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IMPACT: a tool for R&D management of circular economy innovations

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Abstract

It has been suggested that the transition towards a more circular economy requires multiple value creation, but classical R&D management tools are not developed for easy assessment of circular economy innovations. We have developed a framework to support R&D in the assessment of such innovations on three levels of implementation (project, production chain and society) and on three levels of detail (quick scan, brief assessment and thorough assessment). On the project level, capacity building is analysed; on the production chain level, 'circular' performance is measured; on the societal level, the sustainability of the product is evaluated. The framework is being applied to wood products for the construction sector. Waste wood in the Netherlands is currently often incinerated with energy recovery, but in consultation with stakeholders we are considering several potentially more valuable alternatives. With this case study, the developed framework is showing potential to steer R&D decisions in support of a more circular economy.

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Keywords: circular economy; impact assessment; R&D management; multiple value creation;

1. Introduction

Since the 1980s, the concept of circular economy (CE) has gained more and more attention as conceptual framework to come to a more sustainable economy [1]. The concept combines two key aspects: the need for a resource-efficient economy and the need for a more sustainable society. This calls for so-called 'multiple value creation': value creation for both the company (and its customers), and value creation for society as whole. The Ellen MacArthur Foundation has listed a set of alternative designs for products and their production chain, focusing on different End-of-Life (EoL) scenario's for products: maintain, reuse, cascade, redistribute, refurbish, remanufacture, extraction of biochemical feedstock, anaerobic digestion, and recycle [2].

Increasingly, CE is also used as a criterion for steering Research and Development (R&D) investments, for example in Horizon 2020 sub-programs. In this paper, the potential of several methodologies to support R&D management for circular economy innovation is reviewed.

1.1. Background

For the purposes of this study, we have reviewed a large number of methodologies which we will discuss shortly below.

The methodology that is most used in CE research is Life Cycle Assessment (LCA). LCA evolved the last decades of the 20th century as a methodology to analyze the environmental impacts of products over the course of their complete life cycle [3]. Nowadays, LCA is often included in product development, despite its difficulties with, amongst other, data quality and interpretation [4]. To a certain extent, circularity can be measured by an LCA which computes resource depletion and environmental impacts on society.

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However, LCA as methodology to steer circularity in R&D is failing in a few aspects: (1) data gathering is time-intensive; (2) the application of LCA is not straightforward to assess alternative designs related to CE; (3) LCA only focusses on environmental aspects of value creation and not on other societal or economic aspects; and (4) LCA only focusses on the potential impact of innovation, not on potential obstacles to innovate.

Cost-Benefit Analysis (CBA) is a widely applied methodology to compare both direct and indirect costs and benefits of products or systems. Sometimes CBA is used as a more overarching sustainability assessment method, not only including environmental but also social and economic aspects. However, as Iacouvidou et al. [5] point out, CBA is not capable of steering R&D in a circular way because it insufficiently incorporates multidimensional value creation and lacks a straightforward link to circular economy aspects.

In addition, Business Model Design (BMD) can be an important methodology to complement CBA and address value creation. Although product design and business model design seem to be going hand-in-hand, this is not always the case in practice. Several sources identify a lack of circular business models and the need for transformations on a system level [6, 7, 8, 9]. Reasons for this are, amongst others, (1) the role and value for the consumer are not well covered in most BMDs; (2) the network of co-owners and stakeholders is insufficiently supported in current circular BMDs. Novel approaches such as the Business Model Canvas by Ostenwalder et al. [10] are trying to remedy some of these shortcomings, but similar to LCA and CBA, is still not incorporating circular design options as defined by EMF [2], nor societal benefits of product designs.

In conclusion, LCA, CBA and BMD show potential as detailed and solid methodologies to be applied to prove the economic and environmental potential of R&D projects. However, they currently lack a straightforward link between circular economy design options, such as a waste hierarchy and potential societal benefits of products [11]. In addition, we have found that the three above mentioned methodologies experience at least one of two major constraints for supporting circularity issues in R&D, namely (1) the costs or effort involved and (2) the required data. Lastly, LCA and CBA are limited when reviewing new developments or technologies with a low Technology Readiness Level (TRL). This suggests that there is a lack of simplified assessment methods which could guide decision making in early stage developments. Also, any obstacles that might prevent an otherwise high-potential innovation at a low TRL-level to be further developed and implemented are not addressed by LCA, CBA or BMD.

A few methods that can support quantitative assessment of circularity and that could complement LCA, CBA and BMD methodologies are the use of the Material Circularity Indicator (MCI) [12], Input-Output (IO) Analysis [13] or Material Flow Analysis (MFA) [5]. These observations give the impression that only a combination of methodologies can remedy the shortcomings of LCA, CBA and BMD and integrate CE aspects successfully. The only method we have found which could be adapted for R&D studies and which combines both circularity and impact assessment, was developed by Potting et al. [14]; [15]. In this paper, the methodology of Potting et al. is further elaborated into a framework connecting various target levels and phases of product development to the most suitable methodologies for specific situations.

1.2. Aim of this study

The aim of this study is to combine the currently available qualitative and quantitative assessment methodologies into a single framework that allows more circular R&D management based on multiple value creation. In this way, we hope to assist R&D managers and investors by complementing existing R&D management tools, such as LCA, CBA and BMD, with circular economy aspects. In this paper, the framework development is described and its applicability is tested by means of a case study.

2. Methodology

2.1. General approach

The framework was developed as part of a multiannual innovation program aimed at developing commercially viable CE innovations. A clear need to compare R&D projects and evaluate priorities within the program led to the development of the framework.

2.2. Framework development

The first version of this framework was developed in three phases:

1. A literature review, in order to gain an overview of currently available assessment methodologies and CE models.
2. Development of a matrix listing (types of) methodologies according to their intended application and accuracy. This also allowed to identify gaps in current methodologies, which in turn inspired the researchers to develop complementary new methodologies.
3. Use of the framework in multiple case studies to assess its applicability and to improve its design.

In the past year, the first two phases have been completed. The first version of the framework has been developed and it is now tested it in various R&D projects. In this paper we describe the framework in more detail, together with a case study on which the framework is currently being tested. The literature review was summarized in the background section.

3. The IMPACT framework

3.1. Drawing the outlines: technical requirements

The framework development was initiated by defining the technical requirements for the framework. This framework should allow:

- to assess the capacities needed to successfully develop and implement an innovation;
- to quickly assess alternative CE designs of products and their production chains;
- to estimate the sustainability potential of an innovation.

In addition, the framework should be able to remedy the earlier defined shortcomings of current methodologies used to assess R&D aiming at circular innovations.

- The framework should include indicators for various benefits: economic, environmental and societal.
- The framework should clearly link to various circular economy design options for supply chains, including the perspective of the end user and the roles of various involved supply chain stakeholders.
- The framework should be able to guide product developers and researchers both in an early development stage as well as during implementation.

The working title for this framework is "IMPACT": Integrated Method of Product Assessment in Circular Transitions.

3.2. Framework design

The IMPACT framework was inspired by the methodology of Potting et al.. Potting et al. evaluate the CE transition process in four performance areas: Means, Activities, Performance and Impacts. We have adapted these four areas to three levels of evaluation for R&D projects, resulting into three tiers of the framework: 1) context, 2) supply chain design and 3) sustainability.

On the context level, corresponding to 'means' in the methodology of Potting et al., we focus on methodologies that evaluate the capacity of the development team to innovate. Capacity building is analyzed for the following aspects: means, knowledge, experiments, strategy, market and external conditions (i.e. obstacles that can hamper innovation, such as legal barriers). On the level of the supply chain design, which corresponds to 'activities' and 'performance' by Potting et al., we focus on the circular design options and their effects on the product and supply chain. This is done by implementing a waste hierarchy, namely the 'R-strategies' as summarized by Potting et al.: Refuse, Rethink, Reduce, Re-use, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover. Lastly, on the level of sustainability, corresponding to the 'Impacts' by Potting et al., we focus on the impact of the value chain on resources, environment and economy.

Subsequently, we have placed relevant methodologies which are currently available within the framework (Fig. 1.). Included are the aforementioned LCA, CBA, MFA an IO methodologies, but also (Life Cyle Costing) LCC [16], and Constructive Technology Assessment (CTA) [17].

The methodologies are ordered in three levels of accuracy, taking in consideration the variety in needs in all stages of the R&D processes. The accuracy levels range from quick scan to brief assessment to thorough assessment. In principle, the outcomes of all accuracy levels are the same, but differ in their reliability, accuracy and input data requirements: i.e. for the analysis of the impact on sustainability on the thorough assessment level, LCA and CBA studies are combined to calculate the impact on resources, environmental and economic level. Selection of a level of accuracy for a specific study relies on the TRL level of the innovation, available resources and desired reliability, which will differ from situation to situation.

Earlier we have identified that, among other issues, that the required costs and data for most methodologies presents a serious challenge, especially for R&D at low TRL. For this reason we have focused on developing and testing methodologies for such innovations, listed in the framework in the quick scan category. These methodologies, which will be applied in the case study presented below, include:

- *Project self-assessment:* an overview of the strong and weaker capacities identified by answering a short list of questions.
- *Circular quick scan:* an overview and quantitively estimation of the R-strategies used in order to increase the circularity. These strategies can also be used as an inspiration in the design process.
- *Expert opinion on societal benefits:* an estimation of the impact on resource depletion, environment and economic aspects estimated by experts of various disciplines.

4. Case study

4.1. Case study background

The IMPACT framework was tested by the evaluation of circular options for so-called 'B-wood' in the Netherlands: waste wood which is painted, varnished or laminated during

		level of the assessment		
		Quick scan (from TRL 1-2)	Brief assessment ↔	Thorough assessment (until TRL 8)
Assessment of..	1. Context – *the capacity to innovate*	Self-assessment*	Expert assessment	Constructive technology assessment
	2. Supply chain design – *circular performance*	Circular quick scan*	External review	Material flow analysis Input-output analysis
	3. Sustainibility	Expert opinion**	Impact profiles*	Life cycle assessment Life cycle costing Cost-benefit analysis

Fig. 1: Schematic representation of the IMPACT framework dividing established assessment methodologies on their accuracy and result. Tools currently under development by the authors are marked with one asterisk (*). Tools which are not yet developed are marked with two asterisks (**).

its life cycle. This wood is currently unsuitable for re-use by the chipboard industry due to, for example, paint contamination. Therefore, the prevalent waste treatment of B-wood is incineration. The B-wood waste stream largely consists of old furniture, sheet materials like chipboards and MDF, flooring and similar products.

Annually 1 million ton of B-wood waste is produced in The Netherlands [18]. The current waste treatment of this waste stream is not known in hard numbers, although it is known that the combined stream of (untreated) A-wood and (treated) B-wood is incinerated for 40% [19]. Stakeholders estimate that of the B-wood alone, 80% is incinerated. This incineration has benefits in the form of energy recovery, but from a circular perspective other forms of waste treatment would be preferable. Currently, waste treatment alternatives with higher values seem technically feasible. Novel potential recycling and re-use options might be feasible for diverse applications, for example in furniture, the building sector or infrastructure. However, the business case for these alternatives is challenging and multiple aspects play a role. Therefore, this case is a prime example of an innovation for which multiple value-creation can prove crucial for success.

The first step in this case study assessment was a market exploration in cooperation with stakeholders, discussing the potential alternatives for waste wood treatment and the advantages and drawbacks related to them. The involved stakeholders came from various segments in the timber value chain: carpentry industry, waste treatment companies and construction product traders.

The stakeholder consultation resulted in a list of several potentially more valuable alternatives. Subsequently, two alternatives were compared and evaluated by means of the IMPACT framework:

1. Reuse / recycling of hardwood doors, windows and window frames;
2. Reuse of large wood chips, applied in building blocks and sheet materials (example: Fig.2).

In this paper, the approach and results of the first alternative are discussed. The second alternative will be evaluated when the technical characteristics are further developed.

Fig. 2. Example of block made from large wood chips.

4.2. Preliminary case study results

The IMPACT framework was applied to a specific innovation which was identified by the stakeholders as promising: B-wood window frames. The aim of this technique was to develop a window frame based on B-wood, after treatment of the B-wood to remove paint and other contaminations. The window frame was designed to 1) require 10% less wood for construction; 2) would have a 1,5 times longer life span than an average wooden window frame which would last for 25 years; 3) should enable easy reuse of the frame in case of early demolition (estimated at 5% of total demolition); and 4) should be decomposable enabling the repurposing of its components in new window frames. The resulting reductions in material use are listed in Fig. 3.

This B-wood window frame was analyzed on the quick scan level, thus 1) a self-assessment of the innovation capacity on the project level; 2) a circular quick scan of potential value chain designs; and 3) an expert opinion assessment of the societal benefits. The case study was deliberately assessed in a rudimentary way, since technical research was still at a relatively low TRL. This approach fitted well with the study's aim to investigate the applicability of the framework when limited resources and data are available.

Table 1 shows the result of the self-assessment of the innovation capacity of the project team and its environment, including market conditions. This was assessed using a set of self-assessment questions based on Potting et al.. The assessment showed that the project team was making progress in establishing the means necessary to innovate, in developing the necessary knowledge and creating a shared vision among the involved stakeholders. However, significant issues remained in the market and external conditions that could jeopardize successful implementation of the research outcomes.

Table 1. Self-assessment score of the case study. The results are classified in three categories, ranging from green (optimal conditions for innovation) to red (large constraints for innovation). Orange classification lies in between green and red.

Topic	Current situation	After project
Means	red	green
Knowledge	orange	green
Experiments	red	orange
Shared vision	orange	green
Market	red	red
External conditions	orange	orange

Fig. 3 shows the circular design options, based on the 10R waste hierarchy, included in the circular quick scan for the assessment of supply chain configurations. The application of this quick scan on the described window frame design resulted in the MFA diagram as shown in Fig. 4, which is based upon the earlier circular design framework from the Ellen MacArthur Foundation [2].

		Current situation				Target situation			
		Window frame	Wood	Paint	Glue	Window frame	Wood	Paint	Glue
(R1) Recover	%		99%	99%	99%				
(R2) Recycle	%								
(R3) Repurpose	%					45%			
(R4) Remanufacture	%								
(R5) Refurbish	#								
(R6) Repair	#					1,5			
(R7) Re-use	%	1%				5%			
(R8) Reduce	%						10%		
(R9) Rethink	#								
(R10) Refuse	%								

Fig. 3. Overview of circular design options for products, applied to the assessed redesign of window frames based on waste wood. Only grey colored fields represent viable options; white fields represent impossible combinations.

This assessment showed that especially the longer lifespan of the window frame (repair – R6) and the repurposing (R3) of window frame components at the end of their lifespan are expected to have a significant effect in resource consumption. It also showed that various actors in the supply chain stand to lose (in regards of volume of production) from large scale implementation of the assessed innovation.

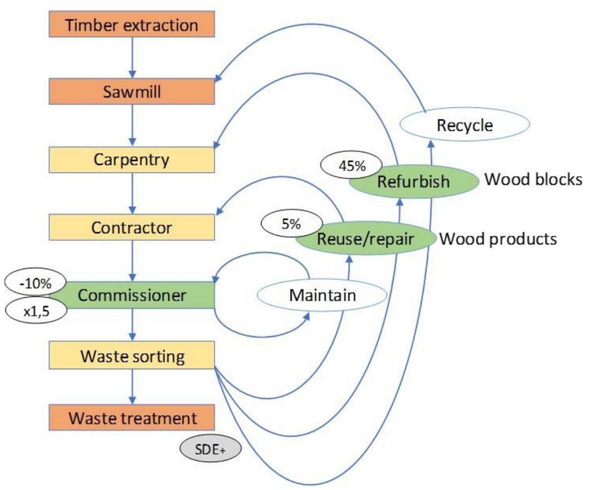

Fig.4. Resulting MFA diagram from the circular quick scan of window frames based on B-wood. The traditional 'linear' supply chain is listed on the left (from "timber extraction" to "waste treatment") and circular design options for the supply chain are listed on the right (from "maintain" to "recycle"). Green actors/options are expected to gain from the assessed innovation. Red actors are expected to lose turnover if the innovation is implemented.

Table 2 shows the result of the expert opinion assessment of societal benefits of a window frame produced from B-wood. For this assessment an LCA expert and a regional economist were asked to give their opinion based on a limited literature review and an interview with the involved researchers. We have developed a set of indicators, shown in Table 2, that lists indicators which are most commonly used in LCA and regional economics and which were deemed relevant for the purposes of the framework.

The results of the expert assessment show the expectation of significant environmental benefits from the large scale implementation of B-wood window frames. Especially resource depletion could be significantly reduced by this technique. However, economic indicators on prosperity show a significant negative impact on resource costs and end-of-life costs. This is mostly due to the relative low price of virgin wood and subsidies given for the incineration of biomass for energy recovery.

Table 2. Expert opinion assessment of the B-wood case study. Positive (++ and +) scores reflect a positive impact on the theme; negative (- or --) scores reflect disadvantages for the theme.

Theme	Indicator	Score
Resource depletion	Material use	++
	Fossil energy use	++
	Water use	0
	Land use	+
Planet	Climate	+
	Air, water & soil quality	+
	Ecotoxicity	+
People	Human toxicity	0
	Employment	+
Prosperity	Resource costs	-
	End-of-life costs	--

5. Conclusion & discussion

The quick scan assessments in the IMPACT framework, of the B-wood case study have shown to generate valuable insights for the involved R&D specialists and their managers. First of all, it showed that this research project still faces serious limitations in their capacity to innovate due to market conditions and external conditions. Also, it showed that the innovation relied on multiple changes in the supply chain, of which the lifetime extension of the window frame was expected to be the most significant. Several supply chain stakeholders were identified that stood to gain or lose from the implementation of the research outcomes. Lastly, it informed the involved specialists and their managers that significant environmental benefits could be achieved, but that this was compensated by significant negative effects on resource and end-of-life costs.

With this case study, the developed framework has shown potential to steer R&D decisions in support of a more circular economy. In particular, it showed the necessity to focus on multiple value creation as well as design and innovation capacity, as the involved innovation will most likely not be implemented solely based on its economic benefits. The study resulted in the advice for the R&D researchers to focus on remedying market unfavorable conditions and convincing stakeholders to reevaluate current external conditions, such as subsidies on B-wood incineration, to enable successful implementation of their R&D efforts.

The case study only tested the quick scan category of the IMPACT framework. This was mostly due to the low TRL level of the assessed innovation. Future research will focus on upscaling of the assessment methods for innovations of higher TRL levels, using methodologies listed in the brief and thorough assessment columns.

In addition, the framework was tested for a relatively simple product. A next step will be more complicated products containing more components and materials.

The research program in which the IMPACT framework was developed, aims to implement an innovation funnel with stage gates based partly on the IMPACT framework, as a variation on the stage-gate model developed by Cooper [20] and many others. In fig. 5 a preliminary design of such a stage-gate model including the IMPACT framework is shown. This figure shows a 'traditional' research funnel, which represents the life cycle of R&D projects starting from a broad scope of early ideas (left) towards a few innovations reaching maturity (right). The funnel is divided into three stages, allowing managers to evaluate innovations at the stage 'gates' before investing more in their development.

The real value of the framework can only be known after assessing the societal impact of innovations from R&D programs after large scale implementation of the framework. However, so far the framework has shown real potential to guide both researchers and their managers in evaluating the potential of circular economy innovation aiming at multi value creation.

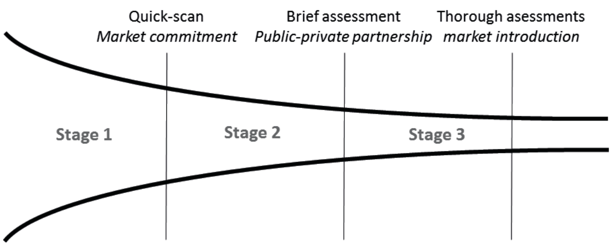

Fig. 5. Stages of the IMPACT methodology in an innovation funnel.

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