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Ministry of Infrastructure and Water Management

Pilot study into the significance of circular economy for the earth chain

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Explanation of some terms as used in the translation of this report

Earth	Soil material (including shells and gravel) that has been excavated/extracted to be used in (civil) works or in products such as asphalt and concrete.
Soil	The solid upper part of the natural landscape consisting of either in situ soil material or earth that has left the earth cycle and been returned to the soil stock.
Earth-moving	All physical activities concerning soil/earth such as excavating soil, transporting earth and building (civil) works (partly) with earth.
Earth chain	The sequence of all possible stages and actions concerning soil/earth during its lifespan.
Earth cycle	A closed earth chain.

Contents

1 Introduction

1.1 Background

The Ellen MacArthur Foundation (1) describes a circular economy (CE) as an economical and industrial system that is based on the reuse of products and raw materials and the restorative capability of natural resources. This system aims at minimising the loss of value in the system as a whole and at maximizing the generation of value.

In the past century worldwide demand for raw materials has grown explosively. As a result the supply of (primary) raw materials is gradually becoming depleted. The Dutch government therefore, following the European Union (EU), has set itself (together with its partners) a first target to reduce the use of raw materials by 50% in 2030 on its way to become fully circular in 2050 (2). The Directorate-General for Public Works and Water Management (in Dutch Rijkswaterstaat (RWS)), being responsible for the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands, aims at operating fully circularly in 2030 (3).

In order to achieve this goal various measures have been taken and RWS has started the impulse programme CE. At this moment it is however not yet clear what the real meaning of circular economy is for the different 'themes' within RWS and how the CE principles could be applied and implemented. The impulse programme CE therefore focuses at 'learning by doing' in the coming years (up to 2020) so CE and working in accordance with CE can be implemented in RWS's operating procedure after 2020.

The impulse programme focuses at various material streams, such as asphalt and concrete. In order to assess whether applying the CE principles to the earth chain contributes to achieving the objects of RWS, this study has been performed with as main assignment:

'Perform a pilot study into the significance of RWS's CE objectives for the earth chain'.

1.2 Scope of the study

From the Carbon Footprint that was previously determined for all of RWS's activities it appeared that the earth(-moving) chain is the most important in terms of material volume and CO_2 emission (see figure 1.1). Based on this fact it seems logical to also look at the earth chain with respect to CE. The question however is to what extent the CE principles and ambitions are applicable to the earth chain. Earth is after all a (raw) material which has characteristics that differ from those of primary 'non-renewable' resources (mineral, fossil and metals) which are generally the subject of CE. The supply of these primary materials is or will become finite, they are non-renewable and might become unavailable on different timescales. Earth however, is a (primary) material which has these characteristics only to a limited extent. Especially in the case of moving earth where earth is not 'used up' but is excavated at one place and subsequently used in another.

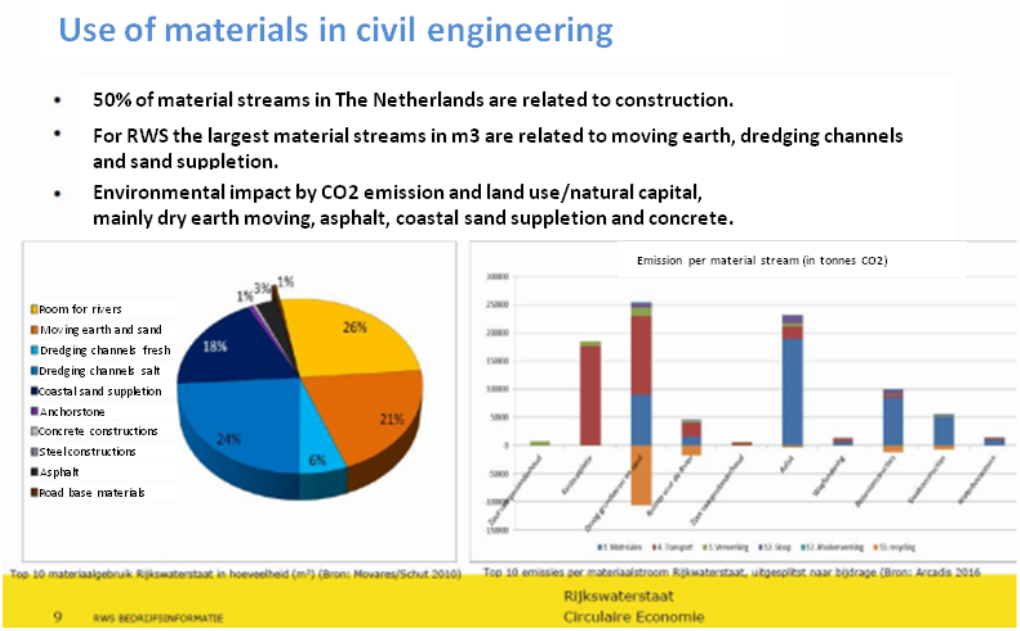

Figure 1.1 Use of materials in civil engineering (based on corporate RWS information).

For earth different definitions exist. In the present context we embrace the definition as laid down in the Dutch Soil Quality Decree: 'solid material consisting of mineral parts with a maximum particle size of 2 millimetres and organic matter in amounts and with structures as found in natural soils, as well as naturally occurring shells and gravel with grain sizes ranging from 2 to 63 millimetres'.
In addition to 'earth' we also frequently discuss 'soil' in this report. With respect to soil we adopt the definition as laid down in the Dutch Soil Conservation Act: 'the solid part of the Earth including the liquid and gaseous components and organisms'.

Central questions in this study were: 'Is the supply of earth finite?', 'Are the concepts of 'loss of value' and 'waste generation' applicable to the earth chain?' and 'Can earth be considered a primary raw material?'. The specific characteristics of earth with respect to CE, combined with the ambitions of the Dutch government and RWS concerning CE, resulted in RWS having a demand for a pilot study in which the significance of RWS's CE ambitions for the earth chain are enlightened. The outcome of this pilot study is meant to direct the implementation of RWS's CE objectives for the earth chain.

In addition to the dimension of the earth chain, the CO_2 emission of earth moving activities is an important topic within RWS (see figure 1.2) in order to be able to operate energy neutrally in the future. Reducing CO_2 emissions is however not included in the CE definitions. Working in accordance with CE does therefore not necessarily result in reduced CO_2 emissions and could indeed result in higher emissions. This could be the case if greater distances have to be covered in order to close chains or to be able to continue the high quality use of specific soil types. However, in this pilot study the CO_2 objectives of RWS are considered in relation to its CE objectives.

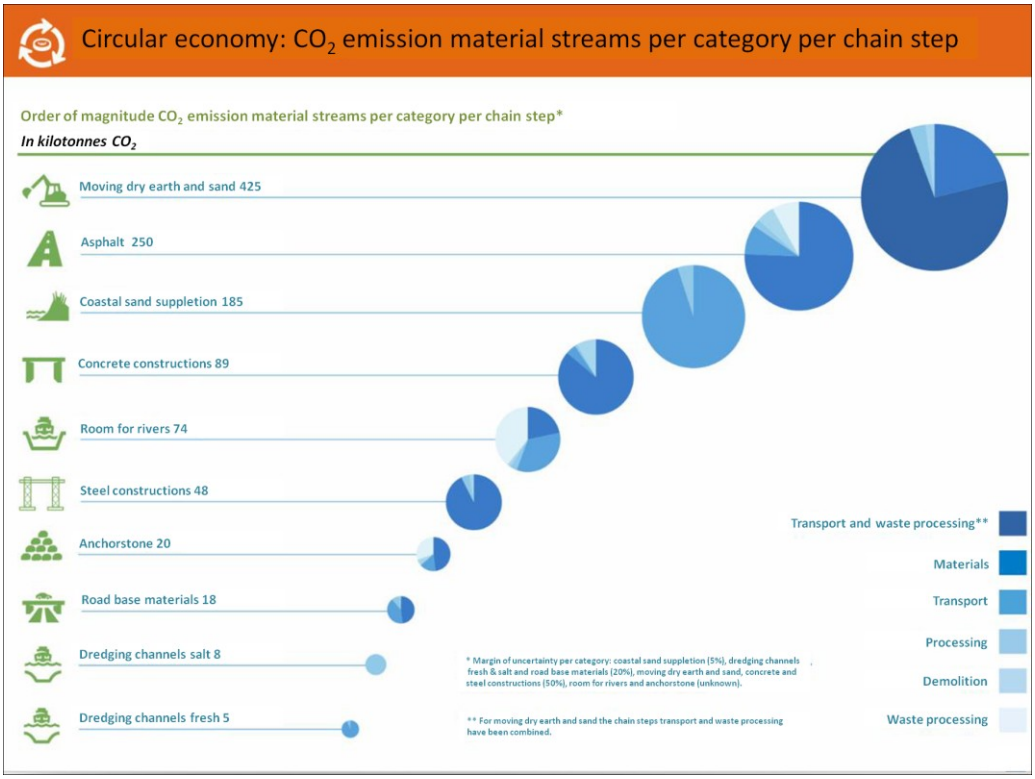

Figure 1.2 CO_2 emissions of materials in different categories of civil engineering.

This pilot study generally relates to the entire earth chain in The Netherlands, but RWS projects are emphasized. Products made of earth, such as glass, bricks and concrete are not considered in the study.

This document contains a first qualitative study of a simplified earth chain in RWS projects. The document is a first step in explaining the significance of CE for the earth chain.

1.3 Method of the study and lay-out of the report

The study into the significance of the CE objectives for the RWS earth chain has been performed by means of a designing research process in which RWS and TAUW have closely cooperated. During this process many choices have been made in order to get a concrete result. This document contains the main results of the pilot study and therewith offers leads to further elaborate the significance of the CE ambitions for the earth chain in a follow-up process.

Chapter two describes the policy framework and the theoretical framework of CE. In the first phase of this pilot study various policy documents of the EU, the Dutch government and of RWS were studied as well as several CE theories and conceptual CE models.

Chapter three contains the circular earth chain model. This model was formulated on the basis of both the policy framework and the theoretical framework. In this model several CE principles were related to aspects from the earth chain, as a result of which the earth chain can be describes as being circular instead of linear.

Chapter four describes the results, based on six different perspectives. This approach with different perspectives made it possible to test the significance and applicability of the various aspects of the circular earth chain model against practice. This approach shows where in the earth chain CE is relevant and where not or only to a lesser extent.

Chapter five contains the conclusions and recommendations. The recommendations discuss control of the process through purchase, management and design and can be considered leads for a follow-up study.

2 CE framework

The CE framework for the earth chain in this pilot study was based on two elements: a policy framework and a theoretical framework. The policy framework contains the main findings from the CE policy documents of the EU, the Dutch government and RWS and discusses the general principles of CE. The theoretical framework mainly discusses the theory of the Ellen MacArthur Foundation (1). This theory is explained in more detail in Annex B. In the theoretical framework the relation between the earth chain and the CE principles was established and a framework for CE in the earth chain was elaborated, consisting of principles and corresponding operational principles.

2.1 Policy framework

The policy framework constitutes the starting point of the pilot study because studying various policy documents on CE gives an insight into the way the EU, the Dutch government and RWS look at CE. How do these authorities interpret CE and how is that expressed in the different policy documents?

Definitions of CE

EU (4)

> CE is: an ***economy*** where the ***value*** *of* materials, products and resources is maintained in the economy as long as possible and where the generation of ***waste*** is minimised.

Dutch government (2)

> CE is: **dealing with** the earth's capacity and its products, materials and resources in an efficient and ***responsible way*** (taking into consideration the next generation).

RWS (3)

> CE is: a ***cycle*** of materials in which minimising the ***loss of value*** is the main thing and in which cooperation between the different stakeholders is very important.

From the definitions of the concept of CE in these three policy documents both differences and similarities arise. All definitions indicate that CE is about materials, products and resources but they differ with respect to the main scope that is attributed to CE.

How is Circular Economy implemented?

The way CE policy is implemented also shows similarities, although the scopes may differ.

According to the EU (4) four steps have to be taken when implementing CE:

1. Addressing ***production*** (both the product itself and the production process have to be made more efficient).
2. Addressing ***consumption*** (demand has to be changed).

3. ***Waste*** management (raw materials should maintain a high quality level as long as possible).
4. Waste as ***source for new products*** (waste should be recyclable).

The Dutch government (2) designates three principles that it wants to follow:

1. Use raw materials at the **highest possible quality level**.
2. If demand for certain raw materials continues to exist, replace these raw materials by **more sustainable versions**.
3. See to a **changing demand** for raw materials by means of new production methods and new consumption patterns.

RWS (3) follows two principles:

1. A long cycle by **prolonging the lifespan** of products, repairing an reuse.
2. Keep raw materials as long as possible within the **cycle**.

Examining the different policy documents leads to the conclusion that CE deals with the question how the use of materials, products and (re)sources can be minimised by means of a different economy. The main characteristic of such a different economy is that cycles are closed, materials keep their value and are used in a socially responsible way, reducing the environmental impact.

2.2 Theoretical framework

The theory of the Ellen MacArthur Foundation (1) takes a central position in the theoretical framework. This model, schematically shown in figure 2.1, distinguishes three main principles, which have been adopted in the theoretical framework for the earth chain. In order to be able to implement these three principles in the earth chain several conceptual models have been analysed. Two useful supporting models that helped defining the operational principles are the model 'Seven pillars of the circular economy' (5) and the '7R model for a circular economy' (6) (see Annex B for more details of these conceptual models). Both models contribute to a broader positioning of the theory of the Ellen MacArthur Foundation.

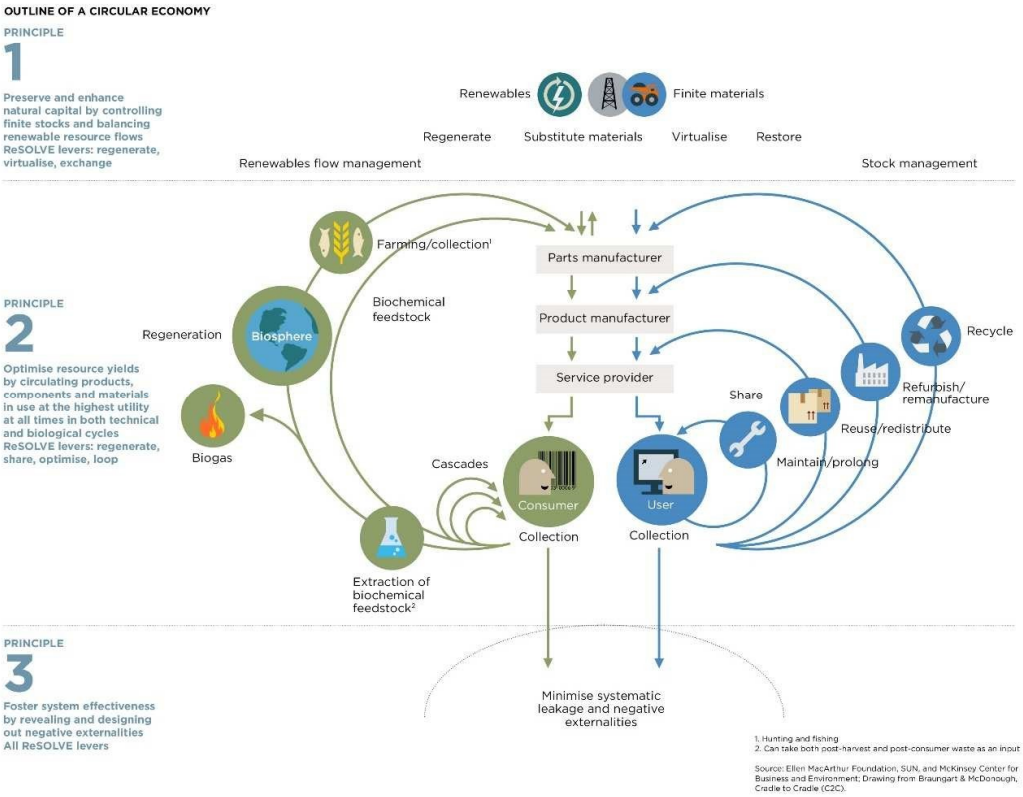

Figure 2.1 Circular conceptual model by the Ellen MacArthur Foundation (1).

The CE framework can best be described by defining three main principles:

1. Limiting the use of raw materials.
2. Closing cycles and preserving value.
3. Avoiding leakage and negative impact.

In the next paragraphs these three main principles of the CE framework are further elaborated into operational principles and described in terms of their significance for the earth chain.

2.2.1 Principle 1: Limiting the use of raw materials

According to the Ellen MacArthur Foundation the first principle stands for preserving and enhancing natural capital (raw materials) by controlling finite stocks and balancing renewable resource flows. Following the ambitions from the policy frameworks, one operational principle stands out from this main principle: 'limiting the use of raw materials'.

Operational principle: Limiting the use of raw materials

Finite primary raw materials slowly become depleted. As a result of this we won't be able to use these raw materials in the future anymore if we continue our present way of consumption. If we want to be able to use these raw materials in the future, we need a different economy. In concrete terms this means according to the Ellen

MacArthur Foundation that we have to limit our use of raw materials. This may concern both production method and consumption pattern (the demand for a product).

Significance for the earth chain

Given the scale of the earth streams within RWS projects, it is important to examine whether the use of raw materials should be limited in the earth chain. However, in RWS projects earth is mostly used in a 'retrievable way'. Because of this the earth can be reused in time and the claim on the stock of primary raw materials is therefore limited.

The question is however whether earth is really a finite raw material. Earth as (building) material is not finite, but some special soil types with specific properties are scarce (for example clay suitable for building dikes or silver sand for glass production). Therefore sand or clay extraction can result in the loss of natural capital from the soil.

Ecosystem services & natural capital

In this document the terms natural capital, ecosystems and ecosystem services are used.

An **ecosystem** is a system in which interaction between organisms (humans, animals, plants) and their environment (soil, water, air) takes place.

Ecosystem services are services provided by a specific ecosystem (see figure 2.2 for some examples).

Natural capital is the stock of ecosystem services.

In addition, some natural capital values are scarce (for example specific soil related ecosystem services). Basically, many of the soil related natural capital values are renewable, but earth used in works should get sufficient time to recover in order to become soil again. Several natural capital values in soil are however not renewable (geological values and cultural ecosystem services). The meaning of this first CE principle clearly shows the special position of the earth chain. Basically, earth is not a finite raw material but specific soil types (for example erosion resistant clay, silver sand for glass production and clay suitable for building dikes) are. On the one hand the natural capital values of earth are renewable on the other hand they are not. After all, earth can return to its stock (earth becomes soil again) and in that case is just temporarily used and not 'used up'.

2.2.2 Principle 2: Closing cycles and preserving value

The second principle of the Ellen MacArthur Foundation is about optimizing the use of primary raw materials by closing cycles and by reusing materials at the highest possible quality level. These aspects also make up the essence of the policy frameworks and can be described in the following two operational principles: 'Closing cycles' and 'Preserving and generating value'.

Operational principle: Closing cycles

The use of the term 'circular' in CE already shows that CE is about closing cycles. In order to be able to comply with the first principle (limiting the use of raw materials) cycles have to be closed. After all, if a raw material has become unsuitable for further use after being used only once, new raw material is needed. Closing cycles is therefore an essential element of CE. The theory of the Ellen MacArthur Foundation distinguishes between a technical cycle involving non-renewable raw materials and a biological cycle involving renewable raw materials.

Significance for the earth chain

Closing cycles is essential for CE and therefore also for the earth chain. The earth chain however has both features of the biological cycle and the technical cycle. The largest part of the earth chain, where earth is used in a work, follows the biological cycle. Earth being released from a work can be reused in another work so the input of primary raw materials is reduced. Earth being used in this way can also return to the stock, which is a distinctive feature of the biological cycle in the CE theory of the Ellen MacArthur Foundation. In order to be able to return to the stock the earth as it were has to (temporarily) leave the cycle to allow pedogenetic processes to do their work and ecosystem services to recover. Frequent extraction, transport and treatment of earth can after all in the long run result in a loss of ecosystem services. These ecosystem services can be (partly) regenerated as a result of the self recovering potential of earth outside of the earth chain.

Concretely, this implies for this part of the earth chain that closing the cycle can be managed by balancing the amounts of earth being extracted from and returned to the stock (the soil).
Another part of the earth chain, where earth is used in products (asphalt, concrete, glass) and where earth is treated in situ with, for example, immobilisation techniques, follows the technical cycle. Material which is released during the processing of such products cannot be reused as earth in the biological cycle just like that. In most cases the properties of the material have changed too much for this. Reuse within identical (or comparable) product chains is however often possible. The use of earth in an product chain should therefore be considered as a separate cycle largely apart from the biological earth chain (earth returns to soil). Earth is however 'used up' in product chains (although several studies are currently being conducted into recovering basic raw materials from concrete and asphalt).

Operational principle: Preserving and generating value

In order to enable the closing of cycles, the value of raw materials should be preserved. After all, if the value constantly diminishes the raw material will have to leave the cycle because it cannot be used anymore. If the value indeed decreases, generating value is necessary to keep the raw material within the cycle. Preserving and generating value are therefore essential in a circular economy.

Significance for the earth chain

With respect to preserving and generating value in the earth chain, the concept of 'soil ecosystem services' is the central point. Ecosystem services are services provided to society by a specific ecosystem. In that context natural capital is often regarded as the stock of ecosystem services, that is 'the potential of the natural environment to provide us with useful goods and (ecosystem) services'. Soil ecosystem services are often divided into production services, regulating services, cultural services and abiotic services (see figure 2.2).

Figure 2.2 Examples of ecosystem services (Source: PBL, WUR, CICES, 2014).

2.2.3 Principle 3: Avoiding leakage and negative impact

The third principle involves minimising systematic leakages and negative externalities. With regard to the policy frameworks, the aspect of 'minimising systematic leakages' can be translated to the operational principle 'reducing waste'. The aspect of 'avoiding negative impact' can, in line with the conceptual model of the 'Seven pillars of Circular Economy' (5), be translated to the operational principle 'CE should not be the aim at all costs'.

Operational principle: Reducing waste

Reducing the amount of waste is a CE principle that is mainly aimed at by the EU. Closing cycles is the logical result of aiming at reducing waste. RWS and the Dutch government look at it from the opposite side: preserving value results in better closed cycles and therefore in less waste. This proves that the individual operational principles have to be considered in conjunction with each other. Reducing waste is an important impulse for preserving and generating value and therewith contributes

to closing cycles. However, reducing waste alone is no CE (reducing waste can also be achieved by recycling, which not automatically results in high quality materials).

Significance for the earth chain

Within the earth chain avoiding waste is also important. However, as a result of legislation reducing waste has been common practice for years within the earth chain. Within the earth chain earth is considered waste if it has become too polluted to clean it up in an efficient way and its only possible destination is a landfill. In The Netherlands annually between 500 and 1.500 Kton of earth is transported to a disposal site. In addition, between 2 and 2.5 Mton of heavily contaminated earth has to be decontaminated on an annual basis. Both the amount of waste and the amount of decontaminated earth are peanuts in comparison to the total amount of earth being moved. The fact is that on an annual basis more than 60 Mton of (secondary) earth is reused in The Netherlands. The total use of earth, including primary extracted earth, is even higher. Therefore, the amount of waste is less than 2% of the total amount of earth being moved[1]. Even this small percentage could be reduced, but this would hardly have any impact on CE. By focussing more on preserving value, the waste stream will automatically become smaller than it is now.

Operational principle: CE should not be the aim at all costs.

As described by the Ellen MacArthur Foundation, negative externalities must be minimised. With this, this theory mainly focuses on negative effects of raw materials that leave the cycle. Conceptual models such as the 'Seven pillars of Circular Economy' (5) point out that CE itself can also have negative effects on the environment. For instance, closing a cycle is not advisable if this results in much higher CO_2 emissions or in loss of biodiversity. The operational principle can however also be applied the other way round. The socially added value of CE can be increased by optimizing for positive external effects, such as enhancing biodiversity or climate adaptation.

Significance for the earth chain

Making the earth chain circular can also affect other social issues. For example, reusing earth in the highest quality work possible may result in higher CO_2 emissions if the new (high quality) work is situated much further away than a (lower quality) work close by. The use of earth can also negatively affect biodiversity and returning earth to the stock may result in extra transport.

Taking CE principles as a starting point in thinking can contribute to positive effects, but one should also consider possible negative effects. The pros and cons should be weighed against each other. In short: CE should not be the aim at all costs.

This implies that one should not only consider 'hard' CE principles when using earth in projects , but that one should also consider the social impact (both positive and negative). This asks for a careful assessment in every project.

[1] 2% is already a high estimate, the real percentage is probably lower. The data originate from Bodemplus and are national data (7).

3 The conceptual CE model for the earth chain

In this chapter the earth chain is elaborated on the basis of chapter 2 'CE framework'. In the first paragraph the conceptual CE model for a circular earth chain is worked out and explained. In the second paragraph the theoretical framework is combined with the circular earth chain model on the basis of the three principles of the Ellen MacArthur Foundation. The conceptual model assists in relating the earth chain to the CE principles, contributes to interpreting the connections and dependencies, and provides insight into the parts of the earth chain where CE is relevant.

3.1 The conceptual CE model for the earth chain

3.1.1 The earth chain

The earth chain in RWS projects is often described using the following three steps:

1. Excavating the earth (becoming available).
2. Transporting and possibly treating the earth.
3. Applying the earth in a (civil) work.

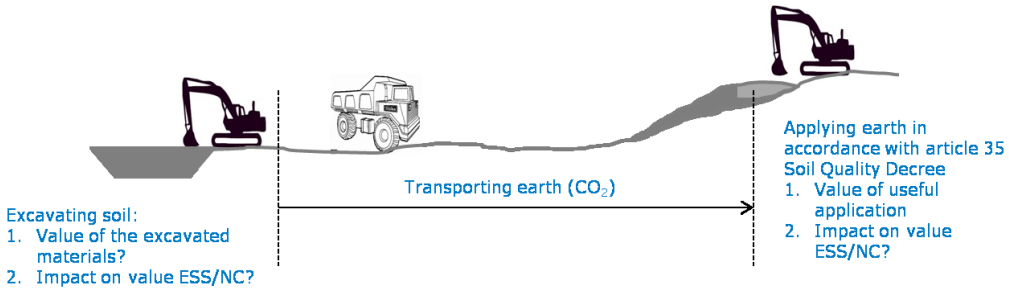

Figure 3.1 Basic description of the earth chain.

After construction of a (civil) work the phase of its use follows. After the function of a works ends, the earth is retrieved and reused as much as possible in other works. Not looking at the level of individual projects but at the whole, the earth chain can be regarded as a cycle consisting of four phases: excavating/becoming available, treating/processing, applying/designing and being in use.

These four phases define the basis of the conceptual model for the circular earth chain as shown in figure 3.2. In the following paragraphs the individual phases are further explained.

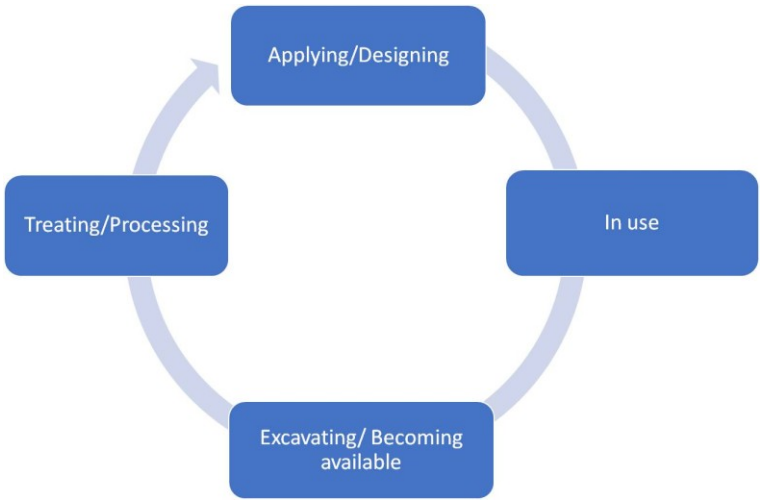

Figure 3.2 The conceptual model for the circular earth chain.

3.1.2 Earth entering and leaving the circular earth chain

Excavating/becoming available

Earth can enter the chain from the soil during the phase 'excavating/ becoming available'. As soon as soil is excavated it is characterized as earth. In addition earth can be excavated during this phase from an existing work. Furthermore waste can originate after excavating earth if this earth is too polluted to be of further possible use. If this is the case the earth leaves the chain.

Treating/processing

Earth that has become available can be treated/processed in a next step. Depending on the desired use and the quality of the earth, different types of treatment can occur. Within the earth chain earth can be treated in order to be used in the earth chain, but earth can also be treated in order to be sold to a product chain (such as the glass or concrete chain). In this case the earth leaves the chain and cannot return to the earth chain. Products from the product chain can however affect the total amount of earth needed in a work because some products can be used to replace earth (for example: granulated material).

Applying/designing

Both treated and untreated earth can be used in works. Before use one should consider the highest possible quality of using the earth (material and use). One can consider the most optimal and highest quality use by reflecting on the specific use in a work and on the scarcity of a raw material outside of the earth chain. In addition, an alternative design can facilitate reusing earth or reducing the amount of earth needed.

In use

Earth employed in a work is 'in use'. This can have a temporary character but can also last many years, depending on the life span of the work. Earth being used in an area that cannot be considered a work, leaves the chain and returns to the soil stock again. Earth leaving the chain as soil can re-enter the chain in the future.

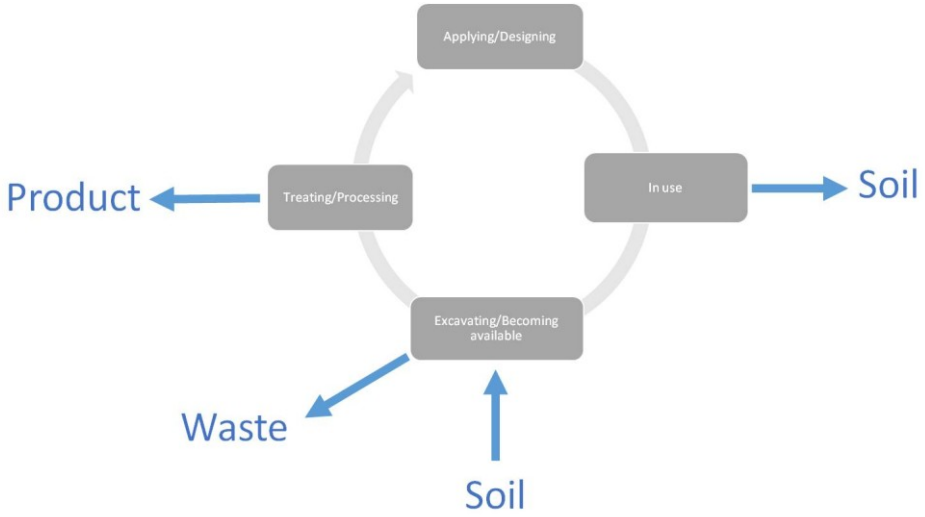

Figure 3.3 The circular earth chain with its possible ways of earth leaving or entering the chain.

3.2 Linking the theoretical framework with the earth chain model

As indicated when elaborating the CE principles, it is useful to regard the entire earth chain also with respect to broader social issues. This is represented in figure 3.4.

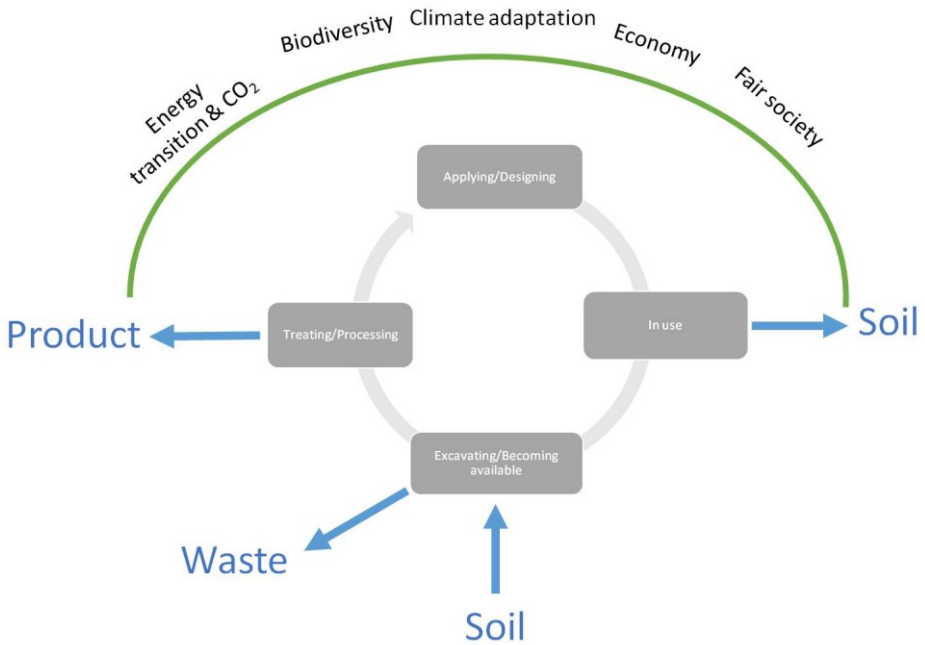

Figure 3.4 The circular earth chain regarded with respect to broader social issues.

In figure 3.5 the relationship between the three CE principles of the Ellen MacArthur Foundation and the circular earth chain regarding broader social issues is shown. This relationship is subsequently explained per principle.

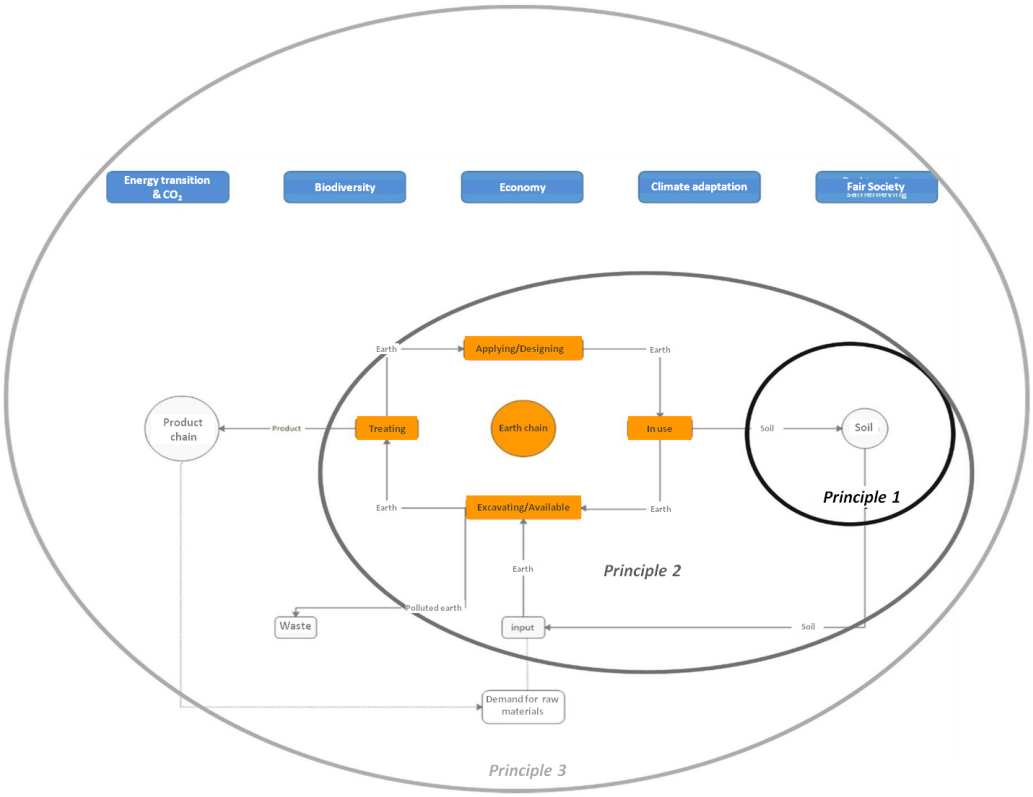

Figure 3.5 The circular earth chain in relation to the three CE principles.

Principle 1: Limiting the use of raw materials.
Principles 1 is about limiting the use of raw materials from the stock. In the circular earth chain this stock is presented by the soil. Whenever earth is needed for an RWS work and this earth cannot be acquired within the earth chain, the earth (at that moment still soil) is removed from the stock. If the earth leaves the chain and is used as soil again, it is added to the stock again.

Principle 2: Closing cycles and preserving value.
Principle 2 is about closing cycles and preserving value. The circular earth chain can be considered a closed system if one also takes into account the soil stock. Generating value takes place both within the earth chain and within the soil stock. Within the earth chain value can be generated when going through its four different steps. The steps 'treating/processing' and 'applying/designing' for example can contribute to a higher technological or use value. In case of applying/designing or of use as soil, one can optimize with respect to the natural capital value of earth.

Principle 3: Avoiding leakage and negative impact.
Principle three is about reducing negative impact and reducing waste. The earth chain as a whole must contribute in a positive way to various social issues (represented in the blue rectangles). By closing the cycle hardly any earth will leave the chain as waste. Use of earth in products should be considered a different chain.

4 Results

In order to test the significance and applicability (and therewith the robustness) of the discussed conceptual model against practice, six perspectives have been developed. These perspectives came up during the designing research process as receiving the most attention. Upon analyses the six perspectives have been subdivided into three types of relations with the circular earth chain model. See table 4.1.

Table 4.1 Approach using six perspectives.

Perspective	Relation with the circular earth chain model
Value of use	Part of the 2nd CE principle
Natural capital	
Treatment of earth	Part of the circular earth chain model
Product made of earth	
Policy, legislation	Preconditions
Guidelines for design and production	

The results of applying the perspectives to the conceptual model have contributed to deepening and testing of the functioning of the conceptual model.

4.1 Results with respect to principle 1: limiting the use of raw materials

The raw materials for the earth chain are retrieved from the soil stock. With this, not only earth is retrieved from the stock but also the accompanying natural capital. Excavation results in temporary loss of stock volume but by returning earth from the chain to the stock again, this loss is minimised. In an ideal situation the earth balance fluctuates around equilibrium and the net loss of earth is zero.

However, earth can also leave the chain as waste or leave the earth chain by entering the product chain. This earth cannot return to the stock and because of that causes a negative earth balance. Within RWS these losses are expected to be limited (less than 2% leaves the chain as waste and less than 5% as product[2]). Due to these limited losses they have little impact on the earth balance. In addition to these two losses from the earth chain, certain operations within the earth chain can also prevent the earth being able to return to the soil stock. Some types of treating the composition of earth (immobilisation) can for example result in the loss of

[2] We didn't find exact data on the loss of earth to products. If we look at the RWS products that contain the largest amounts of earth (concrete and asphalt), we estimate the amount of earth lost to the product chain to be less than 5% of the total amount of earth moved annually in The Netherlands. This is based on the fact that on an annual basis 65 million tonnes of earth are newly extracted or imported in/into The Netherlands and that approximately 26% of this earth is used as raw material for concrete and asphalt. In addition between 15 and 20 million tonnes of earth are imported. This earth is also mainly used in civil engineering. The total amount of earth used in concrete and asphalt is therefore around 40 million tonnes. (http://www.clo.nl/indicatoren/nl006716-winning-en-verbruikvan-oppervlaktedelfstoffen).
These data also indicate that demand for earth is always bigger than the amount of earth being released. Only a small part disappears as waste, which suggests that part of the earth has a permanent destination and is not released anymore for (re)use.

necessary soil properties. In practice RWS appears to work already to a large extent with a circular earth chain (the earth cycle seems to be closed for 93%).

The question is therefore which reasons RWS could have to close the earth cycle even more. CE primarily concerns primary raw materials and the question is whether soil can indeed always be considered a primary raw material. In addition, the first CE principle mostly concerns cases of scarcity and earth/soil is generally speaking not scarce.

As indicated in chapter 2, some exceptions with regard to scarcity of earth/soil can be distinguished. Necessary earth properties can be so specific that only a limited number of soil/earth types comply with the requirements (for example clay for building dikes). These earth/soil types could possibly be characterised as finite. Extraction of sand and clay can also result in the loss of non-renewable natural capital values or the loss of biodiversity. This is why RWS wants to explore the possibility of further limiting the use of earth and so to fight scarcity. It speaks for itself that the focus is on the scarcity of certain specific soil types and soil related natural capital values and not on the earth chain as a whole.

Rising sea levels due to disrupted sedimentation processes, climate change and subsidence might result in higher future demands for earth, as a result of which earth might become more scarce. Scarcity might therefore actually become relevant for the earth chain in the future. However, in this case scarcity is defined differently than in the case of CE. Here again, earth is not 'used up' when it is used in earth moving measures but in principal becomes soil again.

4.2 Results with respect to principle 2: closing cycles and preserving value

For now we can therefore assume that within RWS the earth cycle has already been closed for the greater part. An important reason for this is that Dutch legislation concerning waste and the environment and guidelines for designing civil works (a closed earth balance) are already strongly directed at maximum reuse and therewith at closing the cycle. Preserving value is therefore the more relevant part of principle 2 at this moment.
In practice the utility value of civil works is the main issue in RWS projects. Generating utility value can only be achieved within the earth chain and by human action. Treatment of earth can also result in a higher utility value.

In addition to aiming at utility value, one could probably also aim at preserving other values such as natural capital values. In case of earth this mainly concerns preserving and generating natural capital both within the soil stock and within civil works. Boosting the utility value and the natural capital value at the same time is not always possible. Increasing one value can result in a decrease of another. For now RWS mainly aims at generating/preserving utility value and less at generating/preserving natural capital value.

4.3 Results with respect to principle 3: avoiding leakage and negative impact

Leakage from the earth chain is currently minimal. This is mainly due to the present Dutch legislation concerning waste and the environment and guidelines for designing civil works. However, earth still leaves the chain as waste (too polluted material) or as raw material (sand) for the product chain. RWS has already given much attention to the waste stream as a result of which this stream can hardly be optimized any further. Recently RWS, in cooperation with the civil engineering branch, has taken earth in the product chain (concrete and asphalt) into further

consideration, due to which the product chain may eventually also be made circular. It is expected that the amount of earth leaving the chain as raw material for products will decrease in the near future.

In addition to avoiding leakage the third principle also concerns avoiding negative impact. Actions within the earth chain can have large consequences for other social issues. Positive consequences can be considered concomitant opportunities in projects and can be very relevant for RWS. If natural capital is stimulated, biodiversity may increase. If we can keep earth longer suitable for high quality use this may affect the economy. A change in the guidelines for designing civil works or a change in policy or legislation may affect energy related themes, such as CO_2 emissions. In addition to these examples many other examples of actions within the earth chain that contribute to other social issues could be mentioned. This shows that CE is a means to an end to achieve various goals.

5 Conclusions and recommendations

5.1 Conclusions

The scale of earth moving activities within RWS is large, as is the contribution of earth moving activities to the total CO_2 emissions of RWS. For this reason the need arose to conduct a pilot study into the possible use of CE principles in the earth chain and into the specific properties of 'earth' with respect to the objectives of CE. The main task was therefore: 'Perform a pilot study into the significance of RWS's CE objectives for the earth chain'.

From this pilot study it appears that the specific properties of earth differ from those of the raw materials which are generally the subject of CE. Contrary to those primary raw materials, earth is not scarce (except for some specific soil/earth types). Furthermore it is questionable whether all earth can be characterized as primary raw material (most of the soil/earth in The Netherlands has been mixed by now). Also, in RWS projects earth is mostly used as earth. Therefore, earth remains earth and does not leave the earth chain as part of a product, as is often the case with primary raw materials. As a result of this, earth can almost always return to the soil stock and is hardly 'used up'. Viewed from that perspective it is advisable to further explore the relevance and suitability of the formulated generic ambitions for 2030 and 2050 (50% and 100% less loss of material respectively) for the earth chain.

These specific properties of earth call for a critical and common sense view on the applicability of CE on the earth chain. This pilot study reveals that the CE principles indeed apply to some parts of the earth chain. In order to implement CE in the operating procedures of RWS it is necessary to make the CE principles concrete and feasible for their use in the earth chain.

Already in the policy framework it became clear that CE is about products, materials and sources. And the theory of the Ellen MacArthur Foundation, as used in the theoretical framework, offered insight into the interaction between stock and chain for biological (renewable) raw materials. Earth can be considered a material or a source and also a biological or a technical raw material, which indicates that the CE principles can be applied to the earth chain.

The pilot study not only provides an understanding of the applicability of the CE principles to the earth chain, but also indicates that the present guidelines for designing civil works and the present Dutch legislation make the earth chain already comply with several CE principles. The waste stream for example is estimated to be less than 2% and the earth chain is already closed to a great extent.

The pilot study also shows where the earth chain can be further optimized with respect to CE. At present the focus is on the utility value of earth in a (civil) work, due to which the natural capital value of the earth or the ecosystem services that this earth can provide might be lost. This loss of value could occur both in the soil stock and in the earth chain. In some cases the loss can even be irreversible (for example geological values can be permanently lost after excavation of earth).

Another important result of this pilot study is that CE should not be the aim at all costs: CE should be regarded in the context of other social issues. In addition to positive impact on the use of raw materials, CE can as it happens also have negative impact, such as increasing the CO_2 emission and decreasing biodiversity.

On the basis of this pilot study we can conclude that the earth chain already complies with the CE principles to a large extent. Circular economy was however never the main reason to make the earth chain circular. Other underlying principles, including costs, suitability of the earth and environmental legislation have resulted in an almost closed cycle. The earth cycle might therefore present an excellent example for other chains. However, the chain is not closed completely yet, which might be desirable for finite soil/earth types. Finally preserving natural capital values is hardly taken into consideration yet when realizing earth related projects.

5.2 Recommendations

This pilot study provided us with various new views. These were presented in the previous paragraph. The aim of the pilot study was not only to explore the significance of CE for the earth chain, but also to come up with some concrete recommendations with respect to a follow-up study. These recommendations are presented in this paragraph. The recommendations are formulated for each CE principle and focuses on the possibilities for design, management and purchase. In addition we have pointed out some possible research topics in order to make some recommendations more concrete and practicable.

The focus on the possibilities for design, management and purchase stems from the fact that we found out in this study that within RWS these elements control almost the entire earth chain as presented in chapter 3. These three control elements can contribute in various ways to the further use of the three CE principles within the earth chain.

Because the recommendation partly concern the issue of natural capital (NC) and the more general CE principles (CE) and partly concern an integral approach (Int), every research subject is categorized and labelled according to these topics.

5.2.1 Recommendations with respect to principle 1: limiting the use of raw materials

Design & management

Through design one can control the criteria which determine whether earth can be returned to the soil stock. In doing so it is important to consider not only the utility value but also the natural capital values that are necessary for the earth to fully function as soil again. With that it is important to understand the conditions for an optimal recovery of natural capital values.

Main question with respect to design and management:

How can earth optimally be returned to the soil stock in such a way that ecosystem services can recover and the earth balance is in equilibrium?

Just returning earth to the soil stock is not enough to ensure recovery. The earth type should match with the existing ecosystem services and as soon as the earth performs soil functions, management is essential.

Corresponding research topics are:

- What is needed for ecosystem services to recover sufficiently and how could this knowledge be applied in a design? (NC).
- When can earth be returned to the soil stock? (CE & NC).
- Which ecosystem services are scarce at the moment? (CE & NC).
- Is added value generated if designing differently results in earth being more easily separated? (CE).

Purchase

Through purchase one can control the type of earth to be used in a project. By controlling the purchase of earth that is suitable for and contributes to a type of ecosystem similar to the one present at the site of the project, it is easier to return the earth to the soil stock eventually. Also through purchase one can prevent non-renewable ecosystem services to vanish.

Main question with respect to purchase

How does RWS want to define new conditions for earth in the purchase process for civil works? In addition to purchasing earth with comparable ecosystem services and not buying very scarce earth types, other social issues such as the CO_2 emission which depends on the transport distance from the source are of concern.

Corresponding research topics are:

- What is needed to be able to purchase earth for the benefit of a specific ecosystem service? (CE).
- When become other social issue more important than CE in the purchase process of earth or are some social issues such as CO_2 emission always deemed more important?(Int).

Other interesting research topics may be:

- What is the amount of earth RWS really uses annually and how much does newly extracted earth contribute to this amount? (CE).

5.2.2 Recommendations with respect to principle 2: closing cycles and preserving value

Design & management

Through design one can control preserving and generating value within the earth chain. By considering the future destination of earth as soil preceding its use in a work, it is easier to preserve or generate value. With respect to functionality and utility value already a lot has been regulated. However, with respect to optimizing the natural capital value in a work, hardly any principles regarding design are available. But just considering designing in a different way is not enough, it is also essential to focus on management, so 'new' principles regarding design can be observed in practice.

Main question with respect to design and management:

How can we define a mission with respect to design focussing on natural capital where practicability is the main thing? A specific mission

with respect to design should after all be workable. Most probably this calls for other types of monitoring instruments focussing on natural capital.

Corresponding research topics are:

- To what extent are designing principles already now focussing on natural capital and how could one focus on natural capital values during the designing phase? (NC).
- What is necessary to make designing principles focussing on natural capital practicable? (NC).

Purchase

Through purchase one can ensure to focus on the closing the cycle further, especially for specific (finite) earth types with special properties. In addition purchase may contribute to optimizing the natural capital value in works by purposely buying specific earth types.

Main question with respect to purchase

How can the earth that is purchased be assessed for its natural capital value and how can the damage to the excavated site be assessed? Earth having similar natural capital values as the earth on the site of use or earth having the desired natural capital values for the site of concern may contribute to a 'better' (recovery of the) ecosystem.

Corresponding research topics are:

- Can a 'performance ladder for natural capital' be of use in assessing the natural capital values of earth? (NC).
- What are the timescale and the nature of the damage inflicted on the excavated site and how can these be made evident? (NC).

Other interesting research topics may be:

- Which types of earth/soil are scarce and how can the earth chain be closed further for these types of earth? (CE).
- What is the impact of in situ treatment of earth on closing the earth chain? And what is the scale of this earth stream? (CE).
- Can future sea level rise cause scarcity of earth? If yes, do we already want to adjust our designing principles to this now? (CE).

5.2.3 Recommendations with respect to principle 3: avoiding leakage and negative impact

Design & management

When designing it is important not only to look at the usual aspects but also to consider the added value of the design with respect to other social issues. This could be compared to the Dutch approach of 'Sustainable civil engineering'.

Main question with respect to design and management:

Which social, CE and sustainability issues does RWS want to assess in its earth moving projects? It is possible that these issues have already been incorporated in the 'Ambition web' of the 'Sustainable civil engineering'

approach. It is however also possible that RWS prefers to assess other issues such as natural capital or CE. Finally RWS could want to adjust its designing principles in order to come up to a certain standard in all of his projects.

Corresponding research topics are:

- On which social, sustainable and CE issue does RWS want to focus? (Int).
- Can designing principles be adjusted in such a way that for example less earth is needed or that a designing standard contributes in a positive way to a social issue? (CE).

Purchase

Through purchase one can control the use of earth in a way that it has as little as possible negative impact and has as much as possible positive impact on other social issues. This probably sounds like stating the obvious, but it requires a comparative assessment between the different social issues.

Main question with respect to purchase

Which values do we want to assess when purchasing earth? When thinking about purchasing earth, most of the time we look at the civil engineering properties of the earth or we check whether it complies with the environmental standards. We could however also look at the natural capital value of the earth, the damage arising from excavating the earth, the amount of CO_2 emitted, the degree of reusing the earth, the loss or gain of biodiversity, etc.

Corresponding research topics are:

- Is it possible to use a multi-criteria analysis when purchasing earth and thus to include all important social issues in the purchasing phase? (Int).

Other interesting research topics may be:

- Which concomitant opportunities do exist between CE and the other important social issues? (Int).

Annex A References

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(10) Jonker, J., H. Stegeman & N. Faber (2016). *De circulaire economie.*

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Annex B Theory and conceptual models

In this annex the various theories used in this pilot study are presented. For every theory it is explained why this theory was used and to what extent this theory influenced the final earth chain model.

Ellen MacArthur Foundation

Why this theory?

The conceptual model developed by the Ellen MacArthur Foundation in 2010 (1) is one of the most used conceptual models in the field of Circular Economy. It is a theory that has been used as a source of inspiration by many parties (including the Dutch government and RWS) when formulating their vision. Therefore this theory is essential within this theoretical framework.

Theory & principles

In the figure below the three CE principles are shown, each of which has a different starting point. These three CE principles represent the basis of CE and the starting points within serve as handles to comply with these principles. The following three CE principles are distinguished in this conceptual model:

1. Limiting the use of raw materials.
2. Closing cycles and preserving value.
3. Avoiding leakage and negative impact.

Principle 1 is about preserving and enhancing natural capital by using non-renewable resources as little as possible.

Principle 2 can be regarded as the heart of CE. It is about closing cycles and preserving and upgrading raw material in the chain. Furthermore, in this second principle, a clear distinction is made between biological and technical cycles. Here, the biological cycle contains renewable and the technical cycle non-renewable resources (finite materials). Within each cycle different inner loops are shown (reuse, recycling, etc.), where the loop having the tightest circle is preferred.

Principle 3 is about raw materials leaving the cycle (leakage), of which it is emphasized that this leakage should be minimized and that this leakage should have no negative impact on the environment.

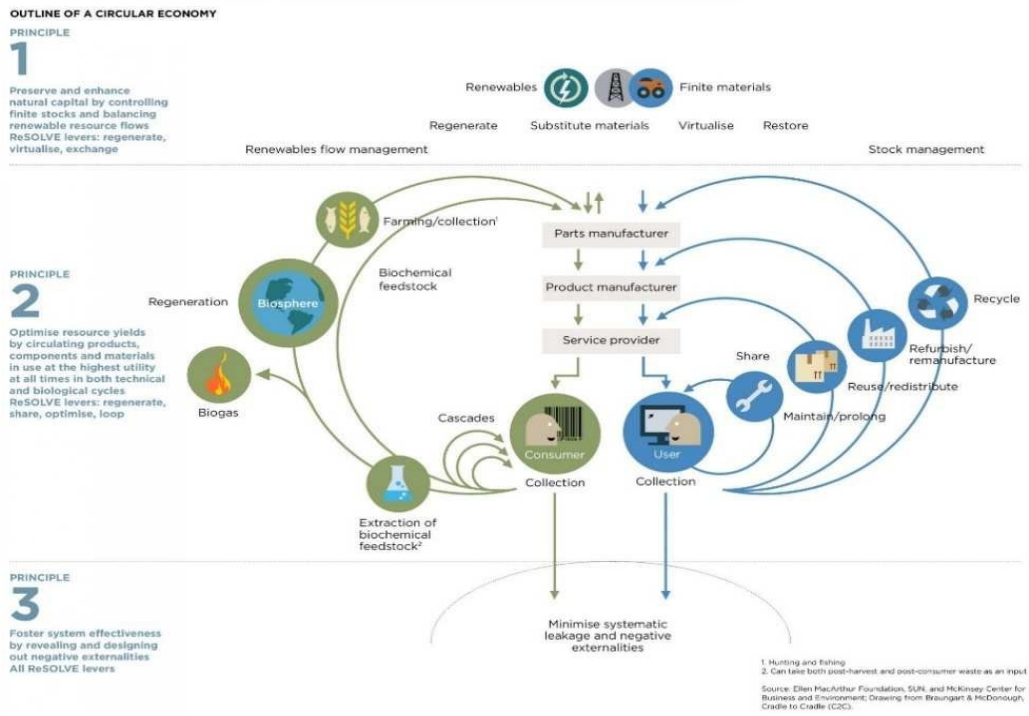

Figure B1. CE according to the Ellen MacArthur Foundation.

In addition to the three principles, the figure shows various RESOLVE levers with every principle. These levers are described below:

1. **Re**generate: Make use of sustainable sources and conserve the Earth.
2. **S**hare: Share assets, buy second-hand products and take good care of products.
3. **O**ptimize: Optimize products and production processes.
4. **L**oop: Recycle or repair products.
5. **V**irtualize: Replace physical objects by digital alternatives (such as a book vs. an E-reader).
6. **E**xchange: Replace certain products and raw materials by more sustainable alternatives.

<u>Theory in relation to the earth chain.</u>
The principles as described in the theory of the Ellen MacArthur Foundation are applicable to any CE model and therefore also to the earth chain model. Preserving natural capital, optimizing the use of resources and avoiding negative impact are principles that apply to the earth chain. Moreover it is possible to distinguish between two important functions in the earth chain: a biological function and a technical function. Earth has both a technical value, i.e. utility value and a biological value, i.e. its natural capital value. Separating these two functions in two chains, as is done in the conceptual model of the Ellen MacArthur Foundation, is however not possible, because both functions exist in earth. What is more, the conceptual model clearly shows that CE is about dealing with a certain stock. This stock is finite and natural capital that we use must return to the stock in the end.

R's of CE

Why this model?
This conceptual model is a much-used model and may facilitate the prioritizing of measures.

Model & principles
The R's of CE is a model of which in time various versions have been developed. All versions are however based on the same principle, that is: the different steps all represent different way of dealing with (raw) materials and the name of every step starts with an 'R'. In addition the order of the steps in the model is important (6). This order helps us in reflecting on the higher and lower quality use of raw materials. The model used by PBL (Netherlands Environmental Assessment Agency) (8) is a good example of how an R-model could look like. But also the model based on the triple-R model (Reduce, Reuse, Recycle), Lansink's ladder (9) and the Economic Most Friendly (EMF) model (Maintenance, Reuse, Refurbish, Recycle, Recover, Redraw) present an nice overview of the different R's.

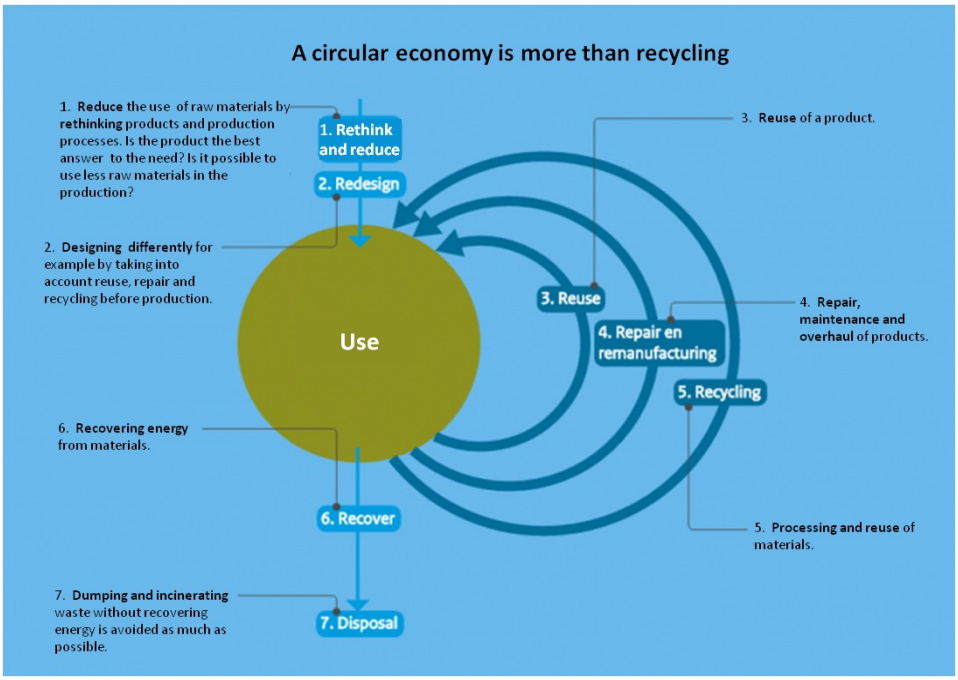

Figure B2. The R-model of the PBL (8).

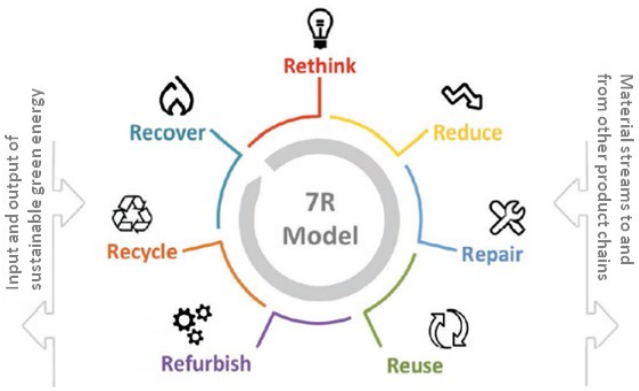

Figure B3. The 7R-model by Ree (2017) (6).

Model in relation to the earth chain.
The R-theory can assist in determining how to deal with raw materials within the earth chain of RWS. It is essential to prioritize the ways you want to deal with your raw materials in order to prevent low quality (re)use. In contrast to the model we do not see any advantages of a predefined order of steps. The degree of treatment should depend on the type of the raw material and its possible uses. We should not want to keep high quality raw materials in a certain type of work if this raw material has higher added value in a different type of work. The R-theory may provide inspiration when determining different possible actions within the earth chain and helps thinking about cascading.

7 Pillars

Why this model?
The 7 pillars conceptual model (5) is less well-known than the models described above. This theory has however such added value that we decided to analyse this theory nevertheless. We decided to do so because this theory offers the possibility to consider CE with respect to other social issues (and with that to the objectives as described in paragraph 4.3).

Model & principles
The 7 pillars conceptual model goes beyond the 'default' CE principles including closing cycles and preserving loss of value. In this conceptual model several other social issues which CE should affect in a positive way are at the centre. In total 7 pillars are distinguished that contribute to a world in which not only the CE principles are aimed for but in which also added value is generated. In the 7 pillars conceptual model integral thinking is the main thing. This conceptual model may help in putting CE in a new perspective with respect to the objectives set earlier, due to which CE becomes indeed practicable and advisable.

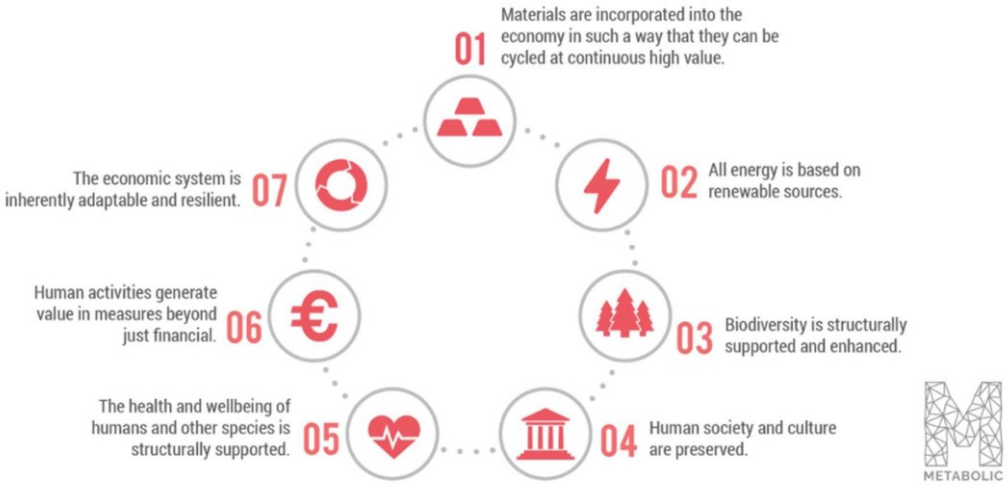

Figure B4. 7 pillars conceptual model by Gladek (5).

Model in relation to the earth chain.
If CE is looked at in a context of other social issues, one can make differentiations to the CE principles such as closing cycles. According to the 7 pillars model closing cycles is no longer advisable if this results in the loss of ecosystem services and reuse isn't always better than recycling if this would result in higher CO_2 emissions. This model indicates that it is sometimes preferred not to strive for full circularity. This is also valid for the earth chain. If earth is kept within the cycle indefinitely, this could eventually result in the loss of ecosystem services. By taking earth

temporarily out of the earth cycle (by taking it out of a work) and allowing it to function as soil, this biological value can recover but the cycle is no longer closed. In addition this model offers the possibility to weigh CE measures against other social issues. This may help in taking decisions with respect to CE.

Cycle ladder

Why this model?
The cycle ladder is a model that shows that working fully circularly takes time and that cooperation between different parties is essential.

Model & principles
CE is about closing cycles, but many cycles concern many different parties. RWS, for example, makes use of raw materials and products that are supplied by many different suppliers. Working fully circularly is in such cases difficult if not all parties are willing and able to cooperate. Working partly circularly is often easier by closing internal cycles. In the cycle ladder different levels of working circularly are described. Here the first level concerns an internal cycle and the last level a full CE. The five levels of the cycle ladder are (10):

1. In house circularity.
   Closing the raw material cycles within a company (for example reusing heat in the same greenhouse).
2. Partial chain integration.
   Within a production chain a cycle is created.
3. Mono-stream cycle.
   A fully closed cycle concerning one material.
4. Organisation ecology.
   Different cycles of different product are connected.
5. Organisational-economical system.
   A fully circular economy.

Model in relation to the earth chain.
The cycle ladder may help RWS to look at CE in a wider perspective. This model may offer help in determining the level of circularity RWS wants to reach in 2030. This might be at the level of partial chain integration, at the level of a mono-stream cycle or even at the level of organisation ecology. The cycle ladder also shows the steps one may follow within the earth chain by focussing first on one raw material and slowly expanding from this.

Predecessors of CE

Lansink's ladder
Lansink's ladder (9) was introduced in 1979 for the first time in a motion proposed by (Dutch politician) Ad Lansink. His ladder intended to introduce a preferential order in waste management. Lansink's ladder is nowadays still a well-known concept and can be considered a predecessor of CE. Lansink's ladder shows much similarity with the R-theory, which also proposes prioritizing measures. Lansink's ladder has seven steps: prevention, reuse, recycling, energy, incineration and dumping. The higher the step, the higher the quality of waste management and therefore the higher its priority.

Figure B5. Lansink's ladder for waste management (9).

The difference between Lansink's ladder and CE is the underlying thought. Lansink's ladder was developed for the purpose of managing waste in a more sustainable way, whereas CE has a broader objective. CE in addition is about preventing waste, whereas Lansink's ladder mainly is about managing waste in a sustainable way.

Cradle to Cradle

In 2002 the concept of Cradle to Cradle was introduced by McDonough and Braungart. The essence of this concept is that materials that have been used in one product are reused in a high-quality way in a next product (upcycling). Within CE both the topics value and waste play a part. CE is about reducing the use of primary raw materials. In order to achieve this, raw materials should not leave the chain (waste) and should be deployed as long as possible in a productive way on the same quality level (preserving value). There exist however also big differences between CE and the concept of Cradle to Cradle. CE considers reducing waste and preserving value as means to achieve its objectives, whereas these two principles are the objectives themselves within Cradle to Cradle. In addition, Cradle to Cradle reaches further than CE. CE is about decreasing the impact on the stock of raw materials, whereas Cradle to Cradle is more about generating added vale (11).