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Sustainability assessment of three districts in the city of Donostia through the NEST simulation tool

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Abstract

Nowadays, urbanists are facing increasing demands regarding the performance of urban development projects in terms of environment, quality of life and socio-economic issues. In order to address these increasing demands, actors involved in urban development projects need tools capable of assessing their impacts. These tools should also enable the comparison of all potential scenarios. Taking into account these needs, Nobatek and Tecnalia have developed NEST (Neighbourhood Evaluation for Sustainable Territories), which is one of the first tools that allows for a simultaneous environmental, economic and social analysis at the district scale, with a life-cycle perspective. Using NEST, the authors of this work carried out an environmental and social evaluation of three districts in the city of Donostia, in the framework of the Essai Urbain research project. The evaluation first consisted of analysing baseline environmental impacts of the three districts. Then, with the objective of reducing environmental impacts and increasing social well-being, the authors proposed several refurbishment scenarios for the studied districts, focusing on energy issues. The study was performed in close collaboration with the city of Donostia, which enabled the identification and selection of the most relevant scenarios from an environmental standpoint. Moreover, the NEST software has caught the attention of the project's stakeholders regarding environmental issues. Finally, NEST seems to be an interesting alternative in accounting for sustainable development issues from the early stages of urban development projects.

Keywords: Decision support tool; urban development projects; life-cycle assessment; district refurbishment.

1. Introduction

Energy security and climate change are driving a future that will require significant improvements in the energy performance of the building sector. The 28 Member States of the European Union (EU) have set an energy saving target of 20% by 2020, which will need to be reached mainly through energy efficiency measures. The EU has also committed to reduce greenhouse gas (GHG) emissions by 80–95% by 2050, as part of its roadmap for moving to a competitive low-carbon economy in 2050 (Directive 2010/31/EU, 2010). The building sector is one of the major sources of environmental impacts worldwide, including in the EU. The building stock is responsible for 40% of primary energy consumption, and for 25% of CO_2 emissions (International Energy Agency, 2014).

In this general context, urban planners are faced with a clear demand from both the public and private sectors for projects with increased environmental performance. This environmental performance is related to numerous interconnected issues such as: resource consumption, waste production, water consumption, GHG emissions, biodiversity protection, air quality, etc. To address most of these issues, the neighbourhood scale has been identified as a relevant scale (Charlot-Valdieu and Outrequin, 2012). It is the most operational scale for urban development projects, and it integrates key levers for urban eco-design. Indeed, this focus on the neighbourhood scale is guided by the need to address district scale levers in order to design buildings and neighbourhoods with higher environmental performances, as well as to address key issues, such as bioclimatic design, shared equipment, urban density and mobility. For instance, decisions made at the settlement level (orientation, compactness, urban density) largely affect heating/cooling loads, a major contributor in the energy balance of an urban area. Finally, it is already

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envisaged that the environmental and energy concerns currently researched at the building scale will soon be transferred to the neighbourhood scale (Oliver-Solà *et al.*, 2011).

As a consequence, urbanists are increasingly integrating environmental and energy efficiency parameters in the design of new districts and the establishment of district regeneration projects. Nonetheless, urbanists are not necessarily experts in these aspects. Consequently, the need for tools that allow for the assessment of these 'sustainable development' parameters appears to be increasingly crucial. Additionally, the inclusion of these parameters in the design stage also appears to be important for the design process. Depending on the purpose of the urban assessment, different Neighbourhood Sustainability Assessment (NSA) tools allow for the realization of different types of evaluations. These NSA tools can be classified in two categories. On one hand, NSA tools associated with Multi-Criteria Voluntary Sustainability Evaluation systems (MCVSE) are used. In order to boost the 'Green building' or 'Sustainable building' concepts, different MCVSE systems have been defined since 1990 to allow the end user to evaluate the overall performance of the building. Furthermore, MCVSE also has been increasingly used as a new benchmarking tool. Therefore, an increasing number of MCVSE systems have expanded their scopes from buildings to districts. Overall, their general structures and working philosophies are quite similar, though. Using different calculation systems, each MCVSE determines a score range for each evaluated parameter. Once the score is obtained for each parameter, the scores are summed or aggregated using a weighting system that allows the end user to receive a final score or rating. The increase in MCVSE systems is well-reflected in the increasing number of research works that analyse those systems (Hamedani and Huber, 2012; Lee, 2013; Schwartz and Raslan, 2013; Sharifi and Murayama, 2013; Braulio-Gonzalo *et al.*, 2015; Reith and Orova, 2015). The main aspects discussed in these works include the direct interrelation among evaluated parameters, the lack of standardization of a comprehensive set of criteria, and the metrics used. Hamedani and Huber (2012) have discussed the advantages and disadvantages of the German Sustainable Building Council (DGNB – Deutsche Gesellschaft für Nachhaltiges Bauen), Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) systems for the assessment of 'sustainable urban development strategies' and 'tools for sustainability assessment in urban communities'. Also, Schwartz and Raslan (2013) have shown that a similar case study building could achieve a considerably different rating in each system. The study carried out by Lee (2013) shows a comprehensive review and comparison of the issues and metrics of five representative qualitative evaluation systems: BREEAM, LEED, Comprehensive Assessment System for Built Environment Efficiency (CASBEE), BEAM Plus (Building Environmental Assessment Method) and the Chinese scheme Evaluation Standard for Green Building (ESGB). By means of a three-level comparison and an evaluation of the indicators used, the different NSA systems were compared in general, as well as in detail, during the study of Reith and Orova (2015). Braulio-Gonzalo *et al.*, 2015 presents a comprehensive analysis of 13 tools used to assess urban sustainability, both internationally and nationally, in a Spanish case study. This analysis reveals a wide difference in the approaches used by the different tools. Although most of the tools cover the majority of the categories proposed in the study, they all focus on physical and environmental issues, while generally overlooking social, economic and institutional issues. Finally, Sharifi and Murayama (2013) analysed seven tools with regard to underlying design, processes and procedures taken to measure sustainability performance. This study shows that despite having a similar approach to sustainability, there are significant differences in how these tools implement the approach. This large degree of divergence can be explained by differences in how, where, and why they have been developed and applied to neighbourhood development plans. Moreover, the process of criteria selection and weighting assignment is often subjective.

On the other hand, in order to avoid weightings and subjective assessment systems, other NSA tools rely on harmonized calculation methodologies, which allow a quantification of the impacts (environmental, economic and/or social) of one or more issues of the district. Depending on the evaluated issues or the considered system boundary, this paper highlights two main classifications: tools that quantify the impact generated by the different issues of a district during its use phase only (Table 1), and tools that quantify these impacts using a life-cycle perspective.

Finally, according to the European Commission (2014), "the life cycle methodology is currently the best framework available to assess the potential impacts of any activity, product or service without geographical, functional or time limits, since it quantifies the impact of the inputs and outputs along its whole life cycle, including the extraction of raw materials, production processes, use and end of life stages". Life Cycle Assessment (LCA) is standardized by International Organization for Standardization (ISO) 14040 (ISO, 2006a) and 14044 (ISO, 2006b) standards, and consists of four phases. The first phase allows for the definition of the goal and scope of the assessment. Basically, it consists of a description of the system to be studied and the methodology to be used. The second phase consists in realizing the Life Cycle Inventory (LCI). The LCI of a system is a list of all flows coming from the environment to the studied system, and all flows going from the system to

Table 1. Summary of issues considered by NSA tools focused on the use phase

	Energy buildings	Energy transportation	Energy water	Energy public lighting	Solid waste	Safety	Health	Quality of and home	Social cohesion	Economic vitality	Future value	Usage value	Urban mobility
DPL (Kortman *et al.*, 2001)	X					X	X	X	X	X	X		
GPR (Hulten, 2010)	X		X			X	X				X	X	
TRACE (Ranjan *et al.*, 2013)	X	X	X	X	X								
Transep-DGO tool (Krikke, 2011)	X												
DECA (District Energy Concept Advisor, 2015)	X												
CITYSIM (Robinson *et al.*, 2009)	X												
Termis (2015)	X									X			
WaterCAD (Bentley Systems, 2015)			X										
SUMO (DLR – Institute of Transport Systems, 2015)													X
Trans Modeler (Caliper, 2015)													X

the environment (air, water, soil emissions and waste production). The third phase aims at assessing the impacts of these flows by calculating the potential contribution of each substance to each predefined impact category. Once the impacts have been calculated, the fourth and final phase is the interpretation, in which the results of the calculations are summarized and discussed. Specifically for the construction sector, standards such as European Standard (EN) 15978:2011, (EN, 2011) already define the different phases of a building's life-cycle, as well as a number of indicators and methods to be used to calculate and declare the results of the analysis. Due to this standardization effort, tools such as Athena (Stek *et al.*, 2011), Bees (Rajagopalan *et al.*, 2012), Ecoeffect (Assefaa *et al.*, 2010), Eco-Quantum (Klunder, 2004), Equer (Rossi *et al.*, 2012), and Sofias (Oregi *et al.*, 2016) now allow for the evaluation of the performance of a building following a life-cycle approach.

Following this effort of standardization and tool development performed at the building level, the life-cycle methodology is now adapting to new evaluation levels through the development of new NSA tools that assess the different aspects of a district with the life-cycle approach. Out of these tools, this article highlights the NEST tool (Neighbourhood Evaluation for Sustainable Territories; Yepez, 2011), which is one of the first tools to evaluate the design of a new or refurbished district with a life-cycle approach.

Using NEST, the authors of this work carried out an environmental and social evaluation of three districts in the city of Donostia. The evaluation first consisted of analysing baseline impacts. Then, with the objective of reducing environmental impacts and increasing social well-being, the authors proposed several refurbishment scenarios for the studied districts, in line with Donostia's strategies for energy efficiency.

2. NEST – Neighbourhood Evaluation for Sustainable Territories

2.1. Presentation

Neighbourhood Evaluation for Sustainable Territories (NEST) was developed through a PhD thesis (Yepez, 2011) in Nobatek and the Groupe Recherche Environnement, Confort, Conception Architecturale et Urbaine (GRECAU) laboratory, and focused on the environmental assessment of eco-neighbourhoods. Currently, the development of this software is carried out between Nobatek and Tecnalia, French and Spanish research centers with extensive experience in assessing environmental, economic and social impacts of buildings and districts. In the beginning, the NEST tool was only used to assess the environmental impacts of a district. That has since changed, and different development phases are used to integrate economic and social impacts in the assessment.

Neighbourhood Evaluation for Sustainable Territories (NEST) is a plugin for Trimble SketchUp, which is the most used 3D modeler among urbanists and architects. Neighbourhood Evaluation for Sustainable Territories (NEST) analysis is performed directly on the 3D master plan of the neighbourhood, and performs the assessment of a set of indicators that was developed through a scientific approach to operational urban planning objectives. Therefore, NEST also presents a graphical and ergonomic interface, which is very useful for promoting analysis and action and confronting theory with reality.

In terms of system boundaries, four major neighbourhood components are taken into account by NEST. These components include buildings, land use (roads, parking, green spaces, etc.), infrastructure (public lighting), and daily mobility of neighbourhood users (inhabitants and non-resident workers). Furthermore, NEST is one of the

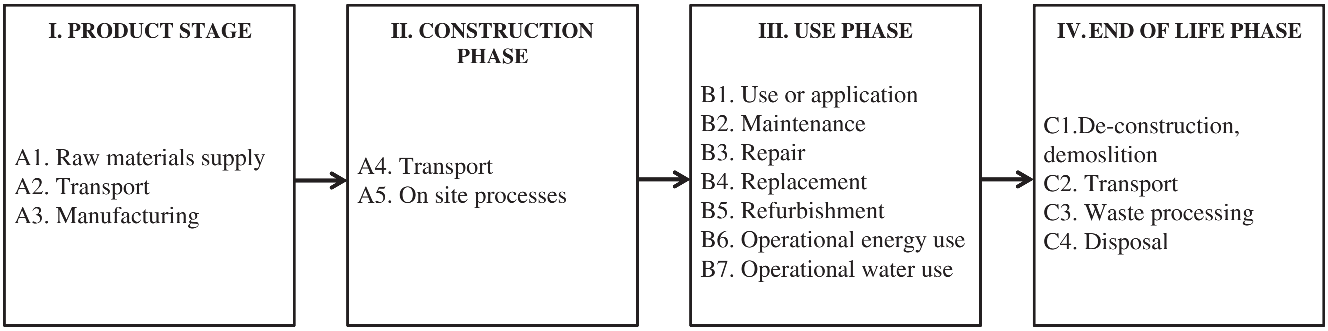


Figure 1. Different stages of the building according to EN 15978 standard (EN, 2011).

first tools that aims to assess the environmental impacts of neighbourhood scale projects, based on LCA methodology (social impacts are not currently evaluated with the life-cycle approach). As indicated in Figure 1, EN15978 (EN, 2011) standard has defined the evaluation scope of a building's assessment through four stages of a life-cycle approach.

Despite the standardization efforts, there are very few studies or LCA tools (Oregi, 2015) that assess all the described life-cycle stages, and most studies and tools have focused on just some of the stages, i.e. the product phase (A1-A3) and the operational energy use stage (B6). For the other life-cycle stages, these omissions are mainly due to lack of information, difficulty of predicting future scenarios and the relatively low impact that the stage has in comparison to that of the whole life-cycle. Regarding the construction stage (A4-5), case studies have shown that this stage normally accounts for less than 1% of energy use during the building's life span (Sartori and Hestnes, 2007). Additionally, some previous studies (Cole, 1999; Wadel *et al.*, 2011) defined that the environmental impacts of the end-of-life stage (C1-4) are not usually considered, since they typically represent less than 1% of the life-cycle energy of buildings. Based on these references, as well as the conclusions obtained in the study carried out by Oregi (2015), Table 2 shows that NEST is focused on the assessment of the environmental impact of some of the life-cycle stages. The replacement stage represents the sum of the environmental impacts associated with the cost required to manufacture and replace materials across the estimated service life of each district component. The length of the NEST analysis is 50 years. Regarding the components of the district, the service life of the buildings is 50 years (Malmqvist *et al.*, 2001), of land use is 50 years and of infrastructure is 30 years (Fthenakis *et al.*, 2009).

2.2. Input–output data

There are four different ways to obtain and define the NEST input data that is used to perform environmental, economic and social analyses (Table 3): Manually (MA), Manually by the NEST dropdown menu (MN), Automatic by NEST (A) and Imported from Integrated Environmental Solutions (IES) software (IES, 2014).

In order to perform the analysis of buildings, NEST applies two different calculation procedures (Figure 2). As for the environmental and economic assessment of the building materials and refurbishment strategies, the economic cost, embodied energy and associated GHG emissions, these are estimated based on a meta-analysis of

Table 2. Building life-cycle stages defined by EN 15978 (EN, 2011) and the stages assessed by NEST

	Product phase (A1 - 3)	**Transport (A4)**	**On site processes (A5)**	**Maintenance (B2)**	**Replacement (B4)**	**Operational energy use (B6)**	**Operational water use (B7)**	**End - of - life phase (C1 - 4)**
Buildings	X	X	X	X	X	X	X	X
Land use	X	X	X	X	X	X	X	X
Infrastructure	X				X	X	X	
Mobility	X	X	N/A	N/A	N/A	X		X

Table 3. Main input data of NEST and their definition levels

	MA	MN	A	IES		MA	MN	A	Ies
G-General data									
g1-Location*		X			g3-Expected number of inhabitants	X			
g2-Climate zone*		X							
B-Buildings									
b1-New or existing		X			b8-Construction system		X		
b2-Building use		X			b9-Energy demand*	X		X	X
b3-Floor surface (m^2)			X		b10-Energy generation system		X		
b4-Envelope surface (m2)			X		b11-Renewable energy generation*	X		X	
b5-Construction year		X							
b6-Energy labelling*		X			b12-Construction cost*	X		X	
b7-Housing number	X				b13-Refurbishment strategy*		X		
L-Land use									
l1-Type of surfaces		X			l2-Surface of each type (m2)			X	
I-Infrastructure									
i1-Public lighting numbers	X				i3-Lighting regulation system		X		
i2-Public lighting system		X			i4-Waster network		X		
M-Daily mobility									
m1-Social profile		X			m3-Distances (Km)	X			
m2-Mobility system		X							

Notes: Manually (MA), Manually by the NEST dropdown menu (MN), Automatic by NEST (A) and Imported since IES (Ies). Due to the current market scope of NEST, the assessment scope of the parameters market by '*' is limited to the regions of France and Spain.

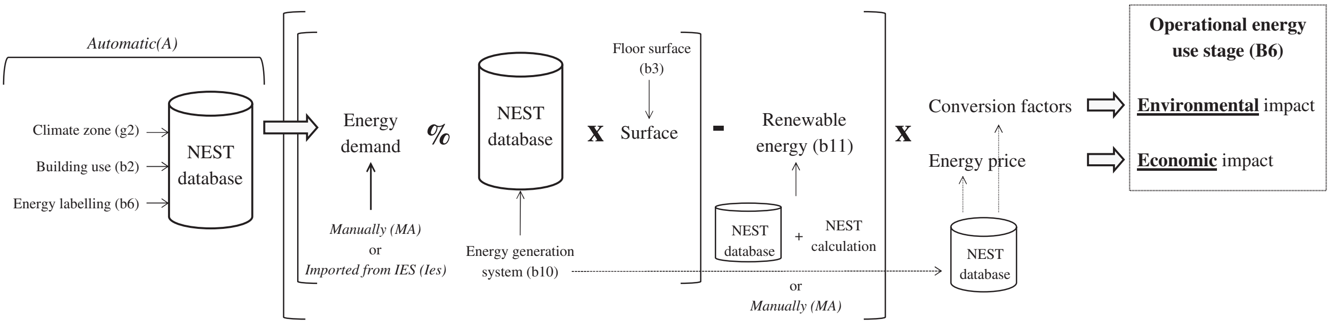


Figure 2. Scheme of the different calculation processes of the operational energy use stage of buildings in NEST.

detailed LCA. Rather than performing a process-based LCA, NEST relies on an internal database of former analyses that estimate embodied environmental and production cost impacts of different constructive systems and refurbishment strategies. This database was designed by Nobatek and Tecnalia using national statistics, publicly available studies (CIMbéton, 2010; CSTB, 2013) and internal data compiled from various studies. Some environmental information also comes from well-known international databases, such as Ecoinvent (Weidema *et al.*, 2013) for environmental aspects and Ecofys – Eurima (2010) for economic aspects.

To estimate the energy demand of buildings (heating, cooling, lighting, domestic hot water and appliances) in the automatic (A) mode, NEST requires as input the climate zone (g2), the use type of the building (b2) and the energy label of the building (b6). In order to convert the operational energy use values into economic and environmental impacts, conversion factors such as energy prices, primary energy (PE) factors or global warming potential (GWP) factors are automatically adapted, depending on the location of each district (in France and Spain). However, if the end user has the energy demand data, NEST makes it possible to manually insert this information and to import energy simulation tools results (IES, for instance).

In order to perform the analysis related to land use, NEST uses two inputs: the type of surface (roads, parking, green spaces, etc.) and the area of the different surface types (m^2). The first input (type) is defined manually by the end user during the modeling process of the district, using a typical 'paint bucket' tool. Area of each surface type is automatically recognized in SketchUp, and is defined through the NEST interface. Then, NEST uses conversion factors to convert those amounts and types of land use to their corresponding environmental impacts.

For public lighting, the user inputs the number of public lighting points (i1), the type of luminaries (i2) and finally a possible regulation system (i3). On one hand, the number of luminaries makes possible the quantification of the environmental and economic impacts of the production (A1-A3) and replacement (B4) stages. On the other hand, and based on data from the NEST database, these three parameters make possible the calculation of the annual energy consumption of the lighting system, which is then converted to operational energy use (B6) using conversion factors.

Finally, the mobility or transportation impact calculation is based on the manual (MN) definition of three inputs: distribution of the different social profiles (m1) of the district's inhabitants (university students, workers, pensioners, etc.), mobility systems (m2) of each social profile (car, bicycle, bus, etc.) and the distance (m3) to different activities in the city (schools, shops, offices, etc.).

From a general perspective, it must be noted that all results (both environmental and economic) are expressed in 'impact per year and per user'. In other words, NEST shows what are the environmental and economic impacts generated by each user (inhabitant and workers) of the assessed district over a one year period.

2.3. Indicators

The list of indicators was expanded upon to be broad enough to address key issues of urban development projects and enable a comprehensive assessment of each project, but still limited enough to remain operational. As already mentioned, NEST assesses both environmental indicators and socio-economic indicators.

2.3.1. Environmental indicators

These indicators are divided into two groups: LCA-based indicators (PE consumption, climate change, air quality and biodiversity) and flow indicators (water consumption and waste production):

- Primary Energy (PE) consumption indicator (in MJ/year/user) is based on CML 2002 method (Guinée *et al.*, 2002). It accounts for PE use for production, transportation and maintenance, replacement of construction materials, building and open space operations, end-of-life of construction materials, and daily mobility.
- Global Warming Potential (GWP) indicator ($kg_{eq}CO_2$/year/user) is based on IPCC 2007 GWP 100a method (Metz *et al.*, 2007). It accounts for GHG emissions associated with production, transportation and maintenance of construction materials, construction works, building and open space operations, end-of-life of construction materials, and daily mobility.
- Biodiversity Loss indicator (Potentially Disappeared Fraction (PDF)/year/user) is a score of potential biodiversity loss related to both land conversion and land use. It is based on the land use indicator of the Eco-Indicator 99 method (Goedkoop and Spriensma, 2000).
- Air Quality (AQ) indicator (m^3 of polluted air/year/user) is based on the **'**air pollution' indicator of the French NF P01 010 standard (AFNOR, 2004). It accounts for emissions of polluted air from transportation and heating systems.
- Water consumption indicator (**m**^{3}/year/user) assesses water consumption for construction works, during building operation and for maintenance of public spaces. Another water-related indicator assesses stormwater infiltration on the neighbourhood.
- Waste production indicator (t/year/user) assesses the production of different categories of waste (reusable waste, sortable waste, non-sortable waste and compostable waste).

2.3.2. Economic indicators

The economic indicator aims to assess construction and use phase costs of the district (€/year/user). It includes the cost of roads, green areas, buildings and other district elements. Due to the preliminary phase of this study, this indicator is not assessed in the case study presented hereafter.

2.3.3. Socio-economic indicators

The socio-economic indicator aims at providing a 'well-being' profile of the district. The socio-economic indicator is composed of eight sub-indicators. These sub-indicators were developed during the ESSAI URBAIN project (Essai Urbain, 2007–2013) through an integrated and collaborative approach in which the stakeholders have participated in defining them. The eight sub-indicators are: medical office availability, school availability, shop availability, public transport service availability, building energy efficiency level, green area availability, population density and bicycle path availability. For each sub-indicator, an assessment was done, and results using a scale of one to five are provided. For instance, for school availability, the NEST tool automatically calculates the amount of housing located in a circular area around each school of the district, and then calculates a ratio of this number in relation to the total amount of housing in the entire district studied. The main objective of the socio-economic indicator is to perform a quantitative assessment, which allows decision makers to have some objective results on which to reflect. However, because the scope of the ESSAI URBAIN project is limited to energy refurbishment strategies, the end user does not have the possibility to change or edit most of the parameters associated with this indicator. As a consequence, this study does not assess and discuss this indicator.

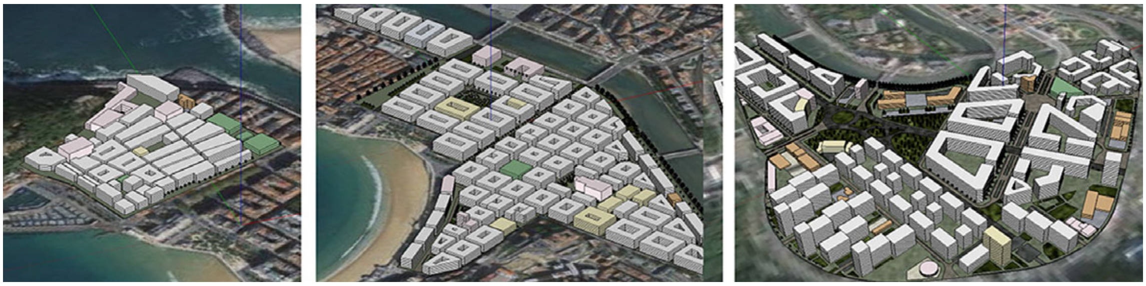


Figure 3. Screenshots of the three areas studied with the ESSAI URBAIN framework (‘Parte Vieja’ – ‘Ensanche Cortazar’ – ‘Amara’).

3. Project

3.1. Goal and scope

The goal of the ESSAI URBAIN research project, carried out by Nobatek, Tecnalia and the municipality of Donostia, is to promote resource conservation and reduction of environmental impacts, adopting a LCA. The project aims at promoting the use of LCA methodology in the design and prioritization between different energy refurbishment strategies phases. Additionally, the objective of this project was focused on the validation of the refurbishment strategies defined during the Sustainable Energy Action Plan (SEAP) of the municipality of Donostia (Sustainable Energy Action Plan of Donostia,).

In order to achieve these objectives, the NEST database was expanded during the project. It was adapted to Spanish building regulations in order to properly evaluate the refurbishment strategies in comparison to the city objectives in terms of environmental impacts.

Using NEST, a sustainability evaluation of three districts of the city of Donostia was carried out: the historical part of the city (‘Parte Vieja’), the centre of the city (‘Ensanche Cortazar’) and the new part of the city (‘Amara’) were studied (see Figure 3).

When designing strategies for district energy refurbishment, NEST enables the assessment and comparison between different scenarios. It allows for the evaluation of the appropriateness between sustainability objectives and real actions. In this paper, the authors present and discuss how the NEST tool was used in order to support the decision-making process of urban energy refurbishment projects.

3.2. Case studies — presentation

To begin, it must be noted that due to time constraints and data availability, it was not possible to use all NEST functionalities during the project. Consequently, only social aspects were assessed for the baseline scenario. Economic aspects were not addressed. This choice was also made because the main city objectives investigated in this project were objectives related to GHG emissions and energy consumption.

The three districts studied were chosen for their representativeness of the city of Donostia. As in most European cities, we can find distinct urban areas within the same city. Due to urban characteristics such as infrastructure age, buildings use, thermal properties, mobility framework, building protection level, etc., the improvement potentials and constraints are different for each district.

The location of the historic centre or ‘Parte Vieja’ on the south side of Urgul Mountain is related to the need to protect the city from strong north-west winds. The historic centre of Donostia, founded in 1180, is protected by various regulations, thus reducing the number of conceivable options in terms of energy refurbishment strategies. This results in a limited set of possible actions for the use of renewable technologies and for indoor renovation plans. The ‘Ensanche Cortazar’ was designed in 1864 in search of an urban planning strategy that could take advantage of the excellent climatic conditions in Donostia, such as mild temperatures and relatively high solar radiation. Here, the distance between buildings was augmented, and large internal courtyards were included in building design. Buildings accommodate mixed residential and tertiary use. The architectural quality of some of these buildings makes them catalogued or protected buildings, prohibiting their energy renovation through strategies such as ventilated facades or window replacement. However, due to the high number of energetically inefficient buildings, the potential for improvement would be high if it weren’t for their protected statuses. In the second half of the 20th century, Donostia grew, and new urban areas were created to make room for the increasing population (‘Amara’ district). However, the city did not take into account the urban climate in the development of this district, because the only objective was to answer the need for buildings. The urban and building

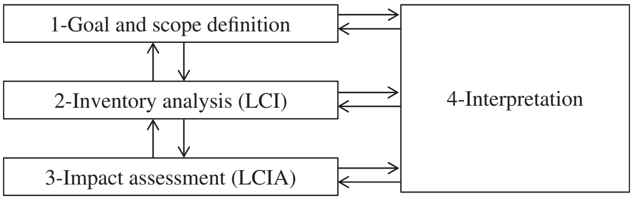
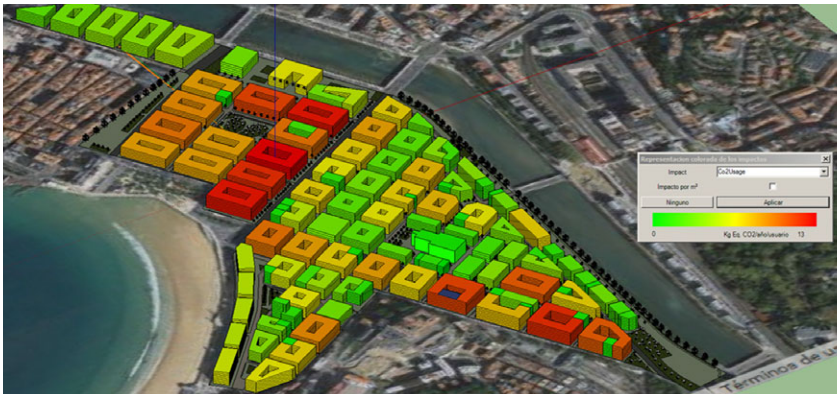


Figure 4. LCA process from the ISO 14040 standard.



Impact: Co2Usage

Impacto por m² ☐

Figure 5. Screenshot of NEST. GWP impact of the baseline scenario of the 'Ensanche Cortazar' district.

typologies changed in order to reduce the street widths and to avoid the use of internal courtyards. The use of buildings in Amara is mainly for residential purposes, and no building is architecturally protected. Consequently, the energetic improvement potential of this district is very high.

3.3. Evaluation methodology

A classical LCA process, similar to the one recommended by ISO standards on LCA (Figure 4) was implemented beginning in the early stages of the study. To start, the goals and scope of the project were defined in close collaboration with the municipality of Donostia. As a result, it was decided that interest in the energy refurbishment strategies selected by the SEAP would be assessed, and would encompass each studied area over several time horizons. Next, the inventory analysis phase was carried out. During this phase, it was mandatory to collect all the necessary information in order to perform NEST calculations. This stage was critical as well as time consuming, because it required the collection of a large amount of data. The third phase consisted in running assessment calculations.

Table 4. Summary of aspects of 'Ensanche Cortazar' district evaluated by NEST

General data			
Location	Donostia-San Sebastián	Climate zone	D1 (Spanish regulation; Ministry of Housing, 2013a)
Service life of the district	100 years	District users	13,926
Total surface of the district	197,539 m^2	Dwelling surface	157,529 m^2
Green surface	25,233 m^2	Open space surface	130,459 m^2
Other activities	12,815 m^2	Parking surface	11,102 m^2
Tertiary building surface	27,195 m^2		
Building characteristics			
Constructive system (existing buildings)		No influence on calculations	
Energy labeling – rating		F (according to current Spanish regulation; Ministry of Housing, 2013b)	
Heating and DHW system		Natural gas	
Cooling		Electricity	
Renewable generation		None	
Water consumption		No recuperation system	
Architectural protection grade		Some buildings, grade III (according urban rules)	
Public transport			
Number of public transport lines		20	
Average distance to a bus stop		1.3 km	
Population			
Active 48%, students <18 years (12%), university students (11%), retirees (29%)			
Mobility scenario and inner district average mobility distances			
Individual car 25%, bus 20%, train 3%, bicycle 5% and walking 47%			
Kindergarten	2 km	Primary school	2 km
School	2 km	Institute	4 km
University	6 km	Commerce	1.5 km
Office	2 km	Bus station	1.3
Public lighting			
Type-number	Mercury vapor-1060	Control system	Electronic ballast

Note: The input information of the two other districts is provided in Annex 1

Table 5. Baseline results for each studied district (per year and user)

Impact indicator	Sector	Life cycle stage	Parte Vieja	Ensanche Cortazar	Amara
PE (MJ/year/user)	Buildings	A1-5, B2, B4, C1-4	0.0E+00	0.0E+00	0.0E+00
	Buildings	B6, B7	4.4E+04	9.7E+04	4.7E+04
	Public lighting	A1-3, B4, B6	1.9E+03	1.5E+03	1.3E+03
	Mobility	A1-4, B6, C1-4	1.2E+00	1.7E+03	2.1E+03
GWP ($kg_{eq}CO_2$/year/user)	Buildings	A1-5, B2, B4, C1-4	0.0E+00	0.0E+00	0.0E+00
	Buildings	B6, B7	2.5E+03	3.4E+03	1.5E+03
	Public lighting	A1-3, B4, B6	1.4E+01	1.1E+01	9.8E+00
	Mobility	A1-4, B6, C1-4	0.4E+00	9.7E+01	1.2E+02
AQ (m^3/year/user)	District		6.6E+03	2.9E+05	6.3E+05

Note: Land use associated impacts are not considered here. During this exercise, no land use changes have been considered as part of the proposed energy refurbishment strategies.

Primarily, a baseline analysis was done for the three districts (see Figure 5). The baseline was defined in 2009, and corresponds to the starting point for Donostia with regard to municipal ordinance implementation (called ‘eco-ordenanza’; Gipuzkoa, 2014). This ordinance aimed at optimizing energy efficiency of new and renovated buildings.

After that, three assessments were performed in order to evaluate the efficiency of the measures taken by the city of Donostia: municipal ordinance, horizon 2020 and horizon 2030. Finally the results provided by NEST were interpreted and compared to the baseline, taking into account three indicators: PE, GWP and AQ. It must be noted that because mobility aspects have already been deeply studied by the municipality, they have been excluded from the calculations.

3.3.1. *Baseline*

The information obtained in close collaboration with the city of Donostia (see Table 4) enabled the definition of a vast majority of the inputs required for modelling the baseline scenario of each of the studied districts. Table 5 shows some of the results obtained after inserting the input data in the tool.

Ninety-three and 91% of PE and GWP impact, respectively, are related to the impact generated during the operational stage of the buildings. During this stage, 43% of PE and 75% of GWP are related to heating consumption. With regard to the air quality impact and with the exception of the historic district, in which mobility is limited mainly to pedestrians, more than 95% of the AQ impact is related to individual and public transport. In terms of comparison among the three districts, it appears that the Ensanche Cortazar has the highest impacts related to buildings. This is explained by the significant number of buildings without insulation (and therefore associated with high energy consumption), as well as by its lower density. With respect to public lighting, the Parte Vieja district has the highest impact due to the relatively low efficiency of its public lighting system. And finally, in terms of mobility, the Amara district has the highest impacts mainly because of the district’s transportation model, which relies more on energy-consuming and GHG-emitting transportation modes than the two other districts (especially the Parte Vieja district, considering its significant number of pedestrians).

NEST models also provided the ‘well-being’ profile (see Figure 6) of each district through the social indicator assessment, which provides a better understanding of the district structures, highlighting their main features.

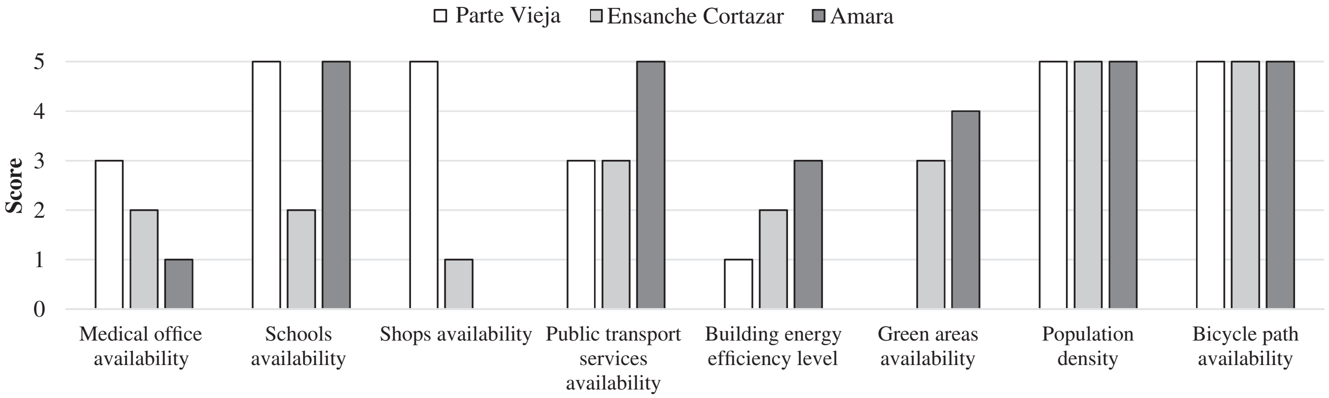


Figure 6. NEST social indicator results assessment of the three baseline scenarios.

Table 6. Refurbishment strategies proposed for 'Parte Vieja' (PV) – 'Ensanche Cortazar' (EC) – 'Amara' (A) districts

Refurbishment strategy		<2009 (Baseline)	Eco-ordenanza	2020	2030
Public lighting	Luminary	Mercury vapour		Low pressure	LED
Public buildings	Boiler	Natural gas	No improvements		Condensation
	Lighting	No improvements			
	Cooling system	Standard		Efficient	
	Heating reduction	No improvements		15%	15%
Residential buildings (RB) boilers	Oil (PV, EC and A)	20%	10%	0%	0%
	Natural gas (EC)	80%	90%	90%	75%
	Natural gas (A)	80%	90%	90%	60%
	Condensation (PV)	0%	0%	10%	50%
	Condensation (EC)	0%	0%	5%	15%
	Condensation (A)	0%	0%	10%	30%
	Biomass (PV)	0%	0%	0%	0%
	Biomass (EC)	0%	0%	5%	10%
	Biomass (A)	0%	0%	0%	10%
RB replacement	Windows (PV)	No improvements		5%	15%
	Windows (EC)	No improvements		10%	20%
	Windows (A)	No improvements		15%	40%
	Façade (PV)	No improvements		0%	0%
	Façade (EC)	No improvements		5%	10%
	Façade (A)	No improvements		20%	40%
RB heating demand reduction		No improvements		4%	7%
Solar thermal (PV)		No improvements			
Solar thermal (EC)		No improvements		970 m^2	2000 m^2
Solar thermal (A)		No improvements		2000 m^2	3500 m^2
Photovoltaic (PV and EC)		No improvements			
Photovoltaic (EC)		No improvements		45 m^2	

3.3.2. *Refurbishment scenarios*

After evaluating the impacts of the baseline scenario, the second phase of the project was focused on the assessment of different energy refurbishment scenarios. The refurbishment scenarios are divided into three different temporal evaluations:

- Municipal ordinance of energy efficiency (from 2009 to 2014) (ENEA, 2014). This ordinance regulates and enables the monitoring of all activities pertaining to energy renovation and carried out over the last five years in the city of Donostia.
- Scenario 2020: Scenario based on the SEAP of Donostia-San Sebastián (Minuartia Enea *et al.*, 2011).
- Scenario 2030: Scenario based on the Hiri Berdea document (ENEA, 2014).

Based on the information provided by these documents and through direct collaboration with the municipality, Table 6 shows the different energy refurbishment strategies for each aforementioned period.

Most of the improvements are manually input in NEST by the end user. However, when the refurbishment is focused on energy renovation of the building envelope, the process is very different. After selecting a building to be rehabilitated, the NEST software proposes different strategies. Refurbishment strategies are applied to each building according to two efficiency levels. The 'basic' efficiency level is based on restoration strategies that enforce the minimum thermal requirements determined by existing regulations and standards. The 'advanced' efficiency level strategies, which improve thermal properties, add very high values to the insulation, such as those used in standards like the Passive House (IPHA, 2014). Each efficiency level strategy presents three configurations. The first strategy is an indoor thermal improvement solution, consisting of a layer of insulation and plasterboard. The second strategy is an external insulation system, composed of a layer of insulation and an outer layer of mortar. The third strategy is an air chamber insulation injection solution, functioning as a layer of insulation. According to the efficiency-level parameter, different insulation thicknesses are proposed for basic and advanced levels. Whether the final user selects one of these six refurbishment building strategies, NEST automatically calculates the new energy demand of the refurbished building, easing the work process. From Figure 7, it can be seen that results vary among the three districts. The 'Ensanche de Cortazar' and 'Amara' districts evolve in the same way, with reductions in terms of PE demand and GWP for the three scenarios (between 1 and 28%, depending on the scenario and the indicator).

However, the air quality indicator increases in the 2020 and 2030 scenarios due to the implementation of wood boilers (instead of gas boilers), leading to higher particulate emissions. It must be noted that this analysis should be deeply investigated while the precise type of wood boiler to be implemented is known. Indeed, for the moment, the

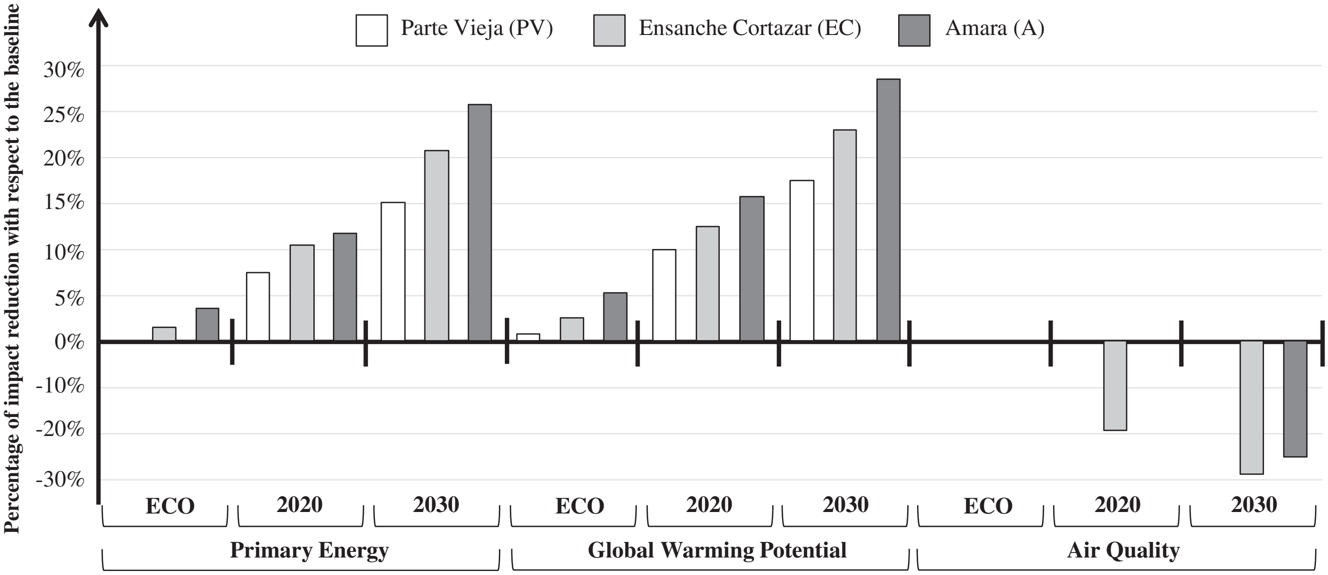


Figure 7. Impact variation (%) for the three districts studied in relation to the baseline.

Table 7. Comparison between ESSAIN URBAIN orders of magnitude and the targets to be reached

(Impact indicator: GWP)		ESSAI URBAIN results (Essai Urbain, 2007–2013) (%)	SEAP (Minuartia Enea *et al.*, 2011) & Hiri Berdea (ENEA, 2014) (%)
Eco	Parte Vieja	1	–
	Ensanche Cortazar	3	
	Amara	5	
2020	Parte Vieja	11	20.5
	Ensanche Cortazar	13	
	Amara	16	
2030	Parte Vieja	18	30
	Ensanche Cortazar	23	
	Amara	28	

modelled wood boilers are generic boilers taken from the Ecoinvent (Weidema *et al.*, 2013) database. For the 'Historic city' district, the impact reduction in terms of PE demand and GWP is lower due to historical constraints, which limit the implementation of energy refurbishment strategies. Also, the less frequent use of biomass boilers leads to a reduction in particulate matter, and thus reduces the influence on the air quality indicator.

4. Discussion

Results provided by NEST allow for the quantification of the performance of the three districts over different time horizons (associated with different refurbishment strategies) in terms of PE demand, GHG emissions and air quality. This evaluation has assisted with the drafting of Donostia's objectives with regard to GHG emissions reduction for 2020 and 2030. As indicated in Table 7, results of the simulations show that the envisaged scenarios are not sufficient to reach the city's objectives. Consequently, these results shed light on the improvements still needed to reach the defined objectives. However, it must be noted that the proposed scenarios only address the existing buildings and their associated impacts. Indeed, some complementary elements are included in the city objectives for 2020 and 2030, such as food and industry. These elements were disregarded in this study, and their integration in the analysis could potentially fill the gap between observed results and city objectives. Second, this evaluation has allowed for the prioritization of actions. To be more efficient in terms of GHG emissions reduction, the city can prioritize its actions on the Amara and Ensanche de Cortazar districts in light of the highest reduction potential observed in these districts. Nevertheless, it must be highlighted that the Historic centre would need some energy refurbishment actions specific to historical buildings. Effectively, it appears that historical limitations in terms of energy refurbishment strategies prevent this area from obtaining better results. Also, the assessment performed has allowed for the identification of building heating and associated energy consumption as the main source of GHG emissions, and thus as the most important point to be tackled through energy refurbishment actions.

One of the next possible areas of work in terms of methodology could be related to the influence of historical restrictions in designing energy refurbishment strategies at the city scale. Discovering new paths when designing refurbishment plans for such areas could significantly increase the refurbishment potential of cities.

Regarding the NEST tool, some possible improvements were identified. The Donostia city council mentioned that it could be useful to have the ability to define the refurbishment strategy on a larger scale. Indeed, for the time being, the refurbishment strategy has to be defined building by building. The municipality has also indicated that such an option could consist of defining the refurbishment strategy directly at the district scale with major trends, such as ‘10% of buildings are refurbished with the X option’, ‘25% of buildings are equipped with wood boilers instead of gas boilers’, etc. This option, although being very interesting, will be deeply investigated since it could lead to some difficulties for the tool, specifically with regard to building selection. Finally, another potential improvement is to make the NEST tool communicate with pre-existing available city information, such as GIS information. This ‘communication’ could significantly reduce the modeling time of the NEST tool by gathering geometrical information from cadastre or satellite data, as well as other building characteristics from the city-specific databases (e.g. characteristics of boilers, building envelopes, etc.).

5. Conclusion

As mentioned, the work carried out during this study aimed at positioning the envisaged energy refurbishment scenarios and associated environmental impacts in relation to the city’s objectives. The results showed some differences between the three districts studied, and helped the city of Donostia answer some critical questions. First, the assessment performed has allowed for the identification of GHG emissions hotspots in the baseline, and thus for the definition of key areas of action both in terms of geography (which districts) and items (which elements). For instance, it was highlighted that the Historical centre, due to architectural restrictions, will not be able to reach the same performance levels as the Amara or Ensanche districts. Also, building heating has been identified as the main contributor to district GHG emissions in the baseline. Finally, this exercise has provided important information regarding the envisaged energy refurbishment plan and its corresponding role in reaching the city’s objectives. This has been particularly useful for the municipality in justifying the need for additional efforts to reach their GHG emission objectives. Those lessons highlight the interest in providing a tool that allows the investigation of different refurbishment strategies with the LCA methodology.

In order to go beyond the scope of this project, it would be interesting to perform more specific simulations at the building level when the energy refurbishment scenarios are more precisely defined. For example, this could be done through Dynamic Thermal Simulation of buildings or more detailed LCA (using building scale tool). Results of these more detailed simulations could then be used individually to refine and aggregate energy refurbishment strategies at the district/city level by the NEST tool, in order to estimate their associated environmental impacts.

6. Acknowledgements

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Annex 1 (a) Summary of aspects of "Parte Vieja" district evaluated by NEST. (b) Summary of aspects of "Amara" district evaluated by NEST.