INNPAPER

Innovative and Smart Printed Electronics based on Multifunctionalized Paper: from Smart Labelling to Point of Care Bioplatforms

D 6.1: Report on Life Cycle Assessments: Scope, System Boundaries and Methodology

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1 INTRODUCTION

INNPAPER project aims at providing a configurable & recyclable common platform integrating paper-based electronic devices on a multifunctional paper sheet. Within the project, three use-cases will be considered.

The objective of this deliverable is to move the first step towards the performance of the sustainability and economic assessment of the paper based printed electronic devices developed under the framework of the INNPAPER project.

The assessment of the common platform and the three use-cases, based on a Life Cycle Thinking approach is aimed at evaluating two aspects of key importance for the INNPAPER devices, such as:

- The environmental sustainability;
- The economic profitability.

The assessment will follow an iterative process that will be undertaken for the entire duration of the project though three main steps:

1. Definition of the goal and scope of the study, identification of the system boundaries and functional unit and description of the methodological approach for the assessment (*D6.1 Report on Life Cycle Assessments: Scope, System Boundaries and Methodology* due at M12);
2. Screening: a first analysis and interpretation will be concluded in order to provide the developers with valuable information regarding process steps and/or components responsible of significant environmental impacts and/or significant costs. At this stage, in parallel with the task of Ecodesign, Vertech Group (VER) will contribute identifying possible strategies for improving the performance of the INNPAPER devices (*D6.2 Report on Life Cycle Assessments: First analysis screening and recommendations* due at M24);
3. Final assessment: a conclusive assessment of the paper-based electronic devices will be finalized. Conclusion regarding the environmental and economic performances of the developed product will be then detailed in the final report (*D6.3 Report on Life Cycle Assessments: Final reports: complete assessment, results and conclusions* due at M40).

2 METHODOLOGICAL FRAMEWORK

2.1 Environmental Life Cycle Assessment

Environmental Life Cycle Assessment, also known as simply Life Cycle Assessment (LCA) is a management tool to evaluate the environmental performance of products (goods and services). LCA takes into account a product's full life cycle, from the extraction of resources and the processing of raw materials, through production, use, possible recycling, to the final disposal of remaining waste [1]. In brief, LCA is a material and energy balance applied to the product's system, combined with an assessment of the environmental impacts related to the input and outputs to and from the product system. In this sense, LCA provides criteria for decision-making on issues such as product development, policymaking, strategic planning, among others. LCA has indeed been promoted in different European directives as a robust quantitative tool, and a keystone in decision making by producers and stakeholders.

ISO 14040 defines LCA as a technique for assessing the environmental aspects and potential impacts associated with a product or service, by:

- Compiling an inventory of relevant inputs and outputs of a product system;
- Evaluating the potential environmental impacts associated with those inputs and outputs;
- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

The methodology is formalized by the International Standards Organisation (ISO) and focused on the evaluation of the environmental burden of the studied process or product according to different parameters such as waste produced, or energy and materials consumed.

In order to reach these objectives, information on inputs and outputs of the whole process need to be gathered and processed. The standardized LCA framework encompasses of four phases [2] (Figure 2-1).

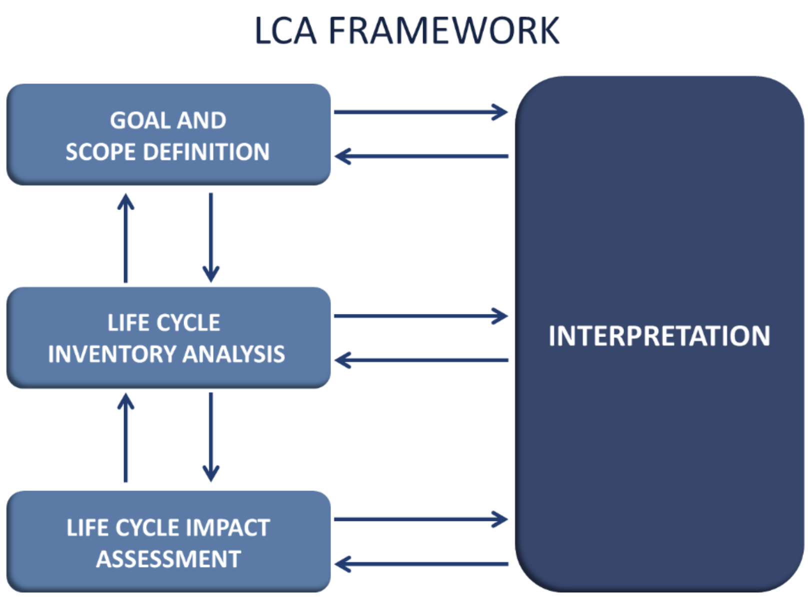

Figure 2-1 Stages of the Life Cycle Assessment [2].

I. **Goal and scope definition**: this is the first step of the study, and probably the most important, given that the purpose, scope and main hypothesis considered are defined in this stage.

Firstly, the goal has to be defined, as well as the kind of decisions that will be made from the results obtained. Secondly, the specific scope is determined. The scope should be well defined to ensure that the breadth, depth and detail of the study are compatible and adequate to address the stated goal. This activity implies defining the system, its boundaries (conceptual, geographical and temporal), quality of date, the main hypothesis and the study limitations.

A key matter on the scope is to define the *functional unit*. This is the "unit of the product or service whose environmental impacts will be assessed and/or compared" (it is usually expressed in terms of amount of product but should be related to the amount of product needed to perform a given function).

The *system boundaries* delimit the unit processes, which will be included into the system. This action is partially based on choices that should be detailed and justified in order to provide confidence in the analysis. The system boundaries should define which stages, process units and flows will be included in the study. As shown in the Figure 2-2, many options are available for the selection of the system boundaries which is strongly dependent on the data availability and their accuracy.

- 'Gate-to-Gate' refers to life cycles considering only the manufacturing process;
- 'Cradle-to-Gate' refers to a life cycle analysis going from the raw materials acquisition to the production of finished goods (no use or end life considerations are included);
- 'Cradle-to-Grave' approach expands the boundaries to the disposal of the finished goods;
- 'Cradle-to-Cradle' is the widest and most complete assessment and it refers to life cycles with potential reuse/recycle loop of the products.

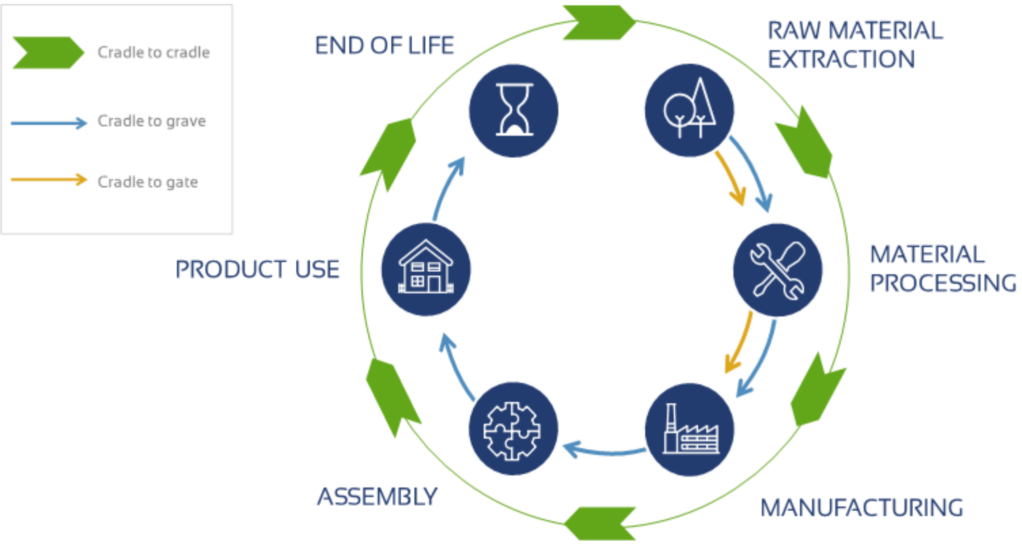

Figure 2-2 System Boundaries definition.

II. **<u>Inventory Analysis (Life Cycle Inventory, LCI)</u>**: this phase is a technical process of *data collection*, in order to quantify the inputs and outputs within the technosphere, as defined in the system boundaries and in relation with the natural environment. In this stage, all emissions released to the environment (air, water, soil and solid waste) and resources consumption (energy and raw materials) along the whole production life cycle, as defined in the scope and in relation to the functional unit [2] will be gathered.

The main steps are:

- data collection;
- relevant and non-relevant element identification;
- mass and energy balances;
- system burdens allocation.

LCI results are the sum of elementary flows entering the system and releasing into the environment.

III. **<u>Impact Assessment (Life Cycle Impact Assessment, LCIA)</u>**: during this stage, LCI results are translated, applying an impact assessment method, into environmental impacts at the midpoint or at the endpoint. It is the process to identify and characterise the potential effects produced in the environment by the system under analysis. A specialised software will be used for this purpose. LCI results will be assigned to the impact categories and potential environmental impacts will be calculated. An *impact category* is defined as a "class representing environmental issues of concern to which life cycle inventory analysis results may be assigned". When referring to impact categories, it must be clarified if either midpoint or endpoint categories are being used. Starting from data collection of energy and emissions, categories at midpoint level require indicators, according to the method taken as model. Eventually endpoints are described by Area of Protection (AoP), it allows easy understanding because they are close to what really matters to society and permits cross comparison on a science basis within the same AoP. End-point categories lack accuracy because many parameters are grouped and classified which leads to inaccuracies and uncertainties [3]. For this reason, the impact categories will be expressed at mid-point level. LCIA consists of four steps [2]:

- Classification: all the items are sorted out into classes, depending on the effect they have on the environment at the midpoint level; the relationship between the environmental intervention and its effects are linked with a cause-effect pathway.
- Characterisation: The classified substances are multiplied by a factor that depends on their relative contribution to the environmental impact, quantifying the impact of a product or service.
- Normalisation: The quantified impact is compared to a certain reference value.
- Weighting: Impact categories are appointed with an importance value in order to generate a single score.

IV. **Interpretation**: in this phase, the findings obtained are presented in a synthetic way, showing the critical sources of impacts and the possible options to reduce them. The interpretation is useful to indicate the results consistency according to all the aspects defined during the goal and scope stage. First of all, significant issues need to be identified (main process contributing most to the results). The interpretation requires consistency checks, ensuring that there is complete information. Sensitivity checks should also be run. The uncertainty and accuracy of results is also addressed at this stage.

A detail of the LCA approach is represented in the Figure 2-3.

The methodological framework follows a clear order. However, LCA studies are iterative, which means that LCA operations are repeated. The iteration allows to increase the detail of the assessment, verify the assumptions and to pay special attention to the most relevant processes, resources and emissions. The most relevant processes will be identified taking into account partners' expertise and supported by the assessment run initially. It is a common practice carrying out one to three iterations before reaching the final results.

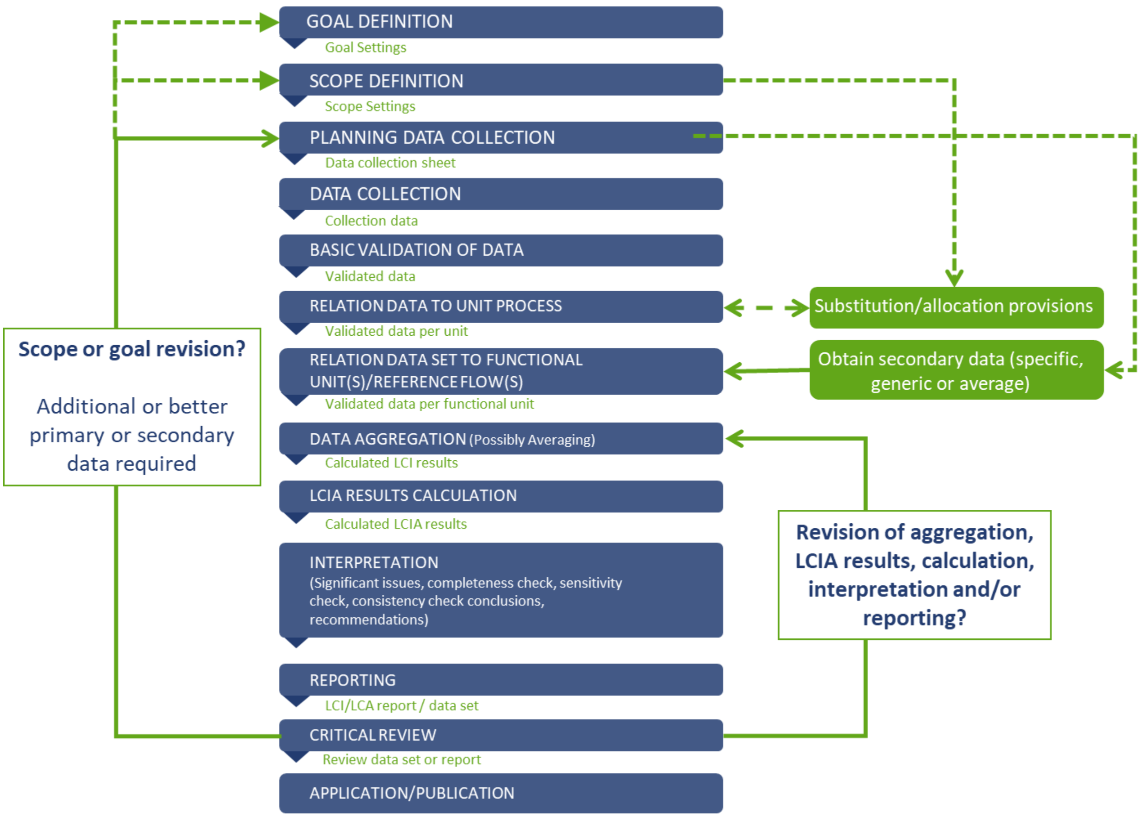

Figure 2-3 Details of the iterative LCA approach [4]

2.2 Life Cycle Cost Analysis

Life Cycle Cost Analysis, also known as Life Cycle Costing (LCC), is an economic decision-making aid tool to estimate the total cost of ownership of a project or production system. It allows aggregated and comparative cost assessments to be made over a specific period of time, taking into account relevant economic factors in terms of both initial capital costs and future operational and asset replacement cost. LCC is a useful support to the decision makers to choose among several possible investments and strategies. Alongside LCA, LCC is seen as one of the three pillars in an evaluation of sustainability, with the third being social assessment [5].

The LCC assessment takes into account initial costs, including capital investment costs, purchase, and installation costs; future costs, including energy costs, operating costs, maintenance costs, capital replacement costs, financing costs and any resale, salvage, or disposal cost, over the life-time of the project, product, or measure [6].

According to [7], end users and suppliers of equipment can take advantage of LCC to perform the following analysis:

- *Affordability studies* - to measure the impact of a system or project's LCC on long term budgets and operating results.
- *Source selection studies* - to compare estimated LCC among competing systems or suppliers of goods and services.
- *Design trade-offs* - to improve design aspects of plants and equipment that directly impact LCC.
- *Repair level analysis* - to quantify maintenance demands and costs rather than using rules of thumb.
- *Warranty and repair costs* - to understand the cost of early failures in equipment selection and use (this analysis might be helpful for suppliers of goods and services as well as end-users).
- *Suppliers sales strategies* - LCC can be used to sell for best benefits rather than just selling on the attributes of low, first cost.

The main expenditures of the production system entering the calculations are the following:

- **CAPital EXpenditures (CAPEX)**: Capital-linked costs (investments). CAPEX is calculated as the sum of initial investments.
- **OPerational EXpenditures (OPEX)**.
    - Consumables: Consumption-linked costs (e.g. raw material, auxiliaries, energy or residue disposal) on a yearly basis;
    - Operation: Operation-linked costs (e.g. labour, servicing/inspection) on a yearly basis;
- **Other costs**: Other additional costs (e.g. insurance, indirect costs, taxes different from VAT or other taxes included in products prices) on a yearly basis.

When possible, the costs are then compared with the revenues. The **Revenues** represents the expected income generated by the sold INNPAPER products.

Figure 2-4 depicts the general methodological approach for the LCC assessment including the cost-revenue structure of the conversion processes.

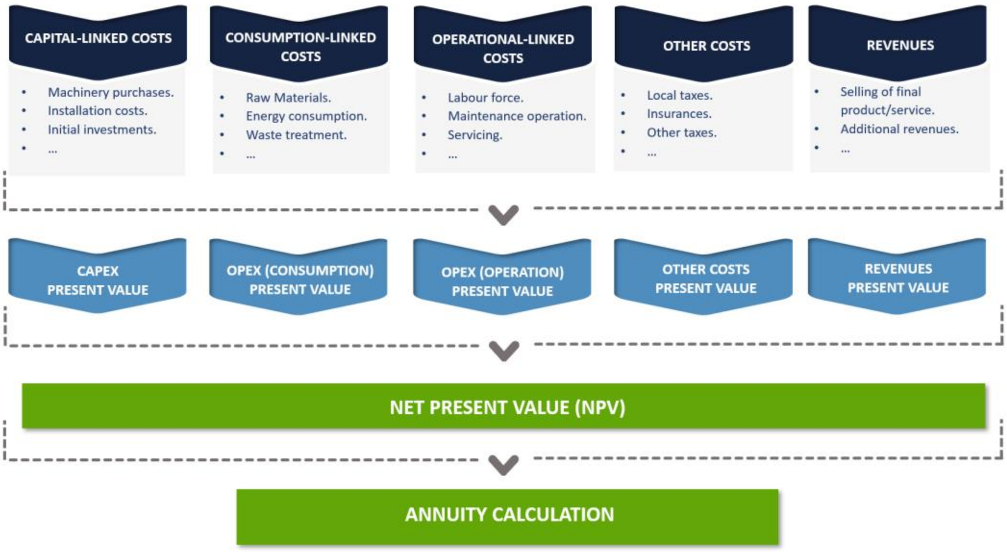

Figure 2-4 Methodological approach for the Life Cycle Cost Analysis

Procurement costs are widely used as the primary (and sometimes only) criterium for equipment or system selection. This single purpose criterium is simple to use, but risks to lead to incomplete assessments or incorrect decisions, that do not take into account the value of money over time. Indeed, a fundamental factor within the LCC concept is time adjustments. Adjustments to place money values expended or received over time on a comparable basis are necessary for the valid assessment of a project's life-cycle costs and benefits. Time adjustment is necessary because any money today does not have equivalent value to that money in the future. There are two reasons for this disparity in value. Firstly, money has real earning potential over time among alternative investment opportunities, and future revenues or savings always carry some risk. Secondly, in an inflationary economy, purchasing power of money erodes over time.

Present Value (PV) is used to reflect the capital costs. PV is used in capital budgeting to analyse the profitability of an investment or project. Determining the value of a project is challenging because there are different ways to measure the value of future cash flows. Because of the time value of money, a euro earned in the future will not be worth as much as one earned today. The discount rate in the NPV formula is a technique to account for this. There are different ways of identifying the discount rate, although a common method is using the expected return of other investment choices with a similar level of risk.

Both CAPEX and OPEX input data are usually expressed as "constant euros", regardless the moment in time in which the expenditure occurs.

Nevertheless, as previously mentioned, in the LCC analysis the Present Value (PV) of future or past money flows should be taken into account and calculated, in order to consider both the cost of capital – i.e. the loss of value of money that is hold in a capital asset and cannot be used for other investments and profits- and inflation – i.e. the fall of the purchasing power of the considered currency related to a rise of prices over time.

PV can be calculated as:

$$PV = \frac{V_n}{(1+r)^n} \qquad \text{[eq.1]}$$

Where:

- V_n = cost value at year n
- n = number of years, where 0 ≤ n ≤ np
- r = nominal or real discount rate
- np= total considered lifespan of the project or time horizon of the analysis

The discount rate is a factor used to discount and transform future cash flows into present value costs. It is usually country and sector specific.

Real discount rates represent the prevailing rate of interest on borrowed funds (equal to the nominal discount rate), less inflation. Real discount rates used in life-cycle cost analysis typically range from 3 to 5 percent.

The rate of interest of borrowed funds reflects - in turn - the cost of capital. Because there is always an opportunity value of time, real discount rates will always exceed zero.

The term 1/(1+r)n Is also known as discount factor and is always less than or equal to 1.

Real discount rates can be calculated using the following formula (derived from the Fisher equation):

$$r_t^{real} = \frac{r_t^{nominal} - i}{1+i} \qquad \text{[eq.2]}$$

Where:

- i = expected inflation rate;
- $r_t^{nominal}$ = nominal discount rate at time t.

The inflation indexes can be withdrawn from the Consumer Price Index.

The nominal discount rates are communicated directly by the project partners (according to their Weighted Average Cost of Capital (WACC) or – when unknown – taken from literature or official sources. In the second case, the input might be less precise, as the rates are sector and country specific.

Usually, the CAPEX values do not need to be actualized, as it assumed they occur during the first year of the analysis; in case they occurred in the past or they are paid in different rates an actualization is necessary, as well as an allocation if they serve also for other production processes or services.

The sum of all present values gives the Life Cycle Cost Net Present Value (NPV) or Total Present Value (TPV), which is the desired output of the analysis.

The possible life cycle times for LCC analyses usually vary from few years to 25 years, the latter representing the general limit of the analysis also for the LCA, as it is assumed that after this period of time new materials or technologies might gain the market. Moreover, discount and inflation rates assumptions lose relevance after several years.

Few years life spans are taken into account as investors are often interested in shorter periods of time, while longer life spans might be chosen to evaluate the Return on Investment (ROI) over different scenarios. As a specific financial measure; ROI is expressed as a percentage over a specific period of time.

ROI differs then from the NPV of a project, that is equal to the benefits minus the costs, and is expressed in monetary units, providing information about the magnitude of the project.

The annual equivalent or annuity (ANN) is the sum of interest and amortisation, which has to be paid every year to finance the investments and maintenance. With the annuity, projects of different life spans can be compared.

The following formula is used to convert the total/net present value of the investment or maintenance strategy into the annuity (ANN) or performance fee [8]:

$$ANN = NPV \frac{(1+r)^{np} r}{(1+r)^{np} - 1} \qquad \text{[eq.3]}$$

3 CONTEXT OF THE STUDY

The increasing volume of electronic waste is an issue of current concern from both environmental and health point of view. Thanks to the consequent reduction of the volume waste, printed electronic devices represent already a step forward to mitigate such an issue. This is also obviously linked to the lower material requirements for printing technologies. In fact, if manufacturing using lithography requires subtractive processes, adopting printing technologies allows the substitution of several process steps with the single process of adding material to the substrate. This alternative process allows reducing considerable material consumption [9].

Printed electronics allow the use of flexible substrates which commonly is Poly(ethylene terephthalate)-foil (PET) due to its low cost and moderately high temperature stability. Higher performance and higher cost alternatives can be Poly(ethylene naphthalate)- (PEN) and poly(imide)-foil (PI). As an alternative, the use of paper as functional material for electronic components has attracted considerable attention for either its characteristics, low cost and recyclability. Despite the high interest for the advantages (both environmental and economic) of the paper-based electronics over the conventional ones, systematic information on the extent of the correlated benefits when in comparison with the current alternatives are still scarce. In this regard, the study carried out under the framework of the INNPAPER project will hopefully contribute fulfilling this lack.

In a study based on the comparison of the environmental performances of paper-based printed circuit boards (P-PCB) versus current organic epoxy based PCB (O-PCB), Liu et al; (2014) already showed significant improved performances [10]. In the study, the LCA of prototyped multilayer printed circuit board (P-PCB) with comparable functions of the currently available organic printed circuit boards (O-PCB) was carried out showing the following results for selected impact categories:

*Table 3-1 LCIA for 10 000 m² P-PCB and O-PCB * (extracted from Liu et al. 2014,* [10]*)*

Impact category	Impact units	P-PCB	O-PCB	O-PCB:P-PCB
Abiotic Depletion	J	8.51×10^{10}	5.50×10^{12}	65 : 1
Global Warming Potential	g CO_2-equiv.	5.55×10^{6}	3.92×10^{8}	71 : 1
Ozone Layer Depletion Potential	g R11-equiv.	3.56×10^{-1}	1.85×10^{1}	52 : 1
Acidification Potential	g SO_2-equiv.	3.63×10^{4}	4.53×10^{6}	125 : 1

* Functional Unit: 10 000 m² P-PCB and O-PCB, cradle to gate approach, impact method: CML 2001-Apr. 2013

The results shown represent an encouraging starting point for the current study of the environmental performances of the INNPAPER devices.

4 LCA AND LCC IN INNPAPER PROJECT

As already mentioned among the objectives of this deliverable, INNPAPER project aims at providing a configurable common electronic platform based on multifunctional paper with tailor-made properties enabling the subsequent customized production of a variety of use-cases. In this regard, individual paper-based devices will be integrated and interconnected in the common electronic platform according to the configuration defined for the specific use-case.

The common platform will be provided with a certain number of common electronic devices, such as:

- Battery;
- Electrochromic display (ECD);
- Communication system.

The common platform will be then integrated with additional devices required for the specific function required. In particular, for the three use-cases, the following component will be added:

- Use-case 1: Smart labels:
    - Temperature sensor;
    - Hygrometry sensor;
    - Pressure sensor.
- Use-case 2: PoC quantitative immunoassays:
    - Electrochemical immunosensors.
- Use-case 3: PoC genetic assay:
    - Electrochemical genosensors.

The technical and functional requirements for each use-case have been described in *D3.1 Report on devices specification* (CID).

In this chapter is described how the Life Cycle approach is applied to the context of the study in order to fulfill de objectives described in the Section 1.

4.1 Goal of the study

This study is aimed to assess the environmental benefits of INNPAPER paper based printed electronic devices by applying an attributional LCA approach. Additionally, the assessment also seeks to measure and analyse the capital and operational costs resulting from the production of common platform and the electronics in the selected application. The assessment will allow investigate the economic feasibility of the final products and guide the optimization of the process by identifying possible bottlenecks in the process chain.

The innovation of the products investigated makes particularly difficult the comparison of their performances with those of other substitute goods fulfilling the same function. The lack on the market (or as prototype) of such goods would might lead to incomparable results and misleading interpretation. However, the main innovation of the INNPAPER devices lies in the core material of the printed electronic devices. Thus, in order to highlight the potential environmental improvements and economic benefits, the INNPAPER devices will be assessed by means of a **comparative evaluation with electronic printed over conventional materials** (e.g. polyamide and epoxy-based material for PCBs and other plastics for printed electronics as PET and PEN).

4.2 Functional unit

Two different functional units (FU) will be used for this analysis, due to the progressive nature of the project, that will proceed with subsequent detail of the products development focusing on the common platform and then on three use-cases.

The assessment will be carried at first focusing on the common platform. This first focus will provide valuable information of the environmental profile and the economic feasibility and profitability of the common item to the three use-cases. The result of the assessment will also represent an important starting point for considering the extension of the INNPAPER devices applications. At the first phase, the functional unit will correspond to the entire life cycle of the common platform (FU: **1 common platform**). The total impact is given by the sum of the impacts of the common platform components. For each single component (battery, ECD and communication system), the comparison will be done taking in consideration the specific size and characteristics to ensure the same function according with the support material. This specification needs to be done to take into consideration the different properties of the substrate material that could lead to variable requirements (e.g. thickness, etc.)

Successively, one of the three uses cases will be selected jointly with the project consortium to perform an extended environmental and economic evaluation. During the second phase, the functional unit will be extended to the life cycle of the final INNPAPER product for the selected use-case (FU: **1 INNPAPER device for the specific use case**). This allows to incorporate in the analysis aspects specifically related to the use of the device and the corresponding end of life options.

An overall understanding of the general performances of the INNPAPER devices (for the three use-cases considered) is then expected to be achieved. Differently, the specific assessment of the other two use-cases might be then carried out.

4.3 System boundaries

Figure 4-1 shows the general flowchart of the processes within the INNPAPER project, grouped according to the relative work packages.

Each production process is composed of several subprocesses that will be depicted, after collecting the information from the project partners, in the intermediate version of the present report.

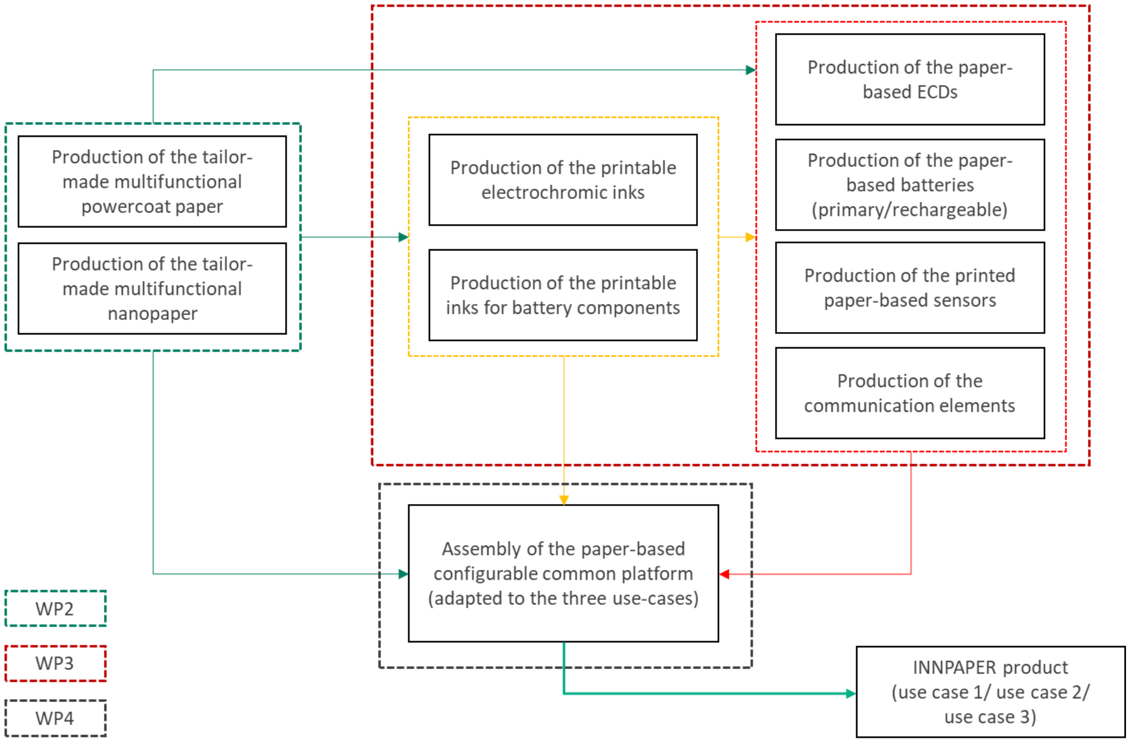

Figure 4-1 INNPAPER production scheme

Further information regarding the design of the three use-cases as well as the definition of a tentative process flow for their manufacture is included in *the D4.1 Design of the use-cases and definition of process flow* (GUA).

The reusability and recyclability of the paper based electronic devices represent two keys parameters of the products to ensure the best option from a sustainability perspective. The evaluation of different end-of-life scenarios will be object of the task 6.4 (lead by GUA). The outcomes of the task will be integrated in the environmental and economic assessment performed by Vertech Group (VER) following a "**cradle to grave**" approach. The life cycle of the INNPAPER printed electronic devices that will be consider to set the system boundaries for the assessment is then represented in the Figure 4-2.

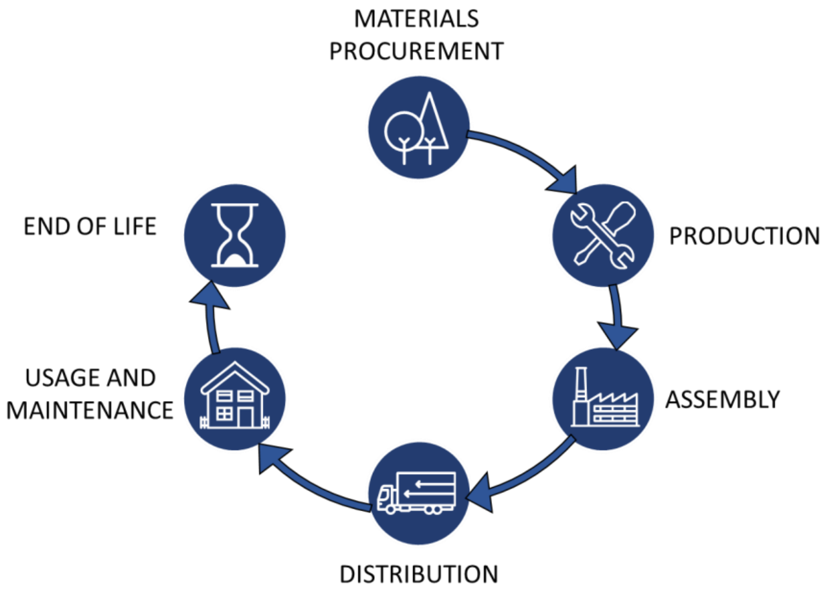

Figure 4-2 INNPAPER Life Cycle

4.4 Spatial and temporal boundaries

Partners within the consortium will provide data that will set the geographical scope of the study. The general framework would set different scenarios at European level, where the INNPAPER materials could be potentially processed without covering long distances.

Temporal boundaries are strictly related to system definition and to the lifetime predict for the systems from INNPAPER partners. Due to the innovative character of the developing products, the temporal boundaries are set to **5 and 10 years**. After this period of time, the possibility that new materials or technologies would gain the market might compromise the truthfulness of the assessment.

4.5 Impact assessment

The potential environmental impacts of the INNPAPER devices will be calculated by means of a specific software employed to create the models for the impact assessment calculation: SimaPro 8 by Pre' Consultants, one of the most widespread LCA software.

The chosen impact assessment method for the evaluation of the environmental performances of the paper printed electronic devices is **ILCD 2011 Midpoint**, released in 2012 by the Joint Research Centre (JRC) of the European Commission.

The ISO 14040 and 14044 standards give a framework for LCA, but leave the expert with a range of possible choices. The ILCD (International Reference Life Cycle Data System) constitutes a general basis for consistent life cycle data, methods and assessments. It has been made with the aim to harmonize existing methodologies for LCIA and rely on high quality and carefully selected datasets. Indeed, the ELCD database accentuates consistency and quality by making method recommendations on each impact. The recommendations are given for the following midpoint impact categories: climate change, ozone depletion, human toxicity, particulate matter/respiratory organics, photochemical ozone formation, ionizing radiation impacts, acidification, eutrophication, ecotoxicity, land use and resource depletion [11].The different mid-point impact categories are described below [12]–[14]:

- Climate change is evaluated with the Global Warming Potential (GWP100) in kg CO_2 eq. The GWP is mainly associated to the greenhouse gases (carbon dioxide, CO_2 and methane, CH_4). It is calculated for a period of 100 years and it determines the contribution to global warming of a substance released into the atmosphere.
- Ozone depletion is calculated thanks to the ODP (Ozone Depletion Potential) in kg CFC-11 eq. It represents the destructive effects on the stratospheric ozone layer over a time horizon of 100 years.
- Human toxicity is the translation of the potential harm of a unit of chemical released into the environment. It is based on the toxicity of a component but also on its potential dose. The toxic chemicals, such as arsenic, sodium dichromate and hydrogen fluoride are mainly produced during the electricity production from fossil sources process. There are two different categories of components:
  - With cancer effects,
  - With non-cancer effects.

  Both are measured in Comparative Toxic Unit for humans (CTU_h). CTU represents an estimate of the potentially affected fraction of species (PAF) integrated over time and volume, per unit mass of a chemical emitted. CTU_h expresses the estimated increase in morbidity in the total human population per unit mass of a chemical emitted.

- Particulate matter/Respiratory inorganics is a complex mixture of very small particles also called particle pollution. They are made up of various components such as acids, organic components, metals and soil and dust particles. They often cause respiratory problems and they are measured in kg PM10 eq to air (particles size of 10 µm).
- Ionizing radiation, human health is measured in kBq U^{235} eq. It is caused by the emissions of radionuclides throughout a product or building life cycle. The radiation can be α-, β-, γ-rays and neutrons type.
- Photochemical ozone formation is harmful because ozone is toxic to humans on the ground-level. Ground level ozone is formed by the reaction of volatile organic compounds and nitrogen oxides thanks to heat and sunlight. Thus, photochemical ozone formation depends on the amounts of carbon monoxide, sulfur dioxide, nitrogen oxide, ammonium and NMVOC (nonmethane volatile organic compounds). The Photochemical Ozone Creation Potential (POCP) is measured in kg NMVOC eq.
- Acidification is caused by air emissions of NH_3, NO_2 and SO_x. These acidic gases react with water in the atmosphere and form “acid rain”. It causes a disturbance of varying

degree in ecosystems. It is measured by the Accumulated Exceedance (AE) in mol H^+ eq/kg.

- Eutrophication is mainly caused by nitrogen and phosphorus in sewage outlets and fertilizers. The concentration of those chemical nutrients in ecosystems leads to an unusual productivity. The water quality and the animal populations are thus reduced because of an excessive plant growth like algae in rivers.
    - Terrestrial eutrophication is measured by the Accumulated Exceedance (AE) in mol N eq (nitrogen is the limiting factor).
    - Aquatic freshwater eutrophication is measured by the fraction of nutrients reaching freshwater end compartment in kg P eq (phosphorus is the limiting factor).
    - Aquatic marine eutrophication is measured by the fraction of nutrients reaching marine end compartment in kg N eq (nitrogen is also the limiting factor).
- Ecotoxicity (freshwater) is due to the emission of some substances such as heavy metals that can have impacts on the ecosystems. Ecotoxicity is measured with the Comparative Toxic Unit for ecosystems (CTUe).
- Land Use represents the occupation impacts. The possible alteration of the land area and the damage of biodiversity are considered. It is measured in kg C/yr, C being the biogenic carbon stocks in vegetation, soil and detritus of the land ecosystems.
- Resource depletion is measured by the value of the abiotic resource consumption of a substance and represents its scarcity. It depends on the amount of resource and on the extraction rate. Resource depletion can be assessed on water, minerals and metals and energy carriers:
    - Water scarcity: User deprivation potential (deprivation-weighted water consumption) measured in m^3 water use related to local scarcity of water.
    - Resource use (minerals and metals): Abiotic resource depletion (ADP ultimate reserves) measured in kg SB eq.
    - Resource use (energy carriers): Abiotic resource depletion – fossil fuels (ADP-fossil) measured in MJ.

If necessary, a selection of the relevant impact categories will be eventually performed, using literature review and appropriate cut-off criteria.

5 NEXT STEPS

5.1 Data Collection

The second step of the Life Cycle Assessment framework (valid for both LCA and LCC) is represented by the Life Cycle Inventory Analysis. In this stage a systematic quantification of the input and output flows of the system under analysis will be carried out. For this purpose, collaborative communication (phone interview and field visit) will be established between Vertech Group and the partners involved in the development of the devices. This will bring to a data transfer from the developer to the LCA/LCC practitioner in order to correctly feed the model and run the simulation for impact and cost calculation. For this purpose, a template for data collection has been prepared (Annex 1).

The data collection can be a critical phase due to the complexity of gathering all the required data. When data are not directly measurable (foreground data), alternative options will be considered to fulfil the spreadsheet. The study will be in fact backed up by the LCA databases and other LCI sources and, in the worst case, through literature review (background data). The accuracy of the data gathered can be compromised moving from values of direct measurement to data gathered from literature (Figure 5-1). Thus, when possible, foreground data will be preferably used for the analysis.

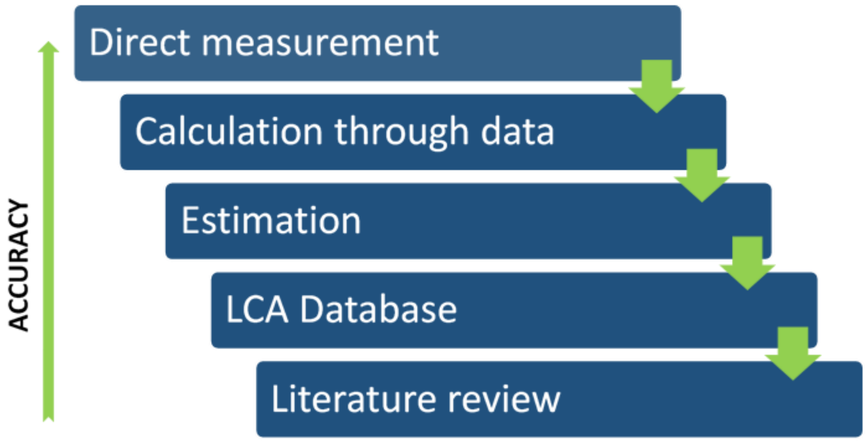

Figure 5-1 Data's accuracy

6 CONCLUSIONS

This deliverable is the first step towards developing a full-competence technical LCA and LCC. It explains the scope and the methodology to obtain the results expected. One of the strengths of described assessments is to provide quantitative results on how feasible and economically viable the final INNPAPER products are from both environmental and economic impacts perspective.

Due to the iterative character of the Life Cycle approach, the boundaries and functional units can be susceptible to adjustments in a further development of the study.

This document represents the starting point of an assessment that will go along the entire development process of the INNPAPER devices. Together with the other two tasks within the WP (Task 6.3: Ecodesign and Task 6.4: Reuse and Recycling), the Environmental Life Cycle

Assessment and the Life Cycle Cost Analysis will provide valuable information to the other WPs to improve and optimize the performances of the final products.

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