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Executive Summary

This report aims to deliver fundamental information regarding the Life Cycle Costing (LCC) model for the NEREUS Project. One of the main goals of the decision support tool (DST) is to evaluate economic impacts for the comparison of technologies and providing information on Life Cycle Costing with the support economic sub-factors in the NEREUS DST. The economic impact of selected technologies through the life time of the train can be assessed by LCC method.

University of Portsmouth (PP6) leads the Workpackage 1.4 and this deliverable is submitted as one of the series of deliverables on LCA within the frame of NEREUS Project. This report provides comprehensive information on the definition of the goal, scope, system boundaries, methods and data which will be intended to use for modelling the life cycle costing (LCC) in wastewater treatment and resource recovery context.

It is important to note that economic evaluation for wastewater treatment and resource recovery technologies will not be assessed only through LCC. The final method that will be integrated to the NEREUS DST can be updated through the versions and LCC method is explained in this report can be subject to adaptation based on the feedback collected from stakeholders and the structure consistent with the integrated business model which is the final deliverable of D 1.5.4.

1. Introduction to Life Cycle Costing

The Life cycle cost analysis (LCCA) is used for project evaluation regarding the owning, operation, maintenance and disposing cost, (Fuller and Petersen, 1996). By the help of LCCA, long term cost effectiveness can significantly increase (Fuller and Petersen, 1996).

LCC methods are intended to be used to support design decision making and to have a strong a customer service leading to competitive advantage, (Fabrycky and Blanchard, 1991; Woodward, 1997). LCC is a systematic evaluation method for the economic aspects that associates with ISO Standards, (ISO 15686-5).

Life cycle assessment (LCA) presents a methodology for the evaluation on environmental impacts of a system throughout its life cycle. In LCA, similar to the LCC, a common function with environmental impact indicators is employed to have a comparative tool. For performing LCA, the functional units that represent performance specifications are used. After defining the functional unit, accumulation of environmental impacts is required for the inputs, output and emissions associated with the product system assessed with actual quantities.

In this report, the goal, scope, and the methodology of the LCC which then will be used in the NEREUS DST will be described, respectively.

2. Goal

NEREUS DST aims to provide sustainable wastewater treatment and resource recovery solutions with the evidence of environmental, economic, technical and social impacts for each solution.

The Life-Cycle Costing (LCC), similar to the LCA (see D 1.4.1) carried out as part of the NEREUS project is intended to be also evaluated in the Decision Support Tool (DST). The numerical results obtained through the LCC will support the economic impact evaluation (Table 1) to provide decision makers with wide ranging information on unit processes and process trains within a wastewater treatment system in addition to the Integrated Business Model (D 1.5.4).

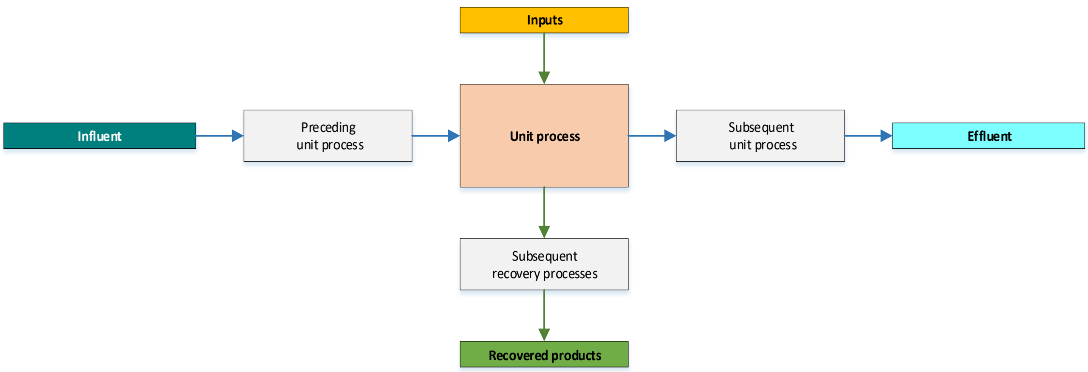
Ideally, the scope of LCC should cover all activities from plant construction and operation, periodic equipment replacement, waste management and recovery of resources to decommissioning of treatment plants after its useful life. However, waste management will not be considered due to the fact that the waste management requires different and complex feasibility study which is beyond the selection of optimal unit processes combination. The NEREUS DST is intended to design focusing on the feasibility, interaction of the unit processes based on their specification, performance, cost component and environmental impact (D 1.4.1).

Ultimately, the goal is to estimate the life cycle costs of the different wastewater treatment and recovery technologies aimed at wastewater reuse, sludge handling techniques aimed at energy and nutrient recovery.

2.1 The NEREUS DST

Similarly, to the approach explained in the LCA report (D 1.4.1), the structure of the DST is based on a series of "Unit processes" which may be assembled by the designer into a process train. Figure 1 shows an example of a unit process with potential preceding and subsequent processes. Each unit process has its own features such as removal and recovery of specific compounds. At the same time, to run this unit process, inputs such as energy or materials are required and potentially unit process might generate recovered products. This information can be embedded in DST and it can be used by a user, to generate a treatment train from the combination of unit processes and investigate the effects of adding a process to an existing train or replacing an existing process with a new one.

Figure 1: Unit process model within the NEREUS DST



2.2 Standards

In order to conduct LCA, a methodology that follows some international standards is required. The standards that needs to be followed are provided in an earlier report, (D1.4.1). To perform LCC analysis;

- Service-life planning, Part 5: Lifecycle Costing for Buildings and Constructed Assets, published by the International Organization for Standardization (ISO 15686-5, Buildings and Constructed Assets) would be preferred, (Perrera et al, 2009).

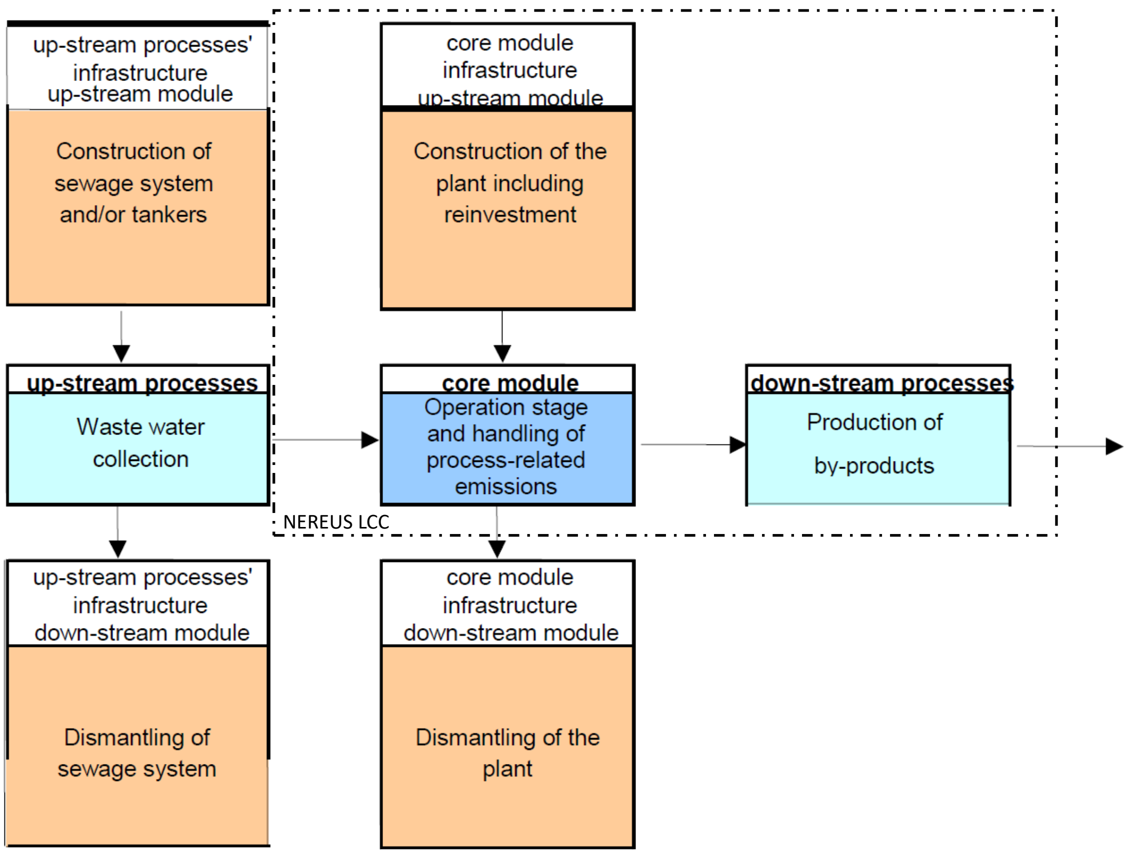
3. Scope

3.1 System Boundaries

3.1.1 Life-cycle stages

In order to achieve certain standards on the LCC assessment, an LCA based LCC method could be used model as a basis for cost evaluation. As previously shown in LCA Report, a general presentation of the core modules, upstream and downstream processes for LCC are also presented in Figure 2. Different from the LCA, in LCC the core module of the infrastructure up-stream module has important role and it would be taken into consideration to represent the capital costs (CAPEX). In addition to that up-stream module, downstream processes are another focus to the NEREUS project which is concerned with the recovery of energy and resources from wastewater treatment and are therefore, included. The whole life cycle costs will consider all inputs both operational (OPEX) and capital (CAPEX) as highlighted in 1.2.

Figure 2: Processes defined in UN CPC 9411 & 9423 (Del Borghi, 2014) *with the system boundary used for the NEREUS LCC*

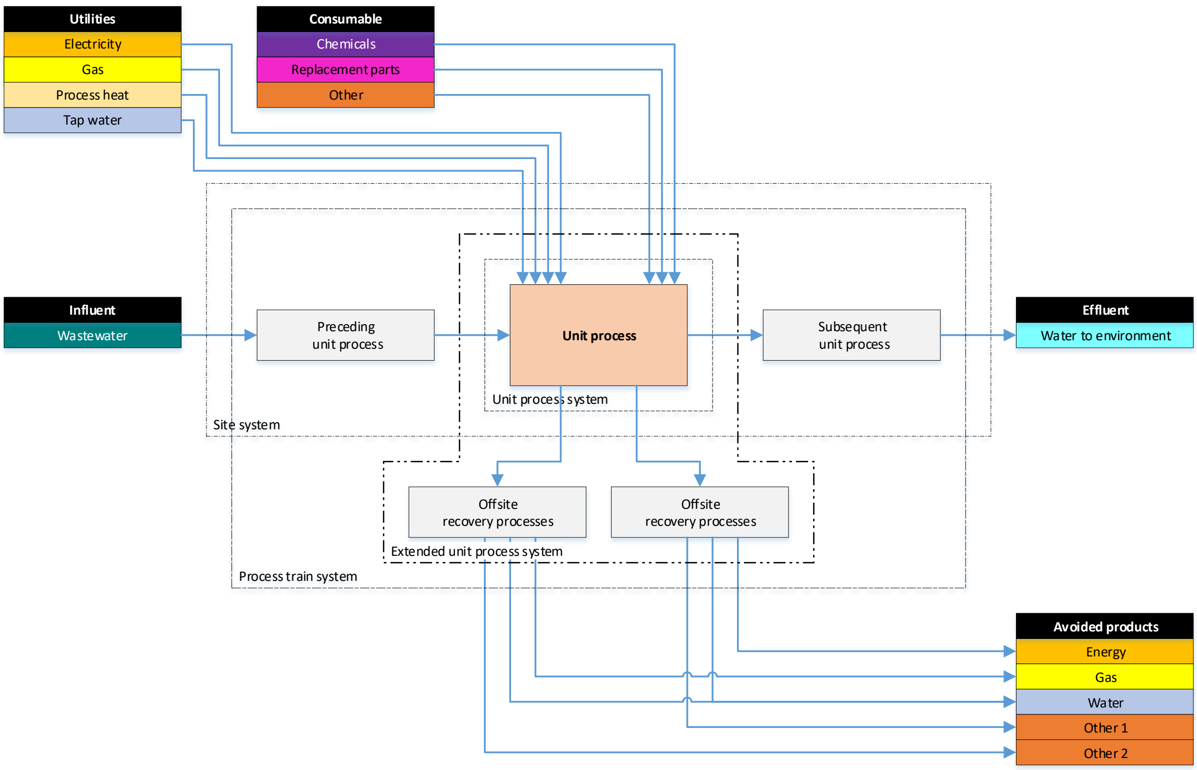


3.1.2 Process groupings & allocations

LCC model as the other evaluation methods are intended to be applied in the NEREUS project such as LCA and NEREUS DST, can potentially be applied on the various projects. Therefore, certain level of flexibility would be needed in the model like the DST requires. This leads to the need of several system boundaries be set-up to include all the scenarios which may be of interest. In addition to the flexibility, certain level of consistency and compatibility between the structure of the tools would be also needed in order to ensure the communication between these tools; NEREUS DST, LCA, LCC and Integrated Business Model.

Unit process-based approach for treatment train evaluation as it is also stated in the DST structure would be helpful to show the system boundaries in Figure 3. The system boundaries for LCC does not differ than the system boundaries are supposed to be employed in LCA boundaries. An example of how potential boundaries are applied to a demo-case for both LCA and LCC is shown in Figure 4 For LCC, consumable can be translated into the cost components as recovered products can be expressed as valorised products.

Figure 3: Boundaries within the NEREUS LCC model

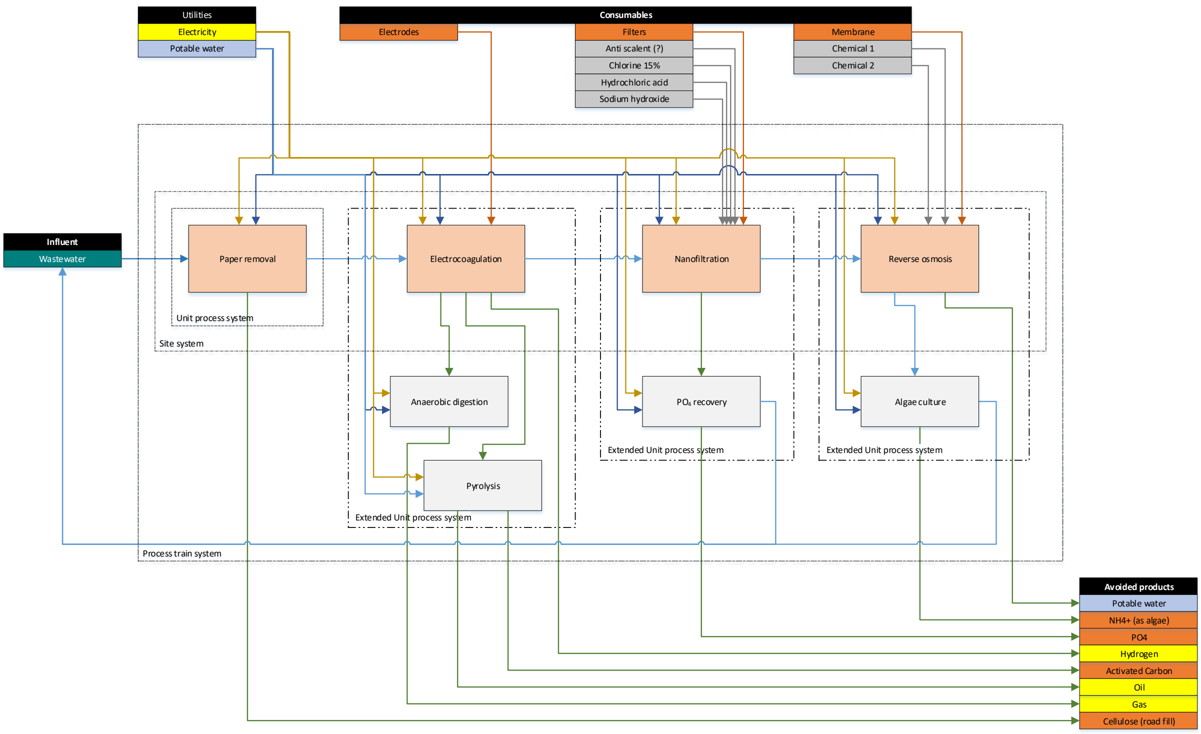


3.1.2.1 LCC Evaluation of Resource Recovery Site through Unit Processes

Unit processes are the core of the impact evaluation in the NEREUS DST as stated earlier. Generalising the input-output balance for only one unit process, across the sequence of unit processes gives the opportunity to measure the impact of whole site. Although it is not that common, it still is possible that a single unit process will be considered alone without further processes in a process train. The balance between the spending for consumables and the potential income can be generated through the recovered products may simply calculated across all unit processes (including recovery processes and sludge handling techniques).

There is possibility that unit processes are not used and also the site can have extended unit processes that does not produce useful products and passes an intermediate flow to another process. Additionally, there can be the situations where the performance has impact on a particular site, for that situations a site boundary might be added. The effect of these type of unit processes and situation on LCC can be assessed with the similar approach suggested in LCA report (D 1.4.1).

Figure 4: Boundaries in the Evides demo case (a larger version is in the Appendix)



3.2 Functional unit

The most commonly used functional unit for LCA in the context of wastewater plants is volume of wastewater treated. With the aim of calculating the cost of certain consumables and also the construction cost of the unit processes with right scale, to carry out the LCC accurately for different scales, volume of the flow is used.

The life-span of wastewater treatment plants in the literature can be seen between 20 to 30 years. For NEREUS LCC, it is intended to use 20 years although the expected life time can be adapted based on the user input as well as the timeline preferred in the Integrated Business Model (D 1.5.4).

3.3 Methods used

In LCC, cost related activities can be categorised as one-off and recurring activities. While installation is a typical one-off activity which realises in beginning of the study period, replacement of an equipment or a component when it reaches the end of its life. Other activities that can be counted under recurring activities category are annual maintenance and consumables to be able to run the unit according to the report on Bisria, (2014) and Woodward, (1997).

In order to compare the alternative options, net present values are employed to express the cost. For this assessment, evaluating future costs and benefits to their equivalent present values, an appropriate discount rate should be applied. It can be taken as %3, (European Commission, 2016).

Through the calculation of net present values for all cost related activities in the system boundaries, LCC can be assessed per alternative solution.

The cost components for LCC can be listed as follows:

CC = capital costs
IRC = infrastructure replacement costs
FC = fixed operating costs
VC = variable operating costs
PIG= revenue from the sales of recovered products
LC = labour costs
r= discount rate

The capital costs *CC* are costs of plant infrastructure, made up of the buildings, equipment and supporting parts such as contactors, pipes and pumps, electrical equipment, pressure pumps, pressure tubes, digesters, etc.
The infrastructure replacement costs *IRC* represents the expenditure for replacing the equipment and other supporting infrastructure. While a useful life of 20 years will be used the replacement period of between 5 years to 10 years or longer depending on manufacturers' specifications.
The fixed operating costs *FC* refers to the cost of materials and energy used regardless of the level of the treatment of wastewater such as electricity for pumping or a dewatering agent.
The variable operating costs *VC* are costs associated with the materials and energy of variable quantum depending on the level of wastewater treatment required to achieve an expected quality of effluent – these costs are only applicable to the wastewater treatment methods (technologies).
The revenue *PIG* of the recovered resources will be based on the amount and market prices of the products that they potentially replace.
Labour costs *LC* for the operation of the plants
The decommissioning costs *DC* is the costs associated with decommissioning the technology at the end of its useful life estimated at 60 years. This however, being new technologies and without necessary data may be excluded in the consideration of the LCC.

The total cost would be represented as the sum of all relevant cost components by taking into account removing the revenues can be extracted from whole cost;
TC= *CC +IRC +FC +VC + LC - PIG*

In order to calculate the net present value with discount rate the formula provided below can be used (Hoogmartens et al, 2014);

NPV: $\sum_{t\in\{1,..T\}} \frac{TC}{(1+r)^{t-1}}$

It would be important to note that the costs of waste management include landfilling and incineration of waste, transportation costs include transport of materials, chemicals and wastes and transport of recovered resources to the point of sale will not be included in this project due to the flexibility, consistency and compatibility between the tools support decision making. The reasons are also explained in greater details in the LCA Report which can be found in WP1 under D 1.4.1. Any existing infrastructure such as for heating and electricity will also be excluded otherwise, they be included in the capital cost where specifically acquired for the technology.

In order to clarify the methodological difference between LCA and LCC within the frame of NEREUS Project, one can claim that in an LCC, comparable impact assessment does not exist. Since all 'inventory' data comprise currency as a single unit of measure. Therefore, there is no need of characterisation or weighting related to inventory data, (Swarr et all, 2011).

3.4 Indicators

The indicators used form a subset of the overall indicators in the wider DST. These have been taken forward as the indicators used in the DST. The 4 categories were included in a larger set of indicators decided upon at the DST workshop in December 2018.

*Table 1: Indicators for the DST (indicators in **bold** are from the LCC analysis)*

Social	Environmental	Economic	Technical
• Visual • Risk of Infection • Risk of toxic components • Health & Safety • Acceptability • Affordability	• Odour • Noise • Footprint • Reducing Local Abstractions • Effluent Quality • Risk of Accidental Emissions • Climate Change (LCA) • Damage to Health (LCA) • Damage to Ecosystems (LCA) • Damage to Resource Availability (LCA)	• **CAPEX (LCC)** • **OPEX (LCC)** • **Willingness to pay for environment (LCC)** • **Potential Income Generation (LCC)**	• Technology readiness level • Flexibility • Reliability • Risk of failure

At present, the weightings of the indicators are undecided as an exercise is planned incorporating views of the stakeholder groups identified in the NEREUS project.

3.4 Inventory data

The cost related data per each unit processes to perform LCC is intended to be collected with primary and secondary data collection. The sources include but not limited to the literature, cross references with the online sources of various wastewater projects, suppliers, and pilot partners.

At present knowledge library of two previous DSTs take place in the literature are under consideration:

1) Poseidon DST (Oertle et al, 2019)
2) NOVEDAR DST (Garrido Baserba, 2013)

Both papers have more than one sources to have a knowledge base for costing. Guo et al (2014) has suggested a logarithmic variant of the Williams Law cost function which can be applicable for some unit processes. Their method can be used as a guidance over the collected data from Pilot partners for scaling various plant size. In addition to these two main papers in the literature, a spreadsheet that aims to collect data from NEREUS Pilot Partners has also been organised and shared with the partners.

Another point that needs to be addressed is that the compatibility of the LCC and Integrated Business Model would be important and increase the robustness and validity of all the tools will be used in the NEREUS DST.

3.5 Process data

The data for process inputs and outputs for the NEREUS LCC will come from the modelling underlying the DST as it is also proposed for LCA. Data on processes within the demo-cases will be used to validate the DST model in terms of energy and martial use and in terms of yields of recovered products. Some calibration may be possible, however discussions at the DST workshop in December 2018 indicated that the DST should model “generic” unit processes resulting in a large multiplicity of possible variants, whereas the demo-cases are much fewer in number. Further investigation from literature and the industry would be needed to improve for processing the data more robustly.

3.6 Cut-off

Similarly it is suggested in LCA report, the level of significance that a cost should have to be included in a study (Hunkeler et al., 2008) is also required. The cut-off point is defined as the “specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study” by ISO 14044.Cut-off criteria can be based on:

- Mass: e.g. <5% cumulative mass input
- Energy: e.g. <5% cumulative energy input
- Environmental significance: e.g. <5% of the results of the selected impact categories

The importance of the goal and scope of the study is emphasized in JRC Report, (Zampori et al, 2016). In NEREUS Project the further investigation on cut-off points will be discussed with Project consortium as well as looking at the compatibility between integrated tools in NEREUS DST, in accordance with Integrated Business Model.

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A. Appendix

A.1 Site map for Evides demo case