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THE APPLICATION OF LIFE CYCLE ASSESSMENT IN CIRCULAR ECONOMY

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Abstract

Circular Economy's concept is becoming more and more widespread in the world. It's fundamental philosophy is that the waste of one system can become the input of another, thereby increasing resource efficiency, and decreasing environmental load. However, the circular economy model does not always mean environmental gains. Therefore, before using it, taking a more in-depth look at the environmental, social, and economic effects of the planned technological solution from the perspective of life cycle, and only introducing it, if their combined effects are more advantageous than the open-chain technological lining. The study takes a look at the basics of circular economy and life cycle, and sheds light on the advantages of realising the economic model via a LCA.

Keywords

circular economy, sustainability, life cycle assessment

1. Introduction

The success of circular economy in Europe and the entire world has become more prominent in recent years, even though the description itself is nothing new. Circular economy combines multiple theoretic concepts and practical applications. We can find within it the thought of industrial ecology [1], the from cradle to cradle theorem [2], and blue economy [3], even bio-mimicry. The latter one is adapting living, naturally developed solutions into technical practice. The material exchange processes happen in closed systems within the circular model, waste and by-products are nearly 100% recycled. Some authors think that CE combines the thoughts of 3R (reduce, reuse, recycle), even 6R (reduce, reuse, recycle, redesign, remanufacture, recover) with zero emission, LCA and resource efficiency's concepts [4]. Within the European Union, an annual 15 tonnes of material is used per capita, of which 4,5 tonnes per capita becomes waste,

more than half of which is dumped. Changing to a circular economy slows down and prevents waste production, as repair and recycling is put into focus, and waste is considered a resource. If environmental considerations were taken seriously even during the planning phase, "preventing waste production could spare up to 604 billion Euros for the European business life, meanwhile, could decrease GHG emission by 2-4%". The model of circular economy means many advantages for Europe. It helps sustainable economic growth, job establishing, and efficiency increase as well [5]. The Ellen MacArthur Foundation is the frontline warrior in serving the model, but circular economy was integrated into the EU's legislation too [6].

2. Basics of circular economy

Circular economy is based on three basic principles. First is to protect environmental capital, and develop it, through the regulated usage of available resources, and the balance of renewable resource flow. This all suggest a strong decrease in material, and f. e. create the conditions for soil regeneration.

The second principle is to optimise resource extraction by way of circulating products, parts and materials, which maximises their appearance in the technical and biological cycle. This means that remanufacturing, refurbishing and maintenance are well-planned, in order to make materials a part of economic processes for as long as possible.

The third principle is to minimise negative externalities, eliminate toxic substances, by either replacing or reducing them. In the planning phase, waste can be reduced by choosing appropriate materials, which also decreases harmful substance emission. However, fossilised energy resources can only be replaced by renewable ones [7]. The model of circular economy is based on closing opened economic flows [7]. In the case of open processes, intervening in the environment starts with resource extraction, and ends with waste entering the environment as follows:



Figure 1. Model of open chain process

However, in circular economy [7]:

- waste is equal to nutrients,
- variety is an important virtue,
- energy has to be extracted from renewable sources,
- prices has to be consistent with reality, and it is important that
- we think in terms of systems.

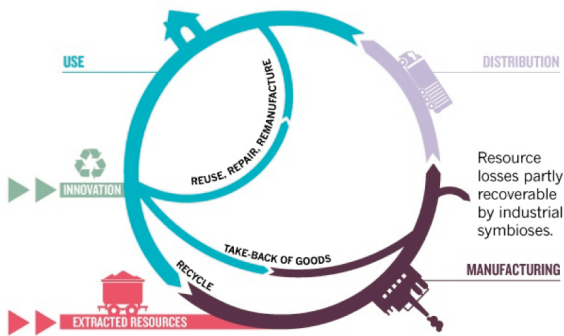


Figure 2. Model of circular economy [8]

The European Committee, and the Circular Economy

The European Committee accepted the legislation package regarding circular economy on the 2. December, 2015,

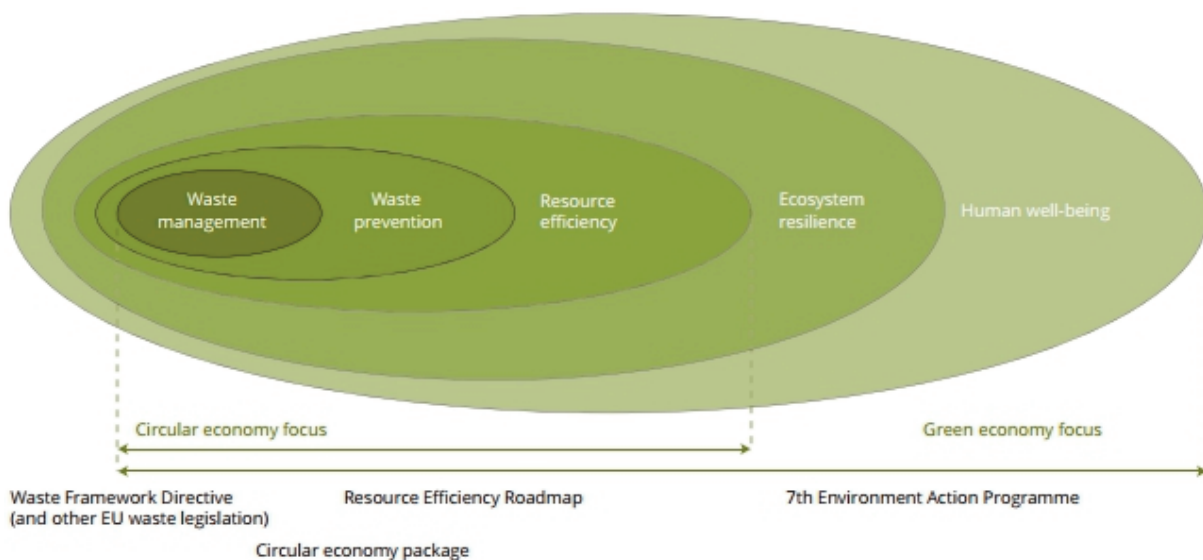


Figure 3. Circular economy and green economy [10]

In Europe, the Netherlands is the most dedicated follower of circular economy. There are many inspirational solutions for the many sectors today, but in order to spread these, there is a need to maintain a continuous knowledge transfer. In order to make CE spread as widely as possible,

which has the goal of "advocating Europe's transition to a circular economic system which increases international competitiveness, helps economic growth, and creates new jobs." [9]. According to the views of the European Committee, the economic model based on circular processes:

- aids recycling and prevents the loss of valuable materials;
- creates jobs and causes economic growth;
- creates new business models, and makes waste-free concepts realisable through eco-design and industrial symbiosis, and
- decreases the emission of greenhouse gases, and detrimental environmental effects.

The package aims to rethink waste management and tries to create a new regulation background by taking long-term conditions into consideration, and by integrating the life cycle perspective in a way that they motivate for the best solutions for the life cycle stages, and make the closure of processes realised. Using circular economy on a company level can spare about 8% costs according to estimates, while the emission of greenhouse gases can be reduced by up to 2-4%.

In order to realise the action plan, many conditions, regulations are needed. For example, environment-friendly planning's principle and regulations related to product requirements, manufacturer responsibility, profession policy requirements, etc.

Characteristics of a circular economy

The most notable characteristics of circular economy are [10]:

- Less input and natural resource usage:
 - minimal and optimised usage of resources,
 - producing more value from less material;
 - decreasing import dependence of natural resources;
 - efficient natural resource utilisation,
 - minimal energy and water consumption.

Renewable, recyclable resources and energy have to have their share increased:

- exchanging non-renewable energy resources for renewable ones, and maintaining sustainable supply,
- increasing the share of recycled and recyclable materials, in exchange of new materials,
- closing material loops,
- materials from sustainable sources.

- Decreasing emission levels:
 - decreased emission compared to the full cycle of less and sustainable material,
 - less environment-polluting clean material cycles.

- Reduced losses and waste material:
 - construction of waste minimisation;
 - combustion and waste deposits are minimised;
 - dissipative losses of valuable resources are minimised.

Protection of products', their parts' and materials' economic value:

- increased life expectancy,
- re-usage of parts;
- value protection of materials
- high-quality recycling.

Naturally, these require eco-design, and the creation of conditions related to repair and remanufacture, well-organised recycling, which also needs us to make a market for secondary material resources. There is a need for economic regulators, tenders, financial tools for domestic establishment, and innovation is indispensable.

Based on the experiences of already realised processes, it seems that the advantages of circular economy really are apparent in the following areas:

- reduced material- and energy usage,
- reduced unpredictability of material price and supply,
- reduction and diminishing of negative environmental external effects,
- creation of new jobs,
- increase in innovation,
- increase in the economy's international competitiveness,
- conserved advantages for a resistant and sustainable economy.

However, we may question if the principles of production processes and their related quality, green workplaces' protection (labour safety and labour health), and environmental protection are properly held onto, in the face of increasing economic advantages.

In order to create good models, taking the life cycle perspective into consideration is indispensable.

Lieder and Rashin studied many publications, and these made it obvious that using a circular model solution confers advantages and positive economic effects [11].

3. Life cycle assessments for aiding circular economy

Background of life cycle assessments

The description of life cycle relates to economy, more specifically, the cyclicity of micro-economies, and innovation, which became widely used due to the works of Schumpeter. Originally, it described products, and meant the timeframe in which a product, product group lasts from the start of manufacture and appearance on the market, until the end of manufacture, or leaving from the market. Later, it was expanded for technology, and even organisations, entrepreneurship, related to the companies' strategic activities, investments, and their quests, long-term goal changes. The life cycle's analysis and evaluation is meaningful because any intended or realised innovation (be it product, technological or organisational) can be called successful based on the investment's return. One of the most important decision criteria of intended innovation, and basis of evaluating the realised investment is to know the return time and excess profits achieved. The curve which describes product life cycle shows the product quantity or production values sold (or sellable) based on time, and generally shows a logistical, overflow tendency. The life cycle in an economic sense is naturally referring to a total amount of products manufactured during in some cycle, or technology which operates for a determined time, similarly to organisations operating as such. The life cycle description used in environment economy is much newer, it appeared in the early 1990's. The definition's appearance, and it's widespread use was caused by the general change induced by the advancement of environment studies and the attitude towards the environment. The main point of this change can be summarised as thought, action programmes and tasks shifted from environmental protection to environmental economy, from treating detrimental effects and making waste "disappear" towards prevention, and to the general definition of what sustainable development actually is. From this perspective, the life cycle can be related to some product, technological solution or organisation by pinpointing the timeframe "from birth to death", or "from cradle to grave". The analysis of life cycle affects the total environmental load for this period. From the input side, non-renewable and partially renewable energy resource utilisation, from the output side, any kind of environmental load and damage is affected by manufacture and usage, and disposal is determined in its chain, in quantities (natural units and / or money). The life cycle assessment's (LCA for short) meaning and goal is given exactly by finding the products, technological solutions and organisations, which offer the most advantageous, optimal environmental effect for a given demand's supply, with the given conditions, during a given timeframe (usually a year), or in other words, offer the solution with the lowest environmental load [12].

Using LCA for planning circular economy

In order to evaluate the effects of circular economy, using the life cycle assessment is a useful tool. LCA is a robust, scientifically based tool which can measure and evaluate products and business models coming from circular economy. It can strengthen advice on closed circular solutions, or may discard them, based on the results.

The analysis has to be, once again, conducted using the ISO 14040:2006 standard, closely following the methodology determined within. It is important to properly determine the system, to create the circular model, defining the function unit, and data requirements, furthermore, registering allocation. Collecting the input-output data along the life cycle has to be followed by an estimation of environmental effects using some kind of method. An often used environmental effect estimation is CML 2001, and the ReciPe method. As for effect categories, greenhouse effect, acidity potential, eutrophication, and toxicity are the focus areas.

LCA is a good addition, and basis for circular economy, as it helps introducing said economy in three steps. In the first step, the advantages or disadvantages of circular economy are analysed with LCA on a hypothetical product or service level. In the second step, after getting to know the limits, it identifies the possible development alternatives along the life cycle. This also includes rethinking developments. Finally, the third step is to determine the goal along the business strategy, by which we can start advancement towards circular economy.

LCA societies have an important role in introducing and spreading circular economy, as they have to give assurance about the legitimacy of CE solutions based on their objective analyses, and through making product declarations, they can aid the sustainability requirements of products coming from a CE more transparent. Therefore, not only the classic environmental life cycle assessment (eLCA) is advised to conduct, but the analysis conducted along the three principles of sustainability as well: apart from the eLCA, doing the life cycle cost analysis and social life cycle analysis (SLCA) are needed as well. These together give the life cycle sustainability analysis.

Using LCA, we can compare open and closed chain technological solutions, and in case the LCSA's result is better for the closed chain, introducing it is advised and legitimised. Meaning:

$$\text{LCSA}_{\text{OPEN}} (\text{eLCA} + \text{LCC} + \text{SLCA}) \geq \text{LCSA}_{\text{CLOSED}} (\text{eLCA} + \text{LCC} + \text{SLCA})$$

where:

eLCA is environmental life cycle assessment;

LCC is life cycle cost analysis,

SLCA is social life cycle assessment.

The latter two also have well-defined methodologies.

The above formula can be used for both products, manufacture processes, services, on either micro-, macro- or regional level. There are a multitude of publications within the international literature, which analysed the environmental effects of circular processes compared to open chain solutions. There were case studies for recycling foodstuff waste by creating circular models, [13] for renovating or

deconstructing buildings, and for processing the waste material from demolition work [14], and developing models based on the LCA of closed urban material flows, to mention a few examples. These were mostly dealing with the innovative processing of waste material.

The advantages of the circular model can also be explained with personal research results. After the sustainability analysis of a chemistry technological solution that works by producing and reusing a solvent, it was obvious that there was an improvement compared to the open chain technology, as we can see on the figure below.

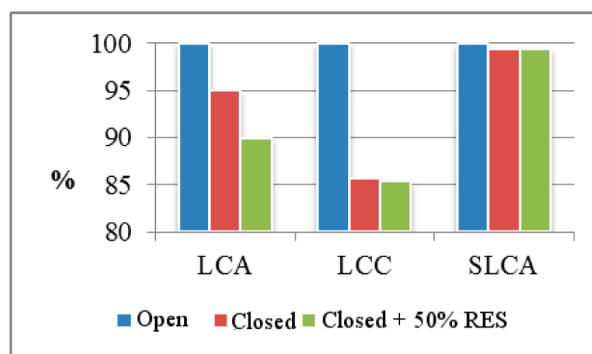


Figure 4. SLCA-based evaluation of technologies [15]

According to the 3D analysis, the highest sparing was at costs, whereas the lowest was from the perspective of social effects, but environmental load also decreased. It was obvious that the technology's material circulation caused advantageous effects. The positive result can be further improved by using renewable resources [15].

4. Conclusions

We can find an increasing amount of programmes related to circular economy, which has become more and more prevalent in recent years. Circular economy most notably reaches – with well-chosen technology – the decrease of environmental effects via economic advantages (waste management and material cost decrease). Economic organisations can move towards sustainable production methods by obtaining tender funding with innovative waste management technologies.

It is obviously advantageous if by the workings of circular economy - when waste is used to regain a part of the materials required for the technology - less material has to be procured, and the amount of waste decreases as well, but we cannot forget that such technologies require further resource usage. We have to decide what additive investment is required for the advantages that come with obtaining materials, and if the emissions of the technological solution made this way aren't more than the base technology. Circular technologies have legitimacy if the product manufactured this way have no greater environmental, social and economic effects for its entire life cycle than those of the original technology's. In order to determine this, we need the comparative effect analysis

based on life cycle assessment. If the total energy requirement is increased, its effect may be somewhat decreased, by using renewable energy resources.

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