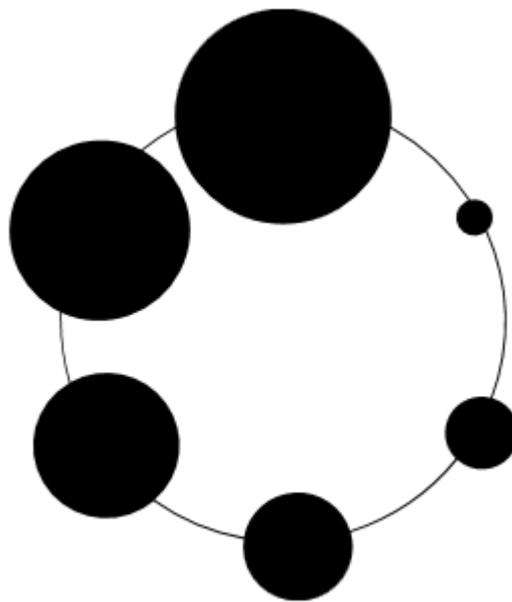


D2.3: STRUCTURED REPOSITORY OF EXISTING LCC CALCULATION TOOLS



COST REDUCTION AND MARKET ACCELERATION FOR VIABLE NEARLY ZERO-EN- ERGY BUILDINGS

Effective processes, robust solutions, new business models and reliable life cycle costs, supporting user engagement and investors' confidence towards net zero balance.

CRAVEzero - Grant Agreement No. 741223
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Framework Programme of the European Union



D2.3: STRUCTURED REPOSITORY OF EXISTING LCC CALCULATION TOOLS

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FOREWORD

This report has been developed within Task 2.3 of the project CRAVEZero that aims to provide a support framework for the planning of nZEBs in a Life Cycle Cost (LCC) perspective by setting-up a structured repository of LCC tools.

Cost optimal and nearly zero energy performance levels are principles initiated by the European Union's (EU) Energy Performance of Buildings Directive, which was recast in 2010. These will be major drivers in the construction sector in the next few years because all new buildings in the EU from 2021 onwards are expected to be nearly zero energy buildings (nZEB).

While nZEBs realised so far have clearly shown that the nearly-zero energy target can be achieved using existing technologies and practices, most experts

agree that a broad-scale shift towards nearly-zero energy buildings requires significant adjustments to current building market structures. Cost-effective integration of efficient solution sets and renewable energy systems, in a form that fits with the development, manufacturing and construction industry processes, as well as with planning, design, and procurement procedures, are the major challenges.

CRAVEzero will focus on proven and new approaches to reduce the costs of Nearly Zero Energy Buildings (nZEBs) at all stages of the life cycle. The main goal is to identify and eliminate the extra costs for nZEBs related to processes, technologies, building operation, and to promote innovative business models taking into account the cost-effectiveness for all the stakeholders.

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EXECUTIVE SUMMARY

Within Task 2.3 eurac research, with the support of AEE-INTEC and ATP Sustain, developed a structured analysis of existing LCC evaluation tools, underlining features, complementarity, overlapping and providing information on the suitability of the tools according to the purpose of the evaluation.

This report presents the results of the activity, with a description of the analysed tools and of the structured repository.

The first part, reports a general overview with a brief description of the main features for each analysed tool, as reported in Table 1.

Table 1. Overview of the analysed tools

	NAME	DEVELOPER	LICENCE	DATA LOCATION	VIEWING PERSPECTIVE	REFERENCE LINK
1	RETScreen Expert	Government of Canada	Viewer: Free Professional: Annual fee	International	Designers	http://www.nrcan.gc.ca/energy/software-tools/7465
2	BLCC5	National Institute of Standards and Technology (NIST)	Free	US	Designers	https://www.energy.gov/eere/femp/building-life-cycle-cost-programs
3	Harvard LCC	Harvard University	Free	US-Harvard specific	Designers	https://green.harvard.edu/topics/green-buildings/life-cycle-costing
4	University of California LCC	University of California	Free	US	Designers, energy managers	Download excel
5	Sweden LCC procurement	Sweden national agency for public procurement	Free	Sweden	Contracting Authorities-Suppliers	https://www.upphandlingsmyndigheten.se/en/subject-areas/lcc-tools/
6	SMART SPP LCC-CO₂	SMART SPP consortium	Free	Europe	Contracting Authorities-Suppliers	http://www.smart-spp.eu/index.php?id=6988
7	GaBi - Thinkstep	Thinkstep Gabi	Free 30-days trial	Europe	Designers	http://www.gabi-software.com/software/gabi-software/gabi/functionalities/life-cycle-costing/
8	Econ Calc	Energy Institute of Vorarlberg	Free	Europe	Designers	https://www.energieinstitut.at/unternehmen/werkzeugkasten/wirtschaftlichkeitsrechner-econ-calc/
9	LZK-Tool ATPsustain	ATPsustain	N.A. ¹	Europe	Designers	Developed by ATP Sustain for internal use
10	LEGEP	Legep	Free trial	Europe	Designers	https://legep.de/?lang=en

¹ The tool is not publicly available, but it has been developed by ATP Sustain for internal use

The repository of the tool is structured in three sections: analysis of the inputs needed for the calculation, analysis of the outputs provided and main features of the tools.

ANALYSIS OF THE INPUTS

The first decision criteria for adopting an LCC tool is the availability of information, thus using a more detailed tool in case of lacking inputs could not be

cost-effective. In order to provide a clear overview of the cost information that the user of each tool is requested to enter as inputs, a structured categorisation of costs over the building life cycle of has been adopted according to the scheme of cost categories elaborated by the European Committee of Construction Economist (CEEC). In particular, the inputs included in the analysis are the following:

- (i) *Site acquisition*: costs associated with the acquisition of the project's site.
- (ii) *Project funding*: financial information, possible grants and subsidies of the projects, taxes on funding.
- (iii) *Construction costs*: building cost inputs and to all external works costs.
- (iv) *Labour costs*: costs and fees associated with labour in any part of the process.
- (v) *Incidental costs*: bidding process, ancillary costs and charges, project budget risk allowances that the user might enter
- (vi) *Costs in use*: maintenance, operation and end of life costs
- (vii) *Incentives*: building rentals or any other utility rebates

The analysis highlights RETScreen as the most comprehensive tool, including most of the inputs, as well as EconCalc that require a high level of detail. Accordingly, the application of RETScreen and EconCalc suits a detailed level of design and evaluations, where there is a significant availability of information about the new building. In case of lack of data or uncertain inputs, other tools could suit more the analysis (i.e. Smart SPP, LCC elaborated by the University of California and the Harvard LCC calculator).

The other tools present an average level of detail and they can be adopted during the final design phase since they include a good insight of the construction costs (in case of BLCC5 the costs are aggregated, while the other tools are more detailed). Figure 1, shows an overview of the level of detail of the tool, considering the suitability for the three design phases: early, definitive and executive

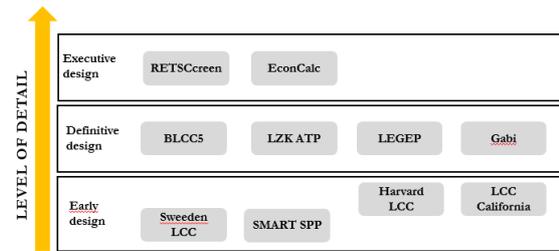


Figure 1. Overview of the level of detail of the tools

ANALYSIS OF OUTPUTS

Starting from the same reference [21], the structure of the output analysis is implemented in a comparative check-list. In particular, output data were gathered and grouped into two categories:

- (i) **Financial outputs**, such as LCC costs, savings and any financial ratios indicating the feasibility of the projects analysed.
- (ii) **Energy-related outputs**; in this category, outputs associated with the environmental impact of the projects (both energy and CO₂ emissions) are listed, as well as energy costs and savings outputs.

The analysis highlighted that EconCalc and RETScreen provide a comprehensive overview regarding financial indicators, including the possibility to compare solutions regarding costs and benefits, calculating savings and the payback of the solutions. On the other hand, the tool developed by the University of California is the more synthetic one, calculating only one indicator (i.e. LCC). LCC is a common output also for the other tools classified, in the previous section, as suitable for the early design stage. Finally, it is important to point out that SMART SPP provide, as an output, the evaluation of the proposed solutions as decision support for assessing the cost-effectiveness in a tender process.

FEATURES OF THE TOOLS

The third pillar of the repository of LCC tools is the analysis of the offered features. Considering that the comparison of the features is sometimes quite difficult since the tools have different structures and characteristic, three categories are identified:

- (i) Software interface and flexibility: user-friendly orientation & User support, flexibility in data inputs/manual entries, transferability to national contexts, suitability for the early stage of planning and renovation projects.
- (ii) Data management: integration of databases, integration of case studies/templates, development of CBS
- (iii) Calculation and export: total cost determination, generation of cost estimates, calculation of energy/ utility savings, determination of high-cost contributors, uncertainty analysis,

CONCLUSIONS

This report includes a significant amount LCC tools summarising the main features and the input-output list. The analysis highlighted some standard features, like the suitability also for renovation projects (and not only for new constructions), detailed documentation for user support, possibility to compare different scenarios.

There are also a couple of limiting factors that occur, like the limitation of the study length (that is maximum 25 years) and the limitation to one currency.

Another significant result of this report is the identification of the uncommon features of the tool, that represent interesting development inputs for the CRAVEZero LCC tool. In particular, the main identified ones are:

- (i) the potential adaptation of the tool to national contexts,
- (ii) the possibility to generate a reliable cost estimation through reference databases for

sensitivity/risk analysis, graphical display of results, comparison of results, creation of report.

Apart from RETScreen, which results in the most comprehensive tool regarding features, the functionalities of the other tools are quite comparable, ranging from 41 % to 59 %. The two easiest tools, i.e. LCC of California University and Harvard LCC, present the lowest compliance with the features, respectively 18 % and 29 %.

construction elements Identification of the elements and costs that mainly affects the LCC

- (iii) Suitability for early design (i.e. possibility to simplify the building features and change the level of the analysis)

- (iv) Sensitivity analysis of the inputs values

Moreover, although is explicitly indicated in the standard EN 15686-5 [9], none of the analysed tools implement an algorithm to perform an uncertainty analysis, that would allow verifying the impact of uncertain input variables (e.g. interest rate, cost of maintenance, inflation) on the building life cycle.

This would be a key feature to be included in CRAVEZero tool/ CRAVEzero pinboard, for providing the user with a higher awareness of the reliability of the results, and for identifying the most suitable design solutions according to the uncertain data.

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1. INTRODUCTION

The project CRAVEZero aims to identify the extra-costs of nZEBs during the life cycle in order to provide solutions for their reduction optimising technologies, processes and business models. In this regard, within the project is under elaboration the CRAVEZero LCC tool, which will implement the achievements of the project to support the designers of future nZEBs in the project preparation having a life-cycle perspective.

Anyway, there are several existing tools available on the market, and Task 2.3 aims to analyse their features in order to create a structured repository of LCC evaluation software.

This repository will be, on the one hand, the base for defining the features of the CRAVEZero LCC tool and, on the other hand, an interesting reference for the designers and decision makers who need to perform an LCC analysis of buildings and technical solutions.

This report, the deliverable D2.3, includes a general overview of ten tools in English or German language, which are online available (at least with a free temporary version). Although the tool is not publicly

available, the report describes also the characteristic of also LZK-Tool, since it has been developed by the project partner ATPsustain for internal use. Moreover, it the report includes the description of the repository structure, including the analysed features and references.

The tools are analysed regarding inputs, outputs and software technical features. For the analysis, it is important to define a common structure for assessing tools having a different level of detail, specific aims and targeted stakeholders. In this regard, the repository is based on the approach developed by the European Committee of Construction Economists (CEEC), which provides an EU-wide structure for LCC analysis [1].

At the current stage of development, the repository includes ten tools. Nevertheless, it could be integrated at any time, according to the approach described in this deliverable.

2. EXISTING LIFE CYCLE COST CALCULATION TOOLS

Planning new nZEB in a life-cycle cost perspective allows to set-up a design process based on a more comprehensive business plan, having the control of the costs on each phase of the building life and a more conscious use of resources. This is the reason why multiple calculation tools have been developed in the last years for LCC analysis purposes. The existing LCC calculation tools that were included in this analysis were chosen upon web and literature research, for the gathering of up-to-date and trustworthy information.

The criteria for the selection of the tools were relatively simple and focused on language, licence and availability of specifications of the tools. In particular, calculation tools available in English or German language that have a temporary trial version free of subscriptions were adopted. In addition, since the project partner ATP Sustain has elaborated it, the

analyses includes also LZK-Tool, even though it is not publicly accessible but only for internal company use. Since the scope of this analysis is to provide a support framework for nZEB, the selected calculation tools have a particular focus on buildings. However, the analysis includes a couple of calculation tools that can also be used for products, systems and services, since it was estimated that the specific tools above' structure could also be adopted for building evaluation.

In particular, the LCC tools included in the comparative analysis are the followings:

1. RETScreen Expert
2. BLCC5
3. Harvard Life Cycle Calculator
4. University of California LCC
5. Sweden LCC tool for procurement

6. SMART SPP LCC-CO2 tool
7. GaBi - Thinkstep
8. Econ Calc
9. LZK-Tool ATPsustain
10. LEGEP

All of the above calculation tools are listed in Table 1, along with some relevant primary information, such as their developers, licences, data location and viewing perspective, in order to rapidly provide a general overview.

Table 1. Overview of the analysed tools

	NAME	DEVELOPER	LICENCE	DATA LOCATION	VIEWING PERSPECTIVE	REFERENCE LINK
1	RETScreen Expert	Government of Canada	Viewer: Free Professional: Annual fee	International	Designers	http://www.nrcan.gc.ca/energy/software-tools/7465
2	BLCC5	National Institute of Standards and Technology (NIST)	Free	US	Designers	https://www.energy.gov/eere/femp/building-life-cycle-cost-programs
3	Harvard LCC	Harvard University	Free	US-Harvard specific	Designers	https://green.harvard.edu/topics/green-buildings/life-cycle-costing
4	University of California LCC	University of California	Free	US	Designers, energy managers	Download excel
5	Sweden LCC procurement	Sweden national agency for public procurement	Free	Sweden	Contracting Authorities-Suppliers	https://www.upphandlingsmyndigheten.se/en/subject-areas/lcc-tools/
6	SMART SPP LCC-CO₂	SMART SPP consortium	Free	Europe	Contracting Authorities-Suppliers	http://www.smart-spp.eu/index.php?id=6988
7	GaBi - Thinkstep	Thinkstep Gabi	Free 30-days trial	Europe	Designers	http://www.gabi-software.com/software/gabi-software/gabi/functionalities/life-cycle-costing/
8	Econ Calc	Energy Institute of Vorarlberg	Free	Europe	Designers	https://www.energieinstitut.at/unternehmen/werkzeugkasten/wirtschaftlichkeitsrechner-econ-calc/
9	LZK-Tool ATPsustain	ATPsustain	N.A. ¹	Europe	Designers	Developed by ATP Sustain for internal use
10	LEGEP	Legep	Free trial	Europe	Designers	https://lekep.de/?lang=en

¹ The tool is not publicly available, but it has been developed by ATP Sustain for internal use

2.1. GENERAL INFORMATION OF THE ANALYSED TOOLS

The following sections describe the main information available for the tools and an overview of the inputs-outputs.

This section aims to provide the reader with the main characteristics of the tools in order to better understand the comparative tables included in the repository described in Section 3.

2.1.1. RETSCREEN EXPERT

General information and scope

RETScreen Expert [2] is a software package developed by the Government of Canada aimed at supporting designers in assessing the technical and financial viability of projects. It is an integrated tool for the energy performance calculation, comparison of technological scenarios and evaluation of the costs during the lifespan of the building.

The software is currently available in 36 languages, and it is structured in a set of worksheets, each one referred to a specific issue to be analysed and connected with a reference database of benchmarks from case studies, products, costs and climate data. The worksheets deal with energy, CO₂ emission, cost, financial and sensitivity/risk.

The Cost Analysis worksheet that is the main object of this review is structured in three (3) levels, from which the user can choose: from level 1 for an initial pre-feasibility study to level 3, where more detailed and higher accuracy information is required. This review is focused on level 3 (more detailed) cost analysis, implemented for residential or commercial buildings. Cost analysis is used to support the user in estimating costs associated with the proposed cases and solutions. These included costs dealing with the initial investment cost standpoint and from the annual /recurring cost standpoint, allowing the comparison of different scenarios. The user can refer to the RETScreen product database for supplier information in order to obtain reference prices or other information needed.

2.1.2. BLCC5

General information and scope

BLCC5 is the latest version of the Building Life-Cycle Cost (BLCC) program developed by the National Institute of Standards and Technology (NIST) of US. BLCC5 conducts economic analyses by evaluating the relative cost-effectiveness of alternative buildings and systems or components. It focuses on costs and benefits of energy and water conservation and renewable energy projects. In particular, it compares the life-cycle cost of two or more alternative designs solutions. BLCC5 contains four modules:

Inputs and outputs summary

As explained previously, the costs are analysed from the initial phase, also considering recurrent and annual costs. The initial costs include:

- (i) costs for preparing a feasibility study
- (ii) costs for performing the project development functions
- (iii) engineering costs (focused on design and energy system installations)
- (iv) construction costs for the balance of the system

The annual costs include:

- (i) operation and maintenance costs - from the Energy Analysis previous worksheet
- (ii) costs concerning land lease, insurances, administrative matters.

Lastly, the user can define the annual savings (according to a reference case) and periodic costs of the project, as well as the disposal value at the end of the lifespan.

The cost evaluation process of the tool is completed with its Financial Analysis worksheet, where financial parameter user inputs are being displayed, such as inflation rate, discount rates, possible grants, taxes etc.

In the Financial Analysis sheet, RETScreen calculates different financial indicators for the evaluation of the project's viability, such as

- (i) Net Present Value (NPV)
- (ii) Annual Life Cycle Savings (ALCS)
- (iii) Benefit to Cost Ratio (B-C ratio)
- (iv) Internal Return Rate (IRR)
- (v) Cumulative cash flow.

- i. Federal Energy Management Program (FEMP): energy and water conservation and renewable energy projects under the rules of 10 Code of Federal Regulations (CFR) 436
- ii. Federal Analysis, Financed Project: For Federal projects financed by Energy Savings Performance Contracts or Utility Energy Services Contracts or even other financed investments in energy or water conservation

- iii. OMB Analysis: For analysing. Cost-effectiveness, lease-purchase, internal government investment and asset sales

Inputs and outputs summary

The project data required from the user of the tool include:

- i. general information (name, location, analysis type, etc.)
- ii. financial information (discount rates and conventions, base date and study length period)
- iii. contract-related costs, annually or non-annually recurring (base-year amounts, debt services, usage indices and so on)
- iv. energy and water costs (consumption, unit prices and escalations, demand charges, usage and disposal indices and so on)
- v. capital component costs (initial costs, replacement costs and annually or non-annually operating, maintenance and repair

(OM&R) costs, along with rates of increase, residual values and base-year amounts)

All input data are entered for the base-case and the alternatives.

As far as concerns the outputs, the program calculates the lowest LCC of the alternative cases, as well as a supplementary set of financial data, such as

- (i) Net Savings (NS)
- (ii) Savings-to-Investment Ratio (SIR)
- (iii) Adjusted Internal Rate of Return (AIRR)
- (iv) Simple Payback (SPB)
- (v) Discounted Payback (DPB)

The LCC estimates and the additional measures are calculated in present-value dollars. LCC estimates are also reported as annualised costs where the entire stream of costs over the study period is “levelized” to an equal annual amount, including an “interest” charge represented by the discount rate.

In all of the modules, the program also calculates energy savings in physical units as well as emissions reductions (CO₂, SO₂, NO_x).

2.1.3. HARVARD LIFE CYCLE CALCULATOR

General information and scope

The Harvard Life Cycle Costing Calculator [3] was designed to aid Harvard decision makers in planning the expenditures dealing with new construction, renovation, equipment replacement, or any other project that needs investment. The calculator is based on an excel file. The methods used in the calculator correspond to ASTM Life Cycle Cost Analysis standards (Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems) and assumptions are specific for Harvard case study: utility rates are forecasted by the campus services, and the discount rate used is Harvard’s internal interest rate. By using standard methodologies and assumptions, individuals and organisations across Harvard can compare results. The criteria and assumptions used in the Harvard Life Cycle Costing Calculator are the following:

- (i) 20-year project lifetime
- (ii) Discount rate 8%, as recommended by the Finance Working Group and approved by the GHG Executive Committee
- (iii) Harvard-specific utility rates and utility escalation rates; maintenance & material costs escalation rate 1.84%, utility escalation rate 4.33%

- (iv) Expected inflation rate from the U.S Energy Information Administration to escalate maintenance and other recurring costs
- (v) Harvard-specific GHG emission conversion factors
- (vi) Use total project costs net of incentives (e.g. utility rebates)

Inputs and outputs summary

The information (inputs) requested from the user of the calculator are the following:

- (i) Project information (project name & type)
- (ii) Initial costs (aggregated: labour, materials, shipping, installations, all included as a total)
- (iii) Incentives (earnings from system installations/utilities)
- (iv) Replacement Costs & Expected life of the system to be replaced
- (v) Recurring operating Costs (materials and labour per year)
- (vi) Utility Annual Consumption (selection from embedded data based on location and unit or customised field)

All of the above-requested information is entered from the user for the base case as well as for the alternative(s).

The outputs exported from the Harvard calculator are summarised in the list right below:

- (i) Financial Costs (total lifecycle cost of ownership)
- (ii) Financial Savings (life cycle savings to rate-payer, life cycle net savings)

- (iii) Investment Performance (first-year Utility Savings, Simple Payback Period, the first year Return on Investment, Savings-to-Investment ratio, Discounted Payback, Adjusted Internal Rate of Return)
 - (iv) GHG Metrics (first year & life cycle savings, Investment Cost/GHG, NPV/GHG)
 - (v) NPV over time graph
- All of the above are presented for each alternative over the base case.

2.1.4. UNIVERSITY OF CALIFORNIA LCC

General information and scope

The Life Cycle Cost tool developed by the University of California [4] is a simple excel file made to calculate the total life-cycle cost of a building. It is exclusively focused on costs related to the building envelope, the HVAC and electrical systems.

For the elements, the tool offers a repository of materials and equipment with their expected life and their annual maintenance. The user should select the building envelope type, HVAC system and lighting system from the embedded data and enter the installed costs information; the tool then automatically performs financial calculations for the selected components. There is also the possibility of user-defined data in the database of the systems and equipment.

The LCC tool from the University of California also includes a set of assumptions:

- (i) Electrical energy & natural gas costs and cost escalations (considered 0.12\$ per kWh and 0.75\$ per unit respectively)
- (ii) Discount rate (considered 7%)
- (iii) "Economic" life of the building (considered 50 years)
- (iv) Hours of operation of the building (considered 06:00 am to 10:00 pm, Monday to Friday).

Inputs and outputs summary

The information (inputs) requested from the user of the tool are the following:

- (i) General information (project and building description, location, address and contacts)

- (ii) Building envelope related (selection from the database or entering of the envelope components, installed costs and areas and also electrical energy/natural gas consumptions)
- (iii) HVAC & Lighting systems related (selection from the database or entering of the systems used, equipment replacement costs and electrical energy/natural gas consumptions)

All of the above input information can be entered into two alternatives.

The tool developers also recommend that annual energy consumptions shall be obtained utilising specific software programs, namely the Department of Energy (DOE-2), Trane Trace, Carrier Hap or EnergyPro. Anyway, also further tools are valuable in different countries.

As mentioned before, the tool automatically calculates financial elements, based on the equipment and systems integrated database sheet. The outputs of the tool are the following:

- (i) Replacement costs and factors for each component/system
- (ii) Annual costs for each component/system
- (iii) Present worth for each component/system
- (iv) Total LCC

2.1.5. SWEDEN LCC TOOL FOR PROCUREMENT

General information and scope

The LCC tool for procurement was developed by the National Agency of Public Procurement of Sweden, [5] for supporting the procurement process carried out by contracting authorities and entities. Although a national government agency has developed the tool, it can be adopted widely, since it provides a quite general structure. Moreover, the tool can be used for products, services or works' life cycle costing, in order to have indications and scenarios of how those might affect the total cost. The tool is an excel file consisting of six (6) sheets:

- (i) Introduction sheet
- (ii) Calculation sheet, where the LCC analysis takes place
- (iii) Parameters explanatory sheet; in this sheet clarifications are being given concerning the parameters and the included data
- (iv) LCC Result sheet
- (v) Climate impact factors sheet
- (vi) Supplier response sheet; this sheet can be attached to the tender process

Some input information requested from the tool should be filled in from the contracting authority, while other from the supplier.

Inputs and outputs summary

The information (inputs) requested from the users of the tool are the following:

- (i) Calculation conditions: this information shall be given by the contracting authorities and include the number of products, usage time,

discount rate, type of energy and price, annual price change (optional), climate impact from energy consumption (optional) and financing cost if there are leasing or renting products.

- (ii) Investment costs per piece: these costs, and all of the rest mentioned from now, shall be given by the supplier. They include product price, cost of delivery, installation, operation start-up and adjustment costs.
- (iii) Operation and maintenance costs per piece: these include energy usage, costs for disposable supplies, services and maintenance costs, as well as labour costs
- (iv) Other costs: this category includes insurances and taxes or fees, renting or leasing costs, licences, disposal costs and residual values

The outputs exported from the LCC tool are the following:

- (i) Subtotals of each cost category, as they are given above
- (ii) Total Costs are given in present value
- (iii) Operating Costs per year
- (iv) Climate Impact per year
- (v) List of the most profitable alternatives given in descending order
- (vi) Graphic representation of total cost categories
- (vii) Graphic representation of energy usage and energy impact

2.1.6. SMART SPP LCC CO2 TOOL

General information and scope

SMART SPP LCC tool [6] was developed in the contexts of the Intelligent Energy Europe project SMART SPP - "Innovation through sustainable procurement". More specifically, Ecoinstitute Barcelona with the support of ICLEI was involved in the set-up process. This specific calculation tool was designed to assist in procurement decision making when tendering sustainable and innovative products and services. In this regard, it is reported in this analysis since it is adaptable also to analyse the LCC of buildings, even though in a simplified way. In fact, it allows the calculation of LCC and CO₂ emissions of

different products or services and it permits their comparison. As for the software itself, it is an excel format file, containing multiple sheets for the calculations and other explanatory or helpful information.

Inputs and outputs summary

Some input information requested by the tool (mostly financial) refer to the procurer, while the rest of the requested inputs can be entered from the supplier. When using the SMART SPP tool, one should enter the following information:

- (i) *General information:* the user should enter the tender ID and select the location and the planning

horizon from a drop-down menu. Other information needed are the discount rate, inflation rate, product offers, number of units to be purchased or leased and lifespan. Lastly, there is a CO₂ emission factor button linked to a database that the user can adapt for the CO₂ calculations.

- (ii) *LCC information*: this information contains acquisition costs, operation costs, maintenance costs, other kinds of costs and residual values. For each category, the user can enter annual aggregated costs or detailed ones. In the latter case, relocations to different sheets are available, where the user can define detailed costs, energy sources used, consumptions, emissions, relevant rates for the calculations, etc. In the “other” costs category, taxes, fees and subsidies shall be included.
- (iii) *CO₂ information*: the user should enter the total embedded emissions or detailed emissions; for the latter, one should enter the embedded emissions for production, transportation, installation and disposal. Annual emissions in the use phase,

as well as emission from electricity supply. Once again, there is a possibility of either aggregated or detailed inputs.

Outputs provided by the calculation tool are the following:

- (i) LCC results in net present value: total cost net value per offer, average annual costs per offer, total costs, the total cost per unit, the annual cost per unit, LCC costs per category (operation, maintenance, etc.) are available.
- (ii) CO₂ results: these include average annual emissions per offer & total emissions per offer.
- (iii) Graphical displays of results: diagrams representing cumulative costs per products and categories and total & annual CO₂ emissions per offer are available.
- (iv) Tenders evaluation sheet: this sheet can be used for evaluating the different offers to identify the economically most advantageous offer. The user needs to input award criteria and weighting schemes in order to use it.

2.1.7. ECONCALC

General information and scope

EconCalc is an Excel-based tool aimed at comparing different energy concepts and design solutions regarding LCC. It is useful to support for evaluating the economic feasibility of different solutions on five building typologies, according to the use.

It is possible to define the level of the analysis (i.e. overall building and single construction element or design choice) and which is the focus (i.e. initial investment-, maintenance and overall costs). Moreover, it includes a light version with a simplified list of inputs that suits the early design stage. The tool has a database of current energy prices that can be adjusted according to the inflation and it allows the user to include subsidies, incentives and residual values.

Inputs and outputs summary

The detailed version of the tool presents a structured datasheet that allows different levels of detail of the inputs. In particular, different sheets deals with:

- Overall evaluation:
- Energy prices and energy consumptions of the analysed variants: it also includes the PV production and related revenues and links to external databases with reference energy prices and CO₂ emissions.
- Economic and financial issues: possibility to perform a detailed analysis including potential revenues
- Detailed costs of the structures and building elements and systems

As outputs for comparing the solutions, EconCalc includes:

- (i) price of energy saved (in comparison to a reference case representing a conventional base scenario)
- (ii) energy consumption
- (iii) the annuity profit for owner-occupied property. Capital value comparison.

2.1.8. GABI THINK STEP

General information and scope

The University of Stuttgart with the collaboration of the spin-off partner PE International GmbH has developed the GaBi Software-System.

GaBi is a comprehensive tool facing different aspects of the building life cycle, supporting the users in data modelling, administration, and evaluation at process, product, or organization level. In particular, it deals with the following topics:

- Life Cycle Assessment (LCA) according to ISO 14040/44
- Life Cycle Engineering (LCE)
- Product and Process Optimisation
- Design for Environment (DfE)
- Environmental Product Declarations (EPD)
- Sustainability Assessment – environmental / economic / social

2.1.9. LEGEP

General information and scope

LEGEP's calculation system [7] works in life cycle assessment and life cycle cost calculation in a parallel process. LEGEP can also be used to create the thermal insulation certificate. For the determination of the LCA and LCC, the results are calculated based on a component database.

The component database contains information on the lifecycle-related ecological and economic parameters of a specific design. These standard component assemblies can be adapted to the real building during the calculation process.

This makes it possible to make calculations regarding environmental impacts and costs in a high degree of detail already in the early planning phases. If you do not want to work with the predefined component assemblies, you can also create your components at any time.

The component assemblies can be divided into three levels:

- Component (with all layers, e.g., outer wall)
- Component layers (e.g., an inner layer, base layer, an insulation layer)
- material level

This structure makes it possible to calculate the LCC and LCA in an early planning phase based on generic data records. As the project progresses,

- Life Cycle Costing (LCC)
- Energy and Resource Efficiency Analyses
- Material Flow Analysis (MFA)
- Greenhouse Gas Accounting
- Sustainability Benchmarking

The tool GaBi is available in English, German and Japanese and it includes a comprehensive database with materials and product costs, LCA and carbon footprint of construction components.

In particular, the LCC module allows to calculate the cost related to all the phases of the element life cycle, including flow, machine and personnel costs. It is important to point out that the tool can be applied at both building and construction element level

specific materials/components can then be adapted to the actual design.

Inputs and outputs summary

The information (inputs) requested from the users of the tool are the following:

- (i) Building areas
- (ii) Building location
- (iii) Review period
- (iv) Interest rates
- (v) Price-increase rates
- (vi) Calculation under certification boundary conditions (DGBN / BNB)
- (vii) Components (from LEGEP database)
- (viii) Components surfaces

Outputs provided by the calculation tool are the following:

- (i) Life cycle costs (if desired, evaluated according to the certification constraints) graphically and numerically evaluated
 - a. Investment costs
 - b. Maintenance costs
 - c. Repair costs
 - d. Cleaning costs
 - e. Dismantling costs
- (ii) LCA results of the entered buildings (if desired, evaluated according to the certification

boundary conditions) evaluated graphically and numerically

- a. phases (A1-A3; B2, B4-B6, C3-C4, D)
- b. environmental impacts (GWP, ODP, POCP, AP, EP)

c. resources (PEIne, PEIe, ADPE, ADPF, freshwater resources)

- (iii) Raw data of LCC and LCA by components including all subsequent elements for the use phase as Excel output for further evaluation

2.1.10. LZK-TOOL ATP SUSTAIN

General information and scope

The planning tool developed by ATPSustain [8] should act as a decision-making basis for planners and builders. The tool is based on Excel and offers the possibility to have the differential life-cycle costs automatically evaluated.

This tool makes it possible to compare building constructions and or technical building installations with each other. This enables planners to quickly calculate the LCC with default settings in very early planning phases. In the further course of the project, the default settings can be replaced by detailed project-specific values.

Cost blur in early planning phases can be neglected by evaluating the difference in life-cycle costs. The most favourable variant is then evaluated using the differential life-cycle costs at the end of the analysis period.

Inputs and outputs summary

The information (inputs) requested from the users of the tool are the following:

- (i) General information:

In order to obtain an expenditure adapted to the purpose of calculation, it is necessary to define the period under consideration, the price increases and the interest rates to be assumed for the calculation in agreement with the client.

- (ii) LCC informations:

For the calculation of the LCC, information on investment costs and, if available, usage costs must be provided. To take the different planning statuses into account, you can use the tool to calculate in varying degrees of detail.

LCC analysis in the preliminary design phase: to keep the level of detail as low as possible, the user can calculate utilisation costs with percentage deductions of the investment. Moreover, the user can specify different energy demand parameters and energy media to be able to estimate the energetic building operation. This form of analysis gives only a rough estimation of the expected life-cycle costs.

LCC analysis in the design phase: To increase the input accuracy, the user can specify the investment costs at the material level and add information about the service live. One can also specify the values for maintenance, servicing- and cleaning costs. For this calculation method, specific cost parameters per component and their service lives are required. With these values, differences between the component material quality can be easily seen in the results. Another advantage of this detailed calculation method is that it simulates the real use (tenant changeover, etc.) to represent the results as realistically as possible.

Outputs provided by the calculation tool are the following:

- (i) Graphical evaluation of the life cycle costs in a line chart in which the break-even point and the differential costs in year 0 and at the end of the observation period are specified.
- (ii) Automatic output of an Executive Summary, at which all relevant results are briefly summarised.
- (iii) Automatic output of a planner document on which all input parameters and results are prepared numerically and graphically in report form.

3.COMPARATIVE ANALYSIS OF INPUTS AND OUTPUTS OF THE TOOLS

The first step leading to the comparative analysis actualisation was to define a well-organised approach to archive the tools and facilitate the comparison. In particular, the repository developed within the task is structured in three sections:

- (i) Inputs to be provided
- (ii) Output calculated
- (iii) Main features and functionalities.

The whole reasoning and framework towards the development of the repository are presented in detail in the following subchapters.

3.1. ANALYSIS OF INPUTS

This section includes a structured overview of the input categories requested from the analysed tools.

The first decision criteria for adopting an LCC tool is the availability of information, thus using a more detailed tool in case of lacking inputs could not be cost-effective. In this context, having an overview of the level of detail requested by the tools is essential for deciding which tool suits the analysis.

3.1.1. FRAMEWORK OF ANALYSIS

In order to provide a clear overview of the cost information that the user of each tool is requested to enter as inputs, a structured categorisation of costs over the building life cycle is needed. In particular, the scheme of cost categories elaborated by the European Committee of Construction Economist (CEEC), was adopted. CEEC is a European non-profit organisation of construction economists that gather information, knowledge, practical experience and research in order to promote the best practices and establish common clear and operative guidelines across Europe. CEEC developed the so-called Code of Measurement for Cost Planning [21], an overall standard basis for the sub-division of costs and measurement of basic quantities of buildings for European budgeting, comparison and analysis at management level. The code covers all the costs of building elements and the intangible cost categories, costs-in-use, as well as project funding. Although it provides an EU-wide common approach and categorisation, needed for comparing costs at EU level, it allows to include also national specificities and local developments.

This is the reason why it was selected as a basis for the cost categorisation implemented into the input analysis. In particular, the main structure of the Code has been adopted as reference for CRAVEZero analysis. Moreover, specific additional inputs and fine-tuning have been done to

create the repository of user inputs, according to the specific needs of CRAVEZero project.

Finally, the cost categories ultimately included in the input analysis are the following:

- (i) *Site acquisition*: this category contains all costs associated with the acquisition, purchase or lease of the project's site.
- (ii) *Project funding*: this category includes all financial information, possible grants and subsidies of the projects, as well as taxes on funding.
- (iii) *Construction costs*: those refer to all building cost inputs as well as to all external works costs.
- (iv) *Labour costs*: meaning costs and fees associated with labour in any part of the process.
- (v) *Incidental costs*: this category includes costs involved in the bidding process, ancillary costs and charges, as well as project budget risk allowances that the user might enter
- (vi) *Costs in use*: the category of those costs refer to maintenance, operation and end of life costs
- (vii) *Incentives*: possible building rentals or any other utility rebates that tools might take into consideration in the calculations

As for the other relevant data, the “basic quantities” inputs, they are presented as well below:

- Site, referring to site areas of the building
- Floor areas, referring to possible specific floor area information requests.
- Financial parameters such as financial rates and periods of study.

All tools require financial information with no exception, apart from the cases where specific rates are already implemented into the tools as assumptions.

As mentioned before, the cost input categories are broken down into specific sub-categories that allow for showing different detail levels of input information for each tool.

3.1.2. RESULTS-PRESENTATION: COMPARATIVE TABLE

The input structure described in the previous section was implemented in a comparative checklist elaborated in Excel environment. It represents the set of inputs requested by each tool, providing a clear overview and a straightforward and easy-to-read repository. In particular,

Table 2 reports an overview of the inputs dealing with site acquisition and financing. From a general overview, RETScreen requests all the inputs

dealing with the initial cost&project financing. The other tools dealing with both of these topics, although with a lower level of detail and inputs, are BLCC5 and SMART SPP tool, while the Sweden tool for LCC includes the project financing but does not allow to take into account the cost of the site acquisition. The other tools neglect entirely these two issues.

Table 2. Analysis of software inputs – initial costs&project financing

	RET-Screen	BLCC5	Harvard LCC	LCC University California	Sweden LCC	SMART SPP	GaBi Think step	Econ Calc	LZK-Tool ATPsustain	LEGE P
SITE ACQUISITION										
site acquisition costs	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
taxes on site acquisition	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
FINANCING										
FINANCE										
interest on loans	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
debt	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
mortgage cost	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
bank charges	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
equity investment	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
GRANTS AND SUBSIDIES	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
TAXES ON PROJECT FUNDING	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Table 3. Analysis of software inputs – Construction and operation costs

	RET-Screen	BLCC5	Harvard LCC Calculator	LCC University California	Sweden General LCC	SMART SPP	GaBi - Thinkstep	Econ Calc	LZK-Tool ATPsustain	LEGEP
CONSTRUCTION COSTS	Included	Included	Included	Included	Not Included	Not Included	Included	Included	Included	Included
BUILDING COSTS	Aggregated	Aggregated	Aggregated							
substructure				x			x	x	x	x
external superstructure/envelope				x			x	x	x	x
internal superstructure				x			x	x	x	x
internal finishings				x			x	x	x	x
services installations				x			x	x	x	x
prefabricated building units							x	x	x	x
EXTERNAL WORKS COSTS		Aggregated	Aggregated							
site preparation	x						x	x	x	x
other external works	x						x	x	x	x
Taxes on construction							x	x		
Labour COSTS	Included	Included	Not Included	Not Included	Included	Not Included	Included	Included	Included	Included
construction labour costs	x	x			x		x	x	x	x
design & project team fees	x	x			x		x	x	x	x
taxes on labour	x	x			x					
INCIDENTAL COSTS	Included	Included	Not Included	Not Included	Included	Included	Included	Included	Not Included	Not Included
ancillary costs & charges	x	x			x		x	x		
competitions, tenders, permits	x				x	x	x	x		
transportation	x				x	x	x	x		
project budget risk allowances (contingencies)	x						x	x		
taxes on incidental costs					x	x				
COST IN USE	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included
MAINTENANCE			Aggregated							
major/minor replacements	x	x		x	x	x	x	x	x	x
repairs	x	x		x	x	x	x	x	x	x
systems servicing	x	x		x	x	x	x	x	x	x
OPERATION			Aggregated							
water	x	x			x	x	x	x	x	x
energy (heating, cooling, ventilation)	x	x		x	x	x	x	x	x	x
waste disposal	x	x			x	x	x	x	x	x
END OF LIFE										
decommissioning	x	x			x	x	x	x		x
demolition	x	x					x	x		x
disposal of property	x	x			x	x	x	x		x
TAXES ON COSTS IN USE		x				x				

	RET-Screen	BLCC5	Harvard LCC Calculator	LCC University California	Sweden General LCC	SMART SPP	GaBi - Thinkstep	Econ Calc	LZK-Tool ATPsustain	LEGEP
REVENUES	Included	Not Included	Included	Not Included	Not Included	Not Included	Not Included	Included	Not Included	Not Included
building rental	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
utility rebates or other	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
BASIC QUANTITIES										
SITE ACQUISITION	Included	Not Included	Not Included	Not Included	Not Included	Not Included	Not Included	Included	Not Included	Not Included
site area	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
footprint area	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
FLOOR AREAS¹	Included	Not Included	Not Included	Not Included	Not Included	Not Included	Not Included	Included	Included	Included
floor area not fully enclosed	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
gross external floor area	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
gross internal floor area	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
usable floor area	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
other/ancillary areas	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
COST INFORMATION	Included	Included	Included	Not Included	Included	Included	Not Included	Included	Included	Included
base date	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
study period length	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
exchange rates	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
inflation rate	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
discount rate	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
escalation rates	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
location	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

¹ The definitions of the different floor areas are reported in Annex 1

Table 3 presents an overview of the analysed tools regarding information required for describing the construction and the operation phase. The yellow cells identify that the input is included in the tool, nevertheless it can be inserted only at aggregated level (i.e. at envelope/HVAC level and, in some cases, at whole building level) RETScreen is the most comprehensive tool, including most of the input analysed, as well as EconCalc, that require a high level of detail. In particular, RETScreen allows an aggregated implementation of the envelope and system cost, while EconCalc presents a dedicated sheet for including the detailed features of the building elements as well as the construction costs. Accordingly, the application of RETScreen and EconCalc suits a detailed level of design and very detailed evaluations, where there is a significant availability of information about the new building. In case of lack of data or uncertain inputs, other tools could suit more the analysis.

In particular, the tool developed by the Sweden government and the Smart SPP require a lower level of detail, since they have been developed for providing a quick evaluation of products and services for supporting the public administration in the decision-making process. They are not explicitly focused on buildings, but they represent suitable tools for preliminary evaluations and for comparing solutions at the early design stage. Moreover, the LCC elaborated by the University

of California and the Harvard LCC calculator suit the preliminary design and they are structured for the analysis of buildings. In particular, Harvard LCC required aggregated costs for both the construction and the operation phase.

The other tools present an average level of detail. Thus they can be adopted during the final design phase since they include a good insight of the construction costs (in case of BLCC5 the costs are aggregated, while the other tools are more detailed). None of them includes the site acquisition costs and does not allow to include revenues. Thus a comprehensive business plan cannot be prepared. Figure 1, shows an overview of the level of detail of the tool, considering the suitability for the three design phases: early, definitive and executive. Although it is possible to apply all the tools during each design phase, it is essential to adopt the one better suiting the scope. For this purpose, the classification reported in Figure 1 is based on the required inputs. In fact, since the data collection for LCC evaluation is the most time-consuming activity, it is important to balance the effort according to the availability and detail of the information, strongly affected by the design stage.

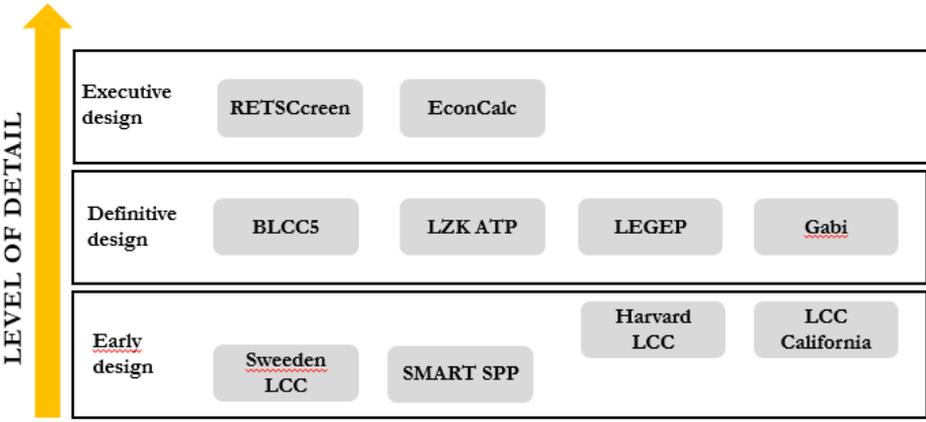


Figure 1. Overview of the level of detail of the tools

3.2. ANALYSIS OF OUTPUTS

3.2.1. FRAMEWORK OF ANALYSIS

Starting from the same reference [21], the structure of the output analysis is implemented in a comparative check-list. In the case of outputs, the categorisation was more standard and had less variability and complexity compared to the case of inputs. After reviewing and browsing on the tools, making sample evaluations and trials, common output data were gathered and grouped into two categories:

- (i) **Financial outputs**, such as LCC costs, savings and any financial ratios indicating the feasibility of the projects analysed.
- (ii) **Energy-related outputs**; in this category, outputs associated with the environmental impact of the projects (both energy and CO₂ emissions) are listed, as well as energy costs and savings outputs.

Finally, to provide a comprehensive overview offered by the tools, additional uncommon outputs are listed.

3.2.2. RESULTS-PRESENTATION: COMPARATIVE TABLE

Table 4 reports the overview of the outputs provided by the analysed tools.

It can be seen that EconCalc and RETScreen provide a comprehensive overview regarding financial indicators, including the possibility to compare solutions regarding costs and benefits, calculating savings and the payback of the solutions. In this regard, EconCalc allows for a more detailed analysis, including also the discounted payback time and the return on the investment, while RETScreen calculated the yearly cash flow.

On the other hand, the tool developed by the University of California is the more synthetic one, calculating only one indicator, i.e. LCC.

LCC is a common output also for the other tools classified, in the previous section, as suitable for the early design stage. Moreover, the tool of the Sweden government and SMART SPP also evaluate the NPV of the solutions and, concerning

the energy-related issue, the savings and the climate impact regarding CO₂ emissions. It is important to point out that SMART SPP provide, as an output, the evaluation of the proposed solutions as decision support for assessing the cost-effectiveness in a tender process.

Despite the reduced number of inputs, Harward LCC provides a long list of outputs, regarding both energy and financial issues, comparable to the tools classified for final design.

In addition, as particular features to point out, BLCC5 also allows a more detailed evaluation of the polluting emissions (CO₂, SO₂, NO_x) of the solutions, and Gabi can perform Monte Carlo simulations in order to provide a more comprehensive overview of the variability of the results according to the boundary conditions.

Table 4. Output overview of the analysed tools

	RET-Screen	BLCC5	Harvard LCC Calculator	LCC University California	Sweden General LCC	SMART SPP	GaBi - Think-step	Econ Calc	LZK-Tool ATPsustain	LEGEP
FINANCE										
Total LCC	x	x	x	x	x	x	x	x		x
Residual Value		x	x					x	x	x
Net Present Value (NPV)	x		x		x	x		x		
Cumulative Savings	x							x	x	
Net Savings (NS)		x	x						x	
Savings -To-Investment ratio (SIR)		x	x						x	
Benefit-To-Cost ratio (B-C)	x							x		
Internal Rate of Return (IRR)	x							x		
Adjusted Internal Rate of Return (AIRR)	x	x	x					x		
Simple Payback (SPB)	x	x						x		
Discounted Simple Payback (DPB)		x	x					x		
Return on Investment (ROI)			x					x	x	
ENERGY-RELATED										
Energy costs	x							x	x	x
GHG/Energy Savings	x	x	x			x	x	x		
Climate impact	x				x	x	x	x		x
ADDITIONAL OUTPUTS										
	-Equity payback -Debt payments -Annual LC savings -Yearly cash flows	-Emissions reductions (CO2, SO2, NOx) -LCC of alternatives	-First Year Utility Savings -First Year -ROI -First Year GHG Savings		-Costs per category -Annual operating costs -List of most profitable alternatives	-Total & annual costs per offer & per unit - CO2 emissions per offer -Tender evaluation	-Monte Carlo Simulation			

4.COMPARATIVE ANALYSIS OF FEATURES OF THE TOOLS

4.1. FRAMEWORK OF ANALYSIS AND CRITERIA OF EVALUATION

The third pillar of the repository of LCC tools is the analysis of the offered features. Considering that the comparison of the features is sometimes quite difficult since the tools have different structures and characteristic, three categories were identified:

- (i) Software interface and flexibility
- (ii) Data management
- (iii) Calculation and export

Accordingly, the repository includes a checklist assessing the compliance of each tool with the selected features. The following sections report a brief description of the categories and the related features.

SOFTWARE INTERFACE & FLEXIBILITY

The software interface is meant to be assumed as the basic screen of the tool with which the user interacts. This feature is evaluated according to the level of user-friendliness of each tool and the possible integration of any user support in them.

Flexibility refers to the capability of allocation of the tools (of costs or data in general) and to the possibility for the users to define specific values or adopt specific units. In lack of user-defined units, the user should consistently convert all entries manually to meet with the software-defined unit demands or inputs in general; that is evaluated as a non-flexible tool. Another important flexibility issue is the possibility to adapt the calculation to national context (e.g. currency, incentives, etc.) since it is one of the key features for a usable tool. Finally, the suitability for both the early design, that is the capacity of the tool to be quickly applied for having preliminary results and the renovation projects is assessed.

In order to summarise, the five features dealing with interface and flexibility are:

- (i) User-friendly orientation and user support
- (ii) Flexibility in data inputs and manual entries
- (iii) Transferability to national contexts

- (iv) Suitability for the early stage of planning
- (v) Suitability for renovation projects

DATA & DATA MANAGEMENT

Under the criterion of “Data and Data Management”, there are features concerning the integrated lifecycle data, databases and data management capacities of each software. In this regard, features dealing with embedded data play a key role in evaluating the capacities of each tool.

The analysed features for this category are the following:

- (i) Integration of databases: availability of databases linked to the tools
- (ii) Integration of case studies/templates: detailed information from examples and case studies already implemented in the tool
- (iii) Development of CBS (Cost Breakdown Structure): user support in the cost-breakdown.

CALCULATIONS AND EXPORTS

The final category evaluates the various ways in which the life cycle calculated results could be viewed, exported and manipulated. This includes the specification of data manipulation capabilities, such as uncertainty analysis, but also other capabilities of information utilisation, namely:

- (i) Total cost determination: the tool complies when it allows the calculation of the total LCC
- (ii) Generation of cost estimates: possibility to estimate the costs over a particular lifespan of the building
- (iii) Calculation of energy savings: comparison of the solutions and energy saving with a reference case
- (iv) Determination of high-cost contributors: identification of the main elements affecting the total LCC
- (v) Performance of uncertainty analysis: definition of ranges of uncertain boundary conditions to evaluate the effect on the results

(vi) Performance of sensitivity and risk analysis: possibility to evaluate how the boundary conditions (e.g. interest rate, cost of energy, etc.) affect the results

(vii) Capability of a graphical display of results

(viii) Capability of comparison of results

(ix) Capability of the creation of reports

4.2. RESULTS-PRESENTATION:-COMPARATIVE TABLE

The analysis of the features was implemented in the repository as an excel-comparative table; a checklist format was again selected for the documentation of each calculation tool's integrated features. **Table 5** also reports the compliance of the tools with the selected features re, in order to rapidly give a visual overview. Nevertheless, for the selection of the most suitable tool, the user is invited to check which are the most significant features according to the purpose of the analysis.

Table 5 presents features of the analysed tools. Apart from RETScreen that results in the most comprehensive tool regarding features, the functionalities of the other tools are quite comparable, ranging from 41% to 59%. The two easiest tools, i.e. LCC of California University and Harward LCC, present the lowest compliance with the features, respectively 18% and 29%.

Table 5. Features of the analysed tools

FEATURES										
	RET-Screen	BLCC5	Harvard LC Calculator	LCC University California	Sweden General LCC	SMART SPP	GaBi - Thinkstep	Econ Calc	LZK-Tool ATPsustain	LEGEP
User-friendly orientation & User support	x	x	x						x	
Flexibility in data inputs/manual entries	x	x				x		x	x	x
Transferability to national contexts	x				x		x			
Suitable for the early stage of planning	x					x		x	x	x
Suitable for renovation projects	x	x	x			x		x	x	x
Integration of databases	x			x	x		x			
Integration of case studies/templates	x					x		x		
Development of CBS	x			x						
Total Cost Determination	x	x	x	x	x	x	x	x		x
Generation of cost estimates	x					x		x		x
Calculation of energy/ utility savings	x	x				x		x		x
Determination of high-cost contributors	x				x		x			
Uncertainty analysis					x		x			
Sensitivity/Risk Analysis	x				x		x			
Graphical Display of Results	x		x		x	x	x	x	x	x
Comparison of results	x	x	x		x	x	x	x	x	
Creation of report	x	x			x	x	x	x	x	x
Percentage of incorporation of aforementioned features for each tool	94%	41%	29%	18%	53%	59%	53%	59%	41%	47%

4.3. ADVANTAGES AND LIMITING FACTORS OF THE TOOLS

To give an additional perspective to the evaluation, during the reviewing process of the calculation tools, a category of advantages and limiting factors for the tools was also integrated into the analysis.

Below, **Table 6** summarising table containing this supplementary information is presented.

Table 6. Advantages and limiting factors of the tools

TOOL	ADVANTAGES (+)	LIMITING FACTORS (-)
RETSscreen	Completeness of the tool	RETSscreen expert available free of charge only in a viewer mode
	Flexibility – possibility to use the tool in several national contexts	Fee for using the complete version
BLCC5	User support	Location & currency limitation
	Flexibility	Orientation towards Federal projects
	Satisfying amount of output information	Not straightforward finance inputs
	Easy-to-read reports	No integration of databases
HARVARD LCC	User support	Location (Harvard) constraints
	The inclusion of formulas and calculations explanations	Non-consideration of future investments and expenditures
	Satisfying amount of output information	Non-calculation of utility/energy savings
	Consideration of GHG emissions and savings Availability of graphical output	No integration of databases
University of California LCC	Easiness	Simplified approach
	Inclusion of formulas implemented for discount factors	Limited outputs
	Integration of maintenance costs database	Limiting the number of alternatives (2) Limiting energy types and fuels (only electricity and natural gas)
General LCC tool for procurement	User-friendliness	Currency constraints
	Possibility of multiple comparisons	
	Integration of environmental impact	
	Suitability for early stages of the procurement process and tenders Availability of graphical output	
SMART SPP LCC	User-friendliness	Limiting study length
	Currency allocation	Hard-to-input data (referring to emissions)
	Incorporation of different kinds of emissions	Restrictions on graphs (possibility of display of up to 5 products at a time)
	Integration of embedded data	
	Integration of formulas used and conversion factors	
	Possibility of multiple alternatives	
	Suitability for tender evaluation Availability of graphical output	

5. CONCLUSIONS

This report includes a significant amount of LCC tools summarising the main features, input-output list and capabilities. It represents an interesting overview for providing a designer with the key information to decide which tool better suits the needs of specific project evaluation. The analysis highlighted some standard features, like the suitability also for renovation projects (and not only for new constructions), detailed documentation for user support, possibility to compare different scenarios.

There are also a couple of limiting factors that occur, like the limitation of the study length (that is maximum 25 years) and the limitation of the currency. In fact, not all the tools allow to switch the currency, and this feature limits the wide applicability of the analysis.

Another significant result of this report is the identification of the uncommon features of the tool, that represent interesting development inputs for the CRAVEZero LCC tool.

In particular, the main identified ones are:

- (i) the potential adaptation of the tool to national contexts,
- (ii) the possibility to generate a reliable cost estimation through reference databases for construction elements
- (iii) Identification of the elements and costs that mainly affects the LCC
- (iv) Suitability for early design (i.e. possibility to simplify the building features and change the level of the analysis)
- (v) Sensitivity analysis of the inputs values

Moreover, although is explicitly indicated in the standard EN 15686-5 [9], none of the analysed tools implement an algorithm to perform an uncertainty analysis, that would allow verifying the impact of uncertain input variables (e.g. interest rate, cost of maintenance, inflation) on the building life cycle costs.

This would be a key feature to be included in CRAVEZero tool and in the CRAVEzero pinboard, for providing the user with a higher awareness of the reliability of the results, and for identifying the most suitable design solutions according to the uncertain data.

6. REFERENCES

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ANNEX 1: MAIN DEFINITIONS

- **Ancillary costs & charges:** general ancillary costs such as project management, documentation, legal fees in association with construction
- **CBS:** Cost Breakdown Structure
- **End of life:** cost of sale or other disposal of property, including decommissioning, disposal inspections, reinstatement to meet contractual requirements, demolition.
- **External superstructure/envelope:** envelope above the substructure; roofs, external walls, windows, doors; facade systems
- **Floor area not fully enclosed:** area of open sided balconies; canopies; covered walkways; fire escapes; open parking areas; usable roof areas; terraces
- **Footprint area:** area of the finished site (building footprint)
- **Gross external floor area:** all floor space which is covered and enclosed to its full height, including the area of basements, measured to the outside face of outside walls, excluding floor area not fully enclosed
- **Gross internal floor area:** all floor space which is covered and enclosed to its full height, including the area of basements, measured to the inside face of outside walls, excluding floor area not fully enclosed and excluding the area of the internal partitions
- **Internal finishings:** finishes; screeds; raised floors; panelling, cladding etc
- **Internal superstructure:** remaining superstructure; suspended floors, balconies, stairs; internal walls, partitions, columns, beams, windows, doors etc
- **LCOE:** Levelized Cost of Electricity
- **Other external works:** external service connections, drainage, external lighting, fencing etc
- **Other/Ancillary areas:** areas supplementary to the main function of the building
- **Services installations:** mechanical, electrical, power, lighting etc. systems installation
- **Site acquisition costs:** all costs associated with the acquisition, purchase or lease of the site & legal fees
- **Site area:** the area within the legal site boundaries measured on a horizontal plain and including areas of buildings, external works and untreated areas
- **Site preparation:** excavations, soil stabilisation works etc
- **Substructure:** all works up to the structural upper surface of the lowest floor slab; basement; foundations
- **Usable floor area:** internal net floor area (excluding the internal partitions)