PBL Netherlands Environmental
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# CIRCULAR ECONOMY: MEASURING INNOVATION IN THE PRODUCT CHAIN

**Policy Report**

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and Aldert Hanemaaijer**

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# FINDINGS

At the request of the Dutch Ministry of Infrastructure and the Environment, PBL Netherlands Environmental Assessment Agency and Utrecht University have explored ways to measure progress of a transition towards a circular economy in product chains. This study focuses on identifying *what* needs to be measured, rather than *how* measuring should be carried out. We developed a conceptual framework about the role of innovation in circular economy transitions (CE transitions) in product chains, and applied it to a number of cases. The framework and case applications serve to determine what type of information is needed to measure the progress of CE transitions in product chains.

The second Dutch coalition government under Prime Minister Mark Rutte aims to establish a *circular economy*. The Dutch Ministry of Infrastructure and the Environment describes a circular economy as an economic system based on the reusability of products and product components, recycling of materials, and on conservation of natural resources while pursuing the creation of added value in every link of the system. The government wants to promote the CE transition through better closing of product and material chains.

This study targets product chains. A product chain tracks products from the extraction of natural resources to waste treatment after they have been discarded. Recovering materials from a discarded product often requires large amounts of energy, and pollution and mixing of materials reduces their quality which means that very often recycled (secondary) materials cannot be applied again for the same type of product. Frequently, these materials do find an application in other products with lower quality requirements. Therefore, a *material chain* may be longer than a single *product chain*.

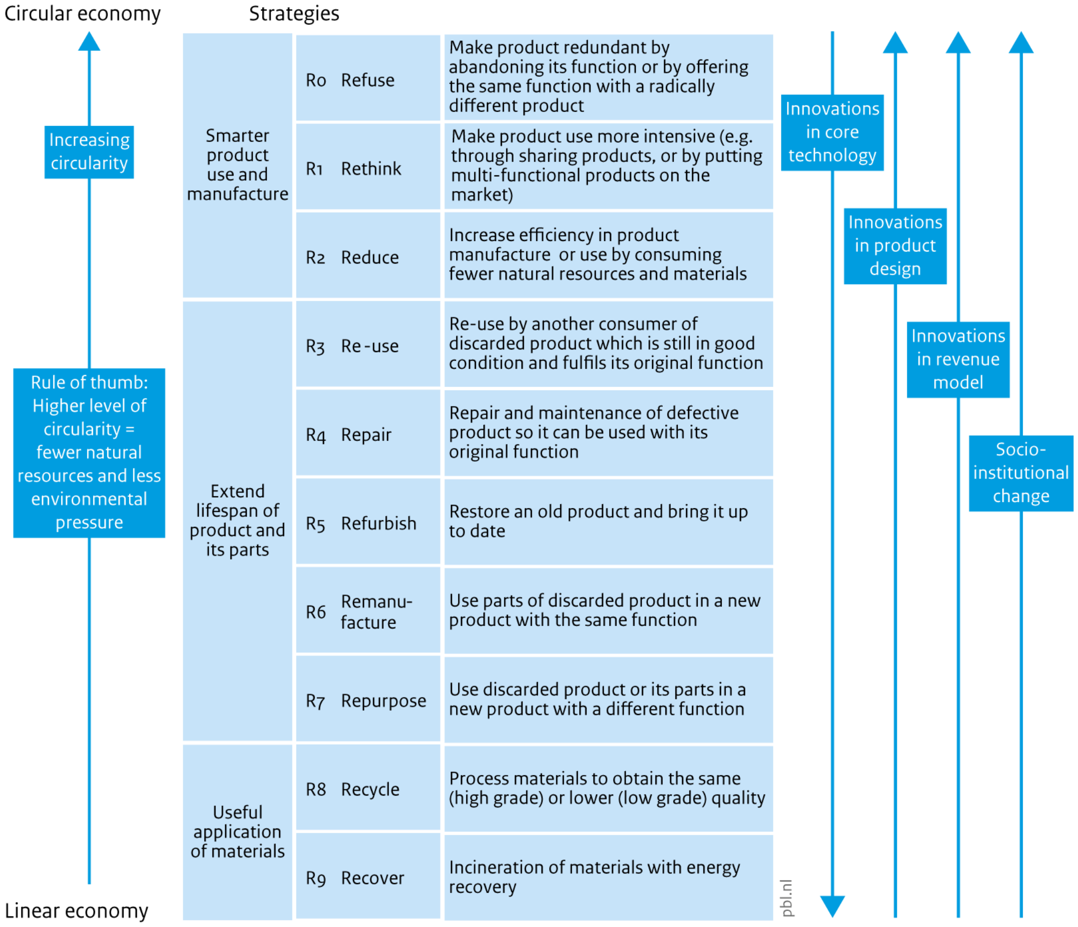
In a circular economy, the materials recycled from a discarded product ideally retain their original quality so that they can be applied again in a similar product. As a result, no additional natural resources are needed to produce materials, and discarded products no longer become waste. This *ultimate circularity*, in which a product chain is closed because the materials can be applied over and over again (Figure 1), is probably not feasible in practice. It is, however, the ideal situation which CE transitions aspire to bring about.

## More circularity is better for the environment

Several circularity strategies exist to reduce the consumption of natural resources and materials, and minimise the production of waste. They can be ordered for priority according to their levels of circularity (Figure 1). Smarter product manufacturing and use, for example by product sharing, are generally preferred over extending the lifetime of products, because this product being used for the same product function or more users being served by one product (strategy with high circularity). Lifetime extension is the next option and is followed by recycling of materials through recovery. Incineration from which energy is recovered has the lowest priority in a circular economy, because it means the materials are no longer available to be applied in other products (*low-circularity* strategy). As a rule of thumb, more circularity equals more environmental benefits.

A higher level of circularity of materials in a product chain means that those materials remain in the chain for a longer period, and can be applied again after a product is discarded, preferably retaining their original quality. As a result, in principle, fewer natural resources are needed to produce *new* materials required for manufacturing products and for their subsequent use. Avoided resource extraction and production of materials benefit the environment. There are of course exceptions to this rule of thumb. For example, making a product chain more circular may lead to increased natural resource consumption, usually in the form of (fossil) fuels. This occurs in chemical recycling of contaminated plastics which usually requires relatively large amounts of energy to decompose the material to its initial

Figure 1
**Circularity strategies within the production chain, in order of priority**




Source: RLI 2015; edited by PBL

building blocks, and then synthesise these building blocks back into material (back-to-monomer recycling). Another example is intensifying product use, by facilitating access to the use of a product (i.e. product sharing or multi-functional products), which may lead to unintended additional forms of use. Car-sharing may motivate people without cars to opt for driving in situations they formerly would not have. It is advisable to examine the possibilities of rebound or secondary effects, but generally speaking, more circularity in a product chain leads to reduced consumption of natural resources and materials, and consequently to fewer environmental effects brought about by that product chain, as well as in related product chains.

## Three types of innovation in product chains

CE transitions may need innovation and socio-institutional change. Innovation can take place in technology, product design and revenue models. Socio-institutional change involves reviewing written and unwritten rules, customs and beliefs. Three types of CE transitions may be distinguished with regard to the use of technology in product chains:

1. CE transitions in which the emergence of specific, radically new technology is central and shapes the transition. This means radical innovation in core technology, i.e. the specific technology around which a product is centred. Socio-institutional change is needed to

give the new technology a place in society. A typical example is the recent emergence of bioplastic which has already secured its place.

2. CE transitions in which socio-institutional change is central and where technological innovation plays a secondary role (incremental innovation in core technology). A good, perhaps somewhat extreme example is that of packaging-free shops.

3. CE transitions in which socio-institutional change is central, but are facilitated by enabling technology. An example is the transition to what has become known as the *sharing economy*. This transition from owning a product to purchasing its services primarily involves socio-institutional change, but this is not possible without information technology to link service providers and users.

There is a major difference between the type 3 transition on the one hand, and types 1 and 2 on the other. In contrast to types 1 and 2, achieving a type 3 transitions needs enabling technology of a *generic* character, such as information technology, or new materials. Type 3 transitions are promoted by technology development in other areas of knowledge than those specific to a given product chain.

When monitoring progress towards a circular economy, it matters which type of CE transition is envisaged and what roles are being played by socio-institutional change and innovation. Besides innovation in technology supporting the three types of CE transitions, this report also looks at innovation in product design and revenue models.

## Radical technological innovation not always needed for CE transitions

This report evaluates a large number of cases in which CE transitions in product chains are central. For each case, the study establishes the circularity strategies, the role of socio-institutional change (changes in written and unwritten rules, customs and beliefs) and the role of innovation in technology, product design and revenue model. The evaluations show that radical technological innovation is mainly of interest for recycling. In most cases, this involves adapting an existing recycling technique to the specific quality requirements of the product in question, following a process of incremental technological innovation. Such adaptations may demand substantial efforts from the companies involved, but they can be made by using existing technological knowledge. When the focus is on radically new technology, the situation for CE transitions is rather different, because radical innovations emerge from a fundamentally new knowledge base and lead to a substantially different product. Successful implementation of radical technological innovation requires a context that supports innovation. We call this the building of a new *Technological Innovation System*. Incremental technological innovations arise from existing knowledge for which technological innovation systems are already present. These systems simply need to be adapted. Radical technological innovation is easier to monitor than incremental technological innovation, since the emergence of a new innovation system is far more conspicuous than adaptations to an existing innovation system.

## Socio-institutional change largest challenge for CE transitions

According to the CE Best Practices' and CE Green Deals' practical cases, recycling usually involves high-grade application of recovered materials into new products and converting biomass waste for useful applications. Generally, recycling does not lead to substantial changes in products which would require socio-institutional change in the form of revisions to written and unwritten rules, and questioning customs and beliefs. These cases under the CE Best Practices and CE Green Deals usually face relatively small obstacles and there is no need for a radical change in the regulatory framework of laws and policies. Nor do they trigger profound changes to our cognitive structures (our understanding of how the world works and what is considered normal), and our normative framework (that which is considered legitimate). However, more radical socio-institutional change is needed throughout the product chain when aiming at strategies for higher levels of circularity. Sharing washing machines and clothes dryers in Dutch apartment buildings, one of the evaluated hypothetical cases, would require a change in the mindset of residents, since at present, privately owned appliances are common in the Netherlands. When sharing involves a usage and service contract, there is an additional requirement for a certain level of organisation of the (association of) owners. Manufacturers and retailers will also need to take planned action geared towards these issues. CE transitions based on higher circularity strategies call for more radical socio-institutional change throughout the whole product chain than transitions based on lower circularity strategies. Such changes are difficult to monitor.

## Measuring CE transitions requires focus on their processes and effects

The evaluation of the roles of innovation and socio-institutional change in CE transitions is used to determine the type of information needed to measure the progress of CE transitions in product chains. It is advisable to distinguish between a transition process and its effects. The process includes all the steps needed to realise a CE transition. The effects are the results of the process with regard to circularity, the environment and the economy. The development of a measuring protocol for the CE transition process would be a beneficial improvement, since until now no clear and workable method has been available. The European Environment Agency (EEA) has already formulated a set of questions to assess circularity efforts, addressing the consumption of natural resources and materials, the use of products and waste treatment issues. These questions focus on the progress of the CE transition at the national level. However, this report deals with CE transitions in individual product chains. Therefore, in this study, the questions of the EEA are adapted to enable the measurement of individual product chains. The study is complemented with additional questions about the CE transition process and the effects on the environment and the economy. Table 1 summarises the questions for monitoring the progress of CE transitions in product chains. These questions are relevant to all types of innovation and socio-institutional change, though strategies for high-level circularity will provide different answers from low-level circularity strategies. High-level circularity strategies more often require socio-institutional changes throughout the product chain, and innovation in product design and revenue model, whereas low-level strategies more often rely on technological innovation.

## Circular economy goes beyond recycling

At present, of all waste generated in the Netherlands about 93% is processed effectively for new uses, with 79% of that volume corresponding to recycling. However, most recycling concerns low-grade solutions, and the consumption of natural resources is still high. Moves forward should preferably include a shift to high-grade material recycling, and substantially higher volumes of product reuse. Almost all the CE Green Deal and CE Best Practice cases examined here, aim at increased volume or higher grade recycling. Along with recycling, other circularity strategies are frequently followed, such as in the lease-a-jeans case and one concerning furniture restoration. However, the strong focus on recycling remains remarkable. This is acceptable as long as recycling is high grade, and the recycled material retains its original quality. The upcycling of biomass waste into useful products also fits in this recycling strategy. However, a more ambitious CE transition towards substantially lower resource and material consumption and less generation of waste will preferably be based on high-circularity strategies, such as smarter manufacturing and use of products, and extending the lifetime of products and product components. Recycling alone, and low-grade recycling in particular, is still closely related to a linear economy.

**Table 1: Diagnostic questions to measure the progress of the process and effects of a CE transition**

| | Diagnostic questions |
|---|---|
| Means | **Mobilisation of means**<br>- Are all relevant product chain partners actively involved in realising CE solutions?<br>- Is there sufficient funding for realising CE solutions?<br>- Are there specific physical means limiting the realisation of CE solutions? |
| | **Knowledge development**<br>- Does the available knowledge suffice to develop CE solutions (with regard to technology, patents, consumer and chain actor behaviour)? |
| Activities | **Knowledge exchange**<br>- Is the level of knowledge exchange on CE solutions high enough in the product chain? |
| | **Experimenting by entrepreneurs**<br>- Are entrepreneurs experimenting sufficiently with CE solutions and revenue models?<br>- Is upscaling of CE solutions already taking place? |
| | **Giving direction to search** (vision, expectations of governments and core-actors, regulations)<br>- Is there a clear vision among product chain partners of the pursued circularity strategy?<br>- Do product chain partners broadly share this circularity strategy?<br>- Does this circularity strategy structure the activities of the product chain partners? |
| | **Opening markets**<br>- Are product chain partners active in creating consumer awareness of CE solutions?<br>- Are companies investing sufficiently?<br>- Does the government have supplementary policies, and do they help in opening markets? |
| | **Overcoming resistance**<br>- Is there resistance against CE solutions (among product chain partners, or in the form of regulatory barriers)?<br>- Is sufficient action being taken to overcome resistance against CE solutions? |
| Achievements | **CE design**<br>- What is the present lifespan of a product and has it increased compared to its original lifespan?<br>- Have products become easier to disassemble?<br>- Does the design foresee the use of recycled materials?<br>- Are the components designed for high-grade recycling (without increasing environmental pressure)? |
| | **Production**<br>- Is the overall (primary and secondary) consumption of materials by companies decreasing?<br>- Do companies use fewer substances which are hazardous to human health and ecosystems?<br>- Is production moving towards lower levels of waste generation?<br>- Are companies moving to CE revenue models with increased reuse of products and components, or models based on providing a service rather than offering a product? |
| | **Consumption**<br>- Is the consumption of CE products increasing (compared to conventional products)?<br>- Do CE products have a longer lifespan or are they used more intensively?<br>- Is reuse of products leading to less waste? |
| | **Waste**<br>- Is the volume of landfill decreasing in favour of incineration?<br>- To what extent is high grade-recycling applied?<br>- To what degree is recycling effective with regard to costs and environment? |
| Effects | **Circularity** (resource efficiency)<br>- Is primary material consumption decreasing (in kg per functional product unit)?<br>- Is primary material consumption decreasing for the whole sector (in kg)?<br>- Is energy consumption in $MJ_{pr}$ for recycling lower than cumulative energy consumption in $MJ_{pr}$ ? |
| | **Environment**<br>For all product groups (over the whole life cycle of a product):<br>- Is cumulative energy consumption in $MJ_{pr}$ decreasing per functional product unit?<br>- Is cumulative energy consumption in $MJ_{pr}$ decreasing for the whole sector?<br>Environmental pressure caused by specific product groups (over the whole life cycle of a product):<br>- Is cumulative environmental pressure decreasing per functional product unit?<br>- Is cumulative environmental pressure decreasing for the whole sector? |
| | **Economy**<br>- Is the added value of products and product services increasing?<br>- Are employment levels in the product chain increasing? |

Source: EEA (2016b); Hekkert et al. (2011); Huijbregts et al. (2006)

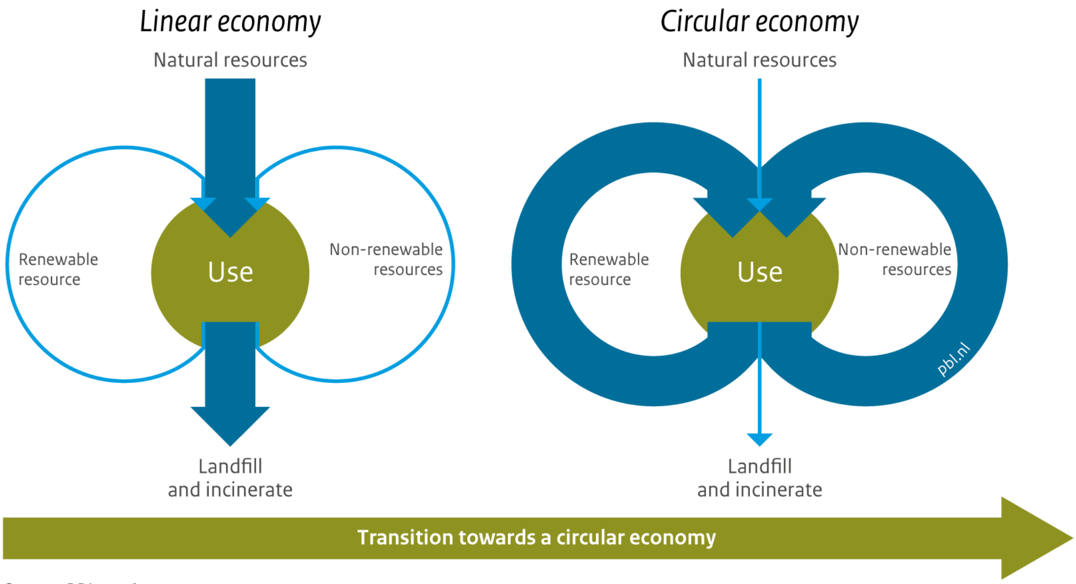
# 1 Introduction

The second government under Prime Minister Mark Rutte specified aspirations towards a circular economy in its 2012 Coalition Agreement. The Dutch Ministry of Infrastructure and the Environment (Ministry of IenM) (IenM) describes it as an economic system based on the reusability of products and materials and on conservation of natural resources while pursuing the creation of value in every link of the system (Ministry of IenM, 2013). Product reuse and material recycling promote conservation because fewer natural resources have to be extracted for the production of new materials. It also means less waste is generated and fewer harmful substances are released into the soil, water and air. In addition, it creates a shift from the use of grey to green resources and energy.

The idea of a circular economy is enthusiastically received in the Netherlands and abroad (Ganzevles et al., 2016). It is seen as a logical alternative to a linear economy. In a linear economy, natural resources are extracted to produce new (primary or virgin) materials which in turn are used to manufacture products that are incinerated or dumped in a landfill after use (Ministry of IenM, 2013, 2014, 2015a).

The Netherlands does not have a linear economy. The Dutch economic system lies somewhere between a linear and a circular economy (Figure 1.1). At present, of all waste generated in the Netherlands, about 93% is processed effectively for new uses, with 79% of the processed volume corresponding to recycling. However, most recycling concerns low-grade solutions, and the consumption of natural resources is still high. Moves forward should preferably include a shift to high-grade systems for material recycling, and substantially higher volumes of product reuse. The national government wants to promote a transition to a circular economy (CE transition) by closing product and material chains more effectively (Ministry of IenM, 2013, 2014, 2015a).

Figure 1.1
**From a linear to a circular economy**




Source: PBL 2016

A product chain includes all steps from extraction of raw materials up to the processing of the discarded product as waste. Recycling materials from a discarded product might be energy intensive, and the recycled materials often cannot be applied again for the same type of product because they are of lower quality due to material mixing and contamination. This is why recycled materials are mostly applied to manufacture products with lower quality requirements, such as road foundation layers in which typically construction and demolition waste is processed. A material chain can therefore be longer than a single product chain. In a circular economy, the materials from a discarded product ideally maintain their original quality so they can be applied again in the same type of product. As a result, no natural resources are needed for the production of new materials, and discarded products no longer become waste. This *ultimate circularity*, in which a product chain is closed because the materials can be applied over and over again (Figure 1), is probably not feasible in practice. It is, however, the ideal situation which CE transitions aspire to bring about.

Different product chains will require different forms of transition towards a circular economy. This is partly due to the diversity of product properties in terms of their function, durability, and composition. These properties may in turn prompt different CE transition goals. This means that CE transition processes can vary greatly with regard to the roles of innovation (in technology, product design and revenue model), and socio-institutional change (in the behaviour of consumers and other actors, and in laws and regulations). The following two examples illustrate this point.

– In the Netherlands, a deposit-refund system is in place for PET bottles larger than 0.5 litres. Collection and recycling of these bottles is relatively effective, because it concerns the waste stream of a single material (OVAM, 2015). A CE transition goal regarding PET bottles might be to revert to the situation before 2006, when large PET bottles were not recycled into secondary PET, but cleaned and refilled (Milieucentraal, 2015). The appropriate technology already exists, but its reintroduction requires a change in the mind-set of companies, and maybe also in national policies. The organisations involved want to cancel the current deposit-refund system, arguing that it is expensive and laborious (Mileucentraal, 2015), although they did commit to increasing the proportion of recycled PET in their bottles (Framework Agreement Packaging, 2013-2022 2012, 2013). At present, the government is leaving the issue to the initiative of companies, albeit subject to the conditions set forth in 2013 in the Framework Agreement Packaging 2013-2022.

– Waste Electrical and Electronic Equipment (WEEE) should be recycled through the organisations Wecycle and ICT Milieu. In practice, however, they only collect about 30% of all discarded equipment. About 80-90% of what they collect is recycled (ICT Milieu, 2014; Wecycle, 2016). Records show that approximately 30% of all electrical and electronic equipment is disposed of in otherwise documented ways, with large household appliances in particular going directly to recycling stations. A further 10% of discarded equipment is exported for reuse and roughly 10% ends up as residual waste (Huisman et al., 2012). There are no data on the destination of the remaining 20%.
  This means there is considerable scope for improving the current collection of WEEE. A CE transition goal could be a different revenue model in which electrical and electronic equipment remains the property of the manufacturers and is returned to them at the end of the equipment's service life. This stimulates the manufacturer to design and manufacture products in ways that favour repair, component reuse and material recycling. It also gives both manufacturers and consumers a more active role in WEEE-collection. This revenue model, however, also calls for a new cooperation agreement between manufacturer and consumer to ensure good service and careful use of electrical and electronic equipment.

## 1.1 About this study

The Ministry of Infrastructure and the Environment is interested in knowing how much progress has been made in the transition from linear to circular product chains. This includes the CE transition process as well as its effects on the consumption of natural resources and materials (i.e. circularity), the environment and the economy. Numerous measuring instruments and indicators are currently available to monitor the *effects* on circularity, the environment and the economy (MVO-Netherlands, 2015; RIVM, 2016; CBS et al., 2014 and EEE, 2016a). However, the challenge lies in compiling the multitude of indicators into a manageable set that adequately reflects the effects of a CE transition. Measuring progress of the CE transition *process* is more difficult. There are, after all, large differences across product chains and their CE transition goals with regard to innovation, required efforts or resistance from actors in the product chain and other socio-institutional factors.

The Ministry of Infrastructure and the Environment has asked PBL to investigate how progress towards a circular economy, which includes both the CE transition process and its effects, can be measured in an individual product chain. PBL has researched this question together with Utrecht University. In this study, we focus on identifying *what* needs to be measured, rather than *how* measuring efforts should be carried out. We have developed a conceptual framework for circular economy transitions in product chains, and applied it to a large number of cases. The framework and its application evaluate the role of innovation in CE transitions. This is instrumental for the next step of determining what type of information is needed to measure the progress of CE transitions in product chains.

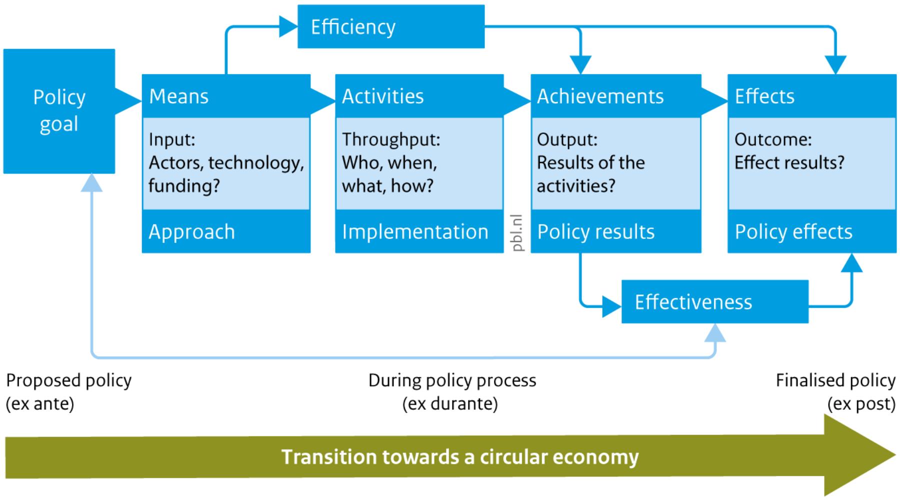
## 1.2 Approach

The conceptual framework is based on the 2005 policy evaluation scheme of the Netherlands Court of Audit (Figure 1.2). Since 1991, Dutch ministries are bound by law to periodically evaluate the results of their policies. The policy evaluation scheme is relevant for all deliberate initiatives towards CE transitions, including those where the government does not play an active role because these also operate towards achieving specifically set transition goals.

The policy evaluation scheme drawn up by the Netherlands Court of Audit (NCA, 2005) is based on the generic policy process. Each policy process consists of four aspects (means, activities, achievements, and effects), which can also be considered process stages (input, throughput, output, and outcome). A policy process starts with setting the policy goal, which, for our purposes, is the CE transition goal for a given product chain. It specifies the aspired achievement needed to realise the transition (CE achievement goals), and preferably also the desired effects on circularity, the environment and the economy (CE effect goals).

A core CE achievement goal within each CE transition is to consume fewer natural resources and new materials in product chains, in other words, to achieve a higher level of circularity. Examples of circularity strategies are high-grade material recycling or product reuse. A circularity strategy can require cooperation from consumers and other chain actors, and adjustments to certain laws and regulations, financing, technology use, product design, revenue model and other matters. If these 'means' are not available at the beginning of the policy process for transition, they may be included as goals, and 'activities' need to be planned to meet the goals. Means, activities and achievements are the main elements of the CE transition process in this study. Unlike the policy evaluation scheme (applied to the policy process), here we distinguish between the process to achieve a CE transition and the effects of the CE transition process on circularity, the environment and the economy.

Figure 1.2
**Policy assessment framework for measuring the progress of the transition towards a circular economy**




Source: Netherlands Court of Audit 2005; edited by PBL

A policy evaluation investigates if the intended policy outputs (achievements) have been delivered and the desired policy effects have been realised (effectiveness evaluation), and whether the cost of the entire policy process is reasonable or not (efficiency evaluation) (NCA, 2005). This study focuses on measuring policy achievements and effects. In other words, it is an effectiveness evaluation, complemented with an examination of activities and means, including chain actors and innovation and budget issues. Means, activities and achievements together constitute the CE transition process. An evaluation of the progress of CE transitions in product chains needs to address both the process itself and its effects on circularity, the environment and the economy.

Innovation plays a special role in CE transitions. Though often associated with technology, in CE transitions in product chains innovation also applies to product design and revenue models. For all three types of innovation to gain a foothold, socio-institutional change might first be needed. In this study, we evaluate the roles played by these types of innovations and socio-institutional change in CE transitions in product chains. This is necessary to be able to determine, in the next step, the type of information needed to measure the transition's progress.

The conceptual framework is the result of integrating the relevant literature, and linking the joint and complementary expertise of the authors. It has been further strengthened by the interaction with its application to a large number of cases in which CE transitions in specific product chains are central. First, hypothetical circularity strategies are formulated and evaluated for two product groups, plastic packaging and electrical and electronic equipment. Then, we identify and evaluate the circularity strategies adopted in two sets of practical cases, 36 CE Green Deals and 32 CE Best Practices, covering a wide range of product chains. The evaluations show whether different circularity strategies for CE transitions in a range of product chains lead to differences in the call for innovation and socio-institutional change.

National government officials who are involved in circular economy policies have agreed to discuss the conceptual framework and its applications, and have provided valuable feedback to further refine our model. Please refer to the Colophon for individual acknowledgements.

## 1.3 Report structure

The conceptual framework is described in Chapter 2. In Chapter 3, the framework is applied to a series of hypothetical and practical cases. Chapter 4 discusses the results of Chapters 2 and 3, and also reflects on the framework's relevance for progress towards a circular economy in the Netherlands and in other countries, seen in the context of international policy. Chapter 5 rounds off the report and presents the conclusions.

# 2 Conceptual framework

The Dutch national policy programme From Waste to Resource (Ministry of IenM, 2013) and the European Commission's action plan for a circular economy (EC, 2015) highlight the importance of being able to measure the progress towards a circular economy. Until now, no generally accepted methods have been devised (EEA, 2016b), but the European Commission has announced a framework for measuring the progress in its CE Action Plan (EC, 2015). It is to be developed by the European Commission together with the European Environment Agency (EEA) and the European Statistical Office (Eurostat) in consultation with the Member States. The question of how to measure CE progress has become relevant in the Netherlands in the context of the recently released government-wide CE policy programme *A circular economy in the Netherlands by 2050* (Ministry of IenM, 2016a), and the CE advice 'Working on a circular economy: No time to lose' (*Werken aan een circulaire economie: Geen tijd te verliezen)* published recently by the Social and Economic Council of the Netherlands (SER, 2016).

## 2.1 Goals for the transition towards a circular economy

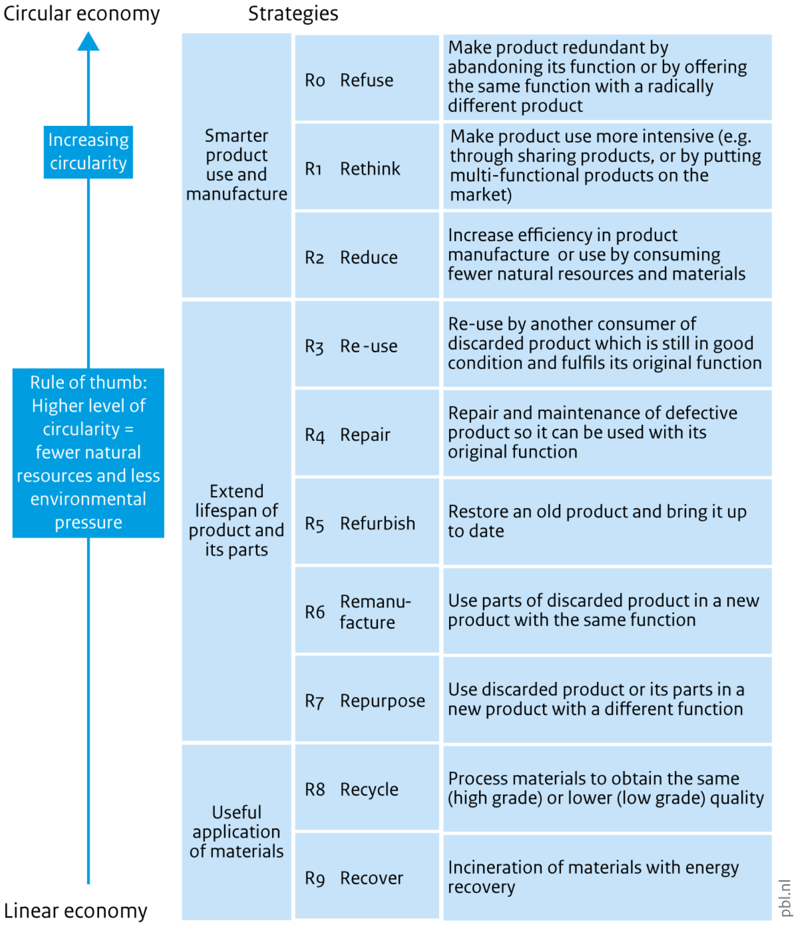
The Dutch Government recently released the Government-wide CE policy programme *A circular economy in the Netherlands by 2050* (Ministry of IenM, 2016a), coordinated by the Ministry of Infrastructure and the Environment, which is the successor of the former policy programme From Waste To Resources (VANG). The Ministry wants to achieve a number of core CE goals with the programme (Ministry of IenM, 2013; 2014; 2015):

- Reduced consumption of natural resources, sustainable resource extraction, and security of supply of resources;
- Less waste, less emissions, more natural capital;
- More earning power, more jobs.

A higher level of circularity of materials in product chains means that, in principle, smaller amounts of natural resources are needed for the production of new (primary or virgin) materials. The avoided material production benefits the environment. In practice, however, increasing the circularly of one product chain may lead to *less* circularity in another. For example, increased application of recycled materials in one product chain might result in fewer recycled materials being available for application in other product chains (Ganzevles et al., 2016). Making a product chain more circular could also require *more* natural resources, often in the form of fossil fuels. This occurs in chemical recycling of highly contaminated plastic through recycling in which the material is decomposed to its initial building blocks, and then these building blocks are synthesised back into material again (back-to-monomer recycling). This usually requires more energy than producing new plastic. Furthermore, intensifying product use by facilitating access or multiple functionality might lead to an unintended additional increase in product use. For example, car-sharing may motivate people without cars to opt for driving in situations they formerly would not have . It is advisable to examine the possibilities of secondary or rebound effects, but, as a rule of thumb, more circularity in a product chain leads to reduced consumption of natural resources and production of new materials, and consequently has fewer environmental effects (Ganzevles et al., 2016).

Various approaches, known as R-strategies, have been developed to achieve less resource and material consumption in product chains and make the economy more circular. Several R-lists exist (CE and MVO, 2015; EMF, 2013; RLI, 2015; Vermeulen et al., 2014). In this study,

Figure 2.1
**Circularity strategies within the production chain, in order of priority**

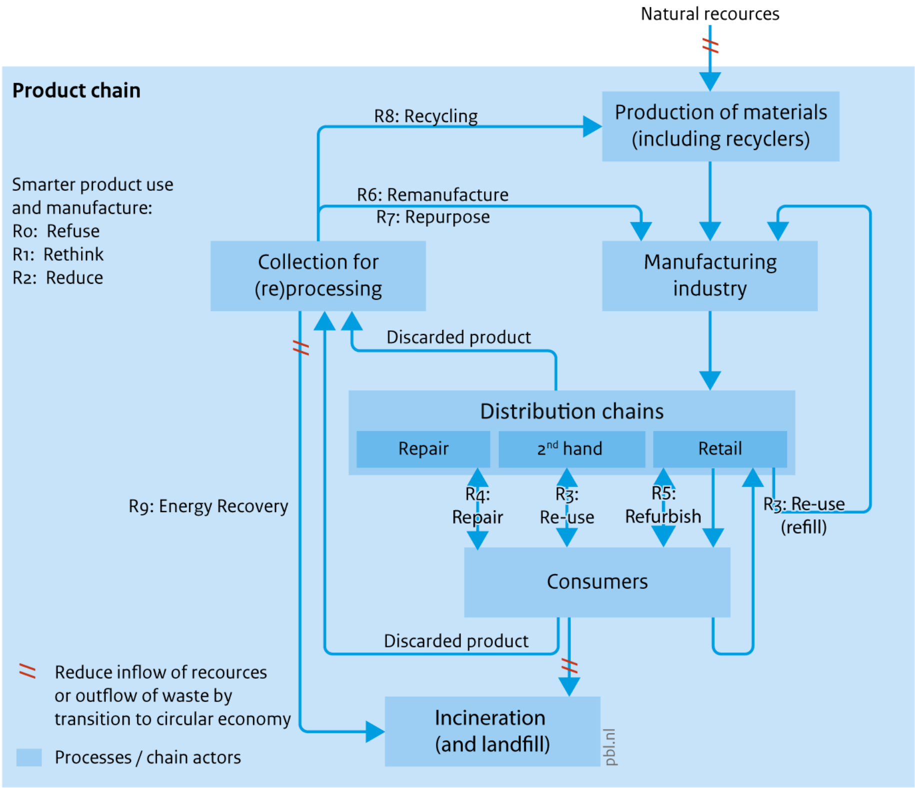



Source: RLI 2015; edited by PBL

we have used the R-list represented in Figure 2.1. All R-lists resemble each other and differ mainly in the number of circularity strategies they put forward. They typically present a range of strategies ordered from high circularity (low R-number) to low circularity (high R-number). R0 and R1 strategies decrease the consumption of natural resources and materials applied in a product chain by less product being needed for delivering a same function. Therefore, R0 and R1 are generally also considered circularity strategies, even though they do not necessarily involve increasing the reuse of products and components, or reapplication of recycled materials.

The available R-lists all elaborate on the *Ladder van Lansink* which establishes a priority order for waste treatment methods. The name is derived from a government resolution which was adopted in 1979. Since then, it has played an important role in Dutch policies on waste treatment, similar to the marked influence of the waste hierarchy on an international level (EC, 2010). The R-list in Figure 2.1 is a combination of the R-lists drawn up by Rli (2015) and Vermeulen et al. (2014). It enables the formulation of circularity strategies in which the primary function of a product is maintained. Figure 2.2 shows the points in a product chain where different circularity strategies are relevant, and the chain actors who play a role in those strategies.

Figure 2.2
**Circularity strategies and the role of actors within the production chain**




Source: PBL

## 2.2 CE Transition and innovation

Sustainability transitions often involve a radically different organisation of societal services, such as the supply of energy, transport and food production and distribution. A typical element in sustainability transitions is socio-institutional change, that is, the changes in regulations, customs, standards, manufacturing practices and consumer behaviour. Sustainability transitions are frequently induced by radical technological innovations though, and therefore often labelled as technological transitions (Geels, 2002). The socio-institutional changes, however, typically make sustainability transitions more complex. After all, a radically different organisation of societal services quickly calls for changes in legislation and policy, in the cognitive structures that underpin people's perception of the world and sense of what is normal, and in the normative frameworks that define what people consider legitimate (Fuenfschilling and Truffer, 2013).

CE transitions differ from most other sustainability transitions in their focus on change from a linear to a circular application of natural resources and materials. Three types of CE transitions can be distinguished with regard to the use of technology in product chains:

1. CE transitions in which the emergence of a specific, radically new technology is central and shapes the transition (radical innovation in core technology). Socio-institutional change is needed to give the new technology a place in society. A typical example is the recent emergence of bioplastic which has already secured its place.
2. CE transitions in which socio-institutional change is at the forefront and technology is not as dominant as in type 1 transitions. Technological innovation plays a minor role or no

role at all (incremental innovation in core technology). A good, perhaps somewhat extreme example is that of the packaging-free shops.
3. CE transitions in which socio-institutional change is central, but which are facilitated by enabling technology. An example is the transition to what has become known as the *sharing economy*. This transition from owning a product to purchasing its services primarily involves a socio-institutional change, but this is not possible without information technology to link service providers and users.

The major difference between the type 3 transition on the one hand, and types 1 and 2 on the other hand, is that the enabling technology needed for type 3 is generic. There is thus no need for specific technological innovation to achieve a type 3 transition. Type 3 transitions are promoted by technology development in other areas of knowledge than those specific to a given product chain. For monitoring progress towards a circular economy, it matters which type of CE transition is being aspired.

**Type 1: CE transitions in which radically new technology is central**
Radically new technology arises from a fundamentally new knowledge base (Shaz and Maw, 2012). The central role of radically new technology leading to a fundamentally different product, features a transition as a struggle between existing and new technology, and between the vested interests around existing technology and challengers and new entrants in the field (Chandy and Tellis, 2000; Penna and Geels, 2012; Shaz and Maw, 2012; Smink et al., 2013). Radically new technology is often expensive, suffers from technical imperfections and usually deviates from various socio-institutional rules and norms (Smink et al., 2014). Existing technology, on the other hand, enjoys the advantage of large-scale application and has network benefits and is therefore often cheap and, after years of co-evolution, perfectly adjusted to various socio-institutional structures (Kemp, 1994; Unruh, 2000). The interests around existing technology are considerable, and established players act strategically to protect their positions. This unequal struggle is difficult to win by radically new technology (Wilson, 2012).
Hekkert et al. (2007) suggest that radically new technology should go through the process of building-up the same perfect socio-institutional embedding as existing technology enjoys. The establishment of the Technological Innovation System they have put forward is a time-consuming and risky process, which largely accounts for the slow and uncertain progress of technological transitions. For monitoring, it needs to be identified to what extent a new technological innovation systems has been built-up. If the development of radically new technology to manufacture a substantially different product takes place under a new Technological Innovation System, the results will be perfectly distinguishable from the output of existing technology with its conventional products and innovation systems.

**Type 2 and 3: CE transitions in which socio-institutional change is central**
Radically new technology is less relevant for transitions in which socio-institutional change is central. Such transitions can usually rely on simply adapting existing technology. This kind of incremental technological innovation, leading to modifications to existing products, leans on the existing knowledge base and takes place within an existing innovation system. They do not need a completely new innovation system to be built up. For example, it is possible to design, without fundamentally new knowledge, a washing machine that lasts longer, is easier to repair and can be readily disassembled at the end of its lifespan. This is technologically far less invasive than developing a radically new technology, leading to a fundamentally different product grounded in a fundamentally new knowledge base and within a new innovation system.
CE transitions around incremental technological innovation lead to adaptations to an existing product within an existing innovation system. Consequently, this makes the adapted products less easy to distinguish from their previous versions. After all, there is little technological difference between the old and the new product, and no new innovation system has had to be built. Here, to keep track of progress, the subtle changes in existing innovation

systems need to be monitored, rather than the development of distinct new innovation systems.

Characteristic for all three types of CE transitions is a change in the innovation direction from a linear to a circular application of materials. This distinguishes CE transitions from most other sustainability transitions in which radical technological innovation is often central, but the circular application of materials hardly plays a role.

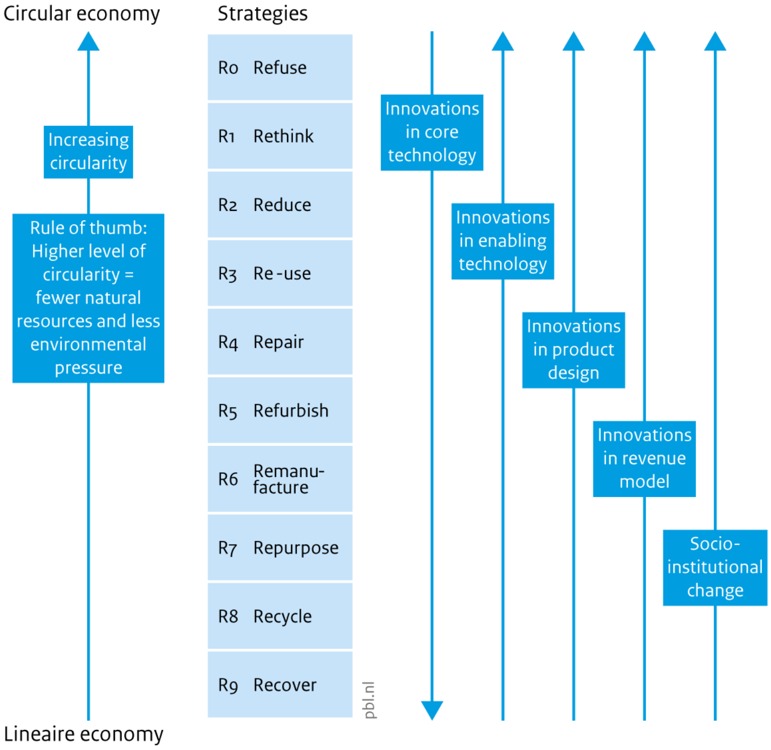
The innovation literature speaks about *directionality failure* (Weber and Rohracher, 2012). This refers to the situation where the course of innovation does not correspond to the ambitions of society. The current economy has, for example, a strong focus on cost reduction and functionality improvement for consumers, and hardly addresses the issue of making consumption of resources and materials more efficient.

The innovation literature also talks about *coordination failure* (Weber and Rohracher, 2012; Wieczorek and Hekkert, 2012). It concerns the problem for economic operators to find each other and work out joint solutions to problems. This is important for CE transitions, since the reuse of products and their components and the recycling of materials require more cooperation between economic actors than in linear chains. The central question is how companies, other organisations and consumers together can best set up a circular system. Socio-institutional inertia makes CE transitions complex. The biggest obstacle to CE transition is socio-institutional lock-in (Unruh, 2000) in existing ways of consuming, producing and doing business. Monitoring the CE transition process should provide insight into the development of new chain relationships.

According to Linder and Williander (2015), a circular revenue model requires technological expertise to close the product chain. However, in circular revenue models, the majority of risks to business investment are attributable to socio-organisational obstacles. Linder and Williander do not distinguish between core technology and enabling technology, or between different circular revenue models. Nor do they address the issue of product design. Innovations in enabling technology, product design and revenue model can be important to facilitate socio-institutional change.

In this study, we conceptualise the role of innovation, particularly that of technological innovation, in the circular economy by evaluating its importance for strategies whose circularity ambitions range from high to low (R0 to R8). We expect to find that radical technological innovation plays an important role in less ambitious circularity strategies (closer to R8), and is less relevant in more ambitious circularity strategies (closer to R0). For the latter, we also expect to see crucial functions performed throughout the product chain by socio-institutional change and by innovations in enabling technology, revenue model and product design (Figure 2.3). We will evaluate this in more detail, for a number of cases, by relating their transition goals to whether innovation and socio-institutional change is a radical (dominant) feature, of secondary importance (clearly present without dominating the process) or hardly relevant (occupying a subordinate role or none at all).Technology of secondary importance or hardly important both belong to incremental innovation.

Figure 2.3
**Role of innovation in circularity strategies for production chains**




Source: PBL

## 2.3 Measuring progress of CE transitions

Which circularity strategies are more appropriate to reduce the consumption of resources and materials and the generation of waste? Figure 2.1 shows the priority order, indicating that smarter product manufacture and use (R0-R2) are preferred over product lifespan extension (R3-R7). Material recycling and energy recovery from incineration and anaerobic digestion (R8-R9) have the lowest priority. Each of these circularity strategies places different demands on socio-institutional change and innovation in core or enabling technology, product design and revenue model. The policy achievements required to realise a successful CE transition can cover the entire product chain from resource extraction and processing, material production through product manufacturing and product use, to the collection and processing of discarded products.

At present there is no systematic method in place to measure the progress of CE transition processes, and their effects on circularity, the environment and the economy. The European The European Environment Agency (EEA, 2016b) only measures CE transition processes to a limited extent, not covering means, activities or effects on the environment and the economy, but focusing only on achievements and effects in relation to circularity. The agency frames diagnostic questions, such as:

- Does the consumption of primary materials decrease in absolute terms?
- Does the design take reuse and recycling into account?
- Is the proportion of hazardous substances in products decreasing?
- Are products used more often or for longer periods of time?
- Do materials retain their value and undergo high-grade recycling?

In principle, the EEA (2016b) also focuses on the progress of CE transitions, but only at the national level. The study presented here is not really concerned with the national level, but examines CE transitions in individual product chains. It builds on the approach of the EEA (2016b), with modifications to enable the measuring of individual product chains, and it is complemented with diagnostic questions covering the entire CE transition process and the effects on the environment and the economy.

It is useful to evaluate CE transitions by measuring progress before (*ex ante*), during (*ex durante*) and after (*ex post*) the transition process. An ex ante evaluation is relevant to explore whether proposed CE transitions actually have potential to bring about the intended CE effects. In other words, whether they are in accordance with the CE transition goals described in Section 2.1. An evaluation of CE Green Deals, the voluntary agreements between government and social partners to remove obstacles for CE transitions, shows that such ex ante evaluations are hardly ever conducted. A brief analysis of five selected CE Green Deals shows that several may not produce positive CE effects. Under these CE Green Deals, achieving increased circularity in certain product chains could actually lead to less circularity in others (Ganzevles et al., 2016). Ex durante evaluation is important to monitor whether a CE transition process follows the planned route, and leads to the desired effects. Ex post evaluations should determine whether the effects of the CE transition process are in accordance with the set goals, and whether they actually are the result of the transition activities and the accomplished achievements or were produced by external factors.

Measuring progress of CE transitions means gathering quantitative or semi-quantitative data and compiling them into indicators which provide meaningful information. Quantitative indicators can, in principle, be expressed in a single figure (by addition, subtraction, multiplication, division, or calculating averages). Semi-quantitative indicators are often binary (e.g. yes or no), but may also be arranged in classes, such as "all, many, few, none" or “red, yellow, green”. Semi-quantitative indicators can be compiled by tallying items into classes. Quantitative and semi-quantitative information and indicators are relevant for the three evaluation types, although semi-quantitative material will be more prominent in measuring the CE transition process than in measuring the CE effects.

The CE transition process consists of means, activities and achievements. Information on means can help to determine what is necessary to achieve the CE goal, such as the choice of actors, and the amount of financing. Information about activities provides insight into whether all relevant actors are indeed engaged in those activities which should bring about the pursued CE achievements and CE effects. Achievement information indicates whether the activities have actually led to the pursued achievements, such as a shift in circularity strategy. Table 2.1 lists the questions used to gather information about the CE transition process. Much of this information is difficult to measure (see Section 2.2 for details), and must be provided by the actors in the product chain itself.

Chapter 1 mentions the large number of indicators of environmental effects in use today. The large number is partly due to the diversity of specific methods to measure indicators for given environmental questions (Swanborn, 1987), and partly to the broad spectrum of environmental questions for which effect indicators exist. To keep measuring of the environmental effects of product chains manageable, the notion of Cradle-to-Grave Primary Energy Consumption has often been proposed as a proxy for other environmental effects (Huijbregts et al., 2006). Several studies have shown that there is a strong correlation between cradle-to-grave primary (fossil) energy consumption and other environmental effects. At the same time, there are considerable uncertainties, though within product chains these can often be explained (Huijbregts et al., 2006; Pascual González, 2016). One of these uncertainties concerns the low correlation between cradle-to-grave primary (fossil) energy consumption and toxic emissions from chemicals production. For some products it may therefore be appropriate to include indicators for specific environmental effects, but in principle, cradle-to-grave energy consumption seems suitable as a generic proxy for environmental effects over the lifespan of a product. Cradle-to-grave energy consumption must be measured for the individual product *and* for the corresponding sector as a whole, to prevent the figure from dropping at the level of the single item, while it increases at the level of the product sector.

Energy consumption in the recycling process, including collection, transport and production of recycled material, has also been proposed as an adequate proxy for circularity. Obviously, in recycling processes energy consumption should also be measured per product unit and for the sector as a whole. In addition, cradle-to-grave consumption of natural resources needs to be quantified per product unit and for the sector as a whole. These serve as a measure of circularity.

To get insight into the economic value of a circular economy, an obvious move is to look at existing economic indicators, focussing on a circular economy. Monitoring should cover at least added value, employment, patents and investments in a circular economy.

The diagnostic questions in Table 2.1 are relevant to all CE transitions, and do not depend on the followed circularity strategy. However, changes to some questions are expected to be more marked for the higher circularity strategies in which a bigger role is played by socio-institutional change and innovations in enabling technology, product design and revenue model. Accordingly, other questions are expected to undergo noticeable changes for the lower circularity strategies in which the dominant role is assigned to innovation in core technology.

**Table 2.1: Diagnostic questions to measure the progress of the process and effects of a CE transition**

| | Diagnostic questions |
|---|---|
| Means | **Mobilisation of means**<br>- Are all relevant product chain partners actively involved in realising CE solutions?<br>- Is there sufficient funding for realising CE solutions?<br>- Are there specific physical means limiting the realisation of CE solutions? |
| | **Knowledge development**<br>- Does the available knowledge suffice to develop CE solutions (with regard to technology, patents, consumer and chain actor behaviour)? |
| Activities | **Knowledge exchange**<br>- Is the level of knowledge exchange on CE solutions high enough in the product chain? |
| | **Experimenting by entrepreneurs**<br>- Are entrepreneurs experimenting sufficiently with CE solutions and revenue models?<br>- Is upscaling of CE solutions already taking place? |
| | **Giving direction to search** (vision, expectations of governments and core-actors, regulations)<br>- Is there a clear vision among product chain partners of the pursued circularity strategy?<br>- Do product chain partners broadly share this circularity strategy?<br>- Does this circularity strategy structure the activities of the product chain partners? |
| | **Opening markets**<br>- Are product chain partners active in creating consumer awareness of CE solutions?<br>- Are companies investing sufficiently?<br>- Does the government have supplementary policies, and do they help in opening markets? |
| | **Overcoming resistance**<br>- Is there resistance against CE solutions (among product chain partners, or in the form of regulatory barriers)?<br>- Is sufficient action being taken to overcome resistance against CE solutions? |
| Achievements | **CE design**<br>- What is the present lifespan of a product and has it increased compared to its original lifespan?<br>- Have products become easier to disassemble?<br>- Does the design foresee the use of recycled materials?<br>- Are the components designed for high-grade recycling (without increasing environmental pressure)? |
| | **Production**<br>- Is the overall (primary and secondary) consumption of materials by companies decreasing?<br>- Do companies use fewer substances which are hazardous to human health and ecosystems?<br>- Is production moving towards lower levels of waste generation?<br>- Are companies moving to CE revenue models with increased reuse of products and components, or models based on providing a service rather than offering a product? |
| | **Consumption**<br>- Is the consumption of CE products increasing (compared to conventional products)?<br>- Do CE products have a longer lifespan or are they used more intensively?<br>- Is reuse of products leading to less waste? |
| | **Waste**<br>- Is the volume of landfill decreasing in favour of incineration?<br>- To what extent is high grade-recycling applied?<br>- To what degree is recycling effective with regard to costs and environment? |
| Effects | **Circularity** (resource efficiency)<br>- Is primary material consumption decreasing (in kg per functional product unit)?<br>- Is primary material consumption decreasing for the whole sector (in kg)?<br>- Is energy consumption in $MJ_{pr}$ for recycling lower than cumulative energy consumption in $MJ_{pr}$ ? |
| | **Environment**<br>For all product groups (over the whole life cycle of a product):<br>- Is cumulative energy consumption in $MJ_{pr}$ decreasing per functional product unit?<br>- Is cumulative energy consumption in $MJ_{pr}$ decreasing for the whole sector?<br>Environmental pressure caused by specific product groups (over the whole life cycle of a product):<br>- Is cumulative environmental pressure decreasing per functional product unit?<br>- Is cumulative environmental pressure decreasing for the whole sector? |
| | **Economy**<br>- Is the added value of products and product services increasing?<br>- Are employment levels in the product chain increasing? |

Source: EEA (2016b); Hekkert et al. (2011); Huijbregts et al. (2006)

# 3 Cases

This chapter evaluates a large number of cases in which CE transitions in product chains are central. We investigate, in particular, the roles of socio-institutional change and innovation in these cases. In parallel with the conceptual framework, hypothetical circularity strategies have been drawn up and evaluated for two product groups: plastic packaging and electrical and electronic equipment. In addition, circularity strategies (Figure 2.1) are identified and evaluated for two sets of practical cases, 36 CE Green Deals (CE GDs) and 32 CE Best Practices (CE BPs) with CE transitions taking place in a range of specific product chains.

The evaluation of the cases is based on an examination of socio-institutional change and the three types of innovation to determine whether they play a dominant role (radical innovation), are clearly present without dominating the process, or occupy a subordinate role or none at all (incremental innovation). The evaluation distinguishes between the roles of innovation in core technology, enabling technology, product design and revenue model.

## 3.1 Plastic packaging

### 3.1.1 Existing situation

In 2014, the demand for plastics in the Netherlands totalled 1.95 million tons, of which 39.5%, 0.77 million tons, for use in packaging (PlasticsEurope, 2014/2015; PlasticsEurope, 2015). PlasticsEurope (2014/2015, 2015), claims 45% of used packaging in the Netherlands would have been recycled, and according to Nedvang figures (2015), 50% would have been recycled in 2014.[1] Nedvang monitors the collection and recycling of plastic packaging (and other packing materials), and is funded by the packaging industry (producers and importers of packaged products) through the Packaging Waste Fund.

In line with the Dutch government decision on package waste management (*Besluit Beheer Verpakkingen* (2014)), the packaging industry is responsible for the collection and recycling of packaging waste. PET bottles larger than 0.5 litres are collected for recycling by soft drink retailers within a deposit-refund system (Ministry of IenM, 2016b). Other plastic packaging from households has been collected through the *Plastic Heroes* collection system since 2008. This system is also funded by the packaging industry through the Packaging Waste Fund. In the Plastic Heroes system, plastic packaging waste is collected through separation at the source (in 360 municipalities) or separation from residual waste (in 48 municipalities). Separation at the source means people put plastic packaging waste in Plastic Heroes bags which are then collected at their homes, or people take the plastic waste to on-street Plastic Heroes containers. Of the municipalities that previously used separation at the source only, 36 now combine the practice with further separation of residual plastic packaging waste(KIVD, 2014a; Nedvang, 2014; Plastic Heroes, 2015). Figure 3.1 shows the figures for demand, collection and recycling of plastic packaging.

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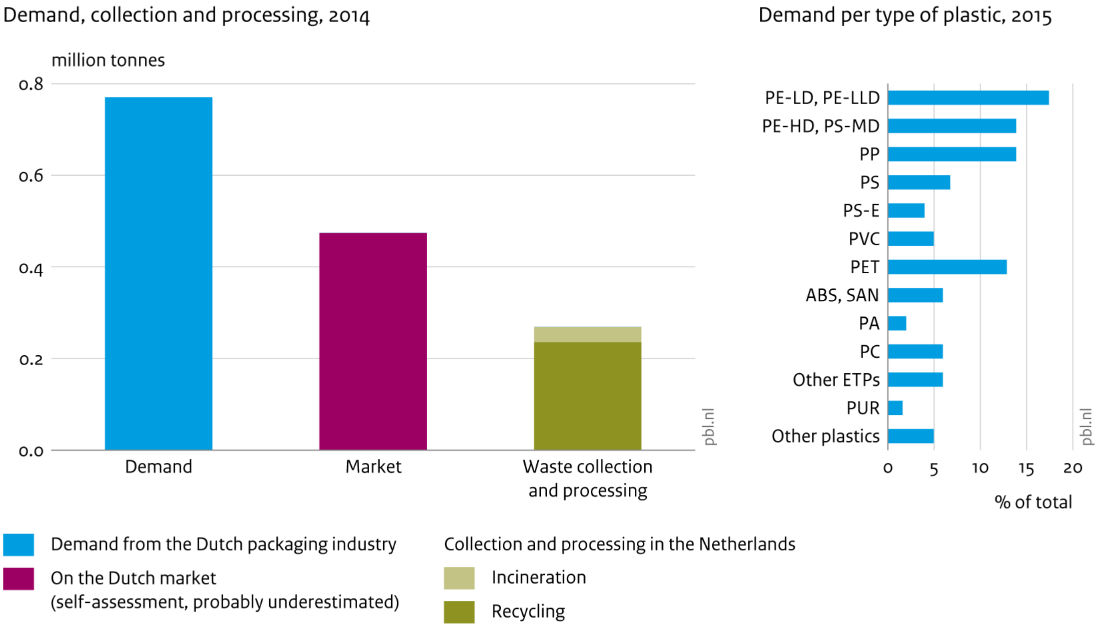
[1] This is probably an overestimate caused by the monitoring method. Nedvang (2015) bases its percentage on absolute quantities of plastic packaging being recycled as a proportion of the total volume on the Dutch market. The market volume figures used by Nedvang come from self-reporting by packaging companies which put more than 0.05 million tons of packaging on the market, and for other companies estimates are made. The total market volume is nearly 40% lower than the Dutch demand for plastics used in packaging as calculated by PlasticsEurope (2015a, b). This difference does not seem to be explained by Dutch exports of plastic packaging (Nedvang, 2014). The quantities of recycled plastic packaging waste are based entirely on self-reporting by municipalities, collecting companies, and waste processors for recycling and incineration of plastic packaging in the Netherlands. The Human Environment and Transport Inspectorate (ILT) reviews data on recycled packaging from household waste and has evaluated this data as valid and reliable (Nedvang 2015). Nedvang (2014; 2015) does not make statements about the reliability of its reports on recycled industrial waste. Figure 3.1 shows the figures.

Figure 3.1
**Demand, collection and waste processing of several types of plastics used for packaging**




Source: PlasticsEurope 2015; Nedvang 2015

## 3.1.2 Circularity strategies for plastic bottles

Every year, Dutch consumers use nearly one and a half billion (1.5 E9) soft drink bottles made of polyethylene terephthalate (PET). There is a deposit-refund on plastic bottles larger than 0.5 litres, which can be returned to the retailers (Ministry of IenM, 2016b). In 2013, 0.02 million tonnes of returnable PET bottles were recycled (Nedvang, 2014). As yet, there is no deposit-refund on plastic bottles of 0.5 litres or smaller. The website of the Ministry of Infrastructure and the Environment (Ministry of IenM, 2016b) reported that from January 2016 an experimental trial would be run with a 'return premium' on small PET bottles. At present, after collection the large PET bottles are shredded, upon which the fragments are cleaned and melted, before being transformed into granules which can be applied for making new PET bottles, or other products such as jerry cans, sweaters, toys, chairs, pipes and tubes (Plastic Heroes, 2015). In 2012, the proportion of recycled PET in PET bottles was approximately 18%. Current technology can achieve a proportion of 40-60% in multi-layer or laminated bottles (WRAP, 2005).

Upon signing the Framework Agreement Packaging 2013-2022 (2013) with the Dutch government, the packaging industry has promised to increase the proportion of mechanically recycled PET in bottles to 25%. The agreement sets 2018 as the deadline for operating with the highest possible proportion of recycled PET in bottles. This means figures of at least 23% of mechanically recycled PET in small bottles and 28% in large bottles. To achieve this, the volume of PET bottles collected for recycling needs to go up, probably through some form of post-collection sorting procedure (R8 in Table 3.1).

The Agreement leaves the initiative to the packaging industry under the conditions of the Extended Producer Responsibility scheme. Soft drink producers and retailers consider the deposit-refund or premium system to be rather expensive, and prefer to collect and recycle plastic bottles together with other plastic waste. Until 2006, large PET bottles were not recycled but refilled (Milieucentraal, 2015). This alternative could be re-introduced for large and small PET bottles (R3b in Table 3.1), but this requires a change in the mind-set of soft drink producers (switching to cleaning and refilling), and to some extent also in the attitude of retailers (more collection) and consumers (returning more bottles). Consumers could also clean plastic bottles themselves and re-fill them, for example through a system in which retailers set up refill stations (R3 in Table 3.1). The technology for these systems already exists, but implementation requires changes in the chain of logistics, particularly for the soft drink producers and retailers. In addition, producers and retailers cannot be held responsible for how well consumers clean their plastic bottles. So this probably also requires a change in regulations on food safety and quality. These changes can be avoided, however, if consumers are willing to prepare their own drinks by using powdered drink mixes and carbon dioxide cartridges (R0 in Table 3.1). This is in fact the procedure followed by soft drink producers, and occasionally also by the hospitality sector in their drinks dispensers. Technology for smaller volumes aimed at the individual consumer has been around for quite some time, and, while market-wide introduction must be coupled to a big change in logistics, the move will provide advantages for consumers, producers and retailers with regard to transport and space. Producers could distinguish themselves from others and attract end keep customers by designing a soft drink preparation system and associated packaging for powdered drink mixes and carbon dioxide cartridges, all under a single brand. The three variants all lead to significant reductions (R3a and R3b), or even the complete phasing out (R0) of PET bottle production. Similar circularity strategies are appropriate for bottles used for other liquid foodstuffs.

### 3.1.3 Circularity strategies for other types of plastic packaging

The focus in this section is on the packaging of other food types. The present system of collection and (low-grade mechanical) recycling of plastic packaging can be continued (R8b in Table 3.1) or further developed into high-grade mechanical recycling (R8a in Table 3.1). The mix of many types of contaminated plastics that is currently collected by Plastic Heroes for sorting at their facilities, should be source-separated straightaway into clean plastic fractions for high-grade recycling. Technology for mechanical waste separation at the source is available, and being improved to achieve better separation and cleaner fractions.

**Table 3.1: Circularity strategies, socio-institutional change and innovation for plastic packaging and electrical and electronic equipment**

| | | | CT | ET | PD | RM | SI |
|---|---|---|---|---|---|---|---|
| Plastic packaging | **Circularity strategy for plastic bottles (liquid foodstuffs)** | | **CT** | **ET** | **PD** | **RM** | **SI** |
| | R0 | Refuse: No bottles required. Consumer prepares drinks at home from concentrate (e.g. cola from concentrated soft drink flavours and $CO_2$ cartridges) | | | D | D | D |
| | R3a | Reuse: Consumer cleans bottle and refills at the retailer | | | P | | D |
| | R3b | Reuse: Consumer returns bottle to retailer who sends it to manufacturer for cleaning and refilling | | | | | D |
| | R8a | Recycling, high-grade, mechanical: Harmonisation of plastics. Consumer takes bottle to central collection point | P | | | | D |
| | R8b | Recycling, low-grade, mechanical: Consumer takes bottle to central collection point. Current situation | | | | | |
| | R9 | Energy recovery from incineration. Current situation | | | | | |
| | **Circularity strategy for plastic foil (solid foodstuffs, fresh produce)** | | | | | | |
| | R0 | Refuse: Where possible avoid plastic foil (e.g. no shrink wrap for cucumbers; no use of foil for mailings) | | | | | D |
| | R8a | Recycling, high-grade, mechanical: Harmonisation of plastics in foils. Consumer takes foil to central collection point | P | | | | D |
| | R8b | Recycling, low-grade, mechanical: Mix of different plastics. Consumer takes foil to central collection point. Current situation | | | | | |
| | R6 | Energy recovery from incineration. Current situation | | | | | |
| | **Circularity strategy for other plastic packaging (solid, non-perishable foodstuffs)** | | | | | | |
| | R0 | Refuse: Avoid packaging where possible | | | | | D |
| | R3 | Reuse: Consumer cleans packaging and reuses it at the retailer | | D | P | | D |
| | R8a | Recycling, high-grade, mechanical: Harmonisation of plastics in foils. Consumer takes packaging to central collection point | P | | | | D |
| | R8b | Recycling, low-grade, mechanical: Mix of different plastics. Consumer takes packaging to central collection point. Current situation | | | | | |
| | R9 | Energy recovery from incineration. Current situation | | | | | |
| Household appliances | **Circularity strategy for washing machines and dryers** | | **CT** | **ET** | **PD** | **RM** | **SI** |
| | R1a | Rethink: Shared use of washing machines and dryers, in a central location, in apartment buildings; use & service contracts which include maintenance, repairs and refurbishing | | D | | D | D |
| | R1b | Rethink: Single-family homes with use & service contracts which include maintenance, repairs and refurbishing | | D | | D | D |
| | 3a | Reuse: Consumer gives away old devices which are still in working order through private network | | | | | |
| | 3b | Reuse: Intermediate trade sells old devices which are still in working order | | | | | |
| | R4 | Repair: Consumer pays for each repair | | | | | |
| | R5 | Refurbish: Intermediate trade replaces old parts for modern ones, and sells the refurbished devices (unused parts sent to recycling facility) | | | D | | D |
| | R6 | Remanufacture: Intermediate trade uses old parts which still work to repair broken-down or new devices (unused parts sent to recycling facility) | | | | | |
| | R8 | Recycling, mechanical: Consumer takes discarded items to intermediate trader or recycling station. Current situation | | | | | |
| | R9 | Energy recovery from incineration | | | | | |
| | **Circularity strategy for refrigerators and freezers** | | | | | | |
| | R1a | Rethink: Use & service contract which includes maintenance, repairs and refurbishing. Contract is included in dwelling rental | | D | | D | D |
| | R1b | Rethink: Owner-occupier has a use & service contract which includes maintenance, repairs and refurbishing | | D | | D | D |
| | R3a | Reuse: Consumer gives away old devices which are still in working order through private network | | | | | |
| | R3b | Reuse: Intermediate trade sells old devices which are still in working order | | | | | |
| | R4 | Repair: Consumer pays for each repair | | | | | |
| | R5 | Refurbish: Intermediate trade replaces old parts for modern ones, and sells the refurbished devices (unused parts sent to recycling facility) | | | D | | D |
| | R6 | Remanufacture: Intermediate trade uses old parts which still work to repair broken-down or new devices (unused parts sent to recycling facility) | | | | | |
| | R8 | Recycling, mechanical: Consumer takes discarded items to intermediate trader or recycling station. Current situation. | | | | | |
| | R9 | Energy recovery from incineration | | | | | |

Socio-institutional (SI), core technology (CT), enabling technology (ET), product design (PD) and revenue model (RM)

Rating: D=dominant, P=present, empty cell=hardly present/no presence

A large part of the other plastic food packaging waste from households can also be reduced. Consumers could clean and re-fill plastic packaging themselves with non-perishable food products, and with a significant part of the other fresh food types, similar to the refilling of soft drink bottles (R3a in Table 3.1). Perhaps this calls for more durable, heavier plastic packaging, but frequent reuse will sharply reduce the amount of packaging used per unit of food. Furthermore, this also calls for a shift in mind-sets, similar to that described in the case of soft drink bottles above. Packaging for fresh vegetables such as cucumbers and aubergines could be eliminated entirely (R0 in Table 3.1). This may require stepping up the supply of fresh produce, and more frequent replacements of products that are no longer saleable (possibly resulting in larger volumes of food waste). Fresh vegetables are now often shrink wrapped for protection during transport and to increase shelf life. This means that eliminating this kind of packaging for fresh foods would go against the current trend. The use of shrink wrap can perhaps not be avoided for fresh foods, such as meat. Once discarded, it is probably better to collect the heavily contaminated foil and incinerate it along with other unusable waste from the commingled stream of residual waste (R8 Table 3.1).

## 3.2 Electrical and electronic equipment

### 3.2.1 Existing situation

The European legislation on Waste Electrical and Electronic Equipment (WEEE), requires producers and importers to collect and recycle the discarded items from households. In the Netherlands, this is organised by Wecycle and ICT Milieu which are commissioned and funded by producers and importers. Execution of collection and recycling tasks lies with Wecycle. Consumers can leave electrical and electronic items in the shop where they buy new equipment, or take them to municipal recycling centres or second hand shops. In addition, many stores have bins for the collection of small electrical and electronic devices. Wecycle retrieves the equipment from all collection points, and transports it to one of their eight regional sorting centres. Here all items are sorted (large household appliances, refrigerators and freezers, televisions and monitors, small electrical and electronic devices, computers and related hardware and energy-saving lamps), and then sent to specialised recycling companies in the Netherlands, Belgium and Germany. Recycling companies disassemble the devices to remove environmentally harmful substances such as mercury and coolants, and to achieve a cleaner separation of recyclable materials (such as iron, aluminium, copper, plastic, glass, wood and PUR). Wecycle collects and recycles 30% of electrical and electronic equipment discarded in the Netherlands, and 70% is disposed of in other ways (Huisman et al., 2012). Table 3.2 provides an overview of the volumes of collection and recycled items. According to Huisman et al. (2010), 10% of the collected equipment is exported for recycling. Umair et al. (2016) show that discarded computing devices are mainly recycled by informal businesses under dire conditions.

### 3.2.2 Circularity strategies for washers and dryers

Dutch households are accustomed to having their own washing machine and many also own a dryer. In other northern and western European countries, however, residents of flat complexes typically use centralised laundry facilities. In those cases, the costs for maintenance, repair and renewal are factored into the rent or contributions to the owners' association. Former minister for the environment Hans Alders was heavily criticised in 1993 when he proposed to follow this example in the Netherlands (Van der Malen et al., 1993). Yet, sharing washing and drying facilities has great advantages. The fact that fewer washers and dryers are needed, and that they deteriorate faster due to intensive use, means they can be replaced sooner by newer equipment which is usually more economical with regard to

**Table 3.2. Collection and recycling of discarded electric and electronic equipment**

| | Collection in kiloton in 2012 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Large devices | Refrigerators & freezers | Small household devices | Information technology | Screens & Televisions | Light | Professional electronics | Total |
| Dutch market | 131 | 64 | 125 | 50 | 42 | 4 | 24 | 440 |
| Discarded equipment | 106 | 49 | 106 | 50 | 61 | 4 | 17 | 392 |
| - *Export* | 4 | 10 | 4 | 10 | 12 | 0 | 0 | 44 |
| - *Wecycle & ICT Milieu* | 31 | 25 | 26 | 10 | 31 | 2 | 0 | 125 |
| - *Documented otherwise* | 46 | 6 | 24 | 12 | 10 | 0 | 1 | 110 |
| - *Not documented* | 24 | 7 | 25 | 9 | 12 | 0 | 0 | 75 |
| - *Incineration* | 0 | 0 | 27 | 9 | 0 | 2 | 0 | 38 |
| | Recycling in percentages of collected equipment in 2014 | | | | | | | |
| Via Wecycle & ICT Milieu | Large devices | Refrigerators & freezers | Small household devices & Information technology | | Screens & televisions | Lights | | |
| - *Regulatory aim* | 75 | 75 | 63 | | 65 | 80 | | |
| - *Realised* | 85 | 85 | 78 | | 84 | 92 | | |

Source: Huisman et al. (2012); Wecycle (2016)

electricity consumption and use of water and detergents. An example of a recent innovation launched onto the market is the washing machine with automatic detergent dosage based on the weight of the laundry in the drum. The largest environmental pressure related to laundry equipment is posed by its use. Dutch households probably still feel the same about sharing washing machines and clothes dryers as in 1993, and current building practices do not foresee any suitable spaces for centralised laundry facilities. If they did, sharing washing machines and dryers could readily be organised (R1a in Table 3.1), especially if digital systems are in place to facilitate 'booking' a machine and paying for use.
Households in single-family houses could refrain from buying a washer and dryer and instead go for a service& use contract with the manufacturer (R1b in table 3.1). This encourages manufacturers to continuously improve their equipment, for example, by designing them to be easy to repair and refurbish by replacing components (which may lead to less energy, water and detergent use). Such refurbishing may be part of a service & use contract, but can also be relevant for privately owned equipment which is discarded (R4 and R5 in Table 3.1).

### 3.2.3 Circularity strategies for refrigerators and freezers

Sharing refrigerators and freezers with other households seems less obvious. However, unlike in the Netherlands, in other northern and western European countries, refrigerators and freezers are often included in the rental of flats and houses. This enables the landlord to timely replace old appliances with new, energy-efficient ones. If the landlord signed a collective use & service contract with the manufacturer on behalf of all tenants, rather than each household having their own, this could encourage manufacturers to design their products to be easy to repair and refurbish by replacing components, and, for example, make them more energy efficient. This type of scheme can also be used to repair and refurbish refrigerators and freezers discarded by private owners (R4 and R5 in Table 3.1). Alternatively, homeowners could enter into a use & service contract instead of owning refrigerators and freezers (R1b in Table 3.1).

## 3.3 Circular Economy Green Deals

Since 2011, the Dutch government has employed *Green Deals* to promote green growth. Green Deals are agreements between the national government on the one hand, and companies, social organisations, or regional or local governments on the other. The national government commits itself to remove obstacles for concrete, sustainable projects by modifying regulations. These obstacles can vary from one Green Deal to another. Once an obstacle has been removed for a specific project, many other similar projects may benefit from the situation (EZ 2011). On average, the Green Deals have a duration of three years.

A total of 180 Green Deals were entered into over the 2011–2015 period. Although they were not signed with the purpose of achieving CE transitions, the Ministry of Economic Affairs labelled 56 of them as contributions to the circular economy and to the conservation of natural resources (EZ, 2015). Of these 56, Ganzevles et al. (2016) selected a subset of 36 circular ones to evaluate their role as a trendsetters for similar CE transitions. This study subjects the same subset (labelled here as CE GDs) to further analysis, focussing on the roles of innovation and socio-institutional change in relation to the circularity strategy adopted by each CE GD. The results are summarised in Table 3.3.

Recycling (R8 in Figure 2.1) plays a role in all the analysed Green Deals, except CE GD 183. In 19 cases, recycling is the only circularity strategy or it is combined, at the very most, only with the lower classed strategy of incineration and energy recovery (R9 in Figure 2.1 In one case (CE GD 92), recycling is combined with reduce (R2 in Figure 2.1), and in another with both reduce and energy recovery strategies (CE GD 6). A reducing strategy involves increased efficiency with respect to the consumption of materials and resources, including energy efficiency, in manufacturing and the use of products. It is a rather traditional strategy, but it does achieve relatively high circularity. The remaining 14 CE GDs combine recycling with circularity strategies which, other than reducing strategies, aim for higher levels of circularity (strategies with lower R numbers). However, these 14 CE GDs are frequently found to be insufficiently explicit about how higher circularity is to be attained. This is indicated by question marks next to the grading of the circularity strategies in Table 3.3.

**Table 3.3: Circularity strategies, socio-institutional change and innovation in Green Deals**

| No. | Working title CE Green Deal: description | Circularity | CT | ET | PD | RM | SI |
|---|---|---|---|---|---|---|---|
| 2 | Biomass streams (platform agro-paper-chemical): Draw up at least six new business cases to valorise biomass and residual streams through bio-refining in 2014 | R8 | D | | | | P |
| 6 | Energy saving in waste processing: Achieve more recycling and energy saving by: 1) Conducting a social cost-benefit analysis as a first step towards a multiannual agreement, 2) Setting up a gasification plant to process post-sorting residue and use waste heat for district heating 3) Setting up an anaerobic digestion plant to transform waste into green gas | R2, R8-9 | | | | | |
| 11 | Sustainable processing of carpets: Separate collection of carpets and rugs by sorting at recycling stations, use as fuel for the cement industry and, where possible, recycle into high-grade material | R8-9 | P | | | | |
| 27 | Sustainable heat from biomass: Aim to establish a Net-Zero-Energy mushroom farm by employing used substrate to produce energy; recovery of nutrients from incineration ash by artificial fertiliser industry | R8-9 | P | | | | |
| 28 | Separate waste collection: Set up a website for consumers to provide information on collection points for discarded materials and items | R8 | | | | | |
| 30 | Make the concrete chain sustainable: Sustainability in the whole chain, from biodiversity and gravel extraction to energy and natural resource saving in the production stage along with reuse of crushed concrete as aggregate. Also make design and logistics sustainable | R2-R8? | | | D | | D |
| 41 | Bio based park Westland: Establish a bio based industrial estate in which companies take advantage of industrial symbiosis to valorise waste vegetable matter into high-grade materials such as fibres, biocides, fruit juices and green gas | R8 | P | | | | D |
| 57 | Union of Regional Water Boards: Set up large-scale power plants which generate and recover biogas, green electricity and sustainable heat, nutrients and materials | R8-9 | | | | | P? |
| 76 | Make the useful applications of incinerator bottom ash more sustainable: investments by waste incineration plants in sustainable and useful applications of incinerator bottom ash throughout the whole chain and contribute to the development of initiatives and corresponding communication tasks | R8 | | | | | P |
| 81 | Alternative materials for paper manufacturing: Industrial pilot projects using alternative materials to produce paper and cardboard | R8 | P | | | | |
| 87 | Sustainable traffic barriers: promote the use of renovated traffic barriers | R5, R8 | | | | | |
| 92 | Insects for feed, food and pharma: large-scale insect farming, using waste residue as bulk input for feed and food | R2, R8 | | | | | D |
| 94 | Sustainable processing of digestate and protein production for livestock: the Franico company wants to grow duckweed on a substrate of digestate produced in its own digester installation and use it as a source of protein for fodder and for biogas production | R8-9 | | | | | P? |
| 96 | Advantages from horse manure: Equfec, Stichting iNSnet, Staal Agritech and Paard&Zo are organisations which want to set up an installation to dry horse manure and plant litter and then transform the matter into pellets | R8-9 | P | | | | P? |
| 109 | Sustainability label for outdoor spaces: development of a Dutch label, a standardised method to assess integral sustainability of products and materials used in exterior spaces (ranging from paving materials and plants to urban furniture) | R2-R8? | | | D? | | D? |
| 114 | Natural plastics BV: new method for planting trees: underground tree anchoring system made of biodegradable plastics instead of using posts | R1, R8 | | | | | D? |
| 116 | Nova lignum: Building materials such as dry wall panels made of residual waste (e.g. aubergine stems from greenhouse farming) | R8-9 | | | | | P |
| 117 | Chamber of Commerce Noord-Nederland (use of green materials): make an inventory of bottlenecks for the development of a bio based economy, eliminate them and set up an experimental site in the area Veenkoloniën-Eemsdelta | R8-9 | | | | | P |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 131 | Turntoo: Procurement experiment to study performance-based contracting and uncover legal and administrative obstacles | R1-R8? | | | | D | D |
| 142 | Sustainable collection of textiles: in 2015 there was aimed 50% less textile in residual waste than in 2011 thanks to the promotion of separate collection | R3, R8 | | | | | P |
| 147 | Collection, environmentally-friendly disassembling and recycling of mopeds: Collect and disassemble discarded mopeds for recycling | R8 | | | | | |
| 149 | Dealing with sustainability in civil engineering: From 2009 to 2012, organisations in the railway and civil engineering sector developed an approach for sustainable purchasing practices and for making better use of opportunities for sustainability and innovation. The *Duurzaam GWW* approach is now ready for implementation and further promotion within the sector and development is ongoing | R2-R8? | | | D? | | D |
| 156 | The Netherlands as a hotspot for the circular economy: Speed up CE transition by executing scalable circularity projects. By achieving synergy among private company projects, carrying out umbrella analyses for regions and sectors and implementing Green Growth policies the Netherlands can position itself internationally as a hotspot for circular economy | R1-R8? | | | | | D |
| 157 | Production of bioplastic from organic household waste: Organisations in the organic household waste sector aim to make collection more sustainable and develop a high-grade processing alternative through collaboration agreements for research into PHA bioplastic production and experimenting in a pilot installation for PHA production built in 2014. Develop bags for organic household waste collection for the city of Venlo | R8 | P | | | | |
| 158 | Fair electricity meters: In the production processes use a minimum of new, sustainable and responsibly produced raw materials ('fair') and, above all, use of recycled and recyclable materials, so that in 2020 every newly-installed meter is composed of at least 98% recycled material and is designed for reuse. To be started with a controlled experiment involving at least 1,000 fair meters. | R5, R8 | | | P? | | |
| 159 | Circular purchasing: Contribute to CE through a purchasing scheme formed by organisations which start up at least two circular purchasing chains in 2014 and share their knowledge and experience with other Dutch organisations which are interested in adopting purchasing policies (initiative promoted by Pianoo, NEVI, MVO-Nederland and Circle Economy). Integration of purchasing processes of participants where possible. | R1-R8 | | | | D? | D |
| 160 | Grasses and plants: Develop business cases and open a market for bio based products based on grasses and vegetable matter. | R8 | D? | | | | D |
| 166 | Waste chain from shipping activity: Stop further marine pollution caused by patches of floating plastic. The parties involved aim to contribute to closing the plastic chain through prevention of plastic waste generation, separation and recycling of waste, improved surveillance and more uniform waste collection procedures in ports and harbours | R0-R8 | | | | | D |
| 168 | Circular city: Support the transition towards a circular and inclusive economy with regard to material cycles in the building sector in five other cities by adopting a project approach similar to the one used in Rotterdam (applicable to new structures and alteration and renovation works). The parties involved collaborate to secure practical experiences | R8 | | | | | D |
| 170 | Take back chemicals: Put into practice innovative business models which achieve sustainable and efficient use and reuse of chemical substances and materials. Eliminate obstacles encountered | R2, R3, R8 | | | | D | D |
| 171 | Fishery for a cleaner sea: Reduce the amount of waste dumped in the sea by the fishing industry. Collaboration throughout the fishery waste chain to achieve waste separation and storage on board and in the Dutch ports, and maximise recycling | R8 | | | | | D |
| 174 | Materials used by the Union of Water Boards: Promote, accelerate and, where possible, upscale extraction and recovery of material from sewage. The parties aim to set up pilot projects and demonstration activities and focus initially on producing and supplying phosphate, cellulose, bioplastics, alginate and $CO_2$ | R8 | P | | | | |
| 178 | Circular building: Record the circularity features of buildings in 'building passports' to facilitate minimal use and reuse of materials and products during design and exploitation of industrial buildings by selection of materials and products, and lifespan extension by working towards maximum adaptability in functionality of buildings | R1-8 | | | D? | | D |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 180 | Reducing the volume of waste and introducing recycling at train stations and on trains: Limit the generation of waste at stations and on trains from 12,000 tons in 2014 to 9000 tons in 2020. Achieve recycling of 75% of the volume by using less and more recyclable packaging (Dutch Railways and retailers in the stations), by installing new waste collection facilities (ProRail) and encouraging passengers to separate waste | R0, R8 | | | | | P |
| 183 | Carsharing: Aim for a fleet of 100,000 vehicles in 2018 (fulfilling prior goals set in the energy agreement of the Social and Economic Council of the Netherlands) thereby ensuring that car-sharing and the sharing economy overcome growing pains. Ensure that providers of mobility services make better use of opportunities for growth by increasing their visibility, promoting knowledge exchange, organising pilot projects to gain experience, mutual learning programmes and improved coordination. | R1 | | | | D | D |
| 184 | Improve waste management in the Caribbean Netherlands: improve waste management on the BES islands Bonaire, Sint Eustatius and Saba by mapping local waste generation (volume, quality, origin) as a first step towards improved separation of waste streams and by creating a knowledge platform to reinforce local governments focussing on understanding the functions of waste processing and becoming familiar with the relevant interest groups | R8 | | | | | P |

Socio-institutional (SI), core technology (CT), enabling technology (ET), product design (PD) and revenue model (RM)

Rating: D=dominant, P=present, empty cell=hardly present/no presence

It is striking that technological innovation is of little to no importance in the majority of the CE GDs (indicated by a blank cell in Table 3.3). Innovation through adaptations to existing (core) technology is clearly present in 7 CE GDs, and in all cases related to recycling. Only two CE GDs assign what might be a dominant role for (radical) innovation in (core) technologyl (CE GD 2 and 160). Also relatively few CE GDs feature dominant (radical) or clearly present (incremental) innovation in product design (CE GD 30, 109, 149, 158 and 178) and revenue model (CE GD 131, 159, 170 and 183). That has to do with the fact that most CE GDs are concerned with recycling. Recycled material can, in principle, be used in a new product with a similar design and marketed following the existing revenue model.

Socio-institutional change is more relevant. In 16 CE GDs it plays a dominant or a possibly dominant role, while in 10 others it is clearly present. Socio-institutional change usually involves the supply and recycle chains, but in a number of cases it also relates to consumers. Within the supply and recycle chains, socio-institutional change requires cooperation among chain actors and must overcome restrictions posed by laws and regulations and seek acceptance by businesses promoting products or materials derived from new natural resources or from waste streams.

## 3.4 Circular Economy Best Practices

MVO-Netherlands[2] and De Groene Zaak[3] are Dutch business organisations which are intimately concerned with the circular economy. They have launched a website[4] with CE Best Practices (CE BPs) to which companies can submit their CE initiatives for inclusion on the Dutch map. This study evaluates the best practices listed on the website with regard to the roles of innovation and socio-institutional change in the adopted circularity strategies. The results are summarised in Table 3.4.

The analysis of the Green Deals in the previous section shows that in one initiative recycling played no role at all. Among the Best Practices we see that five initiatives do without recycling. Still, also in the analysis of the Best Practices, recycling is found to be the most frequently used strategy, playing a role in 27 of the 32 Best Practices. The Best Practices combine recycling with other, higher level circularity strategies less often than the Green Deals. That is, 11 out of 32 Best Practices as compared to 16 out of 36 Green Deals. In general, however, the Best Practices are slightly more ambitious than the Green Deals. This is probably why socio-institutional change is assigned a prominent role more often by the Best Practices (in 25 out of 32 cases) than by the Green Deals (26 out of 36).

Among the Best Practices, only four initiatives employ dominant (radical) innovation in (core) technology (CE BP 25 and 28), but (incremental) technological innovation is far more common, appearing in 12 initiatives (10 in core and 2 in enabling technology). As in the Green Deals, in almost all cases this involves recycling waste. Radical or incremental innovation are applied to product design in 8 cases, and to revenue model in 13 cases. These innovation strategies are probably more common in the Best Practices than in the Green Deals because of the higher circularity ambitions of the former. The same reasoning applies to the strategies aiming for socio-institutional change, which are employed more frequently in Best Practices, appearing in 25 cases.

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[2] MVO-Netherlands was established in 2004 by the Ministry of Economic Affairs as a national knowledge and network organisation for corporate social responsibility (CSR).
[3] De Groene Zaak is a business association whose goal is to promote sustainability in the Dutch economy.
[4] http://bestpractices.circulairondernemen.nl/

**Table 3.4: Circularity strategies, socio-institutional change and innovation in Best Practices**

| No. | Working title CE Green Deal: description | Circularity | CT | ET | PD | RM | SI |
|---|---|---|---|---|---|---|---|
| 1 | Moonen Packaging has developed a disposable paper cup made of sugar cane waste, along with the Stack-it waste collection system and an anaerobic digestion procedure to transform the discarded cups into compost and biogas | R8 | P | | | | D |
| 2 | BB Bricks engages a conventional plastic production plant to inject recycled plastic into its own moulds to produce modular elements for furniture and similar objects. Collaboration with the plastic producer and maintaining the correct temperature are proving to be difficult. Leasing and product return schemes are possible | R3, R8 | P? | | D | P | D |
| 3 | Van Houtum sells restroom items made of recycled materials, such as a recycled plastic toilet paper dispenser and toilet paper made of low-grade waste paper (using labels and packaging, e.g. for beverages, price stickers). The dispensers are sold under a return system | R8 | P | | | | D |
| 4 | MUD Jeans has set up a lease-a-jeans scheme. Returned jeans are reprocessed into vintage jeans or recycled (the jeans are 100% bio cotton, which means they contain no lycra and have no leather labels) | R1, R3, R4, R5, R8 | | | P? | D | D |
| 5 | Kromkommer is an initiative to process vegetables with slight imperfections and surplus vegetables into conserved food products (such as perishables) and thus bring about substantial change in a rather rigid sector and among consumers to discourage the wasting of food | R8 | | | | | D |
| 6 | Repurpose is an engineering firm which aims to promote the reuse of building materials, initiated by assignments, by bringing together the suppliers (demolition companies) and users (contractors) of used building materials | R6-R8 | | | | | D |
| 7 | Vitens is a water company which has developed technology to extract humic acid from groundwater (decolourisation) and sell it as a liquid agent for soil improvement. The volume of liquid humic acid they obtain is enough to satisfy the total demand of the Benelux countries, currently covered by solid humic acid extracted from coal in the USA | R8 | P | | | | P |
| 8 | Stichting Recover-E, a foundation set up by Royal HaskoningDHV and SISO, aims to close (optimise) the computer cycle by collecting used computers at large organisations (which are not easily persuaded), and refurbishing them to give them a second life under a computer use contract, which means that, when discarded, they will return to Recover-E once again | R4-R6, R8 | | | | D | D |
| 9 | Bicycle factory Roetz Bikes uses old bicycles of the OV-fietsen rental service, disassembles, screens, cleans, repairs and paints them to transform them into new vehicles (containing 70% reused materials). Most of the work is carried out in social enterprises | R6 | | | | | |
| 10 | Ricoh, a company specialising in office automation systems, offers service contracts (which cover management and maintenance) for multifunctional photocopiers and printers. Used machines are refurbished, or their parts are reused or recycled. In this sector, service contracts have been common for quite some time | R3-R4, R6, R8 | | | | | |
| 11 | Waste2Wear produces high-quality workwear made of 100% polyester obtained from recycled PET bottles. The company co-funds and collaborates with a programme run by the Ocean Recovery Alliance to improve fishers' environmental awareness and living conditions by paying them for any plastic they retrieve while out at sea | R8 | P? | | | | D |
| 12 | Meerlanden is a waste processor which uses anaerobic digestion of organic household waste to supply heat, $CO_2$ and compost for horticulture, water for cattle trucks and green gas for vehicles (enough for all the refuse lorries operated by Meerlanden | R8 | | | | | |
| 13 | Modulo designs, builds and manages recycling centres whose circular design enables relocation and adaptation (occurring on average every nine years due to changing municipal boundaries, changes in regulations, etc.) | R3, R5 | | | D | P | D |
| 14 | Carbon black is used, among other things, as a pigment and a filler. It is a black material resulting from the incomplete combustion of heavy petroleum products. The company Black Bear recovers carbon black from old car tyres for use in the production of new tyres and other applications. Resulting by-products are steel, gas and oil. The | R8 | P? | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | sale of recycled carbon black is rather slow due to sluggish market adoption (although no resistance is mounted against the product itself) | | | | | | |
| 15 | Green mobile is an initiative of the Telga telecommunications company which involves purchasing used smartphones and refurbishing them so they can be used again with the aim of pushing the market share of refurbished phones up from 13% to 20% | R5-R6, R8 | | | | | D |
| 16 | Ecover produces bottles for washing-up liquid from plastic which has been recovered from the sea and the Amsterdam canals. The necessary technology has been developed by the company itself. It is proving hard to establish the product chain. Awareness raising is an important goal of the project. | R8 | P | | | | D |
| 17 | Rotterzwam has developed a method to cultivate oyster mushrooms on coffee grounds (determining the ideal conditions for cultivation). They cultivate the mushroom on locally collected coffee grounds and sell it locally too. They also make and sell grow kits, and promote similar initiatives in other cities by providing training and transferring knowledge | R8 | P? | | | | P? |
| 18 | Herso is a furniture works which makes furniture from waste timber. They offer user contracts for furniture | R8 | | | | D | |
| 19 | ACE Reuse Technology BV re-manufactures existing electro-mechanical drives for reuse with the same function | R6 | | | | D? | |
| 20 | Dutch Awearness, a company owned by fashion designer Rien Otto, makes workwear from 100% (recycled) polyester (up to 8 times recycled). A track-and-trace system is in place to monitor the entire chain and ensure circularity principles are adhered to. All items return to the company via a return system | R8 | | P | | D | D |
| 21 | EnvelopeBook produces notebooks and paper for office use from recycled stationery and unused paper surpluses (for example, due to changes in corporate house style). Companies which deliver surplus paper are acknowledged on the EnvelopeBook website and have the opportunity to 'repurchase' their own paper | R8 | | | | P? | P |
| 22 | Fungi Town cultivates, like Rotterzwam, oyster mushrooms and shiitake on a substrate of coffee grounds. A plan for the future is to find uses for excess substrate too (for example by reconditioning it into terra preta). The initiative is currently on hold | R8 | P? | | | | P? |
| 23 | Gispen makes designs, in consultation with its customers, for the refurbishing of old furniture, or new modular furniture for offices. Several revenue models are possible, including concession against payment, but all models imply that used furniture, in principle, is returned to Gispen for reuse or recycling. Gispen has no problems finding customers for the initiative | R5, R8 | | | D | D | P |
| 24 | Stichting InStock collects produce with slight imperfections and those which are nearing their best-before date at Albert Heijn supermarkets in Amsterdam. The products are used to make and sell meals in restaurants, a small shop and a food truck. With this initiative the foundation aims to bring about a change in mentality in a rather rigid production and marketing chain and among customers to avoid wasting food | R8 | | | | | D |
| 25 | Interface is a world-wide market leader in the production of carpet tiles, using yarns made of castor beans and old fishing nets. The company offers service contracts for the carpet tiles which include maintenance and recovering unused tiles. Used tiles are cleaned and can be employed in a new cycle under a new service contract. Yarn to yarn recycling is also carried out | R2-R4, R6-R8 | D? | | | D | D |
| 26 | LENA The Fashion Library is an initiative which organises the loan of exclusive clothing by young designers or owned by subscribers to other subscribers. This means the items are worn more often (rather than kept on a hanger in a wardrobe). Dedicated software has been developed to support the loan system. They have the ambition to set up a 'loan counter' in clothes stores | R1 | | P | | D | D |
| 27 | Mijn Waterfabriek produces and sells systems for net-zero water consumption in buildings based on 1) saving water, 2) use of rain water, and 3) reuse of waste water | R2, R8 | | | P? | | D |
| 28 | Coffee roasting house Peeze and Advanced Technology Innovations have collaborated in the development of coffee | R8 | D? | | | | |

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|---|---|---|---|---|---|---|---|
| | capsules as an alternative to the Nespresso capsule. They are made of polylactic acid obtained from waste material from sugar beet processing (thermostable polylactic acid, injection into capsule moulds in three layers, and a pierceable three-layered covering foil). Polylactic acid is bio based and can be used in industrial composting processes | | | | | | |
| 29 | Gerrard St. (formerly known as Pelican House) offers service contracts for high-quality modular headphones and sends the customer spare parts if a headphone breaks down. The initiative is still in the pilot phase. As yet, Gerrard St. does not repair headphones itself, but does take charge of recycling discarded sets. Production takes place in China | R4, R5, R6 | | | D | D | D |
| 30 | Philips and Turntoo have developed the 'pay-per-lux' concept which uses a service contract to sell the provision of light, rather than light fittings and fixtures and lamps. The service contract, which includes management and maintenance, encourages Philips to develop energy-efficient and environmentally efficient lighting. | R4, R5, R8 | | | D | D | D |
| 31 | Slimbreker has developed a 'smart crushing' technology to recover clean cement from concrete rubble. In principle, this cement can be used again to prepare concrete, but the parties in the product chain are not collaborating very actively | R8 | P | | | | D |
| 32 | Weder carries out assignments from businesses to design second opportunities for refurbished old furniture. Weder collects the old furniture and looks for materials and appropriate techniques to upgrade the items. They collaborate with specialised companies and training centres to execute the new design | R5, R8 | | | D | | P |

Socio-institutional (SI), core technology (CT), enabling technology (ET), product design (PD) and revenue model (RM)

Rating: D=dominant, P=present, empty cell=hardly present/no presence

# 4 Discussion

## 4.1 CE transition and innovation

The evaluation of hypothetical and practical cases presented in this study has been conducted using currently available information and the joint expertise of the authors. The scoring of the cases includes a degree of subjectivity, but nevertheless gives relevant information. The results show that achieving socio-institutional change is a bigger challenge than spurring technological innovation. Radical technological innovation is even found to play a minor role only. This underlines the notion set forth in Section 2.2, that CE transitions are different from most other sustainability transitions in which radical technological innovation is the main driver and circular application of resources and materials has no role to play. Characteristic for all three types of CE transitions is the change from linear to circular application of natural resources and materials brought about by innovation efforts.

Major technological advances can, of course, still influence CE transitions. The rise of 3D-printing for example is having a major impact on the choice of materials to be applied in products. The continuing miniaturisation of electronic components, resulting in more compact and multifunctional equipment, is likely to lead to increased efficiency in the consumption of resources and materials, and can also positively affect the practice of recycling. These effects are not the result of planned CE transitions, but are produced by developments with other motivations. In the case of 3D-printing, this is the will to personalise products, and for companies the motivation can be to reduce overhead for stock management or to promote experiments to develop new products. Lower energy consumption and increased processing power play a role in the case of miniaturisation of computer hardware.

Any major change to the existing industry structures may, depending on how it is induced, have a positive or a negative influence on CE transitions in product chains. The personal computer could have led to a paperless office, but initially provoked a more intensive use of paper. LED technology is ideal for designing screens with lower energy consumption, but instead it caused a trend shift towards the design of increasingly larger screens. Currently, immense LED displays are used to replace traditional billboards. In short, new technology with a potentially positive influence on the circular economy does not necessarily have the desired effect. Current innovations and design trends are not yet focused on increasing the circularity of resources and materials and decreasing the effects on the environment.

## 4.2 Circular economy indicators

The European Environment Agency (EEA, 2016b) has formulated questions to measure progress towards a circular economy at the national level. These questions mainly concern circularity (resource and materials consumption, and waste treatment). Measuring of the other aspects of the CE transition process (means and activities), however, and of environmental and economic effects is only addressed marginally. Building on the EEA (2016b), this study presents a set of diagnostic questions to measure the progress of CE transitions in individual product chains. The questions can be used to measure the CE transition process itself, and its effects on circularity, the environment and the economy.

The diagnostic questions used in this study are mainly based on earlier work by Hekkert and De Boer (2011). We are not aware of any other sets of questions or indicators which can be used as a standard for measuring CE transition processes. An evaluation by Ganzevles et al. (2016) of CE Green Deals shows that measuring of those initiatives takes place on an ad hoc basis. For each CE Green Deal, it is established which indicators are to be monitored and as a result the sets of indicators vary widely across CE Green Deals. Substantial improvement would be made if the government developed a protocol for measuring CE transition processes, enabling progress monitoring in product chains, and at the national level.

Numerous instruments and indicators are already available to measure the effects of a CE transition on circularity, the environment and the economy (MVO-Netherlands, 2015; RIVM, 2016; CBS et al., 2014; EEE, 2016a). We recommend formulating an approach which should at least include:

- A focus on cradle-to-grave resources and materials consumption as a proxy for circularity;
- Cradle-to-grave monitoring of energy consumption as a proxy for other environmental effects in the product chain;
- Tracking the energy consumption of the circularity process itself.

Several studies show that cradle-to-grave (fossil) energy consumption is a good proxy for environmental effects (Huijbregts et al., 2006; Pascual González, 2016). This is because the combustion of fossil fuels for energy generation makes a dominating contribution to environmental effects in many product chains. An increase in the share of renewables in the energy mix may make cradle-to-grave energy consumption a less adequate proxy. However, the share of non-fossil energy in the Dutch energy mix is presently still very low. Eventually, this share will rise in line with national and European policies to achieve the climate goals set out in Paris in November 2015.

We advocate measuring materials and energy consumption in physical units per functional product unit and for the sector as a whole. Earlier research into the energy consumption per financial unit (energy intensity) of material production, including the studies by Farla et al. (2000) and Worrell et al. (1997), show that physical indicators of energy consumption provide a better impression than financial indicators. Financial indicators are strongly influenced by market price trends, and therefore have no direct relationship to actual material flows and environmental effects.

The diagnostic questions in this study can be used for ex ante, ex durante and ex post measuring of the CE transition process and its effects. Ex durante and ex post measuring seem obvious steps for monitoring the progress of CE transitions in product chains, but ex ante measuring is also relevant to explore whether proposed CE transitions do indeed have the potential to lead to the intended CE effects. Ganzevles et al. (2016) show that ex ante evaluations are usually not conducted when settling CE Green Deals. The analysis of five selected CE GDs by Ganzevles et al. (2016) reveals Green Deal efforts to make a product chain more circular sometimes result in other product chains becoming *less* circular.

This study focuses on identifying *what* needs to be measured to be able to evaluate CE transitions in product chains. It would be beneficial to extend the results obtained here with a subsequent study on *how* things should be measured. Applying this knowledge to a number of product chains can then teach us if the relevant information can actually be uncovered and what the quality of this information is.

## 4.3 CE progress in the Netherlands and internationally

Both VANG, the national policy programme From Waste To Resources (Ministry of IenM, 2013) and the European Commission's action plan for a circular economy (EC, 2015) emphasise the importance of measuring the progress of CE transitions. The European Commission wants to develop a measuring framework, together with the European Environment Agency and in consultation with the Member States (EC, 2015). The European Environment Agency (EEA, 2016b) has made a head start by identifying relevant questions to evaluate the consumption of resources and materials at the national level. Since this study focuses on measuring the progress of CE transitions in individual product chains, it specifically adds to the EEA list, questions about the CE transition process and its effects on the environment and the economy. With this we aimed to provide input to the meanwhile released government-wide CE policy programme *A circular economy in the Netherlands by 2050* (Ministry of IenM, 2016a), and the recently published CE advice 'Working on a circular economy: No time to lose' (*Werken aan een circulaire economie: Geen tijd te verliezen)* of the Social and Economic Council of the Netherlands (SER, 2016). Both documents address the question of measuring progress towards a circular economy.

When measuring progress in the transition towards a circular economy, whether at the national level or that of individual product chains, it is important to realise that the process goes through several stages. The starting point and the final stage are shown in Figure 1.1, and Figure 2.1 provides details of the priority order of the circularity strategies that may be adopted along the way. Major differences exist between countries with regard to their advancement within product chains and at the national level. Some European economies, especially those in eastern Europe, are still considerably linear. Though the economic situation in these countries may cause consumers to extend the use of products for longer periods than in Western European countries, many materials still leave product chains relatively quickly as discarded products that do not enter recycling streams but end up in a landfill site (CBS, 2015). Other European economies have made more headway in recycling.

The information gained by asking the questions presented in this study may be valued differently depending on the stage of the CE transition and the circularity strategies being employed. In an economy that is still almost entirely linear, it is important to reduce the volume of waste, for which (high grade) recycling (R8 in Figure 2.1) can be an option. Another alternative preferable to landfill is energy recovery from incineration or by anaerobic digestion (R9 in Figure 2.1). In addition, with regard to new products, it is advisable to find smarter forms of manufacturing and use (R0-R3 in Figure 2.1), and to extend their lifespan (R4-R7 in Figure 2.1). In situations where sizable levels of recycling are in place, it is interesting to see if higher grade application of recycled materials is possible, but, here too, the main challenge is formed by smarter manufacturing and use along with lifespan extension.

Of the 36 CE Green Deals (Ganzevles et al. 2016) and 32 CE Best Practices almost all aim at increasing recycling. In addition, many cases, several CE Best Practices in particular, are following other circularity strategies. The prominent role of recycling is nonetheless remarkable. As long as this involves high-grade recycling, in which the recycled material retains its original quality, this is a practicable strategy. Another possibility is upcycling biomass waste into useful products. For a more ambitious CE transition though, with substantially lower levels of resource consumption and waste generation, higher circularity strategies are preferred. After all, recycling, and low-grade recycling in particular, is still very much a linear solution. In addition to aiming for less resource consumption and waste generation, it is also important for a circular economy to focus on creating less environmental impact (including more value for ecology), and generating more added value for the economy. The latter aspect provides an important explanation for the enthusiasm of companies to work towards a circular economy.

## 4.4 Support for the circular economy indicators

This report presents a conceptual framework for measuring the progress of CE transitions in product chains. It can be applied to initiatives in which CE transitions are central, and forms the basis for a set of generic questions, designed to gather the relevant information. The study has been carried out following a request by the Ministry of Infrastructure and the Environment which needs to inform the Dutch parliament about the progress being made towards a circular economy in the context of the policy program From Waste To Resources (VANG). The results are also relevant for the recently released government-wide CE policy programme *A circular economy in the Netherlands by 2050* (Ministry of IenM, 2016a), and SER.

A small number of government officials from the Ministry of Infrastructure and the Environment, the Ministry of Economic Affairs, and Rijkswaterstaat were asked to provide feedback on the conceptual framework, its applications to CE cases, and the diagnostic questions. In 2010, the Social and Economic Council of the Netherlands published the recommendation *Further work towards sustainable growth* (SER, 2010) which focuses on sustainability indicators. The Council emphasises that support for aggregated sustainability indicators requires political acceptance of the process establishing them. Such political acceptance follows from acceptance by society. Scientific literature teaches us that acceptance of the results of policy research by societal stakeholders is essential for the successful integration of those results into a policy process. Acceptance must meet the following three conditions (Kunseler et al., 2015.):

- Legitimacy: Stakeholders need to have the feeling that they are contributing to policy research, and that the corresponding process is transparent and fair.
- Salience: The research policy needs to comply with the specific activities and interests of the stakeholders.
- Credibility: Stakeholders need to acknowledge the scientific quality and validity of the policy research and its results.

With regard to the conditions of legitimacy and salience, it is important to acknowledge that there seems to be general agreement about what a circular economy means and what aspects of the transition process and effects need to be measured, but, in actual practice there are also substantially different viewpoints. For example about whether CE transitions should contribute to environmental improvement. Some companies regard environmental improvement as a "collateral benefit" of CE transitions, while many other stakeholders take it to be an integral part of a circular economy. Broad acceptance of indicators for measuring CE transitions requires making these differences of opinion explicit, and preferably reconciling them in a consensus process.

A large body of knowledge is available on measuring the progress of CE transitions, in particular for how to measure its effects, including sets of operational indicators and data for implementing them. Even though there is a fair degree of agreement, the debate among scientists and consultants is ongoing. There is also a certain degree of competition//rivalry among the professionals in the field with regard to their knowledge input and the employed data, indicators, models and software. The credibility of CE transition strategies can also be affected by the degree to which scientists and consultants feel their efforts are acknowledged within the policy process of deciding on indicators for measuring CE transitions in product chains.

# 5 Conclusions

The conceptual framework presented here has been applied to a large number of cases in which CE transitions are central. The hypothetical cases concern plastic packaging and electrical and electronic equipment, and the practical cases in 36 CE Green Deals and 32 CE Best Practices. This facilitates the evaluation of the roles of socio-institutional change and innovation in CE transitions as a first step towards establishing which types of information are needed for measuring the progress of CE transitions in product chains. This is done with the R-list, which is based on a priority order of circularity strategies.

The evaluation reveals the limited role assigned to technological innovation in CE transitions. Technological innovation is found to be relevant for CE transitions which adopt recycling as a circularity strategy. It almost always takes place, however, in the form of adaptations to existing technology to meet the specific requirements of the product in question. This process is known as incremental technological innovation. Radical technological innovation on the other hand, is supported by a fundamentally new knowledge base and is hardly applied in the studied initiatives.

Socio-institutional change appears to be a much greater challenge than technological innovation in the evaluated cases. CE transitions which adopt strategies geared towards higher levels of circularity require more socio-institutional changes throughout the product chain. These changes are difficult to monitor. Innovations in product design and revenue model also become more important in higher circularity strategies.

There is no consensus yet about how to measure the progress of the CE transition process and its effects on circularity, the environment and the economy. The European Environment Agency has formulated diagnostic questions about circularity which deal with the consumption of natural resources and materials, and waste treatment at the national level (EEA 2016b). This study focuses on CE transitions in individual product chains. Therefore, the EEA questions have been modified to enable measuring those chains, and complemented with new ones which address the CE transition process as a whole and the effects it has on the environment and the economy. The questions are relevant for measuring progress in radical and incremental innovation and socio-institutional change. The questions may be more or less pertinent, however, depending on the type of CE transition being analysed. There is a need to develop a protocol to harmonise measuring activity to ensure appropriate progress in the monitoring of the CE transition process and its effects.

Of all the waste generated in the Netherlands, about 93% is now processed effectively, with 79% of that volume going to recycling. However, most of that is low-grade recycling and our consumption of natural resources is still high. This means the Netherlands still has a long way to go towards more circularity. In the cases studied here, recycling is also found to be the most frequently used circularity strategy. However, higher circularity strategies are clearly preferred if we are to achieve a highly ambitious transition towards a circular economy which operates with a substantially lower consumption of natural resources and materials and generates far less waste.

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