Consultancy report: Contributions of Maintenance to Circular Economy

HZ University of Applied Sciences: Industrial Engineering and Management

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Study year: 2021/2022 Semester 7, 4th year
Course name: Focus on the Future
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Date: 13/01/2022

Executive summary

KicMPI has problems with measuring the effect on the environment, and potential reductions of CO2 emissions and improving circularity through targeted maintenance solutions. There is too little understanding of the CO2, and waste quantities that result from maintenance activities. Without measurement, it is impossible to demonstrate the improvements and effectiveness of the actions being taken to increase circularity. In addition, a framework strategy is required to position future efforts and define how priorities will be set. To address the above problem, we propose the following:

- A method that can measure the circularity & reduction of CO2 emissions of a product and keeps the improvement of the product ongoing.
- A method that can measure the reduction of CO2 emissions of a product and keeps the improvement of the product ongoing.

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1. Problem analysis

1.1 Project description

In recent years, the awareness of the need for a circular economy has grown enormously. There is a worldwide drive, within most industries and organizations to reduce material and equipment disposal, reduce (CO2) emissions and increase focus on circularity.

The process industry is very strong in the Zeeland-Flemish region. However, as factories become older, more maintenance is needed to extend asset life. Investment in new plants and equipment is expensive, but also results in a higher impact on the environment. As part of a regional Interreg project, circularity in maintenance is being addressed. Several case studies have been chosen and the project partners are exploring the opportunities to increase the level of circularity in use of equipment and materials.

The main problem being addressed is the effect on the environment and potential reductions through targeted maintenance solutions. This manifests itself in CO2 emissions and material waste. There is too little understanding of the CO2 and waste quantities which result from maintenance activities. Without measurement, it is impossible to demonstrate the improvements and effectiveness of the actions being taken to increase circularity. In addition, a framework strategy is required to position future efforts and define how priorities will be set.

1.2 Scope

Strategic report on measuring CO2 footprint and circularity in maintenance. Subjects of the report are longevity prediction and elongation, material efficiency, chain renewal and sharing economy and reuse of equipment.

1.3 Objective of the project

The goal is to define a strategy, methodology and model to measure the effectiveness of circularity in the case studies, with a focus on quantification of CO2 emissions reductions and material circularity. This project will be considered a success when, a fitting methodology has been advised to measure the effectiveness of circularity in the case studies.

2. Findings

2.1 Description of options

Now that the objective of the project is known for the organization regarding the environment, and the economy, there must be methods that will indicate if the organization is on the right track. As this project focuses more on measuring the circularity of the maintenance activities, a method is required that focuses on how the services are performing regarding circularity. Some potential measuring methods are described here:

- **IMPACT (Integrated Method of sustainable Product Assessment for Circular Transition):** The IMPACT method quantifies for products which savings could be made in terms of the usage of raw materials, and other materials for the production process. The IMPACT method visualizes the saving on resources, reduction of impact on people, and the environment, and the reduction of external economic losses. (the-impact-method-helping-businesses-make-their-products-circular, n.d.)

- **C2C (Cradle to Cradle):** The certification Cradle to Cradle gives a degree for the circularity of a product on a stepped scale with the lowest degree of Bronze, and the highest of Platinum. Cradle to cradle measures the environmental, and social sustainability of the product in five categories, these are. (product-certification, n.d.) (measuring-sustainability/cradle-to-cradle/, n.d.)
- **Optimal SCANS (Sustainability & Circularity Assessment & Normation System):** The Optimal SCANS is a system for the assessment, and monitoring of products, services, and organization of the production process. This method is designed to have support with the circular purchase, and it is scientifically proved. (Nooij, n.d.)
- **Circularity Calculator:** The Circularity Calculator measures the circularity of products on a scale from 0% to 100%. This tool gives insight and options for a new product design and re-design. (circularitycalculator.com, n.d.)
- **Madaster Circularity Indicator:** This method measures the circularity level of a building on a level of 0% to 100%. The circularity level is measured by the Circularity Indicator [CI], and separates different stages of the life cycle of the building;

  Construction phase: CIconstruction = FR + FRR + Fu
  Use phase: CIuse = L / Lav
  End of life phase: CIEnd of Life = CR * EC + CU
  (Rau-Oberhuber, 2019)

- **Circular IQ:** The software of Circular IQ measures the circular performance of products, and the materials which are used for the products. Buyers can assess their suppliers based on circular characteristics, and criteria.
- **ReNtry:** The ReNtry model generates passports for products, and projects on the levels of items, components, materials, and raw materials. ReNtry measures the circular potential, this is based on how much raw materials, energy is used to manufacture the product; how much is still usable after the period of usage. (Rendemint, n.d.)

2.1.1 Circularity ladder of strategies

The circularity ladder provides an order of priority for developing the intended more efficient products and services in existing (first strategic goal) and new product chains (third strategic goal). Other circularity ladders usually focus on products (see for example CE & CSR 2015; EMF 2013; RLI 2015). As a rule of thumb, resource use, and therefore also the environmental pressure, decreasing with the higher on the ladder of the circularity strategies (and the lower become of the R's). Fewer primary materials are needed as secondary materials are recovered from no longer reuse products and product parts, if there are fewer materials are needed because products and their parts are used longer, and if products be used and made smarter. If there are less raw materials are needed to make new materials produce, this also reduces the environmental pressure for raw material extraction and in all subsequent steps pushed back. In Table 1 the circularity ladder of strategies is explained in combination with the transition from linear economy to circular economy.

Table 1 - Strategies for Circular economy

Circular Economy	Strategy		
Increasing Circularity ↑	Using and producing products smarter	R0 Refuse	Making a product redundant by using its function, or those with a radical to deliver another product
		R1 Rethink	Intensify product use (e.g. by sharing products, or multifunctional products)
		R2 Reduce	Make the product more efficient in use or manufacturing using fewer raw materials, and materials in the product
	Lifetime prediction of products and components	R3 Reuse	Reuse of discarded still good product in the same function by another user
		R4 Repair	Repair and maintenance of broken product for use in its old function
		R5 Refurbish	Refurbishing and modernizing old product for use in an enhanced version of his old function
		R6 Remanufacture	Waste product parts use in a new product with the same function
		R7 Repurpose	Discarded product or parts of the product used in a new product with another function
	The useful application of materials	R8 Recycle	Processing materials into the same quality or lower quality
Linear Economy		R9 Recover	Burning materials with energy recovery

(leefomgeving, 2018)

2.1.2 CO2 Performance Ladder

The CO2 Performance Ladder is a sustainability instrument that helps organisations to reduce CO2 in their business operations, project and supply chain. It is a CO2 management system that stimulates organisations to reduce CO2 in a structural way. The ladder is mainly concerned with energy saving, CO2 reduction, the efficient use of materials and the use of sustainable energy. This system is intended for organisations in the hydraulic engineering and construction sector. Although this Ladder is also intended for companies that want to reduce their energy consumption and CO2 emissions.

The performance ladder consists of five levels, increasing from 1 to 5. To achieve a certain level, the organisation and its projects must meet the set requirements. The requirements per level are based on four aspects, each aspect has its own weighing factor:

- Insight into energy flows and CO2 footprint
- Reduction in CO2 emissions by developing targets
- Transparency by communicating about CO2 policy
- Participation via initiatives in the sector

The more in-depth score sheet of the weighing factor are in Appendix 2.

Level 1 to 3 relate to the emissions and the energy consumed in the organisation itself and the related projects. At the levels 4 and 5, the emissions and energy consumption in the chain and sector are considered and work is done on innovations. The position of the organisation or project on this ladder is determined by the highest level at with all the requirements are met. (certification/system-certification/system-certification-co2-performance-ladder, n.d.) & (Ondernemen, 2020)

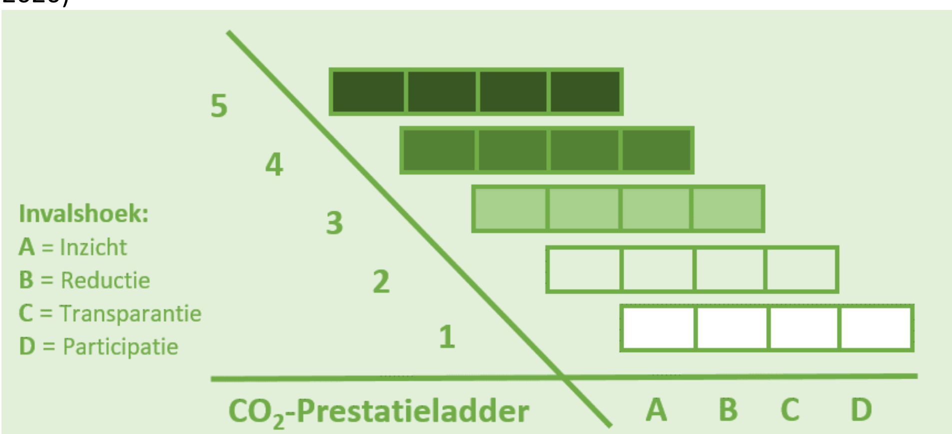

Figure 1 - CO2-prestation ladder

2.1.3 Project: Decision model for Industrial cleaning

Before that this project was provided, there was another project that had KicMPI as a client this project was focused on industrial cleaning. The goal statement of that project was to build a decision model that supports a companies' choice of industrial cleaning methods to reduce the environmental footprint of the process industry in the south of the Netherlands, and Flanders while gaining economic advantages. The main focus of this research was to build an application system that allows companies to calculate their environmental impact, and reduce the harm caused. Additionally, this system provides other quantifying sheets for three other factors, costs, quality and safety, which are deemed important for companies for choosing a cleaning method. The outcome of the research was proven to be beneficial for companies that have a hard time to be more sustainable. (Korichi, 2021)

In Figure 2 an example is shown of how the environmental footprint could be calculated for industrial cleaning.

Process step	Elements involved (Environmental impact)	Time required (In hours)	Production period	Distance travelled (In kilometers)	Units required	Sub-totals	Carbon foorprint (kg CO2)	Totals CO2 kg	Chemical environmental hazard	Totals Water Litres
							2.62			
6- On-site cleaning process	Pump Fuel	6.00	X	X	1	736.01	1928.34			
	Water usage	6.00	X	X	1	46800				
	Chemical usage	0	X	X	X	0				
	recycling of water	X	X	X	-1	-30420				
	Incineration	1	X	X	X	659	1726.58			
	Electrical generation (during incineration)	1	X	X	-1	-500	-116			
	Environmental footprint							3538.92	0.00	16380

Figure 2 - Example of environmental footprint calculation

2.1.4 Neely Performance Record Sheets

In earlier executed research by KicMPI and Hz University of Applied Sciences, there was concluded that there is a lot of potential on measurement models although this was still in the concept phase. It was not fully applicable to the maintenance, and its indicators have to be designed. To create these indicators, the Neely Performance Record Sheets were introduced.

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Table III.
Performance measure – customer service

Title	Customer service – adherence to customer schedule
Purpose	To enable us to monitor factory completion performance
Relates to	Business objectives – "meet quality standards", "delivery on time" and "no customer complaints"
Target	100 per cent schedule completion on time at least by end of 1996
Formula	Percentage of pieces to arrive at the customer's location when promised
Frequency	Weekly
Who measures?	Despatch manager
Source of data	Delivery receipts
Who acts on the data?	Production manager
What do they do?	Investigate reasons for late delivery, set up problem-solving teams to eliminate root causes
Notes and comments	Early deliveries are not on time

Figure 3 - Neely Performance Record Sheet

(A. Neely, 1997)

2.2 Evaluation of options

As the needs for each sub-project are different, each sub-project must have a different method or combination of methods. This in order to really help the project, with gaining insight of how circular the topic of the project is. Also, it would show where there are CO2 emissions which then could be prevented. The decision to use certain methods is based on criteria like the ability to work with other methods, providing a degree on how circular the process is, circularity degree at the end of life is also important for the decision. The other criteria are shown in Table 2, the decision matrix.

Table 2 - Decision matrix

Method	Criteria				
	Ability to work with other methods	Providing a degree on circularity	Circularity degree at the end of life	Adds value to sub-projects	Free to use
Circular IQ					
Circularity calculator					
Circularity ladder					
Cradle to Cradle					
IMPACT					
Madaster					
Neely					
Optimal SCANS					
ReNtry					
W. Korichi					
CO2 Performance Ladder					

Based on this matrix, there has been decided to use the following methods:

- Neely
- Madaster
- Circularity Calculator
- W. Korichi
- Circularity Ladder
- CO2 Performance Ladder

The reason to use methods that may have scored red in the matrix is that these red scores are able to be solved by the other methods. For example, Neely will be used as it will add value to the sub-project in terms of describing the desired situation and as a tool to measure the progress of the project. They would really complete the strategy as mentioned the Neely Performance Record Sheets could be used a tool where the desired situation is designed. While the research of W. Korichi will provide a great baseline for the calculations of CO2 footprint for each process. The circularity ladder will be used as a base for each company or project to see the state of circularity. This would give a great outline for the strategy to follow, it would provide focus areas to work on if the company would like to make the next step in the transition to circular economy. The last two methods that will be used are the Madaster method and the Circularity Calculator. These two will be used because it would really give a good overview of where the circularity could be improved. Furthermore, Madaster is great for calculating the end-of-life circularity index. With this index there could be decided if a component or material is re-useable or re-cyclable. Also, with Madaster the usage circularity index is calculated and that would help with deciding at which inspection interval the component should be inspected or what the lifetime is.

2.3 Evaluation of needs per sub-project

2.3.1 Predicting lifetime of electromotors

The goal of this project is to predict the status and longevity of electromotors. The ideal situation is that in the future there will be a methodology for the prediction of the lifespan. This has to be widely applicable; this effectively determines the optimal replacement strategy. The model/methodology will be turned into a practically usable tool which the residual life can be determined based on measured data.
In order to be in this ideal situation several needs need to be fulfilled. These needs are that research needs to be performed on the refurbishment of the motors. Furthermore, there is a need for a method that calculates the CO2 footprint and the circularity. The second need will be combined with a method for lifetime prediction.

2.3.2 Predicting lifetime of valves

The goal of this project is to have a validated method for predicting the (residual) life of control valves that, with a view to continued effect, can be used within the process industry. The ideal situation is that the companies who use control valves within their production process know when a control valve is close to failure. This to know when a control valve should be taken out of the process to be inspected. Especially with the shutdown of a plant this would really be beneficial in terms of costs.
The needs that need to be fulfilled to get to this ideal situation are that a connection has to be made between data analysis and the data collection system. Then there is a need for collecting data of the failure types of the control valves. With that data conclusions can be drawn.

2.3.3 Reducing the fugitive emissions in the process industry

There is more information needed in this project, the goal is that the seals do not have any leakage anymore so as a result of this CO2 emissions and leakage of gasses will go down resulting in a rise in productivity of the plant. The ideal situation is when there are no or minimal leaking seals to prevent production losses and prevent damage to the environment. Also, an ISO norm will be in place for a new type of stem seal testing. The needs that are essential to achieve this ideal situation are that intensive research has to be performed on stem seal tightening and stem seal emissions. Furthermore, the ISO norm on stem seal testing must be finalized.

2.3.4 Sharing equipment

The goal of this project is to have a business model for a sharing platform, this should be widely applicable within the process industry. The ideal situation is that specialized tools/technology and associated expertise sharing between those responsible for maintenance from asset owners. This would increase circularity and the Return of Investment (ROI).
The requirements in order to get to this ideal situation are that data has to be collected from possible interested parties. Another requirement is to conduct a study on the compatibility of electronic engines. With this research eventually a proposal with possible solutions can be presented to interested parties. Eventually this all needs to be combined into one platform.

2.3.5 Servitisation of Light

The goal of this project is to implement smart lighting at every company that wants to collaborate in the project. There are a few main requirements for the lighting; it must be explosion resistible, fitting in the light housing that is already on site and there must be a possibility to have a wireless network coming from the lighting. The ideal future state is a smart lighting system for all companies that are interested which fits in the housing that is already there, providing a wireless network and being explosion resistible. All of this will make the lighting successful to reduce CO2 emissions and increase the circularity. Furthermore, a material passport on elements of lighting will be in place to calculate the circularity of the lighting project.
In order to close the gap to this ideal situation, the following requirements have to be fulfilled. The first requirement is that an organization has to be found that provides the lighting system that fits all the requirements of KicMPI. The second requirement is that the creation of a material passport is essential, with this passport the ability to calculate the rise of circularity and the decrease of CO2 arises.

2.3.6 Reuse of electromotors/transformers

The goal of this project is to have clear insight in the re-useability of components of electromotors. The ideal situation for this project is to have an overview of which elements can be re-used and to make the components valuable. This would benefit in terms of producing an electromotor of re-used materials and components.
The needs for this project are creating a material passport, data collection on circularity and eventually calculating a circularity index based on the previous needs.

3. Conclusions

Within this methodology the project group has differentiated two flows of contribution of maintenance. Whereas one is the circular flow of maintenance the other is the CO2 reducing flow of maintenance. Therefore, it was decided to differentiate these two flows to make the methodology more manageable.

3.1 Proposal for CO2 reduction

This proposal concerns the CO2 reduction of the methodology which consists of 3 main stages within this cycle. As this is a continuous cycle the first step may differ for the example that will be given here. The first step to use the CO2 Performance Ladder in order to have an understanding of what the current status is of the organisation, project and/or process. Based on what the current situation is a plan created to be where the organisations wants to be, in terms of CO2 emissions. That plan and desired situation will be described in the Neely Performance record. This method should function as a plan to get to the desired situation and it should give an overview of who is involved. Furthermore, Neely will be used a tool to measure the progression of the projects. During the execution of the projects the baseline calculations of W. Korichi will be used to calculate the CO2 emissions/footprint. These calculations are based on each step, which are involved in the project and/or process. With the outcome of these calculations new

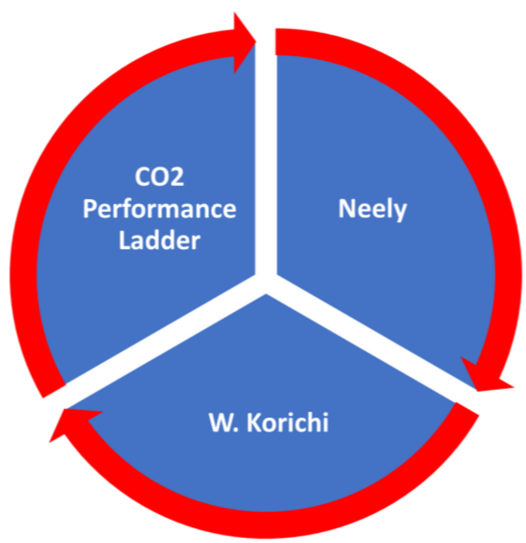

Figure 5 Proposal for CO2 reduction

innovations are needed to reduce these emissions. Although before these innovation projects are started a new measurement has to be made with the CO2 Performance Ladder. The cycle keeps going so that continuous improvement is stimulated.

3.2 Proposal for Circularity

This proposal concerns the circularity of the methodology which consists of 4 main stages within this cycle. For the cycle it does not matter where the company is at regarding circularity, they are able to step in anywhere in the cycle.

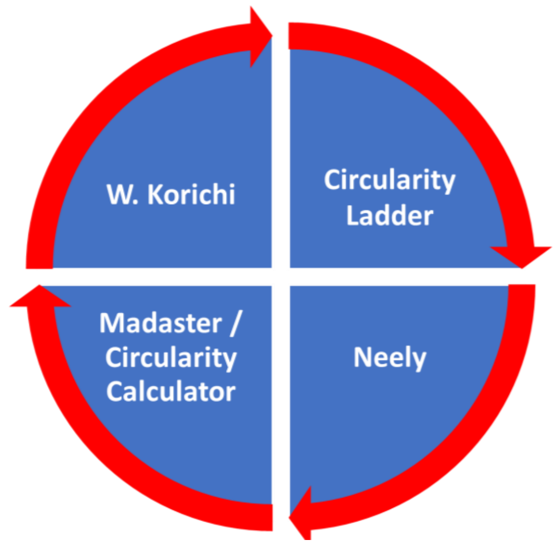

Figure 6 Proposal for Circularity

Let's assume that the first step to use the methodology is the circularity ladder, this ladder will give an overview of where the circularity is situated now. As a second step the Neely form is used to indicate the (realistic) ideal situation of the circularity at the end of new implementations. During the new implementations of the plan that came out of Neely, a material passport according to Madaster must be made to be able to measure the circularity. And (in this cycle) 'as last' is the methodology of W. Korichi to measure the eventual CO2 footprint that came out of the new implementation(s).

This cycle must be seen as a cycle for continuous improvement. Therefore, when the first full cycle is done, the company can go to the next cycle.

4. Recommendations

Since the final proposal for methodologies on calculating the impact of maintenance on both CO2 footprint and circularity has been explained and being able to quantify the means, it is decided to continue to the overall recommendations part. We will discuss the overall recommendations in this part, not every subproject is relatable to every recommendation.

The following are the recommendations that are drawn from the implemented product and the interviews that we have had with our stakeholders:

- These systems could be used by any organization/project that is trying to become more circular and have less CO2 emissions.
- The use of the CO2 emissions calculations and the use of the circularity measurement methods will give companies that use the methodology a good overview of where they currently stand within their goal to decrease the footprint and improve the circularity.
- The decision matrix of the several methods provides a good way to choose a method that fits a certain task. It allows the user to see which method would fit best for their project.

- The differentiation of the two proposals will provide the user two options to use for his/her focus area. If the project is more focused on CO2 reduction, the cycle for CO2 reduction should be used. If the project is more focused on circularity the cycle of circularity should be used.
- The cycles involved in the methodology have been built in such a way that these can be used continuously and do not stop at only one cycle. Furthermore, the methodology could be set up as a whole inter-company system to improve and adapt maintenance to decrease the CO2 emissions and increase circularity as much as possible. Because of this, it is highly advisable to let the IT department build it into the company's software to make the methodology workable for everyone within the company.

4.1 Benefits

Looking at the benefits of the methodology, the focus mainly lays at the long-term benefits due to the fact there was a lack of data provided to see the effect on the short term. Furthermore, the aim of the project is that the non-financial benefits are interesting for the stakeholders than the financial benefits. The financial part is more a side effect that results from having insight in the circularity potential and the reduction of CO2.

4.1.1 Benefits of Circular Economy for the environment

Less greenhouse gases

By following the principles of the circular economy, greenhouse gas emissions are automatically reduced on a global scale. Climate change and the use of materials are closely linked. According to Circle Economy calculations, 62% of global greenhouse gas emissions come from the extraction, processing and production of products that have to meet the society's needs. The other 38% are emitted during the supply and use of the products. The reduction in emissions measured on a global scale will be even greater because the European Union will no longer import primary raw materials from the countries outside the Union, which will also reduce greenhouse gas emissions in those countries. (circulariteit-binnen-facility-management/wat-is-circulariteit/, n.d.)

Conservation of nature reserves

The extraction of raw materials and the dumping of waste have a negative impact on nature reserves. These nature areas are important for the preservation of ecosystem services, natural and cultural heritage. At the moment, many governments and organisations participate in protecting nature from extraction and the dumping of raw materials and waste. In order to systematically preserve nature, this extraction and dumping must stop in general. This is achieved within the circular economy. (circulariteit-binnen-facility-management/wat-is-circulariteit/, n.d.)

4.1.2. Benefits of Circular Economy for the economy

Innovation stimulus

Circular economics challenges innovative solutions based on a new way of thinking. That means thinking about circular rather than linear value chains and striving for optimizations for the entire system. This results in new insights, interdisciplinary cooperation between designers, producers and recyclers and therefore also in sustainable innovations. (what-are-useful-tools-for-organizations-that-want-to-get-started-with-the-circular-economy/ , n.d.)

Substantial resource savings

While the attention for the circular economy is increasing, the extraction and prices of primary raw materials are still increasing. According to Circle Economy calculations, 9% of all raw materials were fully recycled in 2019. In 2018, this percentage was slightly higher at 9.1%. In theory, in the circular economy, 100% of all the raw materials are fully recycled and no new unused raw materials are required. It will take a very long time for this scenario to be achieved because methods will have to be found to fully recycle materials that are currently used in products. (what-are-useful-tools-for-organizations-that-want-to-get-started-with-the-circular-economy/ , n.d.)

Economic growth

An important principle of circular economy is to decouple economic growth from the consumption of raw materials. As a result, the economy is not hampered by the shortage of raw materials to grow. It is assumed that a move towards the circular economy will promote economic growth. The United Nations Environmental Plan (UNEP) calculated that in 2050 the global economy would benefit from more effective resource use by $2 trillion a year. In a circular economy, this gain would certainly be achieved. On the one hand through increased turnover from new circular activities and on the other hand by the creation of more functionality from the same number of materials and means of production. The development, production and maintenance of these circular products requires a specialised workforce, which will increase these jobs. On the contrary, there will be less demand for the extraction and processing of raw materials, which will reduce the number of less specialised jobs. This will increase the value of labour, which is good for the employment and the GNP.
(what-are-useful-tools-for-organizations-that-want-to-get-started-with-the-circular-economy/ , n.d.)

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6. Appendices

Appendix 1: Methods to measure circularity

- **IMPACT (Integrated Method of sustainable Product Assessment for Circular Transition):** The IMPACT method quantifies for products which savings could be made in terms of the usage of raw materials, and other materials for the production process. The IMPACT method visualizes the saving on resources, reduction of impact on people, and the environment, and the reduction of external economic losses. IMPACT is a method to set a value to both circularity, and sustainability for producers, and retailers. It expresses the degree to which new products have a less footprint, the saves that can be made in the manufacturing process, and the economic effect of the production is. (the-impact-method-helping-businesses-make-their-products-circular, n.d.)

- **C2C (Cradle to Cradle):** The certification Cradle to Cradle gives a degree for the circularity of a product on a stepped scale with the lowest degree of Bronze, and the highest of Platinum. Cradle to cradle measures the environmental, and social sustainability of the product in five categories, these are.
    - Material health: this ensures that all materials are safe for humans, and the environment
    - Material Reutilization; enabling a circular economy through regenerative products, and process design.
    - Renewable energy & carbon management; protecting clean air, promoting renewable energy, and reducing harmful emissions.
    - Water stewardship; safeguarding clean water, and healthy soils
    - Social fairness; respecting human rights, and contributing to a fair, and equitable society.

(product-certification, n.d.) (measuring-sustainability/cradle-to-cradle/, n.d.)

- **Optimal SCANS (Sustainability & Circularity Assessment & Normation System):** The Optimal SCANS is a system for the assessment, and monitoring of products, services, and organization of the production process. This method is designed to have support with the circular purchase, and it is scientifically proved. To measure the circularity of the processes, and products Optimal SCANS divides the processes into five different levels as shown in Figure 2. The main questions that need to be answered within these levels are:
    1. Is there attention for sustainability, and the circular economy?
    2. Which themes are being worked on, with which actions?
    3. What are the actual measurable results of all those actions taken?
    4. How broad and deep is the long-term strategy to become fully circular?
    5. Are the stakeholders/ participants collaborating to be fully circular?

The second step within this method is to measure and have insight into the themes on certain levels. These levels are based on the Sustainable Development Goals (SDG), and circular economy. The final step within this method is to rank the measurements based on specific criteria, which would be for this project to have low CO_2 emissions or increasing circularity. (Nooij, n.d.)

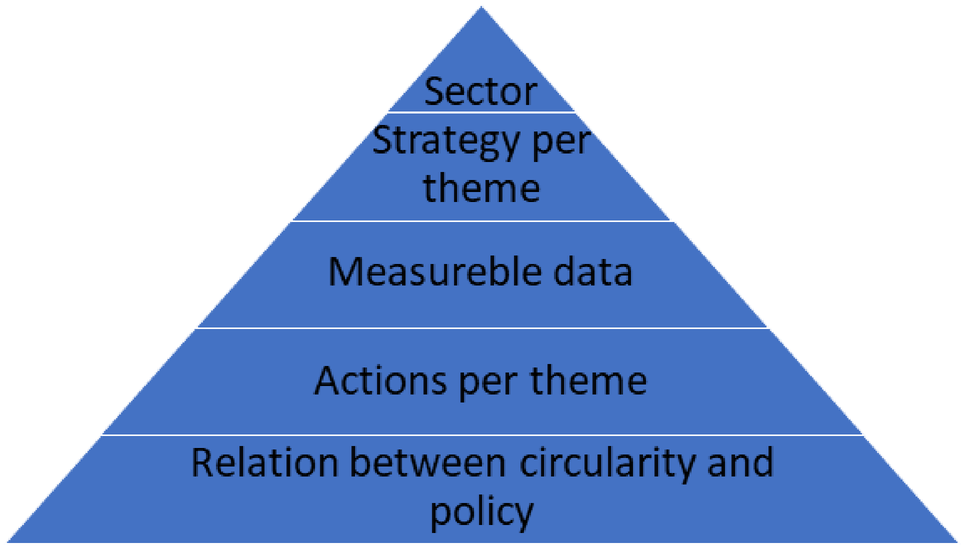

Figure 7 - The pyramid of levels Optimal SCANS

(Nooij, n.d.)

- **Circularity Calculator:** The Circularity Calculator measures the circularity of products on a scale from 0% to 100%. This tool gives insight and options for a new product design and re-design. The tool has been created with manufactures leading the circular economy, validated with in-market cases and endorsed by the EllenMacArthur foundation. (circularitycalculator.com, n.d.)

- **Madaster Circularity Indicator:** This method measures the circularity level of a building on a level of 0% to 100%. The circularity level is measured by the Circularity Indicator [CI] and separates different stages of the life cycle of the building.
  Construction phase: $CI_{construction} = F_R + F_{RR} + F_u$
  Whereas F_R is the fraction of recycled materials in % of the total mass, F_{RR} represents the fraction of rapidly renewable materials in % of total mass, and F_u represents the fraction of reused products, and/or components in % of the total mass.
  Use phase: $CI_{use} = L / L_{av}$
  Whereby L represents the potential functional lifespan of a product, and L_{av} represents the industry average lifespan of the product.
  End of life phase: $CI_{End\ of\ Life} = C_R * E_C + C_U$
  Whereby C_R represents the fraction of materials that can be potentially recycled at the end of its useful life (in % of total mass), E_C represents the efficiency of the recycling process in the end-of-life phase (%), and C_U represents the fraction of components, and/or products that can be potentially reused ad the end of their useful life (% of total mass).
  This percentage is based on a materials passport. The material passport starts with data of all the materials which are processed in the following order.
  1. Collection, and verification of necessary building material data, and specifications for materials, and products passports
  2. Data input into the madaster platform, and creation of corresponding material, and product data sheets including a step of manual data enrichment on the platform.
  3. Calculation of the Building Circularity Indicator

4. Evaluation of the results with the available data, the principles of CE as well as the design parameters.

During the data input, the platform distinguishes between materials, and products, to generate relevant numbers for the re-use and recycling on product, component, or material level. (Rau-Oberhuber, 2019)

- **Circular IQ:** The software of Circular IQ measures the circular performance of products, and the materials which are used for the products. Buyers can assess their suppliers based on circular characteristics, and criteria. This method has three circularity programs with different degrees which vary from software to start the process to make the switch to the circular economy or really optimizing the circular process. The three applications are the Circular Procurement Program, Product Circularity Improvement Program, and Circular Transition Indicators Program.

- **ReNtry:** The ReNtry model generates passports for products, and projects on the levels of items, components, materials, and raw materials. ReNtry measures the circular potential, this is based on how much raw materials, energy is used to manufacture the product; how much is still usable after the period of usage. This model is made to analyze certain appearances from components, materials, raw materials, and even after a certain number of cycles. ReNtry will generate a passport on every level:
  - Item passport
  - Component passport
  - Material passport
  - Raw material passport

  (Rendemint, n.d.)

Appendix 2: In-depth score sheet

Requirement	S/M/L	Aspect	Requirements	Max score
1A	All	The organisation has partial insight into energy consumption	1.A.1. Identification and analysis of energy flows of the organisation and the projects for which a CO2-related award advantage has been obtained have taken place.	10
			1.A.2. All energy flows of the organisation and the projects for which a CO2-related award advantage has been obtained have been demonstrably recorded	10
			1.A.3. This list is regularly followed up and kept up to date	5
		Objective: The organisation knows which types of energy are used		
2A	All	The organisation has insight into its energy consumption	2.A.1. All energy flows of the organisation and the projects for which a CO2-related award advantage has been obtained have been quantitatively identified.	10
			2.A.2. The list is complete, and is regularly- and demonstrably followed up and kept up to date	5
			2.A.3. The organisation has an up-to-date energy assessment for the organisation and the projects for which a CO2-related award advantage has been obtained	10
		Objective: The organisation knows how much energy is used per type, classified according to the organisation's various activities		
3A	All	The organisations has converted its own energy consumption into CO2 emission(s).	3.A.1. The organisation has a detailed and up-to-date emission inventory for its scope 1 & 2 CO2 emissions and business travel in accordance with ISO 14064-1 for the organisation and the projects for which a CO2-related award advantage has been obtained	15
			3.A.2. The 3.A.1. emissions inventory has been verified by a certifying organisation to at least a limited degree of certainty	10
		Objective: The organisation has a CO2 administration where there is no discussion about the amounts and the calculation method. The organisation has insight into the main basic principles for a reduction approach.		

4A	All*	the organisation reports its CO_2 footprint for scope 1, 2 & 3	4.A.1. The organisation has a demonstrable insight into the most material emissions from scope 3 and can present at least two analyses of these scope 3 emissions of GHG-generating (chains of) activities.	15
	All		4.A.2. The organisation has a quality management plan for the inventory	5
	All		4.A.3. At least one of the analyses from 4.A.1 (scope 3) has been professionally endorsed or commented on by a recognised professional and independent knowledge institute.	5
		Objective: apart from scope 1 and 2, the organisation has determined the relative extent of scope 3 emissions. The management is aware of the influence of the organisation in the various value chains, upstream and downstream, in which it performs. On the basis of this knowledge, the organisation identifies promising energy and CO_2 reduction measures in the value chains and potential value chain partners for its approach.		
5A	All*	The organisation has a portfolio-wide understanding of scope 3	5.A.1. The organisation has insight into the material scope 3 emissions of the organisation and the most relevant parties in the value chain that are involved in this	10
	All*		5.A.2-1. The organisation has a portfolio-wide, substantiated analysis of its options to influence material scope 3 emissions.	5
	M/L		5.A.2-2. The organisation has insight into possible strategies to reduce these material emissions.	5
	M/L		5.A.3. The organisation must know the specific emission data of direct (and potential) value chain partners that are relevant to execution of the scope three strategy	5
		Objective: the organisation broadens and deepens its understanding of scope three and how the organisation can reduce emissions in scope 3.		