of the most important determinants when the decision has to be made. The case study, where 27 projects are evaluated, shows that the model is discriminant, with a CV=0,31.

If technical community want to give to society of developed countries a tool capable of promoting sustainable policies in investments that fund public infrastructures, it is necessary a global tool that can evaluate together all kinds of public infrastructures (that is to say: buildings, hydraulic constructions, transportation systems...). A group of infrastructures that are very different from each other in terms of utility, dimension, cost and lifetime. Another argument that strengthens the need to develop a single global tool is that the public budget that all governments use to build infrastructures is normally all in the same box that needs to be divided to fund all chosen projects, no matter their utility, placement or characteristics.

The main problem that the definition of a model of this kind presents is finding, amongst the influence groups, the necessary agreement to delimit the concepts to be measured, either by variables or attributes. The sustainability, whose main goal is optimizing the management of all kinds of resources in any activity, avoiding all unjustified use, has prevailed as a valid argument when creating agreement in the definition of the variables to use, and this is despite the fact that sustainability is a recent discipline (Brundtland report, 1987). Any sustainable development is based on a long term approach that takes into account the inseparable nature of environmental, social and economic aspects of the development activities (UNEP, 2002, Quebec National Assambly, 2006; Mory & Christodoulou, 2012; United Nations, 2013; and Veldhuizen *et al.* 2015, among others). This three topics concerns need to be seen and solved in the context of each other through interdisciplinary research that cuts across traditional boundaries between the social sciences and humanities on the one hand, and natural sciences on the other (Haberl, Wackernagel & Wrbka, 2004).

2.2. MIVES Method

The MIVES method is a system that helps in decision-making, which was born in the field of industrial construction to evaluate their sustainability. The great key of the system is that it combines in a simple way the theory of the multi-criteria methods and the theory of the multi-attribute utility (San-José *et. al* 2007; San-José & Garrucho, 2010; Aguado *et al.*, 2012; Pons & Aguado, 2012; and de la Fuente *et al.* 2016).

According to Pardo-Bosch & Aguado (2015), the configuration of the decision model is divided into 4 stages. 1) Identification of a problem and the precise definition of the decision that has to be taken. 2) Development of the decision tree, a diagram (figure 1) that organizes and structures the concepts that will be evaluated (indicators). The classification is made through the criteria and requirements. (3) Defining the relative weight of each of the aspects that are to be taken into account in the decision tree using AHP (over time, these weights can be modified, but the structure of the decision tree should not be modified.). (4) Establishment of, for each indicator, a value function that in each case reflects the appraisal of the decision-maker. When the model has been developed, the decision-makers can assess as much projects as they want. They only have to evaluate each indicator (through the variables that defined them) and multiply their values, which are obtained by the value function, for corresponding weights, as the arrows show in figure 1.

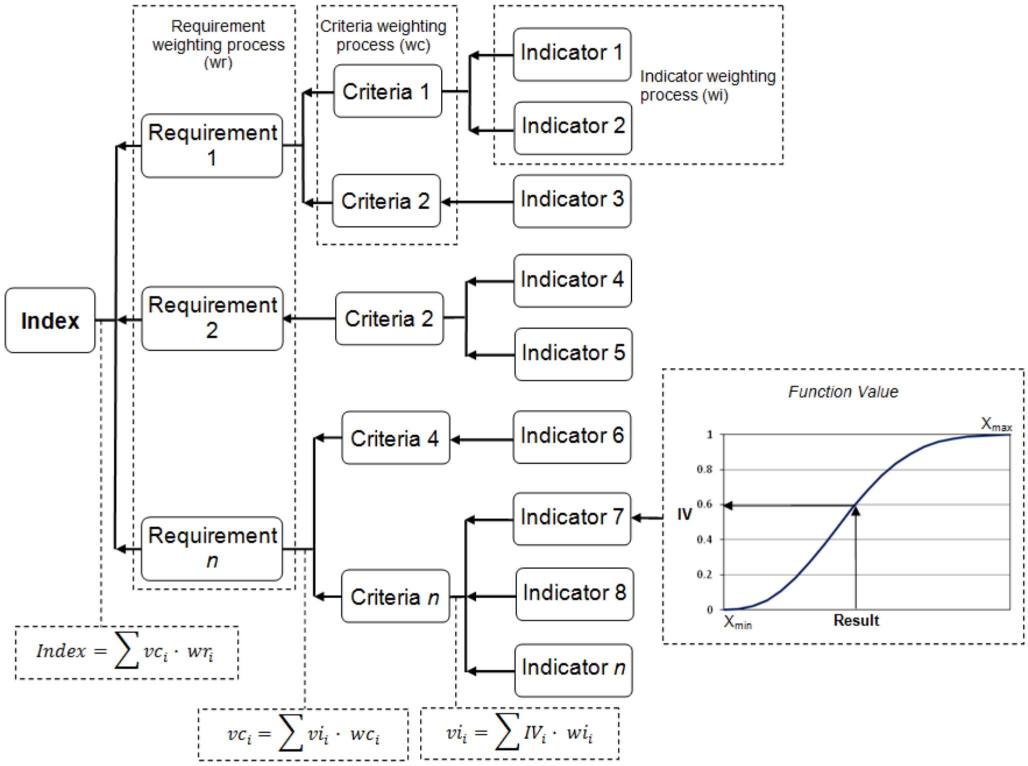

Figure 1. Theoretical structure of MIVES (Pardo-Bosch & Aguado, 2015)

The indicators are the only concepts of the tree that are evaluated, a task done with qualitative and quantitative variables, with different units and scales. That is possible thanks to the fact that the model embeds a mathematical function (value function) that allows the conversion of these variables to a unique scale from 0 to 1 (see figure 1). These values represent, respectively, the minimum and maximum degree of satisfaction of the decision-maker. The value function used by MIVES (equation 1) relies on 5 parameters, which are described in Alarcon *et al.* (2011), whose variation produces all kinds of functions: concave, convex, linear or S shaped, depending on the decision-maker.

$$\mathrm{VI_i} = \mathrm{B_i} * \left[1 - e^{-\mathrm{Ki}*\left(\frac{|\mathrm{x}-\mathrm{x}_{\mathrm{min}\,i}|}{\mathrm{C_i}}\right)^{\mathrm{P_i}}}\right] \tag{1}$$

where: X_{min} is the minimum x-axis of the space within which the interventions take place for the indicator under evaluation. X is the quantification of the indicator under evaluation (different or otherwise, for each intervention). P_i is a form factor that defines whether the curve is concave, convex, linear or an "S" shape. C_i approximates the x-axis of the inflection point. K_i approximates the ordinate of the inflection point. B_i is the factor that allows the function to be maintained in the value range of 0 to 1. This factor is defined by equation 2.

$$B_i = \left[1 - e^{-Ki*\left(\frac{|X_{max_i} - X_{min_i}|}{C_i}\right)^{P_i}}\right]^{-1} \quad (2)$$

Alternatively, functions with decreasing values may be used: i.e. they adopt the maximum value at X_{min}. The only difference in the value function is that the variable X_{min} is replaced by the variable X_{max}, adapting the corresponding mathematical expression.

3. Material and methods

3.1. Introduction to the decision model

As mentioned in section 2, the decision-makers have to evaluate very different projects, each with genuine structural and functional features. It is necessary to find a method to standardize and homogenize certain features to determine what actions have priority amongst others, considering that the decision is one only, because the institution that has to finance all projects is only one and with only one budget. For this reason, the decision process is divided in two stages (see figure 2), as presented in Pardo-Bosch & Aguado (2015):

- Phase 1, in which, regardless of the infrastructure nature, the need of materializing the project is homogeneously evaluated depending on several factors as: the territorial balance, the range of the problem, the degree of response to the service or the risk of not acting.
- Phase 2, in which the consequences derived from the implantation of the infrastructures in the territory are evaluated, giving as result a priority order in the Sustainability Index of Infrastructure (SIIP). In this phase, the result of phase 1is used to modify the value of some indicators.

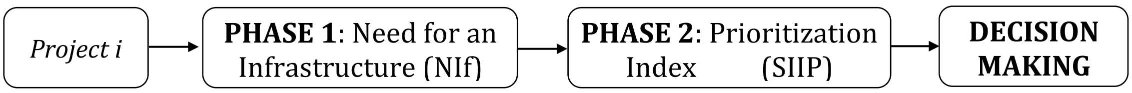

Figure 2. Decision's phases

3.2. PHASE 1: Need for an Infrastructure

A structural project should only materialize if it solves an existing problem in a certain territory. In order to evaluate how necessary an infrastructure is, the Need for an Infrastructure (NIf) has been defined. NIf is a new universal unit valid for any structural typology, which is measured with a semi-quantitative system. Measuring this variable allows the conceptual official approval of different structural typologies, making possible, from this moment on, their comparison, because NIf interprets the particular usefulness of each project as a general social necessity.

The NIf is evaluated with four independent variables that, in spite of having a generic nature, ensure the accuracy and representation that an analysis of this sort needs. Each one of them responds to a strategic question, as shown in figure 3. As Williams (2009) recommends, the score assigned to each variable (treated as attributes) can vary between 1 and 5 points. As they are independent variables, their scores are not conditioned by the others ones.

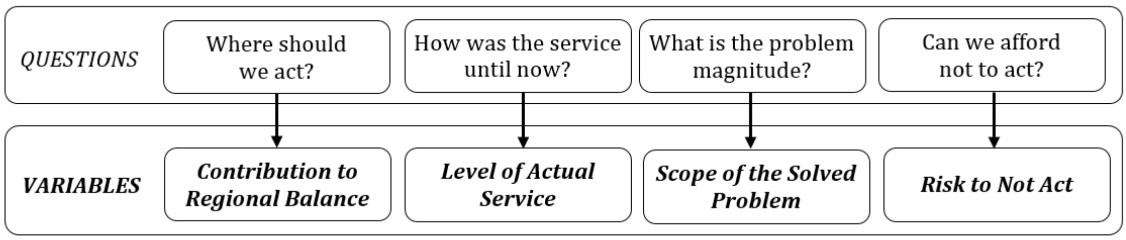

Figure 3. Phase 1. Variables that define the Need for an Infrastructure (NIf)

3.2.1. Contribution to Regional Balance (CRB)

The Contribution to Regional Balance (CRB) evaluates how the degree of investment in public construction in a certain zone (city or county) has been in the last ten years. The degree of investment is based on the importance of the zone (population, area, GDP) within the territory (region or state). The lower the investment, the higher the score. As some zones have had more investments in infrastructures for undefined reasons, favoring somehow their development, this variable tries to readjust the investments, planning the upcoming infrastructures in the neglected areas, because, as Mory & Christodoulou (2012) point out, social sustainability has to be based on equal opportunities. Thus, wealth distribution becomes more homogeneous. To obtain the CRB score (table I), the Zone Inversion Deficit (ZID) needs to be calculated, as shown in equation 3 and, the bigger the ZID, the higher the CRB score.

$$ZID = \left(1 - \frac{\frac{IPI_Z}{IPI_T}}{\frac{Pop_Z}{3 \cdot Pop_T} + \frac{Ext_Z}{3 \cdot Ext_T} + \frac{GDP_Z}{3 \cdot GDP_T}}\right) * 100 \qquad (3)$$

where IPI is the public investment in infrastructures in the last ten years (10 years are more than two terms, so it's possible to correct political bias of one government), *Pop* is the population, *Ext* is the area and GDP is the Gross Domestic Product. Sub-index *Z* refers to the zone where the new infrastructure would be located and sub-index *T* includes all territory.

Table I. Variables to evaluate NIf

Variable	**Zone Inversion Deficit**	**Points**
CRB	55 % < ZID	5
	35 % < ZID ≤ 55 %	4
	15 % < ZID ≤ 35 %	3
	- 5% < ZID ≤ 15 %	2
	ZID ≤ - 5 %	1

Variable	**Accessibility**	**Maintenance State**	**Points**
ASt	>2 hours	Ultimate Limit State	5
	1 < hours ≤ 2	Service Limit State	4
	30 < min ≤ 60	Minor Defects	3
	10 < min ≤ 30	Esthetic Defects	2
	10min ≤	Without Defects	1

Variable	**Level of use**	**Demand/Offer (D/O)**	**Points**
ASa	Very Saturated	D/O > 100 %	5
	Saturated	80% < D/O ≤ 100%	4
	Right	60% < D/O ≤80%	3
	Underused	40% < D/O ≤ 60%	2
	Very Underused	D/O ≤ 40%	1

Variable	**Attribute**	**Users**	**Points**
PoS	Country	>3 million people	5
	State	500,000 < people ≤ 3 million	4
	County	100,000 < people ≤ 500,000	3
	Intercity	50,000 < people ≤ 100,000	2
	City	people ≤ 50,000	1

Variable	**Type of Service**	**Points**
SeI	Fundamental	5
	Main	3
	Secondary	1

Variable	**Risk**	**Points**
RNA	Big	5
	Normal	3
	Small	1

3.2.2. Level of Actual Service (LAS)

The variable evaluates how a service has been executed until the moment when the public administration proposes the construction of the new infrastructure. It is very important to consider that this variable evaluates the service and not the system by which the service is provided. Two concepts are taken in account: *Alternative State* (ASt) and *Alternative Saturation* (ASa), which are combined as shown in equation 4. If there is not an alternative service, this variable will be directly evaluated with 5 points.

$$LAS = 0{,}5 \cdot ASt + 0{,}5 \cdot ASa \tag{4}$$

The *Alternative State* (ASt) evaluates the level of service that the old infrastructures offer in the studied area. To evaluate this variable two concepts are considered (picking the one which has greater scoring), on one hand the time spent by the user to get to the infrastructure that provides the service and, on the other hand, the current condition of the infrastructure. The possible scores are described in table I. In order to define the accessibility interval time in table I, it is necessary to note that the considered territory has an area of 32,000 km^2 and a population density of 233,92 people/km; this could easily be modified to adapt it to the features of another territory.

The *Alternative Saturation* (ASa) evaluates the functional quality of the service offered (table I). In this case, the degree of exploitation of the existing infrastructure is analyzed, confronting the demand and offer. Indicators as this one are very common in transportation infrastructure studies as shown in Tsamboulas (2006).

3.2.3. Scope of the Solved Problem (SSP)

The variable evaluates the scale of the problem solved by the infrastructure to be built. Two different concepts are measured: *Population Served* (PoS) and *Service Importance* (SeI), combined as presented in equation 5.

$$SSP = 0{,}5 \cdot PoS + 0{,}5 \cdot SeI \tag{5}$$

The *Population Served* (PoS) evaluates the population that can benefit with the new service. The more people can use the infrastructure, the greater the score, as shown in table I. To establish the user interval in table I, we are considering a population of 7 million people. Also, in this case, this could be modified to adapt it to the features of other territories.

The *Service Importance* (SeI) evaluates how important the service offered with the new infrastructure is. The services can be divided in three categories: fundamental (essential for the population welfare: education, health and security), main (all that are not fundamental and not secondary) and secondary (unnecessary, focused on leisure activities and in improving of existing public goods). Its scores are showed in table I.

3.2.4. Risk to Not Act (RNA)

This variable tries to evaluate the economic consequences or damage that a territory can suffer, including its population, if a certain investment is not made at a specific time (lost opportunity cost). The bigger the losses or damages incurred from not acting, the bigger this variable's score is. The risk of not acting is very high when the evaluated project is considered to be strategic in a time period below 5 years. The risk of not acting is normal when the evaluated project is considered not to have direct short-term economic consequences, in spite of having them over the long term (15 - 20 years). The risk of not acting is irrelevant or very low when the evaluated project does not have much interest besides satisfying several voters. Its scores are showed in table I.

3.2.5. NIf value

The final value of Need for an Infrastructure (NIf(P_x)) is calculated with the sum of the variables CRB, LAS, SSP and RNA, as shown in equation 6, where each one has an associated weight based on its relative importance. To calculate these weights, the analytic hierarchy process (Saaty, 1980) has been applied by a group of experts.

$$\boldsymbol{NIf(P_x) = 3,5 \cdot CBR(P_x) + 2 \cdot LAS(P_x) + 3,5 \cdot SSP(P_x) + 1 \cdot RNA(P_x)} \tag{6}$$

3.3. PHASE 2: Sustainability Index of Infrastructure Projects (SIIP)

The Sustainability Index of Infrastructure Projects (SIIP), which is calculated in stage 2 of the decision making process (see figure 3), evaluates through the decision making tree (see figure 4) the degree in which each infrastructure would contribute to the sustainable development of one territory if it was built. The assessment is made with a deterministic approach, but, as shown in del Caño *et al.* (2012), it is possible to do it with a probabilistic one.

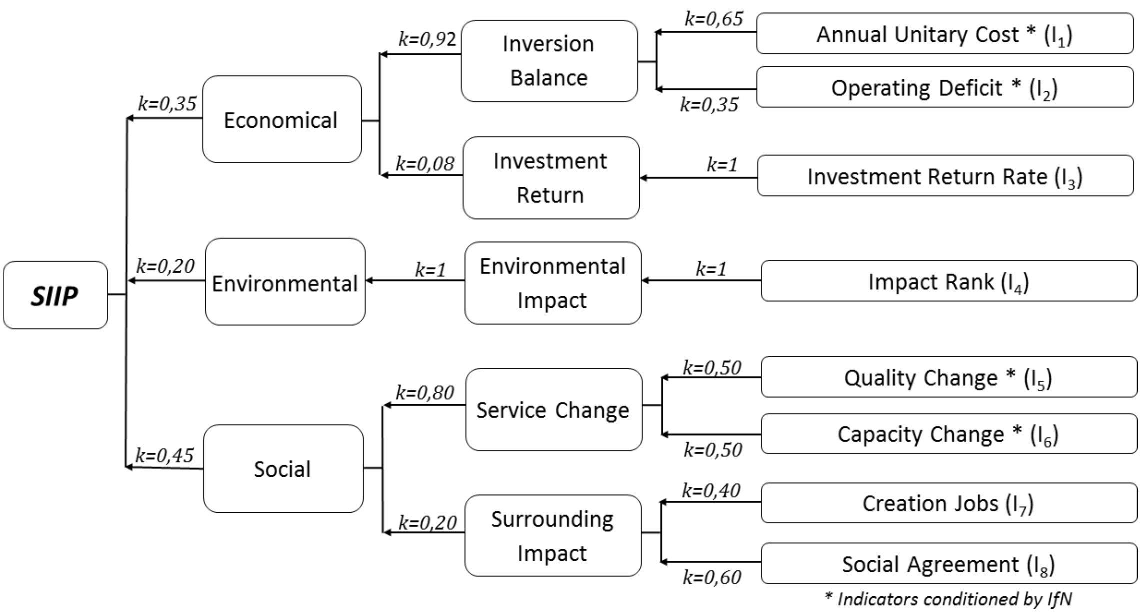

Figure 4. Decision tree for SIIP

As can be seen in figure 3, the three requirements of the decision tree are the three axioms of the sustainability, because the consequences (positive and negatives) of each project will be economic, environmental and social.

The *Economic Requirement* evaluates the use given to the limited economic resources of the decision-makers. Executing a project 'A' can mean not executing project 'B', so public administrations should strive for maximum yield. For this reason, the project expenses are considered (criteria: investment balance) on one hand and, the profit (criteria: investment return) on the other.

The *Environmental Requirement* considers the capacity of the project to preserve the environment (natural and constructed) in which the new infrastructure should be located. The goal is to promote those projects that encourage this preservation.

The *Social Requirement* evaluates the consequences (direct or indirect) that an infrastructure could generate in people that use or live with it. With the aim of having a complete analysis, this requirement evaluates the service offered (criteria: service changes) and the collateral impact that can affect citizens (surrounding impact).

The final result of SIIP for each project is calculated with the sum of each indicator, $IV_j(P_{i,x})$, weighted on three levels, integrating the relative weight of each indicator (k_{I_j}), criteria (k_{C_y}) and requirement (k_{R_t}), as shown in the decision making tree in figure 1, as well as in equation 7. The weights are calculated by adjusting the obtained values with the Analytic Hierarchy Process (AHP) (Saaty 1980). In this case, the greatest weight corresponds to the social requirement because, after all, the most important mission of public institutions is satisfying the needs of their citizens, who pay the taxes that allow project funding. Note that the environmental requirement weight is low because only the projects considered as compatible (negative environmental impact really low) are accepted; therefore, a very strict selection has been made beforehand.

$$\mathrm{SIIP}\ (\mathrm{P}_x) = \sum \mathrm{k}_{\mathrm{R_t}} \cdot \mathrm{k}_{\mathrm{C_y}} \cdot \mathrm{k}_{\mathrm{I_j}} \cdot \mathrm{IV_j}(\mathrm{P}_x) \qquad (7)$$

The score of the indicators marked with an asterisk (*) in the decision-making tree shown in figure 3 (I_1, I_2, I_5 and I_6) are conditioned, as shown in following subsections, by the variable NIf. Thus, the two stages in the decision making process are integrated.

Thanks to the SIIP, *n* number of projects can be evaluated, where each one of them receive a value between 0 (not important) and 1 (very important); a result that allows sorting and prioritizing with a clearly objective and transparent guideline. The contribution of the different evaluated projects to sustainability can be classified according to the SIIP in the five levels presented in table II. Level "A" represents the maximum contribution to sustainability. This is a very intuitive classification system that, in other fields, has been applied by different international institutions, as shown in ICE (2010) and ASCE (2013). In normal situations, the projects should be classified between groups "B" and "D". A project will hardly get a score over 0.8 because the model is very demanding. At the same time, it is unlikely that the score is very low (level “E”) because projects that could get this consideration are rejected beforehand for their obvious lack of contribution to sustainable development.

Table II. Levels of SIIP to classify the projects

Level A	Level B	Level C	Level D	Level E
1≤SIIP<0,8	0,8≤ SIIP <0,6	0,6≤ SIIP <0,4	0,4≤ SIIP <0,2	0,2≤ SIIP <0

With the aim of giving traceability to the presented methodology, then the authors describe the 5 criterion and the 8 indicators that make up the decision tree. All these elements define a set with the properties that Keeney & Raiffa (1993) claim that every decision-making method should have. This means that the set is complete, operational, decomposable, non-redundant and minimal. The variables are also discriminant, comprehensive and measurable. A variant of the generic function of the MIVES model (Equation 1) is proposed for each indicator, in order to calculate the value of the indicator (VI_i) in each case, thereby setting equivalences between the different units that they present. Appendix A presents the coefficients that allow us to define the value function of each indicator in Figure 3. The coefficients were chosen by consensus within a group of experts from both the public and the private sectors.

3.3.1. Inversion balance criterion

In technically economic terms (not financial), when an infrastructure is built, one of three strategies can be chosen, as shown in figure 5 with corresponding letters “X”, “Y”, and “Z”. Strategy “X” consists of making a strong initial investment and developing a ‘high quality product’, so the maintenance is reduced to a minimum and future government budgets are not put at risk. Strategy “Y” makes an initial investment that guarantees quality, but it will require substantial maintenance. Finally, strategy “Z” makes a minimum initial investment, obtaining a ‘low quality product’ that requires huge maintenance expenses to guarantee the same lifetime as the other two methods.

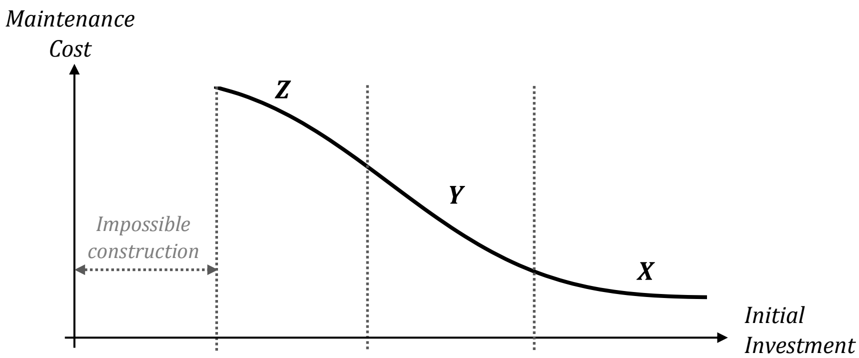

Figure 5. Initial investments strategies

To take into account all different factors that determine these strategies, two indicators have been developed: *Annual Unitary Cost* and *Recurring Cost*.

The *Annual Unitary Cost* (AUC), based on an indicator of Pardo-Bosch & Aguado (2014), establishes a relation between the initial investments (InI), the Need for Infrastructure (NIf parameter) and the expected lifetime (LT) of the infrastructure, as shown in equation 8 in table III. The bigger the NIf and longer the lifetime, the better investment.

The *Recurring Cost* (ReC) assesses the Operation Cost (OpC) that the public administration will have to pay every year to ensure the proper functioning of the infrastructure. It can be divided in two different costs (equation 9 in table III), the maintenance (MaC) and the production (PrC). The NIf is also incorporated to take into account the public service.

Table III. Equations to calculate each indicator

Indicator	**Equation**	**Nº**
Annual Unitary Cost	$\mathrm{AUC} = \frac{\mathrm{InI}}{\mathrm{LT} \cdot \mathrm{NIf}}$	[8]
Recurring Cost	$\mathrm{ReC} = \frac{\mathrm{OpC}}{\mathrm{NIf}} = \frac{\mathrm{MaC} + \mathrm{PrC}}{\mathrm{NIf}}$	[9]
Inversion Profit	$\mathrm{IPr} = \mathrm{PPA} + \mathrm{PCz}$	[10]
Impact Rank	$\mathrm{ImR} = \frac{\mathrm{EIE}}{\mathrm{Max(EIE)}} \cdot 100$	[11]
Quality Change	$\mathrm{QuC} = \left(\sum_{i=1}^{5} \mathrm{ImF_i}\right) \cdot \mathrm{NIf}$	[12]
Capacity Change	$\mathrm{CpC} = \frac{\Delta\ \mathrm{Capacity}}{\mathrm{Old\ Capacity}} \cdot 100 \cdot \mathrm{NIf} = \mathrm{CpV} \cdot 100 \cdot \mathrm{NIf}$	[13]
Creation Jobs	$\mathrm{CrJ} = \frac{\mathrm{JCo} \cdot \mathrm{t}}{\mathrm{LT}} + \mathrm{JOp}$	[14]

3.3.2. Investment Profit

Public administration, because of its mandate to serve citizens, should execute projects that, in many cases, won't have a return big enough to satisfy the private sector; and that is why classic indicators such as IRR or NPV (they would always be negative in these projects) cannot be used. This does not mean that the investments should not yield maximum returns. To consider this factor an indicator has been developed: Investment Profit.

The Investment Profit (IPr) gives value to the profit (real and virtual) that the infrastructure can generate both for the public administration (PPA) and for the citizens (PCz), as shown in equation 10 in table III. In case of lack of data, this indicator is evaluated by attributes (see table IV). In case of doubt, 2 and 4 points can be assigned.

Table IV. Scores of variables PPA and PCz

Level of profit	P. P. Administration (PPA)	P. Citizens (PCz)	Points
Very high	Income and Saving	Saving (time and money)	5
Normal	Saving	Saving time	3
Insignificant	Without profit	Without profit	1

3.3.3. Environmental impact criterion

The effects that an infrastructure can have on population, fauna, flora, landscape, climate, water, cultural heritage, etc. need to be studied. To do it, only one indicator has been defined: the *Impact Rank*.

The Impact Rank (ImR) typifies the environmental consequences that any project has on ensuring natural resource conservation and environmental protection. ImR uses the environmental impact assessment that all projects have to include in their project statement by law to obtain its score. In all developed countries, the Environmental Impact Evaluation (EIE), which was created by the National Environment Policy Act (United States Congress, 1969), is the base of this assessment. Even so, there are some differences on the results among countries, because each county has its own laws to regulate these assessments, depending on their environmental sensibilities. In order to standardize the results (presented in different scales), ImR normalizes the scores on a scale from 1 to 100 (1 being the ideal score), according to equation 11 in table III.

In whatever case, according to this methodology, and regardless of local law, only projects defined as compatible (ImR $\leq$25) or moderate (25< ImR $\leq$50) will be considered. Those with severe (50< ImR $\leq$75) and critical (75< ImR $\leq$100) impact will automatically be rejected by SIIP.

3.3.4. Service change criterion

The last and main goal of any investment is to materialize a change in service offered to citizens, either directly or indirectly. The change can be produced in two different ways: the quality of the service offered can be increased or the amount of users of that service could be increased. To take those two options into account and without disregarding the possibility that both can happen at once, the indicators *Quality Change* and *Capacity Change* have been defined.

Quality Change (QuC) aims to evaluate how the infrastructure can modify the quality of the service that is being offered. The improvements can affect 6 different fields: security

(ImF_{sec}), accessibility (ImF_{acc}), comfort (ImF_{com}), time saving (ImF_{tis}), profitability (ImF_{pro}) and information and communication technologies (IMF_{ict}). A field of improvement (ImF) experiences a *Small* (1 point) quality improvement when it is imperceptible, in spite of the execution of the project in question. When the increase in quality becomes noticeable, but in an indirect way, the improvement level is *Medium* (3 points). Finally, when a decision is made for the purpose of improving a specific quality, it can be considered of a *Big* (5 points) quality improvement. The final *QuC* score can be obtained from equation 12 in table III, where only the 5 fields of improvement (ImF) with the highest score are considered.

Capacity Change (CpC) evaluates how an action can increase the number of users, vehicles or fluids that could use an infrastructure per unit of time, ensuring a minimum quality of service. Thus, for example, an extra lane can be added to a road, the diameter of a canal can be increased or a new school can be built. In order to calculate the CpC, equation 13 in table III is used. In the case the service offered is new, CpV will be equal to 1. If capacity is reduced, CpC will be null (CpC=0).

3.3.5. Surrounding impacts criterion

All infrastructures generate both profits and collateral damage to people who share the same area. To evaluate them, the following indicators have been defined: *Creation of Jobs* and *Social Agreement*, considered the most important amongst the group of possible impacts in civil society.

The Creation of Jobs (CrJ) refers to the job positions that would be created directly thanks to the construction (JCo) and operating (JOp) of the infrastructure, according to equation 14 in table III, where *t* is the estimated duration in years of the construction stage and *LT* the lifetime of the infrastructure. This kind of indicator appears in different papers, as for example on Lambert *et al.* 2012 and Veldhuizen *et al.* 2015.

The indicator Community Acceptance (CoA) evaluates the specific acceptance of projects by local stakeholders, particularly residents and local authorities (Wustenhagen *et al.*, 2007). Any construction that starts with little acceptance can generate several drawbacks that can represent a big outlay (interruptions, delays, changes in the project...) but also non-negligible social-political consequences. The score is determined by attributes, depending on the degree of acceptance of the project: Very High (5 points), High (4 points), Medium (3 points), Low (2 points) and Very Low (1 point).

4. Case Study - Results

The methodology shown has been used to evaluate 9 different projects that correspond to 9 very different infrastructures, especially in cost and utility, placed in different spots of an area greater than 30,000 km^2 and populated by 7,500,000 people. The evaluated projects are detailed in table VI. All of them had to be financed by budget of the same government, la Generalitat de Catalunya, which have done it through Infraestructures de la Generalitat de Catalunya S.A.U, even though they will be managed and operated by different departments.

The study of all the projects starts with the calculation of the Needs for an Infrastructure (NIf), corresponding to stage 1 of the evaluation. Table VII presents, for each of the 9 projects, both the final value of the NIf and the value of all the variables that allow its calculation. Taking in account that the NIf can range between 10 and 50 points, the selected projects are not very necessary because 8 out of 9 do not reach 30 points (which corresponds to the middle of the range).

Table VI. Case study: Proposed projects to evaluate

Ref.	**Name**	**Description**	**Cost (€)**
A	Metro line extension	2.8 new kilometers of rail and two new stations that will allow the connection of a big city with its airport	$5.24 \cdot 10^{8}$
B	Health Center	1800 m^2 municipal medical installation to offer the first level of medical assistance.	$3.20 \cdot 10^{6}$
C	Police Station	1585 m^2 construction to cater for a police station operating in a 500 km^2 area.	$2.50 \cdot 10^{6}$
D	Road conversion	13 km regional road in tourist area. From one-lane road to two-lane road.	$1.02 \cdot 10^{8}$
E	Bus lane	New 7.5 km integrated (centered) bus lane in local road to give access to a big city.	$3.1 \cdot 10^{7}$
F	Water treatment plant	Construction for the treatment of city waste water before returning it to the river (the resulting water not being potable)	$1.0 \cdot 10^{7}$
G	Transportation interchange complex	New metro station underground lobby. Intended to improve the connection (already existent) between two metro lines so accessibility and security requirements are in compliance.	$2.3 \cdot 10^{7}$
H	Road turnoff	1.5 km road surrounding a small town to avoid traffic going through it to improve public safety.	$5.9 \cdot 10^{8}$
I	Watering distribution network	An irrigation system to serve a 555 hm2 agricultural area transforming it from non-irrigated land into irrigated agricultural land, with the aim of recovering lost production in previous.	$4{,}1 \cdot 10^{6}$

Table VII. Case of study: NIf of each proposed projects

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
CBR	1	3	3	2	1	3	1	2	4
LAS (ASt/ASa)	4 (4,4)	3 (3/3)	4 (4/4)	4 (3/5)	5 (5/5)	5 (5/5)	4 (4/4)	3,5(4/3)	5 (5/5)
SSP (PoS/SeI)	4 (4/4)	3 (1/5)	3,5(2/5)	3 (3/3)	3 (2/4)	2 (1/3)	3 (3/3)	2 (1/3)	2 (1/3)
RNA	3	2	2	2	2	1	2	1	2
NIf	**28.5**	**29**	**32.75**	**27.5**	**26**	**28.5**	**24**	**22**	**33**

The second evaluation stage results are presented in table VIII. In this table, the score of the different variables used to obtain each indicator and the value of each indicator (IV_x) are shown. The last row shows the final value of the SIIP. Figure 6 presents, for each of the 9 projects, the value (from 0 to 1) of each indicator, before applying their weight. It is easy to see that the value of each indicator varies significantly depending on the project.

Table VIII. Case of study: SIIP of each proposed projects ($0 \leq SIIP \leq 1$)

		A	B	C	D	E	F	G	H	I
I_1	InI	$5.2{\cdot}10^8$	$3.2{\cdot}10^6$	$2.5{\cdot}10^6$	$1.0{\cdot}10^8$	$3.1{\cdot}10^7$	$1.0{\cdot}10^7$	$2.3{\cdot}10^7$	$5.9{\cdot}10^6$	$4.1{\cdot}10^6$
	LT	50	50	50	75	50	25	25	25	30
	AUC	$3.6{\cdot}10^5$	$2.2{\cdot}10^4$	$1.5{\cdot}10^4$	$4.9{\cdot}10^4$	$2.4{\cdot}10^4$	$1.4{\cdot}10^4$	$3.8{\cdot}10^4$	$1.0{\cdot}10^4$	4165.9
	IV_{AUC}	**0**	**0.97**	**0.98**	**0.28**	**0.65**	**0.80**	**0.43**	**0.85**	**0.94**
I_2	OpC	$1.3{\cdot}10^6$	$7.1{\cdot}10^5$	$6.7{\cdot}10^5$	$6.2{\cdot}10^5$	$3.7{\cdot}10^5$	$7.6{\cdot}10^5$	$1.1{\cdot}10^6$	$5,9{\cdot}10^4$	$2.6{\cdot}10^5$
	ReC	$4.5{\cdot}10^4$	$2.4{\cdot}10^4$	$2.0{\cdot}10^4$	$2.2{\cdot}10^4$	$1.2{\cdot}10^4$	$2.6{\cdot}10^4$	$4.8{\cdot}10^4$	$2.6{\cdot}10^3$	$7.9{\cdot}10^3$
	IV_{ReC}	**0.15**	**0.50**	**0.58**	**0.54**	**0.75**	**0.46**	**0.12**	**0.94**	**0.84**
I_3	PPA	4	1	1	1	3	1	2	1	3
	PCz	4	2	2	5	4	1	2	3	1
	IPr	8	3	3	6	7	2	4	4	4
	IV_{IPr}	**0.87**	**0.22**	**0.22**	**0.69**	**0.79**	**0**	**0.41**	**0,41**	**0.41**
I_4	ImR	7	15	6	9	15	0	0.34	50	15
	IV_{ImR}	**0.85**	**0.58**	**0.88**	**0.80**	**0.58**	**1**	**0.05**	**0**	**0.58**
I_5	ImF_1	5	5	5	5	5	3	5	5	5
	ImF_2	5	3	5	5	5	3	3	5	3
	ImF_3	5	1	3	5	5	1	3	5	3
	ImF_4	5	1	3	5	5	1	3	3	1
	ImF_5	1	1	1	1	1	1	3	1	1
	QuC	598.5	319	556.75	577.5	546	256.5	408	418	429
	IV_{QuC}	**0.57**	**0.18**	**0.52**	**0.55**	**0.50**	**0.11**	**0.30**	**0.32**	**0.33**
I_6	CpV	100	0	100	100	100	0	15	0	35
	CpC	2850	0	3275	2750	2600	0	360	0	1155
	IV_{CpC}	**0.75**	**0**	**0.81**	**0.73**	0.71	**0**	**0.14**	**0**	**0.39**
I_7	JCo	439	12	12	100	57	15	120	20	20
	t	4	1.25	1.25	3.3	2	1.5	3.3	1	0.75
	JOp	30	2	10	5	2.28	3	0	0	2
	CrJ	65.1	2.3	10.3	9.4	0	3.9	15.84	0.8	2.5
	IV_{CrJ}	**0.68**	**0.03**	0.15	**0.14**	**0.03**	**0.06**	**0.2**	**0.01**	**0.04**
I_8	CoA	4	4	5	4	4	4	5	3	4
	IV_{CoA}	**0.75**	**0.75**	**1**	**0.75**	**0.75**	**0.75**	**1**	**0.50**	**0.75**
SIIP		**0.52**	**0.46**	**0.76**	**0.57**	**0.62**	**0.48**	**0.27**	**0.38**	**0.60**

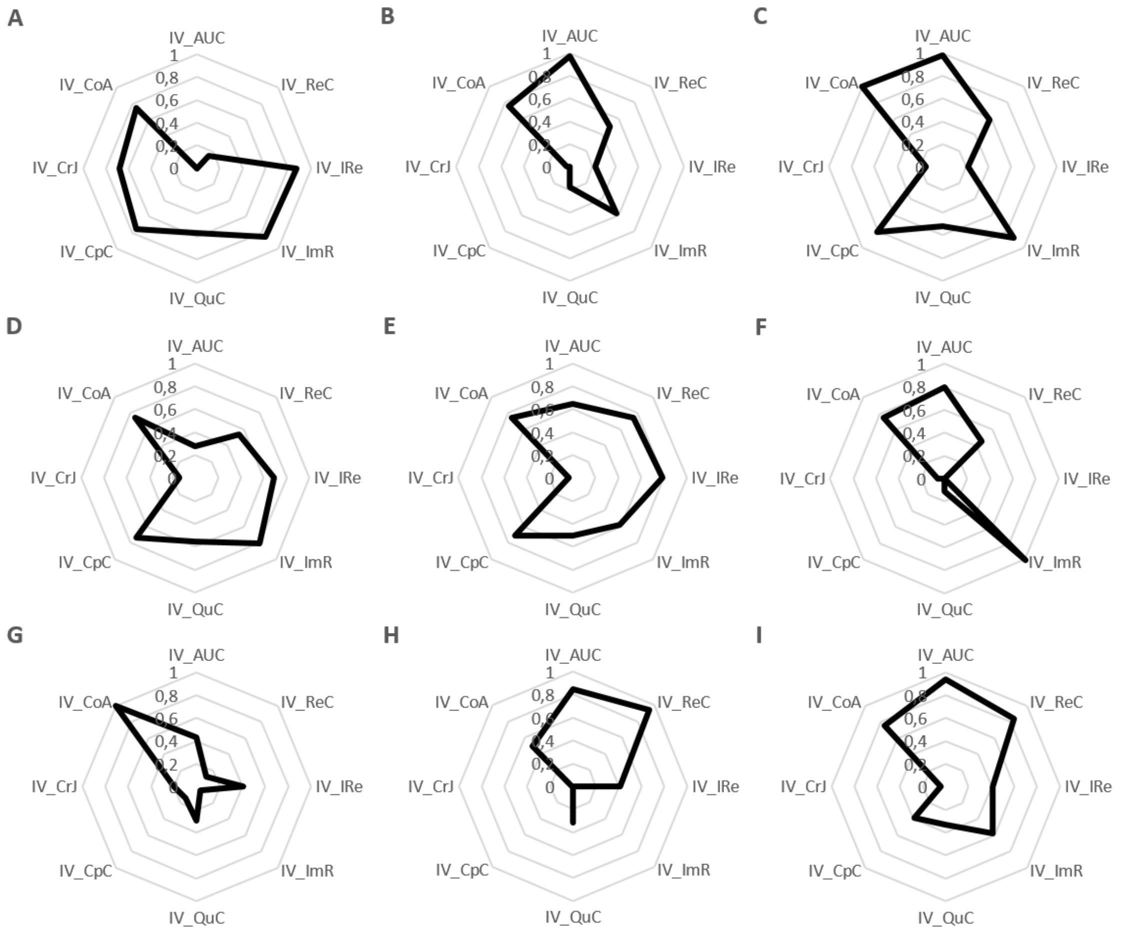

Figure 6. Indicators value (from 0 to 1) for each project

Figures 7 and 8a show the visualization of the result. In figure 7 the numerical contribution of each requirement in the final SIIP score can be seen. The results presented in figure 7, where it is possible to see the value of the three main dimensions of sustainability of each project, are calculated dividing the assessment into three different parts (one for each dimension of the sustainability). In order to calculate each sustainability dimension, its necessary to add up the value of the indicators located in the corresponding requirement (see figure 4), multiplied each one by its own weight, by the weight of its criteria and by the weight of that requirement. For example, to assess the economic dimension, the decision makers have to multiply the weight of this requirement by the summation of the value of the indicator CUA (multiplied by its own weight and by the weight of the Criteria Inversion Balance), the value of indicator ReC (multiplied by its own weight and by the weight of the same Criteria) and the value of indicator IPr (multiplied by its own weight and by the weight of the Criteria Investment Return). Moreover, in figure 8a, the classification of the projects based on SIIP is shown.

The classification obtained with the SIIP allows differentiation, as proven by the Coefficient of Variation ($CV = \sigma/|\bar{x}|$) of 0.27 (which is bigger than 0.25 (Morales, 2008)), which means that the scores are different enough so the decision-maker can choose the most sustainable projects. In this case, it is certain that project “C” (Police Station) will contribute to sustainable development if it is materialized. In the same way, projects “E” (Bus Lane) and “I” (Watering Distribution Network) are also very interesting. On the other hand, projects G

(Transportation Interchange Complex) and H (Road Turnoff) should not materialize with the present conditions.

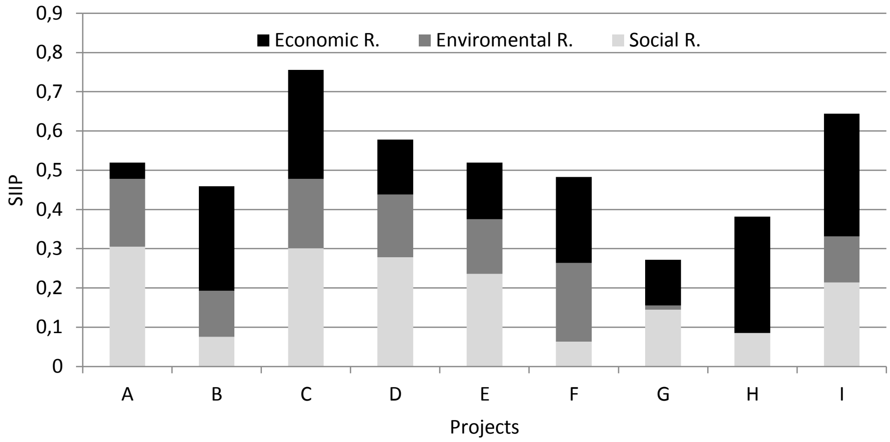

Figure 7. SIIP of each project

It is important to note the 4th position of project "D" (Road Conversion). It presents quite a high score (0.57), in spite of being the second most expensive project. It means that expensive projects will be materialized if they are appropriately justified.

To conclude with this section, figure 8b presents a comparison between the classification obtained by the SIIP and the classification obtained if the prioritization was made using NIf (meaning using only the first stage results). As seen in the plot, the position changes are very considerable (the change produced in project E being the most significant, which differs from 2nd position to 7th out of 9 projects in total). This proves that both stages of evaluation are necessary.

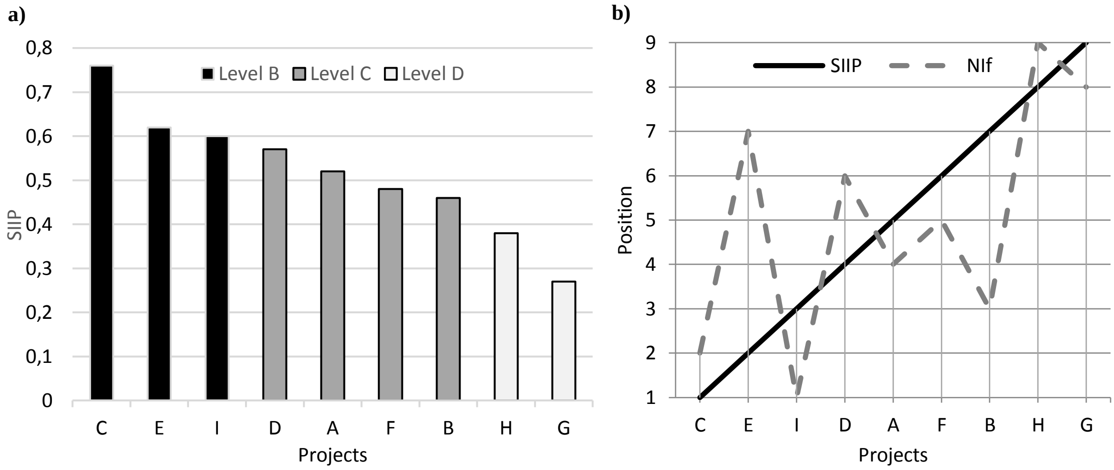

Figure 8. a) Prioritization order of projects; b) Order SIIP vs Order NIf

5. Discussion

Sensitivity analysis are essential in any multi-criteria decision-making tool. These studies involve changing the value of variables to determine the impact that they can have on the final outcome (French, 2003).

In this case, to do this study, three new alternatives are presented, which have been obtained from the weight change of the requirements of the decision tree (see table IX). Alternative 1 (A1) and (A2) are two combinations of weights considered consistent. Alternative 3 (A3) is a combination that could be described as absurd.

Table IX. Weight of the requirements in each alternative

	Social	**Environmental**	**Economic**
Original Weight	0,45	0,20	0,35
A1	0,33	0,33	0,33
A2	0,60	0,20	0,20
A3	0,10	0,10	0,80

In A1, all requirements have the same weight, i.e. 33.3%. In A2, the weight of social requirement rises to 60%, so it increases its value by 15%. This 15% is lost on the economic requirement, so its final weight is 20%. In this alternative (A2) the weight of the environmental requirement remains unchanged. In A3 the weight of social and environmental requirement is only 10%, and the weight of the economic requirement is 80% (representing an increase of approximately 130%).

Table X shows the value of SIIP obtained for each project depending on the alternative studied (the original SIIP is also presented to facilitate comparison). In the same table, final classifications are shown. To facilitate the interpretation of these results, see figure 9. As expected, A1 and A2 alternatives present very similar results as the original study, so the robustness of the model is demonstrated at least on the consistent cases (A1 and A2).

Table X. Results of the sensitivity analysis

		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Original Weight	SIIP	0,52	0,46	0,76	0,57	0,62	0,48	0,27	0,38	0,6
	Position	5	7	1	4	2	6	9	8	3
A1	SIIP	0,54	0,50	0,77	0,60	0,61	0,58	0,23	0,34	0,60
	Position	6	7	1	4	3	5	9	8	2
A2	SIIP	0,60	0,37	0,73	0,60	0,60	0,41	0,26	0,28	0,52
	Position	4	7	1	5	2	6	9	8	5
A3	SIIP	0,25	0,68	0,79	0,46	0,67	0,62	0,30	0,69	0,79
	Position	9	4	2	7	5	6	8	3	1

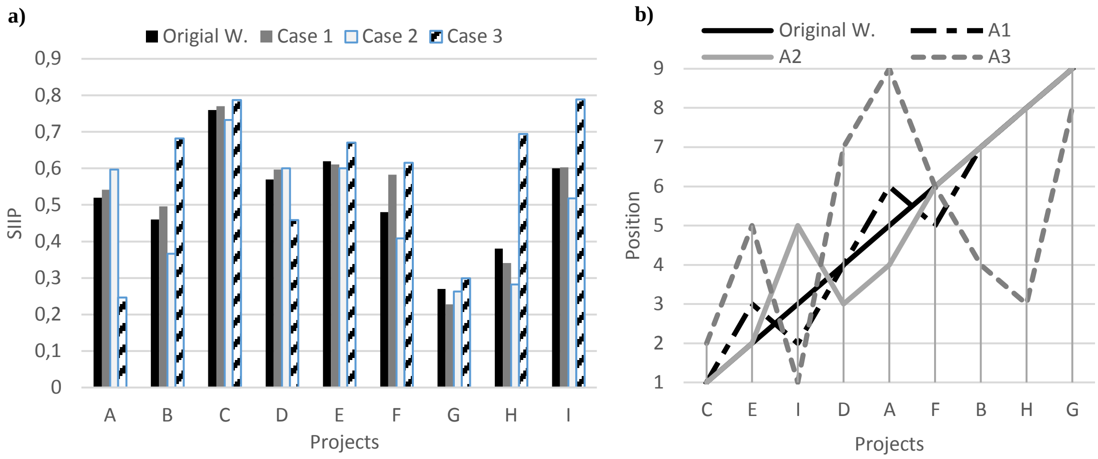

Figure 9. a) SIIP value for each projects in each alternative;
b) Classification of each alternative

The case of A3 is different. The result evokes significant changes in both the scores and the classification. This can be seen in figure 8. Therefore, although the model has performed robustly when the changes in the weights are logical, this result shows that the model is sensitive to significant changes in the weights, modifying the scores and therefore the final classification.

In this section, it is also important to compare SIIP and the models presented by Ziara *et al.* (2002) and Lambert *et al.* (2012), which are very important because they were the first to have been developed in this field, although there is some evidence showing that SIIP is different and an advanced model. The most important differences is that Ziara *et al.* (2002) and Lambert *et al.* (2012) were developed to prioritize investments in developing countries, and the SIIP has been developed to prioritize investments in developed countries, as it has been mentioned throughout the paper. Moreover, SIIP uses more variables than the other two models. Both Ziara *et al.* (2002) and Lambert *et al.* (2012) use only one variable to assess all their indicators, so they only use 6 and 14 variables respectively, while SIIP uses 30 variables to assess each project. Otherwise, SIIP, like the model of Lambert *et al.* (2012), presents a discriminant result (Cv = 0.27), therefore it facilitates the prioritization of the assessed projects. Finally, another important difference is that SIIP can evaluate projects with very different costs (€ 4 million - € 520 million) instead of Ziara *et al.* (2002), which compare projects with very similar costs (€ 160,000 - € 550,000).

6. Conclusions

The defined methodology allows prioritizing with technical rigor all kind of public infrastructure projects (in different areas, with different costs or territorial impacts) that one administration has to finance with only one budget in a developed country. This multi-criteria decision model based on MIVES will minimize the subjectivity in the entire decision-making process. Sustainable development is, at all times, the main argument that guides the process through the decision tree requirements: economic, environmental and social.

The great contribution of SIPP is that it allows the evaluation of projects that are not easily compared such as hospitals, schools, roads, hydraulic structures, bridges, metro lines... This is possible thanks to the concept of NIf (phase 1), which interprets the particular usefulness of each project as a general social necessity. This attribute converts the SIIP into a very innovative system. The analysis of each project is very exhaustive and complete, even so the study of one project (if it is done by an expert) is simple and fast, and does not require difficult calculations. Moreover, to run the model is not necessary a complex software. SIIP can be implemented in software such as Microsoft Excel or a similar one.

The case study has showed a very accurate and consistent result. The method can be adapted simply if the decision-makers criteria changes by modifying the weights and value functions assigned. Moreover the robustness of the proposed approach allows its application in other countries, regions, or cities.

Using SIIP, governments will be more transparent, at a time in which this is a very important quality for public administrations to have, because the decision model has been defined without knowing beforehand the projects that will be evaluated, so the results won't be able to be manipulated.

There is still a long way to go, but methodologies such as SIIP will help to build the base to achieving a better future. The administration that implements the SIIP to decide which projects should be executed will be able to line up with strategic plans, which promotes a sustainable and inclusive growth as is the case with Strategic Euro 2020. Furthermore, those administrations will give added value to its construction policies because the resources will be optimized. In addition, the implementation of a policy of this sort will allow the government to be more transparent and to justify the decisions that they make. This, without hesitation, would help to regain the credibility of the political class.

In order to end the conclusions, it is interesting to emphasize the following final remarks about the Sustainability Index of Infrastructure Projects (SIIP):

- Phase 1 (homogenization) based on the NIf concept is a key to perform the analysis using a single decision tree. The variables that conform the NIf (Contribution to Regional Balance, Level of Actual Service, Scope of the Solved Problem and Risk to Not Act) give value to the utility of the infrastructure.

- In spite of the importance of phase 1, the SIIP cannot be understood, as seen in the case study, without phase 2 where consequences are evaluated. In this sense it is very important to emphasize that all analyzed variables contribute to having a global vision of the project and any single variable (regardless of its value) conditions in itself the result of the prioritization.

- The weights of the different components of the decision tree can be modified according to the philosophy or political principles of the institution, which has to make the decision. Therefore, the method can be adapted to different necessities without having to modify the decision tree.

- Furthermore, and thanks to how the different variables have been defined (both in stage 1 and 2) the methodology can adapt to any territory, without introducing any big changes (only the accessibility range in ASt, and users range in PoS).

- Projects that come from different institutions or projects that have to be financed with different budgets cannot be assessed with the same run of model.

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Appendix A. The value function, their parameters and shapes

The shapes of the functions are the result of the opinions of a panel of expert with different profiles. If the needs of the decision-makers change, It is possible to adapt or correct the shape of these functions.