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# LIFE CYCLE ASSESSMENT OF METALLISED TEXTILES. THE CASE STUDY OF MATUROLIFE PROJECT

## OCENA CYKLU ŻYCIA METALIZOWANYCH TKANIN. STUDIUM PRZYPADKU PROJEKTU MATUROLIFE

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**Abstract:** This article provides an overview of the Life Cycle Assessment (LCA) method which supports manufacturers' environmental information needs by evaluation of the environmental aspects and potential influences throughout the lifetime of the product. In the article results are presented of the first phase of the life cycle assessment of metallised textiles and the context for the analysis is a new project: „Metallisation of Textiles to make Urban living for Older people more Independent & Fashionable – MATUROLIFE", implemented under the HORIZON 2020 Programme – "Advanced materials & innovative design for improved functionality & aesthetics in high added value consumer goods".The article presents the most important assumptions for assessing the environmental effects associated with the metallization of various textiles, including primarily electroless copper coating, by calculating the demand for materials and energy, and taking into account emissions to air, water and soil, and by assessing their impact on the environment. The use of LCA as a management tool with great potential for making decisions within strategic business planning was analyzed.
**Keywords:** life cycle assessment, environmental impact, MATUROLIFE, metallisation

**Streszczenie:** W artykule przedstawiona została metoda Oceny Cyklu Życia (LCA), która wspiera potrzeby producentów w zakresie pozyskiwania informacji o środowisku poprzez ocenę aspektów środowiskowych i potencjalnych wpływów w całym okresie życia wyrobu. Zaprezentowano rezultaty badań w ramach pierwszej fazy oceny cyklu życia metalizowanych tkanin, nazywanych także inteligentnymi tkaninami. Kontekst dla analizy stanowi nowy projekt pt.: „Metalizacja tekstyliów w celu uczynienia życia miejskiego osób starszych bardziej niezależnym i stylowym – MATUROLIFE", realizowany w ramach programu HORYZONT 2020: „Zaawansowane materiały i innowacyjne projektowanie dla poprawy funkcjonalności i estetyki dóbr konsumpcyjnych o wysokiej wartości dodanej". W artykule przedstawiono najważniejsze założenia do oceny skutków środowiskowych związanych z metalizacją różnorodnych tekstyliów, w tym przede wszystkim bezprądowego powlekania miedzią, poprzez obliczenie zapotrzebowania na materiały i energię, oraz z uwzględnieniem emisji do powietrza, wody i gleby oraz poprzez ocenę ich wpływu na środowisko. Przeanalizowano zastosowanie LCA jako narzędzia zarządzania o ogromnym potencjale do podejmowania decyzji w ramach strategicznego planowania biznesowego.
**Słowa kluczowe:** ocena cyklu życia, wpływ na środowisko, MATUROLIFE, metalizacja

### Introduction

The basic idea of the LCA is that all environmental burdens connected with a product or service have to be assessed in all consecutive and interlinked stages, from raw material acquisition or generation from natural resources to final disposal. This idea is called in short „from cradle to grave".

In the early 70s when the first LCAs were carried out in the United States and the United Kingdom, the main issue of the LCA was a comparative analysis of the environmental aspects of packaging, in particular in terms of saving resources and energy. Later on, in the 80s many other products started to be analyzed and in the 90s the first international standards were developed by the International Organization for Standardization (Klöpffer, 1997). Apart from the LCA there are also other analytical tools for the assessment of the environmental aspects of a product, for example checklists, environmental benchmarking or the simplified LCA. Depending on the nature of information generated by the tool they are quantitative and/or qualitative tools. The quantitative approach provides measurable values based rather on objective methods, but it is complicated and requires highly skilled experts. The qualitative approach provides less reliable information, although it is simpler and quicker. The LCA is best known for the quantitative analysis of environmental aspects of a product, and the presented paper is focusing on this tool as follows.

The goal of all LCA analysis is to compare the environmental performance of products. Such information can be a significant premise for taking informed decisions by anybody who needs to choose less burdensome products. However, there are more applications of the LCA. It can assist in:

- *identifying opportunities to improve the environmental performance of products at various points in their life cycle,*
- *informing decision-makers (…), e.g. for the purpose of strategic planning, priority setting, product or process design or redesign,*
- *the selection of relevant indicators of environmental performance,*
- *marketing (e.g. implementing an eco-labelling scheme, making an environmental claim, or producing an environmental product declaration)* (the ISO 14040: 2009).

When managers decide about carrying out an LCA, no matter for what purpose it is used, it is very important that all stakeholders accept the methodology and the results of the analysis. That can be assured by using international standards such as the ISO standards.

Recently, in the era of the circular economy, the new version of the LCA motto could be „from cradle to cradle" instead of „from cradle to grave". The "Cradle to cradle" concept, which is a design philosophy and is built on the principle that all materials involved in industrial and commercial processes can be used as raw materials („waste equals food"). The waste, which becomes nutrients, are considered in two categories: technical and biological. Moreover, thanks to the precise specification of the molecular composition of materials, the flow of industrial materials can be guided in a way similar to biological materials - „biological metabolism" as a model for „technical metabolism" (McDonough, Braungart, 2010; Gheorghiu, Szajczyk, 2018).

Whereas LCA is focusing on the assessment of the environmental impact of a given product throughout its lifespan, the new trends in economy require a wider approach to product evaluation. In the new emerging performance economy, products are sold as services through rent, lease and share business models (Stahel, 2010). In such a new approach the manufacturer retains ownership of the product and resources embodied in these products. There are also manufacturers who will carry the responsibility for risks related to the product exploitation stage and also waste when the product is no longer usable.

**Literature review**

*a. International standards for the LCA*

There have been some standards developed recently, which include environmental metrics for both the product and organization level. Many of these standards include a life cycle approach, which means that the environmental impact of a given product is assessed throughout its lifespan. (Ross, Evans, 2002). Among the life cycle-based standards the best known is the ISO 14040 series of standards on the LCA developed by the International Organization for Standardization. The 14040 series is part of the overall ISO 14000 series on Environmental Management Systems (EMS), which have a commitment to continual improvement as a basic requirement for the EMS policy statement (Finkbeiner, Inaba, 2006). Thus the ISO 14040 series provide the basic requirements for consequential LCA and there are two standards included under the series, which are supporting the LCA implementation:

The ISO 14040:2006 – *Environmental management – Life cycle assessment – Principles and framework*, provides an overview of the practice, applications and limitations of the LCA to a broad range of potential users and stakeholders

The ISO 14044:2006 – *Environmental management – Life cycle assessment – Requirements and guidelines*, is designed for the preparation, conduct and critical review of life cycle inventory analysis. It also provides guidance on the impact assessment phase of the LCA and on the interpretation of the LCA results, as well as the nature and quality of the data collected.

There are four phases of the LCA study specified in the ISO14040 standard:

1) Goal and scope definition phase;
2) Life cycle inventory analysis phase (LCI);

3) Life cycle impact assessment (LCIA);
4) Interpretation phase.

The relationship among these four phases is shown in the Figure 1.

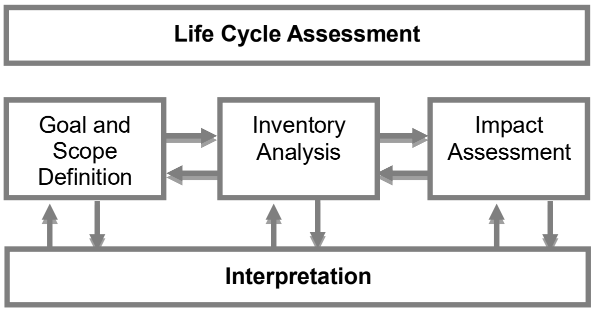


**Figure 1.** Phases of an LCA
Source: figure developed on the base of the ISO14040: 2006 - *Environmental management – Life cycle assessment – Principles and framework,* p. 24.

- Phase 1. Goal and scope definition

In this phase, the product or service which is going to be assessed should be defined and during the defining of the goal the intended application and reasons for carrying out the LCA study should be stated. Moreover, in this step a clear answer should be given for the question of to whom the results of the study will be addressed and whether the results will be disclosed to the public. The scope of the LCA study should include a clear description of the product system, the functions of the product system and the product system boundaries.

- Phase 2. Life cycle inventory analysis phase (LCI)

In this phase qualitative and quantitative data are collected for each unit process which is included in system boundaries, in order to quantify the inputs and outputs of unit process. For consistent understanding of the product system, it is recommended to take the measures such as process flow diagrams and detailed description of unit processes; lists of flows and units, descriptions of data collecting and calculating methods. Collected data may include the groups such as energy, raw materials and other physical inputs; products, co-products and waste; releases to air, water and soil.

- Phase 3. Life cycle impact assessment (LCIA)

The goal of the LCIA is to evaluate the significance of potential environmental impacts using the inventory analysis results. In this phase the indicator results for different environmental impact categories are collected and the inventory data is associated with those impact categories. In order to performed the above-mentioned, different techniques can be used, such as: environmental performance evaluation, environmental impact assessment or risk assessment.

- Phase 4. Interpretation

In this phase the findings from inventory analysis and the impact assessment are considered together and they can be used for taking informed, environmentally friendly decisions. The obtained outcomes, presented in the form of conclusions and recommendations, should be consistent with the goals and scope of the analysis. It should be noted that the results of the life cycle impact assessment indicate only potential environmental effects not the actual impact or safety margins or risks. The interpretation phase can be an iterative process and through the repetition of reviewing and revising can lead to both tuning or deeper changes in the product or process design. Thus, the previous phases of the LCA would be carried out again and an iterative process of the whole LCA would take place. In case the LCA does not show a certain environmental preference of one scenario over one or several alternatives, some decision-making support tools can be used. For example, measuring uncertainty, multi-criteria decision analysis; visualization of results (Laurin et al., 2016).

*b. Introduction of the MATUROLIFE Project*

The MATUROLIFE Project is implemented under the HORIZON 2020: NMBP-05-2017 – *Advanced materials & innovative design for improved functionality & aesthetics in high added value consumer goods* and funded under H2020-EU.2.1.3. – *Industrial Leadership*.

As part of the HORIZON 2020, the topic NMBP-05-2017 – *Advanced materials and innovative design for improved functionality and aesthetics in high added value consumer goods* addresses the development of innovative advanced material solutions, among others smart textile for use in the creative industry sectors defined above to make urban living significantly easier, more sustainable, more comfortable, more secure and more functional. The assumption of the project is "to deliver a product and/or process, excluding commercially usable prototypes, but convincingly demonstrating scalability towards industrial needs. (NMBP-05-2017).

The overall goal of the MATUROLIFE project is to include creativity and artistic design in the process of creating innovative products. Designing will be combined with advanced innovative materials to get high added value, aesthetic and functional products for assistive technologies (AT), which makes the urban living of older people easier and more independent. The project cooperates with SMEs operating in the creative industries industry and scientists working on novel, highly advanced technologies in the field of electrochemistry and nanotechnology. Thanks to the involvement of SMEs in the supply chain of materials, very innovative, conductive, multi-functional textile products and intelligent fabrics will be created, enabling the production of new AT prototypes. The newly created products will respond to current and future social challenges related to the urban life of older people, while ensuring the competitive and sustainable development of SMEs. The project responds to the key challenges presented in the Health Action Plan: e-Health 2012-2021, and more specifically the European Innovation Partnership for Active and Healthy Aging (MATUROLIFE, 2018).

The MATUROLIFE project works on integrating creative artists and fashion designers into the research team to facilitate design-driven innovation. The project builds on existing technological advances in materials which have produced a highly innovative selective metallisation process that utilises nanotechnology, electrochemistry and materials science to encapsulate fibres in textiles with metal and thereby provide conductivity and electronic connectivity. In this way, better integration of electronics and sensors into fabrics and textiles will be possible. It is expected that this will give the fashion designers and artists the tools to produce AT for older people that is not only functional but is more desirable and appealing as well as being lighter and more comfortable. (MATUROLIFE, 2018).

The Project Consortium consist of 20 partners from 9 European countries, representing SMS enterprises, research and development institutions, non-governmental organizations and universities. The leader of the Consortium is Coventry University from the United Kingdom.

One of the Project activities is preparing the business plan for the developed products and the LCA is its integral element.

*c. Textile metallisation and protective coatings*

According to the definition given in the "English Oxford Living Dictionaries" to metallise means "to coat with a thin layer of metal" (*English Oxford Living Dictionaries*). Metallisation can meet decorative or technical purposes, in particular for electrical conductivity or abrasion resistance and can be performed by vacuum evaporation, sputtering or chemical vapour deposition (Gao, Sammes, 2006).

Taking into account the subject and scope of research carried out within the MATUROLIFE project, this article focuses on issues related to the metallisation of textiles, which is defined as "a metal coating process that adds value to and improves the functions of textile materials" (Bertuleit, 1991). Metallisation in conjunction with the advent of synthetic fibres made it possible to take full advantage of their unique properties and to create decorative paintings on them (Jiang, Guo, 2009).

S.Y. Zhang, G. Guan and others claim that using copper for metallisation of textiles has been and still caters to various needs in modern society. According to their research sequentially nondiffusive copper (II) patterning and rapid copper deposition can be incorporated into various textile materials, including cotton, polyester, nylon, and their mixtures. Furthermore, the copper-metallised textile exhibits excellent electrical conductivity that is ~3 times better than that of stainless steel and also effectively inhibits the growth of bacteria. This new copper metallisation approach holds great promise as a commercially viable method to metallise an insulating textile, opening up research avenues for wearable electronics and functional garments (Zhang et al., 2015).

Although, copper (Cu) is one of the cheapest metal options for application on flexible substrates, it is prone to oxidation and corrosion upon exposure to sweat, extreme temperatures and water environment. Also, the poor adhesion between the coating layer and textile surface causes loss of the textiles´ desired functionalities after laundering or long time wearing, and consecutively limits the widespread application of wearable devices (Zhu et al., 2018). In order to minimize the impact on the fabrics' comfort as well as to enhance flexibility, washing and wearing durability, diverse compounds can be applied as encapsulants/casting compounds using industrially-acceptable techniques such as coating, laminating and (screen) printing preventing degradation of conductive tracks.

Considering different methods for corrosion protection of metallic materials, the use of organic coatings is the most widely applied approach. The mechanisms of corrosion protection by organic coatings can be described by distinguishing two types of coatings: (1) barrier coating; (2) coatings containing substances, which are active chemically or electrochemically (Baldissera and Ferreira, 2012).

Kazani et al. (2013) improved the washing durability of screen-printed silver on woven fabrics and the dry-cleaning durability of screen-printed silver on both a polyurethane flexible foam and a non-woven PES by laminating a thermoplastic polyurethane layer over the conductive silver. Paul et al. (2014) fabricated electrodes from electrically conductive fabrics. They first printed a polyurethane paste on a woven textile to create a smooth interface with high surface energy and then printed an Ag paste on top of this interface layer to provide a conductive track, which was then encapsulated with another layer of polyurethane paste to protect the Ag-track from abrasion and creasing. Cho et al. (2007) applied a polyurethane sealing, which is extensively used in waterproof treatment for sportswear, on a previously stitched seam, protecting metal plating during wear and laundering. Vervust et al. (2012) used different polydimethylsiloxane (PDMS) for completely embedding electronic modules in elastomer material. Firstly, PDMS was screen printed on textile, then electronic modules were positioned on the wet printed PDMS layer, then PDMS was cured, and a thin layer of PDMS was applied to the top of the fabric.

In everyday life the metallised textiles (smart textiles) can have many different applications. Some examples are described below:

1. Military / defence – The requirements for such situations are to monitor vital signs and ease injuries while also monitoring environmental hazards such as toxic gases. Wireless communication to a central unit allows medics to conduct a remote triage of casualties to help them respond more rapidly and safely. Moreover, detecting conditions that will prevent danger, preventing accidents by sending a signal when dangerous conditions are detected, providing instantaneous protection against thermal radiation and for anti-static protection.
2. Health – Smart textiles for healthcare include textile sensors, actuators and wearable electronics systems embedded into textiles that enable registration and transmission of physiological data, and wireless communication between the wearer and the 'operator', i.e. warning patients on the evolution of their disease; helping physicians in diagnosing a disease; monitoring the physiological variables of a patient; automatically alerting; collected data is then sent to telemedicine centres via a communication network.
3. Sport – providing thermal comfort; recording aspects of performance, e.g. foot pressure; a precise measure of physiological parameters, e.g. monitoring heart rate, breathing, body temperature, etc.; measuring activity, e.g. determining the number of steps taken, the total distance travelled; acting to actively stimulate muscles e.g. using electrical muscle stimulation.

## Methodology and results

a) Context of the LCA study for the MATUROLIFE project

The MATUROLIFE project activities include development of low cost sustainable copper (Cu) catalyst and demonstration of industrially scalable methods of selectively electroless deposited Cu tracks on a fabric surface; integrate electronics and sensors into conductive textiles; produce conductive textiles with a prolonged lifetime by developing organic and/or inorganic protective coating, and finally, the production and validation of three Assistive Technology prototypes.

b) Objectives

In order to industrialize the textile/fabrics metallisation the main objectives of the analysis are to:

- evaluate the environmental impacts of the metallisation of textiles over their entire life cycle by means of LCA,
- compare the environmental performance of copper metallisation/organic-inorganic protection of different textiles,
- guide the development of the metallisation of textiles towards sustainable solutions while ensuring the study conforms to the ISO 14040-14044 standards,
- printing electronics on textile material as an alternative method of measuring and transmitting data on clothing is not the subject of this study.

c) Scope of the study

This section describes the goal and scope of the study, along with the methodological framework of the LCA. It includes the objectives of the study, a description of the product system, the system boundaries, data sources, and methodological framework. This section also outlines the requirements for data quality as well as a review of the analysis.

d) Functional unit and reference flows

As far as the LCA study relies on a "functional unit" as a reference for evaluating the components within a single system or among multiple systems on a common basis. It is therefore critical that this parameter is clearly defined and measurable. The functional unit for this study is: the metallisation of 1 $m^2$ textile.

Three metallisation applications are considered: 1) textiles for shoes; 2) textiles for clothes and 3) textiles for furniture. The different scenarios are based on the different products studied: copper coating with an organic protection layer and copper coating with an inorganic protection layer. In total, 6 scenarios will be hence studied.

The layout of the metallisation scenarios is presented on Figure 2.

From the life cycle perspective point of view, the main interests expected for these new technologies are to decrease the use of metals and compounds/chemicals needed for the metallisation process.

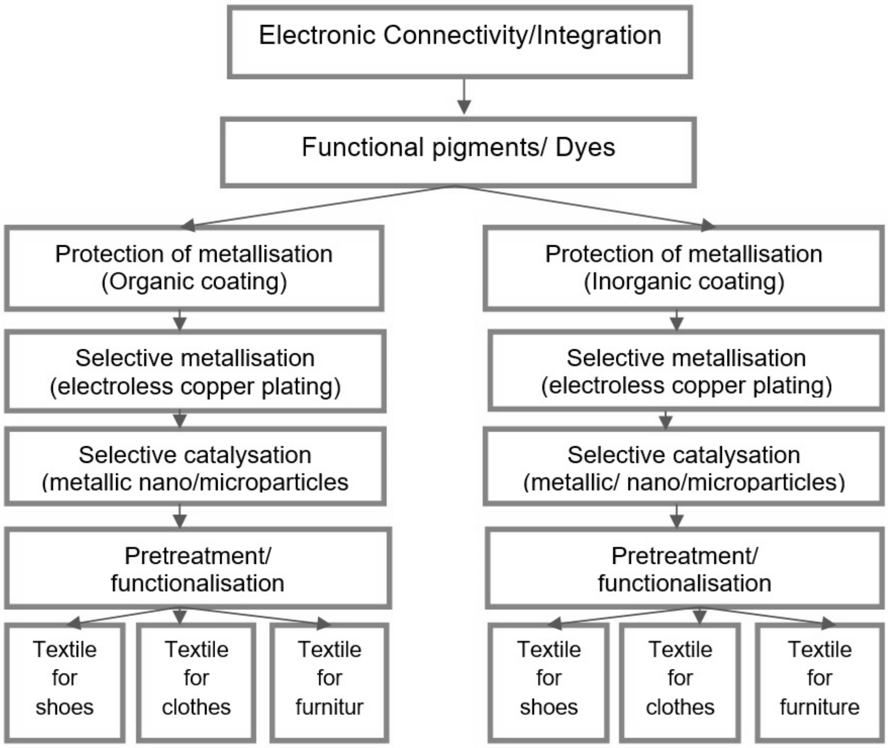


**Figure 2.** The metallisation scenarios
Source: figure developed on the base of the MATUROLIFE project assumptions, 2018.

e) The system boundaries

The system boundaries identify the life cycle stages, processes, and flows considered in the LCA and include all activities relevant to study objectives. Therefore, it is necessary to provide the specified function and to identify the boundaries of the LCA analysis, including the boundaries of the system both, temporal and geographical. Relevant for the objectives of this study are activities such as:

1) Production of raw materials for pre-treatment (raw materials extraction, material processing, material transportation to pre-treatment production site).
2) The pre-treatment process of textiles (energy and water consumption, chemicals, supplies, waste and direct emissions – water, soil, air).
3) Production of raw materials for catalysation (raw materials extraction, material processing, material transportation to catalysation production site).
4) The catalysation process of textiles (energy and water consumption, chemicals, supplies, waste and direct emissions – water, soil, air).
5) Production of raw materials for metalizing (raw materials extraction, material processing, material transportation to metalizing production site).
6) The metalization process of textiles (energy and water consumption, chemicals, supplies, waste and direct emissions – water, soil, air).
7) Production of raw materials for protective organic and inorganic coating (raw materials extraction, material processing, material transportation to coating production site).
8) The protective organic and inorganic coating process of metallised textiles (energy and water consumption, chemicals, supplies, waste and direct emissions – water, soil, air).
9) Production of raw materials for electronic connectivity/integration (raw materials extraction, material processing, material transportation to electronic connectivity/integration production site).
10) The electronic connectivity/integration process of metallised textiles (energy and water consumption, chemicals, supplies, waste and direct emissions – water, soil, air).
11) Distribution (transportation to customers - train, truck, plane).
12) Use (maintenance: energy and water consumption, chemicals, supplies, waste, direct emissions).
13) End of life (transportation to waste treatment site, land filling, incineration, recycling) and/or back to life.

The LCA will be representative of materials handled in Europe and sold in Europe at the time the study is conducted (2018-2020). Most manufacturing processes reflect experimental practices by the MATUROLIFE project partners. Data and assumptions are intended to reflect the current equipment, processes, and market conditions. It should be noted, however, that some processes within the system boundaries might take place anywhere or anytime, and therefore some of the actual impacts related to earlier life stages (before use in the cycle) may happen outside the EU, whereas the impacts related to the use and end-of-life will generally occur within the EU. It should also be stated that due to those experimental conditions, some data may not be at the highest level of robustness. In addition, certain processes may generate emissions over a longer period than the reference year. This applies to land filling, which causes emissions over a period of time whose length depends on the design and operation parameters of the burial cells and how the emissions are modelled in the environment.

It should be noted that the capital equipment and infrastructure available in the database will be included in the background data for this study in order to be as comprehensive as possible.

Some processes may be excluded from the study due to the lack of reliable data, expected contribution lower than the cut-off criteria, and common contribution amongst the scenarios. These aspects will have to be decided at a later phase of the project, but will include at least: marketing and commercial activities, packaging, employee commuting, etc.

## Conclusions

In this article the authors focused on the first phase of the Life Cycle Assessment (LCA) and introduction of the MATUROLIFE Project for which the assessment will be carried out. It is worth emphasizing that the objectives of the MATUROLIFE Project, which is implemented under the HORIZON 2020: NMBP-05-2017 – *Advanced materials & innovative design for improved functionality & aesthetics in high added value consumer goods* and funded under H2020-EU.2.1.3. - *Industrial Leadership*, are in line with the EUROPA 2020 Strategy. The activities carried out under the Project respond to the needs of elderly people living in cities, to protect their health and improve their physical activity.

The Consortium partners for the needs of the Project apply modern, experimental methods of metallisation of textiles, which have not been used in such a form so far. Moreover, the added value of the project presents a combination of creative & artistic design and advanced (nano) material engineering.

Textile metallisation could be described as the deposition of metallic nanoparticles onto a textile surface, creating smart or e-textiles. Within the project different methods of metallisation, preferably electroless plating of Cu nanoparticles, of different textiles will be investigated. Metallised textiles will be applied to different products such as clothes, shoes and furniture and thereby, provide conductivity and electronic connectivity. In this way, better integration of electronics and sensors into fabrics and textiles will be possible. Additionally, to prevent degradation of conductive tracks on fabrics and to increase the durability of applied metal nanoparticles, different organic or inorganic protective coatings should be employed, by means of industrially acceptable techniques such as coating, laminating and screen printing. Integrated electronics in clothing will include printed electronics and control of selected parameters using software tools, but this is not the subject of this study.

In the MATUROLIFE project the LCA is an important part of the business plan. For the first phase of the LCA, six scenarios were defined, and for each of them Inventory Analysis will be conducted in the following months. The authors recommend considering the ”cradle-to-cradle” approach for analysed products in which manufactures would offer services, such as the rent, lease and share business model of the prototypes, instead of selling them to the users. The manufacturers would retain ownership of the products and carry the responsibility for the costs of remanufacturing or other treatment of the products after the period of exploitation by customers.

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