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Part of the Special Issue: PoLicy For a Resource Efficient Europe

Ecological Economics 155 (2019) 20–35

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

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Cite as:

Díaz López, F.J., T. Bastein & A. Tukker. (2019) *Business model innovation for resource-efficiency, circularity and cleaner production: what 143 case studies tell us*. **Ecological Economics**. 155, 20-35. https://doi.org/10.1016/j.ecolecon.2018.03.009

The supplementary material included in **Annex 2, 3, 4.** is available at:
https://www.diazlopez.eu/wp-content/uploads/2026/10/2019_DiazLopez_Bastein_Tukker_Business_model_Ecolec_Annex3.xlsx

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Business model innovation for resource-efficiency, circularity and cleaner production: what 143 cases tell us

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Abstract

This paper analyses 143 cases about the implementation of various and often interlinked, integrative, Resource Efficiency Measures (REMs). These REMs have been brought in a framework distinguishing on the one hand a cluster of supply side measures, demand side measures and life cycle measures with a synergistic mode of operation. They further have been related to clear classes or Business Model Changes (BMCs) that can support their implementation, notably changes in the supply chain (SC), internal processes (IP), customer interface (CI), financial model (FM) and the value proposition (VP). The BMCs were further characterised in terms of typical Implementation Barriers (IBs) that were reported in the cases, i.e. institutional, market, organizational, behavioural and technological barriers. Our study could not confirm some common theoretical wisdom, such as that firms mainly focus on 'simple' REMs like cleaner production and green products. Indeed, we could not confirm that REMs with a high scope and degree of change, often perceived as complex to implement, faced more implementation barriers than others. In general most implementation barriers play a role in all types of REMs and BMCs, although also some weak patterns were found. Internal processes BMCs were mainly hampered by institutional and technological factors. Value proposition and Financial model BMCs faced mainly behavioural and market barriers. Customer interface BMCs encountered additionally organizational barriers, while supply chain BMCs face a mix of all classes of barriers distinguished in this study. This is one of the first studies on business models and resource-efficiency looking at a large set of cases which is a step forward from the single case studies that dominate current literature. Yet, follow-up research should overcome weaknesses in our approach, such as a possible bias towards success cases and be more quantitative in analysing the effort it takes to overcome IBs.

Keywords: resource efficiency, business models, eco-innovation, sustainability, circular economy, cleaner production.

Acronyms	
BMC(s) = business model change(s)	GS = Green services
C2C = Cradle to Cradle	GSCM = Green supply chain management
C2C=Cradle-to-cradle	IB(s) = implementation barrier(s)
CC = Customer Channels	ICT = information and communication technologies
CE = Circular economy	IS = Industrial symbiosis
CI = Customer Interface	KA = key activities
CoS = Cost Structure	KP = key partners
CP = Cleaner production	KR = Key resources
CR = Customer relations	PC = Pollution control
CS = Customer segments	REM(s) = resource efficiency measure(s)
EE = Eco-efficiency	RS = Revenue Stream
EMS= Environmental management systems	SC= supply chain
FM = Financial model	SP = Services instead of products
FS = Functional sales	SS = Service Substitutes
GE – Green entrepreneurship	TBM= Take-back management
GP= Green products	VP = value proposition
	WM = Waste management

1 Introduction

This paper focuses on the business perspective of the transition to resource-efficiency. We analyse how changes in business models can support measures for resource efficiency implemented by companies, but also identify what barriers to implementation exist.

While research into business models and business model innovation in general is mature, this cannot be said of research into business models for resource efficiency and circularity. The body of literature consists of just over 200 references, close to half of them from conference proceedings. As we will show in section 2, much of this work is conceptual and covers individual company-cases reported in the literature. In this paper, we perform one of the first analyses across a broad set of cases of resource-efficient or circular business models. To analyse these cases, section 2 first develops an analytical framework consisting of a classification of Business Model Changes (BMCs), Resource Efficiency Measures (REMs), Radicalness of Change, and Implementation Barriers (IBs). Section 3 applies this framework to 143 cases present in authoritative resource efficiency literature. This results in section 4 in a reflection on what this literature suggests are currently the dominant types of REMs and BMCs being pursued, and what are dominant IBs hindering change.

2 Concepts and classifications used in this paper

2.1 Analytical concept and research questions

The concept of business models was developed in the 1990s (Teece, 2010). Building upon manifold existing concepts and precepts (Morris et al., 2005, p. 728),: e.g. *business strategy (e.g. Porter 1985), resource-based view of the firm (Barney, 1991), transaction cost economics (Williamson, 1981), strategic network theory (Jarillo, 1995) and cooperative strategies (Dyer and Singh, 1998)*, authors such as Morris et al. (2005), Osterwalder et al. (2005) came to define a business model as *a conceptual and analytical construct used to describe a series of components guiding companies in processes of value creation and appropriation* (Lambert and Davidson, 2013). Since that period, research into business models has exploded. For example since 1995, annually, hundreds of refereed papers per year have been published leading to over 20.000 entries listed in Scopus - a bibliographic database containing abstracts and citations for academic journal articles[1].

In contrast, research into business models for resource-efficiency and circularity is much less developed (Lüdeke-Freund and Dembek, 2017). When the key word 'business model' is combined with 'resource efficiency' or 'circularity', Scopus gives a list of just 212 documents. Some 80 (40%) of them are conference proceedings or book chapters, which are not always peer-reviewed, (figure 1), over 80% have been published in the last 3 years (figure 2), and the vast majority has been authored by research institutes in Europe (figure 3). From these papers, Scopus classified 17 of them as 'reviews'. But upon checking the abstracts and where needed the papers themselves, we found these were mainly conceptual reviews and covered a few business cases each at best. The best cited papers are often conceptual. They propose for

[1] www.scopus.com, searched on the key word 'business model', accessed 20 August 2017. Detailed information obtained from this search is included in the supplementary information.

instance strategies derived from theory on how certain design or business modelling strategies could stimulate resource-efficiency or circularity (e.g. Bocken et al., 2016, Lewandowski, 2016), or simply indicate that new business models are required for radical resource efficiency (Schulte, 2013) without addressing implementation barriers of how society can find a critical mass for supporting policies (Tukker and Ekins, 2017). Empirical analyses usually focus on one or a few cases (e.g. Bocken and Short, 2016) . Literature hence mainly comes up with implementation barriers derived from theory (Evans et al., 2017), rather than from in-depth practical research. A common assumption is that relatively small 'regime compliant' or 'marginal' sustainability improvements that leave existing production-consumption networks intact and incumbent firms unaffected face less implementation challenges than more 'systemic' or 'radical' changes (e.g. Elzen et al., 2004, Loorbach, 2014).

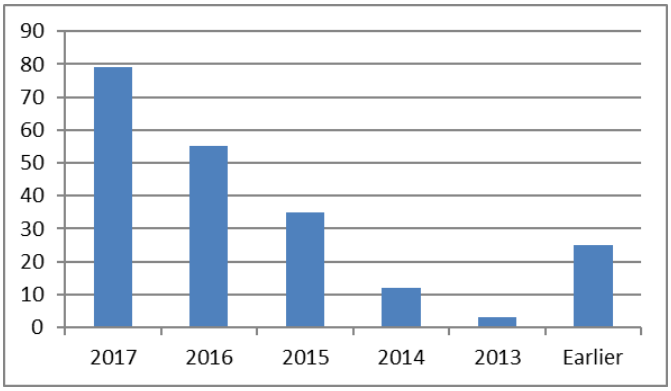


Figure 1 : Papers on business models, resource efficiency and circularity published per year. Source: Scopus search (See additional information).

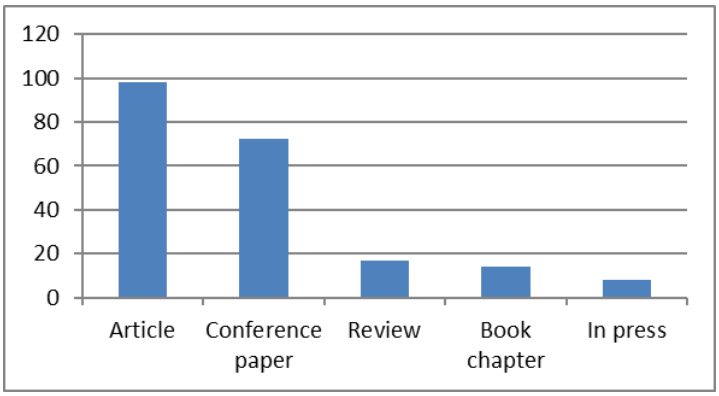


Figure 2 Papers on business models, resource efficiency and circularity by type. Source: Scopus search (See additional information).

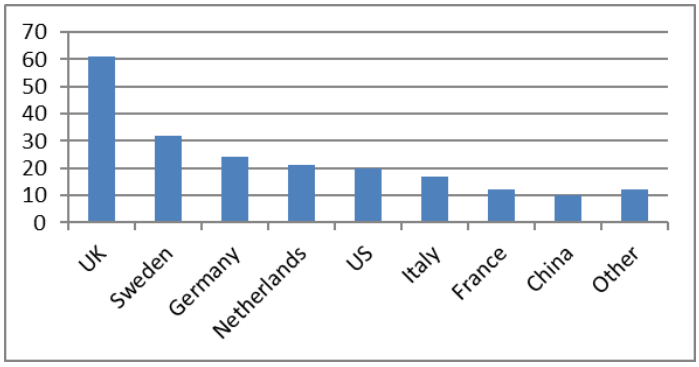


Figure 3 Papers on business models, resource efficiency and circularity by country of origin. Source: Scopus search (See additional information).

So, as we concluded in earlier reviews on product-service business models (Tukker, 2015, Tukker and Tischner, 2006b), business model research in the sustainability field, with a few exceptions, still lacks the in-depth and robust insights provided by meta-reviews and statistical analyses of large number of case studies we see in the general business modelling literature (c.f. Johnson, 2008, Chesbrough, 2010, Massa and Tucci, 2017, Zott et al., 2011).

This paper sets out to perform one of the first ever analyses of a large number of cases in which companies tried to make their business model more circular and resource-efficient. Being one of the first attempts, we feel it would be a bridge too far to reach in one go the rigour and level of insights we see from research into business models and business model innovation in general. In our analysis, we use a fairly straightforward concept to frame our research. First, to make networks of production and consumption more resource-efficient and circular, measures to enhance resource-efficiency have to be implemented. These are technical and organisational measures such as the use of more resource-efficient technologies, the design of products that use less materials and energy over their life cycles, or taking back product components for re-use in new products. We call such measures in this paper Resource Efficiency Measures (REMs). Second, for a successful diffusion of such REMs they have to be supported by business models that are more successful as the linear take-make-waste model. So, as for instance exemplified by the large body of literature on Product-Service business models (e.g. Halme et al., 2007; Tukker et al., 2015) a change in business model can be a strong incentive to implement REMs. This leads to a need to assess what type of Business Model Change (BMC) can help implementation of REMs. But third, any change in the physical and organisational structure of production consumption networks, and hence implementation of REMs and BMCs, will encounter barriers to implementation. This leads to a need to assess what type of Implementation Barriers (IBs) can be at stake when implementing certain types of REMs or BMCs. And finally, since literature usually indicates that incremental sustainability improvements tend to be implemented easier than radical sustainability improvements, an assessment of the degree and scope of change is desirable as well (e.g. Eco-innovation Observatory (2013), OECD (2009), e.g. Hopwood et al., (2005), Tukker and Tischner (2006a).

In short, this brief conceptual analysis implies that a categorisation of REMs, BMCs, IBs and degree and scope has to be developed, by which our 143 cases can be analysed and categorised. We do a proposal for the categorisations to be used in the next sections. These categorisations then can be used to make counts of the types of REMs, BMCs, IBs and degree and scope of

change found in the cases. These counts then also can be used to see if relations between these elements can be found. Given the early stage of the type of research we do for the sustainable business modelling field, we opted for making mere counts first, rather than already embarking on statistical techniques to analyse such relational patterns. This approach allows questions to be answered such as: *'what types of measures do companies tend to implement when they aim to realise resource-efficiency? What in business models do these measures imply? How radical are these changes and what are the main barriers to implementation companies face, and how do these relate to the type of BMC?*

2.2 Resource efficiency measures (REMs)

This paper is interested in the implementation of resource-efficiency. Against this background, we define resource efficiency measures (REMs) as the implementation of (technological and non-technological) concepts, methods, tools, techniques and technologies applied by companies in order to reduce the resources needed for their goods or services. Based on 19 of the most prominent studies and references describing resource-efficiency approaches in industry, Table 1 gives an overview of examples of REMs that can be implemented in value networks. In relation to Figure 5 on BMCs, we cluster them in 3 main categories: supply side focused (dealing with the supply chain, internal processes, and cost structure), demand side focused (dealing with the value proposition, customer interface, and revenue streams), and life cycle focused (dealing with a large number of elements in the business model including the use and waste phase of products).

Main category of REMs	Strategies, concepts, eco-innovations	Example of a REM	For definitions and examples see the following authors and/or studies
Life cycle-focused	Industrial ecology	Industrial symbiosis	(Chertow, 2000)
		Remanufacturing	(Savaskan et al., 2004)
	Radical re-design	Circular economy	(Ellen MacArthur Foundation, 2012, Bastein et al., 2013)
		Cradle to Cradle (C2C)	(Braungart et al., 2007)
		Green chemistry	(Anastas and Breen, 1997)
Supply side focused	Process integrated measures	Pollution control	(3M and UNEP, 1982)
		Waste management	(Theodore et al., 1997)
		Cleaner production	(UNIDO, 2006)
		Eco-efficiency	(WBCSD, 2000)
	Management measures	Green Supply Chain Management	(Sarkis et al., 2011)
		Energy efficiency (in production)	(Bunse et al., 2011)
		Environmental management systems	(BSI, 1994)
Demand side focused	New ventures	Green entrepreneurship (GE)	(Isaak, 2002)
	Goods	Green(er) products	(Miller, 2009)
	Services	Green services	(Halme et al., 2007)
	Product-service systems (PSS)	Services instead of products	(Tan et al., 2010, Tukker, 2004, Tukker and Tischner, 2006a)
		Product-related services	
		Advice/ consultancy	
		Product lease	
		Product renting or sharing	
		Product pooling	
		Pay-per-service unit	
		Take back management	
		Functional sales	

Table 1 Unstructured overview of Resource Efficiency Measures. Source: Own elaboration based on literature cited.

For further use in this paper, we decided to consolidate the rather long list of REMs presented in Table 1 into a more condensed format. For the supply side focused REMs, energy efficiency was seen as part of eco-efficiency, and environmental management systems (EMS) as related to the 'good housekeeping' segment usually covered by Cleaner Production. We deleted Green entrepreneurship as a category of its own, it is a very generic REM and indeed, we did not find any case where it was applied in itself (it was always in combination with more concrete REMs). For the demand side focused REMs, we located most categories of PSS into the categories services instead of products. For the life cycle focused REMs, cradle-to-cradle, green chemistry and remanufacturing were combined into one category 'cradle to cradle'. This ultimately led to the list of REMs as indicated in Table 2.

Supply side REMs	Demand side REMs	Life cycle REMs
Pollution control (PC)	Green products (GP)	Industrial symbiosis (IS)
Waste management (WM)	Green services (GS)	Cradle to Cradle (C2C, including remanufacturing and green chemistry)
Cleaner production (CP, inc. EMS)	Services instead of products (SP)	
Eco-efficiency (EE, inc. energy efficiency)	Functional sales (FS)	Circular economy (CE)
Green supply chain management (GSCM)	Take-back management (TBM)	

Table 2 Consolidated list of Resource Efficiency Measures used in this paper.

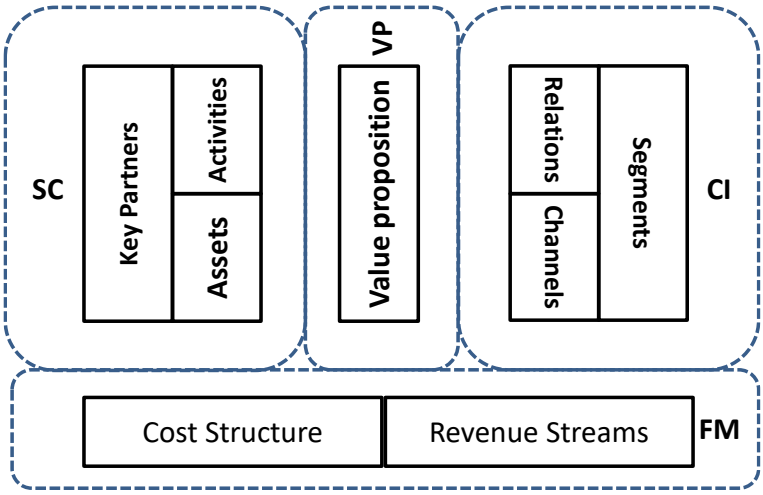
2.3 Components of business models and their change

It has been only since the 2000s that a number of scholars summarised empirical and theoretical work and proposed definitions and several classifications in terms of operational models and functions, components, and type of change in business models (Linder and Cantrell, 2001, Morris et al., 2005, Shafer et al., 2005, Lambert and Davidson, 2013, Goethals, 2009).

The identification of functions in the core operational logic of the company to create value can be grouped into components of a business model (Morris et al., 2005). The literature reports different categories of components (Doganova and Eyquem-Renault, 2009, Osterwalder and Pigneur, 2010). The business model canvas by Osterwalder and Pigneur (2010) is probably the best known example of a representation of business models, providing a simple and intuitive tool to describe and think through the different elements of a business model (Figure 4). In this business model canvas, it is possible to identify four generic categories, namely: supply chain (SC), customer interface (CI), financial model (FM) and value proposition (VP) (Boons and Lüdeke-Freund, 2013) .

While such 'maps' of business models usually reflect how a business model is organised in a current situation, they also point to elements that can be changed. Or, in the words of Chesborough (2010): "*One promising approach is to construct maps of business models, to clarify the processes underlying them, which then allows them to become a source of experiments considering alternate combinations of the processes*". We hence decided pragmatically to use the widely used business model canvas as an entry point to identify elements of a business model that can be changed[2] Figure 5 gives a number of examples of changes of business model components. The Figure makes clear on the one hand that business model change can go clearly beyond an adjustment of the value proposition, and, on the other hand, that some forms of BMC by necessity imply a change of several business model components. For instance, introduction of an added service to a product or offering leasing instead of selling a product induces a change in value proposition, but also will result in a change in the customer interface and probably the financial model as well.

[2] There are of course many other categorisations of change provided in the literature. These range from realisation, renewal, extension and journey (Linder & Cantrell, 2000), to adjustment, adoption, improvement, and actual redesign (Schaltegger, S. et. al. 2012; 2016).



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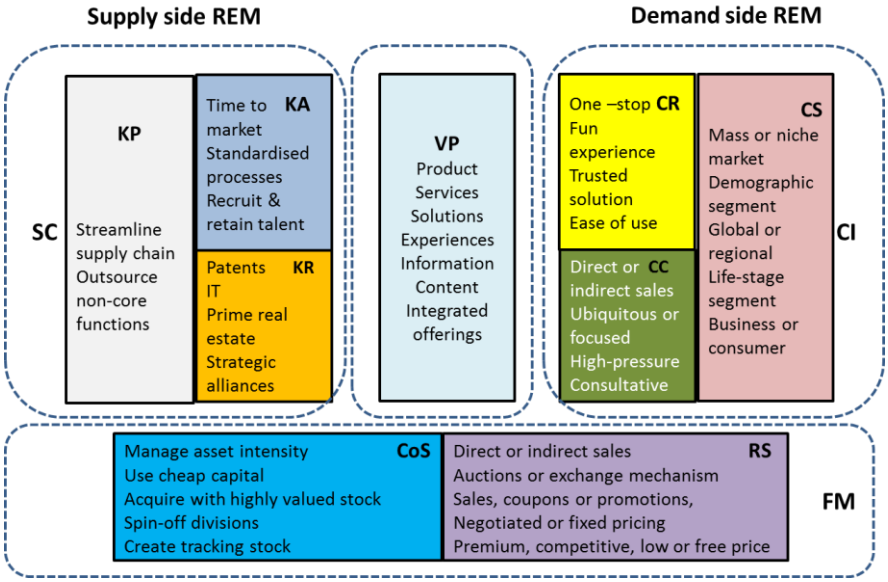
207 **Figure 4 Four Categories of Components in the Business Model Canvas. Source: (Osterwalder and Pigneur,**
208 **2010) (SC= supply chain; VP = value proposition; CI = Customer Interface; FM = Financial model)**



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210 **Figure 5 Business Model Changes – Specific Activities or Functions. Source: Modified From Linder & Cantrelli**
211 **2000 and Osterwalder and Pigneur (2010) (SC= supply chain; KP=key partners; KA=key activities; KR = Key**
212 **resources; VP = value proposition; CI = customer interface**

213 ## 2.4 Implementation Barriers

214 Business barriers to resource efficiency could be understood as internal and external negative
215 stimuli hampering the (eco)innovation activities of companies towards an efficient use of
216 resources, including changes to business models. Early literature classified barriers in the
217 following categories: institutional, market, economic and finance, behavioural, technological
218 and organisational (Michaelis and Carey, 1973). Of course, since then, multiple studies have
219 examined implementation barriers in the context of energy efficiency measures (York et al., 1978;
220 Weber, 1997), environmental technologies (OECD, 1985) and eco-innovation (Kemp, 2011). In
221 2008, the Journal of Cleaner Production published an extensive special issue on this topic
222 (Montalvo, 2008). As highlighted by scholars in system innovations and transitions (Geels, 2005;
223 Grin et al, 2010), barriers may have their roots at different system levels (e.g. landscape: the
224 overall socio-technical setting; regimes: dominant practices, rules and technologies; and

niches: spaces providing for experimentation with (radical) innovation). As a result, barriers can be relatively concrete and internal to the firm, or more generic and systemic, having to do with non-alignment of existing technologies, regulations, user patterns, business models, infrastructures and cultural discourses (e.g. Kemp and van Dijk (2014)).

Based on the literature cited above, we decided to use the categorisation of barriers given in Table 3. We found that literature (e.g. Montalvo, 2008) often ended up with variations of the Michaelis and Carey classification. The categorisation is further broad enough to cover both company internal and company external elements, and also, via the institutional and market barrier types, to a reasonable extent the systemic context as exemplified in the literature on system innovation and transitions.

Barrier Type	Definition	Examples
Institutional	Barriers caused by (e.g. political) institutions framing the "rules of the game".	Regulations and laws, fiscal measures, conditions for investment
Market	Market conditions, economic climate, and value network conditions	Monopolies, lack of information, subsidies, supplier leverage, relative cost of labour, materials and energy, etc.
Organisational	Firms as social systems influenced by goals, routines, organisational structures, etc.	Company strategy or focus, lack of funds, lack of management systems, etc.
Behavioural	Individuals' values and attitudes within companies	Lack of attention, lack of perceived control, lack of information, risk averse nature of existing market actors, etc.
Technological	Availability or lack of knowledge, technical artifacts or know-how.	Lack of equipment or other tools, undeveloped technology from the market, cost of technology, unable to support technology, etc.

Table 3: Main categories of Implementation Barriers for resource efficiency. Source: Bastein et al. (2014), after Michaelis and Carey (1973), Weber (1997), Ashford (1993) , Montalvo (2002), and von Weiszäcker et al. (2009).

2.5 Degree and scope of change

The ambition to understand how radical changes to resource-efficiency can be made (compare Ellen McArthur Foundation, 2012) brings us to the field that studies system innovations and societal transitions. An important notion from that field is that (eco)innovations – in our case REMs and BMCs - must be classified according to what extent they 'fit' with the existing situation, or that they truly create an upheaval in the system. Usually, literature suggests that the latter type of innovations encounter much more complexities and resistance to change. Some authors even argue that apart from the question of how to build up the new system, how to break down the old system needs just as much attention (Loorbach, 2014). In this context, differentiations between e.g. regime-compliant and revolutionary innovations or system optimization, redesign and system innovation have been proposed (Geels, 2005, Grin et al., 2010, Kemp, 2008).

In this special issue, Tukker and Ekins (2017) have analysed a number of concepts that provide such dimensions characterising the radicalness of change. They based themselves for instance on work of the EU Eco-innovation Observatory (Eco-innovation observatory (2013)), OECD (2009) and others (e.g. Hopwood et al., 2005, Tukker and Tischner, 2006a). From this, they suggested two relevant dimensions:

a) Scope of change. This is the scope of the system that is being affected by the innovation (e.g. a component of the system (e.g. a technology or product), a subsystem (value chain

or sectors) or a societal (sub) system; a larger scope hence usually must engage more actors to realise change.

b) Degree of change: incremental versus radical change.

We propose to use these dimensions as well to classify our REMs.

2.6 Classifications used in the further analysis

The former sections provide us with 4 types of classifications – one on REMs, one on BMCs, one on IBs and one on degree/scope of change. They are summarized in Table 4. The various REMs that can be considered, usually must go hand in hand with a BMC, a change for which in relation to the scope and degree of change, various IBs must be overcome. In the next section we now will use this classification in a further analysis of cases. As indicated the BMC is seen as a change in the configuration of the business model canvas, from one configuration to another. In Figure 6 we illustrate a hypothetical example where the introduction of several REMs produced changes to the coloured blocks of the business model of a given company.

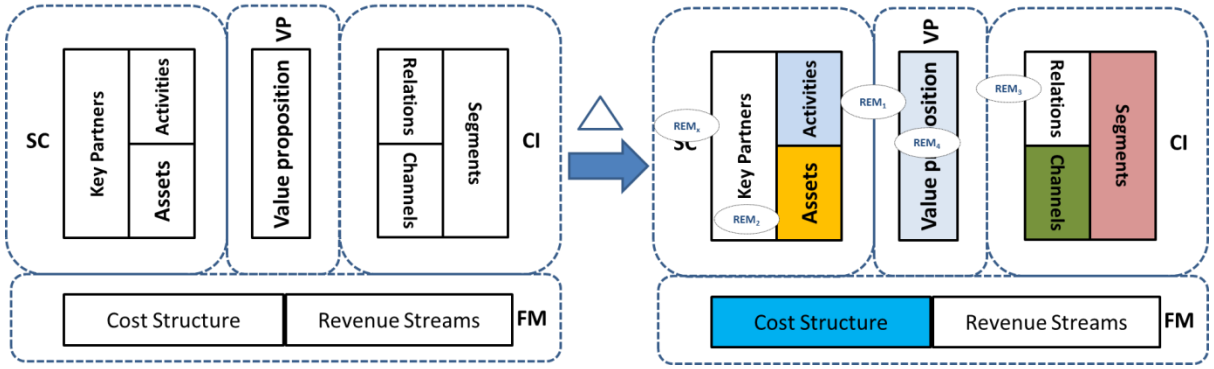

Figure 6 Conceptual Model: Changes In Business Models Supporting Resource Efficiency. Source: Own elaboration, based on Osterwalder and Pigneur (2010) (SC = supply chain; IP = Internal processes; VP = value proposition; CI = customer interface; FM = financial model)

Assessment category	Variables assessed
Resource Efficiency Measures	Demand side –focused: *Green products (GP); Green services (GS); Services instead of products (SP); Functional sales (FS); Take-back management (TBM)* Supply side –focused: *Pollution control (PC); Waste management (WM) Cleaner production (CP); Eco-efficiency (EE, inc. energy efficiency); Green supply chain management (GSCM)* Life-cycle focused: *Industrial symbiosis (IS); Cradle to Cradle (C2C, including remanufacturing and green chemistry); Circular economy (CE)*
Business Model Change	Supply Chain Internal processes Customer Interface Financial Model Value Proposition
Implementation Barriers	Institutional Market Organisational Behavioural Technological
Scope and degree of change	Scope: Specific firm, full value chain or societal sub-system Degree: incremental versus radical

Table 4 Summary of Analytical Categories and Variables

3 A meta-analysis of 143 cases of business model innovation for resource-efficiency, circularity and cleaner production

3.1 Method to select and review cases

Having defined now a conceptualization of business models, a classification of resource-efficiency measures (REMs), and a list of Implementation Barriers (IBs), we set out to analyse a large number of a cases with this framework. For the selection of cases we had the choice of two routes. First, we could have created a long list of cases from the scientific literature. Yet, as indicated in section 1 and 2, there are just over 200 scientific papers published that introduce some elements of business models in relation to resource efficiency or circularity. A fraction of them consist of case studies, and most of such papers discuss just one single case each. While several of such papers have become well-cited landmark analyses, such as the analysis of Interface Inc. and the Bendigo Bank by Stubbs and Cocklin (2008), via this strategy we would at best end up with a dozen or two, repeatedly cited cases at best.

To ensure a broader case base, we hence decided to use an alternative approach and to look at the non-scientific literature. Policy actors like the EU and OECD, and societal actors like the Ellen MacArthur Foundation, all have identified a large number of cases in resource efficiency and circularity, the EU for instance via the Eco-innovation Observatory it has set up. These actors have a clear strategy to highlight success stories and disseminate promising examples, and hence had an incentive to identify a large number of such cases. We hence based our case selection on such 'grey' literature (COWI, 2008, Greenovate! Europe, 2012, WRAP, 2010, Bisgaard et al., 2012, BIS, 2012, EIO, 2010, 2012, 2013), technical/ policy reports (Ellen MacArthur Foundation, 2012, 2013, von Geibler et al., 2011), books and book chapters (Sommer, 2012, Weterings et al., 2013), and web-articles focusing on resource efficiency cases relating to changes in business models. Specific cases were obtained from the website of the Eco-innovation Action Plan of the European Commission (European Commission, 2009b, 2009a, 2009c, 2009d, 2010, 2011, 2012, 2013a, 2013c, 2013b)[3].

Annex 1 provides an overview of the studies used to identify and further analyse cases reported as having business models impacting resource efficiency at the company level. The reports cover a wide array of sectors and countries, as well as perspectives. Of course, this selection method has its own problems from a scientific viewpoint (e.g. unclear if the list is representative, with for instance a potential bias to success stories). But we at least managed to create a base list of 300 cases reported in the studies – which to our knowledge goes well beyond the number of cases in any earlier assessments of business models for resource efficiency and circularity. We also feel such a broad analysis has the potential of being a major step forward given the current state of the art in this field.

[3] Cases included in an OECD report on business model innovation by Beltramello et al. (2013) were not included anymore since the research on which this paper is based had already started well before its publication. Our initial long list of 300 cases included many of the cases covered by the OECD report.

The initial list 300 examples was subject to a filtering exercise in order to determine which cases were compelling and had the potential to provide added value to the intended enquiry. To this end, the list of 300 was narrowed down. The criteria for exclusion of cases were as follows:

1. The case showed no real business model changes, but simply described a company and the business model they were using.
2. The case description was too vague and could not be classified in terms of the concepts provided in section 2 (for instance, no clear description of which resource efficiency measures have been implemented).
3. The case was focusing on business model innovation, but did not show a clear impact on resource efficiency.
4. The case did claim resource efficiency improvements, but without any explicit foundation - independent proof was not provided.
5. The case did not describe commercial or for-profit entities, but charities or services like food banks.
6. The case was R&D related, and there was not (yet) a market implementation and hence not yet an operational business model.

The list of cases was then again reviewed to ensure quality and sufficiency of information. The filtering criteria rendered a refined list with a total of 143 cases (see Annex 1 and 2). These cases were then used for our final analysis where we assess the following aspects. Using the categories, variables and names of each case in Table 5, the cases reported in documentary sources were evaluated in terms of the following information (See Supporting Information in Annex 1):

- Case name; brief description of case;
- Category of BMC (value proposition (VP), supply chain (SC), internal processes (IP) customer interface (CI), financial model (FM)); followed by one short example of a BMC identified.
- IBs addressed with this BMC (Institutional (I), Market (M), Organisational (O), Behavioural (B), Technological (T)); followed by one short example of the barrier addressed.
- Category of resource efficiency measure (REM).
- Scope of change and degree of change.

The analysis and classification was done by 3 different team members, each looking at all cases. There was obviously interpretative space in classifying the different cases. By having cases reviewed by different team members, and discussing differences in classification and interpretation, a consensus result was produced. The consensus reaching from this discussion was usually at such a level, that we did not think it to be useful to add a reliability score to classifications. While in assessment procedures like the one applied here interpretation bias cannot be excluded, the approach and results are in our view sufficiently robust to be used in the analysis performed.

3.2 Results: Resource Efficiency Measures and related Business Model Changes identified

3.2.1 Characteristics and diversity of cases

The procedure we followed resulted in a set of cases of a high level of diversity. Cases came from over 19 countries (predominantly in Europe), and covered large corporate enterprises, SMEs and small start-ups. Over 10 industries were included, including: construction and housing, agriculture, automotive, energy and chemical industries (see Figure 7 and 8). The data show a good distribution across REM categories (see Figure 9). While this good distribution was to some extent built in the selection of the 143 out of 300 cases, we can also cautiously conclude that companies apparently try to implement a broad diversity of REMs. An important remark has to be made about Figure 9. Many cases covered more than one REM, resulting into 252 REMs identified in the inventory. For analytical purposes, the team selected which REM was dominant in the case, and these 143 REMs counted in Figure 9 were used in the subsequent analysis[4].

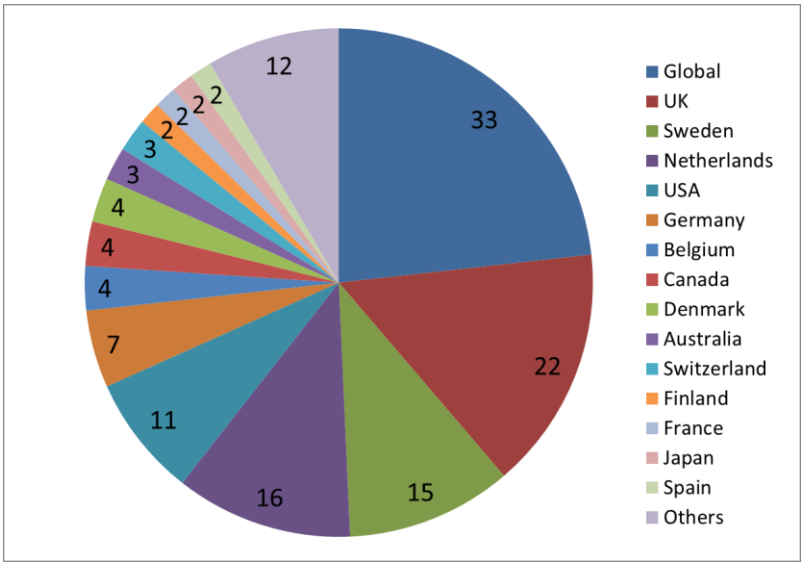

Figure 7 Distribution of Cases Per Country

[4] Particularly cases claiming to support a Circular Economy appeared often based on Take back management, Greening products, or Services instead of products. See the SI for such overlaps and which REM we selected as being dominant per case.

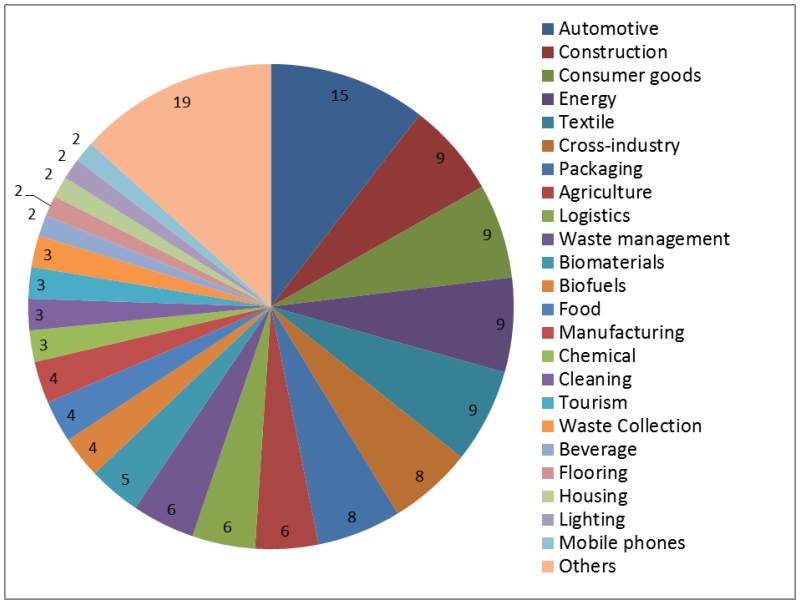

Figure 8 Distribution of Cases per Industry

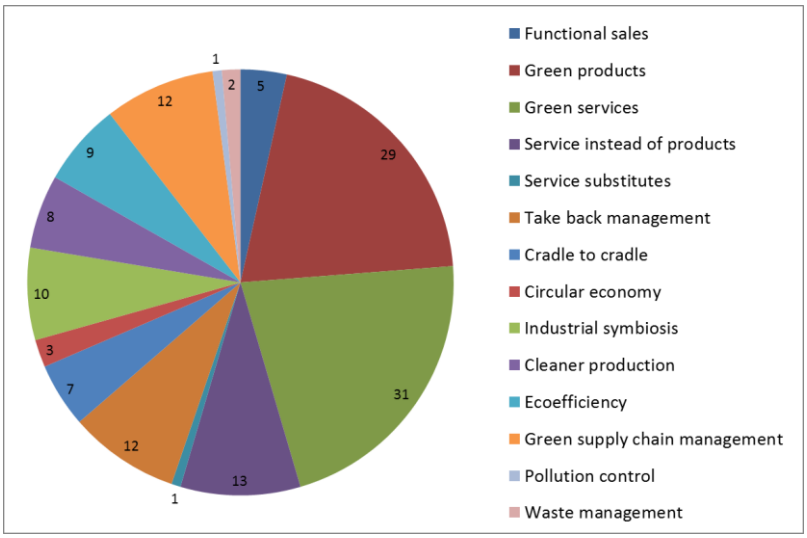

Figure 9 Number of Resource-Efficiency Measures by sub-category

3.2.2 Demand side measures

A relatively large number of the studied cases were associated with products or services that contribute to resource efficiency (green products or green services). A relatively small number of the studied cases are associated with the functional sales concept, where the customer pays for the functionality or performance of the product instead of buying the product itself. This is possibly caused by the fact that it is more difficult to introduce this concept in a distinct market or because of the relative newness of this concept. The services instead of products concept could be seen as the forerunner or a simplified version of functional sales.

Certain demand side REMs, such as greening products by eco-design (e.g. ensuring a low stand-by power of a TV set), often do not need a major change in the business model. The customer interface and financial model can stay the same. The value proposition, in this case the product, will have the same functionalities for the user. In contrast, resource efficiency measures such as

379 functional sales and services instead of products demand relatively large changes in the
380 customer interface of the business model. In general, cases about product-services reported
381 changes related to market, organisational and behavioural change (which are in turn related to
382 the customer interface).Take-back management requires cooperation between different parties
383 both upstream and downstream in the value chain. It can lead to the creation of new companies
384 and a green business plan, e.g. following a producer responsibility principle, requiring significant
385 BMCs or the design of a new one.

386

387

Demand side REMs	No. occurrence in cases	*Analytical category*	Observations from the cases
Green Products	29	REM	Relatively little combination with other types. No specific industry focus. Characteristic groups of change: Small-scale product changes. New product introduction or other complete product overhauls.
		BMC	Mostly on the value proposition and some in supply chain and internal production.
		Barriers	Mainly technological, behavioural and market barriers, driven by the value proposition and the internal production changes.
Green Services	32	REM	A very broad 'catch-all' category. A promising number of combinations with Industrial Symbiosis. Characteristic groups of change: Services to Value Chains ('X as a Service'); Services in Value Chain.
		BMC	Prevalence of value proposition changes.
		Barriers	Consequently confronted with market and organisational barriers, either when the service is in an existing market (competition) or when the service is in a new market.
Service Substitutes	1	REM	A single case: a manufacturer of dispensing machines leased to retailers to sell liquid products without the use of individual product packaging
		BMC	Value proposition and customer interface.
		Barriers	Market, organisational and behavioural barriers.
Services instead of Products	12	REM	A focus on sharing and renting, sometimes extended with additional services such as insurance and take-back management (TBM).
		BMC	Value proposition and financial model.
		Barriers	Behavioural barriers due to the new way of offering and market barriers due to competition in traditional product market.
Functional Sales	9	REM	Characteristic groups of change: Alternative for ownership focuses on material sharing: straightforward renting and leasing; added value services. Performance contracting allows for choices by the provider.
		BMC	This class typically needs changes in the value proposition to change both products to services in function and change incentives in usage. Therefore a change in the financial model is often occurring too. Sometimes with added value services such as TBM the supply chain is affected as well.
		Barriers	Because the class radically changes the consumer proposition, market barriers will have to be overcome. It also involves drastic changes within companies and a restructuring: therefore behavioural and organisational barriers are involved.
Take-back management (TBM)	21	REM	Characteristic groups of change: reusable packaging; packaging and food waste for recycling through the retailer or a third party; equipment for reuse or refurbishing.
		BMC	The supply chain is affected as in most cases the material taken back is fed into production. In some cases the relation with the customer is also changed, thus the customer interface is affected.
		Barriers	The market barrier is related to companies that need to change the way they deal with the customer. Achieving collaboration in the chain implies an organisational barrier.

388 **Table 5: Business Model Change and Implementation Barriers to demand oriented resource oriented measures**

389 ### 3.2.3 Supply side measures

390 A second large group consists of cases including green supply chain management and industrial
391 symbiosis, focusing on resource efficiency in the supply chain in cooperation with partners or

suppliers. Only a few of the studied cases are related to the pollution control and cleaner production concepts. This is most likely caused by the fact that these are rather specific concepts, frequently related to a firm's own production process, that are linked with eco-efficiency and green supply chain management.

Supply side REMs	No. occurrence in cases	*Analytical category*	Observations from the cases
Pollution Control	1	REM	Only case: Stena Metal Landfill Mining project
		BMC	A change in the supply chain and somewhat in the internal processes.
		Barriers	Institutional due to dealing with regulated landfill.
Waste management	9	REM	It includes effective collection of waste streams; very often linked to more holistic approaches such as industrial symbiosis (IS) and/or circular economy,
		BMC	Mostly about internal processes; when part of circular economy then the effect of change is perceived in the value proposition.
		Barriers	Due to the sensitive nature and consequently regulation of the waste streams that are treated in IS institutional barriers are apparent.
Cleaner Production	8	REM	Cleaner production methods are often linked to other transformations, such as supply chain management or pollution control.
		BMC	Typical changes in the supply chain and internal process. If serviced then the value proposition is affected.
		Barriers	Market barriers due to power in the value chain and behavioural barriers if change is not in primary interest.
Eco-efficiency	12	REM	Internally focused cases use less input materials or replace materials used. There are also service implementations, in these cases focused on training and behaviour.
		BMC	Surprisingly in many cases the value proposition was affected. In some cases actually a service was developed. In other cases internal processes were affected and in others the supply chain.
		Barriers	Dominantly technological barriers. If services also market barriers.
Green Supply Chain Management	23	REM	Characteristic groups of change: source green materials; code of conduct; co-operation between suppliers; benefit sharing
		BMC	Changes affect the supply chain component, although in different ways. Sometimes also the value proposition is affected as the service is advertised as green(er).
		Barriers	Coordination in the supply chain is considered an organisational barrier. Economical acceptance issues of chain partners represent a market barrier.

Table 6: Business Model Change and Implementation Barriers to supply oriented resource efficiency measures

Supply side resource efficiency measures like pollution control, waste management, cleaner production and eco-efficiency can often be arranged within one company and entail none or a small business model change in the supply chain. Green supply chain management often requires considerable changes in components of the business model, because more parties or parties across the value chain have to be involved.

3.2.4 Life cycle oriented measures

The third dominant group of cases focusing on cradle-to-cradle, industrial symbiosis, and circular economy, is oriented towards the product life-cycle and ultimately aims to close the recycling (or reuse / refurbishment) loop. In terms of scope of change, life-cycle oriented

406 resource efficiency measures like cradle-to-cradle and circular economy involve BMCs on both
407 supply and demand side and their presence in cases is often intertwined. For instance, green
408 service BMCs imply that costs in the use and waste phase now are the responsibility of the
409 service provider, resulting in an incentive to offer circular value propositions in which energy and
410 resource use over the life cycle are minimized..

411 All life-cycle oriented resource efficiency measures involve BMCs on both supply and demand
412 side. For this type of resource efficiency measures normally more parties, including those that
413 are further up- or downstream than the direct suppliers and customers, are required. As a
414 consequence, the required BMCs are relatively large and it often involves two or more other
415 REMs, especially in circular economy initiatives.

Life cycle REMs	No. occurrence in cases	*Analytical category*	Observations from the cases
Cradle-to-cradle (C2C)	20	REM	Characteristic groups of change: companies that produce components that can be used in C2C products or services, such as packaging; services based on development of (bio-) (processing) technology; C2C implementations that are driven by and scoped to a specific company.
		BMC	Achieving C2C starts with dealing with your inputs via the supply chain and internal processes and adopting technologies to do that. In cases also involves TBM (also Supply Chain). Some cases put C2C prominently in the value proposition and even service it. We term this class 'C2C as a service'.
		Barriers	Technological barriers for the technologies required are often observed. Competing on either existing markets with a C2C enhanced product or a new type of service implies market barriers. The necessary collaboration in the supply chain implies organisational barriers.
Industrial Symbiosis	23	REM	Closely related to waste management. Characteristic groups of change: (Bio-) (processing) technologies that turn waste into valuable products; platforms that connect supply and demand of residual stream
		BMC	Since IS typically relays a waste stream as an input this implies that the supply chain is affected. The cases where IS is being serviced do affect the value proposition. This class is named 'IS as a service'.
		Barriers	The service concepts also face market barriers, because the demand for such concepts has to be found.
Circular economy	49	REM	Largest degree of combination with other REMs, in particular those related to green products and services and cradle to cradle.
		BMC	Changes to most elements of the business model, especially when in combination with two or more other REMs. When combined with TBM changes are mostly perceived in the customer interface and when combined with products and services the change is in the value proposition.
		Barriers	A number of technical barriers are encountered as technologies for circular economy are not always ready for the market.

416 **Table 7: Business Model Change and Implementation Barriers to life cycle oriented resource efficiency**
417 **measures**

3.3 The relation between Resource Efficiency Measures, Business Model Changes and Implementation Barriers

3.3.1 Pair-wise relations included in the analysis

Section 3.2 gave a first overview of types of Resource Efficiency Measures, Business Model Change and Implementation Barriers. In this section, we do a more quantitative analysis. We simply made counts of the following relations, using the 143 cases as a starting point, without having the ambition to statistically analyse relations. Counts were made on the following aspects.

a) For each REM, what kind of BMC was implemented in the case?
b) For each REM, what kind of IBs were encountered?
c) For each REM, what was the scope and degree of change and how does this relate to IBs?
d) For each type of BMC, what kind of IBs were encountered?

We discuss these findings in the next sections.

3.3.2 Resource Efficiency Measures and required Business Model Change

Table 8 reviews the following. For all 143 cases, we counted how many reported changes (to a component of their business model) could be related to what type of REM. In this, cases that combined various REMs, the REM that was deemed most dominant in the case analysis in Annex 1 was selected as the REM that would 'carry' the case. We then counted which BMCs were related to the implementation of such a REM. The result is provided in Table 8.

Resource efficiency measure (REM)			Freq.	Business Model Change (nominal count)						Business Model Change (weighted value presented as % of cases)					
				SC	IP	VP	CI	FM	Combinations	SC	IP	VP	CI	FM	Combina-tions
Demand side	Functional sales	FS	5	2	0	3	0	5	4	40%	0%	60%	0%	100 %	80%
	Green products	GP	29	9	7	14	1	0	2	31%	24%	48%	3%	0%	7%
	Green services	GS	31	6	8	17	4	3	8	19%	26%	55%	13%	10%	26%
	Service instead of products	SP	13	1	0	12	0	9	9	8%	0%	92%	0%	69%	69%
	Service substitutes	SS	1	0	0	1	1	0	1	0%	0%	100 %	100 %	0%	100%
	Take back management	TBM	12	6	1	1	4	0	0	50%	8%	8%	33%	0%	0%
	TOTAL in this category		**91**	**24**	**16**	**48**	**10**	**17**	**24**	**26%**	**18%**	**53%**	**11%**	**19%**	**26%**
Life cycle	Cradle to cradle	C2C	7	5	2	2	0	1	3	71%	29%	29%	0%	14%	43%
	Circular economy	CE	3	3	0	1	0	0	1	100 %	0%	33%	0%	0%	33%
	Industrial symbiosis	IS	10	9	1	4	0	0	4	90%	10%	40%	0%	0%	40%
	TOTAL in this category		**20**	**17**	**3**	**7**	**0**	**1**	**8**	**85%**	**15%**	**35%**	**0%**	**5%**	**40%**
Supply side	Cleaner production	CP	8	6	1	2	0	0	1	75%	13%	25%	0%	0%	13%
	Ecoefficiency	EE	9	4	3	5	1	1	5	44%	33%	56%	11%	11%	56%
	Green supply chain management	GSCM	12	11	0	2	0	1	2	92%	0%	17%	0%	8%	17%
	Pollution control	PC	1	1	0	0	0	0	0	100 %	0%	0%	0%	0%	0%
	Waste management	WM	2	0	2	0	0	0	0	0%	100 %	0%	0%	0%	0%
	TOTAL in this category		**32**	**22**	**6**	**9**	**1**	**2**	**8**	**69%**	**19%**	**28%**	**3%**	**6%**	**25%**
	TOTAL present in cases		**143**	63	25	64	11	20	40						

Table 8: Resource efficiency measures and business model change

As expected, we see that supply side REMs mainly are related to BMCs in the supply chain and internal processes. As expected, we see that demand side REMs mainly are related to changes in the value proposition. As expected, we see that Life cycle REMs require in many cases a combination of BMCs. What is more interesting though, is that the picture is more scattered than one would expect from a theoretical perspective. It is surprising to see that almost 30% of the supply side REMs involve a change in value proposition and that a large number of demand side REMs also entail a change in Supply Chains and Internal Processes. The rationale for this is that various improvements at the demand side need an improvement of technology (hence supply), or new value propositions provided by a new network of providers (which changes the supply chain).

3.3.4 Resource Efficiency Measures and Implementation Barriers

Like Table 8, Table 10 counts for all 143 cases which IBs were related to what type of REM. Again, cases that combined various REM, the REM that was deemed most dominant in the case analysis in Annex 1 was selected as the REM that would 'carry' the case. We then counted which IBs were related to the implementation of such REM. The result is provided in Table 9.

454

Resource efficiency measure (REM)			Freq.	Implementation Barriers (nominal count)					Implementation Barriers (weighted value presented as % of cases)				
				I	O	B	M	T	I	O	B	M	T
Demand side	Functional sales	FS	5	0	2	2	2	1	0%	40%	40%	40%	20%
	Green products	GP	29	1	5	11	9	10	3%	17%	38%	31%	34%
	Green services	GS	31	11	11	5	15	10	35%	35%	16%	48%	32%
	Service instead of products	SP	13	0	4	9	6	1	0%	31%	69%	46%	8%
	Service substitutes	SS	1	0	1	1	1	0	0%	100%	100%	100%	0%
	Take back management	TBM	12	1	5	1	6	0	8%	42%	8%	50%	0%
	TOTAL in this category		**91**	**13**	**28**	**29**	**39**	**22**	**14%**	**31%**	**32%**	**43%**	**24%**
Life cycle	Cradle to cradle	C2C	7	2	1	1	3	3	29%	14%	14%	43%	43%
	Circular economy	CE	3	0	1	0	2	1	0%	33%	0%	67%	33%
	Industrial symbiosis	IS	10	5	3	4	5	3	50%	30%	40%	50%	30%
	TOTAL in this category		**20**	**7**	**5**	**5**	**10**	**7**	**35%**	**25%**	**25%**	**50%**	**35%**
Supply side	Cleaner production	CP	8	1	2	3	5	3	13%	25%	38%	63%	38%
	Ecoefficiency	EE	9	2	2	3	3	5	22%	22%	33%	33%	56%
	Green supply chain management	GSCM	12	3	6	1	3	5	25%	50%	8%	25%	42%
	Pollution control	PC	1	1	0	0	0	0	100%	0%	0%	0%	0%
	Waste management	WM	2	1	0	1	0	1	50%	0%	50%	0%	50%
	TOTAL in this category		**32**	**8**	**10**	**8**	**11**	**14**	**25%**	**31%**	**25%**	**34%**	**44%**
	TOTAL present in cases		**143**	28	43	42	60	43					

455 **Table 9: Resource Efficiency Measures and Implementation Barriers**

456 Like Table 7, Table 9 gives a rather scattered picture. At the supply side, technical barriers seem
457 to dominate, where at the demand side and for life cycle measures market barriers are the most
458 important. We see however a quite distributed total. It seems that for the implementation of
459 different REMs, institutional, organisational, market, behavioural and technology barriers all can
460 play a role depending on the case, with market barriers being mentioned the most in the case of
461 demand side measures.

462 ### 3.3.3 Resource Efficiency Measures and scope and degree of change

463 In Annex 2, we analysed for each REM the degree of change (incremental or radical) and the
464 scope of change (small BMCs with few actors involved, or larger, more systemic BMCs with many
465 actors involved). Figure 10 plots the REMs against the degree of change and scope of change,
466 leading to four clusters:

467 1. Green dots: Process oriented measures: pollution control (PC), waste management
468 (WM), cleaner production (CP) and eco-efficiency (EE).
469 2. Purple dots: Value offering measures: green(er) products (GP) and services (GS).
470 3. Blue dots: Life cycle measures aiming at radical re-design: green supply chain
471 management (GSCM), industrial symbiosis (IS), cradle-to-cradle (C2C) and circular
472 economy (CE)
473 4. Grey dots: Product-service combinations: services instead of products (SP), functional
474 sales (FS), and take-back management (TBM)

475 Categories low on the y-axis and x-axis (i.e. cluster 1) in principle concern a small change in
476 business model. It concerns e.g. cleaner production and pollution control at the supply side, but
477 also green products and green services (cluster 2) on the demand side. Such changes can often

be achieved within one company or caters to an already existing market. Categories high on the x and y axis (i.e. cluster 4) involve a large change in business model, e.g. involving multiple stakeholders in the supply chain or large changes in the customer interface of the business model, leading to the creation of a new market or the need to strongly persuade customers. This is the case for e.g. functional sales and services instead of products. Plots like Figure 10 often are used in literature to classify options according to complexity of change (e.g. Eco-innovation Observatory (2013), OECD (2009), e.g. Hopwood et al., (2005), Tukker and Tischner, (2006a). Simply said, such literature suggests that options in the upper right corner are considerably more difficult to implement than those in the lower left corner in Figure 10.

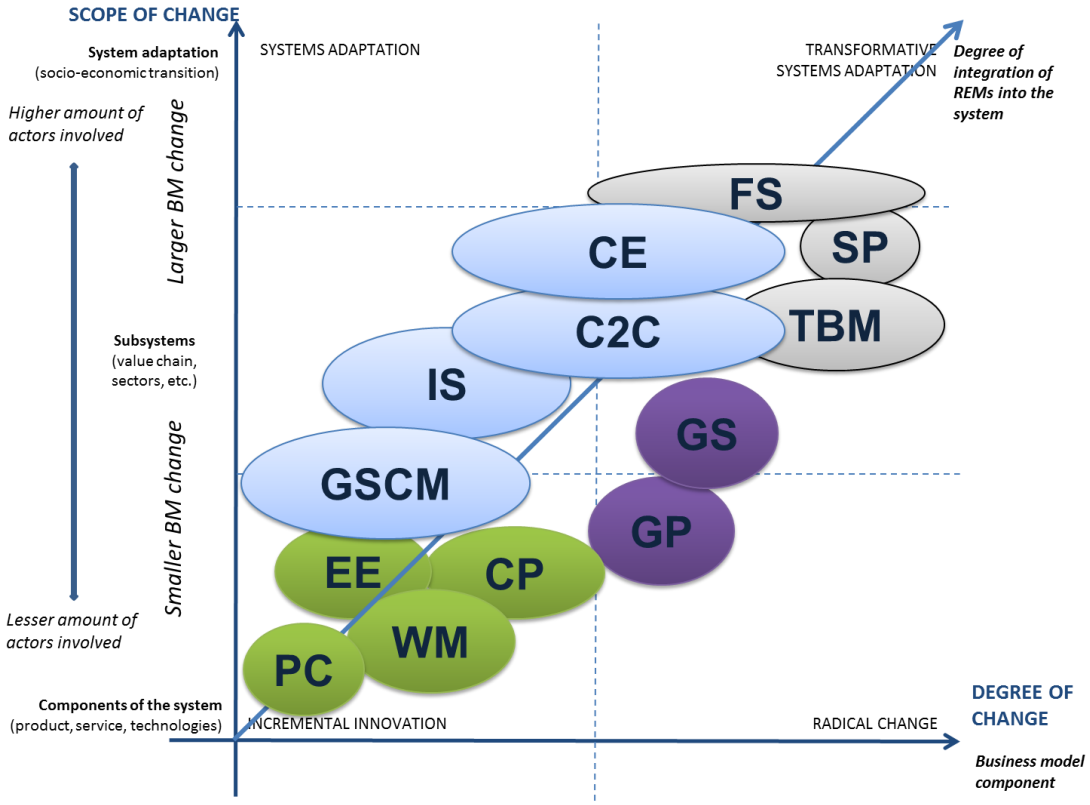

Figure 10 Degree of change and scope of change per Resource-Efficiency Measure

Following up on the count made in Table 9, we hence additionally created a count in which we analysed ,which IBs occurred for which cluster of REMs (see Table 10). As for all counts made in this chapter, we did not analyse relations statistically. The table however makes clear that the distribution of barriers is fairly equal among the categories. Our analysis does not allow for drawing the conclusion that REMs that reflect a high degree and scope of change (category 4), face more implementation barriers than others. With some caution one could conclude that REMs with a high degree and scope of change face less technical barriers than others. Given the limitations of the approach, the analysis must be interpreted with care. It is still very well possible that the same *type* of barrier (like a technical one) is much more difficult to overcome in one case than another. Our simple counting approach, while useful since applied for the first time in this field, should be replaced in follow-up research by a more sophisticated approach that takes this 'difficulty' factor into account.

Cluster colour code	Resource Efficiency measure (REM)			Freq.	Barriers (nominal count)					Business Model Change (weighted value presented as % of cases)				
					I	O	B	M	T	I	O	B	M	T
1: Green	Supply side	Cleaner production	CP	8	1	2	3	5	3	13%	25%	38%	63%	38%
	Supply side	Ecoefficiency	EE	9	2	2	3	3	5	22%	22%	33%	33%	56%
	Supply side	Pollution control	PC	1	1	0	0	0	0	100%	0%	0%	0%	0%
	Supply side	Waste management	WM	2	1	0	1	0	1	50%	0%	50%	0%	50%
		TOTAL in this category		**20**	**5**	**4**	**7**	**8**	**9**	25%	20%	35%	40%	45%
2:Purple	Demand side	Green products	GP	29	1	5	11	9	10	3%	17%	38%	31%	34%
	Demand side	Green services	GS	31	11	11	5	15	10	35%	35%	16%	48%	32%
	Demand side	Service substitutes	SS	1	0	1	1	1	0	0%	100%	100%	100%	0%
		TOTAL in this category		**61**	**12**	**17**	**17**	**25**	**20**	20%	28%	28%	41%	33%
3: Blue	Life cycle	Cradle to cradle	C2C	7	2	1	1	3	3	29%	14%	14%	43%	43%
	Life cycle	Circular economy	CE	3	0	1	0	2	1	0%	33%	0%	67%	33%
	Life cycle	Industrial symbiosis	IS	10	5	3	4	5	3	50%	30%	40%	50%	30%
	Supply side	Green supply chain management	GSCM	12	3	6	1	3	5	25%	50%	8%	25%	42%
		TOTAL in this category		**32**	**10**	**11**	**6**	**13**	**12**	31%	34%	19%	41%	38%
4:: Grey	Demand side	Functional sales	FS	5	0	2	2	2	1	0%	40%	40%	40%	20%
	Demand side	Service instead of products	SP	13	0	4	9	6	1	0%	31%	69%	46%	8%
	Demand side	Take back management	TBM	12	1	5	1	6	0	8%	42%	8%	50%	0%
		TOTAL in this category		**30**	**1**	**11**	**12**	**14**	**2**	3%	37%	40%	47%	7%
		TOTAL present in cases		143	28	43	42	60	43					

Table 10: Resource Efficiency Measures clustered by degree / scope of change and Implementation Barriers

3.3.4 Business Model Change and Implementation Barriers

Finally, in a similar way as done in Tables 8, 9 and 10, we made counts of the type of IBs that were identified in a case in relation to a specific category of BMC (related to the columns 'BMC' and 'Barriers' in table 5-7, and in Annex 2). The data including the nominal count of each case are included in the Supporting information. A summary of results is presented below in Table 11. The results are presented as spin diagrams per category of BMC, see Figure 11.

Component BM	TOTAL count BMC*	Total Count Barriers**					Total Barriers as % ***				
		I	O	B	M	T	I	O	B	M	T
		28	43	42	60	43	28	43	42	60	43
Value Proposition	64	9	19	25	35	15	14%	30%	39%	55%	23%
Supply Chain	63	15	27	13	23	19	24%	43%	21%	37%	30%
Internal Process	25	11	4	5	7	16	44%	16%	20%	28%	64%
Customer Interface	11	2	7	6	6	0	18%	64%	55%	55%	0%
Financial Model	20	1	10	11	11	2	5%	50%	55%	55%	10%
Total	183	38	67	60	82	52					

Table 11: Change in business model components and Implementation Barriers

NOTES:
(*) Total counting were obtained from adding all frequency counts for all REMs as reported in row 42 of the table 8.
(**) Total counting were obtained from adding all frequency counts for all REMs as reported in row 42 of the table 8.
(***) All variables (barriers) were assumed to have the same weight (of 20%). Hence no measure of normalisation was used..

Value proposition (VP) BMCs relate to market barriers and behavioural barriers, because of the positioning of a novel product and/or service in the market.

BMCs in the supply chain (SC) appear to be related with organisational barriers, because of the arrangements which need to be made and possible cooperation with suppliers and other companies in the supply chain. In the cases where a change in the supply chain is combined with a change in the value proposition, market barriers are associated because of introducing a different product or proposition in the market.

Technological barriers have to do with new technology to transform the production process. The influence of technology-related barriers is evident for BMCs in the internal process (IP). Institutional barriers are related to regulations on for instance, waste management. The latter type of barrier was also reported to have an influence on changes in internal processes.

BMCs in the customer interface (CI) are often related to a change in the value proposition. Related barriers are mainly organisational and behavioural barriers, for instance because of the required organisational changes in order to provide the novel product and/or service. BMCs in the value proposition and customer interface can be market or customer driven.

In the studied cases BMCs in the financial model (FM) appear to be a result of changes in one or more of the other BMC categories. Even in possible finance-driven cases, a change in the financial model appears not to be the initial change, but a result of a change in for instance the value proposition. For example, when introducing services instead of products or functional sales, a new revenue model will be introduced. Therefore, as a result changes in the financial model of reported cases can be related to market, organisational and behavioural barriers.

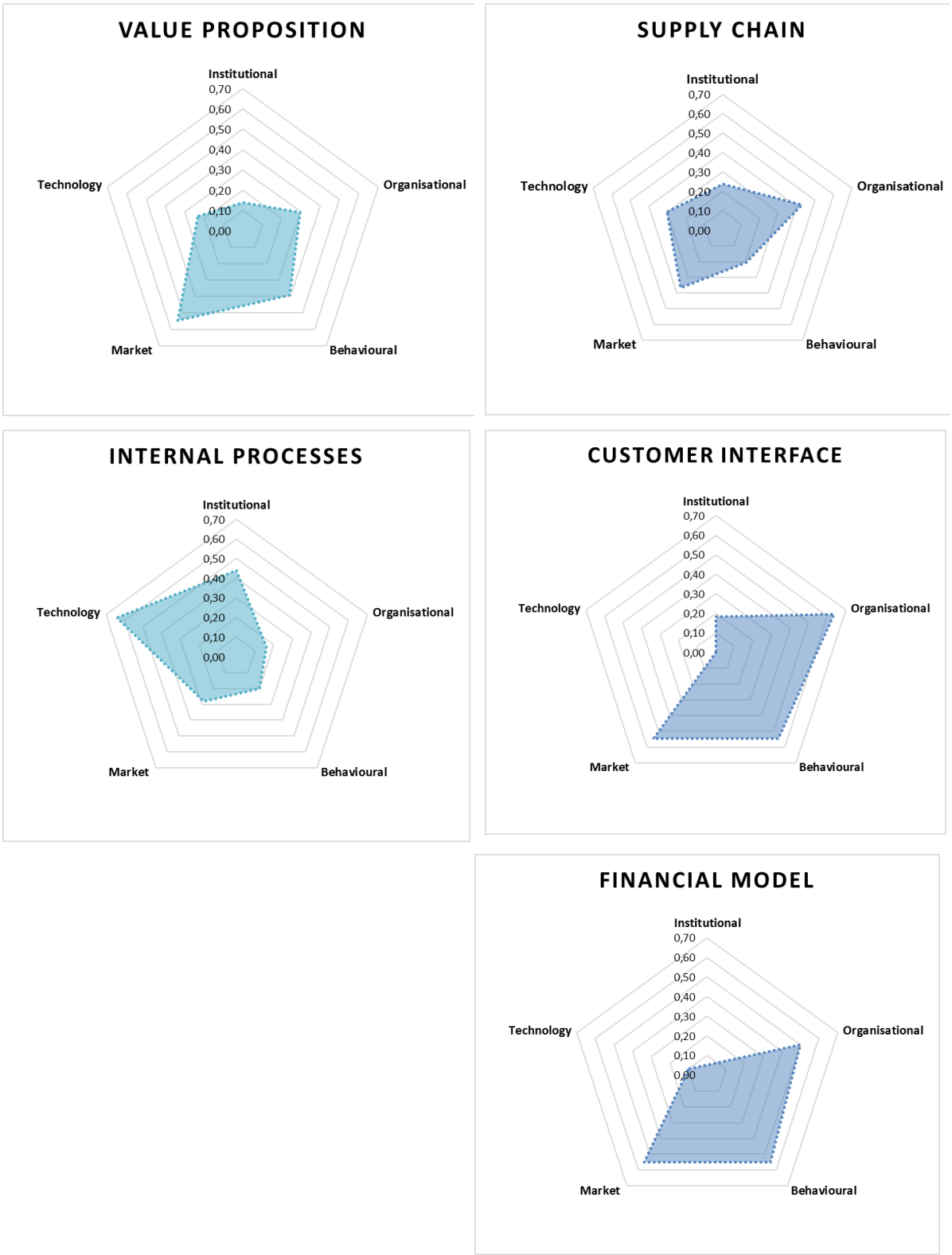

Figure 11 Relation between categories of Business Model Change and Implementation Barriers (SC=supply chain; IP = internal processes; VP = value proposition; CI = customer interface; FM = financial model).

NOTES: Percentage values (in a scale 0 to 1)reported in table 11 were used to produce the illustration of each radar. For this figure a normalised value was not used to estimate the relative importance of the relation between Business Model Change and Implementation Barriers for all 143 cases.

4 Discussion and conclusions

This paper analysed 143 cases of the implementation of various Resource Efficiency Measures (REMs), the related Business Model Changes (BMCs), and Implementation Barriers (IBs). While the literature on business models is in general mature with about 20,000 papers published, this cannot be said of the literature on business models in relation to resource-efficiency and a circular economy. Just over 200 papers have been published in this field, mostly of a conceptual nature and analysing individual case studies.

The present paper is probably the first attempt to analyse a broad set of cases in the field of resource efficiency and circularity. We did so by making a classification of REMs, BMCs and IBs. This allowed us for 143 cases to analyse which REMs, BMCs, and IBs were at stake and how they are related. Being one of the first following this methodological approach in this field, our work suffers from several limitations. An important one may be a bias in cases.

The 143 cases come from a broad set of sectors and cover a broad set of REMs and BMCs. Yet, we collected them from sources such as the EU's Eco-innovation Observatory and the Ellen MacArthur Foundation, which may be biased to present motivating success stories, rather than implementation failures (a variation of the well-known fact that scientific literature in general presents successful experiments, rather than failures). Another important limitation is that we merely made counts of numbers of REMs, BMCs and IBs. The material available did not allow us to analyse if there was a large difference in how difficult it would be to overcome an IB, for instance. Nor did we gain insight into the business value of REMs and BMCs (e.g. impact on return on investment, cost savings, etc.) – high potential financial gains can motivate firms to try to overcome considerable barriers. While this analysis of 143 cases is an important step in research on business models and resource-efficiency, and has provided some new insights, it is obvious that follow-up research should be more sophisticated and overcome these methodological limitations.

Having this in mind, we now will answer the research questions posed at the start of this paper in section 2.

What types of measures do companies tend to implement when they aim to realise resource-efficiency?
In section 3.2.1 we showed a large number of success cases, and the variety in REMs was high. We did not find that specific categories such as cleaner production or green products dominate, despite the fact that the literature often suggests such REMs are easier to implement than more complex REMs like industrial symbiosis or cradle-to-cradle. Our findings suggest that businesses see a lot of different REMs as potentially viable and hence we see efforts to implement all the types of REMs we included in our analysis.

What type of Business Model Changes do different types of Resource Efficiency Measures require?
Section 3.3.2 analyses which BMC is required for which REM. Our analysis confirms some points that theoretically could be expected. Supply side REMs such as cleaner production, pollution control and waste management improvements mainly are related to BMCs in the supply chain and internal processes. We see further that demand side REMs such as the implementation of

services instead of products and take back management mainly are related to changes in the value proposition. Further, we see that Life cycle REMs in many cases require a combination of BMCs. However, often the picture is also more diffuse. We see almost 30% of the supply side REMs involve a change in value proposition and that a large number of demand side REMs also entail a change in Supply Chains and Internal Processes. The rationale for this is that various improvements at the demand side need an improvement of technology (hence supply), or new value propositions that are provided by a new network of providers (which changes the supply chain).

How radical are the different Resource Efficiency Measures and what are the main Implementation Barriers?

Figure 10 classifies REMs according to scope of change and degree of change, since literature often suggests that changes that cover a large number of actors and that are radical are relatively difficult to implement. To test this hypothesis, we counted which barriers played a role in the implementation of which REMs (table 9 and 10). This led to some expected findings, such as that at the supply side, technical barriers seem to dominate. At the same time, at the demand side and for life cycle measures market barriers are the most important. Overall, however, we see that institutional, organisational, behavioural, market and technical barriers can all play a role. Over the 143 cases analysed, we cannot single out a factor that is dominant for specific REMs. Indeed, we could not identify a pattern in which REMs related to a large scope and high degree of change encountered more implementation barriers than others.

How do Implementation Barriers relate to the type of Business Model Change?

When we related BMCs to IBs a somewhat more differentiated picture arises, such as that Supply Chain related BMCs are mainly related to organisational challenges, and that BMCs in the Financial Model are mainly related to behavioural barriers.

To conclude, our meta-analysis results in a quite differentiated and subtle overall picture of business model innovation for resource efficiency. Simple statements such as 'radical REMs are more difficult to implement than simple REMs' could not be confirmed. It seems that for the implementation of different REMs, institutional, organisational, market, behavioural and technology barriers all can play a role depending on the case. This is from a theoretical perspective not surprising. Transition theory (Grin et al, 2010) indicates that institutional impediments can be important in relation to radical change. The same theory stipulates that existing regimes are mature, and hence have market advantages over novel practices and value propositions. Similarly, eco-innovation studies have encountered manifold cases of complementarities between organisational, institutional and technical change (e.g. Mazzanti and Zoboli, 2008, Díaz López and Montalvo, 2015), which is a manifestation of the web of constraints hindering the "greening" of innovation and change (Kemp and Soete, 1992). Even simple improvements like a new recycling technology and new circular business can encounter institutional barriers, such as when 'waste' to be recycled cannot be exported due to the fact that it is still legally classified as 'waste' and not a 'resource'. Technology for new REMs can also be immature. New REMs can go contrary existing behaviours. And it depends very much on the organisational capabilities of a firm, for instance if new REMs can be implemented easily because the firm is used to experiment and create new coalitions, or whether organisational

barriers will be encountered, because the firm lacks these capabilities - see e.g. Tukker (2015), and work of the 'learning school' exemplified by Hamel and Prahalad (1990). The barriers hence seem to a large extent case and company specific.

We have encountered few similar analyses over such a large number of cases in the sustainable business modelling literature. In that sense our research has made a clear contribution to insights in this field. Nevertheless, our approach also has limitations. The reviewed cases are weak in reporting the barriers that had to be overcome upon implementing the business model reported. In particular, the deeper barriers (internal behavioural barriers) are hard to extract from the evidence in such literature. Furthermore, business model attempts that failed, often do not reach the state of being reported. This implies that our analysis is likely to be biased towards success cases, and hence that any barriers that are specific for failure cases will be underreported. Also, our finding that most barriers are case and company specific is to some extent unsatisfactory. Further research should be able to reveal more general patterns and classifications of REMs, BMCs, company typology and barriers that can be related to each other.

Acknowledgements

This paper was written in the context of EU Grant Agreement no. 308371, 7th Framework program, ENV.2012.6.3-2 - Policy Options for a Resource-Efficient Economy (POLFREE). Julianna Becker, Frank Berkers, Beste Eris, Wietske Koers, Hans van Vliet of TNO made major contributions to the report underlying this paper, particularly concerning the frequency count and review of cases from the literature. The authors have no competing financial interests to declare.

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Annex 1 - Literature overview and collected case studies. Source: own elaboration

Document	Short description of content	Cases Studies (Name, Year, Country)
Stubbs and Cocklin (2008)	Seminal paper presenting a framework of a "sustainable business model" based on two case studies.	Interface (NA, USA), Indigo (NA, Australia)
COWI (2008)	Report looking at eight cases of business models and the success factors. Business models are aimed to reduce resource use.	PFI Street Lighting (NA), Houghton (2003), ASML (NA) –all three, Global, Dong Energy (NA, Denmark), PPG industries (1998, Poland), General Motors (NA, USA), Mobility car sharing (2008, Switzerland), TAC Energy Solutions (NA, Sweden).
European Commission (2009a), (2009b, 2010, 2011, 2012, 2013a, 2013c, 2009c, 2009d)	EU website which provides an overview of best practices for eco-innovation across Europe, as well as across sectors. Presents dozens of selected cases includes eco-innovations in transport, water, cities, footwear, electricity, etc.	Grundfos (NA, Denmark), Tallinn (2013, Estonia), Xeros (2013, UK), Naturalista (2012), Samsung (2009), both Spain, Bionic Power (NA, Canada), Eco-Cities (NA, Global), Heerlen-mine water power station (2008), DutchRainmaker (2010), both Netherlands.
EIO (2010), (2012, 2013)	A series of reports collecting and analysing information on eco-innovation trends and markets in Europe and around the world.	Werner Sobek (NA), Slow tourism (NA), both global. AirDeck (2006), Econation (2009), both Belgium, Curitiba (NA, Brazil), DigiEcoCity (2007, Finland), Tamyca (2010, Germany),Green ambulance Stockholm (2005), Hammarby (1998), both Sweden, Eastgate (1996, Zimbabwe),
WRAP (2010)	Report with a case study of infrastructure (motorways) demonstrating the benefit of an integrated approach to resource efficiency.	A-one+ Integrated Highway Services (NA, UK).
von Geibler et al. (2011)	Report containing an international perspective on technologies and products with resource efficiency potential. Presents various technologies and examples of implementation.	Groasis Waterbox (2010, Netherlands), Universal Charging Solution (2009, UK), International Synergies (2005), Oyster (2009), Seawater Greenhouse (2009), all three UK.
Greenovate! Europe (2012)	Report summarising experiences companies within the manufacturing industry have had in regards to improving resource efficiency. It also highlights trends in the industry towards resource efficiency.	Aubineau Constructeur (NA, Global), Bourgeois (NA, France), TRI-VIZOR (2010), Volvo Trucks (2009), both Belgium.
Sommer (2012)	Book providing an assessment of business model transformations across various sectors with several case examples. The report looks at the types of transformations and the state of transformation per sector	Basf Ecoflex (2012), Basf Ecoefficiency (NA), Daimler (NA), Better place (2010), BMW (2007), Siemens (2009), Maersk Line slow steaming (NA), RWE (NA), all eight Global, Frosta (2003, Germany), Toyota (NA), Google (2008), both USA, Maersk Line C2C containers (2011, Denmark).
Bisgaard et al. (2012)	Report compiling case studies identifying companies having transformed their business model to greener alternatives.	IKEA (NA), PolyPlank core plugs and building systems (NA - 2 cases), Envac Optibag (NA), Trimo (NA) all four Global, Yalumba (NA, Australia), Netcycler (2008, Finland), Eco2Distrib (2011, France), E.ON (NA), SafeChem Europe (1992), Car2Go (2008), Schüco (2011) –all three Germany, Gabriel (NA, Denmark), Philips (NA), Desso (NA), Van Gansewinkel (NA) – all three Netherlands, Biototal AB (NA), ChargeStorm (2009), Econova (NA), HTC Cleaning Technology (2005), Plantagon International (2008), Qlean Scandinavia - construction, industry & surface (2002 – 3 cases), Stena Metall (NA), Svensk Biogas i Linköping (2003), Toyota Material

Document	Short description of content	Cases Studies (Name, Year, Country)
		Handling (NA) – all eleven Sweden, Matorka (NA, Iceland), Siemens Building Technologies (2007, Switzerland), Steelcase (NA, USA), Eastex Materials Exchange / Bright Green (2004, UK).
BIS (2012)	Report documenting case studies regarding resource efficiency across several sectors. The report focuses on the potential for resource efficiency to increase savings for businesses (looks at successful examples).	AeroThermal (NA), Atherstone Accident Repair Centre (NA), ENER.G (NA), Argos Direct (2008), Sainsburys (2008) – all UK.
Ellen MacArthur Foundation (2012), (2013),	Report assessing the impact of moving to a circular economy in the consumer goods section. Analysis includes an investigation into business implications, applications of circular economy, and up-scaling.	Bosch Siemens Hausgeräte (NA), Caterpillar (2004), Cisco (2001), Nespresso (1991), PUMA (2013), SABMiller (NA), Tomra (1972), Sodastream (2007), Marks & Spencer (2007), Waste Producer Exchange (2011) - all Global; MBD Energy (2012, Australia), Ecover (1980, Belgium), Veolia (2012, Belgium - Sweden), Ostara Nutrient Recovery Technologies (2005), Standard Mould Bottle (NA), Solegear bioplastics (2005), all three Canada, Guigan (NA, China), Qmilch (2011, Germany), ReFood (1985, Germany and Netherlands), Aquafil-Desso (2008, Italy), Electrolux (1999, Sweden), Pharma Machines (1975, UK-Germany), Uniqlo (2011), Kajima Construction (NA), both Japan, Patagonia - Teijin (2005, USA-Japan), Pay per wash-Electrolux (NA),Turntoo (2010), PlantLab (2010), Thermfos (NA), all four Netherlands, Borregaard (1989, Norway), London Bio Packaging (2005), Brantano (2008), ASDA (2013), DHL (2010), Cyberpack (NA), Brocklesby (1987), Wornagain (2005), Tamar Energy (2012), all eight UK, Ecovative Design (2007), Seattle & San Francisco (NA), The Plant, Chicago (2012), Essential Dynamics (2011), Zipcar (2000), Appliance Warehouse of America (1997), Oberon FMR (2010), all six USA, Rohner (2010, Switzerland).
Weterings et al. (2013)	Book outlining trends and changes in resource efficiency across several sectors, including strategy and policy implications. Sectors with specific focus and cases include: built environment, food sector, process industry, metal and consumer electronics industry, fashion and furnishing.	Park 20/20 (2012), Green Chemistry Campus (NA), SITA (NA), DyeCoo textile systems (2008), Daas Baksteen (2001), Dutch Phosphate Value Chain Agreement (NA), Teeuwissen (NA), Dutch aWEARness (NA), DSM (NA) -all Netherlands.
Websites	Useful cases found in specialised websites. Often obtained from references in the documents above.	Energy Floors (NA, Global)

Note: NA= year not available

Annex 2, 3, 4.

See Excel file.