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ICM Precinct Carbon Assessment Tool Conversion for Cloud-based Interfaces towards Utilisation

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Executive Summary

The Precinct Carbon Assessment (PCA) Tool was developed at the University of South Australia as part of the Integrated Carbon Metrics Project (RP2007). The main focus of the PCA tool is to examine the whole life cycle of carbon emissions (Scope 1, 2 and 3) on the precinct scale and to calculate different low carbon scenarios, including travel modes and renewable energy systems, for precincts and precinct development projects.

The PCA tool:

- i) assesses predicted and operational carbon performance;
- ii) offers three levels of precinct carbon modelling, i.e. the building level, the product level and the material level;
- iii) quantitatively evaluates low carbon scenarios to inform 'Business as Usual' types of development;
- iv) supports planners, designers, ESD consultants and government agencies for more effective planning and mitigation; and
- v) operate across states, urban settings, and the development project life cycle.

The PCA tool is not bound by data sources. It allows users to adjust precinct morphological settings, building types, travelling modes, renewable system options, and the carbon intensity data of precinct objects for conducting quantitative analysis and finding the optimal solutions.

A web version of the PCA tool, i.e. the PCA-'Light', can be accessed at: <https://precinculators.info/>. It supports 'Basic' assessment and reporting functions. The tool also has a Matlab version, i.e. the PCA-'Full', that is accessible via Remote Desktop Connection. This full version provides advanced modelling and scenario assessment functions and is compliant with the "NCOS Standard for Precincts" (<http://www.environment.gov.au/climate-change/government/carbon-neutral/ncos>). Both versions of the PCA tool have been reviewed and tested for further industry utilisation.

The PCA tool can be applied to Greenfield- or Greyfield-type development for Residential, Commercial or Mixed-use precincts. The spatial scales in modelling and assessments include Street, Neighbourhood, Subdivision and Suburb, as well as CBD. It can support assessment of the potential for realising carbon neutrality for new precinct developments and refurbishments.

Introduction

From a systems perspective, 'City' and 'Precinct' are two dominant and complex urban built forms, at the macro- and the meso-scales respectively, representing embodiment of land, constructed facilities, transport, and physical and social infrastructures. These infrastructures support production and consumption activities in relation to particular social, economic, environmental and technological contexts. A city can be regarded as a 'system of systems' consisting of a cluster of different precincts interconnected with transport and essential service networks. Often referred to as 'neighbourhoods' or 'districts', precincts represent parts of an urban area that have defined geographical boundaries and serve certain functional or planning purpose(s). They can accommodate multiple uses such as residential, commercial, educational, health, administrative or their combinations (Huang et al. 2017a). They involve spatial, physical and functional interplays of landscape, zonings, buildings, infrastructures (energy, transport, water and waste), as well as occupants. A precinct can be treated as a single entity for specific analyses, planning and urban design, as well as recognising its interactions with surrounding urban features and fabrics and the sustainability implications thus incurred.

Based on such notions, 'Precinct' is an appropriate 'spatial lens' for developing low carbon urban forms. It enables urban planners and decision makers to examine and manage carbon signatures of urban settings in accordance with planning purposes at different scales and/or spatial levels. This requires keeping track of not only direct emission reductions instigated by one product, process, technology or activity, but also capturing all indirect changes in emissions instigated by the original change (Ness and Xing, 2017). Therefore, a major challenge is how life-cycle energy and carbon signatures of the fabric and metabolism of different urban forms are defined methodologically, quantitatively assessed, and effectively implemented in planning policies, guidelines and regulations for achieving and sustaining low-carbon outcomes. Although there are over ten precinct design and assessment tools currently in use, they are largely sustainability or Triple-bottom Line (TBL) focused and fall short in providing a detailed assessment of life-cycle carbon (both operational and embodied) and scenario investigation at the precinct level to inform planning and design changes (Newton et al., 2013).

To this end, a quantitative modelling and analysis instrument for carbon accounting is needed for interrogating and assessing the whole-of-life carbon emissions of built forms at city and precinct scale. It is essential that such a tool maps out full carbon profiles, identifies the carbon 'hot-spots', and analyses potential

pathways for transitions to low-carbon urban development.

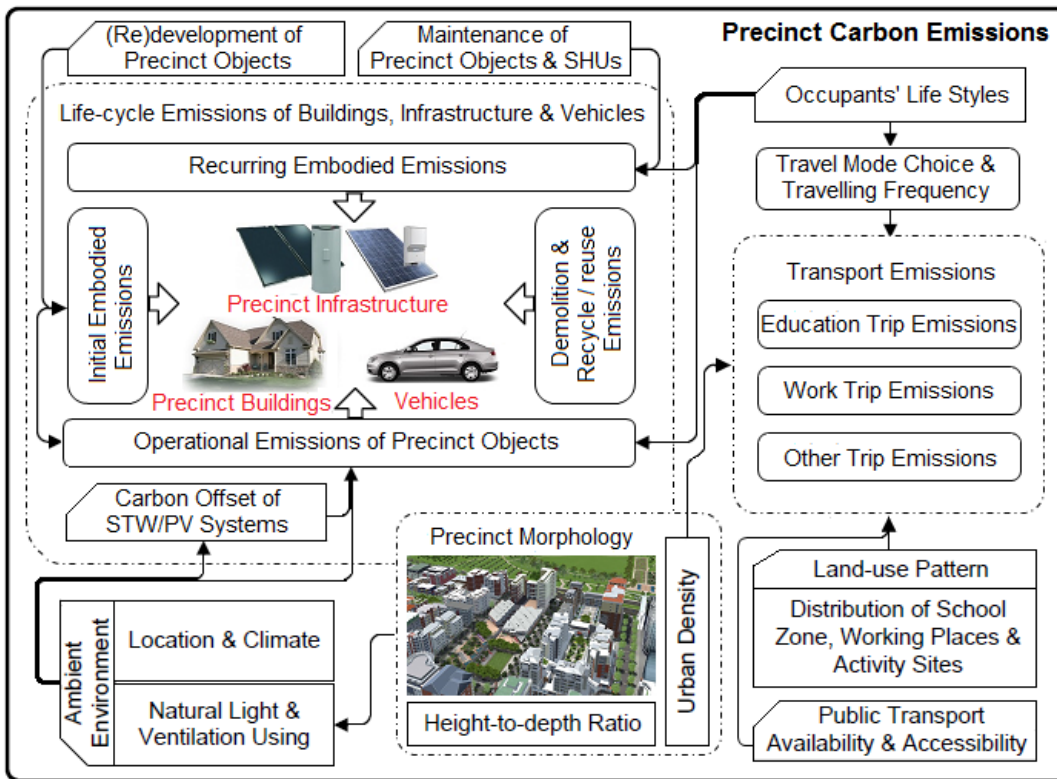
Modelling Method

Precinct Carbon Assessment (PCA) is a carbon modelling and analytics tool developed as part of the Integrated Carbon Metrics (ICM) Project (RP2007) to examine the whole life cycle of carbon of the urban built environment at a precinct scale. It aims to:

- provide both highly aggregated as well as more detailed assessments of the operational and embodied carbon of precinct objects (residential buildings, commercial buildings, and infrastructure), building appliances, transport vehicles, and discrete energy generation via solar PVs and storage units;
- identify and quantify the effects of occupancy and morphological factors on precinct carbon profile;
- be capable of assessing the offset potential of climate rendering and green energy systems at the precinct scale; and
- support the analysis of different precinct types and urban development scenarios.

With such functionality, PCA offers the capability to assess different low carbon development options, including alternative travel modes and renewable energy systems. Figure 1 presents a schematic view of the functional features of the PCA.

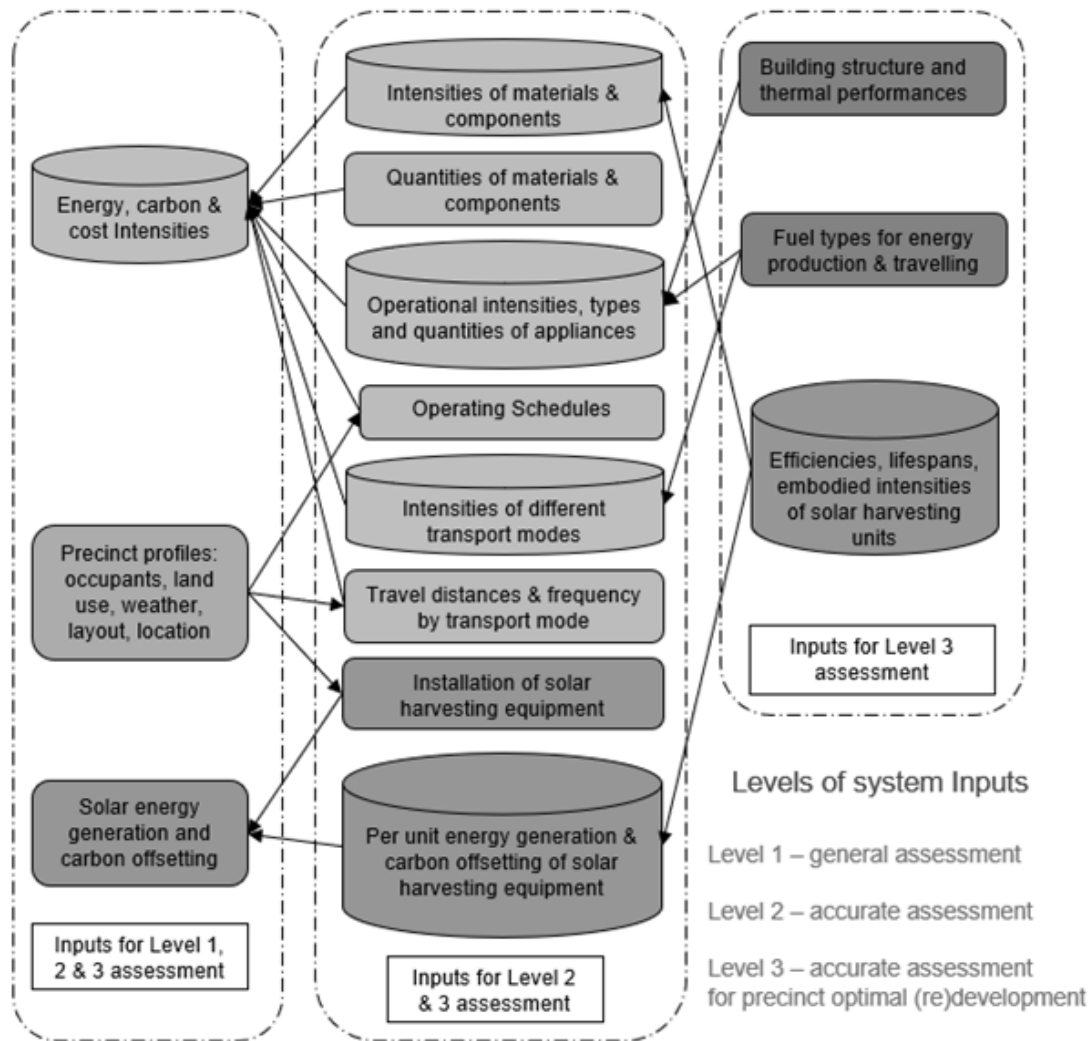
Figure1 A Schematic Representation of the PCA Functions



The PCA tool supports precinct carbon modelling at the building level, the product level, and the material level. Modelling can range from rapid assessments using highly aggregated data and standard/typical precinct object types (provided by the built-in database) to more detailed analysis using refined data and user-defined precinct object types.

PCA performs flexible customized multi-scale assessments of precinct carbon performance. Such features can accommodate the needs of those users having different technical competence, resources and objectives. To support the requirements of different assessment scenarios, the input parameters are structured for three levels of modelling as shown in Figure 2.

Figure2 Levels of Modelling and Input Requirements



Level 1 is designed to suit urban planners and government agencies. It predominantly focuses on early stage planning at a macro level. Therefore, highly aggregated data on energy/carbon intensity per square meter of each object type is used as the primary input for assessment.

Level 2 modelling is intended for the building and construction phase and associated practitioners. It aims to improve the carbon performance by material/components selection and optimal scheduling of operations for precinct objects. Hence, the data on MJ or tCO₂-e per square meter used in the modelling is built up from the product level, including detailed volumetric data of materials used, energy/carbon intensity of each material/product type, as well as units of use and the operating schedule of each appliance type (built-in and plug-in).

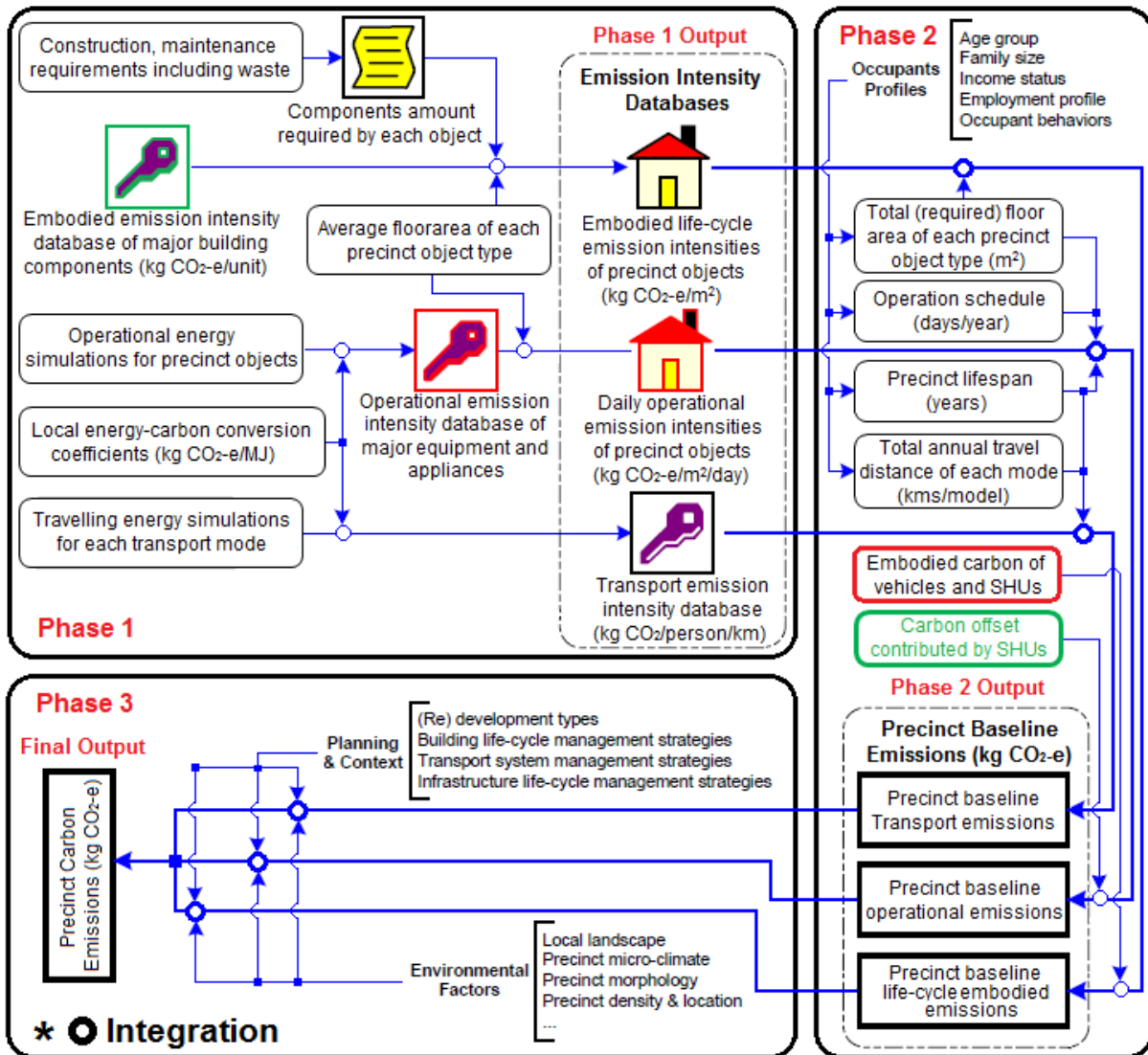
For the Level 3 modelling, more detailed information about precinct object designs and travel mode selection is required as input data to support the examination of

overall carbon performance from the perspective of design and development.

Carbon Assessment Features

The precinct-scale carbon assessment is underpinned by an integrated model that consists of three key phases as shown in Figure 3.

Figure3 System Framework for Carbon Evaluation of Urban Precincts



At *Phase 1*, carbon intensities for embodied, operational and transport-related emissions are identified. The embodied carbon intensity of each precinct object type is determined by the life-cycle carbon intensities of main construction materials, the amount of each material required for construction, replacement and waste ratios of building components, as well as the carbon embodied in construction activities (e.g. material and equipment transportation, equipment use, onsite assembly, etc.). The recurrent embodied carbon is measured as the replacement ratios of major building components over the lifespan of precinct objects. As for operational carbon, operational energy intensities of precinct objects are firstly assessed and then emission factors (with the unit of kg CO₂-e/MJ) determined by local energy production are used to convert into operational carbon intensities. Transport-related carbon intensities are calculated from the fuel consumption considering multiple fuel types, measured as kg CO₂-e/km/passenger.

Phase 2 is designed for the evaluation of precinct baseline emissions associated with buildings, vehicles, as well as infrastructure services including energy, water and waste. In this stage, parameters inter-linked with the environment, local climate, and occupant life-style preference (e.g. total floor area of each building type, schedule of appliances, travelling frequency and distance, etc.) are identified to support the calculation of precinct baseline emissions, together with the carbon offsetting contributed by renewable energy units.

Phase 3 improves the accuracy of precinct carbon evaluation. At this stage, precinct baseline emissions are moderated by morphological factors reflecting the ambient surrounding natural and built environment. The occupants' life-style preferences are considered and integrated into the baseline carbon measurement by affecting operating hours of appliances, maintenance and refurbishment cycles of precinct objects and transport mode selections. The impacts of actual precinct morphology or master plan of an urban

precinct are analysed to define characteristic factors such as urban density and solar potential. Finally, these factors are modified iteratively in order to improve the overall carbon profile of the precinct.

Input Requirements and Performance Metrics

To satisfy the requirements of different assessment types, the input parameters and data types are summarised in Table 1.

Table 1 Description of PCA Input Data

Parameter	Description
Precinct attributes	location (latitude & longitude, degrees), time meridian, local albedo, precinct land size, population size and number of households
Demographic attributes	age groups, employment types (e.g. employed full-time, part-time, casual ...), income levels and household sizes (e.g. one-person family, two-person family, etc)
Land use	building types and numbers (e.g. detached house, semi-detached townhouse ... of dwellings, public buildings such as offices, schools, retails, medical buildings ...), infrastructure types and units (e.g. area of driveways, length of pipeline, area of garden & green space, water, gas and power plants ...), floor area and occupied land size of each building and infrastructure type
Precinct morphology	dimensions and orientations of buildings, total area of land used for building and infrastructure construction, population density (person per hectare), dimensions of construction site
Embodied intensity data	per square meter embodied energy and carbon of each building type (or per square meter material use of each building type, lifespan of each building component, recurrent/maintenance cycle, percentages of raw and reuse materials used in the manufacturing of building component)
Operational intensity data	hourly per square meter energy load for heating, cooling, ventilation and lighting based on standard occupancy assumptions, occupancy and hourly energy consumption of appliances (e.g. white goods, computers, TVs ...), temperature setting of indoor environment, infiltration and air change (max and min) of ventilation, people load, operation schedule of appliances (weeks per year, days per week and hours per day), annual consumption of different energy types
Travel intensity data	Transport mode types (e.g. bus, tram, train, car), fuel type, engine size and built year of each vehicle, travel frequency, average travel distance per trip, travel diary of residents, annual transport energy consumption and carbon emissions
Water and waste	daily household water and hot water consumption, daily household waste generation (recyclable and non-recyclable), non-residential building water use and waste generation, non-residential building occupancy (m ² per capita)
Renewable energy generation	installation of PV systems (number and kWp), grid energy loss in electricity uploading (%), PV panel type (including panel efficiency, per square meter embodied energy and carbon of panels, lifespan of panels), battery storage systems (including installed amount, size of battery bank in kWh, per kWh embodied energy and carbon intensities of batteries), number of solar water heaters installed, efficiency of solar water heaters, annual solar energy harvesting (kWh) or cost saving (A\$).

To support scenario analysis and decision making, the main precinct performance indicators include:

- Operational Energy: Buildings (Residential and Commercial), Appliances, Infrastructures (Transport, Energy, Water, and Waste);

- Initial and Recurrent Embodied Energy: Buildings (Residential and Commercial), Appliances, Infrastructures (Transport, Energy, Water, and Waste) and Vehicles;
- Transport Energy: Vehicle Use (Commute and Lifestyle); and
- Renewables: Solar PV, Solar Hot Water

Based on local power mix and fuel types, these indicators are converted from energy (MJ) to the carbon metrics as detailed in Table 2. Furthermore, life-cycle Cost (in dollar value), Cost-Carbon Intensity (in dollar per tCO₂e) and Payback Period (in years) can also be incorporated for analysis and decision making.

Table 2 Carbon Metrics for PCA Output Measures

Carbon Metrics		Life Cycle	Annual
Total Carbon	For the whole precinct	tCO ₂ -e	tCO ₂ -e per annum
	For object/ building types	tCO ₂ -e per object type	tCO ₂ -e per type object per annum
	For occupancy	tCO ₂ -e per capita, tCO ₂ -e per household	tCO ₂ -e per capita per annum, tCO ₂ -e per household per annum
Embodied Carbon	For the whole precinct	tCO ₂ -e	tCO ₂ -e per annum
	For object/ building types	tCO ₂ -e per object type	tCO ₂ -e per object type per annum
	For occupancy	tCO ₂ -e per capita, tCO ₂ -e per household	tCO ₂ -e per capita per annum, tCO ₂ -e per household per annum
Operational Carbon	For the whole precinct	tCO ₂ -e	tCO ₂ -e per annum
	For object/ building types	tCO ₂ -e per object type	tCO ₂ -e per object type per annum
	For occupancy	tCO ₂ -e per capita, tCO ₂ -e per household	tCO ₂ -e per capita per annum, tCO ₂ -e per household per annum
Transport Carbon	For the whole precinct	tCO ₂ -e	tCO ₂ -e per annum
	For object/ building types	tCO ₂ -e per vehicle type	tCO ₂ -e per vehicle type per annum
	For occupancy	tCO ₂ -e per capita, tCO ₂ -e per household	tCO ₂ -e per capita per annum, tCO ₂ -e per household per annum
Carbon Offsets	For the whole precinct	tCO ₂ -e	tCO ₂ -e per annum
	For occupancy	tCO ₂ -e per capita, tCO ₂ -e per household	tCO ₂ -e per capita per annum, tCO ₂ -e per household per annum

More detailed information about the precinct carbon model and the assessment methods can be found in (Huang et al., 2017a; Huang et al., 2017b).

Versions and Features of the PCA Software Tool

While initially developed in forms of an Excel spreadsheet tool, this PCA tool is currently implemented in two versions, i.e. a web-based 'Light' version that provide a quick and precinct-objects level evaluations (at Level 1), with limited modelling and scenario analysis functions; and a custom software as the 'Full' version, operating in the MatLab environment with Graphical User Interfaces for inputs and outputs that can support detailed modelling and scenario analysis (at Level 2 and Level 3).

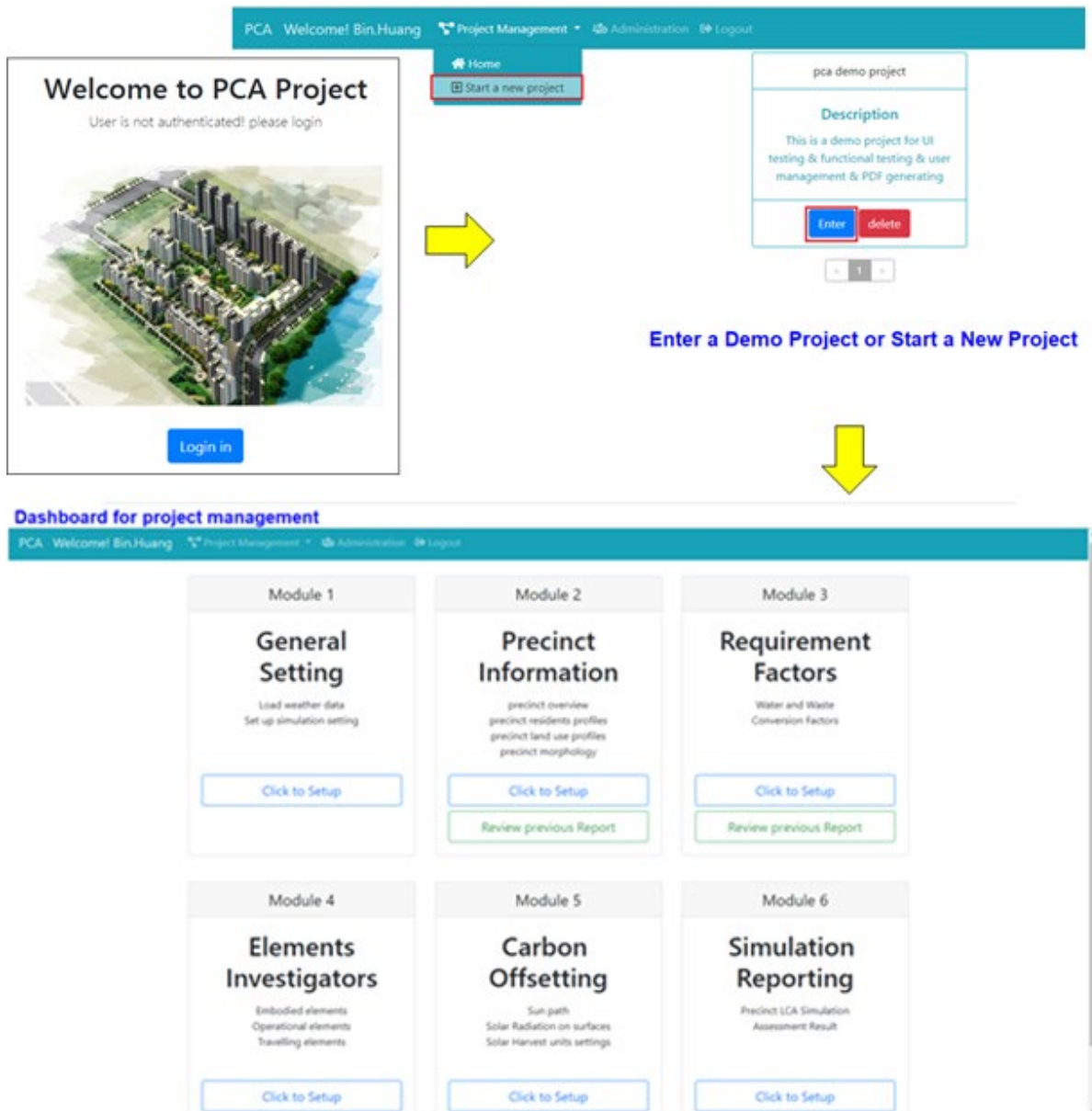
The PCA-'Light' version: a web-based online tool

The PCA-'Light' is a web-based online tool, built on the Internet Explorer (IE) frame and developed in Python. It supports concurrent accesses and simulations by multiple users. Currently, it is hosted on the AMAZON Cloud and accessed via the URL www.precinculators.info. The log in is controlled by User ID and PIN, which are assigned and authorised by the tool administrator upon receiving the request from an end user.

As this 'Light' version is web-based and the computation is performed on a Cloud sever, there is no special demand on operating environment on local devices. The minimum requirement for tool access and use is to have an internet-connected computer with IE, or any other type (e.g. Google Chrome, Firefox) Explorer, installed.

Upon log in, the user can open an existing project or create a new project and to perform modelling and assessment (Figure 4).

Figure4 Operational Features of the PCA-'Light'



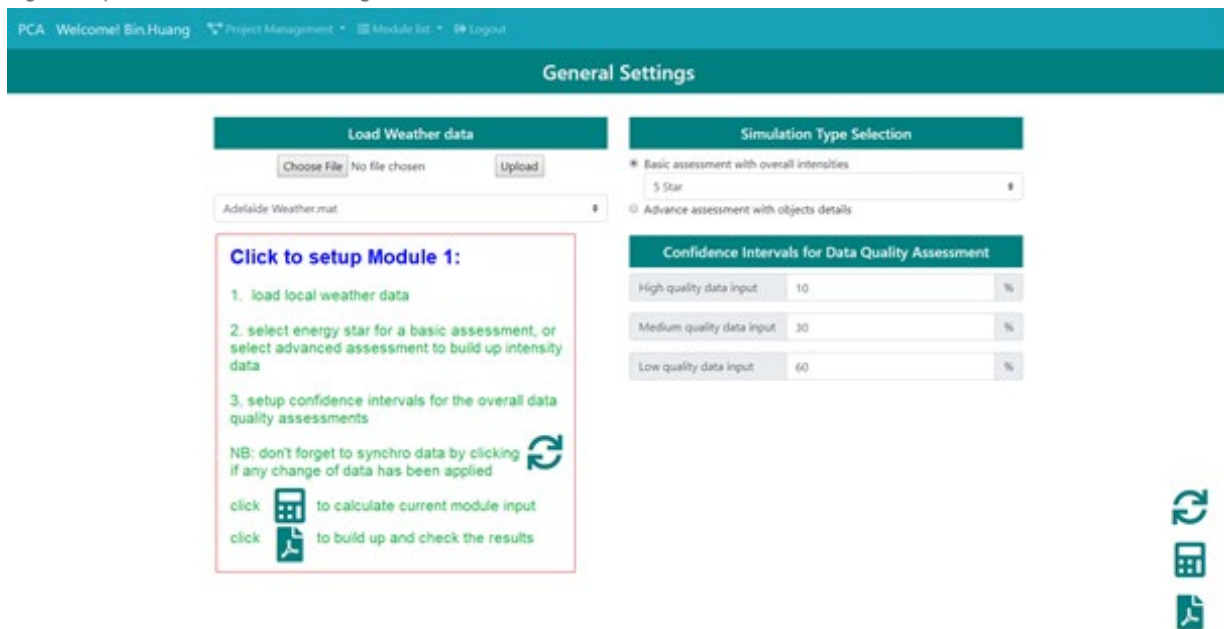
This 'Light' PCA tool consists of the following six function modules for users to define and analysis a precinct project:

- *General Settings* – to setup simulation parameters, as well as to load local climate and LCI databases.
- *Precinct Information* – for the input of precinct generic information, demographic profiles, land use profiles and precinct morphology
- *Requirement Factors* – to calculate water and waste related energy, carbon and cost, as well energy to carbon and cost factors.
- *Element Investigators* – for intensities input and editing, as well as energy, carbon and cost calculation (including embodied, operational and travelling).
- *Carbon Offsetting* – for the assessment of energy harvesting and offsetting contributed by solar PV and solar water heaters, as well as the payback and offsetting period.
- *Simulation and Reporting* – to perform data integration, overall assessment and generating a report on assessment results in numbers, tables and charts according to the selection of precinct

objects (building and infrastructure types) and elements (embodied, operational and travelling).

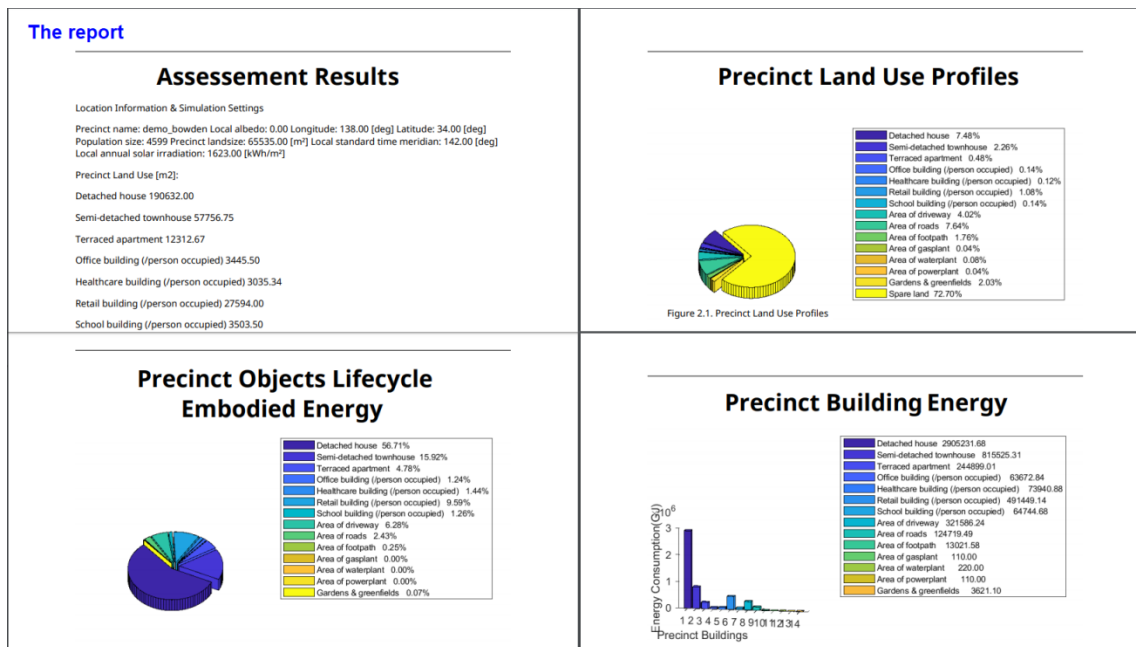
The simulation with the 'Light' version is based on the overall energy, carbon and cost intensities of precinct objects (buildings and infrastructure). Thus, a life-cycle intensity (LCI) database has been developed to support the assessment. However, end-users can also edit the database or customise their own LCI database. As shown in Figure 5, the graphic interface is developed for the PCA-'Light' version, which provides simple operational functions for input of data or upload of databases to initial. Instructions and terms are provided to indicate the type of input and output parameters.

Figure5 Input Interface of the PCA-'Light'



After the simulation is completed, results are generated and presented in both numerical and graphical forms, as illustrated in Figure 6. The output is produced as a PDF report with combined results of each module, which can be printed out, downloaded to a local computer or saved on the Cloud server in the project folder under the user's account. The tool will also send a copy of the report to the user's registered e-mail address.

Figure6 Output of Simulation Results from the PCA-'Light'



A 'User Guide' is prepared for detailed step-by-step instructions on operating the PCA-'Light' tool and presented in [Appendix 1](#).

The PCA-'Full' version: a Matlab-based online tool

In comparison with the web-based PCA-'Light', the Matlab-based 'Full' version, i.e. the PCA-'Full', provides detailed and advanced modelling and simulation capability to support scenario analysis and optimisation in precinct design. Whilst the 'Full' version is also built on energy, carbon and cost intensities, end-users can "customise" their own intensities by building up data with material intensities and usage in construction. Hence, it can support simulations with higher resolutions. In addition, integrated with machine learning and data mining, this expert system can "recommend" intensity data to support assessment. Thus, the full version is more independent of large body data input compared to the 'Light' version.

As the 'Full' version is Matlab-based, the minimum system requirement for its operation is 4G RAM to run the Matlab software, which needs to be pre-installed and compatible to the OS. For the ease of access and use by end users, presently the PCA-'Full' is hosted both in a physical server located at University of South Australia and on the AMAZON Cloud. Users can access and operate the tool through 'Remote Desktop Connection' with no specified requirement on their local

computers. However, this does not support concurrent accesses by multiple users.

The PCA-'Full' is operated with the Matlab Graphical User Interfaces (GUI) for inputs and outputs. Upon log in, users can select to open an existing project or create a new project, as well as to choose the level of modelling desired, i.e. Basic Assessment or Advanced Assessment.

Figure7 Input Interface of the PCA-'Full' Version



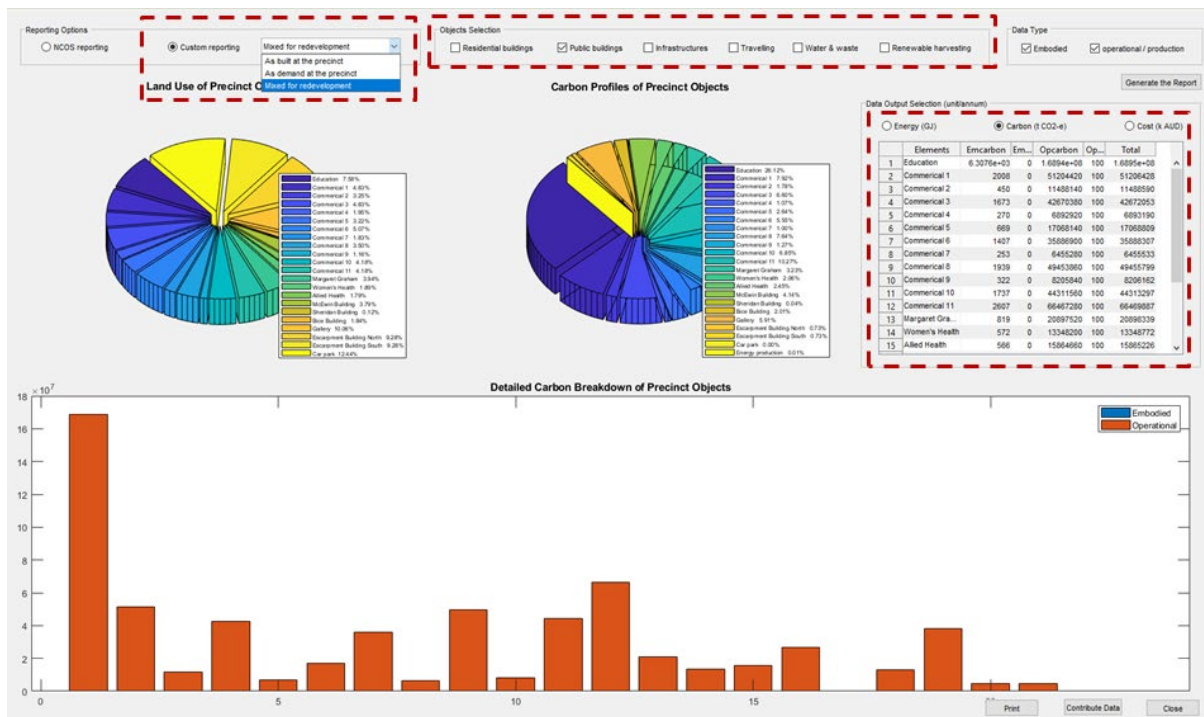
The PCA-'Full' provides six main function modules, each with a drop-down menu to provide detailed modelling and assessment functions, as shown in Figure 7. Help documents and terms are provided within each module to indicate the type of input and output parameters.

- *File* – to provide file management functions, including simulation setting, local climate and LCI databases loading, open / create / save a project, as well as print simulation results.
- *Precinct Profiles* – for the input of precinct general information, as well as the descriptions of precinct demography, land use, objects types and morphology.
- *Energy Production* – to select/specify energy to carbon and cost factors, to describe conventional energy production profiles, to calculate solar energy harvesting and associated carbon offsetting, as well as to identify the payback and offsetting periods of PVs, solar water heaters and battery storage systems.
- *Living Requirements* – to select/define water and waste processing related energy consuming, carbon emission and cost expenditure, as well as to setup the indoor environment of buildings.
- *Objects Investigation* – to build up intensities, as well as to calculate the embodied, operational and travelling energy, carbon and costs. Data mining and machine learning are integrated to recommend qualified intensities, and results presented with tables, graphs and charts.

- *Simulation & Reporting* – to present results with two formats, i.e. 'NCOS Reporting' and 'Custom Reporting'. Qualified intensity data can be collected and inserted into the LCI database, which then can support the “evolution” of the tool.

For the output of simulation, the 'Custom Reporting' option is to assist planning and design decision making. Like the reporting in the PCA-'Light' version, this reporting feature in the 'Full' version supports real time presenting of results with tables, graphs and charts according to precinct objects (building and infrastructure types) and elements (embodied, operational and travelling). As shown in Figure 8, this reporting option allows users to select 'As built', 'As demand' or 'Mixed' object types to support the simulations with different precinct contexts. Also, users can select one or multiple precinct object types with specified data types to review the results. The data can be reported in terms of Embodied Carbon, Operational Carbon (in tons of CO2 equivalent and in percentage), and Total Carbon. Users can also choose the option to show the results in Energy or Cost measurements.

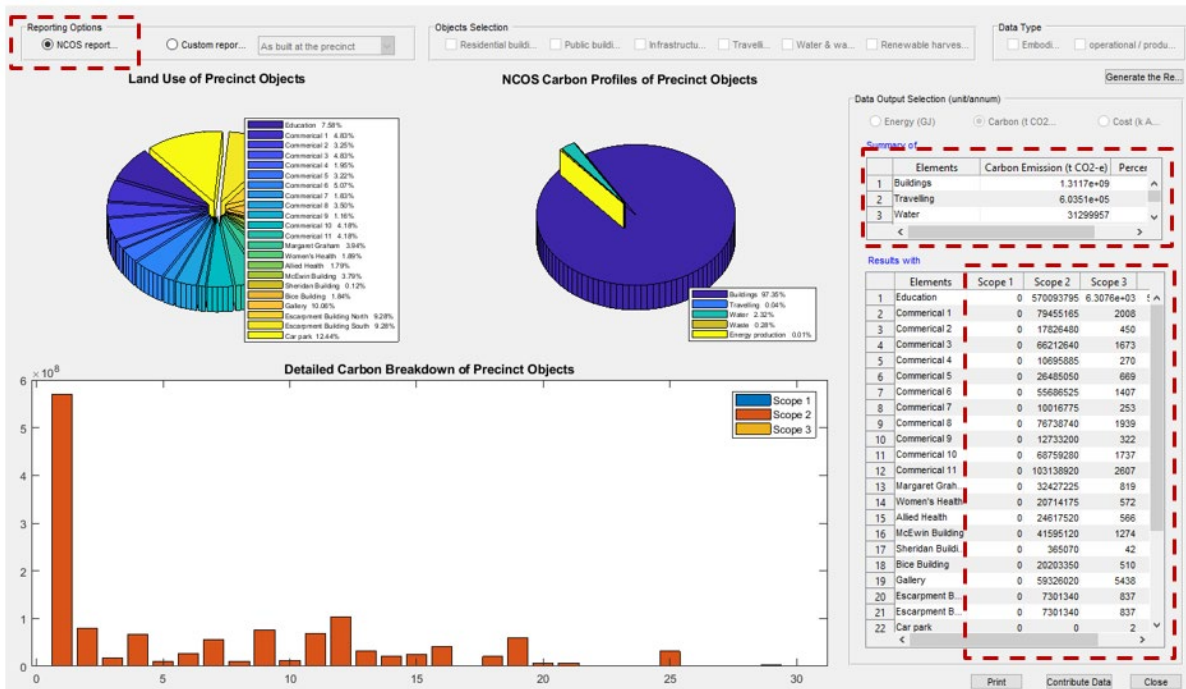
Figure8 'NCOS Reporting' Features of the PCA-'Full' Version



Unlike the PCA-'Light', in this 'Full' version users can also choose the option of 'NCOS Reporting' to meet requirements of reporting and standard compliance. This report has the assessment results presented in carbon metrics and categorised in accordance with 'Emission Scopes' (i.e. Scope 1, 2 and 3) related to each precinct object and 'Emission Sources' (i.e. Energy, Transport, Waste, Water, Waste Water and Offsets from Renewables) as stipulated by the 'National Carbon Offset Standard for Precincts' (NCOS-Precincts) (Australian Government Department of Environment and Energy, n.d.). Figure 9 illustrates the 'NCOS Reporting' features.

A 'User Guide' is prepared for detailed step-by-step instructions on operating the PCA-'Full' tool and presented in [Appendix 2](#).

Figure9 'Customer Reporting' Features of the PCA-'Full' Version



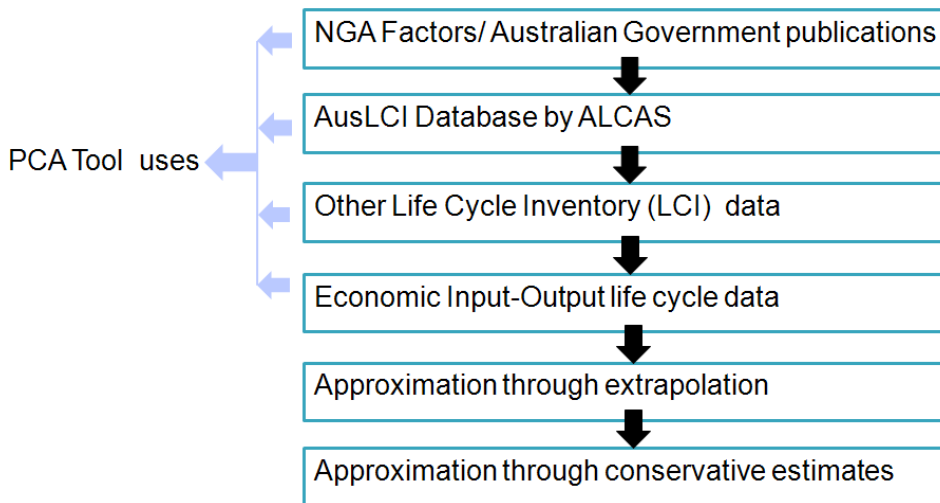
Standard Compliance and Tool Review

Alignment with NCOS-Precincts

The target users for the PCA tool include government planning agencies and private companies (such as developers and consulting firms), sustainability development consultants, as well as urban and infrastructure planners. For this purpose, the tool aims to be an operational precinct carbon rating tool aligned with NCOS-Precincts to make it possible for achieving standard-compliant assessments of precincts' carbon neutrality position.

Figure 10 illustrates the NCOS emission factor hierarchy and its relation to the data method of the PCA tool. Overall, the carbon assessment requirements of NCOS-Precinct can be defined in 8 main categories, with a total of 47 subcategories. Based on comparison, the PCA tool has 'full compliance' (both data and method) in 12 subcategories and 'method compliance' in 15 subcategories. The remaining 20 subcategories are regarded as not directly relevant to the functions of the tool, as they focus on data collection methods for 'as operated' and for products and services, whilst the PCA tool is for assessment of 'as designed' and 'as built' at the building and the precinct system levels.

Figure10 NOCS Emission Factors and the PCA Tool



The detailed mapping between the PCA data and modelling features and the NCOS requirements is presented in [Appendix 3](#).

Tool review

DSquared Consulting, a consultancy firm for sustainable built environment, was engaged with to perform an independent third-party review on the performance of the PCA tool. A full operational testing of PCA tool was conducted to assess user operability, functionality and compatibility with the requirements of NCOS.

The Lot Fourteen Precinct is used as a test case in order to evaluate the usability of the tool and to assess the accuracy of the results produced by the tool. Lot Fourteen Precinct is located on the site of the former Royal Adelaide Hospital (RAH) in Adelaide, South Australia, and comprises adaptive reuse of the existing buildings within the precinct to provide a combination of commercial, retail, education and public realm space.

Based the tool testing and review, it is reported that the format of the results produced by the *Matlab-based PCA-‘Full’* version is consistent with the requirements of NCOS-Precincts. The results of the PCA tool indicate that they capture a broader scope and content than those results obtained via traditional calculation methodologies. The assessment has the following precinct operational emissions accounted for:

- Energy: Include lighting, heating, cooling, occupant energy use, plant equipment and other infrastructure and shared services (Scopes 1, 2 and 3);
- Water: Water consumed and waste water discharged (including Scope 3 emissions associated with off-site water treatment);

- Transport: Transport to and from the precinct (including occupant commuting, occupant travel to and from a place of work);
- Waste: Waste leaving the precinct (including all waste streams and Scope 3 emissions associated with off-site waste recycling, processing, combustion, or disposal to landfill).

The review notes that the outputs of the current version of the web-based PCA-‘Light’ are not yet conforming to the requirements of NCOS, as it is limited to Level 1 modelling capacity (as shown in Figure 2) and supports Basic Assessment at this stage. Modifying the format of outputs to NCOS format, providing a breakdown of results in terms of emission sources is recommended for future iterations of revision of the web-based PCA tool.

With regard to the usability performance, the following main recommendations are made to further align the modelling capability and assessment functions of the PCA tool with needs of practitioners/end users:

- Providing the tool with the capability to allocate different star ratings to different building types, noting that a precinct may comprise a mixture of building types and a mixture of different building states.
- Incorporating an alternative method of displaying the graphics – i.e. exporting the outputs into Excel (or similar) to create clearer, more user-friendly graphics.
- Incorporating features for comparison of scenarios within the same reporting interface.
- Enhancing the operational stability of hosting platform for access to a wider audience.

- Incorporating emissions from refrigeration into the tool to further align the PCA tool with the requirements of 'NCOS for Buildings'.

To date, the PCA tool has been applied to a number of test cases of different precinct contexts and morphological types, as summarised in Table 3.

A full review report is available on request (please inquire with ke.xing@unisa.edu.au for detailed formation).

Tool application

For its applications, PCA can be used as an assessment tool at the final phase of a development project or as a planning tool applied at an early stage of a project. Users may use it in either of the following two ways:

- 1) applying the tool to a new/ongoing project to analyse carbon reduction scenarios for precinct development, or
- 2) applying the tool to completed projects for carbon performance assessment.

The tool can be applied to 'Greenfield', 'Greyfield' or 'Brownfield' types of development for Residential or Mixed-use precincts. The spatial scales in modelling and assessments include Street, Neighbourhood, Subdivision and Suburb, as well as CBD and Corridor. The tool is particularly useful in supporting 'as designed' or 'as built' carbon assessment and scenario analysis on Infill or Renewal types of precinct (re)development with medium- or high-density housing. With its Transport and Renewable Energy modules, the tool can also support analysis of various scenarios in relation to Transit-Oriented Development (TOD) and deployment of renewable energy harvesting units at a precinct-scale for the zero-carbon or carbon-positive target.

Table 3 Test Cases for the PCA Tool Application

Precinct Context	Morphology Type	Scenario Tested	Results
Andrews Farm	Outer-suburban Renewal (for residential)	Effects of energy-efficient buildings and precinct-scale solar PV for carbon reduction vs. 'Business as Usual' (BAU)	Case Study presented in (Xing et al., 2019)
Bowden	Inner-city Renewal (for mixed use)	Impacts of TOD and urban densification on precinct carbon performance	Case Study presented in (Huang et al., 2017b)
Lot 14 (part)	Inner-city Redevelopment (for commercial)	Operational testing and benchmarking of carbon assessment and NCOS compliance	PCA Tool Review report (available on request and inquire with ke.xing@unisa.edu.au for detailed formation)

Lochiel Park	Low-carbon Development (for residential)	Precinct-scale Solar PV with vs. without battery storage and impact on payback (total carbon and cost)	Case study presented in Appendix 4
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Whilst the PCA tool is not directly aimed at any specific carbon abatement target, it is expected that the use of the tool in planning or assessment of a precinct project's carbon profile and reduction scenarios can help to identify and optimise the options for life-cycle carbon reduction. Based on a case study on urban densification scenarios for a residential precinct redevelopment in Adelaide using the PCA tool (Xing et al., 2019), it is estimated that a 6% of carbon reduction per annum can be achieved with a combination of solutions for high energy-efficient new buildings and households, increase of PV coverage and increased use of public transport for commuting. This can contribute to an accumulated carbon reduction of 67,000 tons in total over 20 years. Secondly, embodied carbon contributes significantly to life-cycle carbon and can account for as much as 38%, when infrastructure, especially transport infrastructure (e.g. roads, driveways, paths and pavements), is considered in the assessment (Huang et al., 2017b).

End users engagement

During its development process, the PCA tool has been presented in a number of end user workshops to engage with organisations, including Renewal SA, GBCA, AECOM and Aurecon, for review and feedback.

Since March 2019 to date, there have been 27 external users for the PCA tool based on the online users accounts and accesses registered, i.e. 26 for the web-based PCA-'Light' version and 2 for the Matlab-based PCA-'Full' version, including organisations such as Alberwell, BlueScope, City of Adelaide, DSquared Consulting, Edge Environment, Good Environmental Choice Australia, as well as Sustainable Buildings Research Centre (University of Wollongong). A registry of the PCA User Accounts is available on request (inquire with ke.xing@unisa.edu.au for detailed formation).

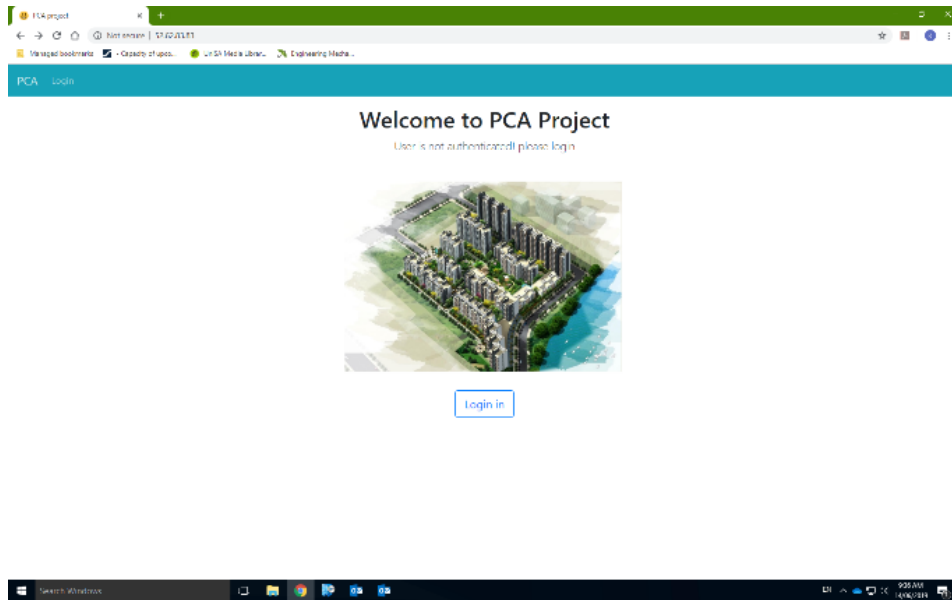
Reference

- Australian Government Department of Environment and Energy (n.d.) National Carbon Offset Standard for Precincts, <http://www.environment.gov.au/system/files/resources/91aadf60-1454-4cde-81dd-587df7cdadd7/files/ncos-precincts.pdf> (accessed on 27/11/2017)
- Huang, B, Xing, K. and Pullen, S (2017,a) Life-cycle Energy Modelling for Urban Precinct Systems, *Journal of Cleaner Production*, 142 (4), 3254-3268
- Huang, B, Xing, K and Pullen, S (2017,b) Carbon Assessment for Urban Precincts: Integrated Model and Case Studies, *Energy and Buildings*, 153, 111-125.
- Ness, D and Xing, K (2017) Towards a Resource Efficient Built Environment: A Literature Review and Conceptual Model, *Journal of Industrial Ecology*, 21(3), 572-592.
- Newton, P., Marchant, D., Mitchell, J., Plume, J., Seo, S. and Roggema, R. (2013) *Performance Assessment of Urban Precinct Design: A Scoping Study*, CRC for Low Carbon Living Ltd, ISBN-13:978-0-9923878-0-8, August 2013.
- Xing, k., Wiedmann, T., Newton, P., Huang, B. and Pullen, S. (2019) Development of Low-Carbon Urban Forms—Concepts, Tools and Scenario Analysis, 227-244, In Newton, P., Prasad, D., Sproul, A. and White, S. (eds.) *Decarbonising the Built Environment: Charting the Transition*. Palgrave Macmillan. ISBN 978-981-13-7940-6

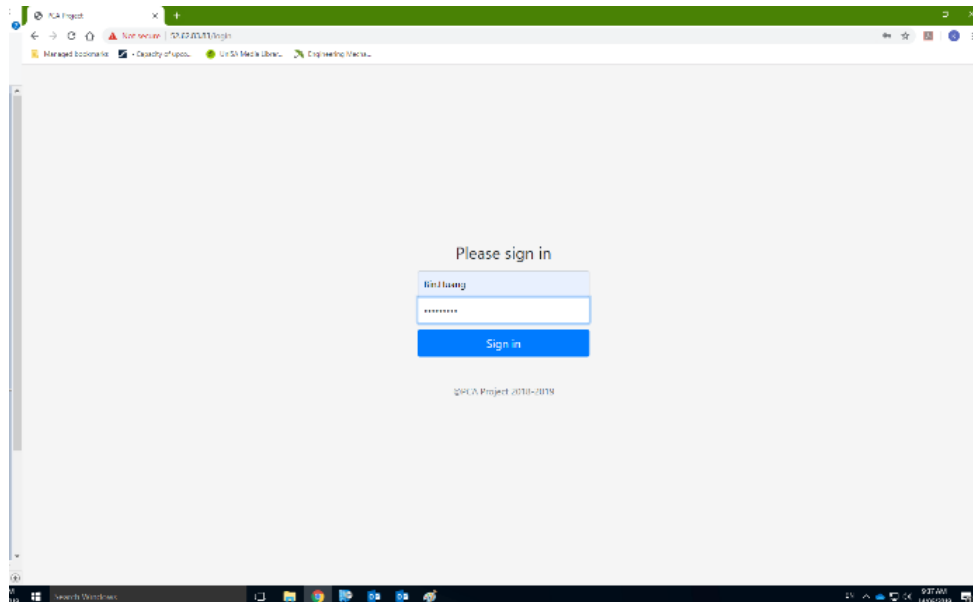
Appendix 1

User Guide of the PCA Tool (Light Version 1.0)

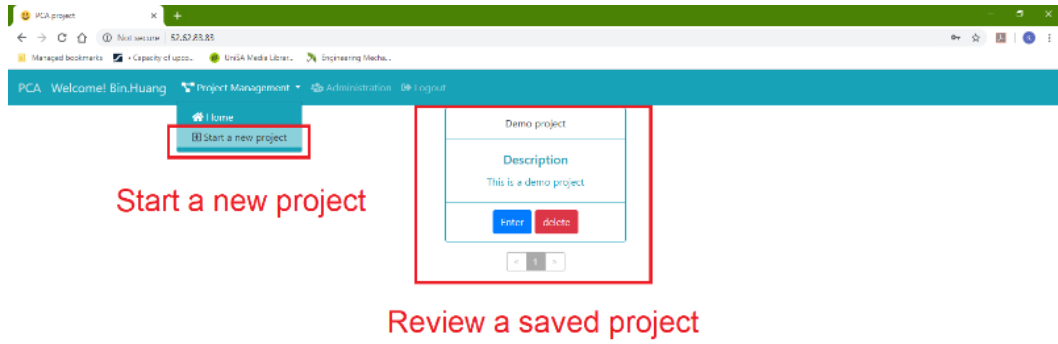
The Light version 1.0 is an online version of the PCA tool developed with the same framework and models used in the Full version 5.0 of this tool. Different from the full version, it is a web-based App allows multiple-user parallel processing by login www.precinculators.info (or IP address: 52.62.83.83). Screenshot of login system:



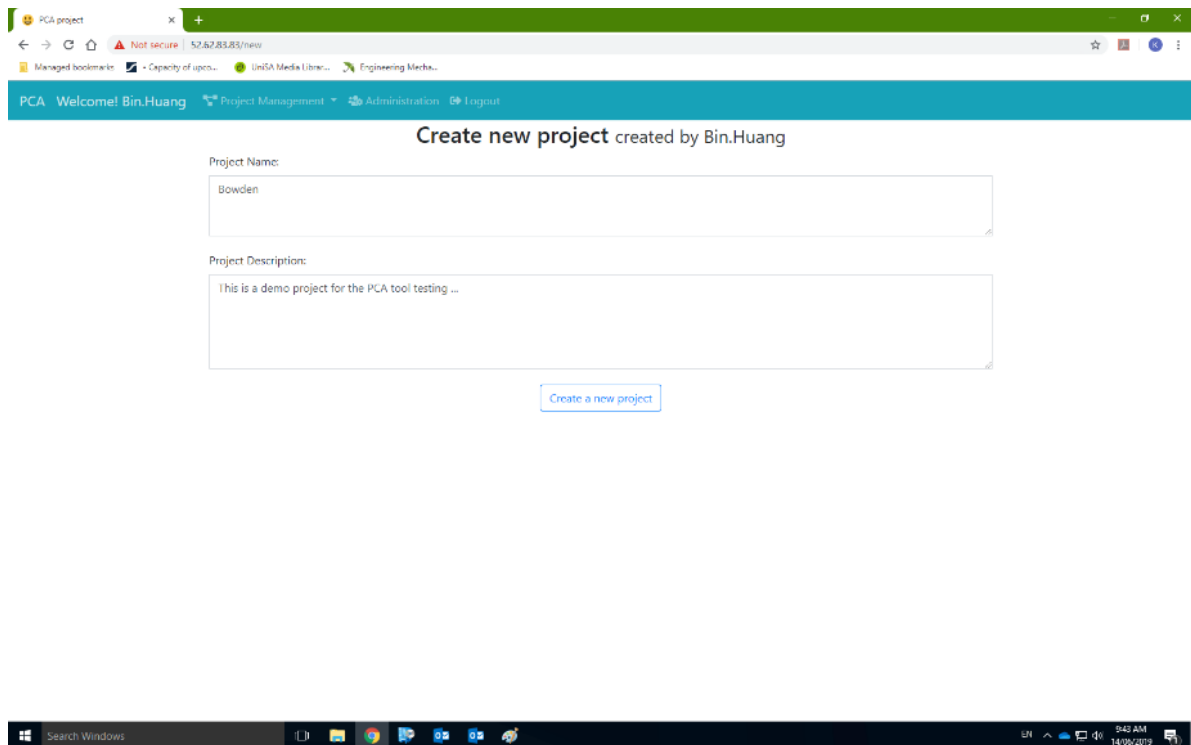
To start using the tool, click 'Log In' and sign in with User ID and Password.



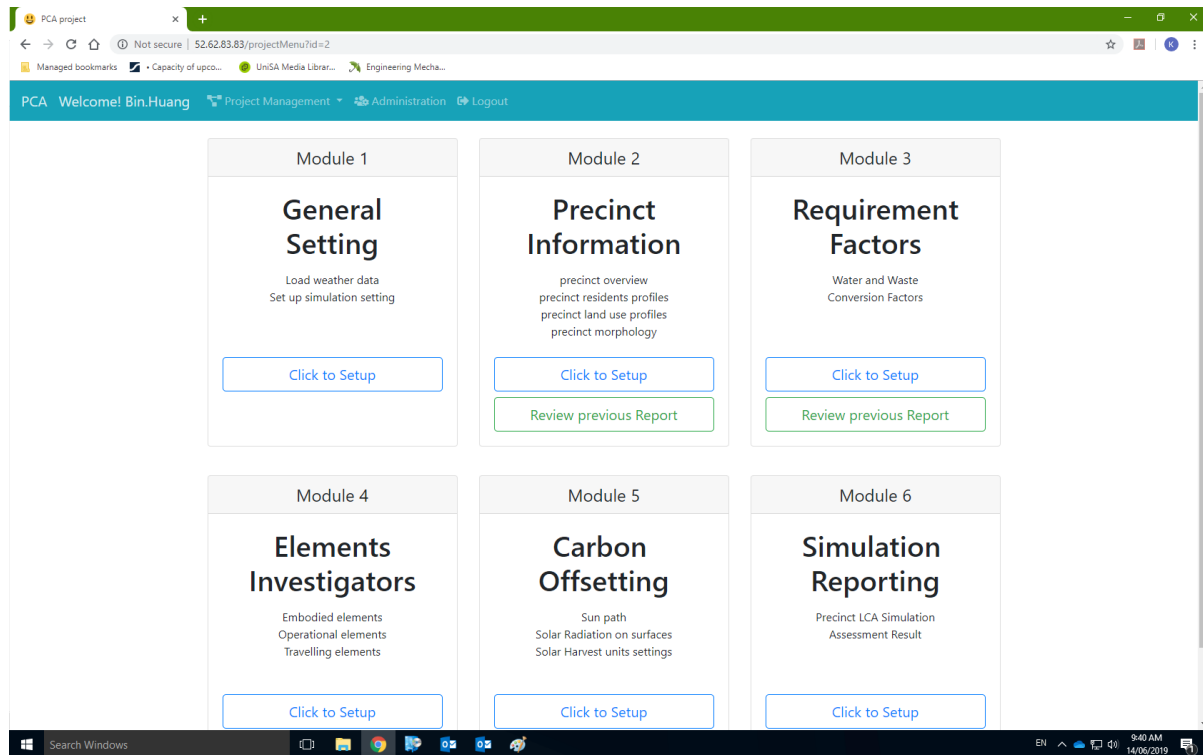
After signing in, the project manage module allows the end user to create a new project, review saved projects, or edit the scenario of a saved project and redo the simulation.



To create a new project, the end users are required to give a project name and a simple description of this project.



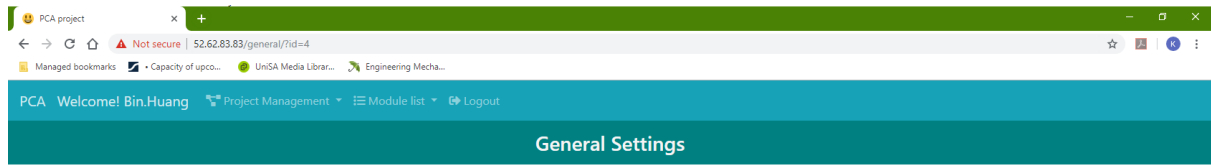
Click "Create a new project" and the project will be created with the project management interface on the screen. Then the simulation can be completed with the following steps:



Step 1: Simulation/assessment setting.

Select Module 1 and Click “Click to Setup” of this module to start the simulation. At this step, the user needs to define:

- Simulation type: *Basic assessment* with NatHERS energy star on per square meter floor area energy use, associated carbon emission and cost expenditures (hereafter termed as ‘Intensities’); or *Advanced assessment* allows to build up intensities according to construction material/element use, appliance type and operating schedules, as well as travel mode profiles such as fuel type, year of vehicle built etc. (the functional modules for *Advanced assessment* is currently unavailable in the online version).
- Confidence intervals setting applied to assess the overall data quality according to the shares and data qualities of components.
- Local weather data (converted from local TMY files) need to be loaded from local end or selected from the preload list to support simulations.



Load Weather data

Choose File No file chosen Upload

Choose Files
Adelaide Weather.mat

Load local weather data from local end or select a preloaded database.

Simulation Type Selection

Basic assessment with overall intensities
6 Star
Advance assessment with objects details

Select NatHERS energy rating for precinct buildings

Confidence Intervals for Data Quality Assessment

High quality data input	10	%
Medium quality data input	30	%
Low quality data input	60	%

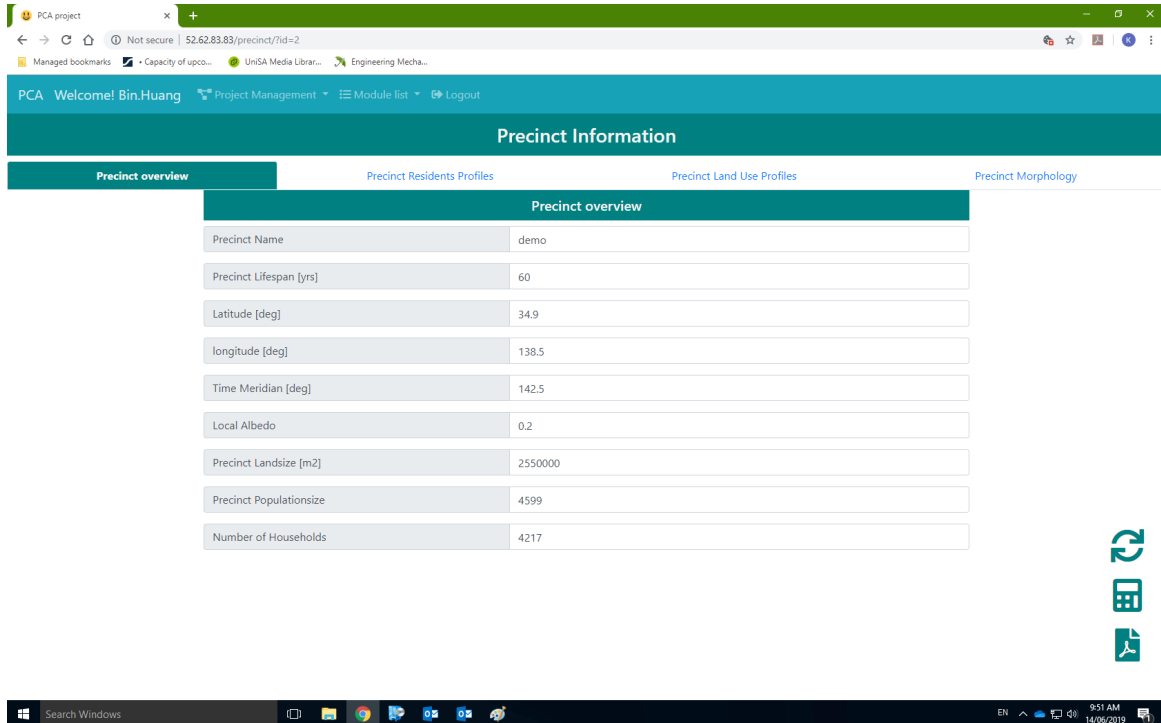
Edit confidence intervals for data quality assessment



NB: if the system did not jump automatically to the next module after the confirmation of current module input, please click "Project Management", return to the management interface and then click "Click to Setup" of the selected module for editing.

Step 2: Precinct Information

After simulation setting, the precinct profiles including Precinct overview and Precinct Residents Profiles, then can be reviewed and edited in modules.



Precinct overview including location and general profiles

Age Structure		
>65	5	%
45-65	20	%
25-45	30	%
18-25	30	%
<18	15	%
Data Quality	Low	

Income Level [k\$]		
>100	5	%
80-100	14.98	%
50-80	30.01	%
20-50	45.01	%
<20	5	%
Data Quality	Low	

Employment Structure		
Employed fulltime	31.33	%
Employed parttime	17.57	%
Employed casually	1.04	%
At Schools	21.31	%
Unemployed	28.75	%
Data Quality	Medium	

Household Size		
1 Person Family	39.29	%
2 Persons Family	36.71	%
3 Persons Family	13.61	%
4 Persons Family	7.99	%
5+ Persons Family	2.4	%
Data Quality	High	

Precinct demographical profiles

NB: please click the synchronous icon to save inputs, the calculate icon to run an inter-modular calculation (unnecessary for each module), and the file icon to check the intermediate results as demand.

Step 3: Define the land use of precinct objects

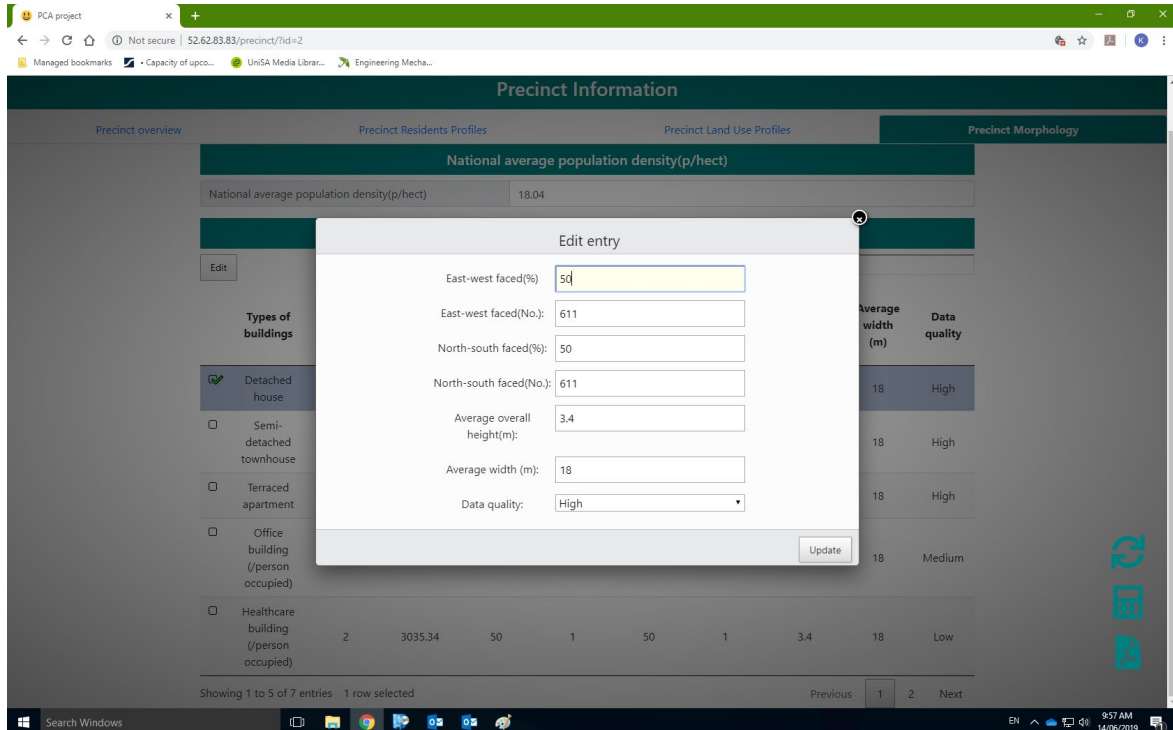
Define the land use of precinct objects, including buildings and infrastructure. If a project is open, then the land use profiles of the precinct would be presented for editing (Add, edit or delete). However, once the objects types and land uses developed in this module, they would be not editable in the following modules.

Building category	Occupants	Data quality
Residential	2413	High
Residential	775	High
Residential	42	High
Public	2297	Medium
Public	4599	Low

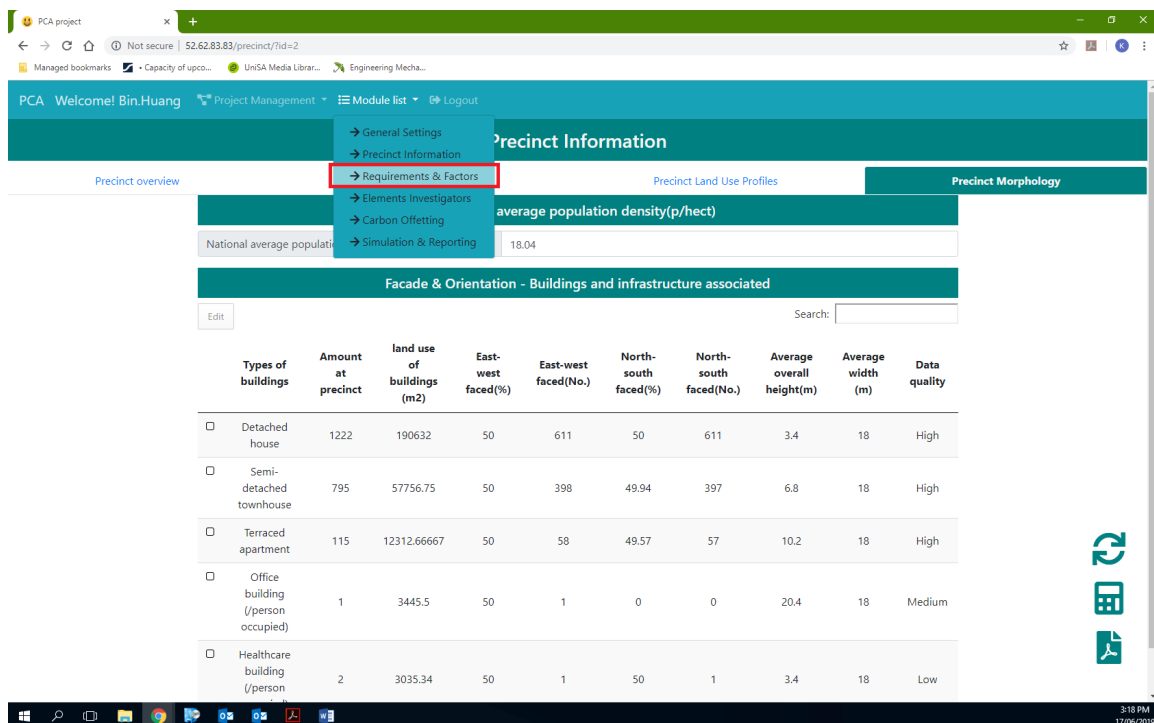
Infrastructure category	Infrastructure type	Occupied land size (m2) / units	Data quality
With landuse	Area of driveway	102416	High
With landuse	Area of roads	194874.2	High

Step 4 Calculate the morphological factors

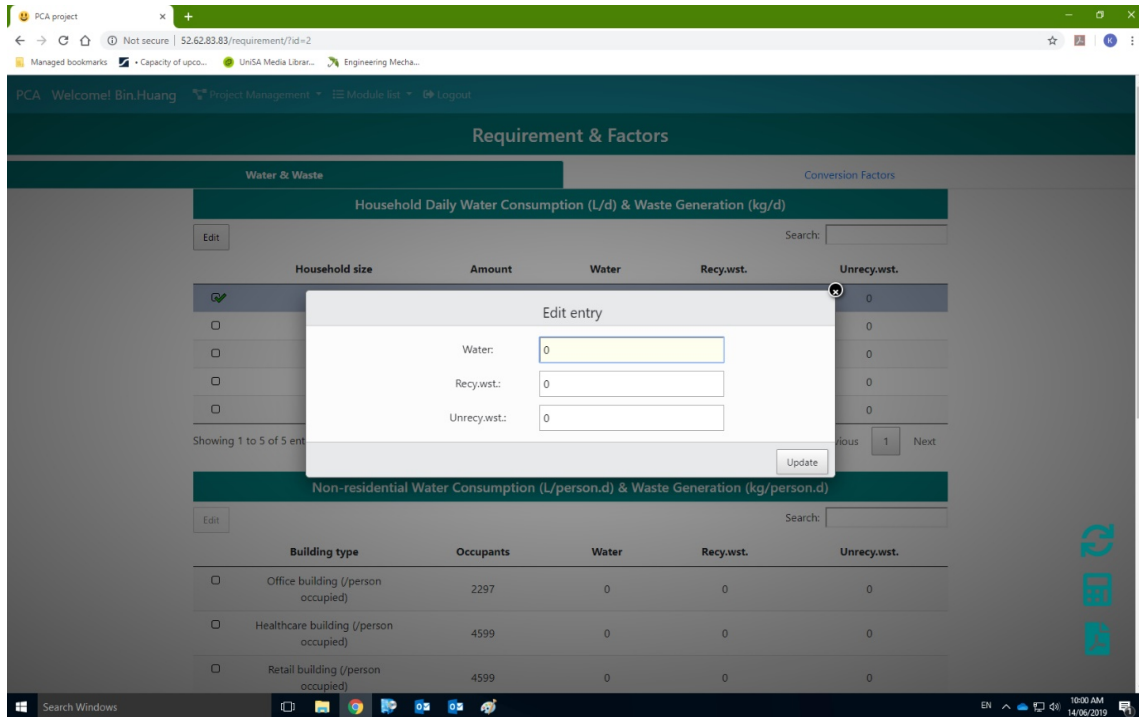
At this stage, only precinct buildings are included for the identification of morphologic factors. Dimensions of buildings can be defined in this module (for default input, average data will be applied), then a mathematical model will convert the real precinct morphology into a notional grid to calculate the factors of HVAC, solar harvesting, artificial lighting and travelling based on density and obstructions.



NB: Please click "Module list" to be directed to the next module for editing, if the system did not jump automatically after the confirmation of current module input.

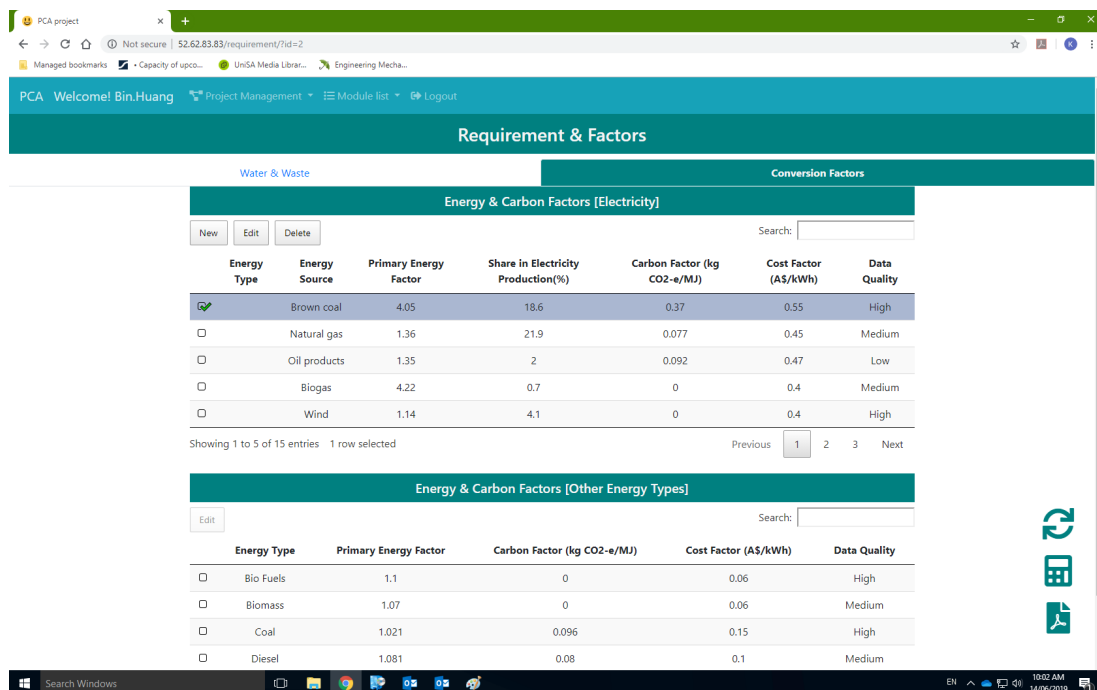


Step 5 Define water and waste processing associated energy, emission and cost. To define water and waste processing associated energy, emission and cost, the values of per unit intensities and demand data are required for accurate assessments. However, without data entry, default data from statistical analysis will be applied.



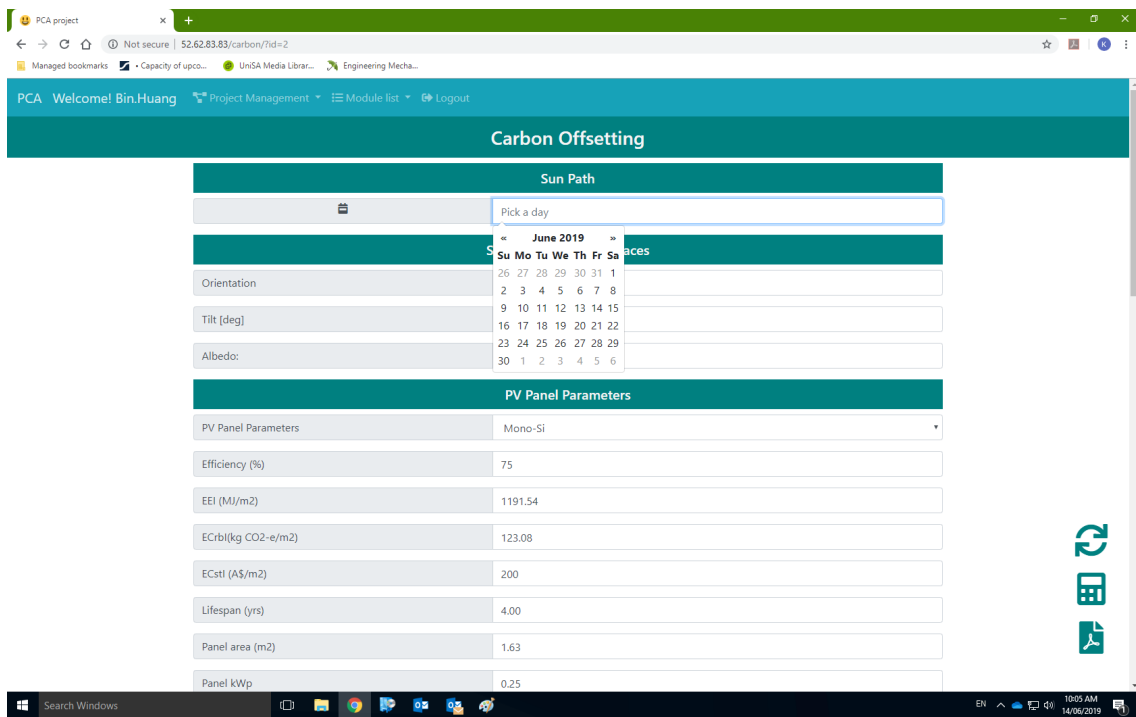
Step 6 Local energy production.

This module is developed to support the identification of primary energy factors, energy-to-carbon factors and energy-to-cost factors of different energy types according to the local energy production profiles. Default data / factors will be applied based on the statistical analysis of relevant data in the LCI database if there is no data entry.



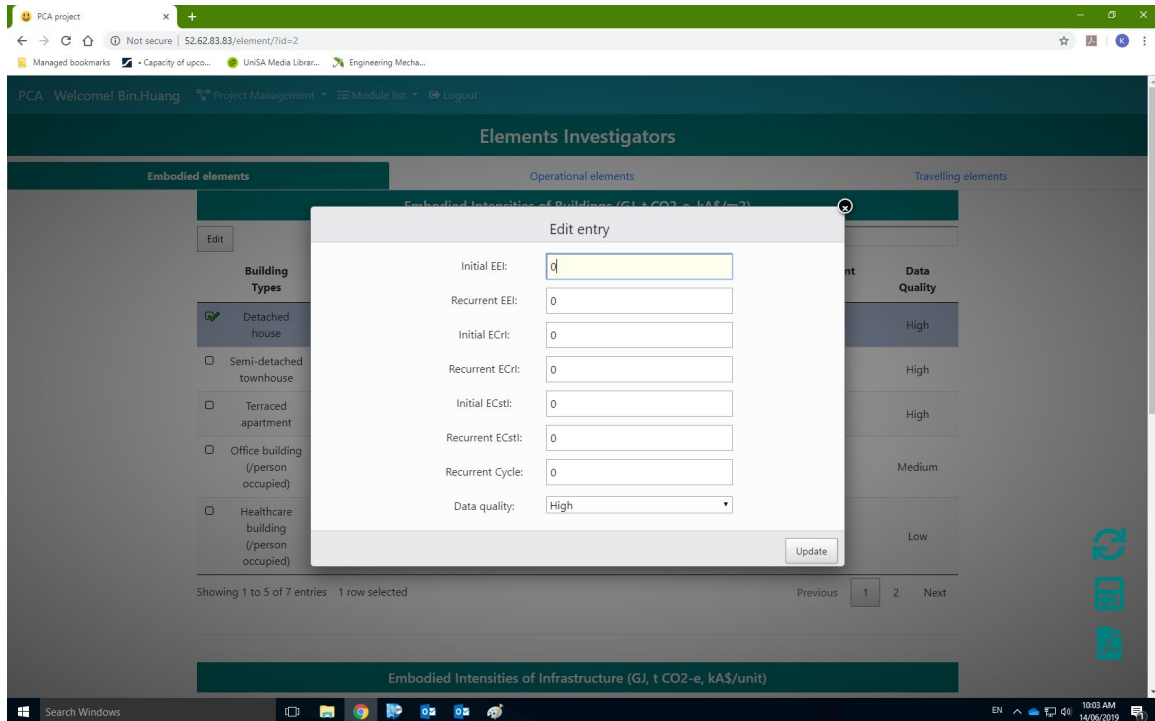
Step 7 Renewable energy harvesting and carbon & cost offsetting.

Firstly, the solar irradiation is calculated according to the local weather data, solar potential is assessment based on the precinct morphological factors. Then embodied energy, carbon and cost are obtained according to the system profiles of renewable energy harvesting units. After that, energy production, as well as associated carbon offsetting and cost saving are obtained according to the efficiency of systems. Finally, payback and offsetting periods are determined to guide the investments on solar energy harvesting. End users can modify parameters and make various combinations for comparative studies, or to find out the optimal solutions.



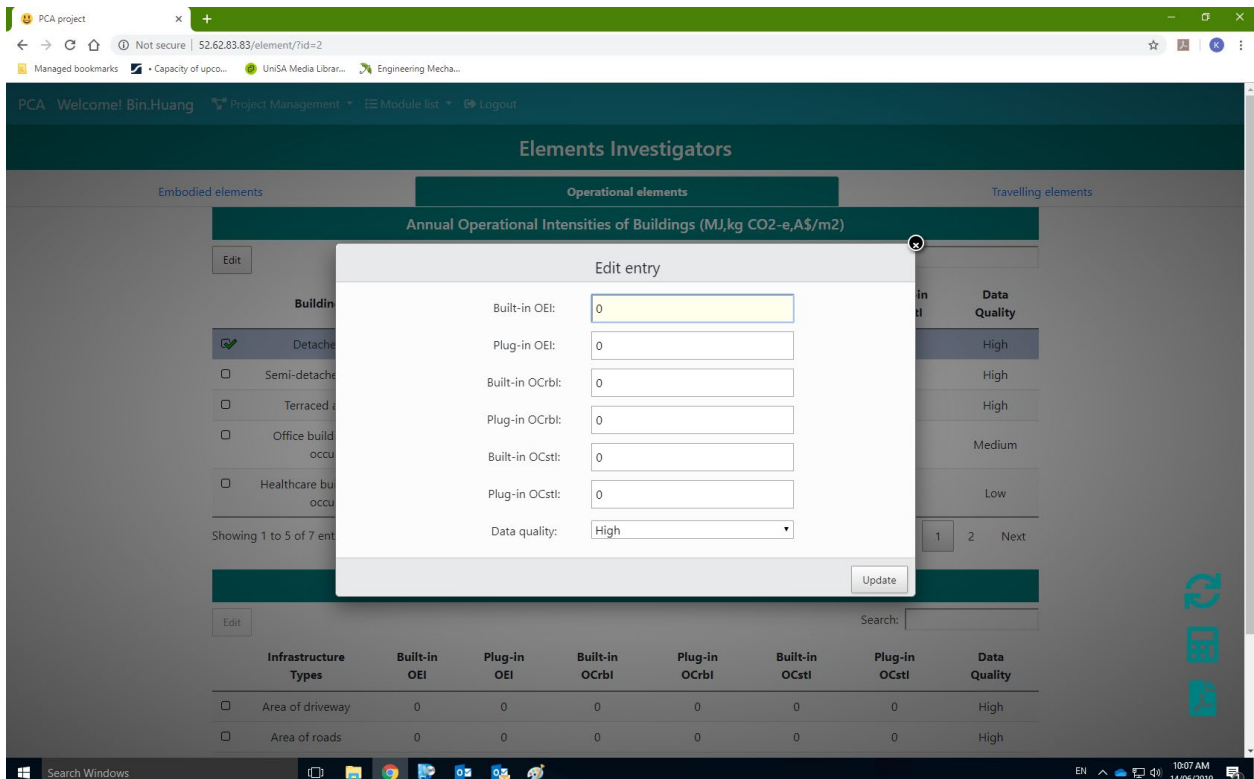
Step 8 embodied energy, carbon and cost (hereafter embodied elements) assessment.

The embodied elements are evaluated with per square meter floor area of precinct objects, and the end users can enter overall intensities for a light simulation or build up intensities for a detailed simulation. To build up intensities, material types, intensities, usage and waste ratios are required. Material intensities and libraries of several typical building types have been integrated into the system LCI database to support a quick build-up of intensities.



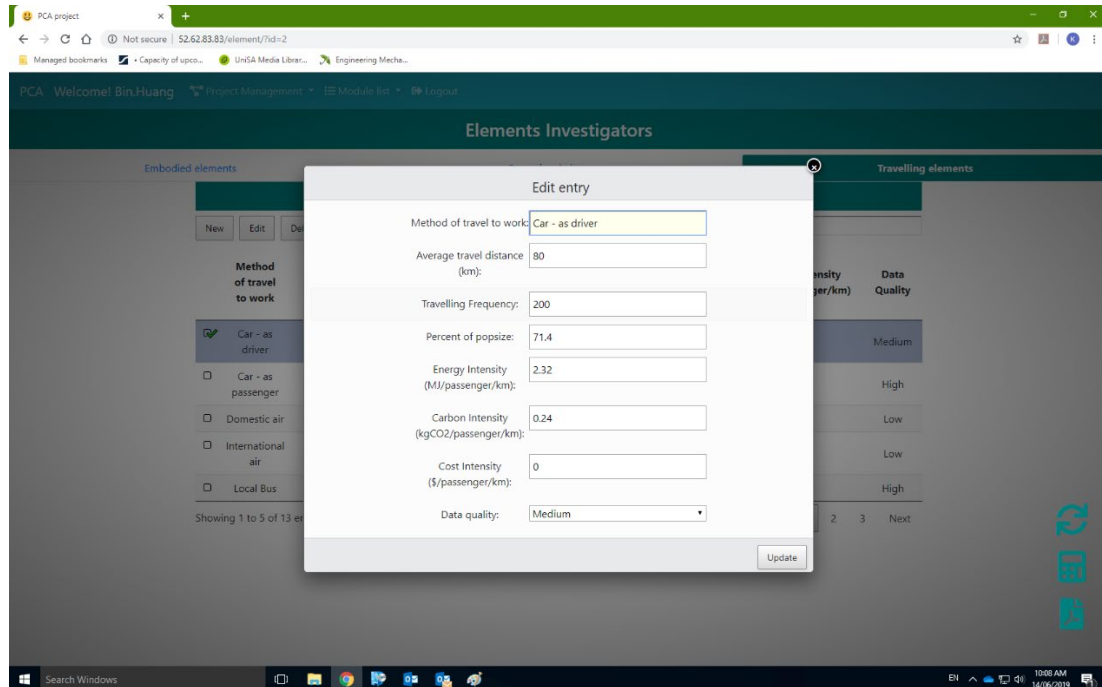
Step 9 operational energy, carbon and cost (hereafter embodied elements) assessment.

The simulation of operational elements considering two types of appliances, built-in appliances such as HVAC, lighting and cooking systems; and plug-in appliances like portable appliances of lamps, TVs, PCs etc. The assessment of operational elements is also based on the principle of per square meter floor areas. However, in a detailed simulation, end users can define the appliance types, energy type of appliances, annual operating hours/cycles or operating schedules for building up of operational intensities.




Step 10 Travelling elements assessment.

Assessment of travelling elements allows to evaluate the commuting and entertainment associated energy consumption, carbon emission and cost expenditure. Per passenger per kilo meter intensities are used in calculations, thus precinct travelling diary is required. Detailed travelling elements evaluations also allow end users to select energy type of traffic modes, as well as modify its intensities.

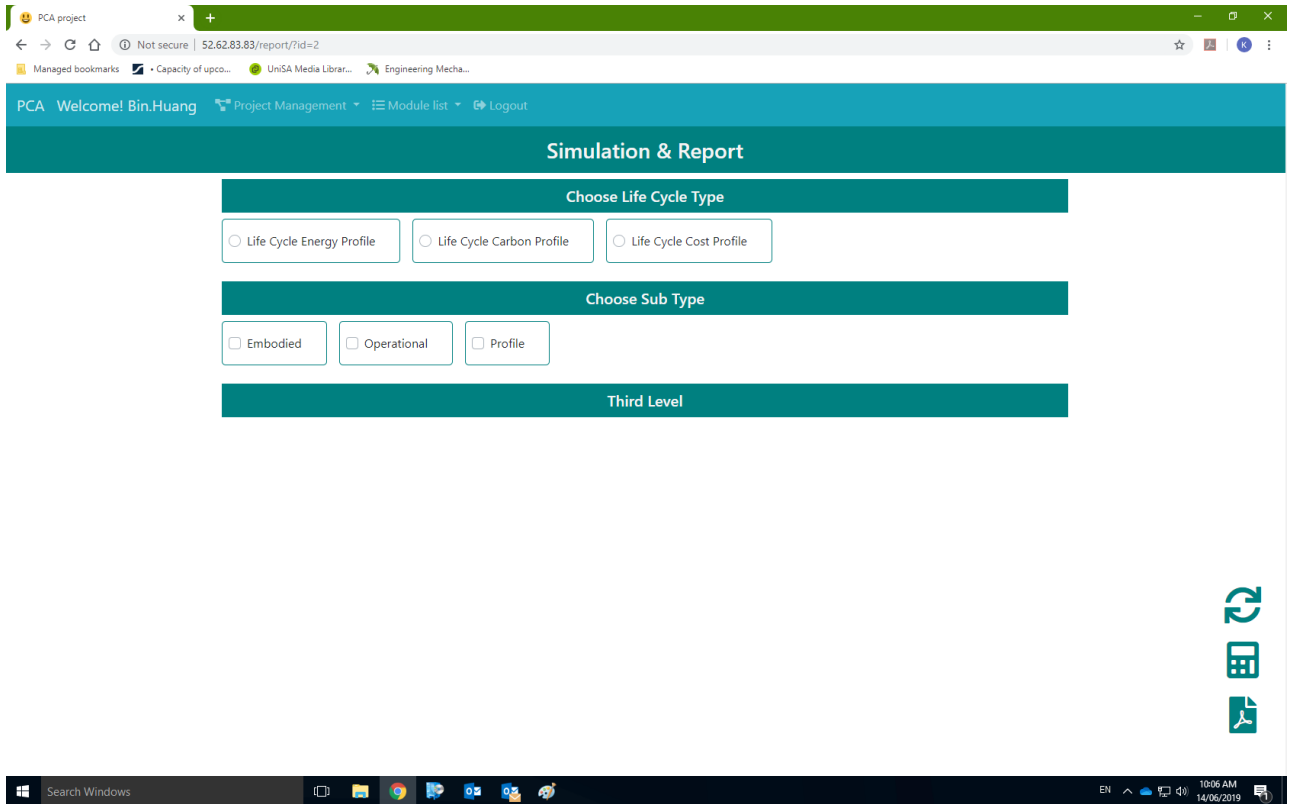


Step 11 Run simulations and compile assessment results for reporting

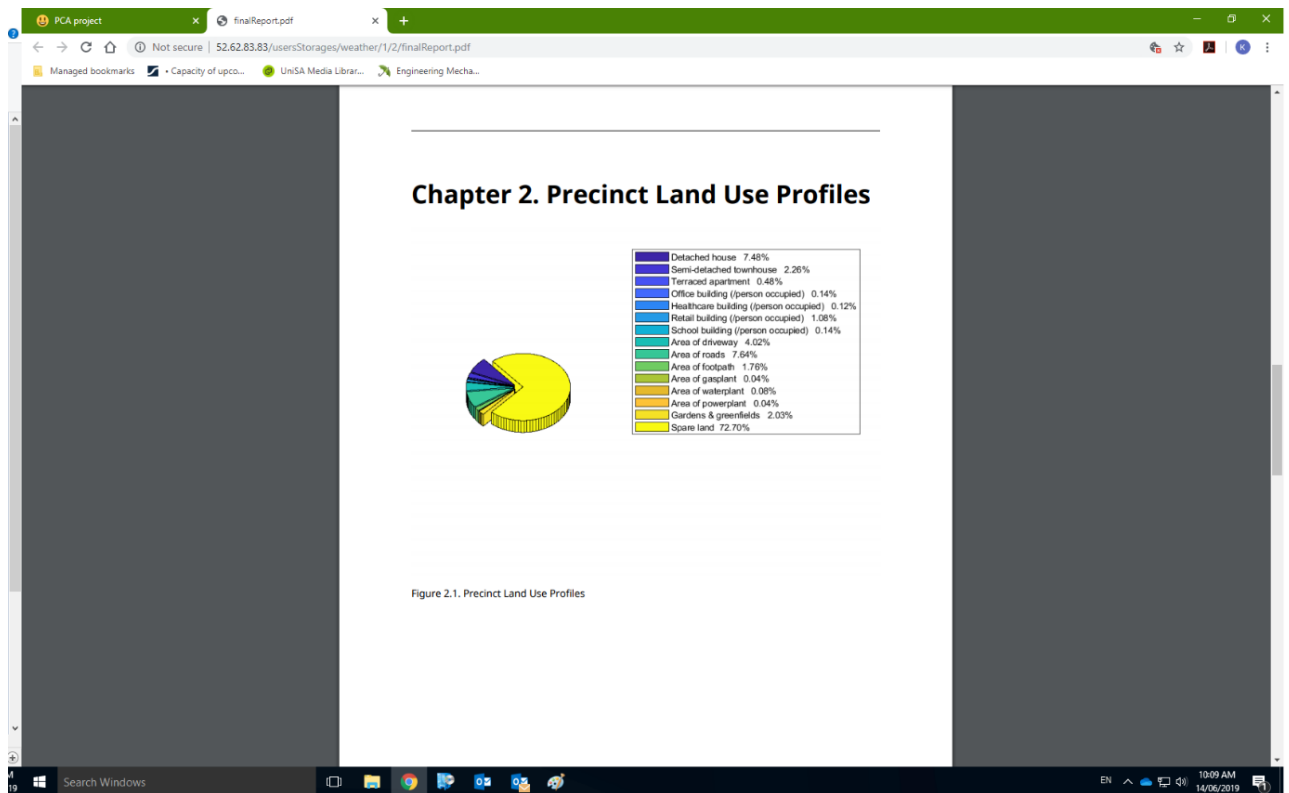
Please just click the calculate icon  to run a systematic assessment with the full scenario described in modules.

Step 12 Reporting.

The light version of the PCA tool is currently supporting custom reporting, end users can select one or multiple elements for observations. The system will combine the relevant data and generate a PDF format report based on end user selections.



Custom reporting



The PDF format report

Appendix 2

User Guide of the PCA Tool (Full Version)

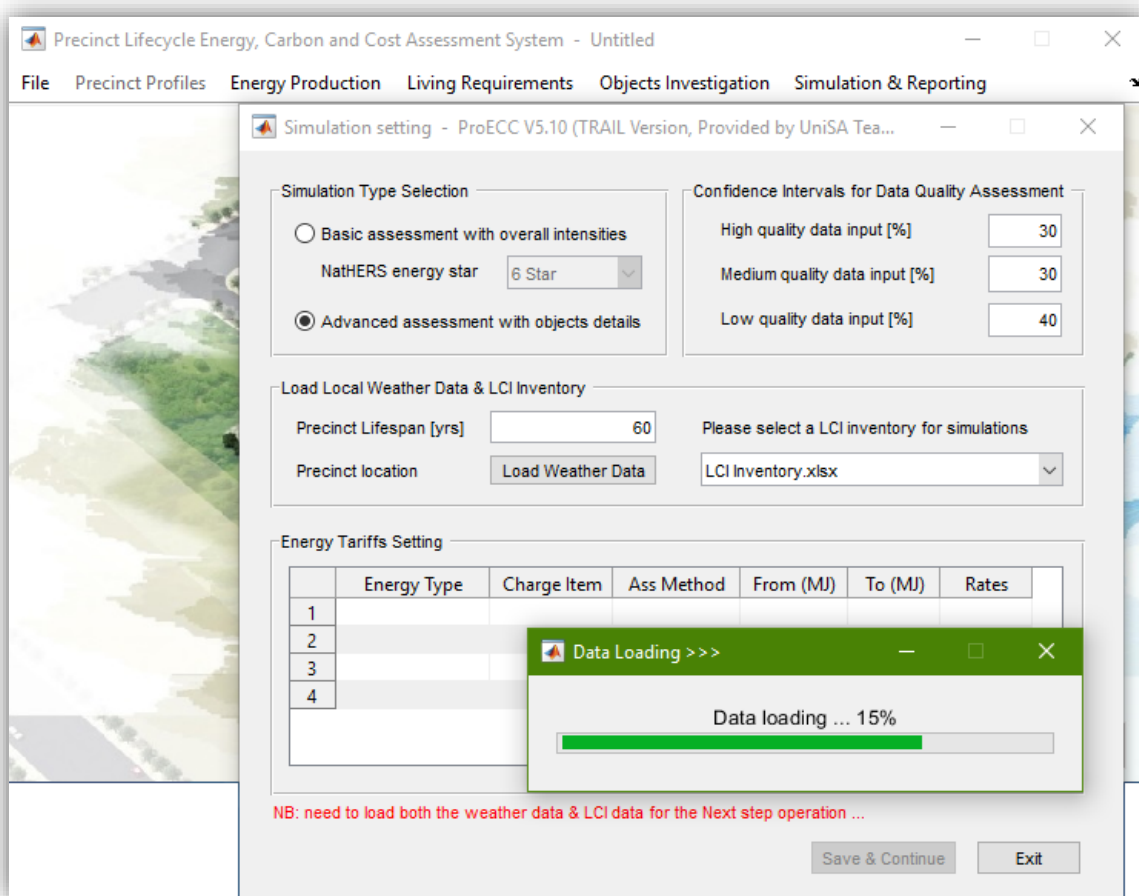
Step 1: Simulation/assessment setting.

a) Simulation type:

- 1) NatHERS energy star for light simulations is based on per square meter floor area energy use, associated carbon emission and cost expenditures (hereafter termed as 'Intensities');
- 2) Advanced assessment allows to build up intensities according to construction material/element use, appliance type and operating schedules, as well as travel mode profiles such as fuel type, year of vehicle built ...

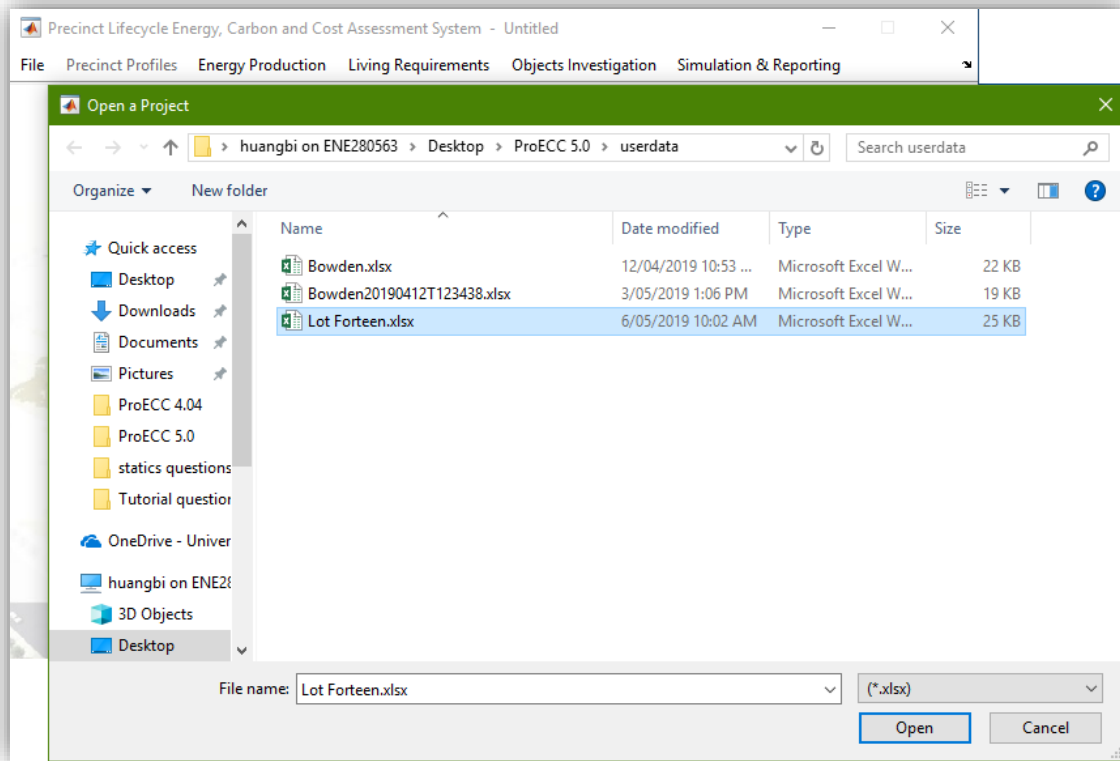
b) confidence intervals setting applied to assess the overall data quality according to the shares and data qualities of components.

c) database uploading: local weather data (converted from local TMY files) and systematic LCI Inventory.

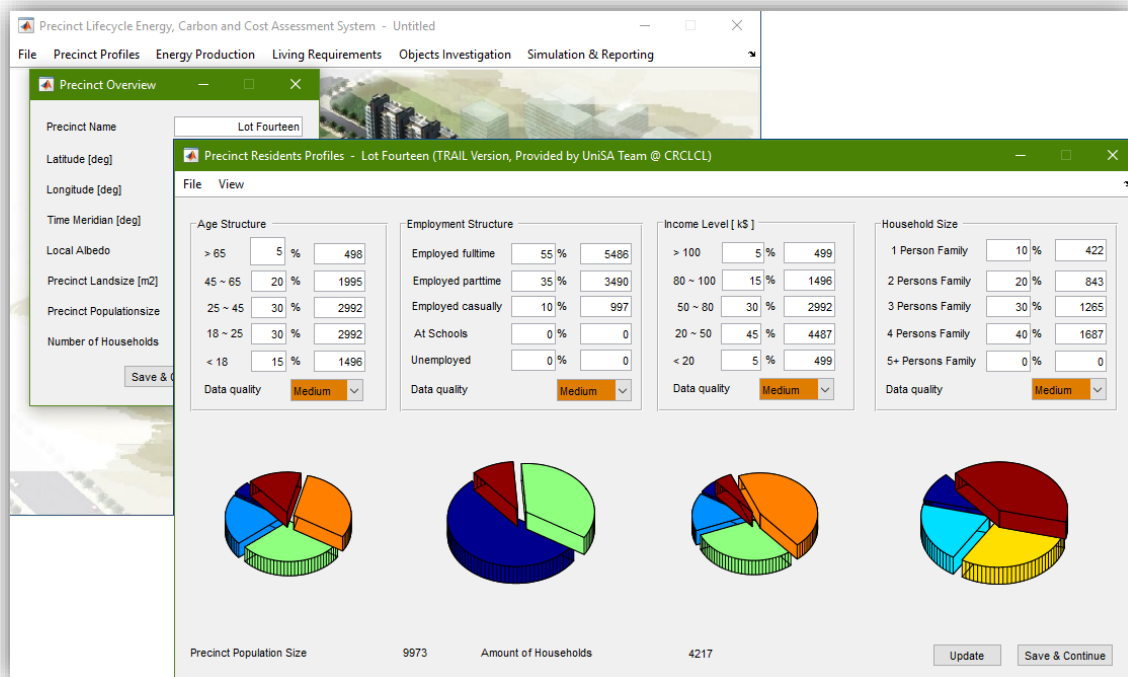


Step 2: Open a project

Open a project developed with a specified format Excel file, or create a project.



After open a project, the precinct and demographic profiles then can be reviewed and modified in modules.



Step 3: Define the land use of precinct objects (buildings and infrastructure).

When a project is open, then the land use profiles of the precinct would be presented for editing (Add, edit or delete). However, once the objects types and land uses developed in this module, they would be not editable in the following modules.

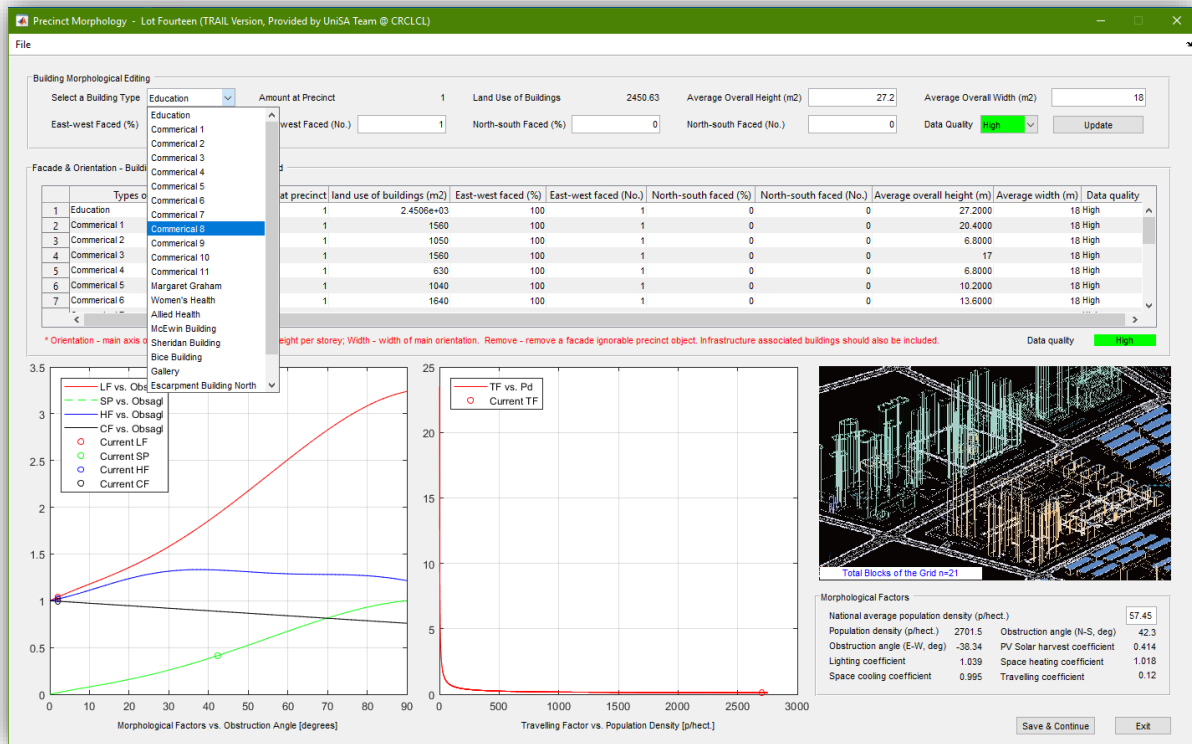
The screenshot displays the 'Precinct Land Use Profiles' software interface. It is divided into two main sections: 'Land use of precinct buildings' and 'Land use of precinct infrastructure'.

Land use of precinct buildings: This section includes a 'Building Land Editing Options' panel with radio buttons for 'Building data editing', 'Building data loading', and 'Path of loaded database'. The 'Building Parameters Input' panel contains fields for 'Building ID (Edit/delete)', 'Category of Building' (set to Residential), 'Name of Building Type', 'Data Method' (As built), 'Floor Area per Building (m2)', 'Stores per Building' (1), 'Number of Occupants' (0), 'Amount at Precinct' (1), and 'Self-occupancy (%)'. A table below lists 12 building types with columns for Building category, Building type, Data method, Per unit floor area (m2), Stores per building, Amount at precinct, Total floor area (m2), Occupied land size (m2), Occupants, Self-occupancy (%), and Data quality. A pie chart on the right shows the distribution of land use for these buildings, with a legend listing categories like Education (7.58%), Commercial 1 (4.80%), etc.

Land use of precinct infrastructure: This section includes an 'Infrastructure Land Editing Options' panel with radio buttons for 'Infrastructure data editing', 'Infrastructure data loading', and 'Path of loaded database'. The 'Infrastructure Parameters Input' panel contains fields for 'Infrastructure ID (Edit/delete)', 'Category of Infrastructure' (With landuse), 'Name of Infrastructure Type', 'Data Method' (As built), 'Land Use at Precinct (m2/unit)', 'Self-occupancy (%)', and 'Data Quality'. A table below lists 2 infrastructure types with columns for Infrastructure category, Infrastructure type, Data method, Occupied land size (m2) / units, Self-occupancy (%), and Data quality. A 'Precinct Overall Land Size (m2)' of 36916 is shown at the bottom.

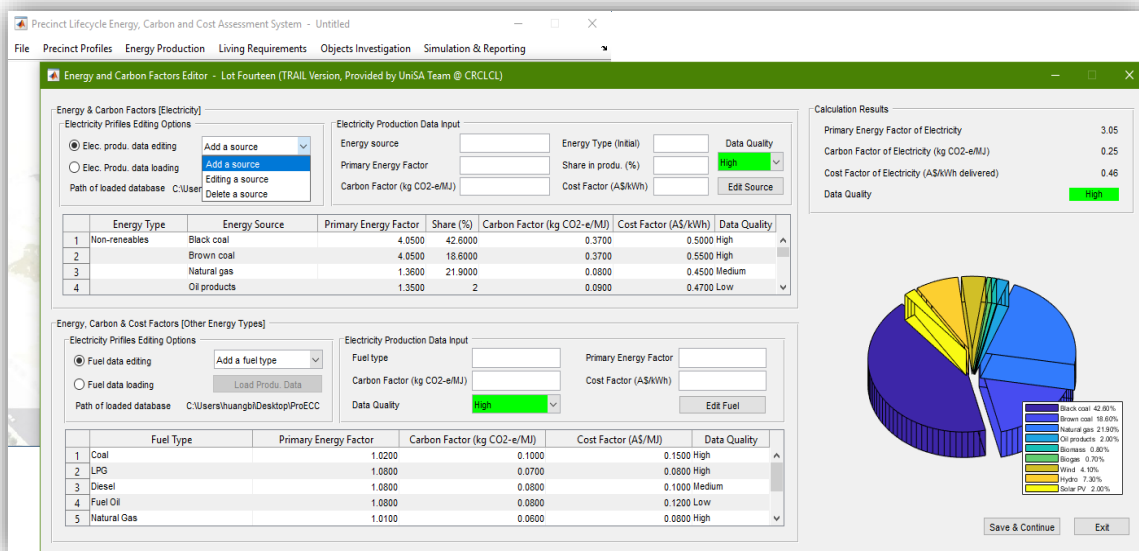
Step 4 Calculate the morphological factors

At this step, only precinct buildings are included for the identification of morphologic factors. Dimensions of buildings can be defined in this module (for default input, average data will be applied), then a mathematical model will convert the real precinct morphology into a notional grid to calculate the factors of HVAC, solar harvesting, artificial lighting and travelling based on density and obstructions.

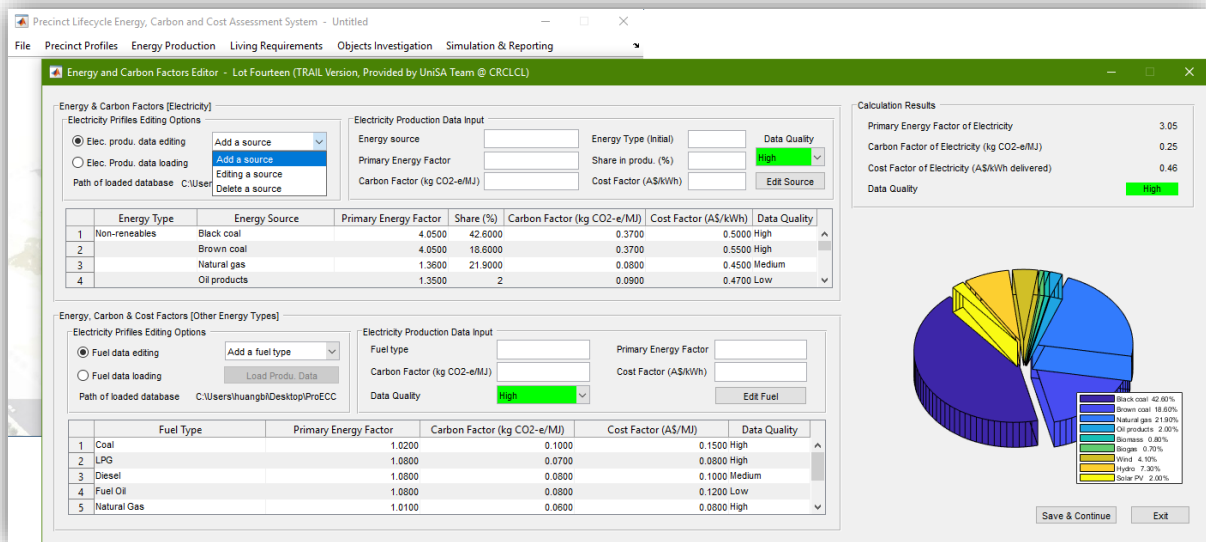


Step 5 Local energy production.

This module is developed to support the identification of primary energy factors, energy-to-carbon factors and energy-to-cost factors of different energy types according to the local energy production profiles. Default data / factors will be applied based on the statistical analysis of relevant data in the LCI database when no data be entered.

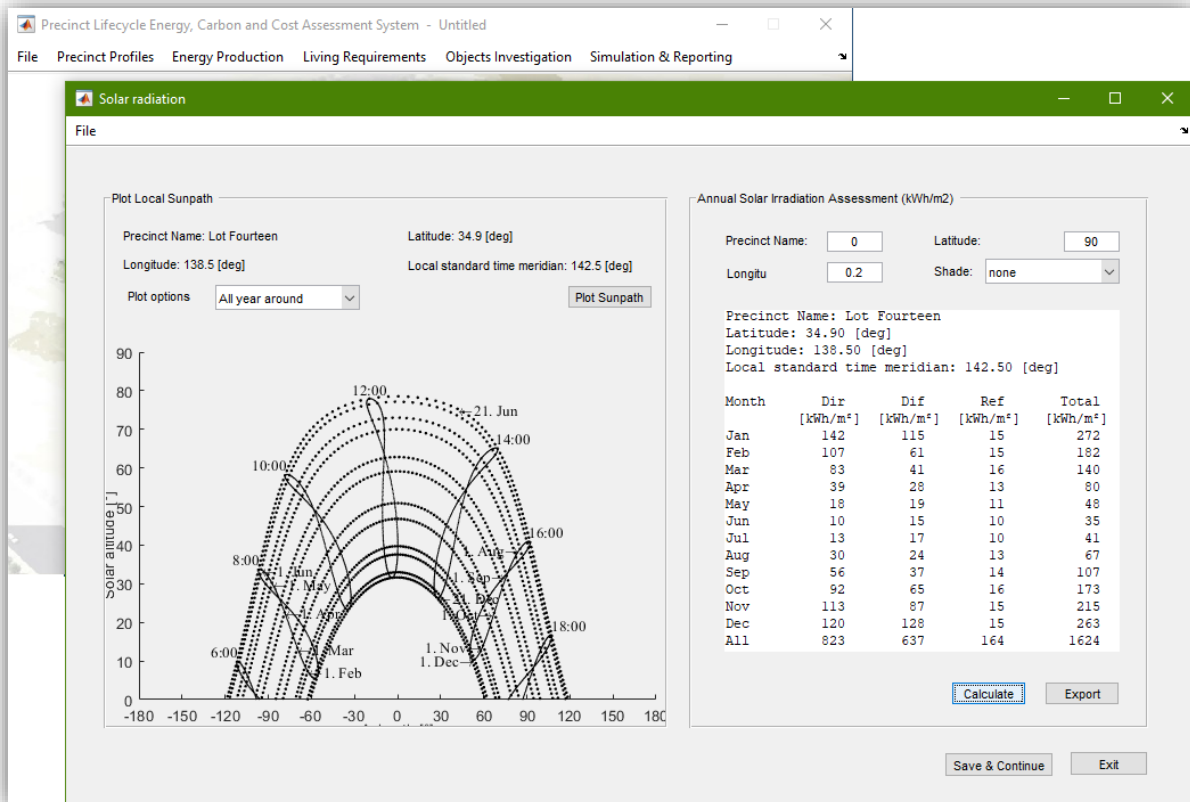


Step 6 Define water and waste processing associated energy, emission and cost. To define water and waste associated energy and emissions, the values of per unit intensities and demand data are required for accurate assessments. However, if there is no direct data entry, default data from statistical analysis will be applied.



Step 7 Renewable energy harvesting and carbon & cost offsetting.

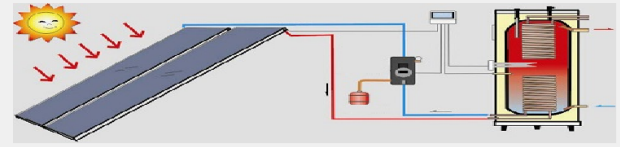
Firstly, the solar irradiation is calculated according to the local weather data. Solar potential is assessment based on the precinct morphological factors.



Then embodied energy, carbon and cost are obtained according to the system profiles of renewable energy harvesting units. After that, energy production, as well as associated carbon offsetting and cost saving are obtained according to the efficiency of systems. Finally, payback and offsetting periods are determined to guide investment. End users can modify parameters and make various combinations for comparative studies, or to find out optimal solutions.

SHU Systems-Setting [ProECC 2018b By Bin Huang]

Solar Water Heating (SWH) System Profiles



Elements	EEl (MJ/ea)	ECrbl (kg CO2-e/ea)	ECstl (AS/ea)	Lifespan (yrs)	Data Quality
1 Thermal collector	2.1855e+03	170.4700	200	15	High
2 Other components	5.8559e+03	458.7600	500	60	Medium
3 Installation	187.8000	14.8500	200	15	Medium
4 Maintenance	665	51.8700	150	5	Low

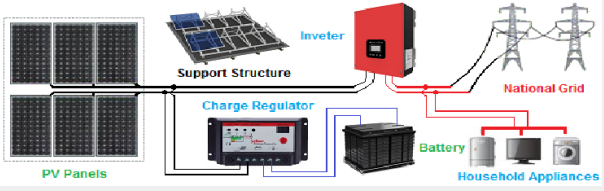
*** Hot water supply is supposed to use natural gas heating for no SWH households.*

PV System Profiles

PV Panel Parameters

PV Panel Type	Efficiency (%)	EEl (MJ/m2)	ECrbl (kg CO2-e/m2)	ECstl (AS/m2)	Lifespan (yrs)	Panel area (m2)	Panel kWp	Data Quality
Mono-Si	13.32	2860	321.24	153.37	26	1.63	0.25	Medium
Polys-Si	15.50	3300	375.00	180.00	25	1.50	0.30	Medium
Thin-Film	7.5	1191.54	123.08	200	4	0.25	0.10	Medium

Elements	Efficiency (%)	EEl (MJ/unit)	ECrbl (kg CO2-e/unit)	ECstl (AS/unit)	Lifespan (yrs)	Data Quality
1 Inverter	93	153.3700	17.2300	4.0200	10	High
2 Support structure	0	200	22.4600	0.5000	60	Medium
3 Installation & maintenance	0	720	60.8700	0.0700	30	Medium
4 Charge regulator	92.5000	613.4800	68.9200	10.9400	10	High



** Battery systems are supposed to run a daily full charge-discharge cycle over the whole lifespan.*
** Units: inverter, support structure, installation & maintenance - /m2 panel-e; charger & airconditioning associated - /kW battery.*

Precinct SHUs Associated Profiles

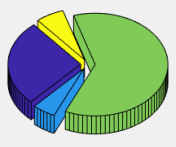
Annual Solar Irradiation (kWh/m2)	1623.9	Solar Potential Factor	0.414
Precinct PV Installation (kWp)	1698.75	No. of PV Systems	566
No. of battery banks	110		
Battery bank size (kWh)	6.4		
No. of SWH Systems	200		
Household Daily Hot Water Demand (L)	80	Precinct lifespan (yrs)	60

System Parameters

ECrbl of grid maintenance (kg CO2-e/kWh)	0.1	Grid Energy Loss (%)	6.86
EEl of grid Maintenance (kWh/kWh)	0.36	ECstl of grid maintenance (AS/kWh)	0.08
Efficiency of SWH System (enable to satisfy % of household hot water consumption)	80		
Water Heating Energy Consumption (kWh/L)			0.0083
Electricity primary factor	3.05	Natural gas primary factor	1.011
Primary electricity carbon factor (kg CO2-e/MJ)	0.25	Electricity rate (AS/kWh delivered)	0.46
Primary natural gas carbon factor (kg CO2-e/MJ)	0.057	Natural gas rate (AS/MJ delivered)	0.08

Calculation results

Embodied energy (GJ)	124850.28	Energy generation (GJ)	382238.85
Embodied carbon (t CO2-e)	13727.47	Carbon offset (t CO2-e)	133811.5
SHUs investment (k AS)	7484.24	Energy cost saving (k AS)	22283.41
Energy payback period (yrs)	19.57	Carbon payback period (yrs)	6.16
Investment payback period (yrs)	20.1	On-grid energy loss (GJ)	234594.61
Off-grid energy loss (GJ)	45057.77	Overall energy loss (GJ)	279652.38

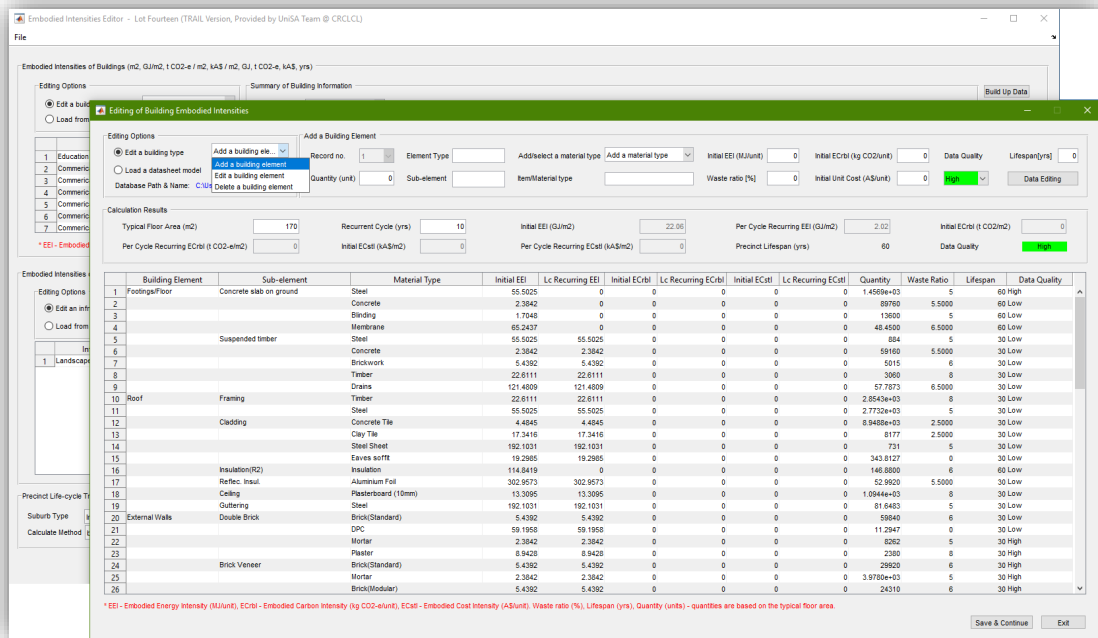


Legend: Energy Carbon Cost

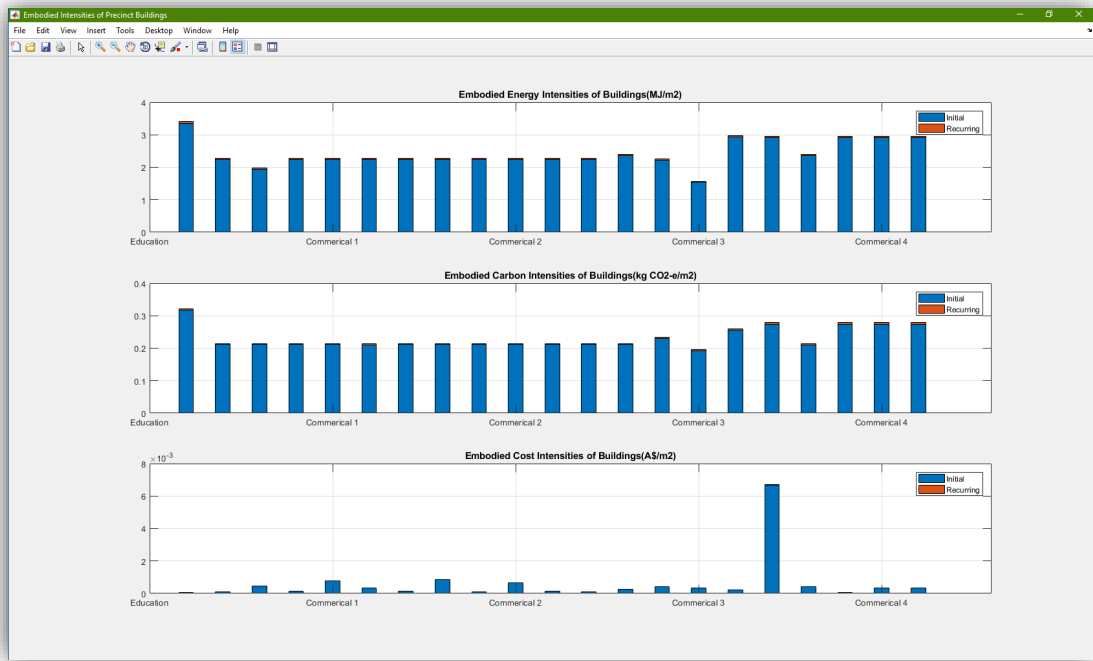
Buttons: Reload Data, Calculate, Save & Continue, Exit

Step 8 Embodied energy, carbon and cost (hereafter embodied elements) assessment

The embodied elements are evaluated with per square meter floor area of precinct objects, and the end users can enter overall intensities for a light simulation or build up intensities for a detailed simulation. To build up intensities, material types, intensities, usage and waste ratios are required. Material intensities and libraries of several typical building types have been integrated into the system LCI database to support a quick build up of intensities. In addition, a smart expert system was developed and integrated which can recommend default intensity data according to the defined object types. Also, data collected from the 'Data Sharing' module can be integrated into the LCI database to support the improvement of assessment. Thus, the tool has the machine learning ability to some extent.



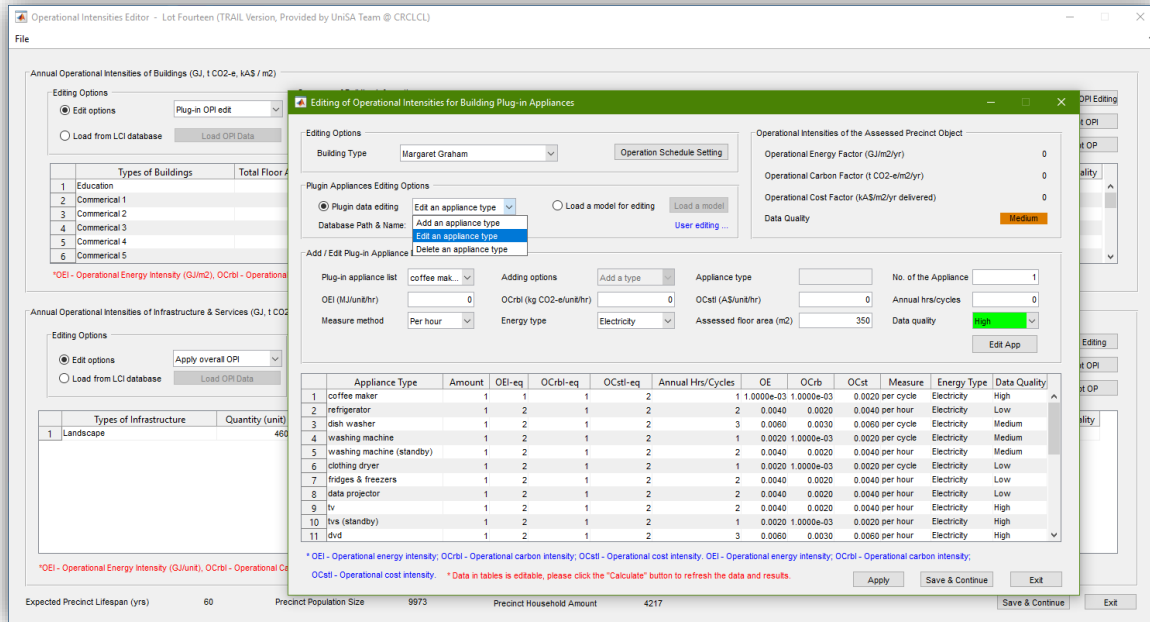
The results of calculation can be plot and observed as the intensities and embodied elements of precinct objects.



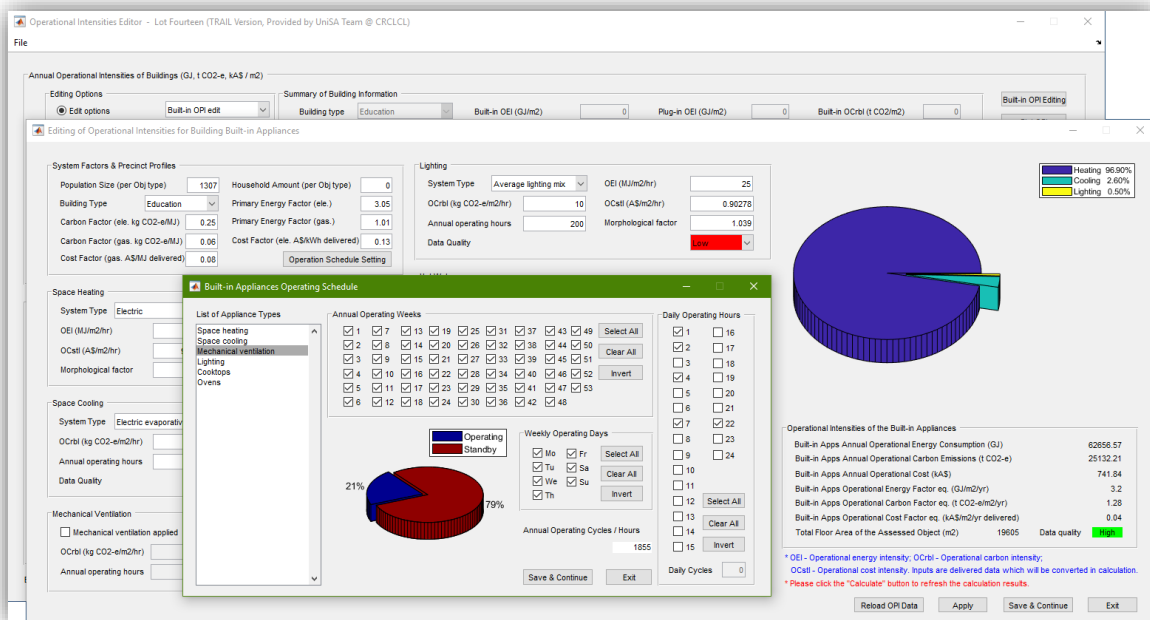
Step 9 Operational energy, carbon and cost (hereafter operational elements) assessment

The simulation of operational elements considering two types of appliances, built-in appliances such as HVAC, lighting and cooking systems; and plug-in appliances like portable appliances of lamps, TVs, PCs etc. The assessment of operational elements is also based on the principle of per square meter floor areas. However, in a detailed simulation, end users can define the appliance types, energy type of appliances, annual operating hours/cycles or operating schedules for building up of operational intensities. Machine learning is also integrated to support default input, which was found valuable to avoid large body input in generic assessments with an acceptable resolution.

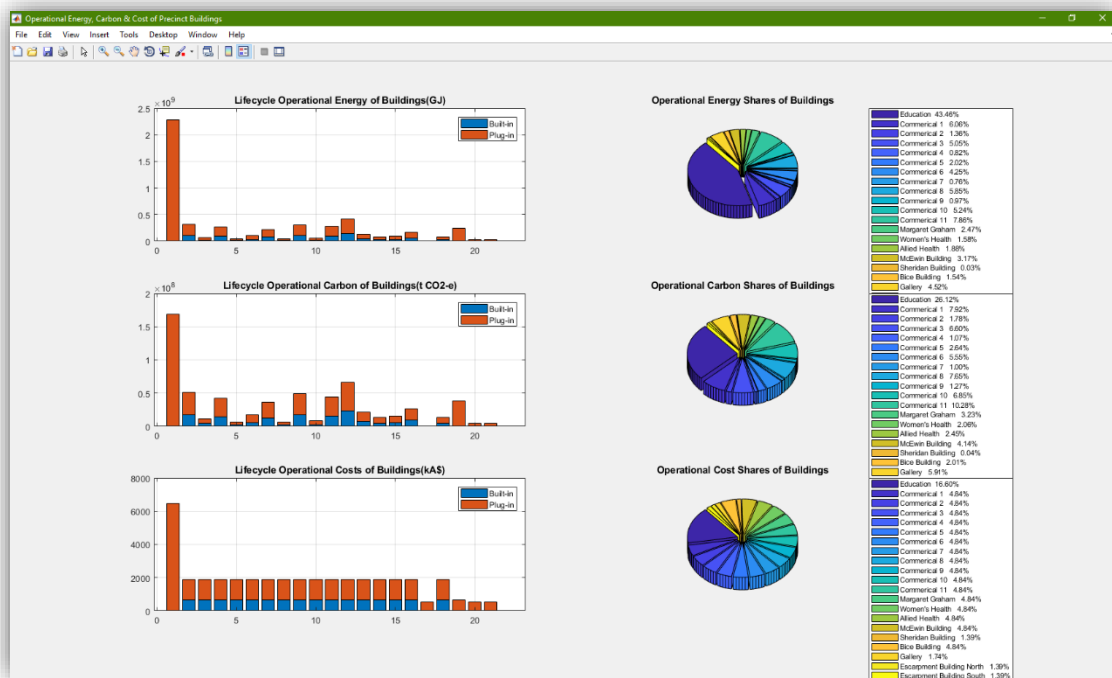
Editing plug-in appliances can be done by selecting appliance types from the drop list and modify intensity values.



Editing operating schedules for an appliance type can be done by selecting the number of hours and days to define its frequency of use.

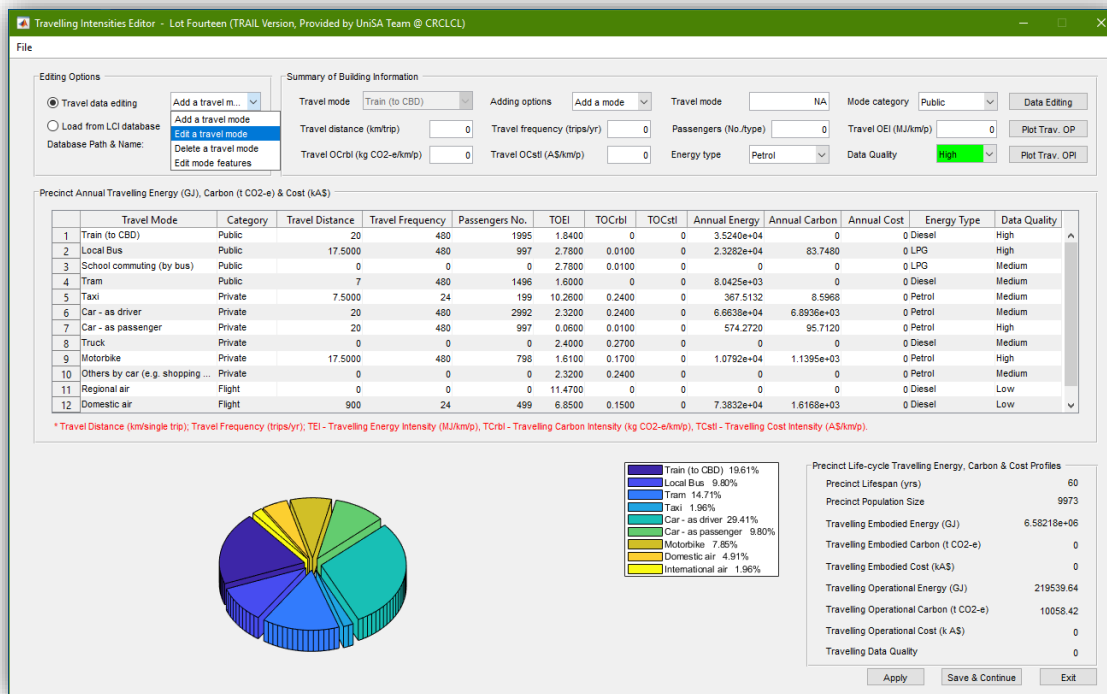


The results of calculation can be plot and observed as the intensities and operational elements of precinct objects.



Step 10 Travelling elements assessment.

Assessment of travelling elements allows to evaluate the commuting and entertainment associated energy consumption, carbon emission and cost expenditure. Per passenger per kilo meter intensities are used in calculations, thus precinct travelling diary is required. Detailed travelling elements evaluations also allow end users to select energy type of traffic modes, as well as modify its intensities. Machine learning is also integrated for the default input of travelling intensities.



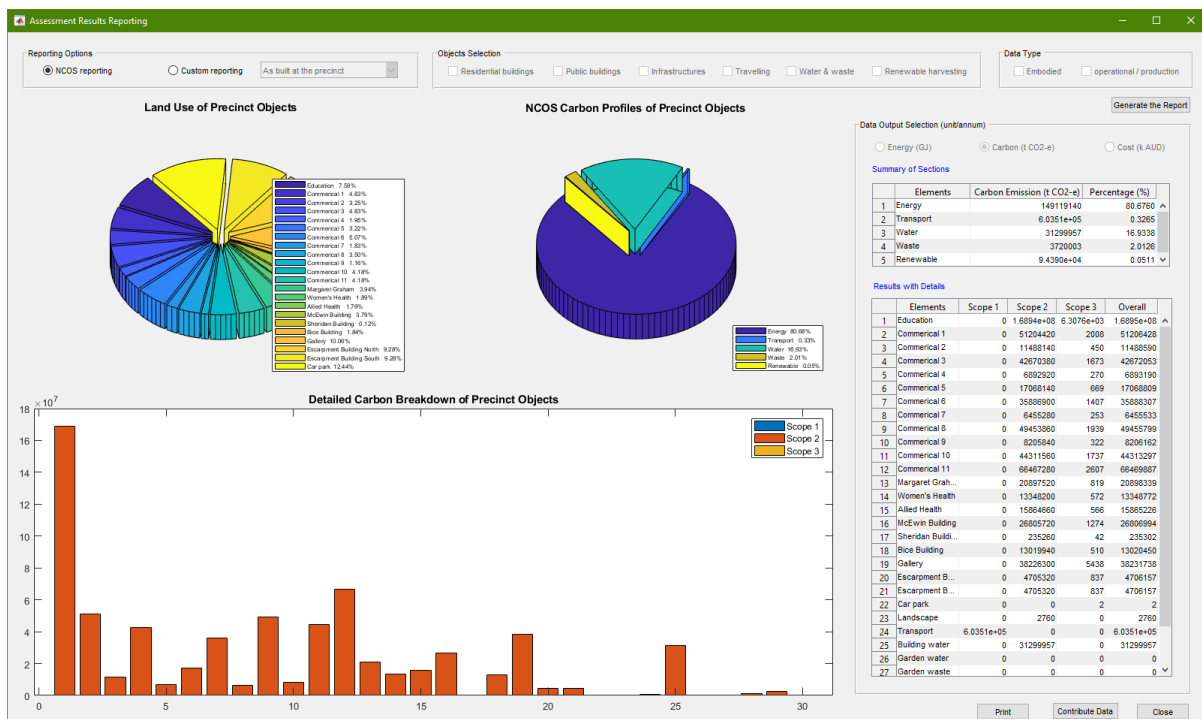
Step 11 Run simulations and compile assessment results for reporting



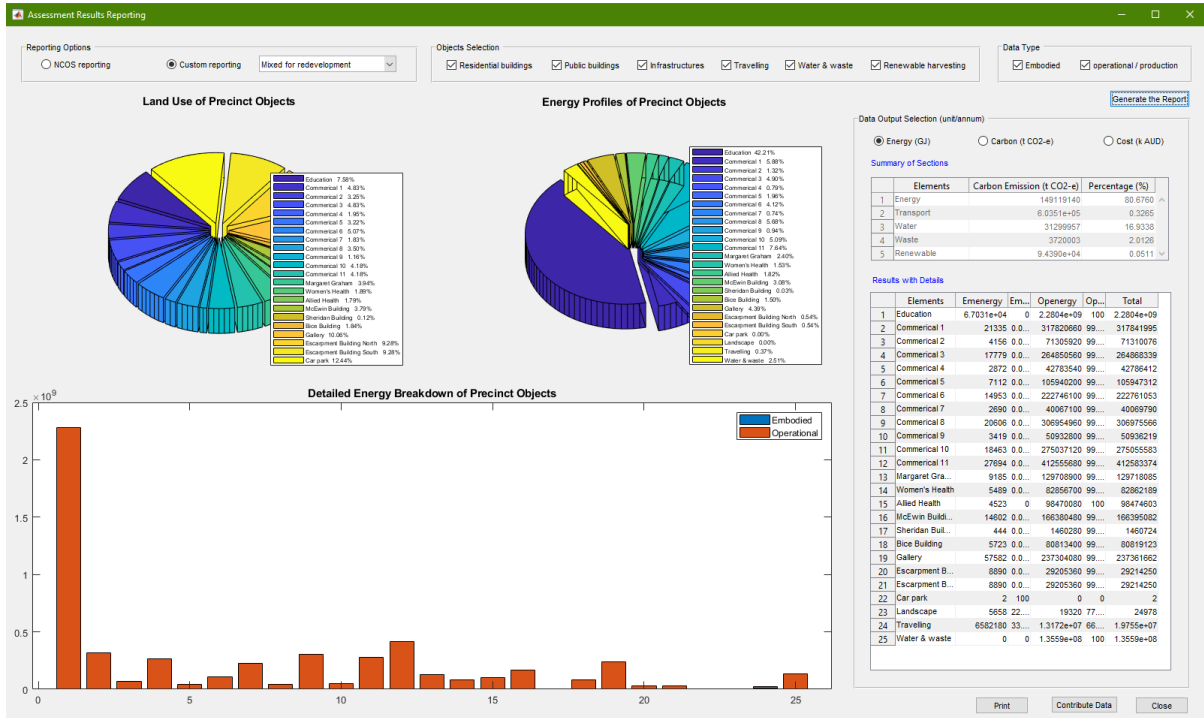
Step 12 Reporting.

As an NCOS – aligned tool, the PCA tool provides two reporting options:

- 1) NCOS reporting. In the NCOS reporting, the output of results will be sorted according to scopes which are defined with an NCOS criteria.



- 2) Custom reporting. While in a custom reporting, end users can select one or multiple precinct object types with specified data types for observations. The datasheet/list will sort data with 'Embodied', 'Proportion of embodied', 'Operational', 'Proportion of operational' and 'In total'. The end users can also select 'As built', 'As demand' or 'Mixed' object types to support the simulations with different contexts namely exist precincts assessment, green area planning or brown area redevelopment. Future versions will allow end users to observe the proportions of 'Self-occupied' for owners and 'Rented' at the precinct.



Appendix 3

NCOS-Precincts Mapping for the PCA Tool

NOCS (Precinct) Requirements	Tool Alignment	PCA Tool Mapping
<p>Establish the Emissions Boundary</p> <p style="padding-left: 40px;">Include all relevant activities and emissions within geographic boundaries</p> <p style="padding-left: 80px;">Reasons for and implications of any exclusions, if made</p>	<p>Method covered</p> <p>Fully covered</p>	<p>Modelling concept covered, elements partly covered</p> <p>Except some elements without data availability</p>
<p>Identify Emission Sources</p> <p style="padding-left: 80px;">CO2, CH4, N2O, HFCs, PFCs and SF6</p> <p style="padding-left: 40px;">Scope 3 emissions should be tested for relevance and materiality (>1%)</p> <p style="padding-left: 40px;">Total amount of emission excluded must not exceed 5% of total carbon account</p>	<p>Method covered</p> <p>Fully covered</p> <p>Fully covered</p>	<p>Indirectly covered as currently using CO2-e</p> <p>Might directly related to the reporting contents and styles, rather than the tool itself.</p> <p>No intentional exclusion, but some elements might missing due to data availability</p>
<p>Collect Data on Identified Emission Sources</p> <p style="padding-left: 40px;">Quality control practices must be in place to ensure data quality</p> <p style="padding-left: 80px;">Documents justifying selection of the monitoring methods</p> <p style="padding-left: 80px;">Documentation of the collection processes</p> <p style="padding-left: 80px;">Emission sources are grouped according to Scope</p> <p style="padding-left: 40px;">Emission factors from National Greenhouse Accounts are used wherever possible</p>	<p>Method covered</p> <p>NA</p> <p>NA</p> <p>Fully covered</p> <p>Method covered</p>	<p>A module developed to assess the data qualities based on statistical analysis</p> <p>As no real-time data required for the tool, this requirement might developed for NCOS Standardised reporting</p> <p>Depend on user data input, but the source of default intensities are stated</p> <p>Results need to be resorted for reporting</p> <p>The tool allows users to adapt NGA data for assessment by develop their own LCI with the given format</p>
<p>Transport</p> <p style="padding-left: 40px;">Emissions related to transport services/activities outsources/purchased (Scope 3)</p> <p style="padding-left: 80px;">Transport activities related to an Organisation (Scopes 1, 2, and 3)</p> <p style="padding-left: 80px;">Transport activities related to a Product/Service (Scopes 1, 2, and 3)</p> <p style="padding-left: 80px;">Transport activities related to a Building (Scopes 1, 2, and 3)</p> <p style="padding-left: 40px;">Scope 1 and 2 emission factors are sourced from NGA publication</p> <p style="padding-left: 40px;">Scope 3 emissions are from converting transport activities to fuel quantities and to identify NGA factors</p>	<p>NA</p> <p>Method covered</p> <p>NA</p> <p>Method covered</p> <p>Method covered</p> <p>NA</p>	<p>Better to include directly collected real-time data than that estimated by the tool for reporting</p> <p>Currently focused on household assessment, but can be adapted in the future</p> <p>Better to include directly collected real-time data than that estimated by the tool for reporting</p> <p>Building embodied emissions included the amount contributed by transport activities</p> <p>The tool allows users to adapt NGA data for assessment by develop their own LCI with the given format</p>
<p>Stationary energy</p> <p style="padding-left: 80px;">Co-generation and Tri-generation</p>	<p>NA</p>	<p>The tool focuses on as built / design, rather than as operated</p> <p>Due to availability of system models and data support. Might be better to use directly collected data for reporting?</p>

Generation Scenario 1: Located within the precinct boundary and Consumed within the boundary	Fully covered	Present style might need to be updated
Generation Scenarion 2: Located within the precinct boundary and consumed outside the boundary	Method covered	Can be worked out from simple calculations with generation data collected
Generation Scenarion 3: Located outside the precinct boundary and imported into the boundary	Method covered	Considered in modelling but has not been specified for reporting
Measurement of fuel quantity	NA	The tool focuses on as built / design, rather than as operated
Fuel characteristics	Fully covered	Considered in carbon conversion
Emisisions factors from NGA	Method covered	The tool allows users to adapt NGA data for assessment by develop their own LCI with the given format
Water		
Emissions associated with the consumption of reticulated water	Fully covered	Using the data from ETWW project
Emissions from treatements and processes captured by water supplier as a single emission factor (kg CO2-e/KL, reticulated water)	NA	Some data collected from references, but better to use data collected directly from water plant
Scope 3 emissions	Fully covered	As a part of infrastructure embodied
Data measured directly or estimated from robust sources (include average water consumption of a piece of equipment)	Method covered	Estimated data from Local Bureau of Statistics (e.g. ABS), SA Water & Sydney Water was used
Emission factors from the supplier or provided by Bureau of Meteorology on Urban Water Utilities	NA	Better to include directly collected real-time data than that estimated by the tool for reporting
Waste water		
Total GHG emissions from wastewater treatment processes before returning into the environment	NA	Data collected from research projects and publications, but lack of system models
Emissions from treatements and processes captured by treatment operator as a single emission factor	NA	Better to include directly collected real-time data than that estimated by the tool for reporting
Scope 3 emissions	Fully covered	As a part of infrastructure embodied
Data measured directly or estimated for the quantity of wastewater generated by activities/processes within the boundary	NA	Better to include directly collected real-time data than that estimated by the tool for reporting
Data apportioning (if the data is related to activities both within and outside the boundary)	NA	Better to include directly collected real-time data than that estimated by the tool for reporting
Emission factors from wastewater treatment operator or calculated by local water/environmental authorities as a benchmark	NA	Better to include directly collected real-time data than that estimated by the tool for reporting
Include BOD and/or COD (if industrial processes producing a highly concentrated wastewater are in the boundary)	NA	Data collected from research projects and publications, but lack of system models
Emission factor covers water distribution and wastewater process can be used if both are operated by one entity	NA	Data collected from research projects and publications, but lack of system models
Waste		
Main types of waste management processes: disposal, recovery for recycling, bio-treatment or composting	Fully covered	Presented with different style
Scope 3 emissions (offsite treatment)	Method covered	But not refer to use research data
Scope 1-3 emissions (onsite treatment)	Method covered	But not refer to use research data
Use the waste-type specific method (if possible)	NA	Due to lack of data
Activity data: amount of waste produced and breakdown by type of waste management activity	Fully covered	Data collection: Local Bureau of Statistics (e.g. ABS), but presented in different style

<p>Activity and quantity data from waste management provider, estimated from waste survey/audit, or estimated from other sources If impossible to account different types of waste seperately, assum all going to landfill and use most conservative emission factors</p>	<p>NA</p>	<p>Better to include directly collected real-time data than that estimated by the tool for reporting</p>
<p>Emission factors from waste management operator or NGA sources</p>	<p>NA</p>	<p>Better to include directly collected real-time data than that estimated by the tool for reporting</p>
<p>Other emission sources</p>	<p>Method covered</p>	<p>The tool allows users to adapt NGA data for assessment by develop their own LCI with the given format</p>
<p>Scope 3 emissions from other typical activities or products consumed, if relevant</p>	<p>Fully covered</p>	<p>by the knowledge of the tool developers</p>
<p>Renewable energy</p>		
<p>Onsite generation-LGCs</p>	<p>NA</p>	<p>Due to data availability</p>
<p>Green power</p>	<p>Method covered</p>	<p>Currently focused on solar PV and solar water heating</p>
<p>ACCUs</p>	<p>NA</p>	<p>Due to data availability</p>

Appendix 4

Case study– Lochiel Park

Lochiel Park, located approximately 8 kilometres north east of the Adelaide CBD, is a model green village developed to practically demonstrate the South Australian Government’s vision for sustainable living. The site comprises 15 hectares of land, is a community of more than 150 residents. All homes within the precinct achieve a minimum 7.5-star energy efficiency rating and equipped with solar photovoltaic cells (173.49 kWp in total) and solar thermal water heaters, resulting in 64% energy saving and 74% reduction in greenhouse gas emissions. Census data collected by Australian Bureau of Statistics (ABS) indicates that approximately 15.2% of households are seniors (65 years and above), 28.3% have children of school age or younger and an extra 56.5% are single families or young families without child at the studied precinct. Monitoring data shown in Fig. 1 indicated that the per household annual energy consumption at the village is 5,177.30 kWh.

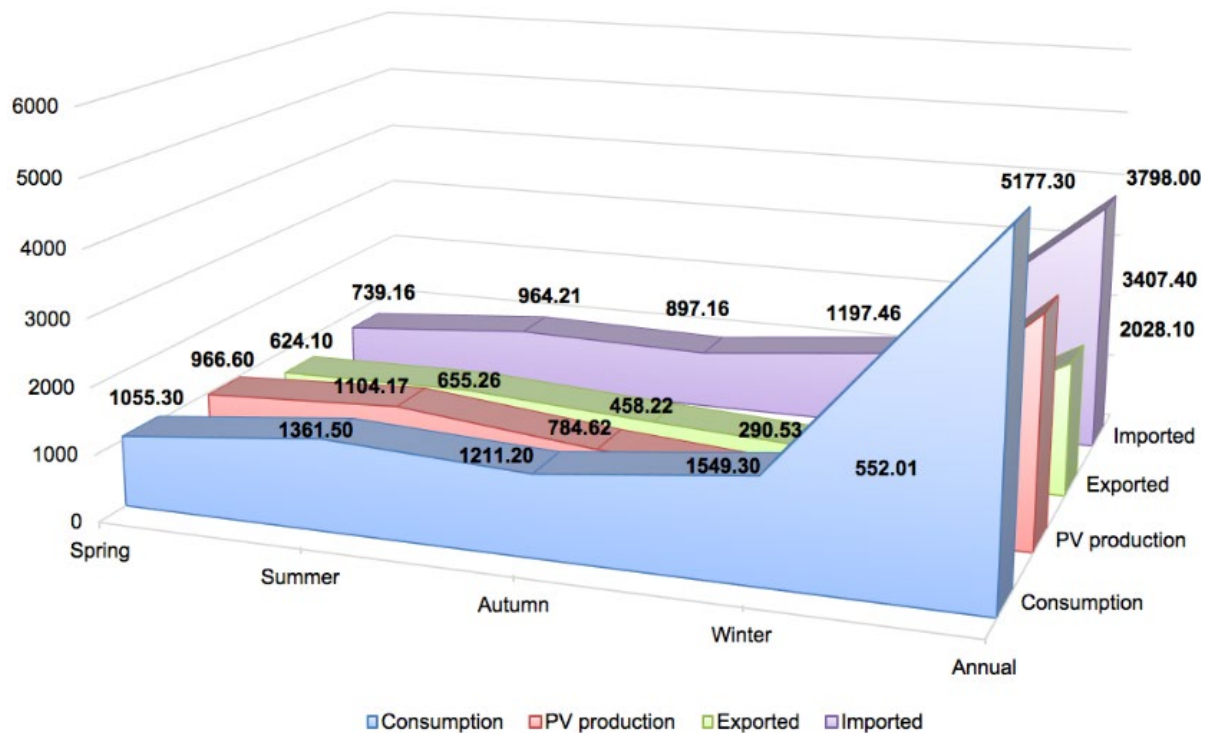


Fig. 1 Energy profiles of the studied precinct

Assessment with the PCA tool developed by the UniSA team at the ICM project shows the energy profile of a typical family at this precinct as Fig. 2.

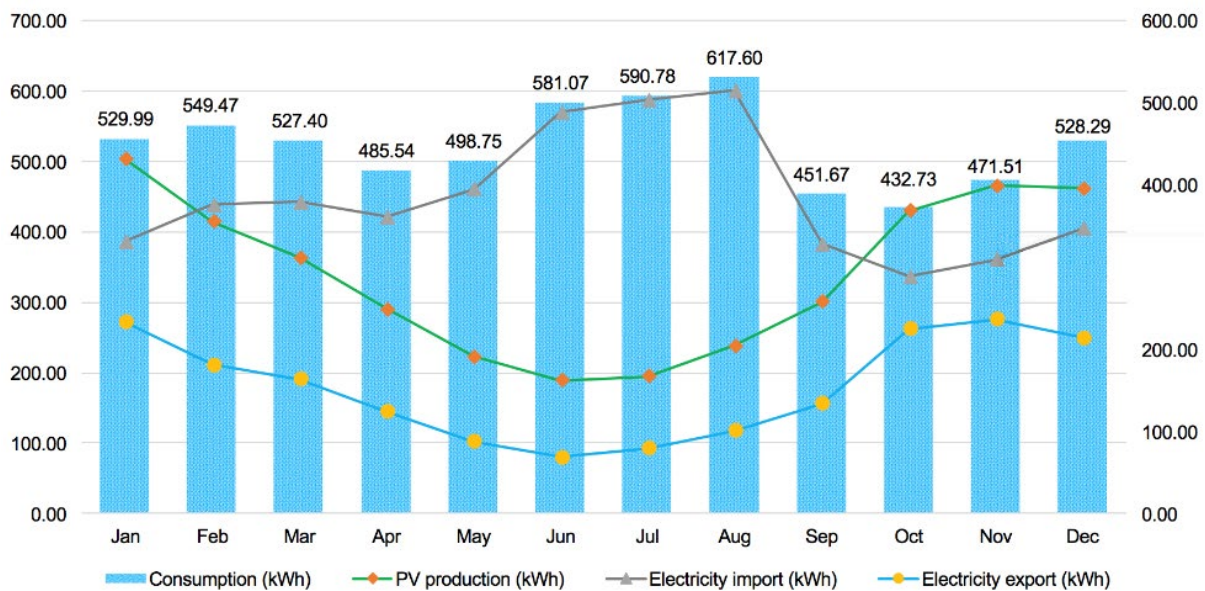


Fig. 2 Energy profiles of a typical family

Carbon offset assessment is conducted using the renewable energy and carbon assessment tool integrated in the PCA tool, with two scenarios considered, the real context (without energy storage, Scenario 1), and an assumed case with battery storage (Scenario 2). As shown in Fig. 3, with the employment of battery storage, both the export and import of household operational energy are reduced. In another word, the integration of storage contributed significantly to self-sufficiency of PV systems, which then applied positive impacts in energy resilience and energy expenditure reduction.

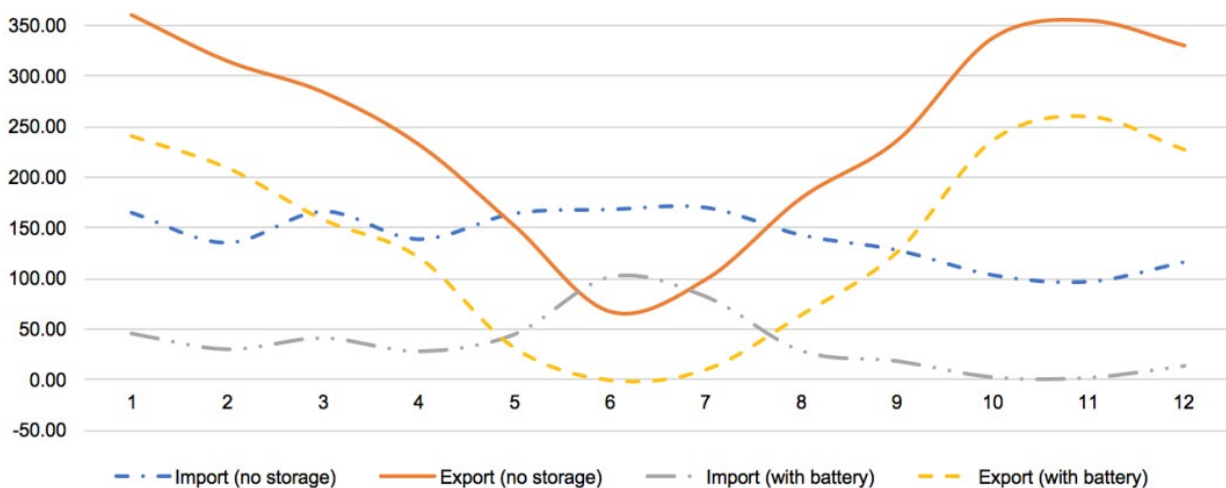


Fig. 3 Precinct annual electricity importation and exportation

Life-cycle assessments have been conducted on the PV system and PV plus battery system, with the consideration of embodied energy, carbon and costs. Detailed assessment results listed in Table 1 show that Scenario 2 is a more economically feasible solution for energy supply with an equivalent electricity rate of 10 cents per kWh over the 60 years' lifespan of precinct, which is 40.00% of the calculated rates in Scenario 1. However, with the integration of PV energy storage systems, the associated embodied elements (energy, carbon and cost) are increased correspondingly, resulting in longer payback and offset periods. Among the three payback and offset parameters, the variation in investment payback periods appears the most significant, which might be attributed to the cost intensive

feature of PV batteries at the present stage. The investment payback period of Scenario 2 might be extended by 158.91% compared to that of Scenario 1. However, the solutions in Scenario 2 is still economically feasible, since the investment payback periods are within the 60 years assessed lifespan. Against this backdrop in investment costs, the energy resilience is enhanced with the integration of storage systems as the PV energy self-sufficient ratio was increased by 52.38% in Scenario 2 when compared to Scenario 1.

Table 1 LCA assessment results of the precinct PV systems

Description	Scenario 1	Scenario 2
Lifecycle embodied energy of PV systems (PJ)	11.98	16.75
Lifecycle embodied carbon of PV systems (t CO ₂ -e)	883.58	1236.08
Lifecycle embodied cost of PV systems (k AUD)	761.80	3315.47
Storage demand/total battery capacity (kWh)	-	705.00
Annual PV primary energy production (MWh)	642.79	675.69
Annual PV carbon offset (t CO ₂ -e)	539.95	567.58
PV energy payback period (years)	5.18	6.89
PV carbon offset period (years)	1.64	2.18
PV investment payback period (years)	17.57	45.49
Annual electricity importation (MWh)	208.14	90.83
Annual electricity exportation (MWh)	143.90	29.53
PV self-sufficient ratio	27.62%	80.00%
Equivalent electricity rate (AUD/kWh)	0.25	0.10

This Case Study indicates that the renewable energy assessment module of the PCA tool is of the ability to guide the identification of carbon offsetting potential of precinct, and guide the investment on solar energy harvesting units. In addition, it can also help with the exploration of precinct solar potentials and optimisation of economical-eco schemes for precinct carbon offsetting.