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Evaluation of different refurbishment or improvement strategies to reduce the environmental impact of University campuses.

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Abstract

Over the past few years, urban planners and architects have searched for solutions to improve the performance of urban projects in terms of environmental impact, life quality and socio-economic problems. NEST is an agile and fast tool developed to assess this environmental impact (baseline scenarios and improvements hypotheses) at the district level by a life cycle analysis. The authors of this publication have used NEST in different research projects and have studied different baseline scenarios and evaluated improvement cases. The article presents a summary of the evolution of the research carried out, explaining each case study and the general conclusions obtained. It also presents the current research project focused on the utilisation of renewable energy sources in the campuses in order to reduce their environmental impact.

Key Innovations

- University Campuses can be considered as small towns due to their size, activity and population.
- NEST is a fast tool to evaluate environmental impact at district level through a life cycle analysis.
- NEST helps to determine the best improvement scenarios.
- University Campuses have a high environmental impact.

Practical Implications

NEST is an agile and fast tool for carrying out analysis of the baseline scenario and the improvement hypotheses.

Do not use it for detailed numerical analysis. The values obtained in the simulations are rough.

You do not need to have very precise data to run the simulations.

Introduction

Over the last few decades, the environmental situation has become critical. Global warming or the depletion of natural resources and the ozone layer are problems that are encouraging an increase in environmental awareness. In 2016, it was estimated that 54.5% of the world's population lived in urban areas, and by 2030 it is projected to rise to 60% (UN, 2016). The reason for this is that cities offer to the population new opportunities for business, education, security, and community. However, carrying out all these activities requires a significant amount of resources, which in turn has an economic and environmental cost (Ahmad, 2018). IEA (2016) suggests that two-thirds of the world's primary energy consumption can be attributed to urban areas, generating 71% of energy-related greenhouse gas (GHG) emissions. Besides, in the European Union, 40% of total energy consumption is related to construction (European Parliament and the council of the European Union, 2016). At the same time, it should be highlighted that Francisco Pinto (2018) has shown in his study that the built environment has the greatest potential to increase energy efficiency.

As a result, the European Union has established strategies and targets to reduce energy consumption. Some of the most important are 2030 and 2050 targets (European Commission, 2020). According to these objectives, it is proposed a 55% reduction of greenhouse gas emissions by 2030 and climate neutrality by 2050. In addition, in 2015, world leaders adopted the Sustainable Development Goals (SDGs) to eradicate poverty, protect the planet, and ensure prosperity for all, as part of a new agenda for sustainable development. These targets should be achieved by 2030 (UN, 2015).

Regarding Spain, some regulations have been established to reduce the energy demand of buildings and promote renewable energy as the main source of electricity and domestic hot water (DHW). As a result of these regulations, concerning the implementation of renewable energies in the construction sector, a new directive was adopted in 2019 to regulate the production and self-production of energy generated from renewable sources (Ministry for ecological transition, 2019). Furthermore, in response to the shared health crisis at European level, produced by COVID-19, new energy measures have been approved in 2020. They promote the need to boost the decarbonisation and sustainability agenda, so that investments in renewables, energy efficiency and new production processes act as a green lever for economic recovery (State Agenda, 2020).

At an urban scale, these impacts, both environmental and energy, are amplified (Oliver-Solà, 2011). They present a clear demand, at public and private level, for analysts and town planners, in the requirement to take environmental awareness into account in the implementation of new projects (León, 2020). Therefore, it is common for urban planners to use energy and environmental efficiency parameters in the design and development of urban spaces

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and district rehabilitation projects (Yigitcanlar, 2015). However, they do not always have the right tools. They should be agile and fast to allow them, when there is no access to real data, to make simple and quick decisions in order to detect the most efficient solution in each case.

Regarding the commented high environmental impact of urban areas, the university campuses can be considered as "small towns" due to their size, population and complex activity. Therefore, it can be observed their environmental impacts are considerable. The larger a campus is, the higher its energy consumption and more natural resources are needed. Generally, this amount of required resources cannot be produced by the campus itself. So they are transported there to be transformed into products and services, and partially returned to the environment in the form of waste and emissions (Leon, 2018).

Universities use energy for several purposes such as lighting, heating, cooling, transportation, and equipment. Across Europe, there are a large number of university buildings that generally have a high electricity consumption, but also a high heating and cooling consumption (Erhorn Kluttig, 2017). For example, Guan (2015) in his study about energy use on a university campus in Norway, shows that electricity use is higher than heating use. According to Leal Filho's (2019) research, among 50 universities analysed worldwide, only 1-20% of the energy consumed comes from renewables and 70% of this, is related to photovoltaic. In terms of biomass, geothermal and wind energy, they have a similar percentage of use (around 18%). Hydroelectric energy does not exceed 6%. As mentioned by Mohammadi (2018), certain institutions have begun to adopt measures to increase renewable energies in the implementation of microgrids or "energy islands".

According to the European Commission (2014) and the international literature set out, the methodology of Life Cycle Assessment (LCA) is currently one of the best methods for evaluating the environmental impact of any activity. LCA conducts an analytical process where the matter and energy flows of a system are quantified and evaluated (Scheuer, 2003). The International Organization for Standardization (ISO) states that, in order to have a global summary of the environmental impact of the product, LCA must be carried out in four phases: (I) definition of the purpose and scope of the assessment (functional unit, quality criteria, system limitations, etc.), (II) life cycle inventory, (III) life cycle assessment, and (IV) interpretation. The LCA covers all phases of the product's life (from cradle to grave). In buildings, the use phase predominates over the others (León, 2018). As commented by Lotteau and Loubert (2015), existing literature in LCA at a district level is still scarce and heterogeneous. Different tools that allow the evaluation of the performance of a building by a LCA approach have been developed, such as Athena, Ecoeffect, Equer,.. (Oregi and Pousse, 2016). In addition, in the last few years, due to the growing interest in sustainability investigation and planning at neighbourhood scale (Lotteau and Loubert, 2015), new tools have been developed to evaluate this environmental impact at the district level through a life cycle analysis (Oregi, 2016). This study has used the Neighborhood Evaluation for Sustainable Territories (NEST) tool (León, 2018, Lotteau 2015, Oregi 2016), one of the first tools to do it. This tool is not related to the Neutral Environment Software Tool (NEST) developed by National Institute for Standards and Technology (NIST).

NEST is a Trimble SketchUp plugin, one of the most widely used 3D modeling systems by urban planners and architects. NEST allows the creation of a 3D model with information. It contains the main characteristics of buildings and the district, which are necessary to carry out an environmental impact assessment through the LCA. NEST evaluates a set of indicators that have been developed through a scientific approach (Lotteau, 2015) but also takes into account the operational objectives and local regulations of urban planning. These indicators are related to energy, CO2, and biodiversity. NEST's calculation system for evaluating environmental impacts is explained in Figure 1. The tool is designed to be used in Spain and France.

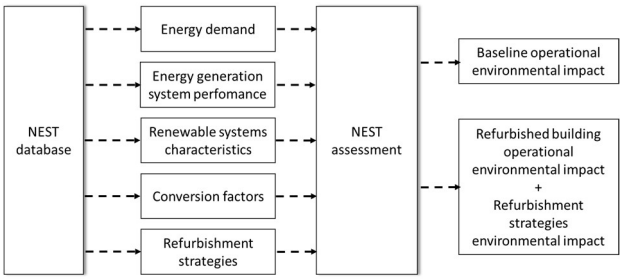

Figure 1. Diagram of the environmental assessment process for buildings at NEST (Leon, 2018).

Lotteau (2015) explains that NEST evaluates both environmental and socioeconomic indicators for LCA of the built environment at neighbourhood level. It is an agile and fast tool for carrying out analysis of the baseline scenario and the improvement hypotheses. In contrast to other tools, in NEST, the characteristics of the buildings that constitute the district or area to be studied have an important weight. The 3D model generated is identified by a simple interpretation and it can be applied effectively to the university campus scale to assess its impact. The tool conducts the evaluation taking into account a life span of 50 years for the buildings and 30 years for the infrastructures (replacements included if required). The components included in the district analysis are (i) buildings, (ii) open spaces, (iii) buildings and open spaces operation (sanitary hot water, heating, ventilation, cooling...), (iv) end of life of the materials that compose the buildings and open spaces and (v) operational requirements for daily mobility. In comparison to other tools analysed in Oregi and Pousse's (2016) study, NEST considers building energy but also energy transportation, energy water, energy public lighting, solid waste and socioeconomic impacts. Thus, it provides a full overview of the impact of the studied district or city. Similar to NEST, Oregi´s (2018) study presents another tool to assess the energy and environmental impact of a district. Nevertheless, in comparison to NEST, it does not

consider the impact of the different life cycle stages or the impact associated with different district processes such as transport or public lighting.

To run the simulations, a baseline scenario is defined which is equivalent to the current situation of the district (existing buildings, infrastructure, and mobility). One of the key elements to analyse the environmental impact is to determine the energy behaviour of buildings. Due to the difficulty of obtaining real data, NEST allows users to use data related to the Building Energy Performance Certificate and the climate zone of its location. From these, it automatically calculates the demand for heating, domestic hot water, lighting and domestic appliances for each building.

The authors of this publication have used NEST in several research projects carrying out the evaluation of baseline and improvement scenarios for different contexts. The article presents a summary of the evolution of the research realised and describes each case of study and the general conclusions obtained. It also presents the research project that has recently been started, focused on the implementation of forest biomass as a renewable energy source in university campuses of different natures, governance, regions and countries. One of the novelties of this study is the utilisation of tools typically used as support for sustainable urban planning (such as NEST), to evaluate the environmental impact and improvement scenarios in university campuses (considered as small cities).

Cases and Methods

Since 2015, the authors of this article have been researching the impact of university campuses on the environment. Within the research carried out, three phases can be highlighted:

First phase (Leon, 2018).

With the support of the University of the Basque Country (UPV/EHU), the study of the environmental impact of the UPV/EHU was carried out by analysing and comparing the four campuses that compose it. Each one has different urban development characteristics: two are urban campuses (Vitoria-Gasteiz, Donostia-Ibaeta) and two are suburban campuses (Eibar and Leioa).

Figure 2. Vitoria-Gasteiz Campus (Ibarrola, 2017).

A study of the current state of each campus was carried out and several renovation strategy scenarios were proposed for 2020, 2030 and 2050 as shown in Table 1.

Table 1. Summary of baseline and 2020, 2030, 2050 strategies: passive refurbishment (Pr), Active strategies (As), Renewable strategies (Rs) and Public lighting (Pl)

Refurbishment strategy (Rs)		**Baseline**	**2020**	**2030**	**2050**
Pr	Facade	None	30%	60%	90%
	Windows	None	15%	25%	50%
As	Natural gas	100%	90%	65%	30%
	Condensation	None	10%	20%	40%
	Biomass	None	0%	5%	10%
	Heat Pump with geothermal support	None	0%	10%	20%
Rs (m^2)	Thermal	0	100	300	750
	Photovoltaic	1.481	1.600	2.500	4.500
Pl		High pressure sodium vapour (HPSV)		HPSV 70%, LED 30%	HPSV 25%, LED 75%

The study aimed to confirm that the University, as an independent entity from the city and with its internal policies, was capable to implement the necessary improvements and refurbishments of its facilities with its own resources to achieve the environmental and energy objectives established by European regulations and the SDGs. Among the results obtained, it is worth highlighting the importance of the impact produced by the buildings' operation and the user's mobility to the campuses. In special, in the case of the Leioa campus, where the use of private vehicles and buses is predominant over bikes, trains and walking. In Figure 3, it has been represented the baseline results considering the impact of Primary Energy (PE) and Global Warming Potential (GWP) for each campus. In this study, no cases of improved mobility have been analysed. The research has focused on improvement scenarios at building and lighting of public spaces level.

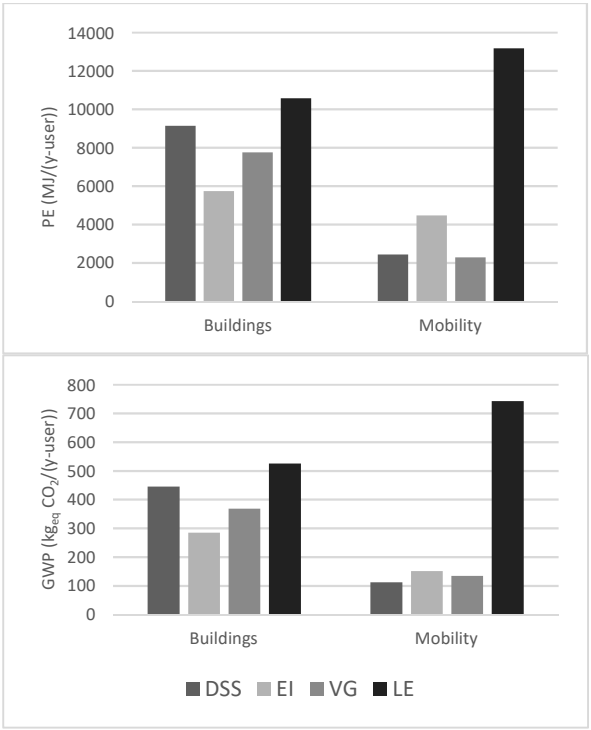

Figure 3. Baseline results for Donostia-San Sebastian (DSS) - "Eibar" (EI) – "Vitoria-Gasteiz" (VG) – "Leioa" (LE) university campuses (per user and year).

In Figure 4 and Table 2, as an example, it is presented the results obtained in the improvement scenarios of the Vitoria-Gasteiz campus: the variation in the impact of PE and GWP. The LCA phases that have been considered in this study are: A1-3 production, A4 transport, A5 on-site processing, B2 maintenance, B4 replacement, B6 operational energy use, B7 operational water use and C1-4 final life phase. It can be observed how, with a minimum increase on the impact of the building's production, maintenance and final life stage, the impact produced by the campus by the operational energy and water use stage, is considerably reduced (Ibarrola, 2017). Regarding the public lighting values, they are very low comparing to the other life phases and its variation between the different scenarios is considered insignificant.

Table 2. Results of PE and GWP for each scenario and sector (Buildings (B) and Public lighting (Pl)) in Vitoria-Gasteiz campus (Ibarrola, 2017).

Impact indicator	Sector	Baseline	2020	2030	2050
PE (MJ/ (year user)	B (A1-5, B2, B4, C1-4)	753,0	787,3	849,4	899,9
	B (B6, B7)	7752,0	7219,7	6344,1	522,3
	Pl (A1-3, B4, B6)	22,0	22,0	20,2	18,7
GWP (kgeq CO_2/ (year user))	B (A1-5, B2, B4, C1-4)	38,0	39,3	41,8	44,0
	B (B6, B7)	368,0	341,5	296,8	196,2
	Pl (A1-3, B4, B6)	1,0	1,0	0,9	0,9

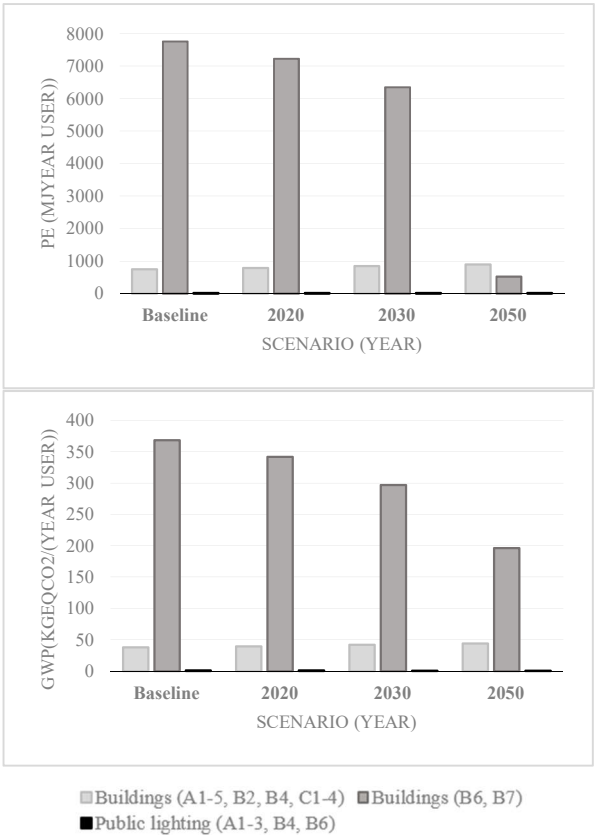

Figure 4. Comparison of the results of the PE and GWP impact indicators for each scenario in the Vitoria-Gasteiz campus (Ibarrola, 2017).

Second phase (Oregi and Pousse, 2016)

The second stage of the study was created as a complement to the study carried out by the European ESSAI URBAN project (Oregi and Pousse, 2016). There, NEST was used to analyse the environmental impact of San Sebastián city, studying its districts. In this European project, the University area was not included in the study. Therefore, it was seen the need to expand the research by carrying out an analyse that investigated the impact of the campus as part of the city. Thus, a new approach was defined which aimed to asses the entire ensemble of environmental and energy strategies to refurbish the city and the university. The whole with joint or complementary actions, establishes synergies between municipal, local and university policies.

Therefore, it was decided to proceed with this new study of the ensemble, which was based on the actions defined

by the Sustainable Energy Action Plan (SEAP) of Donostia-San Sebastián municipality (2011) to be implemented in the coming years. Different refurbishment or improvement strategies or scenarios were evaluated in order to achieve SEAP´s objectives (see Table 3). The results of this second stage showed that municipal and campus policies are not interrelated. But, it also determined that by linking them, better results can be achieved. Furthermore, it is corroborated that, if the University is analysed as an independent entity from the city, it has limited improvement values. Whereas, if it is considered as part of the city, the synergies and combined efforts between the city and the university allow to achieve optimum improvement values using fewer resources (Ibarrola, 2017).

Table 3. GWP emissions per person (Kg CO2-eq/ inhabitant) of the city of Donostia and the Donostia university campus in the baseline scenario (0) and after applying the main actions defined by SEAP (1 to 13), (Leon, 2020).

Description	City (Kg $CO_{2\text{-}eq}$/inhab) (x 10^3)	Campus (Kg $CO_{2\text{-}eq}$/inhab) (x 10^2)
0-Current state	3.73	8.74
1-Improved energy efficiency of equipment in tertiary buildings by 20%	3.71	8.40
2-Reducing energy demand in residential buildings by 25%	3.69	8.74
3-Reduction of energy demand for tertiary buildings by 20%	3.65	7.74
4-Reduction of lighting consumption in tertiary buildings by 25%	3.69	8.25
5-Reduction of lighting consumption in residential buildings by 30%	3.71	8.74
6-Reduction of lighting consumption in commercial buildings by 40%	3.60	8.74
7-Reduction of the heating demand of residential buildings by 30%	3.64	8.74
8-Improving private vehicle emissions	3.71	8.74
9-Improving bus emissions	3.69	8.64
10-Improving the mobility model	2.96	7.71
11-All strategies related to energy efficency	3.31	6.89
12-All strategies related to mobility	2.90	7.59
13-Application of all the strategies evaluated by the study	2.49	5.73

In this phase, the results obtained in the baseline scenarios were compared to the monitoring carried out in the different districts under study. The aim was to validate the tool and its accuracy. This comparison showed that, in general, the monitoring results obtained higher values than the simulation with NEST, between 1–17% less as shown in Table 4. The exception is the case of the UPV/EHU campus, where the simulation has obtained higher values on buildings than those monitored. This may be due to the type of data provided. However, considering the total results, in the case of the campus, the errors in mobility are offset by those of the buildings, giving an average error of 1%. This is due to the quality of input data, which is more accurate on the campus than in the case of the city, that is more difficult to obtain detailed data.

Table 4. Comparison between monitored data and simulated data for the city of Donostia- San Sebastián and the University campus EHU/UPV of the same city.

	Monitored Data (Average 2015–2017 Years) GWP Emissions		Simulated Data—NEST Tool GWP Emissions		Difference between GWP Results
University campus EHU/UPV of Donostia-San Sebastián					
	Kg CO2-eq ($x10^6$)	Kg CO2-eq/hab ($x10^2$)	Kg CO2-eq ($x10^6$)	Kg CO2-eq/hab ($x10^2$)	%
Buildings	4.87	4.40	5.56	5.02	+14%
Transport	4.94	4.46	4.12	3.72	−17%
TOTAL	9,81	8,86	9.68	8.74	-1%
City of Donostia- San Sebastián					
	Kg CO2-eq (x 10^8)	Kg CO2-eq/hab (x 10^3)	Kg CO2-eq (x 10^8)	Kg CO2-eq/hab (x 10^3)	%
Buildings	2,79	1,49	2,48	1,33	-11%
Transport	5,36	2,87	4,48	2,40	-16%
TOTAL	8,15	4,36	6,96	3,73	-15%

Third phase

A third stage has been opened, subsidised by the Euroregion Aquitaine-Basque Country-Navarre. Through the use of NEST, the evaluation of three university campuses with different characteristics is being carried out. On one hand, some are public and others are private. On the other hand, they are located in three different territories and two different countries, which is why they are influenced by different territorial policies and governance (Basque Country and Navarre in Spain and Aquitaine in France).

The research aims to quantify the environmental impact currently generated by each campus due to the use of non-renewable energies. As well as to propose future refurbishment scenarios to supply campuses with renewable energy. In this way, the improvement scenarios

will allow campuses to approach the requirements established by European regulations and the Sustainable Development Goals (SDGs).

In the first and second phases described above, more general improvements scenarios were studied. In this third phase, the novelty is that the research will be focused on the biomass potential (on-site production and consumption) on three representative's campuses, as well as on the possibility of their replicability.

This work will consider different indicators:

• Basic energy demand at a building, infrastructure, and mobility-level (MJ / year) and total heating potential (kg CO2 equivalent/year)

• Energy consumption related to heating, cooling, and hot water supply of each building (kWh / year). This consumption will be defined into different energy sources: natural gas, electricity, diesel or biomass.

• The amount of energy (kWh / year) generated by each building from different renewable energy sources (solar thermal, photovoltaic, and cogeneration).

The university campuses selected for the study are: Anglet campus in Aquitaine (France), San Sebastian-Donostia campus in the Basque Country and Pamplona campus in Navarre. These campuses belong to different typologies of urban development, size, and type of buildings (see Table 5). These campuses will serve as a representative example and they will allow extrapolating the results to other campuses with similar characteristics. Besides, a list of best practices and strategies applicable to the campuses to reduce their environmental impact will be developed. Thus, the research could be initially extended to the other campus belonging to each university analysed (the 5 campuses of the UPV-EHU, 4 of the UNAV and 5 of the UPPA).

San Sebastián Campus is a medium-sized public university (see Figures 5 and 6). It is a campus integrated into the urban network and made up of a group of heterogeneous constructions in terms of construction solution, use and year of construction. It has an excellent model of mobility with the city center and the surrounding towns.

Figure 5. Graphic evaluation of the impacts of the campus through NEST simulation. San Sebastián campus.

In comparison to the San Sebastián campus, the University of Pamplona in Navarre (UNAV) is a large private campus (see Figure 6). It is located on the periphery of the city, has an area of about 400,000 square meters, and it is composed of several faculties, colleges, and sports facilities (Insider Pamplona, n.d, UNAV, n.d). The building complex is heterogeneous at the level of the construction solution, year and use.

Figure 6. Orthophoto of the Ibaeta-San Sebastián, Pamplona and Anglet campuses (from left to right) (Google maps, 2020).

Finally, the Anglet campus is a public and small university (see Figure 6). It is located in the city center, close to the town center of Anglet. It is surrounded by an urban forest and low-density single-family houses.

Table 5. Main characteristics of the UPV/EHU, UNAV and UPPA Campuses

Campus	UPV/EHU	UNAV	UPPA
Type	Urban (city 150.000-200.000 inhabitants)	Suburban	Urban (less than 40.000 inhabitants)
Size	Medium	Large	Small
Public/ private	Public	Private	Públic
Buildings	Heterogenous	Heterogenous	Homogenous
Green spaces	Yes, but limited	Yes, big surfaces	Yes, urban forest
Mobility	Car, bus, train, underground, bike path	Car, bus, bike path	Car, bus, bike path

Based on the results obtained in the baseline scenario, it will be analysed the implementation of the use of forest biomass as a renewable energy source on each campus. Bearing in mind the characteristics of each campus and its possibilities for obtaining a local source of biomass, it will be examined the real possibility of self-production to supply each campus and its impact on the campus energy mix.

At the current stage of the project, the results obtained for the UPV/EHU campus show that, with the implementation of more efficient energy production systems (condensing gas boilers and geothermal heat pumps), renewable energy sources (biomass and solar photovoltaic and thermal energy) and passive improvements (increased insulation of the façade and windows), the environmental impact produced in phases

B6 and B7 of the ACL, is reduced. However, the impact of the phases (A1-5, B2, B4, C1-4) increases as shown in Figure 7.

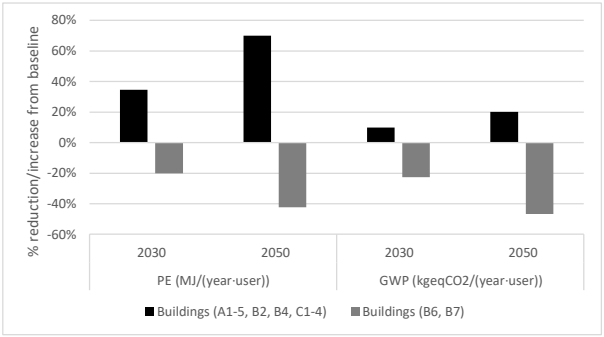

Figure 7. Percentage of increase or reduction of the impact PE and GWP in 2030 and 2050 scenarios from baseline.

Conclusion

Based on the research carried out from 2015 to the present and the last one in progress, the following conclusions have been reached:

Tools such as NEST are needed to be able to analyse in a simple and fast way the environmental and socioeconomic impact, through the use of Life Cycle Analysis. Both the current situation and potential refurbishment scenarios in districts or cities. In addition, they should assist to make quick decisions on the design, definition, development, construction and renovation of campuses, districts, or cities without the need for long-term analyses. Unlike other applications, NEST is an agile and fast tool that allows the calculation of the environmental impacts of the city or district through LCA, mainly focusing on the impact of the buildings that constitute it. Besides, the results obtained enable to compare the environmental impact between different campuses or districts, to exchange information and good practices, and to obtain optimised solutions based on the same assessment methodology.

The use of renewable energies should be encouraged to reduce the environmental impact on operational energy use. NEST makes possible the simulation of these new scenarios and the evaluation and selection of the best solution.

It is necessary to promote synergy between university and city policies in order to achieve greater environmental performance. In this area, universities have a high impact and should be taken into account in the renovation and evolution of cities.

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