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Defining good practices for university vending machines: a Green Public Procurement based approach for sustainable public tenders

TESI MAGISTRALE IN FOOD ENGINEERING

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Abstract: Over the last years, Green Public Procurement (GPP) has become one of the most important tools to drive tenders towards sustainability. In Italy, this transition is enforced by the mandatory adoption of Minimum Environmental Criteria (CAM) for specific sectors like vending machines. Acting as a contracting authority, Politecnico di Milano is legally required to integrate these standards into its procurement procedures to select the economic operator which mitigates the significant impact of the vending system. Therefore, the primary goal of this thesis is to identify the most relevant criteria to include in a call for tenders from the ones defined at the European and Italian level. To achieve this goal an LCA was conducted on the entire vending machine system of Bovisa campus, located in Milan. Three types of machines were evaluated: beverage-only, snack-and-beverage and coffee machines. For every building and every model, energy consumption for "idle mode" turned out to have the highest environmental impact percentage (65% to 95%), while products management had a minor role. A sensitivity analysis confirmed these results introducing a 30% share of renewable energy led to an overall 20% impact reduction. Consequently, the study translated these findings into good practices for future tenders, selecting core criteria to provide a mandatory requirement on machine energy efficiency and recommending award criteria to promote sustainable characteristics of food products.

Key-words: Green Public Procurement, Life Cycle Assessment, Vending Machines

1. Introduction

On a global scale, the food and beverage sector represents one of the largest contributors to Global Warming Potential, as its production is responsible for approximately one third of total anthropogenic greenhouse gas emissions. In fact, the sum of land use and deforestation, storage, transportation, packaging and waste management accounted for 18 billion tons of carbon dioxide equivalent in 2015, with China, Indonesia, the USA, Brazil and the European Union as the top emitters [1].

To mitigate these massive environmental impacts, Green Public Procurement (GPP) has emerged as a structural instrument for public institutions. It introduces environmental criteria into the selection process of goods and services, including vending machines, with the goal of encouraging suppliers to adopt green technologies and more responsible production practices. In Italy, the national implementation of GPP is embodied in the Minimum Environmental Criteria (or CAM), which define mandatory sustainability requirements for public contracts.

Nowadays universities, as major institutional actors, are recognized not only as centres for knowledge creation, but also as one of the first actors in the global transition towards sustainability, introducing new green solutions to minimize impact [2]. Every modern campus operates, indeed, as a small city, with proper management of every building, considering energy flows and a complex framework for supply chains.

In this context, Politecnico di Milano serves as an ideal case study as it has been constantly integrating environmental goals into its present and future achievements. Founded in 1863, it is the largest technical university in Italy and among the top 25 universities in the world for Engineering subjects [3]. It is made up of several campuses, Leonardo and Bovisa are the largest ones, located in Milan, while the others are situated in Lecco, Cremona, Piacenza and Mantua. Within the university's food and beverage supply chain, automated vending machines represent a constant and often silent impact load. By combining the environmental burden of food products with continuous energy consumption, their sustainable procurement through CAM standards represents an important challenge to solve.

1.1 Research Framework and Objective

This study aims to evaluate the environmental footprint of the vending machine system of the Bovisa campus of Politecnico di Milano using a database of regulatory requirements, to outline effective good practices for future tenders.

The proposed framework is developed through a multi-step approach which involves a thematic categorization and a comparative analysis of current regulations of EU GPP and Italian CAM. This initial phase ensures a solid basis for the subsequent analytical stages, highlighting the necessary standards for compliance and sustainability.

The transition from theoretical analysis to empirical application is driven by a specific operational need: the preparation of a public tender by Politecnico di Milano. This procurement process triggered a formal request by the university to quantify the environmental footprint of the existing vending machine system. Consequently, the study transitions into a site-specific Life Cycle Assessment (LCA). The assessment is modeled upon average energy consumption profiles and annual data of product sales volumes for each vending machine in the campus of Milano Bovisa.

The resulting operational data will give the university an approximate calculation of carbon dioxide equivalent emissions and determine whether the criteria outlined in the environmental procurement standards have a real impact on national public tenders.

1.2 Thesis structure

This study is structured in five chapters, organized following a basic structure, from a literature analysis to understanding the main problem to the case study and the definition of the GPP good practices.

The second chapter first presents a literature review on sustainable procurement and its implementation in universities, followed by an analysis of energy and environmental performance through the LCA approach.

Methodology is introduced in the third chapter, where the scopes of the study are detailed, as well as a comparison of Italian and European regulations and all the procedure to build the assessment database. Moreover, the LCA approach is defined according to ISO standards, with an accurate explanation of the data gathering phase for the Life Cycle Inventory (LCI).

In the fourth chapter, the results of the environmental impact assessment are presented, supported by graphics and numerical values to identify and discuss the main issues. These data will be compared with the GPP and CAM criteria analyzed in the previous sections to assess the current procurement policies.

The fifth chapter provides the final considerations and a summary of the study, as well as the out-of-scope of possible future work. Based on the previous chapter with quantitative evidence, it details good practices to support the university for the next public procurements.

2. State-of-the-art

The transition towards sustainable public services in Italy, unlike European regulation, has undergone a structural change from a voluntary choice to a mandatory requirement. As highlighted by Costanzo [4], GPP is one of the most important political instruments to make sustainable choices. The European GPP have been adopted by the Italian legislation with CAM, which aims to identify the best design solution from a green point of view, and with the reform of Articles 9 and 41, the interest in the protection of the environment has been officially included into the Italian Constitution [4]. The promotion and the utilization of these criteria, can influence the market, providing the right incentives to develop green technologies and sustainable products in several sectors. In this university context, the adoption of CAM in public tenders serves as the operational tool to put these principles into their procurement processes.

Beyond the food context, Goggins and Rau [5] showed that public sectors like universities, schools and hospitals have a strong influence on environmental and social impacts through their food procurement practices. The Foodscale method presented here grouped 36 indicators into 11 categories to capture the main aspects of food sustainability, offering an additional opportunity to determine good practices for university public procurement choices [5].

To effectively implement GPP in the university vending sector, it is important to analyse the characteristics of these machines, especially the products sales and how hardware management directly impacts energy performance. Manzano-Agugliaro et al. [6] installed a low-cost sensor network in a Spanish university to monitor the energy usage of the units, including idle and operating mode. That made possible to identify utilization patterns and recognize peak demand periods and vending machine sales efficiencies. Their study then showed that with the installation of "stand-by" modes for snack units, energy consumption can be reduced by 44% to 64%, and 18% for hot drink machines [6]. These empirical findings are relevant to understanding impact of GPP in Europe. Fuentes-Bargues et al [7] found that integration of environmental criteria in universities remains limited, with less than 20% of generic procedures include such requirements.

Moving to global soil, Harnaran and Zaremba [8] evaluated the usage of three types of vending machines at the University of British Columbia: a beverage-only unit, a snack model and a high efficiency Energy Star machine. By measuring their average energy consumption and product temperatures the study aims to understand whether the installation of "vending misers" can reduce the overall impact. This implementation lead respectively to 41% and 43% reduction for traditional machines and 9.7% for the Energy Star. The study also includes a cost-benefit analysis, showing that only low-efficiency units achieve a payback period below the five-year threshold required.

LCA has increasingly been applied to food distribution systems to identify environmental hotspots, following the ISO 14040/14044 standards. Da Costa et al. [9], for example, developed an ISO-compliant LCA tool to evaluate a food supply chain performance, distributing frozen meals through vending machines. In contrast with this study, the authors have found that the raw materials production have the highest impact. It's important to mention that these findings are related only to frozen meals, composed by meat, rice and vegetables, carrying high upstream impacts. This suggests that for vending services providing products with lower upstream impacts than meat-based meals, such as snacks and beverages, the energy consumption of the vending machine might become the main actor concerning environmental impact.

One of the main challenges of the LCA analysis is the calculation of the average consumption of the vending machines. Historically, its industry responded to this need through the Energy Measurement Protocol, developed by the European Vending Association (EVA EMP). This protocol introduced a standardized methodology to ensure that all the data from the same technology, but different manufacturer machines can be read by the same collector by serial numbers and a three-letter code [10].

In summary, the existing studies provide a solid basis for understanding GPP practices and supply chain and energy management. There is still limited research on the application of Italian CAM in Italian universities like Politecnico di Milano, as well as LCA studies specifically dedicated to university vending systems. By focusing on this case study, this thesis aims to connect the national and European regulation with an empirical impact calculation to provide good practices for public procurement.

3. Methodology

3.1 Regulatory Analysis and Scope Definition

The primary objective of the initial phase of this research is to design a structured database to be used as an exhaustive benchmarking tool. This instrument is developed not only to set up an organized framework able to assess the case study, but also to have a preliminary approximation (proxy) for an expandable management model.

To ensure the feasibility of the analysis, the scope of the investigation is delimited according to three aspects: sectoral, normative and geographical, applicative.

From a sectoral perspective, the study does not encompass the entire food-beverage sector, but its range stops at the management of refreshment points, which includes primarily the direction of vending machines, alongside a brief examination of food procurement, on-site food services, preparation and serving of sandwiches and creation of access points for potable water. Consequently, related topics such as catering services for primary schools, universities and hospitals fall outside the scope of the study.

On the normative and geographical side, consistent with the university's requirements, the analysis has its basis within the Italian national context. The reference of the framework consists of the 2019 technical report of the EU GPP standards and the related 2023 Italian CAM regulations.

Regarding the applicative aspects, as already said, the database presented in the first part of the methodology is to be understood as a pilot project, utilized to serve as an assessment tool for the thesis. The logical structure is designed to be scalable in the future, but the current content is limited to the needs of the case study. Moreover, more relatable to the LCA, the research excludes certain technological and economic aspects. Engineering analysis of vending machine hardware (for example refrigerant gases), except energy consumption, will not be taken into consideration, and similarly, neither nutritional values of products nor internal financial feasibility of providers.

3.1.1 Selection of normative and technical sources

Consistent with the scope outlined in the previous chapter, the construction of the assessment framework is based on a double normative analysis. This approach connects the suggested guidelines defined at the European level with the mandatory legislation of the national level. The consideration of these two regulatory bodies allows for an exhausting assessment, balancing international best practices with local compliance.

The European strategic framework is a voluntary instrument defined by the documentation produced by the European Commission within the GPP [11]. Inside this skeleton, the EU has developed specific criteria for food procurement, catering services and vending machines. In each section, every criterion is strictly categorized according to the standard procurement stages: Technical Specifications in which minimum requirements are explained, Award criteria for ranking the economic operators and Contract performance clauses for performance conditions during the execution. For each of these categories, the document offers two sets of criteria: it provides "Core" criteria, designed for easy application of GPP and minimal concerns about administrative costs, and "Comprehensive" criteria, for higher performance for supporting environmental and innovation goals. The GPP is then divided into two documents: the main list of requirements, which includes an overview of the criteria with a brief explanation, and the technical report [12], a more detailed paper which describes the standards in detail and contains the reasons behind them.

Similarly, the Italian CAM of 2023 represents the national transposition of the GPP criteria, but legally mandatory for all public contracting authorities [13]. The decree, specifically made for refreshment points, is divided into specific chapters to deal with different service models: vending machines, bar services, sandwich preparation and management, and water dispensers. As for the GPP, there is a similar categorization of the criteria, but the most important feature of this regulation is the requirement for a "CAM report", included in every chapter. This is a mandatory technical document where the economic operator must describe how the offered solutions will meet the environmental criteria.

Table 1 summarizes the structural and operational differences between the two frameworks analyzed.

Table 1: Comparison of GPP and CAM

	European GPP	Italian CAM
Legal status	Voluntary	Mandatory
Documentary structure	Unitary (Single document for food, catering, vending. Presence of technical report)	Segmented (Different documents, vending divided into chapters)
Ambitions level	Core and Comprehensive ambition levels for technical and award criteria	Unique ambition level for technical and award criteria
Criteria organization	Grouping (Food criteria assessed in lists, minimization of impacts)	Specific (Every food and technical criteria are treated singularly, more thresholds)

3.1.2 Creation of the database

Following the definition of the normative framework, the research methodology proceeded with the creation of the assessing database. Given that both regulations are drafted in a tabular format, the core idea was to create an Excel database, transitioning the static reading of the regulations to a practical management tool, able to isolate specific instructions based on the needs of the economic operator.

The construction of the file considered in one sheet per regulation, each divided primarily in separate tables referred to the main section and then subdivided into smaller dataset following the criteria typologies mentioned above. At this point, each environmental criterion was extracted from the original source and transcribed as a single row in the dataset, allowing for an easier filtering and manipulation.

The data set is structured around two central identifiers: the Code of the criteria and the Common Procurement Vocabulary code (also known as CPV). The former is strictly related to each regulation document, becoming a link which can be used by the operator to navigate among the tool and the original texts. The latter, instead, is an eight-digit identification code designed for cataloguing every product and service in tenders. In this case, operates as a first filter. Indeed, by associating each criterion with a set of suitable CPVs, a future system will be able to isolate all the criteria associated with the CPVs in input, simplifying the analysis.

To provide an exhaustive interpretation of each regulatory requirement, the database is equipped with a brief textual description, supported by either a quantitative value field or a defined scope of applicability. Regarding the GPP standards, the value section can be subdivided to insert both core and comprehensive criteria. If some criteria belong to the same information field, an additional column can be added, with an overall category to enhance navigability. Furthermore, a dedicated "Notes" section is included to specify clauses, external regulations, certifications, or supplementary information. In the award section, the quantitative field can be substituted by a scoring measure, to define the mechanism for point attribution.

Completing the structure, the verification method field has the goal to inform the user on how the criterion can be accomplished. This last column details both the operational actions required to satisfy the standard, like specific actions or technical features to be implemented, and the administrative requirements, such as the submission of lists of conforming products that will be used, prevention plans, declaration of compliance with regulations. Regarding solely the national CAM, the economic operator must include technical sheets, audits, agreements with non-profit organizations and further verifications with external databases to demonstrate compliance. A detailed section of the European database is shown in 6.1Appendix 1.

3.2 Setup of the Life Cycle Assessment

To complement the legislative analysis with empirical data, the methodology adopts the LCA approach performed using OpenLCA software. Following the ISO 14040/14044 series standards, the study consists of three canonical phases: a goal and scope definition, an inventory analysis (LCI), and a life cycle impact assessment (LCIA) visualized with a carbon footprint analysis (CFA).

3.2.1 Goal, Functional Unit and System Boundaries

Translating these protocols into a practical assessment, the goal of the second part of the analysis is to assess the environmental performance of the vending machine system at Politecnico di Milano. The tender for the vending machine service was divided into two separate lots, one for the Leonardo campus and the other for the Bovisa campus of the Politecnico di Milano. The present study focuses exclusively on the lot associated with the Bovisa campus.

Specifically, this case study plans to quantify the environmental impact and highlight the relative weight of operational electricity use versus the emissions associated with the food supply chain, in terms of Global Warming Potential (GWP), expressed in kilograms of carbon dioxide equivalent. In addition, the research also plans a comparative analysis of the emissions under two energy supply scenarios: a baseline one, in which electricity comes entirely from the national grid, and an alternative scenario which integrates a 30% share of on-site renewable energy. The purpose of this analysis is to determine the efficacy of the national and European green criteria as a leverage on the public procurement, stimulating companies to improve their environmental performance.

As every building is characterized by different types and numbers of vending machines, it is to be expected that the sum of energy consumption and sales volumes will vary across the university.

Therefore, the main functional unit is defined as 1 year of operation of the entire Bovisa campus. To provide then a detailed assessment, it is performed distinct LCAs for each building, considering its annual operational activity as the functional unit. This approach is suitable for avoiding yearly trends and seasonality, and it allows for further analysis for environmental impact in different scales of study (single building, small area, whole campus).

The system boundary in this system examines a cradle-to-gate environmental impact analysis, encompassing the resource extraction for electricity, raw material processing, manufacturing and transportation for the products. It then stops when food is sold to the customer, so the post-consumer packaging waste is not considered. Furthermore, the contributions of the routine machine maintenance and logistics for vending machine restocking operations are excluded from the study due to insufficient data.

As mentioned above, this LCA is conducted using OpenLCA 2.4 software, relying on a combination of primary and secondary data, depending on availability and relevance to build the model. The former refers to the specific operational data collected directly from the university, including seasonal annual sales volumes for each item, and technical data regarding quantity and typology of the vending machines installed in the campus.

The latter, instead, introduces additional information for background processes or where direct measurement was not feasible. This includes a literature review and a brief analysis of the machines to find the average energy consumption. To ensure a complete inventory, the background processes are sourced from specific databases like Agribalyse 3.2 to model the food and beverage supply chain and Ecoinvent 3.11 for the national production of energy, tap water and transportation services. Finally, to quantify the system's carbon footprint the LCIA is performed using the E.F 3.1 method, focusing on the Global Warming Potential impact category.

3.3 Life Cycle Inventory (LCI) and Data Collection

The composition of Life Cycle Inventory was performed in three separate steps: the assembly of the energy consumption profile, the reformulation of the sales database and the modelling of the products (food and beverages) within OpenLCA.

3.3.1 Finding the average energy consumption of the vending machines

Starting from the primary data regarding the various machine models installed at the campus, the first step consisted in quantifying the total annual energy demand of each item in the system. Since the literature does not offer a clear reference for categorizing vending machines, they are grouped here according to their functional role and the list of products they can offer, as a modelling choice introduced to simplify the analysis. The categorization encompasses three groups: beverage-only machines, combined snack-and-beverage machines, and coffee maker machines. Furthermore, it is accepted to consider modular or stackable vending units as individual entities for the purpose of this study.

3.3.1.1 Beverage-only machines

The analysis began with cold beverage vending machines, glass-fronted refrigerating units with vertical can/bottle columns. They contain spirals for stocking the beverages and gravity dispensing. These units are primarily characterized by a constant refrigeration cycle required to maintain products at a controlled temperature. In this case, the models present in the university are G. DRINK DM9 [14], and G. DRINK 9 5 [15].

Given the absence of direct on-site tests, energy demand is estimated through a literature review of technical reports of the producers. The energy profile is modelled as a 24-hour constant consumption, neglecting the power required for achieving the steady-state temperature both at the initial switch-on and after power cycling.

3.3.1.2 Combined snack-and-beverage machines

This vending machine has the charge of selling both food snacks, water and soft drinks. As in the previous category, these are all glass-fronted and continuously refrigerated. In this study, the models are SAMBA TOP FOOD 6X8 and 7X8 [16], MINISNAKKY 4x6 [17], [18], ARIA S SL 4x8 [19] and ARIA S MOD.M883 [20], [21].

Unlike the beverage-only machines, direct literature data for the average energy consumption of every specific model is not available, so a parametric estimation approach is adopted to fill the gaps. The reference model is, indeed, found through the literature review for a single machine model that is representative of the category (MINISNAKKY 4x6). The rated power instead, was available for all the vending machines. It is assumed that for machines manufactured in the same period, and with comparable energy efficiency it is proportional to the size of the unit.

To define the relationship between the dimensions of the reference model the ratio of the average energy consumption to the maximum power delivered is determined. This value is then assumed to be constant across similar technology machines. Given the rated power of all the other vending machines, the various average energy consumptions are obtained with the reverse formula.

3.3.1.3 Coffee maker machines

The third category comprehends machines dedicated to the preparation of hot beverages, like coffee. The models studied are LEI 600 PLUS 2ES-7 2B TCH [22], CANTO 2ES 2B TB 9S [23], BRIO UP [24], CANTO TOP 2ES 2B 9S [25], CONCERTO 2ES [26], SOLISTA ES6 [27], BRIO UP BLUE [28], LEI 301 [19], LEI 300-7 SMART/EASY SV [20], [21], LEI 300-7 TCH [20].

Unlike previous cases, the energy profile is influenced by the brewing process. Therefore, the energy consumption is decoupled to "idle state", defined as the period when the machine is on standby but not actively dispensing products, and "brewing state", when it heats water for product delivery. The total amount is calculated as the sum of these two contributions.

Concerning the first component, it refers to the energy required to maintain boiler temperature and standby state, assumed constant. Given the unavailability of literature data for every machine, through a literature analysis two reference average consumption data are identified, one for large "free-standing" units and one for more compact "table-top" units. These values are hence applied to all machines according to their size category.

In the "brewing" phase, instead, the amount of electricity is proportional to the number of products sold. From the brochures there was no information about the brewing consumption, so it was necessary to calculate it with a brief literature review [29]. Discovering that the majority of the models are equipped with a single type of motor, the Z4000 brewing group [30], the idea changed to extract data from OPERA ESPRESSO [31], a similar vending machine operating with the same apparatus.

Consequently, starting from its total and idle mode energy consumption related to the drink volume and the number of cups, the electricity demand for brewing one cup of coffee is determined to be 9,80 Wh. This unit value is then multiplied by the number of cups sold per machine (approximated as equal within each building) to find the total demand.

3.3.2 Product modelling in OpenLCA

Once determined the energy profile, the analysis moved to the main software to model each building. The data source varies according to the product's sales. For water bottles, information about the climate change is collected directly from Ferrarelle Environmental Product Declaration (EPD) [32].

Regarding coffee, instead, it is built a dedicated model of supply chain. This aggregates the raw green beans at distribution, available from Agribalyse 3.2 with the roasting process [33] and the previously mentioned electricity consumption required for the final brewing phase. Examining the overall sales, as shown below in Figure 1, coffee represents the predominant share of total sales. Since the share of the remaining hot beverages constitute, on average, less than 2% of the total amount, these products were not included in the modelling applying a cut-off criterion.

Finally, all other minor commercial products, such as snacks and soft drinks, are mapped as generic processes available in the same database without additional transformation. An exception is made for coffee capsules, which, due to lack of data, are represented through an EPD [34]. Since a limitation is encountered regarding the primary data nomenclature of snacks (e.g. Snack 1, Snack 2…), it is supposed an equal distribution between salty snacks and sweet products, respectively processed as generic crackers and biscuits.

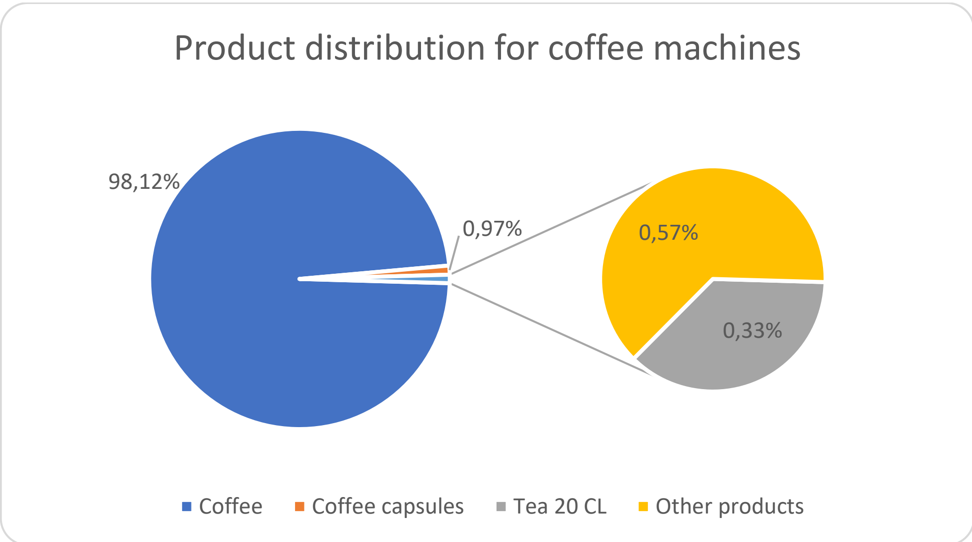

Figure 1: Product distribution for coffee vending machines

The category of interest and the modelling choice considered are summarized in Table 2. Every calculation step is treated as a single one in the same category. Processes modelled with Agribalyse 3.2 are configured with the parameters "Pack proxy" to assume a standardized packaging, "At distribution" which considers both production and transportation impacts, and "Ambient (long)" to prevent the use of refrigerated trucks.

Table 2: LCI of products

Product	Category	Database	Process
Electricity	Energy	Ecoinvent 3.11	Market for electricity, low voltage - IT
Raw coffee bean	Coffee	Agribalyse 3.2	Market for coffee, green bean
Coffee roasting process	Coffee	Literature review	Rahayuningtyas et al., (2024) [23]
Coffee brewing process	Coffee	Literature review	Francesco Vasta, (2020) [19]
Water bottle	Water bottle	EPD	Ferrarelle EPD, (2011) [32]
Fruit juice	Soft drinks	Agribalyse 3.2	Fruit juice, mixed – apple base, standard
Soft drinks (25 cl, 33 cl, 50 cl)	Soft drinks	Agribalyse 3.2	Soft drink, carbonated, without fruit juice, with sugar
Red Bull	Soft drinks	Agribalyse 3.2	Energy drink, with sugar
Tea	Soft drinks	Agribalyse 3.2	Tea, brewed, without sugar
Insalatissime Rio Mare	Snacks	Agribalyse 3.2	Prepared mixed tuna and vegetable salad, canned, drained | Already packed PET
Salamini Beretta	Snacks	Agribalyse 3.2	Dry sausage, pure pork
Gums and candies	Snacks	Agribalyse 3.2	Hard candy and lollipop
Snacks (generic salty)	Snacks	Agribalyse 3.2	Salty snacks, crackers, plain
Snacks (generic sweet)	Snacks	Agribalyse 3.2	Biscuit (cookie), snack w chocolate filling
Coffee capsule	Coffee	EPD	Desole et al., (2024) [24]

3.3.3 Process modelling in OpenLCA

The Life Cycle Inventory was implemented in the OpenLCA environment using a hierarchical structure.

This tree structure, visualized above in Figure 2, reflects the system's physical logic, organized into three operational levels: products, vending machines and buildings (or four, considering the university one). Following a bottom-up approach, the first tier consists in the basic flows and datasets for each component, considering the portioning phase between the database output (expressed in mass or volume) and the product (expressed in units). As explained in the previous section, every product is treated differently depending on its sales. In the graph, for simplicity, every product is grouped following its calculation method.

At the upper level, the LCI for vending machines is populated with electricity contribution and every product sold throughout the entire year. Given the total amount of item sales per building, rather than per individual machine, an average distribution method is applied. Specifically, it is assumed to divide them by the number of compatible dispensing units.

At the highest level of the graph, represented by a generic building N in the Bovisa campus, there is the final system process. This node groups the vending machines physically placed and produces the total environmental profile. Furthermore, this model makes it possible to highlight the aggregated environmental load associated with each machine category.

Finally, if the university level is included, it introduces a top-tier process, acting as the ultimate collector. With this process, broader scenarios can be made, giving the total footprint of the campus and comparing the environmental impact of buildings and/or sections of the university.

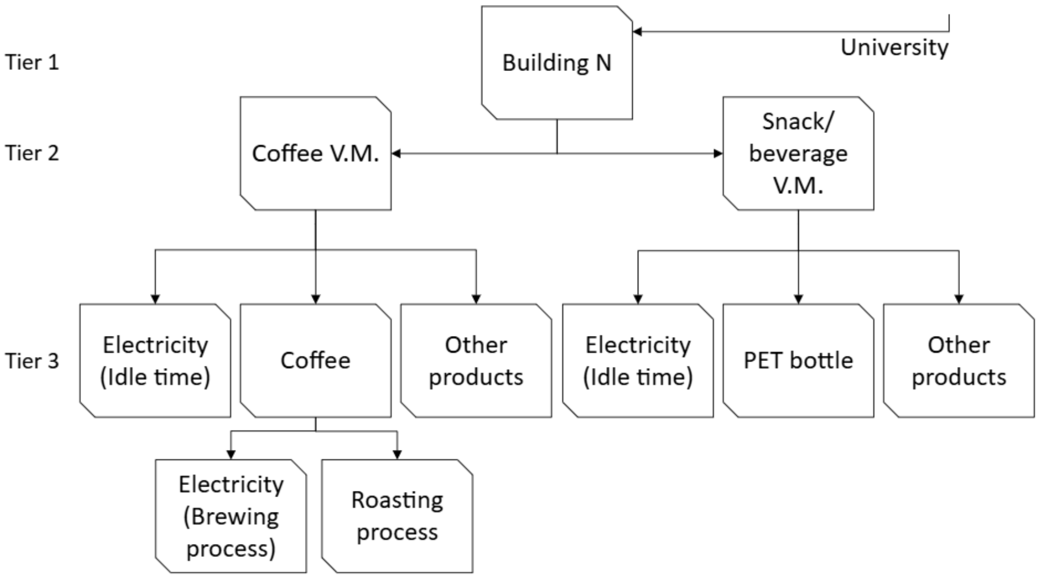

Figure 2: Tree structure of LCA processes

3.3.4 Scenario Analysis

In this case study, the baseline scenario, representing the current standard without sustainability measures (no-ren), is compared to a green one which integrates 30% renewable energy sources (ren). Methodologically, for each vending machine it is calculated the impacts for both scenarios, then the specific impact ratio between the renewable and baseline cases is determined by dividing the renewable case by the baseline one. In addition, to provide a more specific analysis of how the machine typology responds to the decarbonization of the energy supply, the results for coffee vending machines and snack-beverage machines have been decoupled.

4. Results and Discussion

This chapter presents the results of the Life Cycle Impact Assessment (LCIA), obtained from the OpenLCA product systems, in accordance with the methodology detailed in the previous chapter. Specifically, it is run a dedicated simulation for every building and every product, in order to obtain respectively the impact of every vending machine model and the global warming potential of one single unit of each food and beverage.

Consistent with the study's functional unit, defined as one year of operation of the entire system within the university campus, the cumulative GWP amounts to 112242 $kg\ CO_{2,eq}$, obtained by the sum of the total impact of each building. As shown in Figure 3, this value is distributed unevenly across the locations, with classroom and study area buildings like B27, B2 or B12 which together generate 47.47% of the annual GWP. Detailed values about buildings' impacts and number of vending machines can be found in Appendix 2.

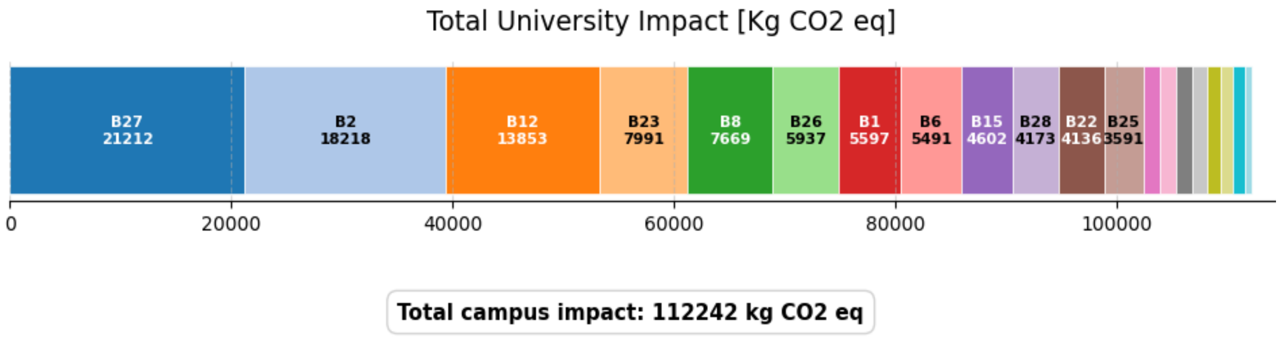

Figure 3: Total impact of the Bovisa campus

The resulting dataset is then grouped and managed via Excel tables and then structured into three levels of study, which include the product impact, the vending machine impact and an overall scenario analysis with a share of renewable energy. Every step is then discussed against the criteria of the database created from Italian and European regulations.

4.1 Product impact

Figure 4 details the percentage breakdown of the product environmental impact for each university building. To facilitate the comparison, the buildings are arranged along the x-axis in ascending order, based on the number of installed vending machines (indicated in parentheses), and the products are grouped following their category in Table 2 (Section 3.4.2).

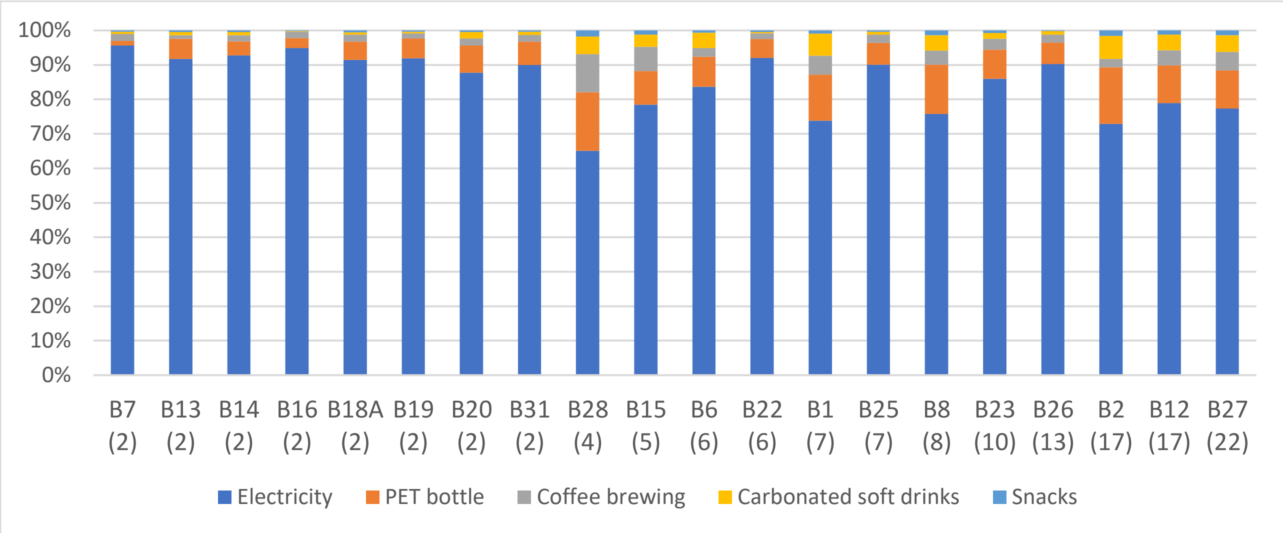

Figure 4: Product impact distribution (n° of machines)

A transversal analysis of the chart explains that the idle time electricity consumption (represented by the blue bars) remains the dominant category across the entire Bovisa campus. However, the relative weight varies significantly between the buildings, ranging from 65.1% in building B28 to 95.6% in building B7. Additional data on sales and percentages can be found in Appendix 3.

Observing the trend from left to right, a correlation between number of units and impact distribution can be determined. In buildings equipped with only 2 units (offices or less busy locations), the electricity share is very high, suggesting that the fixed energy load required for operation totally dominates the low sales per vending machine.

In locations with a high number of units instead, typically correspondent to high traffic areas like canteens or main lecture classrooms, the larger volume of sales allows for an amortization of idle time energy consumption, even though it remains the biggest percentage.

Building 28 is then a notable exception to be assessed. Despite being equipped with only 4 vending machines, it displays the lowest electricity share of the entire campus. This suggests that the units in this location have been operating at near maximum capacity.

To better visualize this difference, the dataset is grouped into three clusters, depending on their vending machine density (the value in the parentheses). The aggregated results, illustrated below in Figure 5, highlight the reduction and confirm that the impacts are associated with the idle mode required to maintain the service, and the number of sales per vending machine.

However, single-use PET bottles rank persistently as the second-largest environmental hotspot, due to their high sales and to their high impact for a single unit (0.064 Kg $CO_{2,\,eq}$), indicating that the material footprint and the water distribution method represent a side impact that should be addressed.

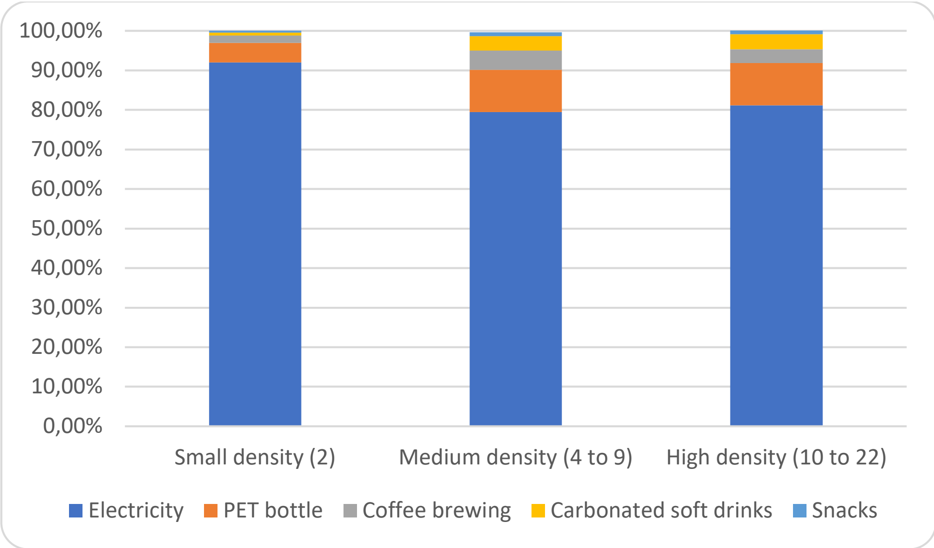

Figure 5: Product impact distribution – clusters (n° of machines)

The observing dominance of the electricity load in the refreshment area empirically validates the CAM's requirements regarding the energy classification of vending machines (codes 2.1.5, 2.2.5) and the core technical criteria of European GPPs, which asks the implementation of smart controls with "sleep mode" for the units (code TS3).

In fact, this empirical study would suggest that the number of each building's vending machines must be structured by its sales in order to enhance overall efficiency. However, the unit density in peripherical buildings is already at the minimum and in the busiest ones to guarantee service coverage it is very difficult to reduce the number. Consequently, the impact reduction must be necessarily driven by hardware performance.

Therefore, the energy efficiency requirements explained in the regulations must constitute the core criteria in future tenders. Since low-traffic vending machines spend their time in "idle mode" many hours per day, a strict compliance with the CAM regulation for high energy classes (according to protocols like EVA EMP or similar ones) and the presence of energy-saving software are non-negotiable "core criteria".

On the other hand, criteria related to sustainable food sourcing and green supply chain with associated organic certifications should be assessed as "award criteria". Indeed, keeping an eye on the empirical results, the impact factors related to food and beverages are mathematically secondary compared to electricity demand. Criteria like the percentage of recycled polyethylene terephthalate in water bottles (Codes 2.1.6, 2.2.3), the presence of drinkable water sources in each building (Code 5.1.1), and the amount of low-impact food (Code 2.2.2) for CAM and the European compliance with organics product standards (Code TS1.A) must act as effective differentiators to select the best bidder.

4.2 Vending machines impact

To isolate the specific hardware impact distribution in a location, the analysis focuses on a vending machine overview, selecting building B27 as the representative case study. As this location is the one with the highest density of vending machines (22 units) and with at least one model for each category explained in section 3.4.1 (only-beverages, snack and beverages and coffee machines), it provides a statistically significant sample to evaluate the environmental performance of the different typologies under high-stress operational conditions. Data for each model are presented in Table 3.

Table 3: B27 vending machines data

Model	Typology	Quantity	Nominal power	Idle time energy consumption
Samba Top Food	Snack-beverage	8	630 W	2538.65 kWh/y
G. Drink DM9	Only-beverage	6	800 W	2084.88 kWh/y
Canto Top	Coffee machine	5	2500 W	1188.81 kWh/y
LEI 600 Plus	Coffee machine	3	2350 W	1188.81 kWh/y

This table highlights the technological differences that drive the impact results. While snack and beverage machines are designed for continuous refrigeration, relying on compressor-based cooling cycles, coffee machines operate on an on-demand basis to heat water up for brewing. Therefore, the former needs a low nominal power distributed along the year to maintain the operational temperature, obtaining this relatively high idle time energy consumption. In contrast, the latter exhibits a high peak power demand during the short dispensing (explaining their high nominal power) but it maintains a lower impact during inactive periods.

The aggregated impact, by typology, shown below in Figure 6, illustrates the total Global Warming Potential (GWP) generated by the cumulative units of every model in the building. In the graph, the categories associated with cold storage, specifically the Samba Top food and the G. Drink, generate a significantly higher impact than the hot beverage units (Canto Top and LEI 600). This is the approximated function of both idle time energy consumption and number of products sales, which spectrum varies according to the machine category. However, as an aggregate value, this data are influenced by the number of installed units for each type and does not isolate the efficiency of the single hardware.

To eliminate this bias a second analysis is conducted by normalizing the dataset, with the results illustrated in Figure 7. By utilizing these values, focused on the performance of a single unit, the disparity between the two categories is confirmed. This refined perspective reveals that a single beverage-only or snack-beverage machine generates approximately twice the GWP of a coffee unit. Such findings validate the hypothesis that the continuous energy demand of refrigeration cycles represents a more significant environmental burden than the intermittent, high-intensity thermal requirements of brewing systems. In light of these results, it is recommended for contracting authorities to incorporate CAM thresholds into procurement protocols, prioritizing the selection of high-efficiency vending machines to lower this primary criterion.

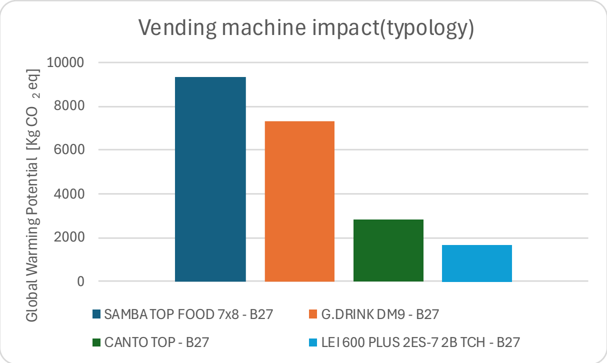

Figure 6: V.M. impact of B27, by typology

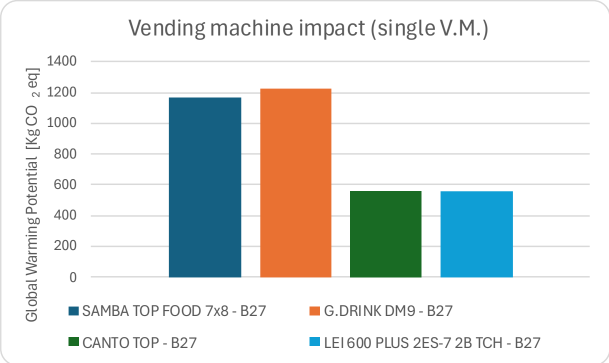

Figure 7: V.M. impact of B27, by single unit

4.3 Sensitivity Analysis

Since the previous analysis revealed that a predominant share of the environmental impacts of the vending machine service is assigned to electricity consumption, a scenario analysis is performed to assess how these impacts would change under a different share of renewable energy. This step is also motivated by the university intention of switching its energy source to renewables, as well as by the CAM principles, which require public institutions to quantify the potential benefit of adopting cleaner energy sources.

As shown below in Figure 8, the final data are normalized to the baseline case (set at 100%) to visually highlight the improvement. As expected, coffee machines reflect a notable impact reduction (22.4%) rather than the snack-beverage ones (19.0%), due to the overall high dependency by the electricity consumption assessed in the previous section.

The observed reduction of both the machine types (approximately 20%) is however particularly significant. This result is in fact obtained only through a partial modification of the energy mix without requiring any hardware replacement. Consequently, prioritizing energy criteria in Italian CAM and European GPP represents a highly cost-effective strategy to significantly reduce the university’s environmental footprint.

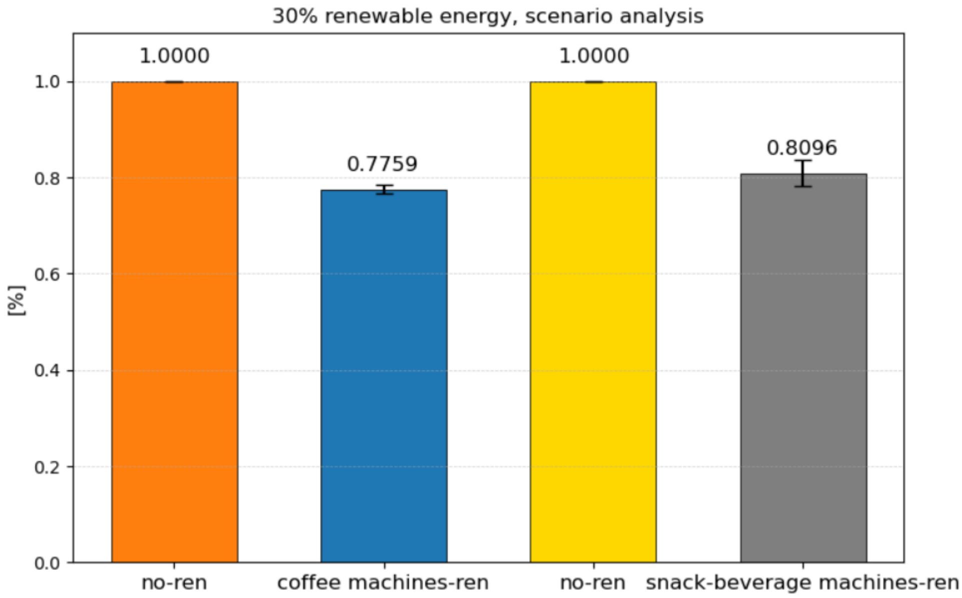

Figure 8: scenario analysis

5. Conclusions

The study investigates the vending machine network at the Bovisa campus of Politecnico di Milano, and utilizes regulations, technical sheets, EPDs and database data (from Agribalyse 3.2 and Ecoinvent 3.11) as secondary sources to conduct an LCA. Concretely, the research aimed to quantify the environmental load of the system and align procurement strategies with European GPP sustainability standards and their implementation into national legislation through the CAM (Minimum Environmental Criteria). As a result, it has been found a clear hierarchy of environmental hotspots, which can provide some guidelines for future tenders.

The LCA analysed every vending machine for each building, considering a full annual cycle of uninterrupted operation. The most striking finding is that across the entire campus, electricity consumption in the "idle/standby phase" is by far the single largest contributor to the Global Warming Potential impact category indicator, over the impact of the food and beverage production itself. This is even more pronounced in buildings with a small number of vending machines, where the sales volume per unit is too low compared to the fixed load required to keep them running.

In second chance, the results revealed a marked difference between the machine typologies, in particular temperature-controlled units (beverage-only and snack-and-beverage ones) and brewing units. The former indeed account for approximately twice the carbon footprint of coffee machines (shown in Figure 7, roughly $1200\, Kg_{CO2,eq}/y$ versus $600\, Kg_{CO2,eq}/y$), confirming that the refrigeration cycle, which must be performed regardless of the utilization level, is more critical than the sum of idle and brewing electricity.

The second-largest impact value is then given by the disposable PET water bottles, accounting for up to 17% where in Building B28 the sales-per-unit reaches the highest percentage. This relatively high amount, compared to the other food and beverage products, implies that the potable water issue should be considered for the procurement decisions, presenting also different ways for impact reduction, like recycled packaging or water delivery methods.

Based on these findings, the research aimed to select the ideal GPP topics to set guidelines for future university tenders. Following the European Regulation, it is chosen to group the environmental requirements into mandatory “Core criteria” and competitive “Award criteria”.

The decisional and obligatory “Core criteria” are structured to be the non-negotiable ones which create the first threshold for economic operators; hence they include all the indicators related to energy performance. Specifically, since the “idle time” electricity consumption has the highest impact, the selected criteria for the national CAM rely on vending machine energy efficiency (Codes 2.1.5, 2.2.5) and the presence of smart controls to track operational hours and standby periods (GPP code TS3). As demonstrated by the scenario analysis, the university should also keep an eye on the green energy procurement. Being also a cost-effective lever, it can reduce the total impact by roughly 20% without any hardware intervention.

After satisfying the mandatory requirements the contracting authority should also award points for criteria which are considered as secondary issues. High scores can be then assigned to sustainability solutions such as the percentage of recycled packaging and the introduction of water dispensers to reduce plastic waste in the water bottle industry. Lower-weighted but still relevant criteria are those related to food and beverage products, assigning scores for circular economy solutions, crucial for a social perspective, such as the introduction of organic and locally sourced food, waste prevention measures and other Triple Bottom Line (TBL) aspects.

This study is then focused on the Global Warming Potential related to energy and materials, future research could expand the scope to include hardware efficiency, especially regarding asset management. Indeed, in accordance with the Cradle-to-Gate approach, an option would be to integrate the impact related to ordinary and extraordinary maintenance, operational life of refrigerant gases and logistics improvements for daily refilling, such as route optimization or transition to electric vehicles.

Concerning the regulatory database, the analysis of GPP requirements served as a primary guideline to identify the main criteria to be considered for a future tender. Since the framework adopted in this case study represents only a first approximation, prospective research should aim to scale up this methodological approach. The ultimate goal of this evolution, out of the scope of the current thesis, would be to enable contracting tenderers and economic operators to simply input the CPV code of a specific product or service and automatically receive the full set of corresponding environmental criteria.

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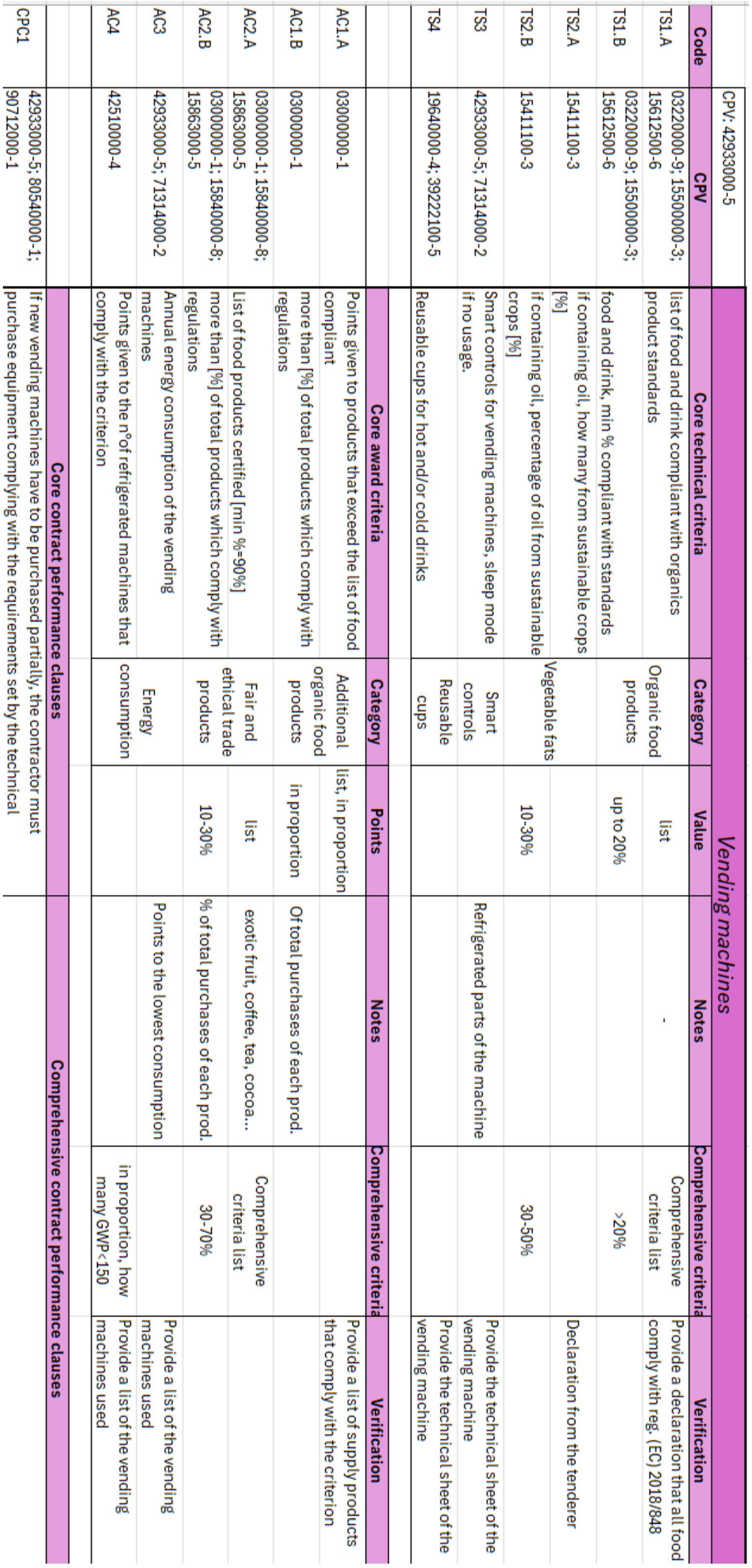
Appendix

6.1 Appendix 1



	CPV: 42933000-5	Vending machines					
Code	**CPV**	**Core technical criteria**	**Category**	**Value**	**Notes**	**Comprehensive criteria**	**Verification**
TS1.A	03220000-9; 15500000-3; 15612500-6	list of food and drink compliant with organics product standards	Organic food products	list	-	Comprehensive criteria list	Provide a declaration that all food comply with reg. (EC) 2018/848
TS1.B	03220000-9; 15500000-3; 15612500-6	food and drink, min % compliant with standards		up to 20%		>20%	
TS2.A	15411100-3	if containing oil, how many from sustainable crops [%]	Vegetable fats				Declaration from the tenderer
TS2.B	15411100-3	if containing oil, percentage of oil from sustainable crops [%]		10-30%		30-50%	
TS3	42933000-5; 71314000-2	Smart controls for vending machines, sleep mode if no usage.	Smart controls		Refrigerated parts of the machine		Provide the technical sheet of the vending machine
TS4	19640000-4; 39222100-5	Reusable cups for hot and/or cold drinks	Reusable cups				Provide the technical sheet of the vending machine
		Core award criteria	**Category**	**Points**	**Notes**	**Comprehensive criteria**	**Verification**
AC1.A	03000000-1	Points given to products that exceed the list of food compliant	Additional organic food products	list, in proportion			Provide a list of supply products that comply with the criterion
AC1.B	03000000-1	more than [%] of total products which comply with regulations		in proportion	Of total purchases of each prod.		
AC2.A	03000000-1; 15840000-8; 15863000-5	List of food products certified [min %=90%]	Fair and ethical trade products	list	exotic fruit, coffee, tea, cocoa...	Comprehensive criteria list	
AC2.B	03000000-1; 15840000-8; 15863000-5	more than [%] of total products which comply with regulations		10-30%	% of total purchases of each prod.	30-70%	
AC3	42933000-5; 71314000-2	Annual energy consumption of the vending machines	Energy consumption		Points to the lowest consumption		Provide a list of the vending machines used
AC4	42510000-4	Points given to the n°of refrigerated machines that comply with the criterion				in proportion, how many GWP<150	Provide a list of the vending machines used
		Core contract performance clauses			**Comprehensive contract performance clauses**		
CPC1	42933000-5; 80540000-1; 90712000-1	If new vending machines have to be purchased partially, the contractor must purchase equipment complying with the requirements set by the technical					

Figure 9: Section of the GPP database

6.2 Appendix 2

Number of machines	B1	B2	B6	B7	B8	B12	B13	B14	B15	B16	B18A	B19	B20	B22	B23	B25	B26	B27	B28	B31	n°
LEI 600 PLUS 2ES-7 2B TCH		1				2			1									3		1	8
CANTO 2ES 2B TB 9S	1	1			1																3
BRIO UP	1																				1
CANTO TOP 2ES 2B 9S	1	3	2	1	2	3			1		1		1	2	3	1	1	5	2		29
CONCERTO 2ES						2								1	1						4
SOLISTA ES6							1	1		1		1									4
BRIO UP BLUE																2					2
LEI 301																	3				3
LEI 300-7 SMART/EASY SV																	2				2
LEI 300-7 TCH																	1				1
SAMBA TOP FOOD 7x8				1											1			8	1	1	12
SAMBA TOP FOOD 6x8	2	7	2		4	7	1	1	2		1	1	1	3	4	2	1				39
MINISNAKKY 4x6	1									1						2					4
ARIA S SL 4x8																	3				3
ARIA S MOD.M883																	2				2
G.DRINK DM9	1	5	2		1	2			1						1			6	1		20
G.DRINK 9 5						1															1
Total per building	7	17	6	2	8	17	2	2	5	2	2	2	2	6	10	7	13	22	4	2	

Climate change [kg CO2 eq]	B1	B2	B6	B7	B8	B12	B13	B14	B15	B16	B18A	B19	B20	B22	B23	B25	B26	B27	B28	B31	TOTAL
LEI 600 PLUS 2ES-7 2B TCH		510,30				1010,9			582,82									1685,5		445,95	
CANTO 2ES 2B TB 9S	522,72	510,30			527,37																
BRIO UP	274,05																				
CANTO TOP 2ES 2B 9S	522,72	1530,9	976,99	445,95	1054,7	1516,4			582,82		449,28		449,47	881,52	1443,2	459,69	438,56	2809,2	1298,9		
CONCERTO 2ES						513,56								192,09	232,39						
SOLISTA ES6							183,10	191,24		179,89		186,97									
BRIO UP BLUE																363,78					
LEI 301																	569,67				
LEI 300-7 SMART/EASY SV																	379,78				
LEI 300-7 TCH																	189,89				
SAMBA TOP FOOD 7x8				925,12											1039,2			9369,8	1428,3	1011,0	
SAMBA TOP FOOD 6x8	2370,7	8998,5	2184,3		4818,4	7916,7	974,96	954,41	2251,2		983,63	969,31	1044,4	3063,1	4156,9	1922,4	966,15				
MINISNAKKY 4x6	646,75									372,23						845,20					
ARIA S SL 4x8																	1475,0				
ARIA S MOD.M883																	1918,7				
G.DRINK DM9	1260,5	6668,2	2329,8		1269,2	2397,0			1185,8						1119,9			7347,6	1445,9		
G.DRINK 9 5						499,32															
Total [kg CO2 eq]	5597,4	18218	5491,1	1371,1	7669,7	13854	1158,1	1145,7	4602,6	552,12	1432,9	1156,3	1493,9	4136,7	7991,6	3591	5937,8	21212	4173,1	1457	112242

Figure 10: Number of V.M. and total impact results for each building

6.3 Appendix 3

UNITS SOLD	B1	B2	B6	B7	B8	B12	B13	B14	B15	B16	B18A	B19	B20	B22	B23	B25	B26	B27	B28	B31
Water bottle - 50 CL	11551	46365	7419	288	16907	23434	1043	732	6880	248	1158	1041	1812	3386	10416	3565	5726	36396	10970	1529
Brik of Fruit juice - 20 CL	248	1908	197	34	591	901	91	82	125	9	72	31	33	148	359	167	129	1004	138	0
Soft drink - 25 CL	46	270	18	36	27	55	0	0	7	0	0	0	0	0	24	102	71	14	0	24
Soft drink - 33 CL	5254	17235	3268	156	5350	10092	177	177	2539	20	154	103	347	316	2318	526	825	15765	3037	171
Soft drink - 50 CL	1948	6999	1553	0	1453	2809	0	0	745	0	0	0	181	0	500	0	329	4818	1240	79
Red Bull	607	1432	262	4	539	896	0	0	252	0	0	0	49	0	97	10	25	1842	403	28
Tea - 20 CL	182	622	120	0	296	468	36	52	104	0	40	4	24	36	156	52	16	468	96	0
Insalatissime Rio Mare	54	248	22	0	88	192	0	0	60	0	0	0	29	0	70	4	0	366	53	0
Salamini Beretta	126	741	77	0	391	567	0	0	293	0	0	0	14	0	85	4	0	603	105	0
Gums and Candies	166	873	133	0	492	746	0	0	154	0	0	0	20	0	126	10	0	769	231	0
SNACK 1	1927	9896	1281	185	3503	6435	302	286	1450	31	334	263	147	720	2470	477	560	8744	2370	556
SNACK 2	1990	11148	1775	362	4315	6761	306	315	2605	34	313	287	295	741	2196	771	591	14081	3279	157
SNACK 3	1017	5373	690	193	1866	2824	76	100	1121	0	279	67	157	402	1303	342	354	7703	1689	96
SNACK 4	1773	9882	1310	177	3780	6151	395	296	2541	110	449	314	344	1097	2578	780	453	11424	3092	298
SNACK 5	2185	13375	2001	318	4399	7055	153	175	2178	13	361	91	286	485	2473	677	0	16466	3730	307
SNACK 6	674	3837	509	48	1181	1755	55	54	1173	0	108	30	110	234	940	121	425	4332	1162	0
SNACK 7	1627	8531	967	84	3662	5058	106	125	1105	10	145	60	135	469	1113	280	325	4827	1350	105
Coffee Capsule	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8100	0	0	0	0

PRODUCT IMPACT	B1	B2	B6	B7	B8	B12	B13	B14	B15	B16	B18A	B19	B20	B22	B23	B25	B26	B27	B28	B31	Unitary impact
Electricity	4132,43	13273,8	4595,18	1311,04	5812,59	10940,4	1062,37	1062,37	3608,63	523,791	1311,04	1062,37	1311,04	3684,46	6874,96	3251,53	5389,21	16407,6	2715,73	1311,04	-
Coffee brewing	308,076	441,59	137,002	27,8153	318,505	596,685	12,5199	20,1676	326,152	10,4287	29,9011	17,3866	30,5963	66,76	246,883	61,9814	142,569	1134,95	459,672	27,8153	0,00638
Water bottle - 50 CL	746,66	2997,03	479,56	18,62	1092,87	1514,77	67,42	47,32	444,72	16,03	74,85	67,29	117,13	218,87	673,29	230,44	370,13	2352,64	709,10	98,83	0,06464
Brik of Fruit juice - 20 CL	5,04	38,79	4,01	0,69	12,02	18,32	1,85	1,67	2,54	0,18	1,46	0,63	0,67	3,01	7,30	3,40	2,62	20,41	2,81	0,00	0,02033
Soft drink - 25 CL	1,43	8,37	0,56	1,12	0,84	1,71	0,00	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,74	3,16	2,20	0,43	0,00	0,74	0,03101
Soft drink - 33 CL	211,21	692,85	131,37	6,27	215,07	405,70	7,12	7,12	102,07	0,80	6,19	4,14	13,95	12,70	93,18	21,15	33,17	633,75	122,09	6,87	0,0402
Soft drink - 50 CL	117,46	422,04	93,65	0,00	87,62	169,38	0,00	0,00	44,92	0,00	0,00	0,00	10,91	0,00	30,15	0,00	19,84	290,53	74,77	4,76	0,0603
Red Bull	19,05	44,94	8,22	0,13	16,91	28,12	0,00	0,00	7,91	0,00	0,00	0,00	1,54	0,00	3,04	0,31	0,78	57,80	12,65	0,88	0,03138
Tea - 20 CL	5,65	19,30	3,72	0,00	9,18	14,52	1,12	1,61	3,23	0,00	1,24	0,12	0,74	1,12	4,84	1,61	0,50	14,52	2,98	0,00	0,03103
Insalatissime Rio Mare	1,42	6,52	0,58	0,00	2,31	5,05	0,00	0,00	1,58	0,00	0,00	0,00	0,76	0,00	1,84	0,11	0,00	9,62	1,39	0,00	0,02628
Salamini Beretta	1,26	7,40	0,77	0,00	3,90	5,66	0,00	0,00	2,92	0,00	0,00	0,00	0,14	0,00	0,85	0,04	0,00	6,02	1,05	0,00	0,00998
Gums and Candies	0,62	3,27	0,50	0,00	1,84	2,79	0,00	0,00	0,58	0,00	0,00	0,00	0,07	0,00	0,47	0,04	0,00	2,88	0,86	0,00	0,00374
SNACK 1	5,38	27,61	3,57	0,52	9,77	17,95	0,84	0,80	4,05	0,09	0,93	0,73	0,41	2,01	6,89	1,33	1,56	24,40	6,61	1,55	0,00279
SNACK 2	5,55	31,10	4,95	1,01	12,04	18,86	0,85	0,88	7,27	0,09	0,87	0,80	0,82	2,07	6,13	2,15	1,65	39,29	9,15	0,44	0,00279
SNACK 3	2,84	14,99	1,93	0,54	5,21	7,88	0,21	0,28	3,13	0,00	0,78	0,19	0,44	1,12	3,64	0,95	0,99	21,49	4,71	0,27	0,00279
SNACK 4	9,40	52,37	6,94	0,94	20,03	32,60	2,09	1,57	13,47	0,58	2,38	1,66	1,82	5,81	13,66	4,13	2,40	60,55	16,39	1,58	0,0053
SNACK 5	11,58	70,89	10,61	1,69	23,31	37,39	0,81	0,93	11,54	0,07	1,91	0,48	1,52	2,57	13,11	3,59	0,00	87,27	19,77	1,63	0,0053
SNACK 6	3,57	20,34	2,70	0,25	6,26	9,30	0,29	0,29	6,22	0,00	0,57	0,16	0,58	1,24	4,98	0,64	2,25	22,96	6,16	0,00	0,0053
SNACK 7	8,62	45,21	5,13	0,45	19,41	26,81	0,56	0,66	5,86	0,05	0,77	0,32	0,72	2,49	5,90	1,48	1,72	25,58	7,16	0,56	0,0053
Coffee Capsule	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	23,81	0,00	0,00	0,00	0,00	0,00294
Sum	5597,45	18218,2	5491,1	1371,07	7669,69	13853,9	1158,06	1145,65	4602,64	552,123	1432,91	1156,28	1493,86	4136,67	7991,65	3591,03	5937,78	21212	4173,08	1456,97	

Figure 11: Product sales and impact by building

	LOW DENSITY								MEDIUM DENSITY							HIGH DENSITY				
N° OF V.M.	2	2	2	2	2	2	2	2	4	5	6	6	7	7	8	10	13	17	17	22
BUILDING	B7	B13	B14	B16	B18A	B19	B20	B31	B28	B15	B6	B22	B1	B25	B8	B23	B26	B2	B12	B27
Electricity	95,62%	91,74%	92,73%	94,87%	91,50%	91,88%	87,76%	89,98%	65,08%	78,40%	83,68%	89,07%	73,83%	90,55%	75,79%	86,03%	90,76%	72,86%	78,97%	77,35%
Coffee brewing	2,03%	1,08%	1,76%	1,89%	2,09%	1,50%	2,05%	1,91%	11,02%	7,09%	2,49%	1,61%	5,50%	1,73%	4,15%	3,09%	2,40%	2,42%	4,31%	5,35%
B_ACQUA 1 PET 50 CL	1,36%	5,82%	4,13%	2,90%	5,22%	5,82%	7,84%	6,78%	16,99%	9,66%	8,73%	5,29%	13,34%	6,42%	14,25%	8,42%	6,23%	16,45%	10,93%	11,09%
B_BRIK 1 20 CL	0,05%	0,16%	0,15%	0,03%	0,10%	0,05%	0,04%	0,00%	0,07%	0,06%	0,07%	0,07%	0,09%	0,09%	0,16%	0,09%	0,04%	0,21%	0,13%	0,10%
Soft drink 25 CL	0,08%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,05%	0,00%	0,00%	0,01%	0,00%	0,03%	0,09%	0,01%	0,01%	0,04%	0,05%	0,01%	0,00%
Soft drink 33 CL	0,46%	0,61%	0,62%	0,15%	0,43%	0,36%	0,93%	0,47%	2,93%	2,22%	2,39%	0,31%	3,77%	0,59%	2,80%	1,17%	0,56%	3,80%	2,93%	2,99%
Soft drink 1 50 CL	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,73%	0,33%	1,79%	0,98%	1,71%	0,00%	2,10%	0,00%	1,14%	0,38%	0,33%	2,32%	1,22%	1,37%
B_RED BULL	0,01%	0,00%	0,00%	0,00%	0,00%	0,00%	0,10%	0,06%	0,30%	0,17%	0,15%	0,00%	0,34%	0,01%	0,22%	0,04%	0,01%	0,25%	0,20%	0,27%
B_THE BICCHIERE 20 CL	0,00%	0,10%	0,14%	0,00%	0,09%	0,01%	0,05%	0,00%	0,07%	0,07%	0,07%	0,03%	0,10%	0,04%	0,12%	0,06%	0,01%	0,11%	0,10%	0,07%
F_INSALATISSIME RIO	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,05%	0,00%	0,03%	0,03%	0,01%	0,00%	0,03%	0,00%	0,03%	0,02%	0,00%	0,04%	0,04%	0,05%
F_SALAMINI BERETTA	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,01%	0,00%	0,03%	0,06%	0,01%	0,00%	0,02%	0,00%	0,05%	0,01%	0,00%	0,04%	0,04%	0,03%
S_GOMME/CARAM. 2	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,01%	0,00%	0,02%	0,01%	0,01%	0,00%	0,01%	0,00%	0,02%	0,01%	0,00%	0,02%	0,02%	0,01%
S_SNACK 1	0,04%	0,07%	0,07%	0,02%	0,07%	0,06%	0,03%	0,11%	0,16%	0,09%	0,07%	0,05%	0,10%	0,04%	0,13%	0,09%	0,03%	0,15%	0,13%	0,12%
S_SNACK 2	0,07%	0,07%	0,08%	0,02%	0,06%	0,07%	0,06%	0,03%	0,22%	0,16%	0,09%	0,05%	0,10%	0,06%	0,16%	0,08%	0,03%	0,17%	0,14%	0,19%
S_SNACK 3	0,04%	0,02%	0,02%	0,00%	0,05%	0,02%	0,03%	0,02%	0,11%	0,07%	0,04%	0,03%	0,05%	0,03%	0,07%	0,05%	0,02%	0,08%	0,06%	0,10%
S_SNACK 4	0,07%	0,18%	0,14%	0,11%	0,17%	0,14%	0,12%	0,11%	0,39%	0,29%	0,13%	0,14%	0,17%	0,12%	0,26%	0,17%	0,04%	0,29%	0,24%	0,29%
S_SNACK 5	0,12%	0,07%	0,08%	0,01%	0,13%	0,04%	0,10%	0,11%	0,47%	0,25%	0,19%	0,06%	0,21%	0,10%	0,30%	0,16%	0,00%	0,39%	0,27%	0,41%
S_SNACK 6	0,02%	0,03%	0,02%	0,00%	0,04%	0,01%	0,04%	0,00%	0,15%	0,14%	0,05%	0,03%	0,06%	0,02%	0,08%	0,06%	0,04%	0,11%	0,07%	0,11%
S_SNACK 7	0,03%	0,05%	0,06%	0,01%	0,05%	0,03%	0,05%	0,04%	0,17%	0,13%	0,09%	0,06%	0,15%	0,04%	0,25%	0,07%	0,03%	0,25%	0,19%	0,12%
R_CAFFE CAPSULA	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,66%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

	B7	B13	B14	B16	B18A	B19	B20	B31	B28	B15	B6	B22	B1	B25	B8	B23	B26	B2	B12	B27
Electricity	95,62%	91,74%	92,73%	94,87%	91,50%	91,88%	87,76%	89,98%	65,08%	78,40%	83,68%	89,07%	73,83%	90,55%	75,79%	86,03%	90,76%	72,86%	78,97%	77,35%
PET bottle	1,36%	5,82%	4,13%	2,90%	5,22%	5,82%	7,84%	6,78%	16,99%	9,66%	8,73%	5,29%	13,34%	6,42%	14,25%	8,42%	6,23%	16,45%	10,93%	11,09%
Coffee brewing	2,03%	1,08%	1,76%	1,89%	2,09%	1,50%	2,05%	1,91%	11,02%	7,09%	2,49%	1,61%	5,50%	2,39%	4,15%	3,09%	2,40%	2,42%	4,31%	5,35%
Carbonated soft drinks	0,60%	0,87%	0,91%	0,18%	0,62%	0,42%	1,86%	0,91%	5,16%	3,50%	4,40%	0,41%	6,43%	0,83%	4,45%	1,74%	1,00%	6,73%	4,60%	4,80%
Snacks	0,39%	0,49%	0,47%	0,16%	0,57%	0,38%	0,49%	0,41%	1,76%	1,23%	0,69%	0,42%	0,90%	0,40%	1,36%	0,72%	0,18%	1,54%	1,19%	1,41%

	Small density (2)	Medium density (4 to 9)	High density (10 to 22)
Electricity	92,01%	79,48%	81,19%
PET bottle	4,99%	10,67%	10,63%
Coffee brewing	1,79%	4,89%	3,51%
Carbonated soft drinks	0,80%	3,60%	3,77%
Snacks	0,42%	0,96%	1,01%

Figure 12: Impact percentages and subdivision into clusters

6.4 Appendix 4

BASELINE CASE

Climate change [kg CO2 eq]	B1	B2	B6	B7	B8	B12	B13	B14	B15	B16	B18A	B19	B20	B22	B23	B25	B26	B27	B28	B31
LEI 600 PLUS 2ES-7 2B TCH		510,3				1010,9			582,82									1685,5		445,95
CANTO 2ES 2B TB 9S	522,72	510,3			527,37															
BRIO UP	274,05																			
CANTO TOP 2ES 2B 9S	522,72	1530,9	976,99	445,95	1054,7	1516,4			582,82		449,28		449,47	881,52	1443,2	459,69	438,56	2809,2	1298,9	
CONCERTO 2ES						513,56								192,09	232,39					
SOLISTA ES6							183,1	191,24		179,89		186,97								
BRIO UP BLUE																363,78				
LEI 301																	569,67			
LEI 300-7 SMART/EASY SV																	379,78			
LEI 300-7 TCH																	189,89			
SAMBA TOP FOOD 7x8				925,12											1039,2			9369,8	1428,3	1011
SAMBA TOP FOOD 6x8	2370,7	8998,5	2184,3		4818,4	7916,7	974,96	954,41	2251,2		983,63	969,31	1044,4	3063,1	4156,9	1922,4	966,15			
MINISNAKKY 4x6	646,75									372,23						845,2				
ARIA S SL 4x8																	1475			
ARIA S MOD.M883																	1918,7			
G.DRINK DM9	1260,5	6668,2	2329,8		1269,2	2397			1185,8						1119,9			7347,6	1445,9	
G.DRINK 9 5						499,32														
Total	5597,4	18218	5491,1	1371,1	7669,7	13854	1158,1	1145,7	4602,6	552,12	1432,9	1156,3	1493,9	4136,7	7991,6	3591	5937,8	21212	4173,1	1457

30% RENEWABLES

Climate change [kg CO2 eq]	B1	B2	B6	B7	B8	B12	B13	B14	B15	B16	B18A	B19	B20	B22	B23	B25	B26	B27	B28	B31
LEI 600 PLUS 2ES-7 2B TCH		397,26				785,76			458,4									1321,9		342,12
CANTO 2ES 2B TB 9S	407,49	397,26			411,62															
BRIO UP	218,05																			
CANTO TOP 2ES 2B 9S	407,49	1191,8	756,95	342,12	823,23	1178,6			458,4		345,13		345,22	675,56	1116,2	353,85	335,87	2203,2	1029,7	
CONCERTO 2ES						406,88								148,34	182,63					
SOLISTA ES6							140,83	147,81		137,94		143,96								
BRIO UP BLUE																283,06				
LEI 301																	439,28			
LEI 300-7 SMART/EASY SV																	292,85			
LEI 300-7 TCH																	146,43			
SAMBA TOP FOOD 7x8				712,44											826,55			7668,4	1215,6	798,34
SAMBA TOP FOOD 6x8	1945,3	7509,8	1758,9		3967,7	6428	762,28	741,73	1825,9		837,87	756,64	831,71	2425	3306,2	1497	753,47			
MINISNAKKY 4x6	562,36									287,84						676,41				
ARIA S SL 4x8																	1171,2			
ARIA S MOD.M883																	1493,4			
G.DRINK DM9	1025,6	5493,2	1859,9		1034,2	1927,1			950,78						884,93			5937,7	1210,9	
G.DRINK 9 5						430,87														
Total	4566,3	14989	4375,7	1054,6	6236,7	11157	903,11	889,54	3693,5	425,78	1183	900,6	1176,9	3248,9	6316,6	2810,3	4632,4	17131	3456,2	1140,5

Figure 13: Climate change impact of Baseline case and new scenario

SENSITIVITY ANALYSIS

New/Old scenario [%]	B1	B2	B6	B7	B8	B12	B13	B14	B15	B16	B18A	B19	B20	B22	B23	B25	B26	B27	B28	B31
LEI 600 PLUS 2ES-7 2B TCH		0,7785				0,7773			0,7865									0,7843		0,7672
CANTO 2ES 2B TB 9S	0,7796	0,7785			0,7805															
BRIO UP	0,7957																			
CANTO TOP 2ES 2B 9S	0,7796	0,7785	0,7748	0,7672	0,7805	0,7773			0,7865		0,7682		0,7681	0,7664	0,7734	0,7698	0,7658	0,7843	0,7928	
CONCERTO 2ES						0,7923								0,7722	0,7859					
SOLISTA ES6							0,7691	0,7729		0,7668		0,77								
BRIO UP BLUE																0,7781				
LEI 301																	0,7711			
LEI 300-7 SMART/EASY SV																	0,7711			
LEI 300-7 TCH																	0,7711			
SAMBA TOP FOOD 7x8				0,7701											0,7954			0,8184	0,8511	0,7896
SAMBA TOP FOOD 6x8	0,8206	0,8346	0,8053		0,8234	0,812	0,7819	0,7772	0,8111		0,8518	0,7806	0,7964	0,7917	0,7954	0,7787	0,7799			
MINISNAKKY 4x6	0,8695									0,7733						0,8003				
ARIA S SL 4x8																	0,794			
ARIA S MOD.M883																	0,7783			
G.DRINK DM9	0,8136	0,8238	0,7983		0,8149	0,8039			0,8018						0,7902			0,8081	0,8375	
G.DRINK 9 5						0,8629														

New/Old scenario	Mean %	% By category	Standard dev.	Reference value
LEI 600 PLUS 2ES-7 2B TCH	77,87%	77,74%	0,79%	100,00%
CANTO 2ES 2B TB 9S	77,95%			
BRIO UP	79,57%			
CANTO TOP 2ES 2B 9S	77,55%			
CONCERTO 2ES	78,35%			
SOLISTA ES6	76,97%			
BRIO UP BLUE	77,81%			
LEI 301	77,11%			
LEI 300-7 SMART/EASY SV	77,11%			
LEI 300-7 TCH	77,11%			
SAMBA TOP FOOD 7x8	80,49%	80,96%	2,63%	100,00%
SAMBA TOP FOOD 6x8	80,27%			
MINISNAKKY 4x6	81,44%			
ARIA S SL 4x8	79,40%			
ARIA S MOD.M883	77,83%			
G.DRINK DM9	81,02%			
G.DRINK 9 5	86,29%			

Figure 14: Sensitivity analysis