Circular Economy - Sustainable Materials Management

A compendium by the International Institute for Industrial Environmental Economics (IIIEE) at Lund University

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– Sustainable Materials Management

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eit RawMaterials ACADEMY

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

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Preface

SOME PEOPLE work with the circular economy every day ... but many of us still have questions! A simple question that we often hear is ***what is the circular economy***? These and other important questions will be addressed throughout this compendium, which complements the Massive Open Online Course, ***Circular Economy: Sustainable Materials Management.*** You can access the course at www.coursera.org/learn/circular-economy.

As a starting point, consider the following related to the "what" question above.

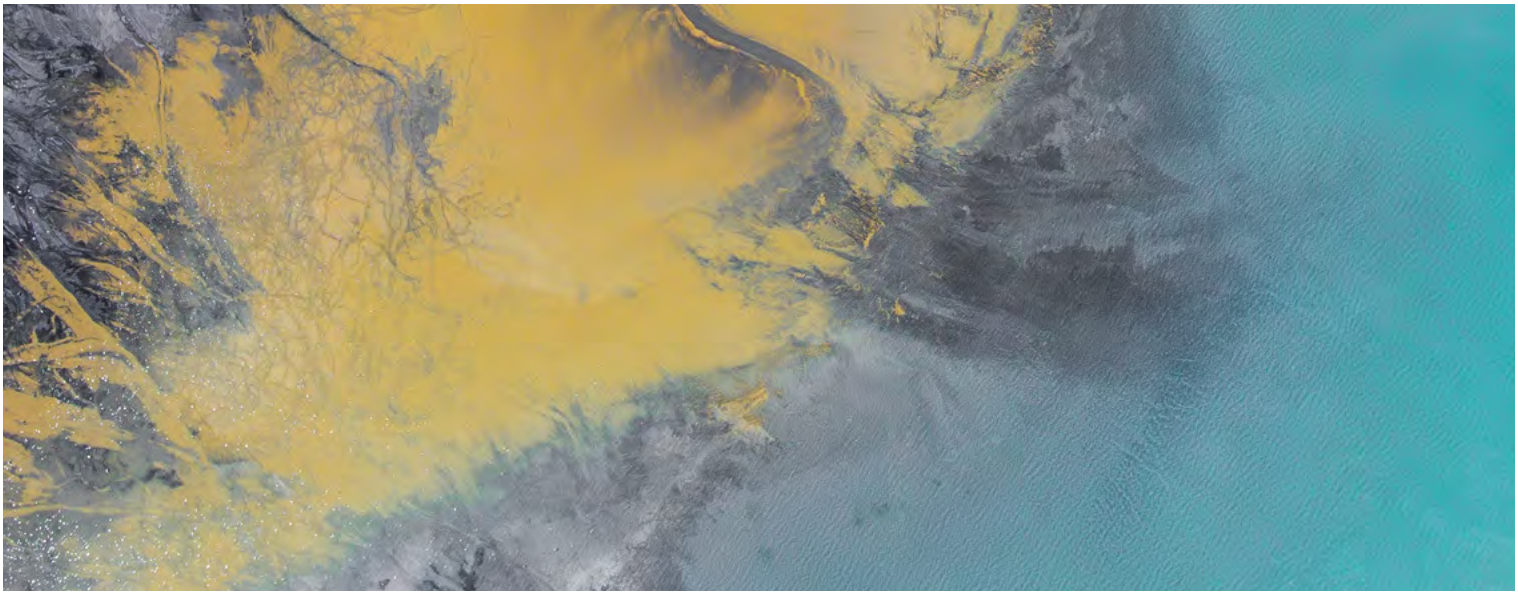
- Have you ever wondered why so many people believe the circular economy is important?
- How is it linked to the function of natural resource production systems?
- Why is the circular economy so important for developing countries?
- How will it benefit society?

Other questions we think are important are related to ***how do we go about it?***

- How can business, industry and society move the circular economy forward?
- What are the technologies involved?
- What issues and incentives motivate businesses?
- How do companies make money in the circular economy?
- Can policy and politicians help the circular economy?
- Does society have to change?

Please read on to find out more!

We have structured this compendium to closely follow the MOOC, and intend that this will serve as an aid to your understanding of the course and as a ready reference source describing many aspects of the circular economy and sustainable management of materials.



Scope for Circular Economy: Sustainable Materials Management

This compendium document describes the first steps of a journey towards circularity. The journey will be different for all countries of the world, but this text is intended to share knowledge so that many more of us can create a path forward.

The scope of the compendium covers many parts of the emerging circular economy. We choose to place considerable focus on some of the substances that we extract from the ground – in particular *raw materials* and *critical materials*. We focus on circularity in these areas, because presently we use too much, too fast, and we are not re-using nearly enough. In turn, this approach demands that we look at the technologies that rely on such materials, and how businesses are innovating to make circularity of materials a reality.

This document provides many concrete examples of what we mean by *sustainable materials management*. We present cutting edge insights on a range of topics.

- Why raw material supply chains are important to society?
- How circularity can benefit us?
- Where changes in our economies are required?
- Who needs to be involved?
- What businesses are doing to make the circular economy a reality?
- How governments and regulators can support the circular economy?

At the start of every subsection in this compendium we provide a brief **Highlights** summary. Here we synthesize the take home messages of each lesson presented throughout the MOOC.

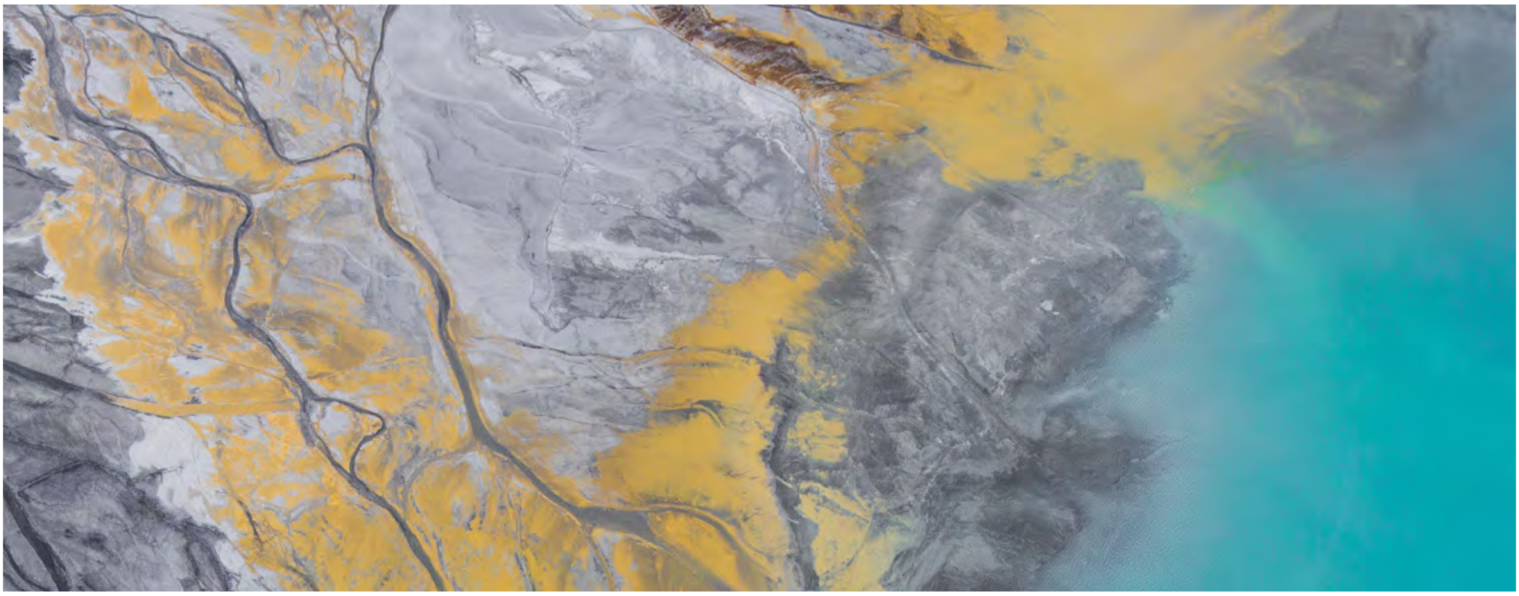
For this introductory section, our highlights appear as follows:

- Key challenges arising as a result of the excessively high material and energy consumption – and the way we eject large proportions of material as waste to the environment – demand that we pursue a circular economy.
- Damage to natural systems and shortages of key resources – both renewable and non-renewable – will negatively affect the development of less wealthy countries unless we achieve a circular economy.
- The creation of a circular economy is about much more than resource flows. It is also about circular product design, business models, and policy formulation. These must be interlinked with social changes to evolve a circular society.

Why do we need a circular economy and how do we pursue it?

Governments and businesses are becoming increasingly concerned about the growing pressures on our global resources due to human activities. Our economies, and our systems of production and consumption, are stressing and damaging Earth's natural systems. We use enormous amounts of raw material and energy to create the billions of products that sustain our lives. At the same time, we send huge volumes of waste into the very atmosphere, waters, land and ecosystems that are vital to our existence. The richer we are, generally, the more we pollute.

An overarching challenge is that billions of people in less developed countries have the same right to live long and comfortable lives as people in developed countries. This



is directly linked to becoming wealthier. But if everyone consumes resources, and emits wastes, at the level that developed countries do at present, then our planet will simply be unable to meet the demands placed upon it.

The underlying problem lies with our linear economies – these have excessively high material and energy consumption, and eject large proportions of material as waste. Something has to change! One thing we can do, is to make our economies much more circular – so that we achieve more using less. Advances are needed in many areas to achieve a circular economy – and a picture of what a circular economy is, or could be, is becoming clearer as more practical real-life examples emerge.

Generally, strategies can be seen as seeking to keep resources and products at as high a value as we can, for as long as possible, and extending their lifetimes so that they function for longer.

To demonstrate how a circular economy can be developed, this document showcases many of the ways that society works towards the *slowing*, *narrowing* and of course, *closing*, of resource flows. Importantly, the creation of a circular economy is about much more than resource flows. It is also about developing and implementing strategies for circular product design, business models, and policy formulation. And it is interlinked with evolving our norms and behaviour to build a circular society.

What are the benefits of a circular economy?

The circular economy can help us do much more, with much less. It can help reduce the burdens on the Earth caused by our material and energy consumption. It can help protect ecological goods and services from the pollution and wastes we generate.

It can also help us limit our overall demand for resources per capita so that there are enough for the wellbeing of all. Many countries are still developing, and they need the resources to do so. The circular economy can help ensure that we secure enough resources for our societies to function and develop.

Achieving a circular economy needs the engagement of society. And it will need plenty of invention and innovation. It will also require the creation of new forms of business; new technologies and processes, and new forms of governance. Such changes offer the potential to generate value to society; for example, via stimulation of employment and an increased demand for educated and skilled workers. This evolution also needs new thinking, new social systems, new forms of engagement, and new institutions. This demands an evolved society.

Exploring five areas of the circular economy

This compendium describes five important areas that need work as we look to the future and achievement of a circular economy to replace the linear economy that dominates today.

Chapter 1 explores where metals and other key materials come from, and outlines some of the key arguments for why society needs more circularity.

Chapter 2 presents circular business models and showcases a range of ways for business to create economic and social value.

Chapter 3 introduces you to circular design. Here you will explore topics such as functional materials and ecodesign; methods to assess environmental impacts, and networks where best practices can be shared.

Chapter 4 provides details of why policy is important for progress towards the circular economy. It explores where we need help from governments, and how policy interventions can enable the circular economy.

Chapter 5, our final chapter, then allows you to examine aspects of circular societies. You will learn of things like new social norms, forms of engagement, systems, and institutions that are needed by the circular economy. You will also explore how individuals can help society become more circular.

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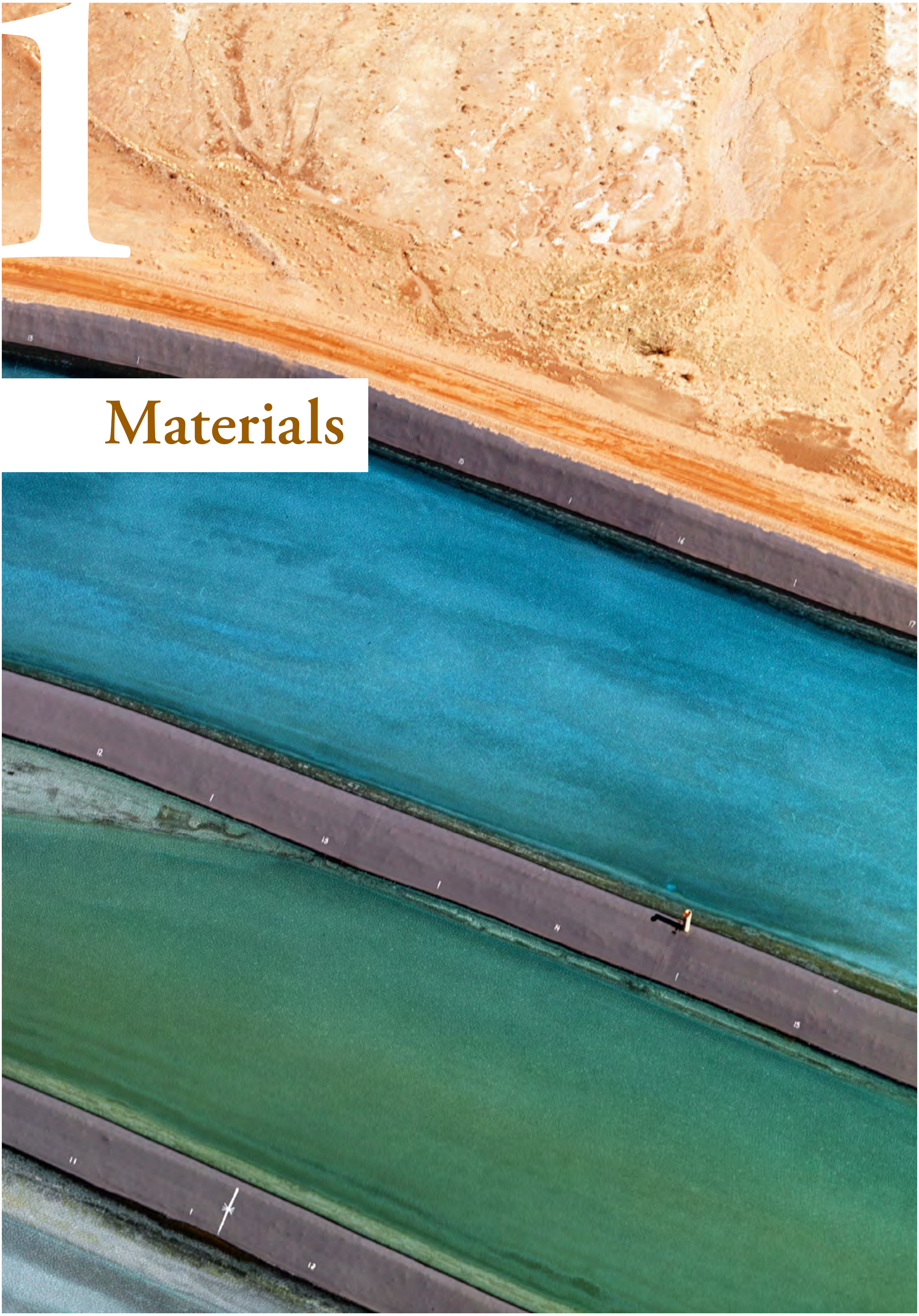
1 Materials



Materials are mined, transformed and used throughout their life cycle within various political, societal and business contexts. This section covers the basics of the material supply chain, including its social, environmental and economic consequences, and explores how the original form of materials management is reimagined in a circular economy model.

1.1 WHAT IS MINING?

- Mining has many steps along its life cycle and each of these has different sustainability implications.
- Mining and minerals processing operations can take many forms and these differ depending upon mineral, metal, ore-type or mining location.
- Mine sites and minerals processing facility activities – and their wastes – must be carefully managed to prevent environmental degradation or negative social implications.

What, when and where?

We use many non-renewable raw materials in our society. These include metals, like iron and gold, fossil fuels such as coal and lignite, and ornamental stones like marble and granite. All of these raw materials are extracted by different forms of mining.

However the extraction, use and recycling of raw materials is not a new thing. In fact, we have mined for thousands of years to obtain metals and minerals that we use to make products crucial for the survival of humanity. The development of human societies through the Bronze Age and the Iron Age has even been described according to those products of mining that defined the key technologies of the time. Some manner of recovery and recycling has also always been performed. Some materials are inherently suited for circularity and have always been considered too valuable to throw away. But this was not the case for all materials, and even today, the average recycle rate recorded is not as high as it could – or should – be.

Mines are located where mineral-rich ores are located! Sometimes they are far away in remote places, and sometimes they are close to places where many people live. The Avlayakan open-pit gold mine in the Russian Far East is an example of a remote mine – it's more than a thousand kilometres from the nearest town. Many cities and towns were actually started as places of mining, and there are often communities attached to mines. The town of Lavrion in Greece, got its start due to mining some 5000 years ago.

Exploration and extraction

There is a lot of work to be done before a mining operation actually begins extracting minerals. The very first step in mining is the search for mineral deposits. For thousands of years, humankind has looked for *ore bodies* to mine. And this search has led them far into remote areas, and essentially to every part of the globe.

Exploration includes a number of steps, from examining a geological map, to site investigations, non- destructive geophysical surveys, and of course drilling holes into the ground to find and define how big and how valuable the deposit is. Exploration activities can last years and cost millions of dollars. An important issue is that even before the creation of a mine, this process of looking for minerals also has the potential to result in significant environmental or social impacts. For example, access roads can open up sensitive areas to human exploitation, and test pits can disrupt ecosystems. It is important that such issues are also given consideration.

After mineral exploration has found a promising mineral body, and depending on the value of the minerals, a model of the sub-surface is developed, and this model is used to figure out which parts are economically viable to mine. Then a mine design and a plan to extract the minerals can be developed. Ideally the mine plan should meet all the three objectives of sustainability: economic viability, environmental protection and societal support.

A mine can be deep underground with only small surface entrances (for example when the deposit extends to great depth), or it can be an open pit if the deposit is very close to or reaches the surface. Sometimes such mining pits are so big that they can be seen from space (Fig. 1.1).

Such a large operation of course has the potential to cause many impacts on ecological and hydrological systems, and on the stability of the landforms. Because of this, the mine plan must also address issues like the protection of flora and fauna, water resources, geotechnical stability and so forth. It is very important that such aspects be considered at the design stage.

Once a mineral deposit has been *developed* into an actual mine, mining typically involves the extraction of huge volumes of rock or soil. For example, in a large iron ore mine, annual production can total tens of millions of tonnes per year. At times, very large volumes of *waste rock* must also be moved to access the ores that contain the minerals that we want (Fig. 1.2).

Once mineral ores are extracted, mining companies process ores to separate the valuable minerals.

This often starts with physical processes such as crushing, grinding, and a sieving process called screening. After this, other physical and physicochemical separation methods are applied based on differences in properties such as specific gravity, magnetism, or colour (Fig. 1.3, next page). Thus, a concentrate of the valuable recovered minerals is produced. This is typically a mineral powder that contains the mineral that we want at concentrations that are suitable for subsequent technologically and economically feasible chemical or metallurgical processing.

The concentrate or metal is then transported to places where it's smelted or further refined, or both. Smelting aims to treat the concentrate and recover the contained metal, and refining is used to further improve the quality of produced metals and remove any remaining impurities.

KEY TERMS

Minerals are composed of the same substance throughout and there are more than 3000 different minerals in the world. Minerals are made of chemicals – either a single chemical element or a combination of chemical elements.

Rocks are made up of two or more minerals. For example, the rock called granite is a mixture of the minerals quartz, feldspar, and biotite.

Ore is a mineral or an aggregate of minerals from which a valuable constituent, especially a metal, can be profitably mined or extracted.

Figure 1.1. Sidewall of a large open pit copper mine.

Figure 1.2. An unprotected waste rock stockpile of approximately 120 million tonnes polluting a stream.

Mining's footprint

For many mineral ores, the concentrate may be just a tiny fraction of the ore. Very large volumes of ore and rock are often excavated, processed and then placed in waste management areas around a mine site for every small portion of concentrate produced. Thus it is no surprise, that we often talk about the large *footprint* of mines; a mine may create large, physical voids in the ground, as well as large waste deposits. These must be properly planned for, managed and then remediated when mining is finished.

Waste rock and tailings constitute most of mining-related wastes. The extra rock and material that was dug out to access the ore is often referred to as waste rock. *Tailings* are materials of little or no economic value that is left over when we have extracted the desirable mineral from the ore. They

Figure 1.3 Flotation process to obtain metal concentrate.

are generally a fine sandy material produced when the original ore is ground so that the mineral of interest can be extracted in the concentration stage. These residuals are usually deposited close to the site of mining in a tailing management facility. In many instances mine wastes can be used to fill the holes that are made by mining – a good mine design may have this as a key objective, as it can both reduce the footprint of the mine and reduce risks to the environment.

Over decades, the price of many metals and minerals have increased or new, improved processes for extracting minerals from ores have been developed, or both. With these advances, there are many tailings deposits that can now be profitably recycled and reprocessed to recover the residual minerals/metals. Hence, many old tailing deposit sites have now become mines again!

Mine life cycle

All mining operations have a *life cycle*. This spans from exploration, through mine development and operation, to closure. Very importantly, this also includes the use of the post-mining site. The planning and design work for mining must consider much more than just the economic viability of a mine during its operational life. Careful management is required to protect ecosystems and society from the potential negative impacts of mining, and this requires the consistent compliance of the principles of sustainability at all stages. In particular, the design of and application of land reclamation works, and ongoing management routines, is needed to make sure that the quality of the natural and manmade environment remains protected during the mine's life cycle.

For example, soils and water need to be carefully considered. The protection of soil and water quality close to the mine is very important to sustain agricultural activities during and after the mining operations and to maintain a clean supply of drinking water for neighbouring communities.

Post closure use of the site also needs to be considered.

Mining is an activity related to the development of mankind and ideally would follow the needs of society, not only regarding a secure supply of raw materials but also a commitment for environmental protection. So, to minimize the footprint of mining, environmental protection measures have to be incorporated in the whole life-cycle of the mine, all the way from initial exploration to the closure of the mine (Fig. 1.4).

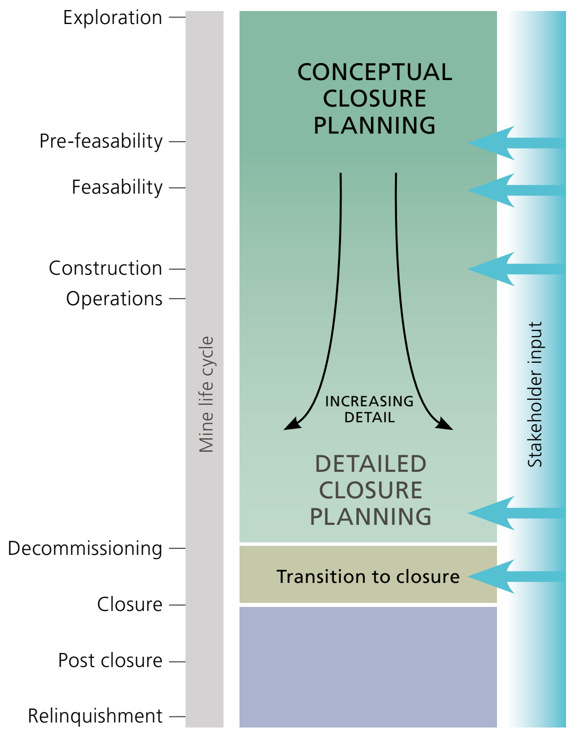


Figure 1.4. Mine Closure Planning. [1]

1.2 SUSTAINABLE MINING

- A set of boundary conditions must be achieved to align mining with sustainability principles.
- Communities and their socio-economic well-being are central to the pursuit of sustainability in mining.
- Fundamental physical and chemical issues must be considered in order to achieve environmental performance that can be considered sustainable.

Boundary conditions for sustainable mining

Throughout the history of mining all the way up to about the 1960s, there was little or no consideration of its environmental and social consequences. Many parts of the world still bear the unsustainable legacies of pollution and disturbed land as a result. But since then, there has been an ever-increasing awareness of the environmental and social liabilities that can be caused by mining.

While many legacy problems remain, a great deal of remediation has been performed, and this work continues today. Leading mining firms and international organizations now know how to prevent problems, and they share such knowledge freely. Governments, regulators and civil society have also learned how to challenge industry to keep improving.

A prime goal for sustainable mining is to achieve four ground conditions:

- maximize socio-economic benefits;
- minimize adverse socio-economic impacts;
- ensure that environmental resources are not subject to physical and chemical deterioration;
- achieve after-use for the site that is beneficial and sustainable in the long term.

So-called *sustainable mining* has certainly not been achieved around the world. But, a number of leading countries do support operations that meet these precursor conditions. Lessons from such activities need to be spread, entrenched, and improved upon everywhere if we are to achieve a global norm for sustainable mining.

Communities and mining

A mine is often a core component of a community. This is especially so when mining is conducted in remote areas or less-developed countries, where they are commonly some of the first true industrial endeavours to deliver vital income. In these situations, mines are often the foundation for economic development, as well as for achievement of sustainable development goals. Even many advanced countries rely significantly on mining.

Therefore, it is very important to consider social, socio-economic, developmental, and inter-generational issues. Countries pursuing sustainable mining must develop and enforce innovative regulations for mining practices that reflect both present and future expectations for environmental and human health protection.

Mining companies and governments must consider how communities grow around a mine. And governments must ensure that the wealth generated by mining is transparently managed, invested for the future of the country, and fairly distributed among the present generation.

However, we should never forget – essentially all mineral deposits eventually run out! This means that miners and governments must plan for what will happen to communities after the mine is gone. This requires that the land use for the mine area is beneficial to the community and sustainable for the long term – and that social and economic structures remain in place to support communities.

Such issues must extend from the pre-mine planning phase, through construction, mining, and mine closure to post-mine stewardship. This requires an inter-generational time frame. Companies that practice sustainable mining plan many years in advance for what happens to communities, as well as the role of communities in the use or protection of land after the mine is gone.

Environmental constraints

A baseline requirement for environmental sustainability is that the management policies, field practices and technologies applied in mining reduce environmental harm to within ecological limits. At the same time, land must be preserved as a repository for biodiversity and for natural ecological services. With such conditions in mind, there are a number of fundamental physical and chemical issues that must be considered in order to achieve environmentally sustainable mining.

- Rocks and ores are often not at *equilibrium* when brought to the surface. They can become chemically and physically unstable when exposed to surface conditions and may release eco-toxic substances. Unless planned for, prevented, or contained, such processes can cause damage that lasts for very long periods of time.
- Mine development often occurs on undisturbed land. When a mine is opened in some areas, access to nearby sensitive or undisturbed areas by other groups – for example loggers or farmers – may not be compatible with overall sustainable land use. For such reasons, access to a mining area may be restricted, and authorities may opt to not develop a town or public access roads. Such strategies can help ensure that valuable natural systems are protected for future generations.
- Mineral ore bodies are finite and all mines reach the end of their viable life at some time. Therefore, sustainable mining requires planning from the very beginning that guides both the mining activities and the closure of the mine site. A mine and all its wastes must be constantly managed, and then rehabilitated and prepared for after-mine life. The final landforms, hydrology and management strategies for the mine areas must ensure that environmental resources are not subject to physical and chemical deterioration in the long term.

1.3 FROM MINING TO METAL

- Form, quality and value transform as ore is processed to metal and then metal to marketable products.
- There is growing demand for metals and society needs both metal recycling AND primary metal production.
- The value of metals increases as their engineering material properties are enhanced.

Metals and other raw materials are essential to our global economy and our social development. But how do we go from mining to metals? After mining, a certain sequence of processing steps is needed to upgrade raw materials to produce marketable products.

Depending on their properties, their areas of application, or even their scarcity, metals are placed in different categories such as non-ferrous, base metals, technological, precious metals, or even critical metals. No matter the category, all of these metals are essential for the production of the high tech devices and engineered systems that modern society relies upon. Each of these types of metals have their own mining and processing sequences, and their own systems that deliver the products – either in a raw form or as refined versions. This is called the *supply chain*.

Engineers have learned how to work with materials in supply chains, and a metal supply chain consists of both upstream (mining and refining operations) and downstream (smelting, casting, and metal working) processing. Mining and metallurgical engineers guide the processing of raw materials into metals, which can then be mixed with other elements to provide special additional properties. This is called alloying.

At each step the value of the material increases due to investment of time, effort and energy. From a scientific point of view, each step increases the cumulative energy input that has been needed for metal production. From an economic perspective, at each step the product cost increases.

Case Study – Aluminium

Aluminium is a light-weight and durable metal which mixes well with other elements and is thus used in a vast array of products and applications. These include transport, construction, packaging, electronics and electricity transmission, among others. Aluminium can also be recycled repeatedly – meaning that much of the economic value in the metal can be preserved for each cycle (Fig. 1.5, next page).

The chain of activities called *primary aluminium production* starts with the mining of bauxite ore. Then chemical refining follows to extract pure aluminium oxide – called alumina. The alumina is then smelted to primary aluminium. After this, production of alloys takes place.

Finally, the metal is formed by a rolling and extruding processes, or cast into moulds and then machined to final products. And at the end of the product life, aluminium scrap can be collected and recycled.

It takes four tonnes of bauxite ore to produce just one tonne of pure aluminium. The investment of energy, work and materials needed to achieve this is reflected in the market value. Consider the base value of raw bauxite ore of around 40€ per tonne; this amount increases to nearly 400€ per tonne for alumina. After smelting, the aluminium metal has an even higher value – around 2000€ per tonne. For many applications, further value adding may take place – for example, special aluminium alloys used in aircraft components are much more expensive than the aluminium foil that we use in the kitchen.

Aluminium also has a highly developed recycling system, because the recycling process requires only about 10% of the total energy used in primary production. This makes it both economically and environmentally attractive. Unsurprisingly, global aluminium recycling rates are high: approximately 95%

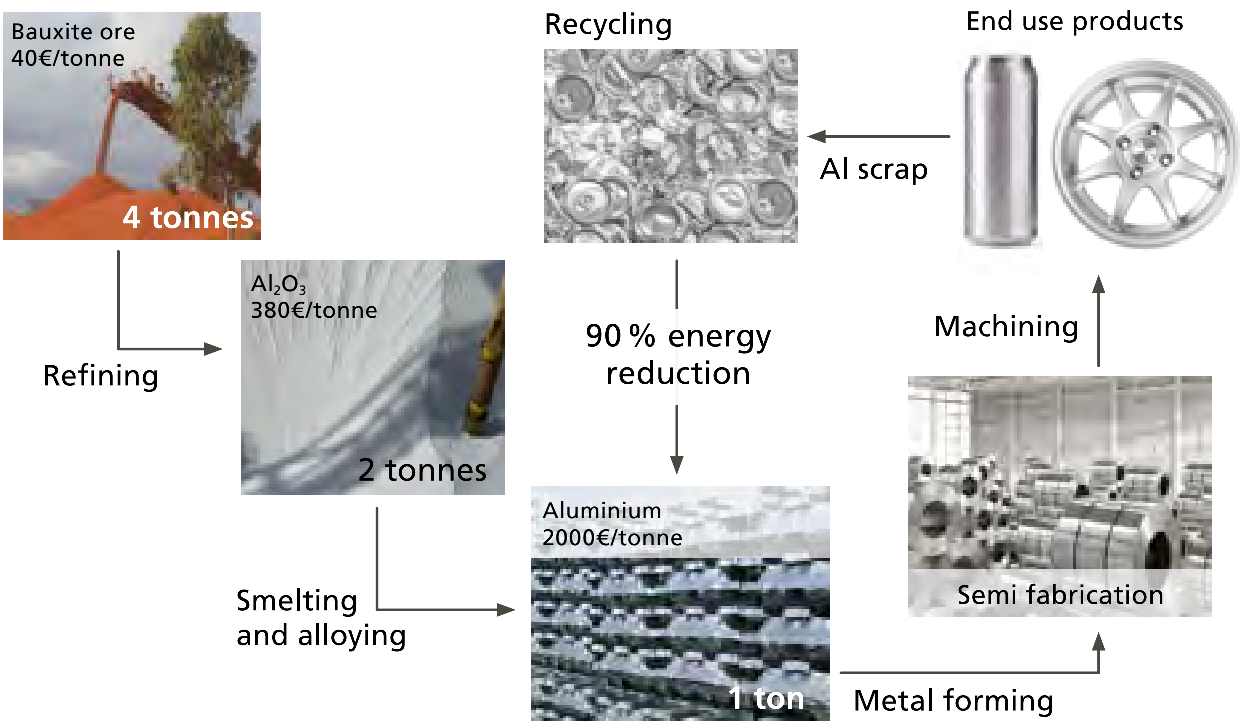


Figure 1.5. Aluminium value chain.

for transport and construction applications, and about 60% for beverage cans. As an example, more than 90% of the aluminium used in a car is actually recycled into new products when a car has reached its end of life. It's estimated that nearly 75 % of all aluminium ever produced is still in use today!

Even though society obtains a lot of aluminium from recycling – the system to produce this is called secondary aluminium production – global demand for aluminium is constantly increasing. This means that we still need to rely on primary aluminium production to provide more than two-thirds of our aluminium demand. So even if we could recycle all of the aluminium we use, we would still need primary production. Very important to note is that this need for primary production will continue to grow to meet global demand, and global demand is expected to increase (essentially) for as long as countries develop. This is true for almost all important metals, like copper, steel, and zinc.

The future of mining – both primary and secondary resources

There is strong global demand for materials to meet the needs of growing populations and the development of countries. That means that we will need production and supply systems for many decades to come.

While material recycling is a key aspect for achieving sustainable development, we must still rely on our primary resources. But this doesn't mean that traditional mines are the only type of mines. Many of the metals that society has discarded can be "mined" in the future. The concept of *urban mining* of landfills, or electronic waste stockpiles, has emerged to capture this untapped mining market. The same metallurgical processing steps used during primary production can also be applied to these types of secondary resources.

However, even though industrial production of many metals is well developed, engineers and scientists still have a large amount of work to do in order to improve and optimize the processes we use to extract metal from both primary and secondary resources. As such processes are improved, then the viability of solutions such as urban mining will improve also.

1.4 VALUE AND GOVERNANCE

- The complexity of global material-/supply-chains makes it difficult to trace the actors, the processes to transform materials, and transfer between geographical areas.
- We need to understand why and how materials flow, and how this benefits the different partners if we are to make our economies more circular and resource-efficient.
- Global value chain analysis – an approach that focuses on the coordination and control mechanisms of the supply chain has emerged as a way to better understand global flows of materials and value.

Global value chain analysis

Materials are transformed throughout their lifecycle. Minerals are mined and processed for use in manufacturing of intermediate components, then assembled into products that are sold for final use. At the end of life, when products can no longer be used and consumers dispose of them, ideally they are collected and recycled so that the material can be reintroduced into the material lifecycle.

All of these transformation steps, or segments, are linked in supply chains. Very often we simplify material supply chains down to a basic model with boxes and arrows. In reality,

supply chains are complex, non-linear, multidirectional and interconnected. The complexity of supply chains makes them challenging to trace; it's hard to see exactly who is part of a supply chain and what they do.

When analyzing a supply chain, it's important to pay attention to what is flowing from one segment to another. While we have materials flowing, there is also money moving from one segment to the next as the materials are sold and bought. The process of identifying and then drawing up which segments are part of a particular supply chain is called *mapping*. In essence, supply chain mapping helps us define the boundaries of the analysis: it details the processes and actors that are part of the transfer of materials and the processes to convert raw materials into more valuable products, also termed transformation here.

It's also important to consider where the transformation processes take place. Are they specific to particular regions or nations, or are they undertaken across many regions or nations throughout a global value chain? The geographical focus is important because access to labour, energy, capital or land varies significantly between regions, and has a huge impact on costs. Laws and regulations also vary greatly between countries, and this can impact how and why materials flow in a particular way.

Despite efforts to map actors and links between transformational processes, or segments in and across particular geographical areas, supply chain analysis cannot explain all the outcomes of trade. Difficult to answer questions remain such as: why some nations seemed to gain relatively more from trading than others? To explain this discrepancy, Gary Gereffi and Michael Korzeniewicz developed an approach called *global value chain analysis*. [2] This focuses on coordination and control mechanisms – also described as the *governance* of the supply chain. In other words, in addition to focusing on what is flowing in a supply chain, we look at the transactions and governance structures linking segments.

Governance arises from the transaction between a buyer and a supplier as they are coordinating and controlling the exchange. So it's important to remember that any value visible in the form of traded materials, services or monetary exchanges is the outcome of a negotiation. Governance describes how this negotiation affects the buyer and the supplier; for example, one partner might be better off than the other due to the conditions or characteristics of the transaction.

Focusing on these transactions enables us to answer why and how materials flow between segments in a global value chain, and what outcomes these transactions have for the different parties involved. These answers are important when determining the "winners" and "losers" of material flows and trade.

The why and how is Important

When we try to make our economy more circular and resource-efficient, answering why and how materials flow becomes crucial. First, this information allows us to better understand the social circumstances related to the material flows, and thus to reconnect materials with their human coordination and control mechanisms. In simple terms it helps us to explore the decision-making processes behind materials entering and circulating in our economies.

Second, it allows us to see value for what it is: a moving target. Value arises not only from the physical attributes of a material but also from the perspectives of different actors, such as buyers and suppliers. Such actors negotiate their values between themselves, but within the larger context of a system of actors at local, regional, national and global levels. All of these factors influence how the value of a material is constructed.

1.5 CRITICALITY

- Raw material supply security has been central to economic systems since early civilization and the modern concept of *critical materials* arose in the 1930s.
- Perceptions of criticality based on the economic importance and supply risk of materials has become more pressing as global trade, and the material complexity of products, has drastically increased.
- Enhancing supply security for critical materials by reducing, reusing, recycling and remanufacturing is an important driver for the circular economy.

Mineral raw materials are essential components of all national economies, and complex decision-making processes define whether exploration or mining for minerals take place. Among other things, countries must first decide if they look for important materials within their territories. Then depending on the outcome, the financial viability, and the willingness of populations to accept industrial activities such as mining, they must decide if they mine for it. Or whether they source it from another country. Such issues have important implications for security of supply.

Raw material supply security has been central to economic activity since early human civilization, and therefore discussed throughout history. This has become even more important as products have become more complex. The number of elements from the periodic table that are used to make some of our contemporary products has increased tremendously. For example, several hundreds of years ago, you could build a windmill with stone, wood, iron and textiles. Today we use hundreds of materials to produce all the different parts of a modern wind turbine (still in essence a windmill!). These include components such as rotor blades of carbon-fibre plastics, rare earth magnets, a multitude of cables, and highly advanced sensors and electronic control systems. These compositional changes allow, among other benefits, for more efficient energy generation (Fig. 1.6).

Understanding the complexity of material access

Raw materials are thus important for many reasons. Raw materials can contribute to technological and economic development that seeks to improve quality of life. Raw materials are also important for industries that are part of and feed into segments of the global value chain. For example, metal and alloy producers feed materials via component suppliers into the global value chain for a wind turbine – even if they are not direct suppliers. So, the links and impact of raw material access is much more complex and goes much further than just the next customer.

Some elements, like copper, zinc or gold, have been in use for a long time and we have a good understanding of how to find and trade them on an open market. Other elements, such as rare earth elements, are not traded on open exchanges, but instead mostly in direct business-to-business transactions. This makes accessing them, and information about their trade, more challenging.

Knowing where and how to access materials, which is important for our economies, is an issue addressed by the concept of *critical materials*. Bridging the challenges of accessing particular elements and judging their *criticality* was first taken up in the late 1930s in the United States. A discussion of critical materials emerged when the issue of raw material supply became related to the politics of national security. At that time, the US government authorized stockpiling of materials for national defense to mitigate potential supply risks. During the 1970s and 80s, amidst two periods of oil crisis that combined with relatively high commodity prices, the political discussion about criticality was revived.

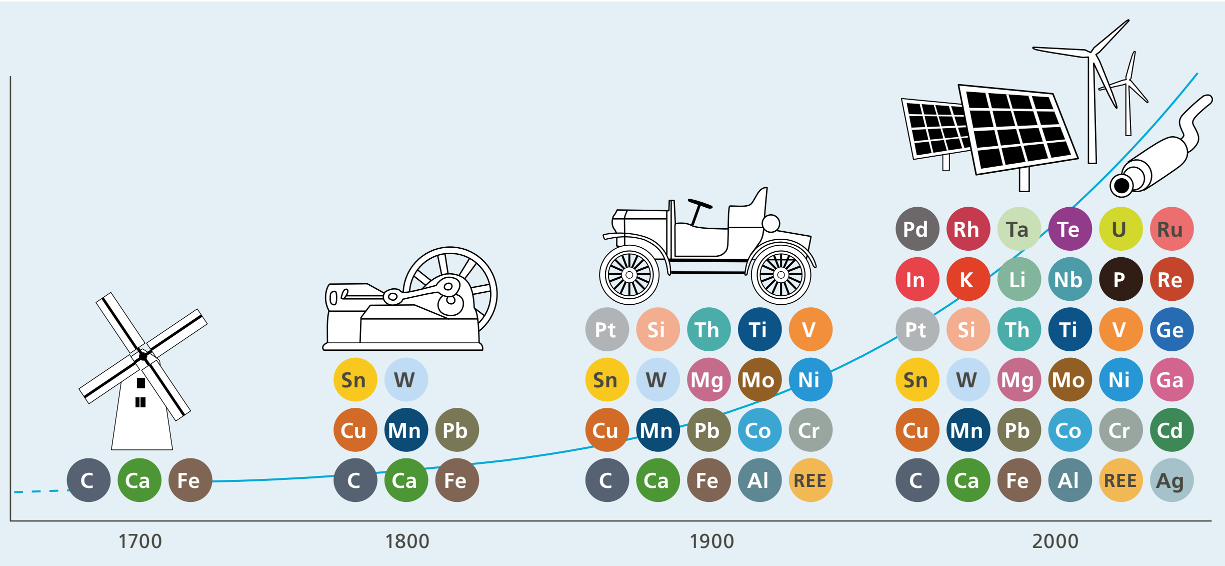


Figure 1.6. The growing material complexity of technologies. [3]

Criticality

In recent years, the US began to consider non-energy minerals as critical, defining a *critical mineral* as "one which is subject to supply risk". In Europe, the European Commission also acknowledged that many of its member states had high levels of import dependency on metals used in high-tech applications. In recognition of this, the Commission launched a European Raw Material Initiative that seeks to address such issues. Here, their experts defined *critical raw materials* according to "their economic value and high supply risks". They visualize raw material criticality in a two-dimensional illustration. This has *supply risk* ("the risk of a disruption to supply of the material") on the vertical axis and a measure of vulnerability and economic importance on the horizontal axis (Fig. 1.7).

Supply risk is derived by examining the extent to which the supply of raw materials is concentrated in a particular country. This occurs jointly with an examination of the governance performance and trade aspects of the country. For example, when determining EU import reliance, which is the extent to which the EU is dependent on imports of raw materials, both the global suppliers and the countries from which the materials are sourced are investigated. The supply risk parameter focuses on the segment of the global value chain where a high supply risk for the EU is detected. This could be, for example, the extraction of the raw material.

A focus on reducing, reusing, recycling and remanufacturing, and to some degree substitution, of the critical materials could contribute both to reducing supply risks and to shaping a circular economy.

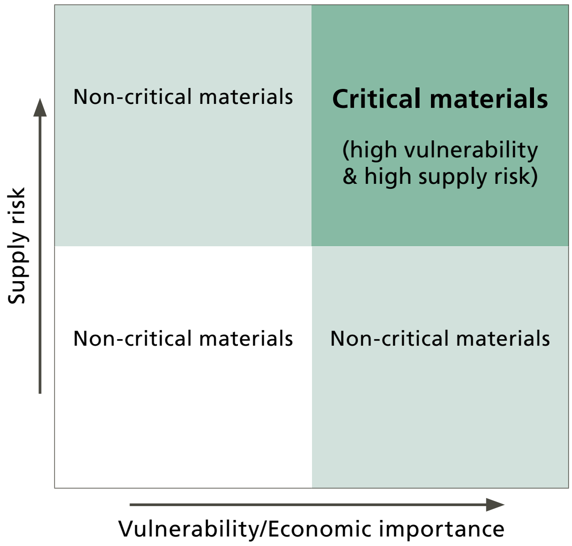


Figure 1.7. Raw material criticality matrix.[4]

Economic importance describes how important a material is for the EU economy. This importance is measured in terms of end-use applications and the *value added* to the relevant EU manufacturing sectors. An assessment of economic importance is conducted by examining a so-called *substitution index*, which looks at the technical and cost performance of substitutes for individual applications. Such data is usually derived from the EU's statistical database (Eurostat).

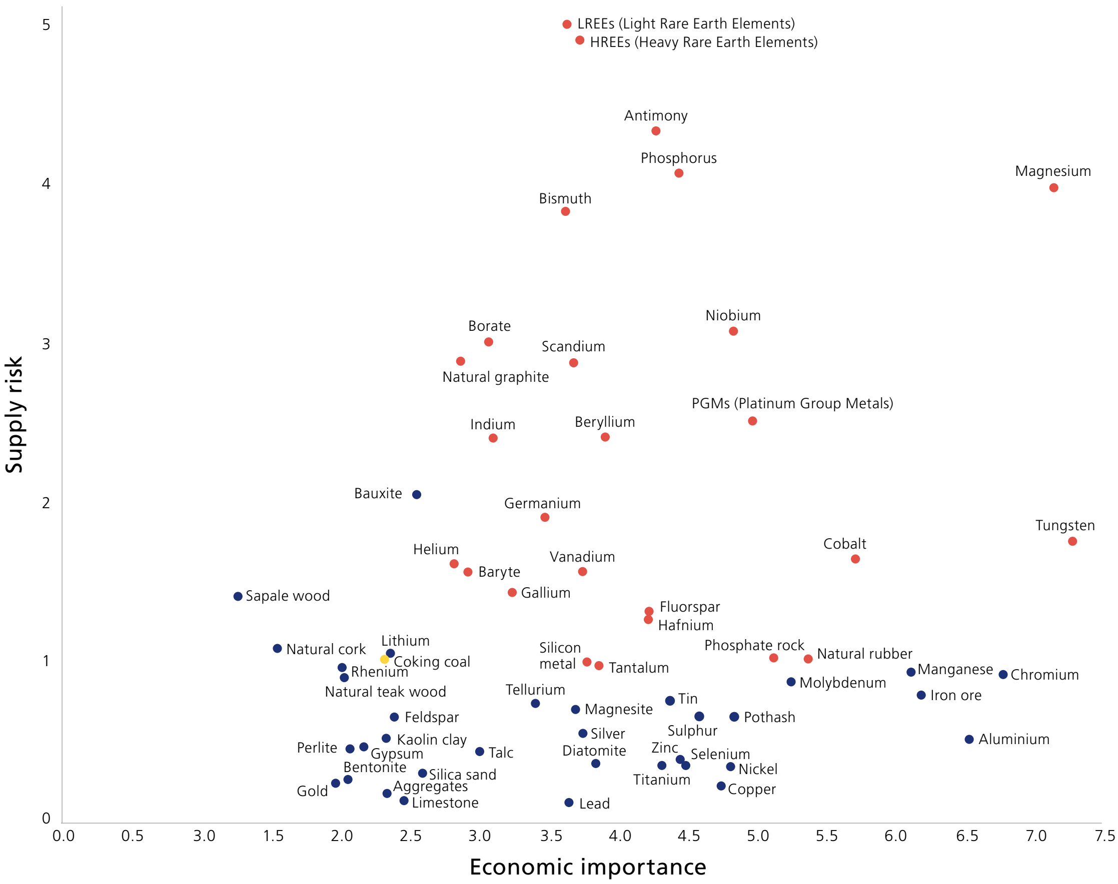


Figure 1.8. EU criticality assessment 2017.[5]

It's important to consider at least three time periods for adjustment related to raw material criticality: the short-, medium- and the long term. Within all of these periods, access to a particular raw material could be restricted for a variety of different reasons.

The EU criticality assessments have been conducted three times so far: in 2011, 2014, and 2017. In the latest assessment, 61 candidate critical raw materials were examined, of which 26 were assessed as critical. For example, tungsten was assessed to be of high economic importance but with a relatively low supply risk, while both light and heavy rare earth elements were identified as having lower economic importance but high supply risk, and magnesium was determined to be both high in economic importance and supply risk (Fig. 1.8, previous page)

The criticality assessment also provides insights from a global perspective on which countries have the largest supply share of a particular raw material (Fig. 1.9, next page). Countries seek to understand their dependence on raw material imports and material criticality in order to support public and private decision-making, build resilience against a material's potential supply restriction and, if required, address potential impacts.

1.6 TRANSITION TO A CIRCULAR ECONOMY

- A product perspective instead of a material perspective is critical to achieving closed-loops where the complexity and functionality of a product is conserved.
- Product design, circular business models and a circular policy context are key enablers for circular economy.
- A society-wide transition to a circular economy requires changes to the way we live our lives with action at all levels of society.

Stepping from a materials perspective to a transition perspective

Up to this point, this compendium chapter has focused on issues and topics immediately connected to materials and the extraction of materials. It has been presented that these activities remain vital (critical!) to the function of our modern economies, but it has also been shown that Circular Economy efforts will serve to reduce impacts related to the delivery of materials to global value chains.

For each portion of the material value chains that has been addressed, an explicit link has been drawn to how one can embed activities that align with the Circular Economy. Further, a number of lessons have detailed how materials increase in value (quite drastically!) as they move up value chains. Consider aluminium that went from ore to fabricated products with orders of magnitude increases in value along on the way.

Let's now circle back to the very reason we are here – to be part of a broad social and economic transition to a circular economy. To set the scene for the following chapters, the concept of *value and function preservation* embodied in the circular economy, and the theme of *transition* are introduced in the next subsection.

Circular economy – preserving value and function

The circular economy is an economic system where products and materials are kept at their maximum value and functionality. A starting point is to take a product perspective instead of a material perspective, and the aim is to set up closed-loops in which the complexity and functionality of a product is conserved for as long as possible. This seeks to avoid breaking a product down into its basic materials after each use cycle. After all, it is in the functionality and complexity of products where most of their value lies (Figs. 1.10, 1.11, next page).

Setting this new system up requires a systemic change: a disruption of the existing patterns and habits of both producers and consumers. We need different types of products and services, a new legislative framework and stronger interaction between people. Digitization and new technology help; it allows us to do things we could not do before, such as to produce things in new ways, manage products more sustainably, and reuse, repair and share.

A circular economy needs durable products that can be repaired, reused, remanufactured and recycled, while trying to use fewer and less scarce materials in the first place. Product design is key to enabling circularity. For example *Design-for-repair* and *Design-for-recycling* are design strategies that aim to integrate circular economy principles at the early stages of product design. An alternative angle is to maximize the functionality of materials, and whenever possible substitute in other materials that perform the same function but that are less scarce, or have less environmental impact. Some products can even be completely dematerialized and sold as a service instead; music streaming is one such example.

The circular economy needs new business models in order to translate circular strategies into competitive advantage, company resilience and successful revenue models. Current business models focus on product sales, which makes it challenging to integrate longer use and reuse in the market approach. How do you create value for your customers while using fewer materials and conserving resources? And how do you deliver this value if not through conventional sales? These are some of the issues that circular economy is trying to address.

Policy also needs to be adapted to support circular economies. Current policies are still rooted in waste management, but in a circular economy the very notion of waste is phased out, as products are designed to prevent waste, and residues are transformed into new resources. Waste policies and product policies become linked to each other, and the resulting new policies need to facilitate circular material flows, and support the creation of circular businesses.

The transition to a circular economy will require changes in the way we live our lives. It will create new patterns of interaction between people, and change the way that we own and consume products. Action needs to be taken at all levels of society: industry, citizens, policy makers and researchers. We will need to embrace a new mindset, shifting from our current take-make-dispose paradigm to a circular vision.

In the circular product life cycle there will still be material losses in each step of the chain. We can minimize the losses through recycling, either back to the start of the cycle or

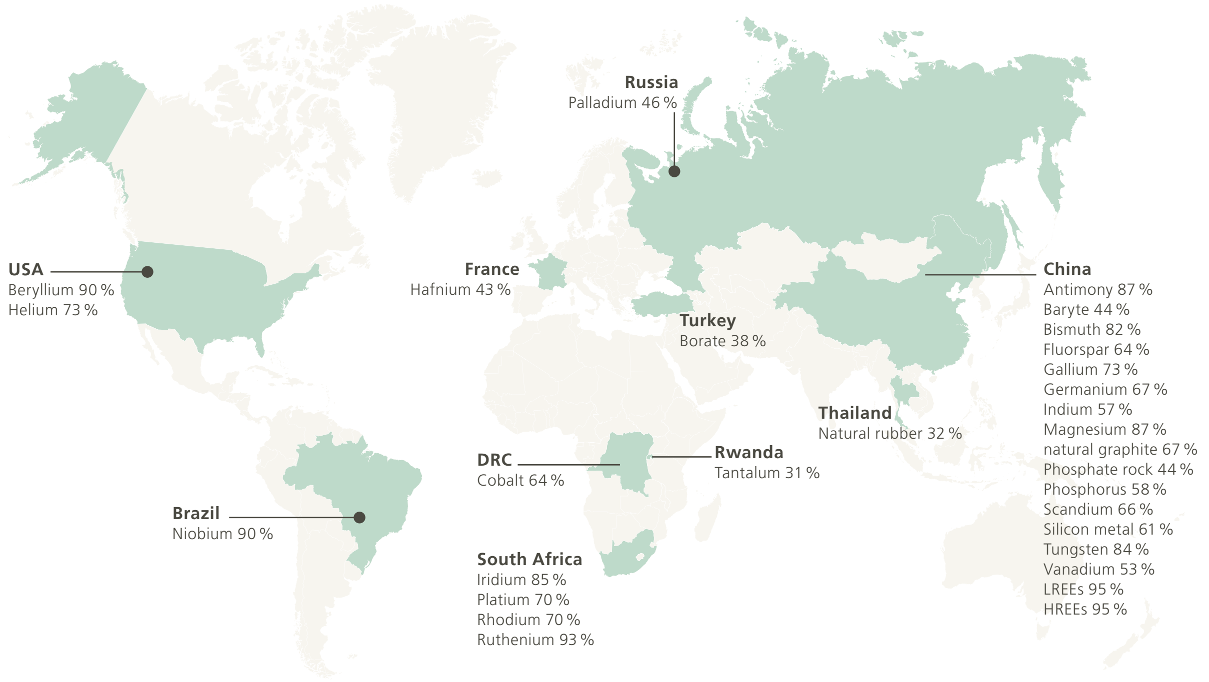


Figure 1.9. Countries with dominant supply shares of raw materials.[5]

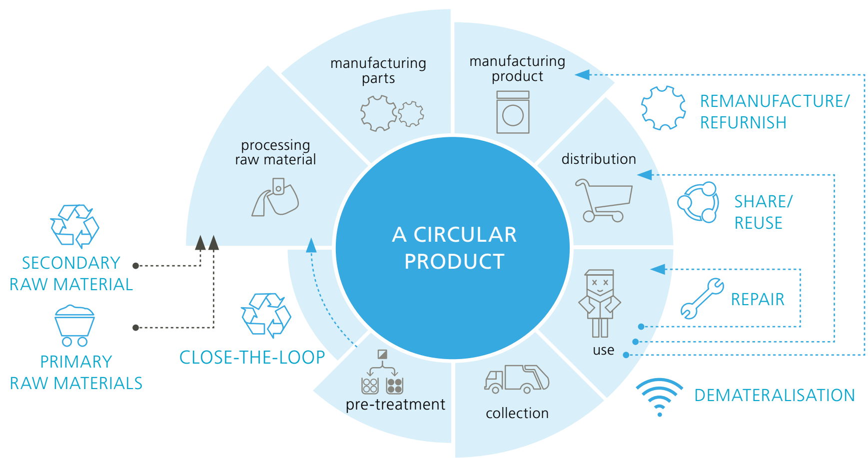


Figure 1.10. Closing the loop for a circular economy.[6]

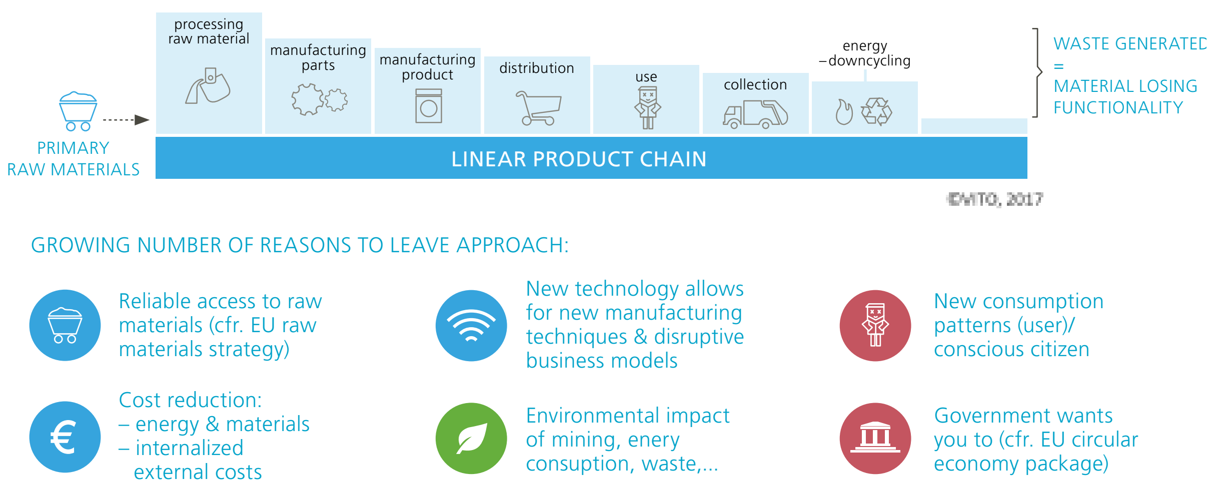


Figure 1.11. Escalating reasons to leave the linear product chain approach.[6]

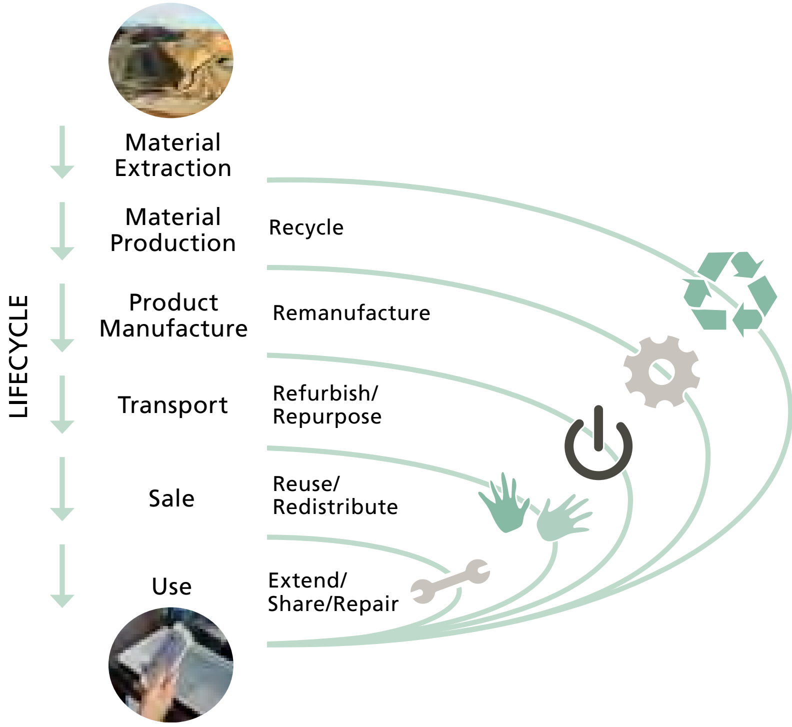


Figure 1.12. Diagram illustrating circular flows (loops) of products and materials in a technical system.[7]

into other products. This means that we need to set up connections between various circular products. As such, the circular economy is not actually a circle; it is rather a dynamic system of interlinked products. This complexity demonstrates that implementing the circular economy will require strong interaction between different value chains and sectors.

Another important element is that we need to ensure that hazardous materials and pollutants are removed from the circular system. We must develop and maintain clean material cycles that do not generate health problems or environmental hazards. Therefore, the system needs safe sinks, such as incineration with energy recovery for combustible materials, or safe disposal for (potentially) hazardous non-combustible materials.

Inner and outer circles

Over the previous decades a lot of effort has been invested to reduce material losses and bring materials back into new material loops. Europe, for example, has become successful at recovering materials from industrial residues and reinjecting them in the production process. At the end of the product life, we can also bring materials back into the loop through, for example, waste collection systems and treatment facilities. Most of the solutions currently in use rely on waste collection and recycling, but material management is more than just recycling; we need to manage the products and materials that we have in a different way, and dematerialize things.

The concept of *outer circles* refers to breaking down end-of-life products and residues into single materials, which can then be used as raw materials for new products. *Inner circles* are a way to retain value by extending the lifetime of the actual parts and products so they can cycle longer in the economy before returning to their material basics. Inner circles are shorter inner loops, that can be achieved for example through repair, reuse and remanufacturing.

By repairing a product we can create a very small loop that feeds right back into the use phase; repairing can extend product lifetime and retain value in the loop for longer.

When we are done with a product that can be reused, we can create a loop back to the distribution phase, and provide a second lifetime to the product (Figs. 1.10, 1.12).

A third way of setting up shorter loops is to refurbish or remanufacture a product. This allows us to create a loop back to the production stage. Remanufacturing involves taking the parts of a used product and reusing them in a new product, possibly after small repairs. By creating these inner circles, we can preserve value and the functionality of products in a circular economy for longer.

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1.3 FROM MINING TO METAL Panagiotis Davris – Mining and Metallurgical Engineering, National Technical University of Athens, Greece.

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1.5 CRITICALITY AND CIRCULARITY Erika Faigen – GEUS, Denmark.

1.6 TRANSITION TO A CIRCULAR ECONOMY Karl Vrancken – Sustainable Materials Management, VITO, Belgium.

2

Circular Business Models

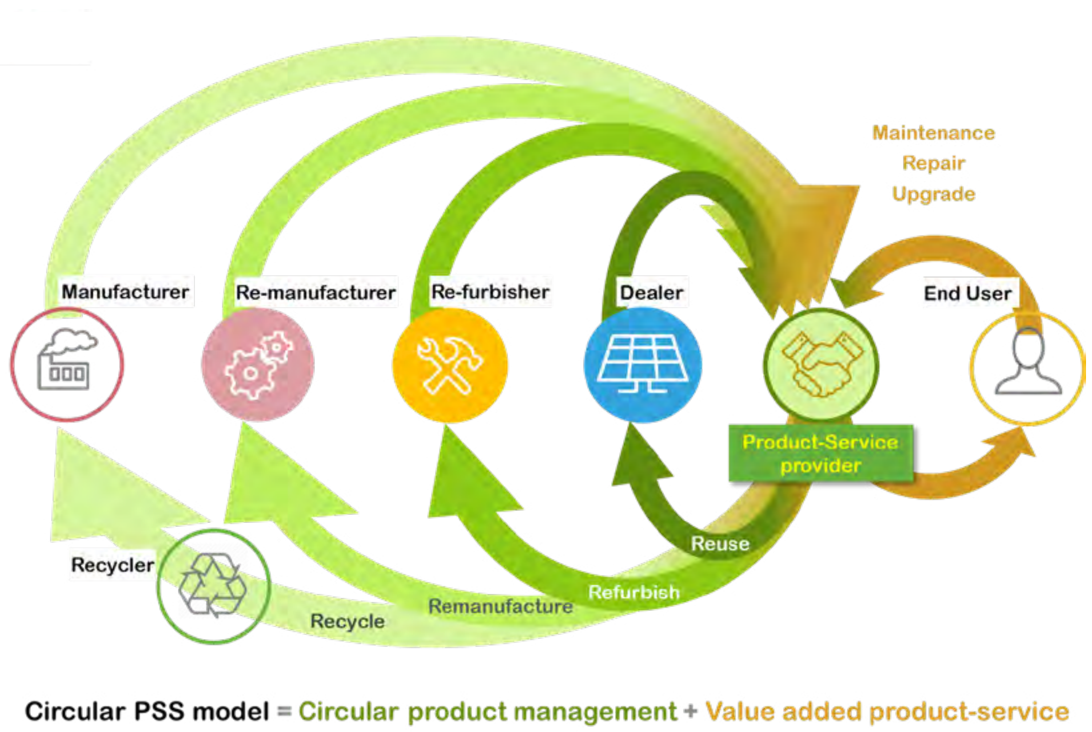


Figure 2.1. Illustration of a Circular "Product-Service System" business model.[8]

This chapter explores circular business models and discusses how business can create economic, environmental and social value.

2.1 THE ROLE OF BUSINESS IN THE CIRCULAR ECONOMY

- Three key strategies help businesses keep resources and products at high value for as long as possible: closing loops, slowing loops and narrowing loops.
- Approaches that pursue resource efficiency, longer product lifetimes, and material recycling are vital to closing, slowing and narrowing.
- The combination of the three strategies in circular business models is an ideal that companies must pursue for the circular economy to be achieved.

The concept of a circular economy allows us to focus on issue of resources and how they are used and managed in a business context. In our current linear economy, we are using too many resources, too fast, and we are not reusing enough of them. In this section, we present three key approaches to address this – strategies to narrow, slow, and close resource loops. The goal is to keep resources and products at their highest value, for as long as possible, and to extend their lifetime to ensure that they can function for longer (Fig. 2.2, next page).

Narrowing loops

In a business sense, *narrowing loops*, is about reducing the amount of materials needed per product or service. Fulfilling the narrowing principle is something we're already quite good at in the current linear economy. It is about *resource efficiency*, or doing more with less, which is also an opportunity to reduce costs.

Narrowing loops is an essential strategy in a circular economy, but narrowing strategies may not account for what happens with the product after it has been used. It may not include consideration of whether the product can be reused or remanufactured; or recycled. In the current linear economy, many efficiently manufactured products are thrown away after only being used once, but in a circular economy we try to retain the value of products and materials.

Slowing loops

In order to put this into business practice, we also need to develop the business models and value chains to support continuous reuse over time. This is called *slowing loops*. Generally, this means we must create products that have a long life span, and which people will want to use for a long time. But there can be trade-offs between durability and resource efficiency in production – building more durable products can actually increase the amount of resources needed for production. Thus, we must also try to design products that are easy to repair, maintain, upgrade, refurbish and remanufacture, so that extra resources used in production can be offset by the longer use-cycle of the product.

Businesses that pursue the design of long-life goods, product-life extension and service loops of repair and remanufacturing can extend or intensify the use of products, resulting in a slow-down of resources used. Out of narrowing, slowing and closing loops, slowing is actually the most important strategy – and also the hardest. This is because it requires us to both change the way that we design and manufacture products, but also how we use these products in our everyday life. If we can slow loops we can decrease the amount of resources that we have to put into the loop in the first place, and then we can also reduce the amount of waste that has to be processed and recycled at the end! (Fig. 2.2)

Closing loops

After many cycles of reuse we need to *close the loop* and recycle. Central to successfully closing loops is to avoid the mixing, or cross-contamination, of materials. When materials are not mixed, such as when glass is separated from plastic, they are much easier to recycle. Most of the clothes we wear are mixes or blends of different materials, which makes them difficult to recycle. But some companies are developing opportunities out of this challenge; the start-up ReBlend (www.reblend.nl/) for example spins new yarn out of these discarded mixed materials for use in new furniture and clothing.

Ideally, though, we want to be able to separate these materials and reuse them in their original form. Separating materials means that flows are not contaminated and products can easily be dismantled and remanufactured or recycled. These strategies of disassembly and reassembly will be instrumental in closing the loops.

How to narrow, slow & close

There are several ways we can narrow, slow, and close resource loops. Narrowing loops can be achieved through using fewer resources per product as well as during the production process. An example of this is lean manufacturing, where the efficiency of production processes is constantly optimized, reducing both costs and environmental impacts. These benefits help explain why narrowing loops is widespread in our current linear economy. Another example is lightweighting cars, which saves materials in the production phase and fuel in the use phase. A British automotive startup company, Riversimple (www.riversimple.com), has worked with this idea to create a prototype car weighing less than 600kg, a fraction of the typical weight of a car. And, Riversimple actually combines narrowing loops with other strategies like moving from ownership of a car to access to a car, which also helps with slowing and closing loops (Fig. 2.3., next page).

Slowing resource loops can be achieved through the design of long-life goods and product-life extension. The time during which we use products is extended or intensified, resulting in a slowdown of the flow of resources. Perhaps the most classic example of loop slowing is where businesses design products to last. A watch or a piece of classic furniture may be designed to be passed on from one generation to the next.

Instead of focusing on product life extension, businesses can also focus directly on slowing consumption of products or resources, but this is very challenging.

Consider the example of a government funded project started by the Dutch university TU Delft (www.homiepayperuse.com), which experiments with business models to slow consumption. This project aims to incentivize customers to reduce the impact of home appliances, starting with washing machines. Rather than buy a washing machine, consumers pay per wash in high quality machines provided by the project. The machines last a long time and are built to be reused and recycled. What is really novel here is that this test project also seeks to change user behaviour by incentivizing fewer and lower temperature washes. Customers only pay when they use the washing machine and they pay less if they wash at cold temperatures.

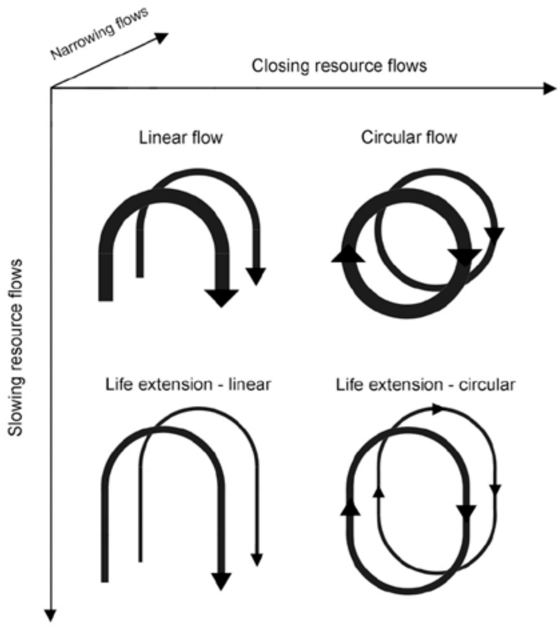


Figure 2.2. Conceptualising slowing, narrowing and closing of loops. [9]

Repairing, cleaning and maintaining products also help to slow down loops, as does making new products from old ones, or *remanufacturing*. This strategy is already being adopted for medical devices. Used devices are thoroughly checked and tested for compliance, worn parts are replaced and software is updated to current standards. In this way the life cycle of the product can be extended, decreasing wastes and delivering cost-savings for medical facilities.

Businesses that challenge current consumption models can also slow resource loops. An example of a company applying this idea is the outdoor apparel company Patagonia (www.patagonia.com). Their Common Threads Initiative encourages people to consume less, and instead repair, reuse and recycle clothing. An advertisement by the company in the New York Times newspaper, "Don't buy this jacket," is a notable example of an effort to create awareness for *slow consumption*. After the ad ran, many people still bought the jacket though, highlighting the practical complexity of slowing loops.

Businesses can pursue the closing of resource loops through recycling, where the loop between disposal and production is closed to create a circular flow of resources. In major industries like paper, metals and plastics, recycling rates

Figure 2.3. The Riversimple (Rasa) prototype vehicle.[10] (Provided by Riversimple. Photographer: Anthony Dawton).

are already quite significant, but there's still plenty of work to be done in terms of design, business models and value chains to improve recovery rates as well as recycling rates.

Closing loops can reduce the amount of waste that goes to landfills, but if done the right way, it can also save on costs for raw materials, as recycled materials can be used in new products. Nike Grind (www.nikegrind.com) for example makes new sports fields out of old shoes and G-Star's (www.g-star.com) Raw for the Oceans turns ocean plastic into new garments. Crossing industry boundaries, the floor covering company Interface (www.interface.com) created the Net-Works initiative to make new carpets out of fishing nets. They also work with local communities to prevent future disposal of fishing nets into the sea.

Of course, work to achieve a circular economy is helped if value chains and business models are designed so that the products do not become a waste in the first place, and are instead recovered or recycled. This would mean that some *waste to value* business models, especially relating to materials which would have been landfilled or dumped in the ocean, would not be necessary. We would prevent the waste in the first place, and create continuous loops of product reuse and material recycling.

Closing loops requires innovative thinking; what might be considered waste in one process can often be a resource for another. In the food industry, In the food industry for example, mushrooms can be grown using coffee waste and salad crops can be fertilized nutrients derived from waste through an aquaponics process; in such ways waste can become "food".

In a perfect world, companies would combine strategies of narrowing, slowing and closing resource loops in a circular business model. While this is still an ideal rather than a norm, some companies are already moving in this direction. One example is the start-up MUD Jeans (www.mudjeans.eu), the first firm in the world to lease jeans to customers, with

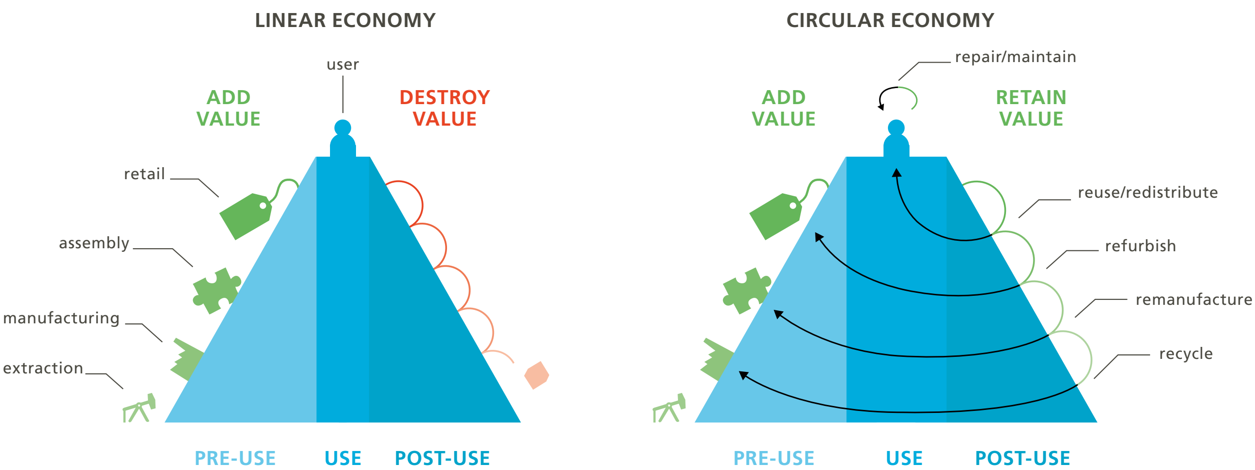


Figure 2.4 The *value hill* in linear and circular economies.[11]

an aim to stimulate a sustainable lifestyle through clothing reuse and recycling.

Companies in a circular economy work to retain the value of resources by encouraging reuse, refurbishment and remanufacturing, followed by recycling; utilising these service loops helps maintain the value of products (Fig. 2.4).

To achieve this goal, the circular economy requires innovations at the technology, business model, design and value chain level that have clear circular intent. These then need to be followed up by assessment of actual impact.

2.2 CIRCULAR ECONOMY BUSINESS MODEL STRATEGIES

- Business models describe the organizational and financial structures where an organization converts resources and capabilities into economic value.
- Innovation is required to deliver business models that create value from cycling products, parts, and materials.
- Strategies from three elements: circular value creation; circular value proposition; and circular value network can be combined to form a circular business model.

To help companies adopt circular strategies that can narrow, slow and close resource loops, business model innovation is essential. By taking a closer look at what a business model is, we can gain insights into what this actually means and why it is relevant.

What is a business model?

A business model is a management tool that is used to present the company's organizational structure and value creation processes. It describes the organizational and financial architecture by which an organization converts resources and capabilities into economic value. A widely used definition, created by analysts Osterwalder and Pigneur, describes the business model as the core logic of how a company creates, delivers, and captures value. Osterwalder and Pigneur created a framework, the Business Model Canvas, for supporting work with business models, including circular business models, that has been acknowledged for its practical relevance (Fig. 2.5).[11]

A business model consists of different elements that can be adjusted in innovative ways to enable and integrate more circularity. These elements can be structured into three value dimensions:

- value proposition – describing the value provided and to whom;
- value creation and delivery – detailing how value is created and delivered;
- value capture – outlining how value is captured and turned into profit.

Each of these value dimensions consist of a number of business model elements.

An example of a fictitious backpack company, Waterproof Bags Incorporated, can be used to help clarify how these fit together.

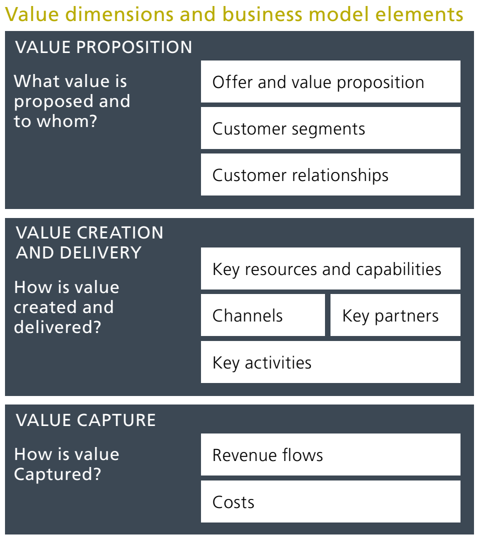


Figure 2.5. The Business Model Canvas visualizing business model value dimensions and elements.[12]

A value proposition dimension, the value that the product or service creates for customers, consists of three elements: *customer segments*; *customer relationships*; and the actual *value proposition*.

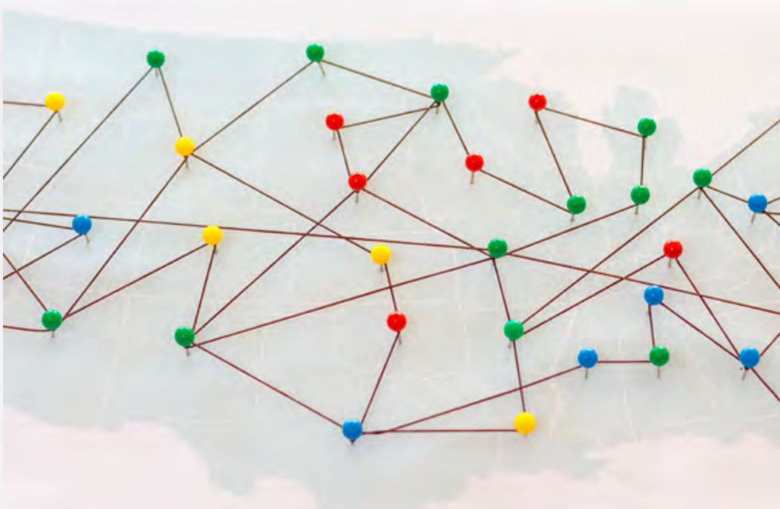
In this instance, Waterproof Bags Inc.'s main value proposition is that its bags are 100% waterproof and the customer segment targeted is "adventurous people" who spend a lot of time outdoors. The customer relationships strategy is "co-creation powered by social media", where the company's customers are involved in the development of upcoming models.

The value creation and delivery dimension consists of four elements: *key resources and capabilities*, *channels*, *key partners* and *key activities*. For Waterproof Bags Inc., the key resources and capabilities include the development of new, lightweight, waterproof materials. To establish channels with customers, they decide to focus on online sales to support their online community. Their key partner is a large cycling parcel delivery company that helps them promote the backpacks in action. Their key activities are lean manufacturing and sales.

The value capture dimension consists of two elements: *revenue flows* and *costs*. In this case, the revenue model is quite simple: Waterproof Bags Inc. receives income from selling bags to its customers. Its main costs are incurred in manufacturing, retail activities, and management of the online community.

Innovating business models

Innovating the business model means to alter or re-link some of the business model elements. Innovating business models can take two forms: the development of an entirely new business model, or the reconfiguration of existing business model elements. As such, innovating the business model can help coordinate technological and organizational innovations. The process can also help secure partner networks or capabilities needed to preserve and utilize the embedded value in resources. Business model innovation can help businesses devise an offer and value proposition

that proactively embeds a circular strategy; for example, by prolonging the useful life of products and parts, or by closing material loops. By rethinking the three value dimensions (i.e. how value is created, delivered and captured), business model innovation provides a more holistic approach for aligning a company's value-creation logic with circularity.

Adding circularity

When performing business model innovation in pursuit of a circular strategy, shaping and adjusting business model elements can make implementation of the strategy easier. This can also help overcome barriers and capture value.

For example, the value proposition can be designed to deliberately use a circular strategy and target customers that find the associated value appealing. A value proposition might be a "long-life product with low maintenance and lifecycle costs". This can be appealing to customers with a high environmental awareness or to customers that are bothered by products that quickly become obsolete. For the same product or products, relationships with customer segments can be designed so as to encourage return of a product after its use, such as through establishment of closer and more service-oriented relationships, or by offering a financial reward upon return – or both.

Value creation and delivery elements can be devised to successfully create and deliver the value of a company's circular offer. Operating a circular strategy requires specific activities, resources, technologies, capabilities, and partner networks to successfully prolong the life of products and close material loops. A company needs to shape these elements in a way that allows it to embed circular practices in its business model. This might require that it find partners that have special capabilities that it doesn't currently have. For example, partners that can test and certify quality of repaired products, or partners able to provide sufficient volumes of discarded products to be upgraded or reused.

Value capture elements in a circular business model might be adjusted to generate additional revenue by selling (essentially) the same product several times, or by capitalizing on environmental benefits associated with resource conservation. There may also be opportunities to reduce production costs via the use of cheaper secondary materials, or to avoid costs for end-of-life disposal.

For every business model, depending on the circular strategies operated, or the type of product, the business model elements will be shaped differently. But through paying close attention to how these elements are shaped and by making sure that they support implementation of the specific circular strategy, circularity can become a part of a company's value creation logic and the barriers can be gradually removed.

A note about value creation in circular business models

The sources and processes of value creation in circular business models differ from those in linear business models to some extent. To preserve and utilize the embedded value in products, parts, and materials for as long as possible, business models need to shift their focus beyond a single use cycle by enabling interventions such as resource recovery, and multiple use cycles.

Emerging research on managing value creation from prolonged life cycles suggests several unique characteristics of business model elements designed for preserving resource value. If additional life cycles of a product are enabled, it can be useful if the value proposition, from the beginning, is thought of as more fluid and subject to re-definition along the product life cycle. For value creation and delivery, different value networks for cycling resources need to be established; for example, partnerships for securing sufficient supply of secondary products. For value capture, some activities along the product life cycle will result in additional costs (e.g. collection), while others can reduce costs (e.g. substituting virgin materials with secondary materials). Revenue streams can be captured multiple times throughout the lifecycle; for example, through extended spare part and aftermarket services during a first use cycle or accessing new markets and customer segments in a second cycle.

Thus, in order to create and capture value from prolonging the useful life of products and parts and closing material loops, separate value creation architectures may need to be designed to create value from each cycle. Business model development needs to consider how business model elements are configured to support each of the envisioned cycles if value is to be preserved and utilized.

To seize opportunities for preserving and utilizing resource value in the business model, timely consideration and integrated planning of the required interventions for each cycle is pivotal.

Key strategies for circular business models

When asked to provide an example of a circular business, many people will likely respond "a recycling company". Others might tell you of "a reuse shop", and a few may probably refer to a "car sharing" platform. Despite these activities being quite different, they would all be correct! With such variety available, it is important to consider what it is that makes us call a circular business "circular".

In this light, it can be observed that actors working with a wide range of circular business models and circular businesses have identified three key ingredients for a circular business model:

- the company should engage in some form of circular value creation;
- the business should make use of value propositions that enable circularity;
- the activities and the business should be embedded in a circular value network (Fig. 2.6).

The first key ingredient, *circular value creation*, stands at the heart of a circular business model. Circular value creation means that the business model should include one or more ways to close, slow or narrow resource loops. Several strategies exist to create circular value, such as recycling, repairing, remanufacturing and reusing. We can also seek to increase the amount of use a good has during its lifetime (i.e. improve its *utility rate*), make products more resource efficient, or avoid the use of toxic substances.

A solid value proposition is the second key requirement. Circularity is important, but it also has to be a part of a viable business, and businesses need customers. The best value proposition depends on the needs and motivations of your customers. If customers are interested in a product made from waste materials for example, then a firm could use a circular branding strategy. This is what a company called Flagbag does for their leisure bags and purses: the design clearly emphasizes the origins of the waste materials they use (Fig. 2.7, next page).

For other customers, a premium brand strategy may be more attractive. Vitsoe, for example, produces furniture products that are intended to last a lifetime; they put product quality and longevity at the centre of their value proposition.

Another value proposition strategy that can enable circularity is a product-service offering. Here, a company delivers the product as a service rather than selling a good directly. In this configuration, the company still owns the product. It is now in their interest to make sure that it lasts as long as possible, which makes repairing, reusing, or remanufacturing more important. This strategy is applied in "pay-per-copy" models, that allow companies like Ricoh (www.ricoh.com) to manage their copy machines like assets.

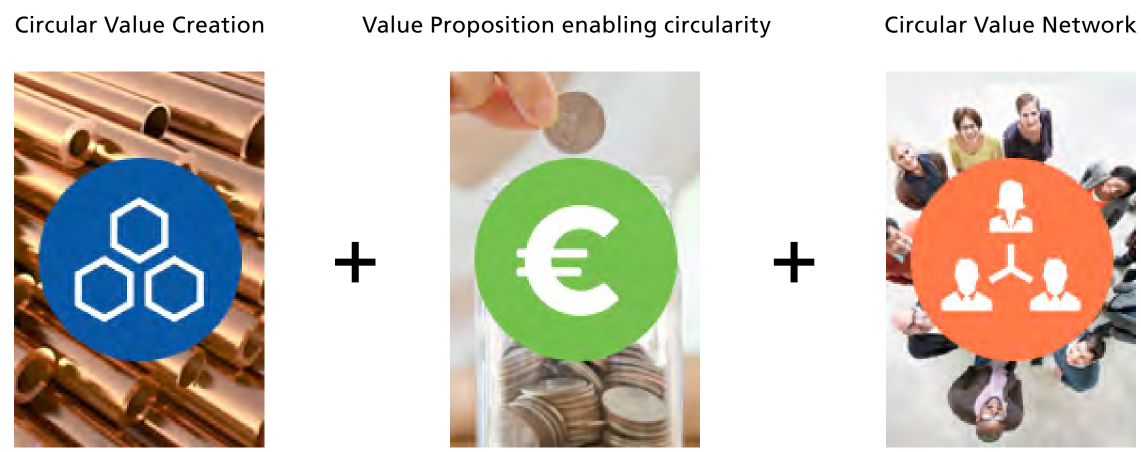


Figure 2.6. Three key ingredients for circular business model application.[6]

Figure 2.7. A Flagbag bicycle bag.[13] (Image provided by FlagBag).

Other value proposition strategies can focus on reducing costs for the customer. For instance, by offering a product or service that is cheaper than the linear alternative, providing a platform to share underutilized capacity, or by eliminating product inventories via production on demand systems.

Some companies have also demonstrated that you can use circular business models to increase business without necessarily branding yourself as a circular business. Nearly New Office Facilities (www.nnof.be), for example, focuses on customer needs for affordable office furniture combined with a healthy work environment. The fact that they use materials from old furniture in the manufacturing of new furniture is something many people may not even notice.

The third and last key ingredient for a circular business model is the *value network* that surrounds the company. Closing, slowing or narrowing resource loops is only possible when the stages of a product life cycle are connected in such a way that the product and its resources can be kept inside the economy. This requires collaboration between the company and other actors in a value network. Such collaboration can be set up with customers or suppliers in the value chain, or with companies, governments, or civil society in a wider value network.

Value networks can be created in many different ways. A deposit refund scheme for example, improves the return of goods to the producer, while online platforms can be used to manage the movement of goods in a network. A value network at a local scale can help reduce the loss of resources in complex global value chains. One famous example of this is the industrial site of Kalundborg in Denmark, where a local closed resource network has been formed. At this location, residue, by-product and waste streams from a range of companies are used as input resources for other business and organizations.

Circular strategies and the Business Model Canvas

It is possible to connect the three ingredients to the Business Model Canvas components to help identify potential strategies to increase circularity. Circular value creation strategies are typically linked to the key activities, key resources and capabilities, or key partner elements in the Business Model Canvas. Value proposition strategies are linked to the product offer, customer segments and customer relationships elements. And value network strategies can be linked to the delivery channel, customer relationships, key partners or key resources and capabilities elements.

While the Business Model Canvas, in combination with the circular strategies, is a very useful place to start designing a circular business model, it is less suitable to use in mapping circular value networks, a crucial part of any successful circular business. Therefore, the next section presents two tools that can be used to design circular business models with the circular value network in mind.

The importance of a circular value network – an example

The success of a circular business model depends on the creation of smart combinations of circular value creation strategies, value proposition strategies, and value network strategies.

Consider a company that produces repairable and recyclable smartphones. While the design for repair and recycling the smartphone is key to creating circular value, such circular value is actually only realized when the product is in a repair shop or recycling facility.

As such, the producer needs to create incentives for their customers to return the phones when they are damaged, or when the customer has finished using them. The producer also needs to work with repairers and recycling companies to make sure the smartphones are repaired when broken, and recycled when repair is no longer possible.

There are a number of combinations of circular strategies that can make these situations technically and economically feasible. A first, and very common one that can be found in Europe, is the creation of an extended producer responsibility (EPR) scheme. This is a collective, government-controlled mechanism in which producers are required to finance the collection and recycling of end-of-life products – including end-of-life smartphones.

Although this value network strategy has been shown to support increased recycling, many smartphones still end up in consumers' drawers at home, as at present there is no real incentive for them to have their phones repaired or collected. The producer of the smartphone, also generally has no direct benefit of its design-for-circularity efforts, as there is no direct link between producers and recyclers. In simple terms, the value of the design efforts gets lost.

However, such challenges can be overcome if actors in the system improve aspects of the circular business model design. For example, the producer can directly cooperate with its customers by offering a discount on new products when an old smartphone is sent back. The producer may then re-market the collected smartphones in other markets, or capture residual material value by having the phones recycled.

An even more effective circular strategies combination that can capture all the circular value of smartphones designed for circularity, can be to introduce a Smartphone-as-a-Service as the value proposition. This scenario allows the producer to keep control over its product both during and after the use phase, and it also creates leverage to maximize the reuse, repair and recycling value of their products. As the owner of the products, the smartphone company can engage in partnerships with repairers and recyclers within its business model. Providing information such as product disassembly guidelines, or the detail bill of materials for the product, or by jointly organizing reverse logistics, can also help these partners to improve their own activities – in turn improving the overall viability of the system.

The role of Products-as-a-Service in the circular economy

Providing services to the customer instead of selling the product is a key strategy to create a circular economy. A *product-service* offering, or Product-as-a-Service (PAAS), is one type of value proposition that can be used to achieve circular value creation.

Viewing this as a value proposition, where a combination of product and service elements are offered to the customer, is one way to understand how this functions. Such models are by no means new! Libraries and cable television for example, have applied this model for many years. With the advent of digital technologies it has become increasingly easy and interesting to use a PAAS strategy for a wider range of products. PAAS has completely changed the music industry in recent years. Start-ups such as Spotify have brought the value of music to its customers without ever having to produce, distribute, or play a hardware form of music such as a CD.

PAAS exists in many forms and variations, but for circularity, it is relevant to make the distinction between three types of PAAS: *product-*, *use-*, and *result-oriented* PAAS (Fig. 2.8).

A product-oriented PAAS still closely resembles a conventional sales offer in that the ownership of a tangible product is still transferred to the consumer. However, it differs because there is an addition of a service offering to provide additional value to the consumer during the use phase of the product. This can include the provision of consumables linked to the product, and the performance of maintenance or repair services.

A use-oriented PAAS reverses the ownership model: the product is leased or rented rather than owned, in addition to the provision of similar services as in the product-oriented model. The use oriented PAAS benefits the provider as the product will generally be returned after the use contract has expired.

A result oriented PAAS takes an additional step towards a service-only model: the provider assesses the need of the consumer, and decides which product or products can help

Product-as-a-Service: a value proposition in which a product and service offering are combined
Three main types:

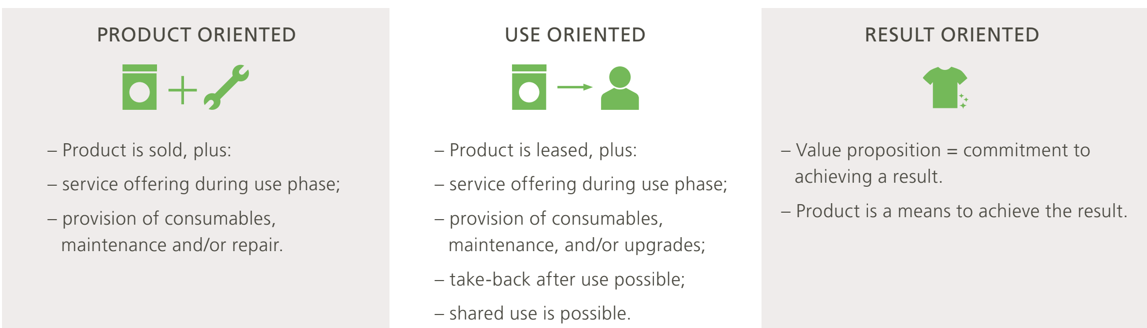


Figure 2.8. Product-as-a-Service orientations.[6]

Circular Value Creation				Alternative models
Repair/Upgrade	✓	✓	✓	Independent repair shops
Repair/Upgrade	✓	✓	✓	Resell platforms
Repair/Upgrade		✓	✓	Extended producer responsibility
Repair/Upgrade	✓	✓	✓	Ecodesign measures
Repair/Upgrade		✓	✓	Sharing platforms

Figure 2.9. PAAS orientations and circular value creation strategies.[6]

her in addressing the customer's need. In such a model, the provider does not sell or lease products anymore, but the function related to those products: the lamp is not leased, but rather the required level of light is provided to the consumer.

PAAS does not lead to a circular business model by itself, rather, it provides the company with the tools to enable more circular production and use of their products. These include: long term relationships with the customer; access to the product during use, and ownership of the product that in turn allows the company to capture the value, or reuse, remanufacture or recycle. It is up to the company to take advantage of these tools in setting up circular value chains.

Figure 2.9 provides an overview of how the three main PAAS types can contribute to different circular value creation strategies. It also lists alternative models to PAAS that may be applied in order to achieve the same, or similar, circular value creation strategies.

EXPLORE FURTHER – THE CIRCULATOR

To help you with the design or analysis of a circular business model, the Circulator (Figure 2.10) has been developed. This can be found at www.circulator.eu. This web-based tool allows you to explore circular strategies, using the "Strategies Mixer", and to combine them according to your own preferences.

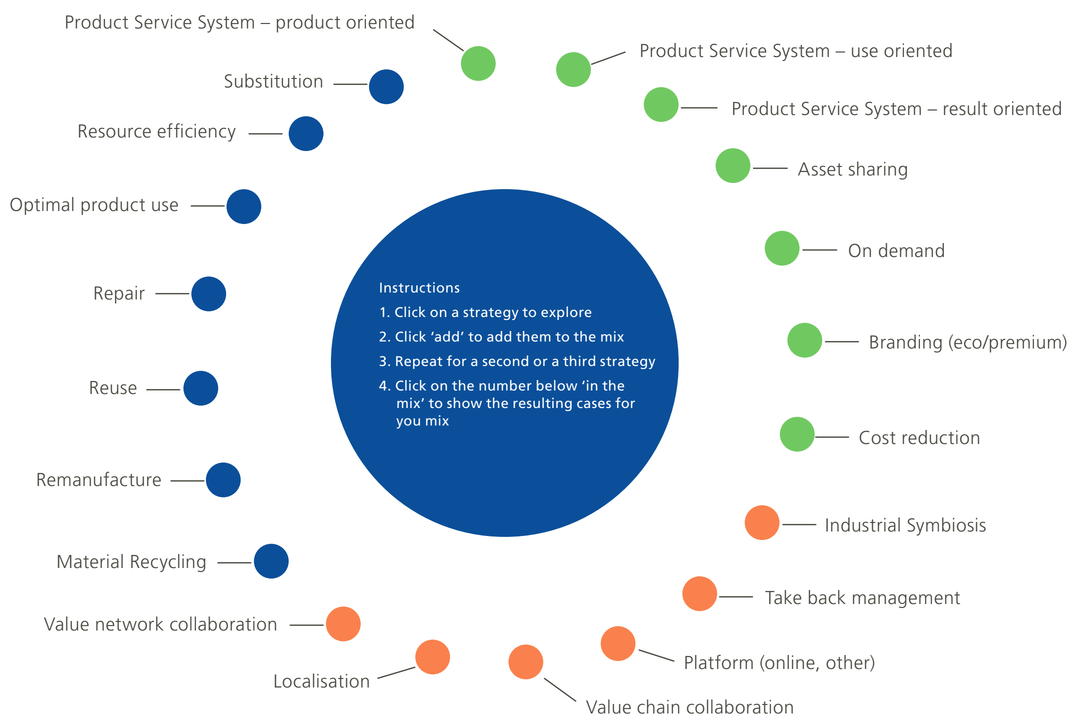


Figure 2.10. The Circulator – an example of a circular business model tool.[14]

2.3 BUSINESS MODEL INNOVATION

- Circular business model planning tools can be used to analyse business models – both strategies that implement circular strategies and those that do not yet do.
- Specific actions can be taken to embed circularity in a business model and create product and material cycles.
- Business elements that need to be adapted to support value creation can be more easily identified and adapted if a specific tool is applied.

As an aid to business model innovation, visualization tools that depict circular business models can be used to help plan product life cycles that create and capture value from multiple use cycles and closed material loops. A visualization tool can also highlight how business model elements may be adjusted to effectively implement each cycle.

The Circular Business Model Planning Canvas is a visualization tool to map circular business models. It offers a standardized representation of the elements, and possible cycles of circular business models, that can prolong the useful life of products and parts, and close material loops. This tool integrates the three value dimensions discussed earlier (value proposition, value creation and delivery, and value capture, and their business model elements, in the left-most column (Fig. 2.11, next page).

Further, it applies four lifecycle interventions (seen at the top of the Canvas):

- collection and reintegration of resources;
- enabling prolonged useful life;
- enabling additional lifecycles of a product or its parts;
- enabling material recovery.

It is important to note that collection and reintegration is mapped twice in planning tool. This is because these processes can take place both upstream and downstream in a company's value chain.

The tool maps business model elements for each of the enabled interventions. It can help you recognize which interventions for circularity are currently utilized and which are not. This can reveal innovation opportunities to embed more circularity in the business model. It can also help you analyse if the business model elements are configured to effectively support each of the envisioned cycles. Lastly, it can help recognize interdependencies between the enabled cycles and how shaping business model elements to support one cycle, enables value creation from another cycle (e.g. customer relationships established in the first sale can be configured in a way that they facilitate collection of products later).

In practice, the tool can be used for:

- integrating innovative ideas into consistent business models;
- the development of the common understanding within teams, and among internal and external stakeholders, that is necessary to support effective implementation of business model innovations;
- collaboration processes among companies that help them recognize interdependencies and align business models;
- the management of value networks and partners.

The Fairphone circular business model

Filling out the Circular Business Model Planning Canvas using details from a mobile phone manufacturer and distributor named Fairphone (www.fairphone.com), provides an example of how it can be applied in practice (Fig. 2.12, next page).

Fairphone offers a modular long-life phone and both replacement modules and repair guides can be accessed via the Fairphone website. Their customers are presented a value proposition of competitive performance standards, reparability and low lifecycle costs, as well as access to a website community where Fairphone users can – among other things – discuss repair techniques.

As part of their business model, Fairphone has an intertwined relationship with a collaboration partner named Teqcycle (www.teqcycle.com); a repair and recycle company. Fairphone offers Teqcycle a resale opportunity and thus the value proposition for Teqcycle includes the modular design of the Fairphone. This in turn makes repair and resale of phones relatively easy. Fairphone also collaborates with Teqcycle for the take-back system. Customers for the re-purposed phones are in fact not direct customers of Fairphone, but are customers of Teqcycle, so they are not mapped in this version of the model.

Filling in the model canvas highlights interdependencies between the interventions, and how shaping business model elements in one intervention enables value creation through other interventions. In the case of Fairphone, the relationship established with users when selling the phone helps them reach out to users and inform them of repair possibilities, and to promote the return of phones. The design for repair and recycling facilitates value creation after use for its partner Teqcycle.

Not all of the interventions have to be addressed in a circular business model. Examination of the last two interventions represented on the canvas, demonstrates that the responsibilities between Fairphone and Teqcycle are more and more divided. And not all business model elements of the focal company Fairphone are filled in. Typical reasons for this are that some interventions may not be more resource efficient or economically desirable, or that they can rarely be realized by one company alone, but are reliant upon networks of companies that align their business models to each other. In the case of Fairphone, no integration of secondary materials in their own products is happening as yet. The blank columns in the circular business model canvas, however, send signals that there may be an opportunity for embedding more circularity in the business model, and that is worth exploring.

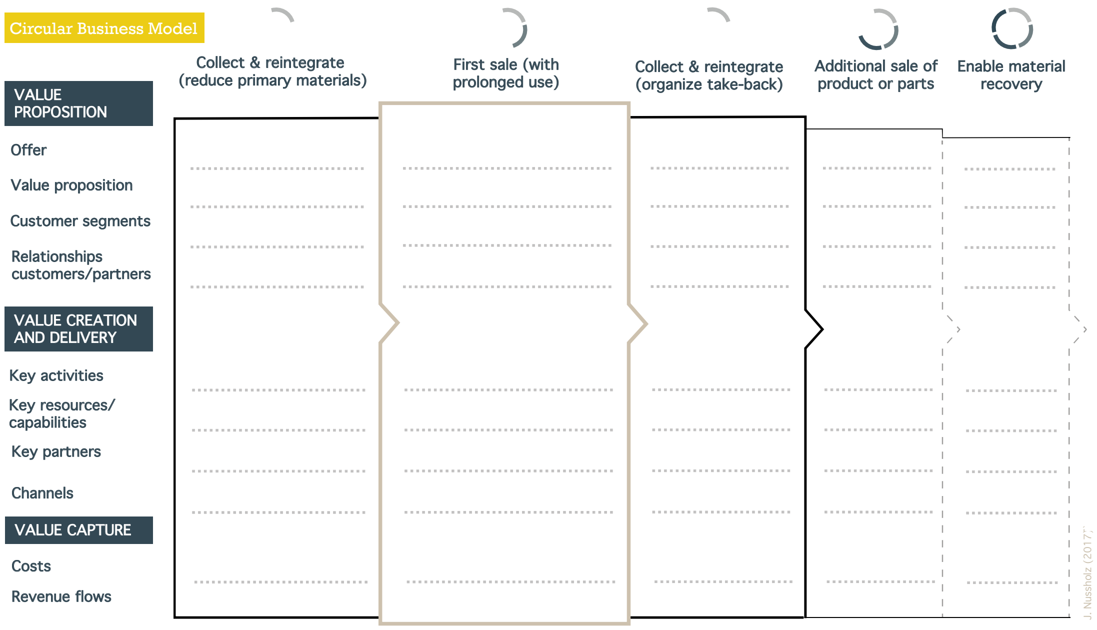


Figure 2.11. The Circular Business Model Planning Tool.[12]

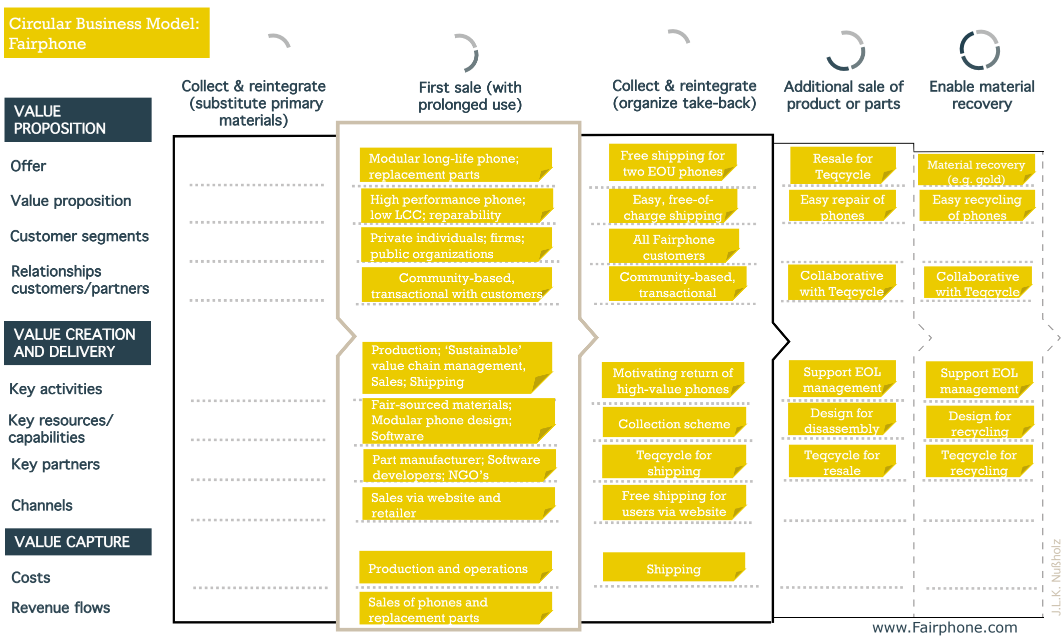


Figure 2.12. Fairphone and the Circular Business Model Planning Tool.[12]

2.4 DRIVERS FOR ENTREPRENEURSHIP IN THE CIRCULAR ECONOMY

- A mainstream business tool, the PESTEL framework can be used to assess a circular business strategy against the external business and social environment.
- Effective use of PESTEL requires clear and strict delineation of factors that are external to a business from those that are firm-internal.
- When factors are categorized correctly, the PESTEL framework is useful for the identification of political, economic, societal, technological, environmental, and legal drivers for the establishment of circular business models.

PESTEL analysis

The transition to a circular economy is not expected to be an easy, gradual evolution. It requires a profound change in the way we live, travel, work and do business. To succeed, radically new ideas must gain momentum and find a window of opportunity to change the mainstream system. These windows of opportunity emerge when different trends and events in society suddenly come together and point in a similar direction, making room for a new mindset, or helping to make a place in markets for products or services that offer something different. When this happens, a new product or a new service may suddenly break through and contribute to a profound change in our way of thinking and acting.

The right idea at the right time is what entrepreneurs are looking for. Unfortunately, the process of creating the right time is largely out of our control. Changes in technology, market conditions, social trends, government policies and regulations, and other factors combining generally define such points in time – and it is difficult, if not impossible to influence so many things. Such parameters have a large impact on whether a great idea can actually turn into a real business opportunity or not. Companies must react and accommodate the changed conditions into their value proposition, company policies, and their marketing strategy. This means that understanding what these external factors may be, and how they work together, is key to recognising ideas that are most likely to be successfully developed.

The PESTEL framework, which is often used in marketing, is a useful tool for this. It lists key external (macro-)influences that can affect a business' strategy and success. They are listed according to the following six factors ascribed to the acronym PESTEL.

P for **Political** – These factors determine to what degree the government and government policies intervene in the economy or a specific sector. This can include government policy, and political stability or instability in local as well as overseas markets, trade restrictions, fiscal incentives and taxes, labour regulations, environmental law, and so forth. Companies must be aware of, and able to respond to, current and anticipated future legislation, and adjust their business strategy accordingly.

E for **Economic** – These factors have a significant impact on the economy, which in turn impacts the profitability of a company and the way in which it can do business. Factors include the level of economic growth, employment rates, interest and exchange rates, inflation, disposable income of consumers, raw material and energy costs, and more.

S for **Social** – Socio-cultural factors determine the customers' needs and wants and are of particular interest to marketers. They include the characteristics, the shared beliefs and attitudes of the customer population. These are assessed by factors such as population demographics, education levels, general health status, lifestyles and attitudes.

T for **Technological** – Technologies change rapidly and can have a huge impact on the way products are made and marketed. Technological factors affect the way in which goods and services are produced and distributed, as well as the way in which customer communication is created and delivered. Factors include parameters such as changes in automation and robotization, and trends in digital and mobile technologies.

E for **Environmental** – These relate to the impact of ecological factors and constraints. Environmental factors have become important due to increasing environmental awareness by both governments and consumers. Concerns – and tangible impacts


E – Environmental

L – Legal

on businesses – related to issues such as resource scarcity, pollution, carbon footprint, and climate change are also notably influencing choices made by companies. In the context of the Circular Economy, the E for Environment parameter in the PESTEL framework is oftentimes stretched to include broader sustainability issues. One leading example is a shift towards more ethical and sustainable business policies. With more and more consumers demanding ethical and sustainably sourced products, corporate strategies that explicitly account for sustainability issues are also gaining importance.

L for **Legal** – Legal factors include parameters such as employment policies, consumer rights, health and safety standards, advertising rules, privacy, product labelling, warranties, liability, trade restrictions, and so forth. It is clear that companies need to understand the legal boundaries within which they must operate. This can become particularly challenging when a company operates on an international level, as each country has its own rules and regulations, and they often differ. There are also a range of legal issues with new forms arising related to circular economy activities – liability and intellectual property rights are just two of these.

By undertaking such as structured assessment of external factors that may affect an organization, a company can improve its resilience to external threats and identify windows of opportunity for new business strategies. This in turn may create a competitive advantage for the firm. In recognition of this, the parameters within a PESTEL analysis are often described as drivers of change as can define issues that stimulate a company to change its strategy, or the manner in which it does business. Ignoring such drivers can negatively affect a business.

It would be prudent to perform a PESTEL analysis before implementing any strategic or tactical plan, and to repeat it at regular times to monitor and respond to any changes in the macro-environment.

Examining today's drivers for circular economy businesses

Although the circular economy is still a relatively new business paradigm, many companies have already taken steps towards becoming more circular. New circular start-ups are emerging every day. Clearly these entrepreneurs have identified windows of opportunity to challenge the current linear strategy of take-make-and-dispose and move towards a circular business strategy.

The PESTEL framework has been introduced here as a tool to analyse firm-external drivers for circularity. Here it will be applied in a 2018 context in order to help understand conditions that appear to be making more and more entrepreneurs believe that now is the right time to include a circular business model in their business.

P – Circular economy is high on the **political** agenda. Many individual countries have adopted policies and tax measures that incentivize circular products and business models. For example, some countries like Sweden have reduced value added taxes (VAT) on repair services and lowered labour taxes for repair works in order to stimulate reuse and repair. At a policy level there are also many discussions happening around the extension of product warranty periods as a measure to discourage products that are designed to break down fast, a feature which is often referred to as planned obsolescence.

E – A key **economic** driver for circular thinking is the current volatility in resource prices. The risk of sudden price fluctuations on the material markets is encouraging companies to take back products after their service life, so that they can be remanufactured, refurbished or recycled into new products. By doing this, a company can reduce its dependence on externally sourced products, and the materials they are made of. This can increase their resilience to market disturbances. Remanufacturing or refurbishment of used goods can also lower production costs, allowing a company to make their products more affordable, while keeping quality standards high. There are now numerous companies offering reconditioned industrial machinery, refurbished electronics and second-hand clothes.

S – **Social** drivers for circular business are linked to understanding and addressing customer needs. For example, people living in crowded city centres increasingly do not wish to own a car, particularly where there is well developed public transport system. As global populations continue to move to cities, cars are becoming even more expensive and difficult to park in many cities. Adding to this is a greater societal awareness of the negative environmental and social impacts of cars – particularly in cities. Existing norms and practices for car ownership and use are being questioned in a number of countries. But even concerned people would often like (or need!) access to a car from time to time; for example, to visit friends in the countryside. If given the opportunity, they would only want to pay for the days or kilometres they are using a car. Such social conditions and drivers help explain the success of car sharing services in urban settings. The focus on access rather than ownership also makes expensive goods accessible to a broader range of customers.

Another social aspect of circular business models is that they often entail service activities, such as maintenance, repair or remanufacturing; and quite a number of these also involve the development of online communities for sharing knowledge and experiences. Such factors strengthen the relationship between providers, customer and communities. They also generate local employment.

T – **Technology** is also a key enabler – and the rate of technological change at present is extremely high when viewed in a historical perspective. Right now, many technologies are being developed that will improve the resource efficiency of production processes. For example, 3D printing allows us to locally print fully customized products and spare parts when and where we need them. This can also remove the need to produce and store large amounts of goods and parts that may never be used.

Digitization is a pivotal technology for circular business. The new digital environment supports a broad range of platforms that connect suppliers of goods and services to potential customers. Some services, such as access to music, can now be fully dematerialized and delivered directly through "the cloud" as a service.

E – For a range of customer segments, **environmental** considerations can be an important driver when choosing a product or service. Circular business models aim to keep products and materials in use for longer. Reuse and recycling can reduce waste, replace the extraction of new primary materials, and reduce the need to produce new products – and thus reduce material and energy use. By providing information on the environmental performance of their products, companies can both differentiate themselves and make it easier for customers to make environmentally conscious choices.

L – There is a strong link between environmental considerations and **legal** drivers for circular business models. Stricter environmental standards, policies such as extended producer responsibility and higher recycling targets often provide incentives to shift to more circular business models. The extension of legal product warranty periods can also contribute to design improvements to make products more durable and easier to repair.

2.5 BARRIERS FOR BUSINESSES IN THE CIRCULAR ECONOMY

- Companies face a range of barriers when attempting to apply circular thinking to their organization.
- When factors are categorized correctly, the PESTEL framework is useful for the identification of societal, environmental, political, economic, and technological barriers to the establishment of circular business models.
- When using the PESTEL framework to identify barriers, internal as well as external issues are considered.

Having posed a range of drivers, it is reasonable that a question be posed: Why aren't all companies transitioning to circular business models if there are so many good reasons to do so? The simple answer is that companies may also face a range of barriers when trying to apply circular thinking to their organization.

These barriers are often dependent on firm size, location, and product or service. In this application of the PESTEL framework, internal issues are also considered. This is largely in recognition of the fact that many structures within the firm – as well as external to the firm – have been formed over time to suit traditional ways of business.

Examples of barriers that are internal, meaning they are driven from within the firm, can include things such as the way that a company judges the value of an investment. For example, there may not be established practices to fairly judge the value offerings. Constraints can be external, meaning that the difficulty in building a new system or practices comes from outside the firm. For example, in the form of regulatory or policy-related structures that disadvantage a new set of circular economy initiatives.

Again, we can compare the PESTEL framework to a range of commonly observed internal and external barriers to circular business models in order to demonstrate the application of the tool.

P – Policies, legislation, or regulations may influence a firm's ability to implement a circular business model. These types of political barriers are most often external and dependent on the location of the firm.

Existing policies that incentivize recycling, incineration, or disposal over other circular strategies, such as reuse and refurbishment, have real potential to negatively affect firms looking to base their value proposition on product life extension. Recent research from the Information and Communication Technology (ICT) field provides several tangible examples. A first is how existing extended producer responsibility policies can create competition between ICT reuse organizations and recyclers or manufacturers. A system has been built to support recycling in the face of waste problems but with new market activities focused on reuse, the two systems may well be set up as competitors.

Tax and labour regulations can also make it challenging for firms to make the business case for repairing, refurbishing or remanufacturing products, as these activities can be labour and cost intensive.

Policies are usually country specific, so firms wishing to expand internationally must comply with all relevant regulation and provide documentation, which can be a challenge, especially for smaller firms.

E – Greater upfront investment, higher costs, and return on investment uncertainty are three main types of economic barriers faced by firms attempting to transition to more circular business models.

Many circular business models require greater upfront investment, influencing a firm's cash flow and lengthening the time of return on investment. In addition to these expenses, circular business models may also require additional resources, leading to higher costs. Undertaking activities such as repair, refurbishment, and remanufacturing often means an increase in firm resources, including additional skilled employees. And in countries with high taxes on labor, firms may find it difficult for this to be economically feasible.

Like any business model innovation, circular business models do not guarantee a return on investment. Remanufacturing and resale of existing products may cannibalize new product sales. External economic factors like high costs associated with product take-back, or the low price of virgin materials, may also discourage firms from implementing circular business activities.

S – On the social side, success of circular business offerings is shaped by consumer acceptance. Customers' desires and pre-conceived notions largely influence their willingness to adopt circular offerings. Customers may for example purchase a new product over a remanufactured product if they believe the remanufactured product is inferior. For example, depending on the type of product, some consumers may have concerns about data security or hygiene when products are reused.

In many cases, consumers are open to circular offerings but are simply unaware of their existence. As a result, many organizations and governments have moved to create more awareness of such business opportunities.

T – Technical barriers can and do hinder a company's ability to adopt circular offerings. For example, it may not be technically possible to reuse, refurbish, or remanufacture existing products to meet current performance demands. There are also often concerns about the technical performance properties of materials that have been recovered and recycled.

E – Circular business models must contribute to the cycling of products and materials and replace primary production in order to contribute to environmental sustainability but there is still uncertainty in some situations. Even though it is expected that environmental benefits dominate studies have shown that this is not guaranteed, and there can be situations when circular offerings do not deliver environmental benefits. Such uncertainties have been observed to slow the adoption of circular business models.

L – Like many of the barriers previously discussed, legal issues surrounding adoption of circular business models differ from country to country, and can also differ according to firm location and type. In circular business models where product ownership is not transferred to the customer, firms must internalize legal risk – for example, taking on some liability for performance. As a consequence, some companies may hesitate to extend responsibility from beyond point of sale. The potential for legal action from other firms can also act as a barrier to circular business models. Intellectual property and other design rights may, for example, hinder or limit companies from reusing other firm's products.

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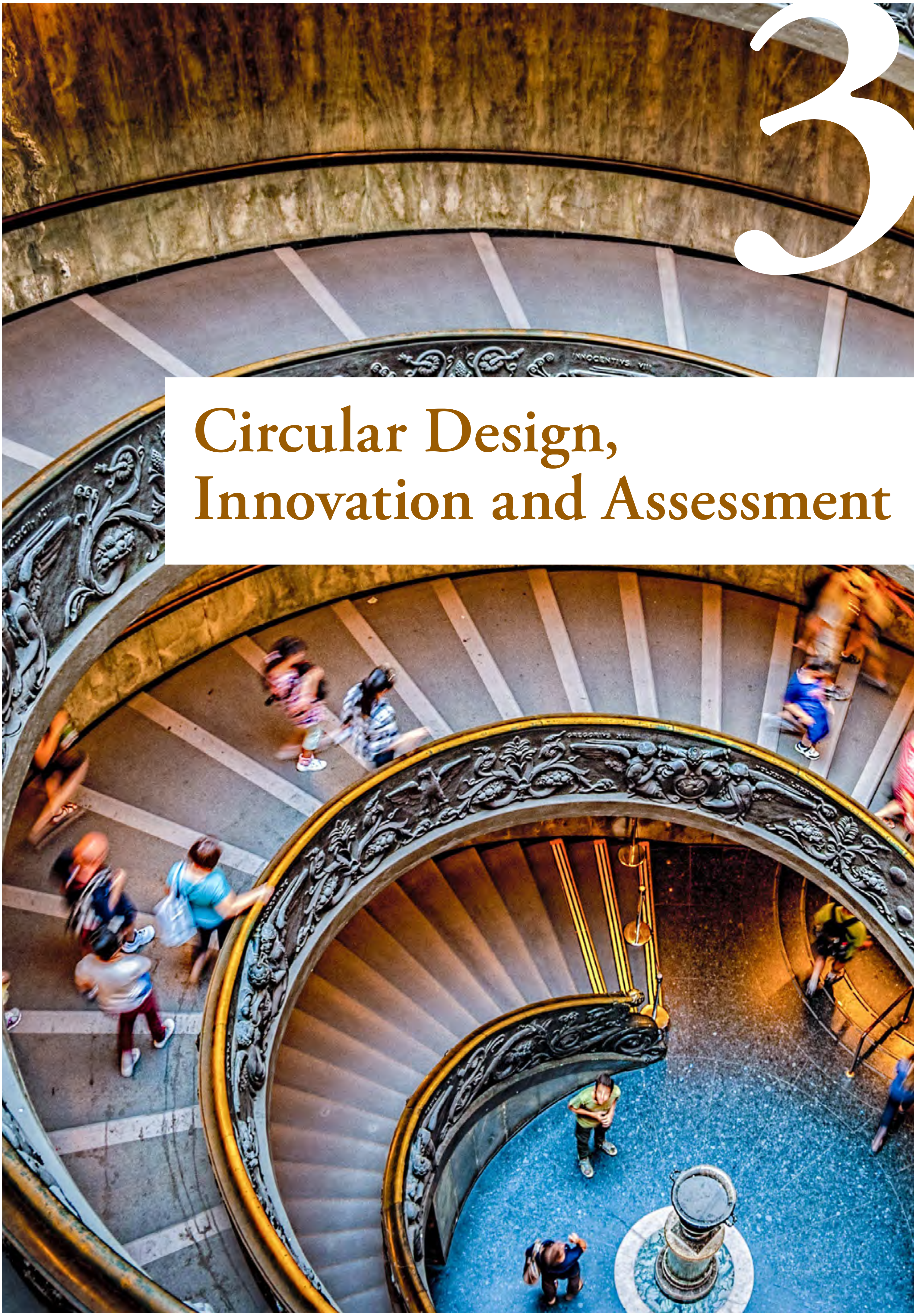
2.3 BUSINESS MODEL INNOVATION Jeroen Gillabel – Sustainable Materials Management, VITO, Belgium and Julia Nußholz – IIIEE, Lund University, Sweden.

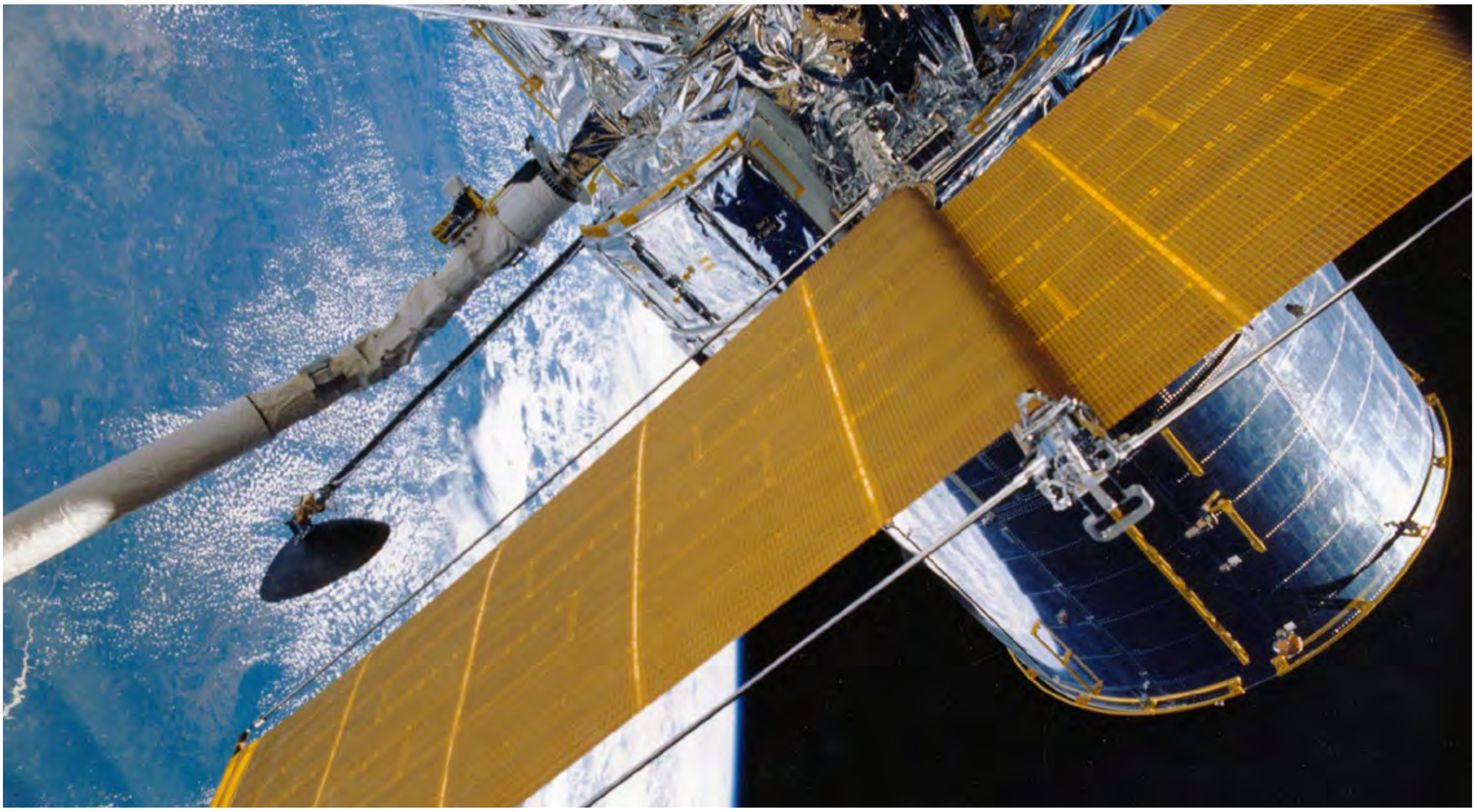
2.4 DRIVERS FOR ENTREPRENEURSHIP IN CIRCULAR ECONOMY Saskia Manshoven – Sustainable Materials Management, VITO, Belgium.

2.5 BARRIERS FOR BUSINESSES IN A CIRCULAR ECONOMY Katherine Whalen – IIIEE, Lund University, Sweden.

3

Circular Design, Innovation and Assessment





This chapter presents functional materials, ecodesign approaches, and methods to assess environmental impacts.

3.1 MATERIAL SCIENCE INNOVATIONS

- Humankind has always developed new materials, but the rates of new design and synthesis – and the number of applications for materials – have rapidly accelerated in recent times.
- Modern demands are stimulating new waves of innovation – and increased circularity also places new demands.
- Traditionally non-degradability and eco-toxicity was largely ignored in material design, but now this has increasing importance for society and it has great implications for circularity.

The types of materials that have been available to society have had enormous importance for the development of societies. This fact is well recognized in human history, with key epochs such as the bronze age and the iron age being named after the key material of the era.

In the past, humans essentially collected "natural" materials based on their suitability for specific functions, or simple criteria such as strength, hardness and weight in structural applications. However, the number and complexity of selection criteria rose dramatically when people discovered that the properties of natural materials can be altered significantly by changing their structure. Importantly, we learned how natural oxides like iron oxide (commonly known as rust), can be extracted into relatively pure metals, in this case iron.

Understanding that metals can be cast, cut and shaped into specific final products was a huge step forward in material engineering. We also learned that strength can be increased and other properties altered dramatically by mixing one element with others, and such mixtures became known as alloys. For instance, bronze is an alloy of copper and zinc, while steel is an alloy based on a mixture of iron and carbon. In essence, the advancement in making new structural and functional materials in this way was the beginning of an industrial revolution. It was a paradigm shift; instead of collecting natural materials and relying on their natural properties, we began designing and synthesising our own materials. The sophistication of modern engineering technologies now allows the fabrication of a large variety of man-made materials that can fulfil a larger number of selection criteria simultaneously. The material selection criteria of today have expanded from the functions of materials alone to also include the characteristics of fabrication technologies, their cost, and the availability of natural resources.

Today, we can fabricate materials that range from oxide ceramics and semiconductors, to metals and polymers, to composite and hybrid materials, and even to living biological tissues. The advances have great significance for parameters such as functionality and resource efficiency. For example, new strong lightweight material-based structures allow aircraft to fly further and faster while using less fuel, and even allow them to reach space. New semiconductors now provide clean solar electricity, and new composite materials form the vanes of the turbines used to generate power from the wind. These are just a few examples of how society can benefit from materials innovation.

However, a common side effect of fabricating artificial materials is significantly reduced ability to decompose or degrade naturally within a reasonable period of time. When we invest a lot of effort into materials taken from nature in order to tailor their properties, it also oftentimes embeds a need to apply additional effort to make the materials safe if they are to be returned to nature. This effect has been ignored by society for a very long time. However, as modern scales of production grow along with population and consumption, the pollution arising from discarded complex materials has grown to levels that pose an existential threat to ecological systems, human health, and society in general. As a result, it has now come into the technological spotlight.

Of course, there are alternatives to the discarding of materials. Instead, additional effort can be applied to make the materials suitable for their original functions again, thus closing material cycles and reducing overall consumption and pollution. This brings us to a more circular society where material technologists face new challenges. While the fundamental challenge is to continue innovating to provide new materials with improved functionality, an increasing demand is to deliver materials that are also recyclable. This defines a new paradigm for materials engineering where materials that both deliver a function desired by society and are recyclable are increasingly preferred. Beyond demands that materials be "environmentally friendly" or "recyclable", the capacity to be a chain link in the emerging circular economy is becoming crucial in material design and selection processes.

This situation is well illustrated by the use of materials in the transportation industry, particularly in car bodies. Steel was an unrivalled structural material until the late 1970s when demands to reduce vehicle weight became stronger. An underlying reason at that time was to decrease (expensive) fuel consumption. This effort was later reinforced by demands to reduce CO_2 emissions. These factors spurred the replacement of some steel body components with light-weight alternatives – and consequently many non-load-bearing panels have been replaced by plastics. More critical components were replaced gradually by aluminium, then by magnesium alloys, and now increasingly by carbon-fibre composites as well. These special materials deliver significant weight reductions. The use of aluminium alloys delivers approximately 65% in weight savings, while magnesium and carbon fibres save another 30%. But these light materials have their own drawbacks, beyond the increased cost of car production. These are related to the new material alloy and structure complexity required to achieve such performance.

Both aluminium and magnesium as pure metals are very soft, so performance targets are achieved by creating alloys of each. For example, without special additions, magnesium is notoriously difficult to fabricate – and it degrades too quickly during service. Aluminium alloys are extremely difficult – or simply too expensive – to recycle to their original grades. Therefore, they are *downcycled* to lesser quality and value products. New composites such as carbon fibres have similar challenges.

This brings us to the most interesting part of this example. The competition from light-weight materials has now stimulated accelerated development of better-performing steel grades. In this case, the weight savings are achieved by reducing component thicknesses. In addition, steel recyclability received an important stimulus as more valuable possibilities for closing material cycle loops with steel were recognized.

In turn, the revival of research in steel industries has further stimulated the development of light-weight materials. This has also created more demand for the analytical capacities of sophisticated tools like electron microscopy, synchrotron radiation and neutron scattering. These tools allow us to design new materials satisfying the dual challenges of improved functionality plus circularity. Materials engineering thus has an important role to play in creating pathways that bring the visions of the circular economy to reality.

3.2 ECODESIGN STRATEGIES

- Product design strategies can be formulated to support circularity.
- There is a range of dilemmas to deal with and tradeoffs to consider when pursuing circular design.
- It is important to match specific product design processes to relevant circular business models.

Why ecodesign?

Ecodesign is an umbrella term that incorporates several sub-strategies that companies can use to improve the environmental performance of their products. Ecodesign takes a product-centric view with focus on reduction or elimination of environmental and human health-related impacts and resource depletion. Smarter design can increase the eco-efficiency of many products, for example by reduction of materials and energy needed for production or the use-phase energy consumption.

There are numerous reasons why businesses engage with ecodesign. One is to comply with present or upcoming regulations. Another is to reduce costs, for example by being able to incorporate recycled materials. Businesses might also attract customers willing to pay a premium price for environmentally superior products.

Building on the idea of ecodesign, a product's entire life cycle could also be examined in the design phase when designing for circularity. To help ensure the reuse of products and their parts, products can be designed to align with the value propositions of circular business models, which typically include this.

Six design strategies

Researchers have identified six different circular design strategies that may be chosen. Which strategy, or combination of strategies, to choose is highly dependent upon the business model being applied.

Strategy 1: *Design for attachment and trust* – This design approach encourages users to bond with the product and can help extend product lifespan, as the user is less likely to discard a product for which they have a strong emotional attachment.

Strategy 2: *Design for durability* – Products are designed to be durable, reliable, and have reduced likelihood of failure. However, when defining a product's durability, designers need to also match the economic and stylistic life span of the product. For example, it does not make sense in terms of both cost and material resource consumption for one-time use packaging to be extremely durable.

Strategy 3: *Design for standardisation and compatibility* – This typically involves designing product parts to be interchangeable and compatible with multiple products. This enables repair and can extend the life of the product. When compatible replacement parts are readily available products may be more easily refurbished or reused. This can also help reduce overall consumption as one product can be used for different purposes. An example is where phones and tablets can be charged with the same charger instead of each item requiring a unique charger type.

Strategy 4: *Design for maintenance and repair* – This design strategy extends product lifetimes by increasing the ease of product maintenance. Repair for many products is often time-consuming and in countries with high labour costs, it can oftentimes be more expensive to repair a product than purchasing a new one. Reducing the number of components in a product, or simplifying how parts are joined – for example by avoiding adhesives – can help companies decrease repair time and cost. And, it can also enable users to more easily repair things themselves. The availability of repair manuals and spare parts is of course also a key enabling factor.

Strategy 5: *Design for adaptability and upgradability* – Here, allowance is made for future product modification. Functional updates can allow a product's function to change over time, such as a child's high chair that can be turned into a dining room chair as the child ages. Technical updates such as the update of a computer with a new operating system allow products to adapt to technological change. Sometimes however, the speed of technological development limits upgradability possibilities. Thus, the rate of technology change in a product segment is a key factor for designers to consider.

Strategy 6: *Design for ease of disassembly and reassembly* – The design of products and parts so they can be taken apart and reassembled not only enhances the reparability and reusability of products and components, but also makes the products easier to recycle.

Parallel strategies

In addition to these six strategies, two other strategies are often discussed in parallel with circular design and sustainable materials management. These are *design for recycling* and *design for dematerialisation.*

Design for recycling focuses on using specific design techniques that can increase the rate of material recoverability in the recycling process. A prime example within this that makes products easier to recycle is the avoidance of the use of mixed-materials.

Finally, product design can also pursue dematerialisation. Examples of approaches are the reduction of packaging or the application of high performance materials that allow less total material to be used, while maintaining or even improving functionality. In some cases of dematerialisation, the product may actually be replaced by a service – an approach that typically consumes significantly fewer resources. One example of this is the move toward streaming films instead of producing DVDs or Blu-ray disks.

3.3 NANOTECH DEVELOPMENTS

- Nanotechnology development is creating man-made structures at scales so small that advanced microscopes are required to see them.
- Nano-structures and nano-materials offer improved properties such as mechanical, electronic, optical, thermal, strength, and density.
- Nanotechnologies offer new opportunities across a wide range of disciplines, ranging from physics and electronics to chemistry, biology and medicine.

The word "nanos" means "dwarf" in Greek, and many people associate nanotechnology with something that is small. This is true! A common definition of nanotechnology is the generation and manipulation of materials and objects with at least one dimension in the size range of 1-100 nanometres. An atom has a diameter of around 0.1 nanometre so nanotechnology works with a limited number of atoms. This is different from atomic physics, where only the single atom is studied. Nanometre-sized objects and materials have existed for a long time (many examples can be found in nature), but to study them we first needed powerful microscopes and other techniques. When these were developed, people consciously started to study, design and manipulate materials on the nanoscale and the field of nanotechnology was born. In addition to small size, interesting material properties arise on the nanoscale, which is one of the key reasons behind the huge interest in this technology. Many of these properties relate to doing more with less, or are embedded in clean technologies, or both. Hence, some applications will play important roles in facilitating the circular economy.

How small is nano?

If a person of average height holds their hand somewhere around stomach level and asks if anyone can estimate the distance between her hand and the ground, it is very rare that people would answer 100 centimetres. By far, the most

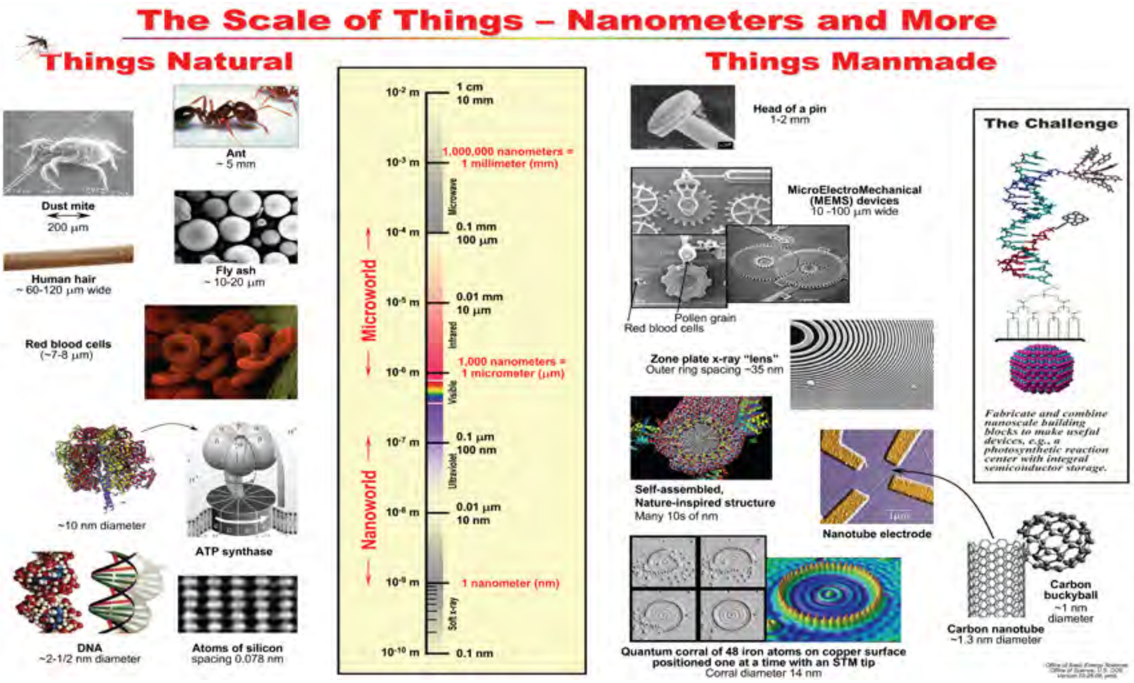


Figure 3.1. The relative size scale of macro-, micro-, and nanoscopic objects (reproduced with permission, US Department of Energy).[15]

common answer is likely to be "something like 1 metre". This is because most people are very used to measuring things in metres: people's height, how tall buildings are, how far away a neighbour's house is, and so on. It is even fair to claim that millimetre scale, which is a 1000 times smaller than a metre, or 10^{-3} metres, is not something most of us have to think about in our everyday life. Most of us know that the tip of a pen is about 1 millimetre, but it is not very often we measure everyday distances in millimetres.

Making the scale yet 1000 times smaller we reach the length of micrometre (also known as microns), which are a million times smaller than a metre or 10^{-6} metres. Structures measured in microns can still be seen with the naked eye; for example, mites can be a couple of 100 microns across, and human hairs are typically 50 microns wide, but often microscopes are required to study micron-sized structures. Other examples of micrometre sized structures are red blood cells, around 8 microns wide and 2 microns thick, and bacteria, which often have a size of between half a micron to 5 microns.

But to reach the scale of nanometres we have to make it yet another 1000 times smaller, which is a billion times smaller than a metre or 10^{-9} metres (Fig. 3.1). A common definition of nanotechnology is the generation and manipulation of materials and objects that consist of some components that are in the size range of 1-100 nanometres. Structures on the nano-scale can no longer be seen by the naked eye, so advanced microscopes are needed. Two examples of nanoscale objects from nature are viruses, which can be around 50-100 nanometres, and our DNA, which is 2 nanometres wide. Today there are also many man-made structures with nanometre-sized dimensions. A transistor, which is the core component in our computers, consists of structures with nanometre dimensions. Other examples include graphene, carbon nanotubes, nanowires and nanoparticles, all with one or more dimensions smaller than 100 nanometres. Although many of us are familiar with some nanometre-sized structures, not many of us can easily relate to and have an intuitive feeling about the nanometre length scale.

To help put nanometres in perspective; consider a piece of paper, which is 100 000 nanometres thick, and that fingernails grow about 1 nanometre per second.

Nanomaterials: properties and applications

In addition to their amazingly small size, materials with nanometre dimensions can have different properties compared to larger pieces of the same material. This is of course a major reason for the substantial interest in nanotechnology. A natural consequence of nanostructured materials is a much larger surface-to-volume ratio compared to larger objects, which simply means that the surface plays an important role. This is utilized in nanobiosensors, for example, where binding of molecules to the surface of the biosensor affects its electronic properties that generate a signal, which can then be detected.

An important part of nanomaterial development is to modify the surface of a material to give it specific properties, and such modifications are often inspired by discoveries from nature. An example is adhesive structures made without glue, similar to the feet of a gecko. Geckos have arrays of millions of microscopic hairs, or setae, on the bottoms of their feet. Each seta ends in an array of nanostructures, called spatulae, that function as a dry adhesive. A product that has the potential to provide adhesion without toxic chemicals often found in adhesives clearly has environmental implications.

It is not only the surface effects that are important for nanomaterials. Graphene, for example, is a nanomaterial that is made of pure carbon, and it exhibits completely different properties on a nanoscale than larger forms of carbon. Compared to these larger forms, graphene has different and

better mechanical, electronic, optical and thermal properties, and it's also stronger and lighter. Nanomaterials like graphene can be added to other materials to create composites with improved properties compared to the pure material. There are now many products that are made with graphene enhanced materials so that they are stronger, lighter and more flexible than traditional materials. Such nanomaterials offer opportunities to do more with less – or in other words they can contribute to narrowing material loops.

Nanomaterials can also be used in the design of new electronic and optoelectronic materials. Since nanomaterials have dimensions on the same order as the wavelength of an electron, they exhibit quantum effects. One example is the quantum dot, where the electrons can only move between certain discrete energy levels that are closely related to the size of the quantum dot. This means that quantum dots will emit light of specific frequencies if electricity or light is applied to them, a feature that is utilized in quantum dot televisions – these offer much clearer and brighter colours at significantly lower energy consumptions. Other types of nanostructures where quantum effects can be used are carbon nanotubes, graphene and nanowires. These make it possible to create new types of transistors, light emitting diodes, lasers and solar cells – these applications all have important roles to play in technologies required for resource efficient and clean development.

Nanotechnology is not only interesting to material science; in the field of medicine, for example, people hope to use nanotechnology to create faster diagnostic tools, directed delivery of pharmaceuticals and improved levels of contrast in medical imaging.

In addition to its very, very small size and its special properties, the third thing to remember about nanotechnology is that it is a truly multidisciplinary field, ranging from physics and electronics to chemistry, biology and medicine.

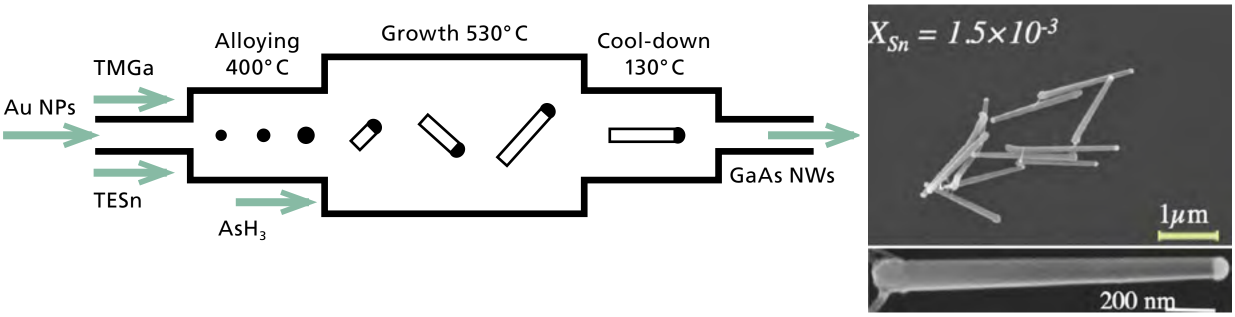
Nanotechnology and the circular economy

Nanotechnology is sometimes referred to as "crafting with atoms", which basically means building up materials atom by atom. It is a bottom-up approach that mimics natural processes, for example how a seed eventually grows into a large tree.

The conventional manufacturing approach, the top-down method, works in the opposition way. This starts with bulk material, from which the desired structure may be carved or etched out. The bottom-up approach can lead to a more efficient use of materials and less waste, and is therefore a promising way to help narrow material loops.

In the production of nanoparticles and nanowires, it is easier to use a top-down approach where we start with a large piece of material and grind it down to nanoparticles. But with this technique, a lot of waste material is created, it requires a high energy input, and there is very little control over the final size of the nanoparticles. In comparison, there is a bottom-up approach to creating nanoparticles with a physical method called aerosol generation is applied. This approach starts with a small piece of bulk material that is evaporated in a carrier gas; this can be done by a laser, in a furnace or with a spark or arc process. This vapor is then transported away from the hot zone by the carrier gas, and starts to form a nucleus, which continues to grow in size into nanoparticles. The size of the particles can be carefully tuned, and the carrier gases can be recycled and reused. The small amount of waste that is created is in the form of material condensation on surfaces in the system, and it can be easily collected and recycled. This makes aerosol generation a more efficient process than the top-down approach.

Semiconductor nanowires are rod-shaped, one-dimensional structures with a nanoscale diameter and they have the potential to radically improve future electronic devices. The top-down approach to create these rods is to start with a bulk piece of the semiconductor crystal and etch out the nanowires, which is not the most material efficient way and often results in nanowires of lower quality. The bottom-up approach is to grow the nanowires atom layer by atom layer in a process called *epitaxy*. Instead of a thick bulk semiconductor, the process starts with a thin semiconductor substrate where either seed particles or a mask is deposited. After that, the growth material is supplied and the nanowires are formed under the seed particle or in the hole in the mask, atom layer by atom layer. Another production technique that can be even more



TERM IN SCHEMATIC	NAME / DESCRIPTOR	CHEMICAL FORMULA
AuNPs	Gold Nanoparticles	Au
TMGa	Trimethylgallium	$Ga(CH_3)_3$
TESn	Tetraethyltin	$(CH_3CH_2)_4Sn$
AsH_3	Arsine	AsH_3
GaAs NWs	Gallium Arsenide Nanowires	GaS
X_{Sn}	Ratio TESn/TMGa	

Figure 3.2. Simplified schematic of a continuous gas phase production (Aerotaxy) system to produce Gallium Arsenide Nanowires (modified from [16])

material efficient is an aerosol process called *aerotaxy*. Here the nanowires are grown in a gas stream, with only a seed particle to initiate the growth. The two main advantages of aerotaxy are that the nanowires are grown in a continuous process, and that there is no substrate, making for extremely material efficient production (Fig. 3.2).

In addition to narrowing material loops, nanotechnology can also help slow material loops, by prolonging the lifetime of products – for example using coatings enhanced with nanoparticles. There are nano-based coatings that can make a structure withstand wear better, or make it more resistant to corrosion.

There are also coatings that can make surfaces super hydrophobic. This property creates surfaces that resist water, where tiny micro or nano structures prevent water droplets from wetting the surface. Such technology can be used to create self-cleaning materials, and indeed they actually function in a way similar to a lotus leaf. When it rains, the water droplets will collect any dirt stuck on the surface and run off, instead of fastening on the surface. A surface that cleans itself has the potential to save important resources over its lifetime.

Nanomaterials can also be used to extend material lifetime. One example is self-healing materials, that are designed to heal themselves from thermal or mechanical damage, with full or partial recovery of their mechanical strength. Common types of self-healing materials are based on polymers that are designed to self-heal their broken bonds. Among different promising materials, researchers have developed both self-healing rubber and self-healing glass.

The research on nanotechnology-based materials has grown significantly in recent years. And there is a wide variety of different applications where nanomaterials can have a huge impact; this area of material science is considered likely to offer much to the circular economy.

3.4 ASSESSING THE ENVIRONMENTAL SUSTAINABILITY OF CIRCULAR SYSTEMS: TOOLS AND METHODS

- Circular systems do not lead to environmental improvements by default.
- Environmental life cycle assessment can be used to assess whether a new product or process can contribute to a more sustainable society.
- LCA practitioners face several challenges when it comes to assessing circular systems, with recycling as a prime example.

Introduction to life cycle analysis

Just because a product is circular does not necessarily mean that it is sustainable, and innovations with new materials may improve some environmental characteristics, but not others. Tools need to be used to assess whether or not a new product or process can contribute to a more sustainable society.

Let us examine a situation where a company wishes to assess the environmental impact of its newly developed circular product system. They need to analyse the product in a structured way, so that they can better understand its environmental impacts, and evaluate if it is actually more environmentally sustainable than the current alternative.

A first step is to examine the process level to see if this process consumes more or fewer resources or emits more or fewer emissions than a non-circular alternative (Fig. 3.3).

When doing so, efforts are made to quantify all the inputs such as electricity, water and chemicals, and all the outputs such as effluents and emissions arising from processes. To assess the impact of a process on the environment, one can apply a risk assessment method. This assesses the potential for impact of emissions in the environment surrounding the process plant. To assess the impact of a process on resource use, it is possible to perform an efficiency analysis, such as an

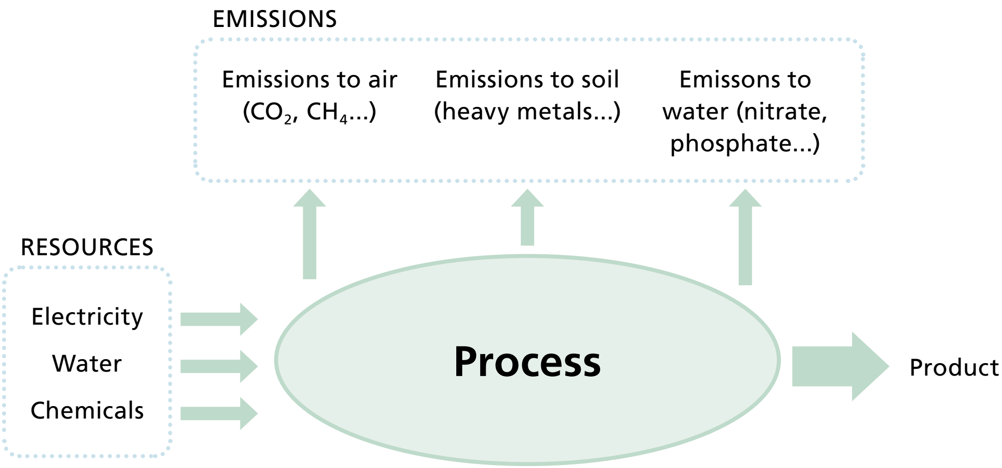


Figure 3.3. Resource inputs and emissions in a process.

energy analysis, which will provide insights on the resource efficiency of a process.

Such work provides a basis for analysis, but the possibility always exists that the energy or material inputs needed in order to make the product may have a higher impact on the environment than inputs used in the non-circular alternative. These cannot be seen when focusing at the process level. Therefore, analysts must look at another level called the life cycle level. This level is analysed by conducting a *life cycle assessment (LCA)*. A life cycle assessment accounts for all the resources consumed and the substances emitted during the life cycle of the product, rather than only considering the process of producing the circular product. Resources can be energy carriers like electricity and fuels, or materials and chemicals. Emissions can be greenhouse gases emitted to air, and effluents can be phosphate contributing to water pollution.

The assessment starts from natural resource extraction and ends at the final stage of a product's life. The end of life stage can include options such as reuse, recycling or disposal (Fig. 3.4).

Life cycle assessment is the most commonly used method to assess the environmental impact of products and services, and it is framed by two standards from the International Organization for Standardization, ISO standards 14040 and 14044. These standards provide a generic framework for LCA that ensures that every practitioner follows the same approach, assuring the quality and the comparability of the studies.

The confidence of the scientific community, industry and policy makers in LCA is growing and the insights that it provides to support decision-making is widely acknowledged. Because of this, LCA is now applied in many ways: for product comparison; product design and improvement; for ecolabelling, and in the public sector to define policies. It is important to note that LCA has been mostly developed to assess the environmental dimension of sustainability. However, increasingly, attempts are being made to account for economic and social dimensions too.

Environmental LCA

Life cycle assessment is a process framed by ISO standards, which define the four steps of an LCA (Fig. 3.5).

The first step in an LCA is to define the goal and scope of the assessment. The goal includes the intended application, the reason for the study and its intended audience. The scope

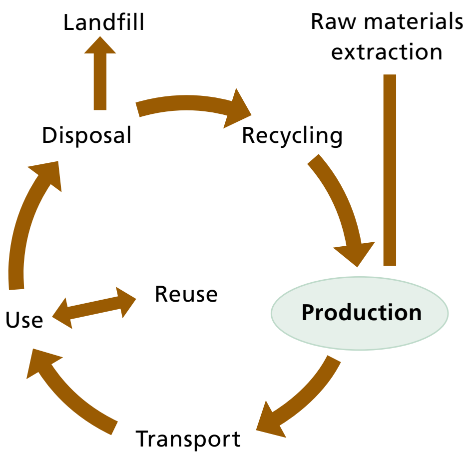


Figure 3.4. An indicative life cycle.

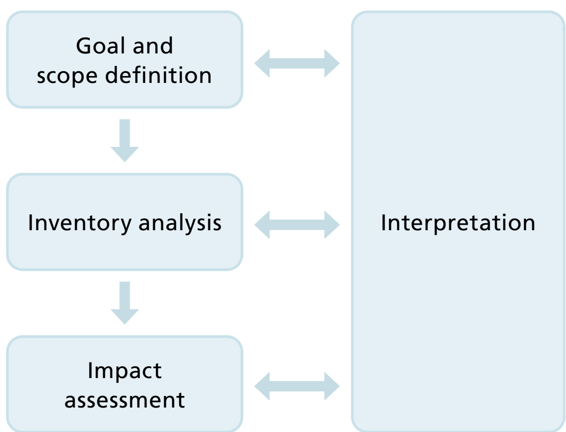
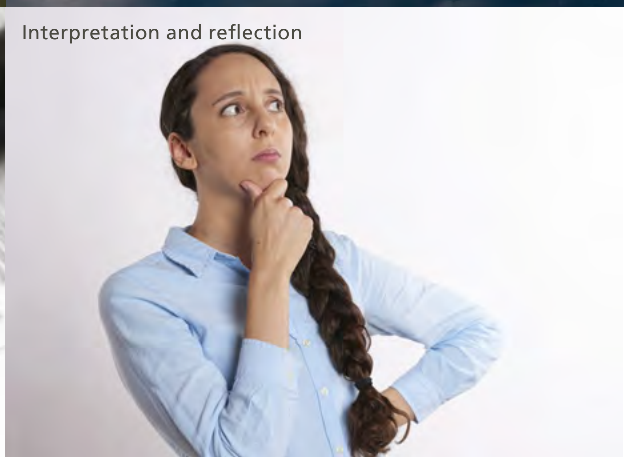


Figure 3.5. Steps in an LCA analysis.[17] [18]



includes the selection of the product for assessment (be it a physical product, or a service), its *functional unit*, and the *system boundaries* of the product's life cycle.

A functional unit is a certain measure of the amount and the quality of service delivered by the studied product. In other words, the functional unit is a measure of product's function. The choice of a relevant functional unit allows consideration of different characteristics including the durability of a product. This is important when establishing the amount of product(s) needed to deliver a chosen amount of service. Note that delivering a service is the actual function of a product! Choosing a functional unit is not always straightforward and can have a large impact on study results. For example, when comparing two light sources (lamps), their light output as well as their lifetimes might differ. So rather than comparing one lamp to one lamp, the functional unit might be the light output (lumens) over a certain amount of time. Similarly, comparing one kitchen blender with another may not be the most suitable way of comparing their performance. Instead, considering hours of use as the functional unit may be more appropriate. So it is very important to remember that the functional unit should reflect the real value and functionality of the product.

The system boundaries of the product's life cycle define the processes of the life cycle that are to be included in the analysis, and for which data will be collected. In theory, the complete life cycle of the product could be included in the system boundaries, from cradle to grave. But often only a part of the chain is covered, mostly from resource extraction until the factory gate. In this case, the use and disposal of the product are excluded. When making a comparison between two products, for example an innovative circular product versus the current alternative, it is important to make sure that the same steps in the life cycle are included for both products.

The second step of an LCA is an inventory analysis. This consists of inventorying all inputs that are used along the product's life cycle (such as raw materials and energy), and the resulting outputs (such as by-products and waste). Data can be collected based on measurements, information received from companies, literature, modelling, and more. As this data collection can be quite labor and time-intensive, databases have been created to provide the life cycle inventory data of certain products. For example, if a product requires 1 kilowatt-hour (kWh) of electricity for its production, databases can provide the complete life cycle inventory for electricity from resource extraction via generation activities through to delivery of the electricity via power grids. Data quality may vary rather significantly so it is important to always validate the data chosen by comparing it with literature, or similar studies.

The third step of an LCA is the life cycle impact assessment. It translates the inventory into an estimate of the impact on the environment by multiplying the amounts of emissions and resources consumed by a characterisation factor. However, the various flows that have been inventoried do not have

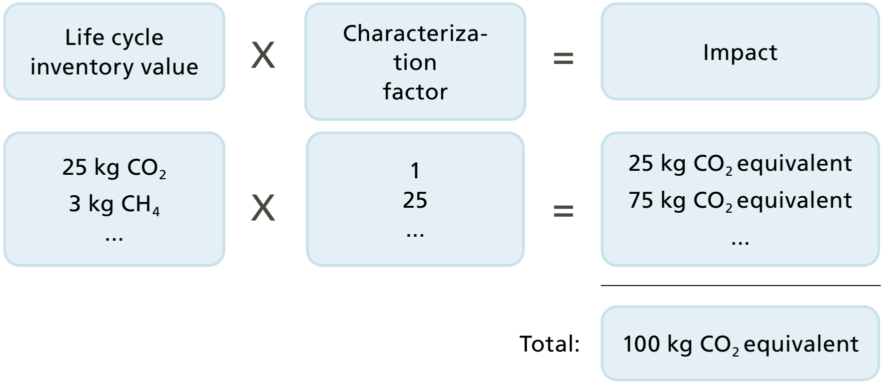


Figure 3.6. Inventory values, characterization factors and impacts.

the same effect on the environment. For example, carbon dioxide and methane emitted to air contribute to climate change while phosphate emitted to water contributes to eutrophication of water bodies. These environmental concerns are called environmental impact categories, and for each impact category, characterisation factors are defined for each contributing flow.

The example of the impact category *climate change* can be used to demonstrate differences within an impact category. A wide range of substances like carbon dioxide, methane and nitrous oxides contribute to climate change, but they do not all have the same potency in their contribution to the warming effect upon the climate. Their potency is usually compared to the one of carbon dioxide, which is defined as a reference substance. For example, the potency of methane to contribute to climate change is known to be some 25 times higher than carbon dioxide (CO_2), so its characterisation factor is 25 kg CO_2 *equivalent* (CO_2-eq) per kg methane. The amounts of greenhouse gases emitted by the product system are multiplied by their associated characterisation factors to obtain the final impact of the product (Fig. 3.6).

Such calculations are performed for all impact categories. In practice, environmental impact assessment is usually done using a software tool which assigns the different flows of the system to the impact categories that must be studied for the product.

The last step of an LCA is the interpretation of the results. During this step, analysis is performed to find areas where improvements may be possible, or to support recommendations for the most environmentally desirable product in the case of a comparison. This is also where an analyst can suggest design modifications to improve the environmental performance of a product. Here it is also necessary to critically interpret the results of the study by taking into account the limitations of LCA, and reflecting on the assumptions made when performing the analysis.

It is important to keep in mind that in each of these four steps, important and sometimes even subjective choices have to be made. All of these influence the final outcome in some way and need to be clearly communicated.

Limitations and assumptions of LCA, software tools, and life cycle thinking (streamlined LCA)

Limitations of LCA

Though LCA is the most recognized tool to assess the environmental sustainability of products and services, its limitations should be recognized while interpreting the results of an assessment.

One important aspect is the subjectivity of the choices that need to be made at several steps of an LCA, including the definition of the functional unit and the approach selected to deal with multifunctional issues. Some products may also have multiple functions or the same materials may be used for several products. This then requires making choices about *partitioning* of the system to allocate processes (e.g. by mass, economic value, etc.) or *expanding* the system boundaries. Moreover, practitioners often lack data, or must use more general data that is less representative of their actual subject.

The conclusions of an LCA also depend on the impact categories that are analysed. Take the example of a comparison of the environmental sustainability of product A and product B. The carbon footprint of product A might be higher than product B, while its eutrophication potential might be lower. If only one impact category is analysed, the conclusions and thus the measures resulting from the analyses (e.g., change of consumer behaviour) might be different as well. Practitioners must keep such issues in mind and understand that there is no single complete impact assessment method or combination of indicators.

All of these issues need to be dealt with and kept in mind when conducting an LCA. It is important for all to recognize that while the results of such studies have real value and support decision-making, the respective outcomes must be regarded as estimates. Thus, despite the uncertainties, these assessments provide valuable information for decision-making and product stewardship. They allow environmental issues to be evaluated strategically, throughout the entire product life cycle. The challenge is to take advantage of these valuable features of life cycle assessments while bearing the uncertainties in mind.

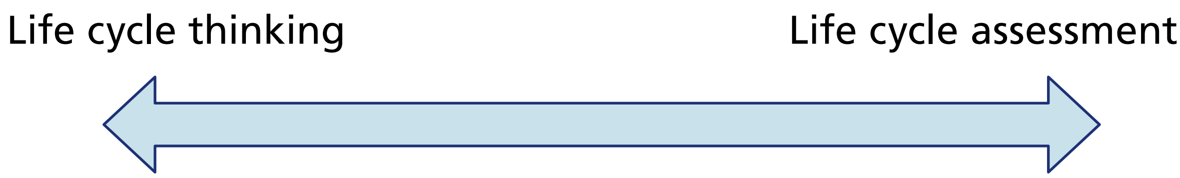


Figure 3.7. A spectrum of life cycle analysis.

Software for LCA

Since conducting an LCA is a time-consuming task, software programs have been developed to help in this matter. Simapro (simapro.com) and OpenLCA (www.openlca.org), which are freeware, are two examples. In these programs, databases and different impact assessment methods can be developed. Through the software interface, life cycles, optionally linked to the database, can be constructed and their impacts assessed.

Streamlined life cycle assessment

The use of life cycle studies falls along a spectrum that runs from a level where practitioners pursue a complete spatial and temporal assessment of all the inputs and outputs over to the entire life cycle (which may never be accomplished in practice due to effort and expense) to efforts that constitute only an informal consideration of the environmental stresses that occur over a product or process life cycle. This spectrum is illustrated in Figure 3.7.

The further a study positions itself to the right side of the spectrum, the more expensive and time-consuming the study will be. An analysis that includes an inventory of all inputs and outputs and all life cycle stages (including an assessment of which ones are significant enough to be included in the inventory), an impact assessment, and an improvement analysis can be considered a life cycle assessment. A study that falls to the left in the spectrum of complexity will be said to involve the use of life cycle concepts.

Studies in between the two extremes are referred to as *streamlined life cycle assessments*. Streamlined life cycle assessments are conducted in order to provide insights into the most important life cycle stages, or type of inputs and outputs, in a product life cycle. These stages, inputs, or outputs may then be targeted for more detailed study. Also, they can be used to identify where the most significant environmental issues occur. The intensive data collection process for a complete life cycle assessment study is one of the main reasons why streamlined life cycle assessments or studies with only life cycle concepts are applied.

LCA challenges: recycling and multi-functionality

LCA practitioners face several challenges when it comes to assessing circular systems. A high-profile example is the case of recycling, which is a difficult issue to deal with in a LCA but is also a key process in many circular systems. Recycling requires the re-processing of a material so it can fulfil another service to society. A material may be recycled to fulfil the same function as in its previous life, which is called *closed-loop recycling*. It might also be recycled to fulfil another function – often at a lower quality. This is known as *open-loop recycling*. One common approach in LCA is to assume that the recycled product replaces a product produced from virgin raw materials. An example can be taken from when a phone is designed so that the parts and components can later be recycled into other products. In this case, the benefit from recycling can be considered by assuming that the system will avoid the production of these other products from raw materials. An example is given below, from a fictive case of the environmental impact assessment of a new phone (Fig. 3.8.)

It can be seen that the impact of the phone's production (extraction of raw materials, transport, and manufacturing) is 30 kg CO_2-eq per phone, the impact of the use phase is 2 kg CO_2-eq per functional unit and the recycling process is 3 kg CO_2-eq per functional unit (in total, 35 kg CO_2-eq per functional unit). Recycling the phone at its end of life enables the recovery of its reusable materials, replacing the use of raw materials like copper, iron, or zinc in future product production. These raw materials have an impact of 10 kg CO_2-eq per functional unit. Hence, the recycling withdraws this impact from the phone production, use and recycling. The total net impact of the functional unit is therefore reduced to 25 kg CO_2-eq per functional unit with recycling.

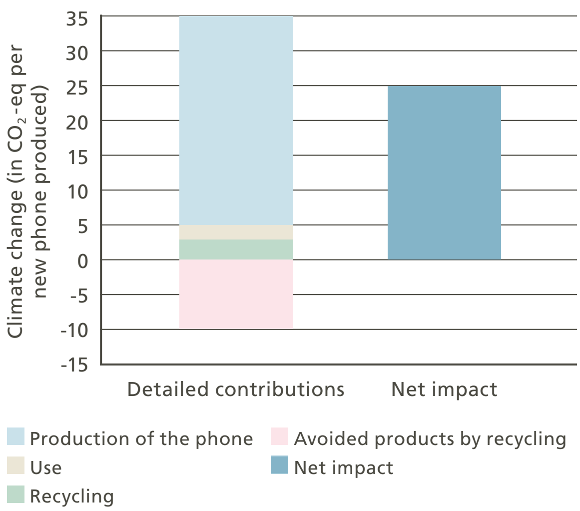


Figure 3.8. Contributions to impact and net impact. Fictive Example.

It should also be noted that there is a subjective aspect in the choice of the avoided products – it's best to carefully identify and make this clear to readers of the analysis.

Multi-functionality in LCA

Another important difficulty arises if a system (a collection of unit processes) of the life cycle has more than one function or, an output of two or more (co)products. For example, the unit process of recycling of a phone produces several products which can be used in different applications. A unit process is a process life cycle system for which there are quantified inputs and outputs. For example, manufacturing of a particular material or electricity use can be a unit process. Recycling of the product can also be a unit process. It is important to decide how the flows and impacts of the process (recycling in the case of the phones) should be attributed to these co-products.

Different options exist to deal with this matter, although there is no ideal solution. The three main options are:

- *Subdivision* of the considered processes into smaller unit processes, of which none have more than one function or, one product. This is often not possible for basic unit processes.
- *Partitioning* (also termed *allocation*) of the process flows and impact between the different functions or products based on a certain partitioning coefficient, for example mass or economic value. This latter coefficient is often linked to a certain property/attribute of the co-products. For example, partitioning can occur based on mass content. In the fictive example where the recycling of the phone results in 3 g of copper, 40 g of plastic and 2 g of zinc, then the recycling process is attributed with a factor 3/45 to copper, 40/45 to plastic and 2/45 to zinc. Priority is given to partitioning coefficients based on physical attributes (e.g. mass, energy content). However economic value is also often used.
- *Substitution* (also called *avoided burden approach*) may be performed. The approach is the same as when dealing with the recycling issue described above. It is often applied in LCA, as it is a way to avoid the partitioning coefficient factor option that is often subjective.

3.5 ASSESSING THE RESOURCE EFFICIENCY OF CIRCULAR SYSTEMS

- Achieving large resource efficiency improvements compared to the current linear economy is a fundamental motivation for pursuing circular systems.
- There are several methods in common use for calculating resource efficiency.
- Well understood and agreed ways to evaluate the resource efficiency of circular systems are important for effective system design and management, and for social acceptance of, and trust in, circular economy initiatives.

Many parts of the world face a huge challenge related to the supply and efficient use of resources. The global population is growing and markets are becoming more globalized, competitive and fluctuating. This makes it difficult for industry to predict market prices and the availability of valuable resources. This is the case for critical raw materials – materials that are important for the economy and have a high risk of supply disruption.

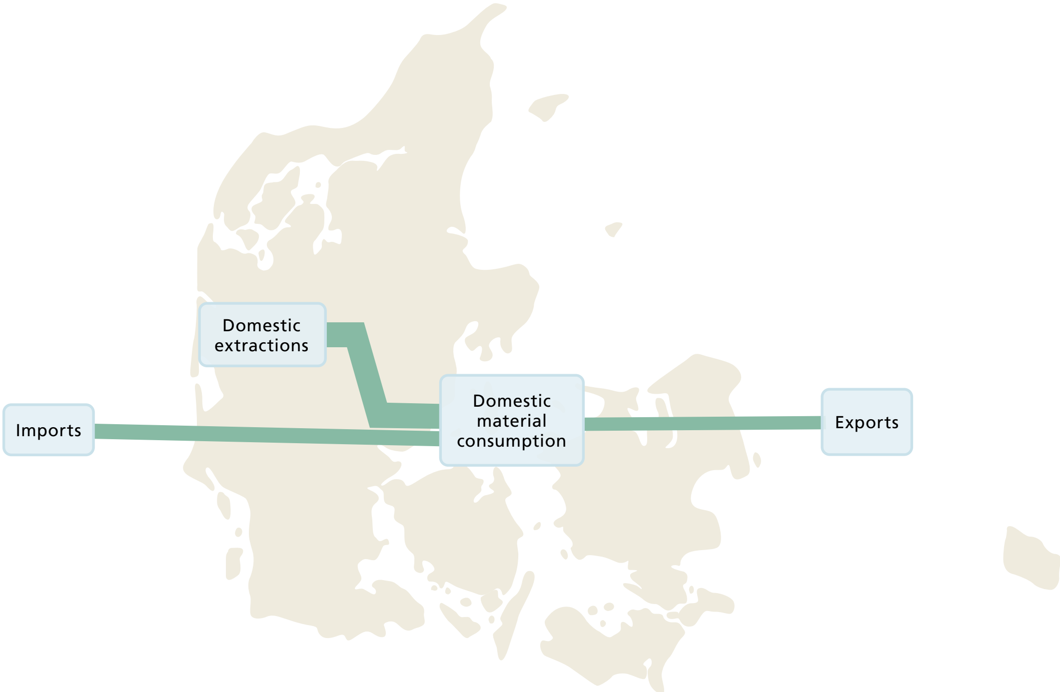


Figure 3.9. Domestic supply, consumption and export of resources in Denmark.[19]

This challenge has become a priority for several countries and regions around the world and many programs have been launched to increase the self-sufficiency of nations. Examples are the Resource Efficiency Program of the United Nations Environment Programme (UNEP), Finland's National Resources Strategy and the Critical Materials Strategy in the United States. In Europe, the European Commission launched the resource-efficient Europe Flagship Initiative in 2011 and a Roadmap to an Efficient Europe. It presents several milestones to be achieved by 2020 on the use of resources such as minerals, metals, water, marine resources, land and soils. The EU strategy places circular systems at the front line of solutions to increase European self-sufficiency.

To encourage the development of such systems, the EU is funding research and innovation programs such as the Horizon 2020 (ec.europa.eu/programmes/horizon2020/en) program. Horizon 2020's call for projects explicitly states that the new technologies or products developed should contribute to increasing the resource efficiency of Europe. For example, it states that project developers are expected to increase "the resource and energy efficiency for the process industries by at least 20%", or to contribute to "gains in productivity, in material and energy efficiency".

Using a Sankey diagram to analyze material flows

The Domestic Material Consumption can be estimated for each country based on a Material Flow Analysis, which consists of a thorough analysis of the fate of materials within a defined geographic area. The results of a Material Flow Analysis can be represented in a Sankey diagram. Figure 3.9 is an example of the Domestic Material Consumption of Denmark portrayed via a Sankey diagram, where the flows of materials going in and out of the country are estimated. The materials that enter the Danish economy are those that are imported into as well as extracted within Denmark. They are represented on the left-hand side of the consumption box, with the width of the arrows proportional to the flow quantity.

The flows that leave the country are those which are exported, as represented by the flow to the right of the domestic consumption box. Hence, the DMC of Denmark is the amount of materials imported and extracted in Denmark, minus the amount of materials exported.

Resource efficiency indicators at the macro level: national and EU

While increasing the resource efficiency of the economy as a whole is one of the core aims of circular systems, ensuring such a result requires measurements. Apart from the fact that measurement helps the management of such efforts, it is also a vital input to avoid greenwashing, a practice that can create doubt and distrust in consumers. It also helps prevent unexpected side-effects that could negatively influence other economic sectors regarding access to specific resources. To measure progress at the European level, a system of indicators called the Resource Efficiency Scoreboard was developed in 2014. The Scoreboard is composed of a lead indicator, dashboard indicators and thematic indicators.

Lead Indicator: The lead indicator is called resource productivity and is calculated as the ratio of the Gross Domestic Product (GDP) over the Domestic Material Consumption (DMC). The DMC of each country and therefore of the EU is derived from the analysis of material flow accounts. It includes compilations of the overall material inputs into a national economy, the changes of material stock within the economy and the material outputs to other economies or to the environment.

Figure 3.10 shows the evolution of the DMC and the GDP/DMC indicators of the EU during the last 10 years. The resource productivity of the EU increased from 1.57 €/kg to 2.07 €/kg of materials. This evolution shows a start of the decoupling of resource use and economic output in Europe. It might also be a consequence of the development of circular systems in Europe.

It is important to maintain a critical stance when interpreting these results. Even if it provides valuable insights on the resource efficiency of the EU, this approach has several limitations. First, it does not consider resources such as water and land. Moreover, it does not follow a life cycle perspective; i.e., it accounts for input and output materials in terms of mass without accounting for the amount of resources necessary to produce them outside of the EU. To tackle this issue, tests are being made to replace DMC with the Raw Material Consumption (RMC), which will allow accounting for upstream resource consumption.

In addition, this resource efficiency indicator can only be used at the national level. When a research department or a company wants to develop an innovative circular product, resource efficiency indicators other than those defined at the macro-level for Europe are necessary. Unfortunately, there can be confusion about the term "resource efficiency", and companies can choose an interpretation and evaluation method which favours their new product – a situation that can lead to confusion.

It's therefore important to understand the different concepts behind the term as well as the ability to choose a resource efficiency evaluation method in the most scientific and objective way possible.

Dashboard indicators: These indicators have been defined to complement the information provided by the lead indicator. They focus on four areas of resource management: materials, land, water and carbon.

- Materials – the indicator to follow this area of resource management is the DMC, as used in the calculation of the resource productivity

- Land – this area is followed by two indicators: the productivity of artificial land, and the built-up areas. The productivity of artificial land is calculated as the ratio of the Purchasing Power Standard (PSS; see Eurostat glossary for more information) over the area of artificial land in square kilometres (km^2). The European Commission is developing a new indicator to better account for the efficiency of artificial land management, especially by also accounting possible deterioration of the environment. The built-up area is defined as the total built-up area in a country in km^2 and the total built-up area as a share of the total surface area of land in the country. The evolution of these two indicators for the EU as a whole over the past years is not available due to a lack of data for some countries. However, national data is available on the Eurostat website. In 2012, urbanisation resulted in the loss of 52 000 km^2 of natural or semi-natural land, half of which is due to the demand for housing, services and recreation. The productivity of artificial land varies a lot between countries, depending on the type of economy of the countries (e.g., service-based economy tends to consume fewer resources and thus land to generate GDP). Luxembourg, the Netherlands, UK and Germany show the highest productivity of artificial land among the member states.

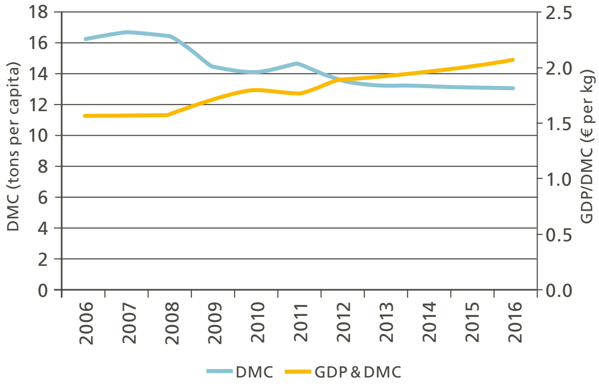


Figure 3.10. Evolution of the Domestic Material Consumption and the resource productivity of the EU.[19]

- Water – the follow up of water usage in the EU is done by following two indicators: the *water exploitation index* (WEI) and *water productivity*. The WEI is the ratio between the mean annual total amount of freshwater abstraction (public drinking, industrial and agricultural uses) and the long-term average amount of available freshwater resources. Therefore, high WEI indicates water stress. WEI varies a lot between member states. The countries with the highest WEI are Cyprus and Malta (severe water scarcity, with a WEI over 50%) followed by Spain, Belgium and Italy (water scarcity, with a WEI between 24% and 34%). Other countries show no stress by water scarcity. Water scarcity is highly related to the climatic conditions of the countries, but not only. Belgium has one of the highest WEI but this cannot be explained by climatic conditions. One explanation is its high dependence on nuclear energy which requires large amounts of water for cooling. Water productivity measures the amount of economic output produced (€ or PPS) per unit of water abstracted (cubic metre or m^3). It indicates how efficient member states are in using the water resource. Luxembourg, UK, Denmark and Malta are the countries with the highest water productivity (between 788 €/m^3 and 129 €/m^3). The analysis of both WEI and water productivity allows identifying the countries that are the most efficient in managing water resource. For example, Cyprus, Malta and Spain are among the countries with the highest WEI. However, while the water productivity of Spain is low, the one for Malta and Cyprus are average to high, showing a more efficient management of water. This can be due to different economic contexts, (e.g., dependence on intensive agriculture, seasonality of water use due to tourism, etc.)

- Carbon – indicators on carbon are sub-divided into four indicators. The first indicator is greenhouse gas (GHG) emissions per capita in tons CO_2-eq. As previously discussed, this indicator considers resources in the broad sense, thus considering atmosphere as a sink to emissions and as a resource to be preserved. The follow up of this indicator shows a decrease in emissions over the past 10 years (-15%). Moreover, the level of emissions varies between countries and seems to be linked to the type of economy. Another indicator is *energy productivity*. It is calculated as GDP over the gross inland consumption of energy. Between 2000 and 2013, there was a 20% increase in energy productivity, which varies from a 4% increase in Austria to a 90% increase in Lithuania. The next indicator, *energy dependence*, is the net imports divided by the sum of gross inland energy consumption plus maritime bunkers (he quantities of fuel oil used by ships operating under the flag of a European Union country). It provides information on the resilience of members states towards external energy supply. From 2001 to 2013, the dependence of the EU towards imported energy increased from 47.4% to 53.2%. This is a major challenge for Europe as it means that the EU is still subject to worldwide energy market fluctuation and price volatility. The last indicator on carbon is the share of renewable energy in gross final energy consumption. Figure 3.11 shows that the share of renewable energy of the EU increased 7% in 10 years and is heading towards the target set by the European Commission for 2020, i.e., 20% of renewable energy.

The lead indicator and the dashboard indicators are complemented by 22 *thematic indicators* sub-divided into sub-themes such as "turning waste into a resources" (e.g., recycling rate of e-waste and generation of waste), "supporting research and innovation", "biodiversity" etc. More information on the evolution of these indicators over time can be found on the EU Resource Efficiency Scoreboard report (available via the EU's Eurostat portal: ec.europa.eu/eurostat), which is updated yearly.

The European Resource Efficiency Scoreboard is a tool to measure the progress of the EU as a whole as well as of each member state regarding their resource efficiency. The lead indicator provides an overall picture, which is complemented and clarified by examination of the more detailed dashboard indicators. Overall, the EU is making slow but steady progress. This is considered to be due to the efforts put by the European Commission to encourage research and innovation as well as orientate national policies of the member states through the publications of European directives. However, the contribution that circular systems can still play to increase the resource efficiency of the EU is tremendous and the further development of new business models developing resource-efficient circular systems is still required.

What are resources and what is resource efficiency?

The definition of resource efficiency starts first with the definition of resources, specifically environmental resources in this context. There are two ways of looking at environmental resources: in the broad sense and in the strict sense. The broad sense considers resources as inputs into a system but also the environment itself as a sink; this perspective accounts

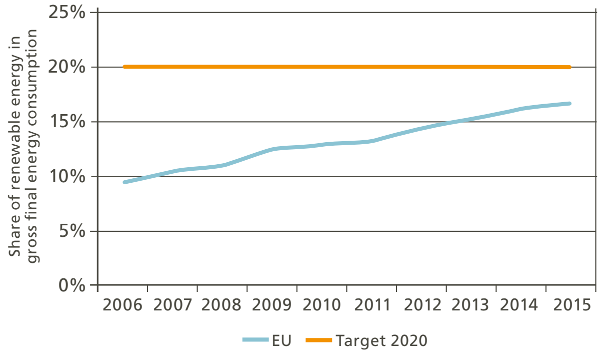


Figure 3.11. Evolution of the share of renewable energy in gross final energy consumption compared to the 2020 target.[19]

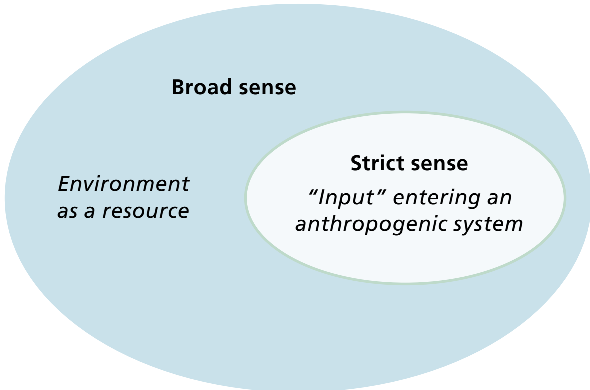


Figure 3.12. Defining resources in both the broad sense and strict sense.[20]

for the environment's role in absorbing emissions. Resources defined in the strict sense only consider inputs specifically entering an anthropogenic system, for example materials consumed by a city, or water consumed at an industrial plant. The broad sense is primarily used in a policy context and the strict sense is mainly applied in industry and engineering, as resource consumption is the starting point for all economic production and consumption activities (Fig. 3.12).

For developers of new circular products, following the strict definition of resources makes more sense. Of course, even if it does not fall into the term of resource efficiency evaluation, it's important to evaluate the impact of emissions on the environment. Coupling resource efficiency evaluation with emission-based evaluation, such as risk assessment and life cycle assessment, thus adds value.

Even when following the strict sense of resources, several approaches that consider various types of resources are still possible. For example, some approaches limit the definition of resources to raw materials while others include energy carriers such as electricity and heat. Moreover, some define resources as objects from nature, which then excludes waste – despite the fact that this could be used as a resource in circular systems.

The definition of resources provided by the EU's public-private-partnership programme Sustainable Process Industry through Resource and Energy Efficiency (SPIRE) Roadmap (www.spire2030.eu) allows the inclusion of non-tangible

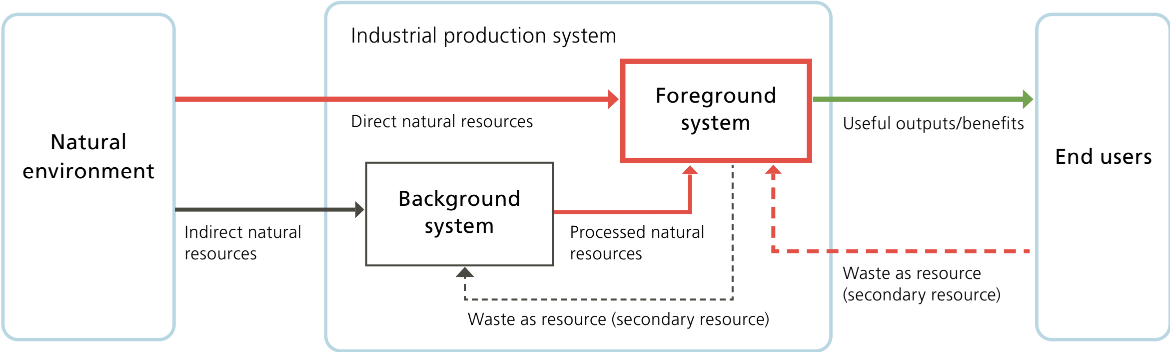


Figure 3.13. Resource consumption in an industrial system: gate to gate.[21]

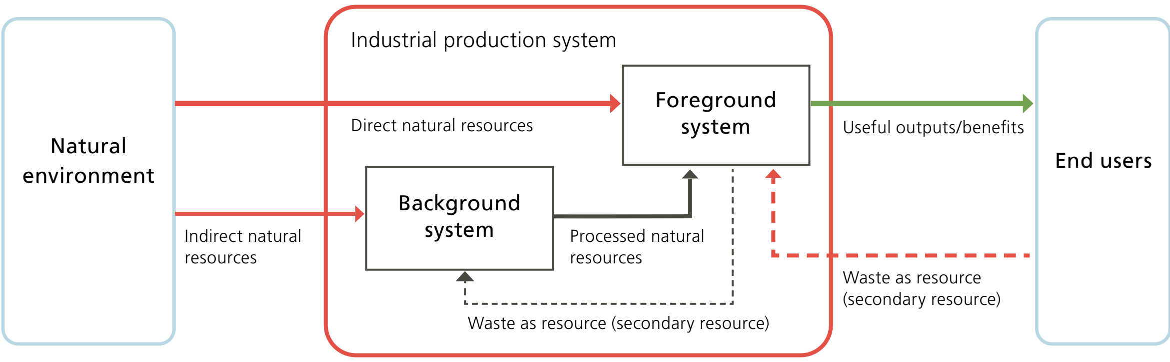


Figure 3.14 Resource consumption in an industrial system: life cycle perspective.[21]

energy carriers and waste as a resource by defining resources as energy, raw materials and water. One major resource, that is becoming more and more scarce around the world, is land. This can also be defined as a resource. Considering land, energy, primary and secondary raw materials and water yields a much more complete vision of the resource use of new circular systems.

Having thus clarified a picture of how resources can be defined for work with circular systems, it is also a requirement that a definition for resource efficiency be supplied. In general, efficiency is defined as the ratio between the benefits obtained from a process or system, and the efforts put into this process or system. The indicator defined by the European Commission to measure the resource efficiency of Europe uses this ratio. There, it is the ratio yielded by dividing the benefits obtained by Europeans from the use of resources (Gross Domestic Product) by Domestic Material Consumption (the amount of resources used). The calculation of the resource efficiency of a system will also depend on the level at which an analyst makes the calculation. Resource efficiency can be calculated at different levels, from a single process unit to that of a whole production plant, an entire industrial sector, or a whole country. This system is called the *foreground system*. It is an entity within the entire industrial production system and is often determined and controlled by the analysts in charge of a specific study. A foreground system consumes resources directly extracted from the natural environment, such as water from surrounding water bodies, as well as processed natural resources such as electricity, and it delivers products and services to end user (Fig. 3.13).

The resource efficiency ratio is then calculated as the ratio of the benefits obtained from resources, in green, and the amount of resources consumed in the foreground process, in red. This approach is called the gate-to-gate approach. Typically, an analyst can use this approach to calculate the resource efficiency of a production process; for example, the recycling process of metals recovered from a waste stream to obtain new materials.

Another approach is to follow a life cycle perspective. In his case, the denominator of the resource efficiency ratio will be the amount of natural resources consumed along the whole life cycle of a product. Typically, an LCA will be conducted to calculate the denominator (Fig. 3.14).

The resource efficiency ratio then becomes the ratio of the benefits obtained from resources over the amount of resources directly and indirectly consumed from the natural environment and from waste streams produced by the economy.

While the first approach quantifies the denominator by accounting for the amount of resources used by the main production process, the other approach accounts for all the resources consumed along the life cycle of the product, from initial resource extraction from the natural environment, to their use in the main production process. These two approaches can give completely different results.

As an example of this, a study in the chemical sector, showed that when comparing the resource efficiency of two techniques to separate chemicals, the conclusion on which one is the most resource efficient varies depending on the level of evaluation chosen. When calculating the resource efficiency of the techniques at the level of the process and the plant (the two foreground systems), Technique A has a lower resource efficiency than Technique B. However, when calculating the resource efficiency at the life cycle level, Technique A is more resource efficient than Technique B (Fig. 3.15).

Another factor that impacts results is the method chosen to calculate the denominator of the resource efficiency ratio (the amounts of resources consumed).

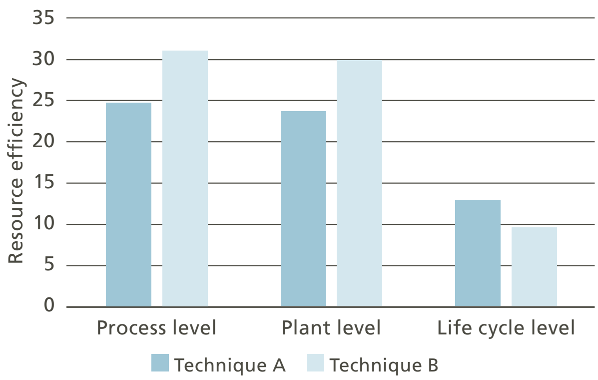


Figure 3.15. Different resource efficiency calculations – different results.[21]

Methods available to quantify resources

The numerator of the RE equation; in this case, the benefits obtained from resources, is often easier to quantify than the denominator. Broadly speaking, this is because benefits are generally delivered to end users and can often be expressed in tangible units: kg, MJ, money, etc. However, this is not always the case, especially when benefits have a social function. The denominator requires additional calculations and discussion. While there is no universal consensus on exactly how this should be done, a classification of methods to evaluate resource use in LCA according to two principles has recently been proposed:

- a physical accounting of resources – the quantity of resources consumed by the studied system is systematically accounted for based on a physical property (mass or volume, energy, exergy* or area); or
- an assessment of the impact from resource use – this is done by considering one of the following elements: the amount of resources available in the Earth's crust, predefined targets, future consequences of resource extraction, or willingness-to-pay (WTP).

Resources can be classified as *renewable* or *non-renewable* and as *biotic* or *abiotic* as shown in Table 3.1. (next page). Renewable resources are able to regenerate within a human lifetime but can be exhausted if they are consumed beyond their regeneration capacity. They can be biotic (i.e., derived from presently living organisms; e.g., wood) or abiotic (i.e., a product of past biological or physical/chemical processes; e.g., air, wind, sunlight and water). In contrast, non-renewable resources either cannot be renewed by natural processes at all, or can only be renewed over time periods much longer than a human lifetime (e.g. metal ores, oil, coal, etc.) The methods used to quantify resources do not all consider these resource sub-categories in the same way.

Resource accounting methods

Resource accounting methods can be used in both gate-to-gate and life cycle-based analyses (Table 3.1, next page). Each method accounts for resources based on a specific physical property. Four main properties are considered by existing methods: mass/volume, energy, exergy and area. As resources have different properties, most resource accounting methods do not necessarily account for the same resources. For example, energy-based methods do not account for water and land, whereas exergy-based methods are considered to account for these resources. Similarly, area-based methods neither account for non-renewable material resources nor for abiotic renewable energy resources. However, some area-based methods, such as the Ecological Footprint (www.footprintnetwork.org), account for bio-productive land necessary to absorb CO_2 emissions, as well as for the amount of consumed nuclear energy carrier. Moreover, some methods are only able to account for a fraction of a resource category. For example, mass accounting methods are not able to account for all energy carriers, typically only wind energy and electricity. Current exergy-based methods account for the largest number of resources.

Impact assessment methods

Impact assessment methods are applied in life cycle-based analyses (Table 3.1, next page). Similar to gate-to-gate analysis, they do not all cover the same resources (for example, some cover nuclear energy whereas other do not). Most developed methods are derived from calculations using one of the parameters detailed below – there are thus several approaches classified.

- *Quantity/quality of reserves:* these methods take into account the decreasing quantity and/or quality of resources available in the natural environment. Thus, they acknowledge that the consumption of resources has an impact on resource availability. Methods based on the quantity/quality of reserves are only able to account for non-renewable resources.
- *Distance-to-target*: these methods compare the quantity of resources consumed to previously defined targets. The most used distance-to-target LCA method is called the Ecological Scarcity method, which places the quantity of

* Exergy relates to the quality of that energy and tells us how much is useful for doing work. While the laws of thermodyamics dictate that energy is never destroyed in processes, exergy is always destroyed (i.e. quality degrades) in irreversable processes.

Table 3.1. Existing methods to quantify resource consumption and examples [19]–[21]

			Scope		Resource classification								
					Water	Land	Materials and substances			Energy			
							Non-renewable		Biotic renewable	Non-renewable		Abiotic renewable	Biotic renewable
Methods based on ...		Examples of methods	Gate-to-gate	Life cycle			Atmospheric resources	Metals and minerals	Biomass	Fossil energy	Nuclear energy	Flow energy resources	Biomass
Accounting methods	Mass or volume	Material flow analysis	X		X			X	X	X	X		X
		ReCiPe Midpoint – Water depletion		X	X								
		EDIP 97/203 – renewable resources		X					X				X
		Material Input Per Service Unit		X				X	X	X	X		X
	Energy	Energy analysis)	X						X	X	X	X	X
		CED/PED		X					X	X	X	X	X
		AP – fossil fuels		X						X			
		Impact 2002+ – non-renewable energy		X					X	X	X		X
		ReCiPe Midpoint – Fossil depletion)		X						X			
	Exergy	Exergy analysis	X		X		X	X	X	X	X	X	X
		CEENE		X	X	(X)	X	X	X	X	X	X	X
		CexD)		X	X		X	X	X	X	X	X	X
	Area	Direct land accounting	X			X							
		Ecological Footprint		X		X			(X)	(X)	(X)		(X)
Impact assessment methods	Resource reserves quality/ quantity	ADP		X				X			X		
		EDIP 97/203 – non-renewable resources		X				X		X	X		
	Distance to target	Ecological Scarcity		X	X	(X)		X	X	X	X	X	X
	Willing-ness-to-pay	EPS200 – land occupation and abiotic stock resources		X		X		X		X	X		
	Future consequ-ences	Impact 2002+		X				X					
		Eco-Indicator 99		X				X		X			
		ReCiPe Endpoint – resources		X				X		X	X		

Empty cells: resources not covered by the method; X: "biotic resources" are repeated for "Materials and substances" and for "Energy" as they can be materials or energy carriers; (X): Indirectly accounted for.[21, 22, 23]

- resources that have been consumed in perspective with political targets, or international policies, that concern themselves with the flows and availability of materials that have been classified as critical.
- *Willingness-to-pay*: these methods estimate the amount of money people are ready to invest to restore damages caused to natural resources. An LCA method that follows this approach in its weighting step is known as the EPS 2000 method (www.lifecyclecenter.se) (weighting is the optional final step in an LCA, which entails multiplying results of each of the impact categories with a weighting factor based on judgement of relative importance of the impact category).
- *Future consequences*: these methods consider the impact of current resource consumption on future parameters such as a result of a decrease in the quality of ore in the natural environment. The parameters most often applied when applying these methods are based on the so-called surplus energy or surplus costs calculated to be necessary to extract the same amount of resources in the future as are extracted today. An example of a method applying surplus energy is Impact 2002+ while an example of a method using surplus cost is ReCiPe Endpoint.

Some tips to calculate resource efficiency

Several choices need to be made when calculating the resource efficiency ratio. These choices are subjective but there are four things that project developers can pay special attention to in order to make informed choices.

First, try to carefully define the numerator of the resource efficiency ratio. It represents the benefits obtained from resources. Thus it essentially defines the functionality of a product. It can be done by taking into account the quality and the lifetime of the products. This is the same principle used in LCA studies.

Secondly, an LCA should always be performed to calculate the denominator of the resource efficiency ratio. For developers of a new circular product, the aim is to create a product that has a solid business plan and contributes to increasing the resource efficiency of the economy as a whole. Life cycle thinking is the only approach that empowers this goal. Gate-to-gate analysis is a limited approach but can be very useful when calculating intermediary indicators and integrating resource efficiency evaluation during the project's development.

Third, give attention to the resource coverage of the method chosen to quantify the resources consumed. As discussed above, each method covers different types of

resources. However, lowering the consumption of one specific natural resource can induce higher consumption of another. As an example, a recent study examined the sustainability of two ways of converting algae grown on aquaculture wastewater into a saleable product (also called *valorisation)*: valorisation as shrimp feed and valorisation as biogas via anaerobic digestion. The study compared the results of the resource efficiency ratio when the denominator was calculated using three different methods: the CEENE method of Ghent University in Belgium, the ADP method of Leiden University, and the Eco-Indicator 99 method, developed by the firm Pré Consultants (Fig. 3.16).

These methods do not cover the same resources, and Figure 3.16 illustrates that choosing one over the other changes the conclusion on which scenario is the most resource efficient. Therefore, one needs to consider a method or set of methods that cover all resource categories: energy, primary and secondary raw materials, land and water.

Finally, the integration of resource efficiency considerations more systematically during the course of product development can help project developers achieve higher resource efficiency goals. However, a drawback in real-life is that most project developers evaluate the resource efficiency or even the overall sustainability of their products at the end of product development; at this stage, the product has already been conceived and there is little room for improvement. Therefore, it may be more effective to implement an iterative resource evaluation process during product development, starting with preliminary indexes and using more elaborate indicators at the end of the project.

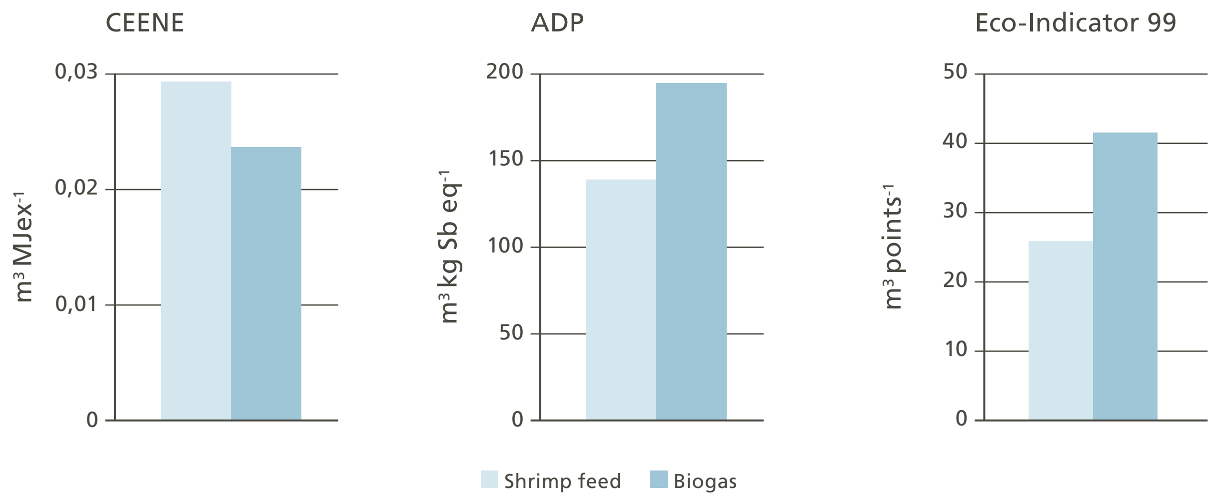


Figure 3.16. Resource efficiency of wastewater valorization: Three different resource efficiency ratios.[21]

Simple indicators, such as gate-to-gate analyses, can be conducted early as they require less time and data. An LCA approach that doesn't necessarily require quantification can also be followed throughout the project, with a full life cycle analysis conducted at the end.

Even though a universally applicable assessment of resource efficiency and consumption impact does not exist, these key methods can be used in product development to calculate the resource efficiency of new products in the most scientific and objective way. Such work is vital to effective pursuit of the circular economy.

In this chapter you have learned about advances with material sciences and assessment methods that can be used to measure impacts and progress. It is important that all assessments of circular economy initiatives consider systems and life cycles.

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4

Policies and Networks

This chapter explores the role of governments and networks and how policies and sharing best practices can enable the circular economy.

4.1 THE HISTORICAL PERSPECTIVE

- Severe material access challenges in Britain during World War II were met with combinations of government-led action – these included actions related to circular economy approaches such as careful use of scarce materials and the development of substitutes using alternative materials.
- Over time, there has been a transition in governance from command & control approaches to a multi-stakeholder platform facilitation.
- A number of societal actors have also had to adopt new roles as governance of waste has evolved towards governance of materials.

Figure 4.1. Severe supply chain disruption to Britain during WWII.

Past policy solutions: scarcity and the case of WWII

Material shortages have always been a problem for societies throughout human history. The technologies and the materials may change, but the challenge of ensuring material availability remains. Analysis of historic periods of material shortages can help us understand the challenges and develop new policies in the future. For example, Britain experienced extreme material scarcity as a result of supply chain disruption during the Second World War (WWII), and they developed a variety of policies to help deal with the shortages (Fig. 4.1).

Of course, many of the critical materials and technologies we use today did not exist during WWII, and a wartime material shortage situation cannot provide an exact blueprint for circular materials policy today. Nevertheless, it is a successful example of how society dealt with material access challenges, and we may be able to learn from it.

As the international situation worsened in the mid 1930's, and war looked likely, the British government developed materials strategies in preparation, and a new Ministry of Supply began operating in August 1939.

From the start, this department developed schemes to deal with the expected changes in global materials supply. Their approach included the careful use of scarce materials and the development of substitutes using alternative materials. Production was based on a system of priorities: the higher the priority, the more material allocated. Legal powers were also introduced to control prices, product volume and product use, and government controls were imposed on most materials.

One example is how furniture production was handled. During this time, timber supplies were halved, many pieces of furniture were lost in the bombing of towns and cities, and

1943 Utility Furniture Scheme – addressing Material Scarcity 2017 Circular Economy Package – including Critical Materials

Technical features 1943:	Technical features 2017:
Less material than pre-war products	Material efficiency considered at all stages
Robust and long lasting product, designed for repair	Enhanced durability and repairability of products
Specified materials, local where possible	Increased recyclability of products
Standardised designs and parts common across products	Critical materials defined, EU insecurity tackled
Complimentary but limited product range	Ecodesign work plan – standards on materials efficiency
No unnecessary decoration or ornament	The Eco-design directive used in the C E action plan
Designs approved by government appointed committee	Use of EU directives and advisory committees
Production 1943:	Production 2017:
Production location specified	Action on Green Public Procurement
Material quantities and timings allocated	Material efficiency in product production
Production licences required for manufacture	Report on critical raw materials and the circular economy
Labour allocated to all in the supplied chain	Aim for jobs and growth in Europe
Early use controlled	Focus on materials for low carbon energy production
Production volumes and timings given	
Society 1943:	Society 2017:
Only product range legally available for purchase	Better enforcement of existing guarantees on products
Permits required, based on need, to access coupons	Use of product environmental eco-footprint information
Coupons reqiured to purchase, fixed price	
Products in catalogues not showrooms	

Figure 4.2. Product design approaches to address materials scarcity in 1943 compared to the EU's 2017 Circular Economy Package.[24]

second-hand furniture prices were rapidly increasing. This fueled a growing black market, but the government was keen to show they were in control of all aspects of the home front. So they acted, and in 1942 they launched the Utility Furniture Scheme. Figure 4.2 provides details of how this furniture scheme applied a range of design principles that share many parameters with modern circular economy design concepts.

Under this scheme a committee was formed that had complete decision-making powers over the design of furniture. To reduce material use they introduced a standard furniture range; the design of this furniture was very tightly controlled, and manufacturing firms had no freedom to adapt the limited range of designated designs. Consumers only had these designs as options to purchase (Fig. 4.3)!

The government selected the firms to make the furniture, and timed production volumes with the allocation of raw materials and location of market, reducing fuel used for transport.

This case demonstrates that we can take on the potential challenge of severe materials scarcity. It also guides us in understanding the difficult choices we may have to make, the policies we may want to enact and the policies we should avoid. Britain saw over a 50% reduction in some material supplies during WWII; the actions they took to successfully manage their materials can provide us with both insights and evidence of how to develop circular economy policy going forwards.

It's also worth noting the urgency of the British challenge; in an emergency situation, we can take action to solve very large challenges.

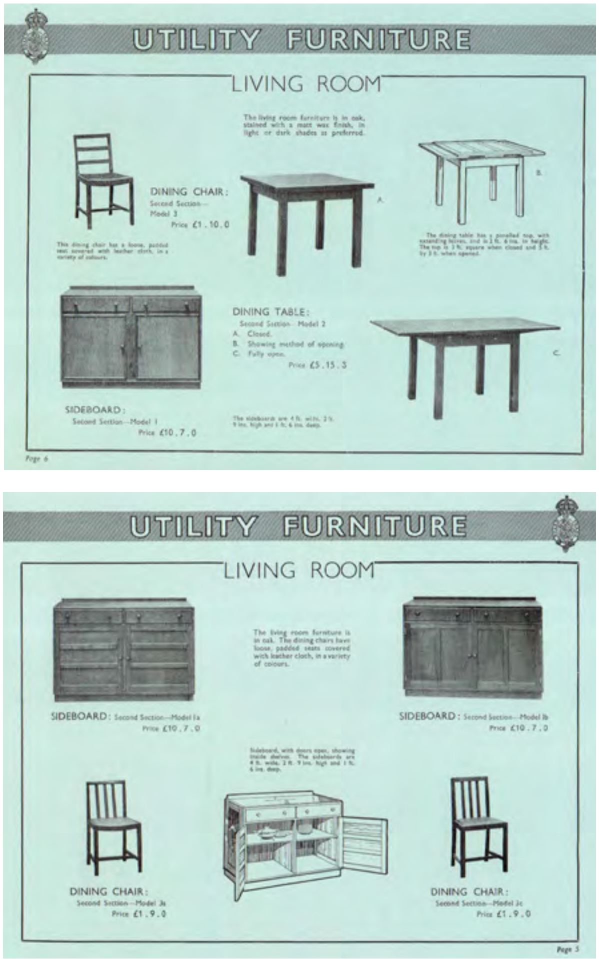


Figure 4.3. Examples of British utility furniture from 1943.[25]

From waste to materials

To better understand evolving policy frameworks for the circular economy, it is useful to examine the recent history of waste management policy in Western Europe. Policy follows a wave-like pattern, with a steep increase in effort and attention in the initial years. Over time, this effort levels off as policies settle into place and are enforced and monitored. As new policies develop, the pattern repeats itself (Fig. 4.4).

Before the 1970s, waste was managed locally, and usually this meant it was collected and deposited in local dump sites. This posed a risk for the environment and public health. Waste management policy in the form of national laws regulating collection and disposal emerged in the early 1970s as waste began to be considered a problem. The authorities responded by developing a policy that was based on containment and risk remediation to secure the health of citizens. This *command and control* policy limited the operation of landfills and their emissions. Sites that clearly had negative impacts on the environment were forced to close and remediate.

Incineration plants were initially considered as simply a practical means of waste disposal, but over the years awareness of the possible negative effects of flue gas emissions on the health of surrounding populations grew. As a result, incineration plants also had to begin monitoring their emissions. The 1980s brought a new policy period with the introduction of permit-based legislation with emission limit values to water and air based on the use of *best available techniques* (BAT). In many cases this led to the closure of existing installations.

This second wave of policy was also driven by the sheer volumes of waste. The authorities became aware of the scale of the volumes of waste materials produced every year, and also that many of these materials were recyclable, such as paper, glass or construction and demolition waste. The second wave aimed to extract these materials from the waste stream and recycle them. This resulted in the introduction of separate waste collection systems and recycling targets for specific waste streams, in an attempt to reduce the overall volume of waste produced.

The policy was characterized by collection and recycling targets in the form of amounts or percentages. For example, Flanders, in Belgium, has set a target of maximum 150kg residual waste per inhabitant, and since 2008 the EU aims for 70% recycling of construction and demolition waste. These targets led to unique collection strategies, in which the high-volume materials were collected separately, close to the point where they were produced. In general, collection could be in the form of door to door collection or via centralized collection systems. Centralized systems were often applied for materials such as glass containers or paper.

The second wave led to the development of waste treatment facilities – as distinct from the earlier "dumps". These were also controlled by permit-based policy. In addition, legislation increasingly controlled the shipment of waste and regulated the treatment of hazardous materials.

In 2006, the European Waste Framework directive introduced a *waste hierarchy* and set recycling targets for 2020 for implementation in each member state. The second

EU definition: "Best available techniques" means the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and where that is not practicable, to reduce emissions and the impact on the environment as a whole.

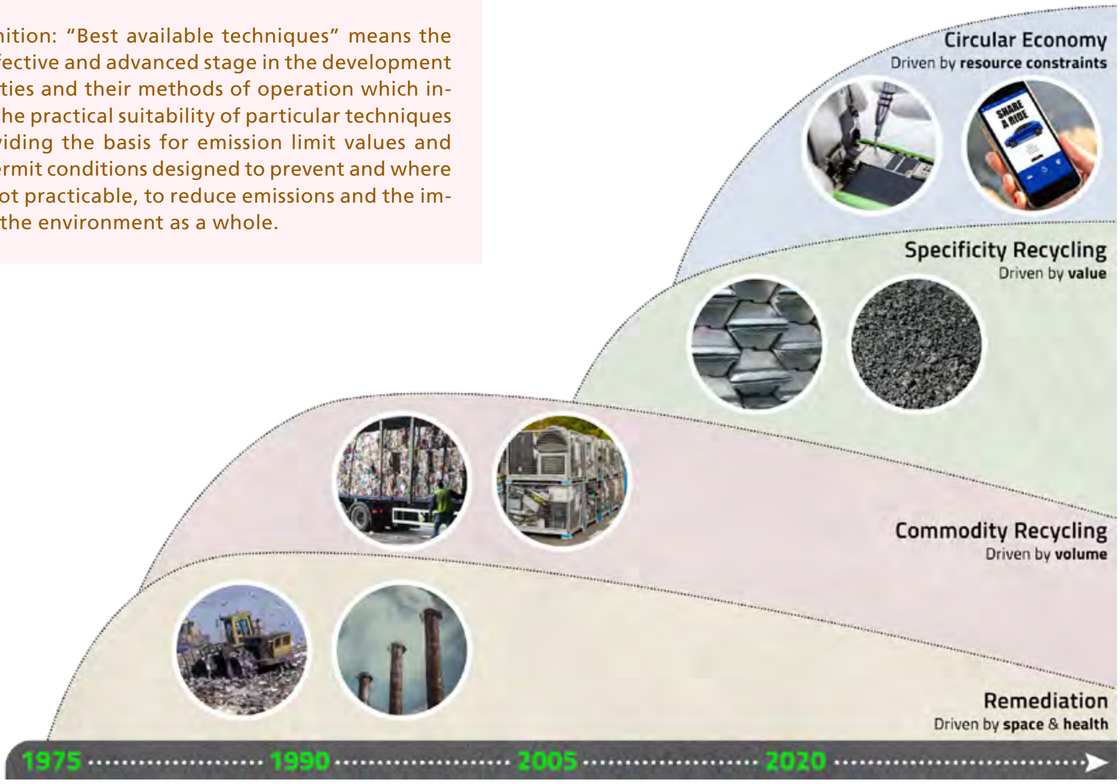


Figure 4.4. Waves of waste policy in Europe.[6]

wave had resulted in the creation of a waste management sector focused on collecting and recycling waste. Initially, this activity was largely subsidized but as it grew it became a private market activity. The introduction of the waste hierarchy shifted the focus of recycling activities from processing large volumes of waste towards the creation of value – the third wave of waste policy.

As the third wave developed, it subsequently led to a shift in focus from large volume, low value materials to low volume, high value materials included in broader societal waste streams, such as metals like copper or gold. Typical of these streams are *flows* for used products such as electronic waste or used cars. These types of material flows need thorough processing in order to extract the metals. Evolving to cater for such flows, waste treatment activities became more complex and capital intensive. This resulted in a tension between waste regulation and market drivers for material recovery and recycling. Waste was no longer necessarily processed close to the source, but increasingly at locations of higher market price or lower processing costs.

The fourth wave of waste management is underway, and here is referred to as the wave of circular economy. It is no longer only driven by the value or the recycling in itself, but also by constraints on the stable supply of materials that are important to our economies and technologies.

This enfolds the concept of critical materials, the idea that our economy needs certain materials that will be more expensive or harder to find as the global economy grows. This wave is driving new policy, which looks not only at how we can use more recycled materials, but also examines the use phase of materials and products. It sets demands on societal actors to increase the lifetime of products and keep materials at a high value throughout their life cycle.

This fourth wave demands that the role of the policy maker has moved from a controlling function in waste management to an enabling factor in materials management and product policy. Policy actions need to focus on waste prevention and on the responsibility of producers, and this requires an approach that stimulates evolution via communication campaigns for consumers and the promotion of responsibility amongst manufacturers and industry players.

In addition to the changing role of the legislator, it is interesting to also review the changing role of the waste sector. In the first wave, the waste sector was considered part of the problem; their waste disposal activities required control and limitation by the government. In the second wave, the responsibility for treating wastes, and therefore limiting the burden on public health and environment, shifted from the authorities to the waste management sector. As owners of the waste problem, they increasingly explored and developed the possibility of recovering the residual value of the material flows that they now controlled. This value capture began to drive waste processing, so much so that primary producers, and larger service companies, also became more interested in waste management activities.

As a consequence, this stimulated the third wave, where small local waste treatment companies were taken over by larger groups and major industrial players entered the market.

In the emerging circular economy, the distinction between raw materials, products and waste is becoming increasingly unclear. Material management is part of the product value chain, and producers remain responsible for the product and material that they place on the market. In leasing models for example, the producers even keep the ownership of the product and provide only a service to the customer. Such developments will drive fundamental changes in the waste sector, and existing players will need to continually redefine their role in this complex system of material management.

4.2. POLICIES FOR A CIRCULAR ECONOMY

- Policy instruments have a very important role to play in the shaping of future socio-economic regimes such as the circular economy.
- There are a range of instruments available and in use – and more are proposed to build a mix that can lead a transition from the linear economy.
- At times policies can result in conflicts within a circular system and both care in design and monitoring of performance is required to deliver effective policy.

Moving from a linear economy to a circular economy requires fundamental changes to current production and consumption systems. We have to change how materials are used and how our products are designed, and we need new business models. However, the circular economy also needs enabling conditions.

If the goal was to be growing potatoes, then sunshine, water, rich soil, and a lot of care would be enabling conditions for growth. Enabling conditions for the circular economy include the need for a supportive policy framework. This needs to remove existing barriers in circular operations and enable the increase of material circularity in the economy.

There are a number of tools and approaches that governments can apply to scale up the circular economy. These include a wide range of policy instruments that can be used to achieve certain goals. The most commonly used distinguish between three types of policy instruments: *administrative*, *economic* and *informative*.

Examples of administrative or regulatory instruments include bans, standards, licenses and voluntary agreements between government and industry. Economic instruments can take the form of taxes, fees, subsidies and charges. Examples of informative instruments are labelling, reporting requirements, certification schemes, and awareness raising campaigns.

All of these approaches can be applied in either mandatory or voluntary forms. Mandatory instruments are implemented and monitored by a central authority, either at the local, national or international level, and voluntary instruments are typically self-regulated among the participating organizations. (Table 4.1)

Table 4.1. Categorization of policy instruments – with examples.

	Mandatory	Voluntary
Administrative	bans, standards, quotas, licences, etc.	standards, agreements between government and industry, etc.
Economic	taxes, fees, tariffs, subsidies, etc.	GPP, loan guarantees, charges, etc.
Informative	reporting requirements (chemicals), labelling, education, etc.	certification schemes, awareness raising campaigns, EMS, etc.

Examples of the three types of policy instruments, organized by "Mandatory" and "Voluntary".[26]

All three types of policy instruments are important and can stimulate the uptake of a desired outcome in different ways. The more all three types of policy instruments are used to complement each other, the greater the catalytic effect towards change.

The way policy instruments are used sparks change by enabling, engaging, encouraging and ultimately, enforcing. Policies can *enable* the circular economy by removing barriers, supporting the development of skills and capacity, and providing information; they can *engage* through media campaigns and voluntary industry agreements either within the sector or across the supply chain. Policies can *encourage* through tax cuts, subsidies, and reward schemes, and they can *enforce* through penalties and fines (Fig. 4.5).

Past and present EU initiatives towards the circular economy

In the period since the early 2000s the strategic resource policy direction of the European Union has increasingly pursued measures towards the sustainable use of natural resources, increased resource efficiency in the economy, and scaling up the recycling and prevention of waste. At the same time, the Union has also sought economic growth (Fig. 4.6).

The EU promotes the circular economy with a package of proposals (the first in 2015 and the latest in 2020), including a comprehensive Circular Economy Action Plan and regulation amendments.[27] The aim of this package is to improve the competitiveness of EU businesses by shielding industries against potential resource scarcities and price volatility, and to help create new business opportunities and innovative ways of production and consumption. The circular economy is expected to create local jobs in the EU at all skill levels in the workforce, as well as present opportunities for social integration.

It is particularly stressed in the Action Plan that economic actors, such as businesses and consumers, are to be the key drivers in the transition process. However, local, regional and national authorities are encouraged to act as catalysts in this transition. The EU is to play a fundamental but supportive role, ensuring that the right regulatory framework is in place for the development of a circular economy in the market. The EU Circular Economy Action Plan outlines potential policy interventions that would enable this development (Fig. 4.7).

The number and complexity of interactions among actors in a circular economy create a complicated policy landscape. This inevitably extends across the different

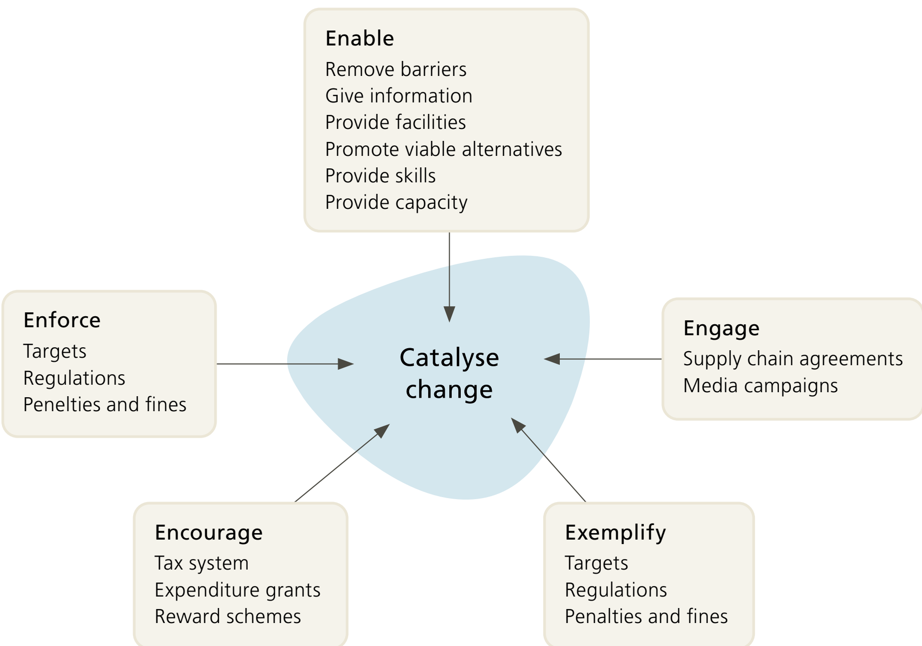


Figure 4.5. Policy approaches for catalysing change.[28]

Figure 4.6. Timeline of EU resource efficiency initiatives 2002–2015.[29]

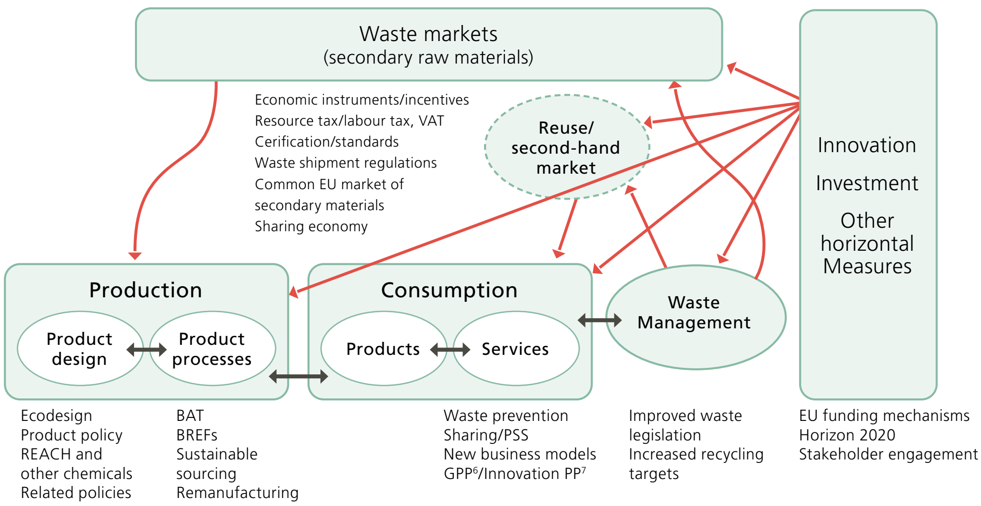


Figure 4.7. Policy proposals in the EU Circular Economy Action Plan COM (2015) 614 final.[30]

parts of production and consumption systems and affects, directly or indirectly, several other parts in the value chain. Such interacting networks might also extend in different geographic locations within or between Member States.

In Table 4.2 (next page), current legislation relevant to the circular economy at the EU level, both mandatory and voluntary, is categorized by life cycle stage. There is a high concentration of mandatory EU legislation towards the end-of-life cycle phases. These aim to limit resource loss and increase the circulation of materials, mainly through recycling. In contrast, policies targeting consumption are rather limited and and in general only indirectly affect resource efficiency – a clear gap! While there are many directives and regulations governing production processes at the EU level, the majority do not explicitly target material resource efficiency, and as a result a policy gap is observed at this life cycle stage as well. This stated, the fact that some policies do exist at that level is considered by many as positive. This, as material resource efficiency considerations can still be added to an existing policy, an easier pathway than seeking to create an entirely new policy framework from scratch. As an example, there is clearly scope for improving criteria for public procurement and eco-labelling so that material resource efficiency becomes more prominent.

At the Member State level, individual countries have the freedom to devise their own resource efficiency agenda as long as they do not counteract EU regulations. Recently, some Member States decided to take resource efficiency policies a step further, leapfrogging far beyond the existing EU policies. Table 4.3 (next page) summarizes a number of ambitious policies at Member State level that aim to increase resource efficiency.

When policymaking intervenes in systems, there is always potential for both conflict or synergy. When applying a single policy instrument there is always a risk of prompting unintended outcomes that change other drivers, particularly when the policy field spans several parts of the economy. For this reason, a more complex approach is needed in a circular economy context, and policymakers are working with a mix of policies and consider a wide range of related issues:

- the full range of available policy instruments targeting resource efficiency;
- the full cost of policies, including implementation costs, transaction costs and compliance costs;
- how to avoid negative interactions between single policies (i.e. instruments already in place vs. new ones), but emphasise mutual benefits with existing policies;
- how to carefully combine the instruments to mitigate side-effects.

To place these issues in context, a hypothetical example of a synergistic policy mix relevant to the circular economy can be drawn. In this example, mandatory ecodesign rules for reparability, together with material and parts certifications, may be put in place to facilitate increased reuse of a product. However, by themselves, these changes may not stimulate changes in the market – there may be limited demand for the product group, or there might not be collection systems that ensure enough of the products are collected to support repair and reuse, or it may be simpler for waste management systems to scrap the products for material recycling. Here additional policy interventions may be added to support progress. An example of a supporting policy intervention

Table 4.2: Existing policies in the EU related to products, materials and resources.[29]

Life cycle stage	Production	Use / consumption	Waste management
Mandatory	Batteries and waste batteries Directive 2013/56/EU WEEE Directive 2012/19/EU RoHS Directive 2011/65/EU Ecodesign Directive 2009/125/EC* Packaging and waste packaging Directive 94/62/EC Standardisation Regulation (EU) No 1025/2012 Marketing of construction products Regulation (EU) No 305/2011 REACH Regulation (EC) No 1907/2006*	Labelling of energy-related products Directive 2010/30/EU Ecodesign Directive 2009/125/EC* Sale of consumer goods and associated guarantees Directive 1999/44/EC	Waste Framework Directive 2008/98/EC Batteries and waste batteries Directive 2013/56/EU Plastic bags Directive (EU) 2015/720 WEEE Directive 2012/19/EU RoHS Directive 2011/65/EU Waste from extractive industries Directive 2006/21/EC ELV Directive 2000/53/EC Landfill Directive 1999/31/EC Packaging and waste packaging Directive 94/62/EC Shipments of waste Regulation (EU) No 660/2014 REACH Regulation (EC) No 1907/2006*
Voluntary	Public procurement Directive 2014/24/EU Ecolabel Regulation (EC) No 66/2010	Public procurement Directive 2014/24/EU Ecolabel Regulation (EC) No 66/2010	

* The Ecodesign Directive and REACH regulation serve as a policy framework out of which specific implementing measures are formulated and applied by case (product group or chemical compound respectively). To date, the application of ecodesign focused primarily on energy efficiency measures and material resource efficiency appears very limited.

Table 4.3: New policy approaches in EU Member States promoting the circular economy.[29]

Member State	Policy measure	Application
France	**Act on consumption and preventing planned product obsolescence.**	Mandatory
	The Act (Law no. 2014-344) addresses product durability and aims to prevent planned obsolescence. The law includes articles related to the lifespan of consumer goods, including the introduction of extended product guarantee from six months to two years; and the obligation of retailers to inform customers about the time horizon that spare parts will remain available for a product in question (EEA 2016).	National
Spain	**Reuse targets for Waste Electrical and Electronic Equipment (WEEE)**.	Mandatory
	In its new Waste Management Plan 2016-22, Spain sets a target of 50% municipal waste to be prepared for reuse or recycled, followed by a specific target of 2% for preparation for reuse in certain waste streams including textiles, WEEE, furniture and “other suitable waste streams” (Ruiz Saiz-Aja 2016).	National
Sweden	**Value Added Tax (VAT) reduction in repair services.**	Mandatory
	The Swedish government suggested a VAT reduction in repair services for a selected group of products (bicycles and shoes). In addition, the government proposed a tax deduction for repair services performed in relation to home renovations (IVA 2016).	National
Sweden	**Public procurement of refurbished ICT equipment by Swedish municipalities.**	Voluntary
	Two Swedish municipalities (Gällivare and Laholm) apply specific criteria in public procurement, tendering the provision of refurbished ICT equipment for use in municipal services (Avfall Sverige 2015).	Local

is introducing public purchasing criteria that favour, or even require, the purchase of reparable and reusable products – thus creating a base market. A second may be the implementation of novel extended producer responsibility rules that support the refurbishment of products over and above recycling. This intervention helps ensure that such products could retain additional value from the item and maintain the resources embedded in the product, either intact or with minor modifications.

The Circular Economy Package

In past decades, policymaking in the European Union most often took an end-of-pipe approach, aiming to fix a problem rather than to prevent its cause. Thus, when examining the product lifecycle, most mandatory policies we find today target the end-of-life and waste phase. At other lifecycle stages the majority of policies are of a voluntary nature. Although significant improvements have occurred in recent years, the old approach is clearly reflected in existing resource efficiency policies.

After a series of discussions around progressive resource efficiency strategies the European Commission adopted the ambitious Circular Economy Package in 2015. This package includes legislative proposals on waste, and a detailed action plan. In addition to introducing more stringent targets for reuse and recycling and streamlining waste rules, the Action Plan includes a complete set of policy proposals targeting all stages of the product life-cycle (Fig. 4.8).

Particular focus is given to instruments that could influence resource efficiency from the beginning of the life cycle, such as ecodesign and extended producer responsibility policies. These aim to change the way products are designed. Other areas of intervention include standardization and certification for increased durability, reparability and recyclability of products. Public procurement is another policy approach that can significantly pull the uptake of circular solutions.

A broader perspective for future circular economy policy

The systemic nature of the transition towards a circular economy implies that while policy measures targeting the waste phase are necessary, they are insufficient to achieve circular products. In this context, two elements are essential: first, the focus of the policy should encompass more than just waste management; and second, policy actions throughout the product's life-cycle need to be aligned to avoid negative side-effects and lock-in situations, and to capitalize on potential synergies.

Initially, waste-related policies were introduced to tackle environmental and health problems related to landfill. Over time, the policy focus shifted towards stimulating recycling as an environmentally and economically sound way of managing waste. Product policies initially focused on the energy efficiency of products and the labelling of products with lower environmental impacts. With the policy focus now being on the transition towards a circular economy in which the value of products is maintained for as long as possible, a new phase in policy-making has been initiated. However, the change that is needed now is a widening, rather than a shift, of the policy focus. Stimulating markets for recycling is an important part of the transition, but the inner circles of circularity (i.e. reuse, repair and remanufacture) also need significant stimulation. At the EU level, durability, reparability, upgradeability, design for disassembly and ease of reuse and recycling will play a bigger role when setting ecodesign requirements according to the Ecodesign Directive.

In general, a wide range of possible policy instruments to improve product circularity can be applied throughout a product´s life-cycle (Fig. 4.8). However, it will be essential to

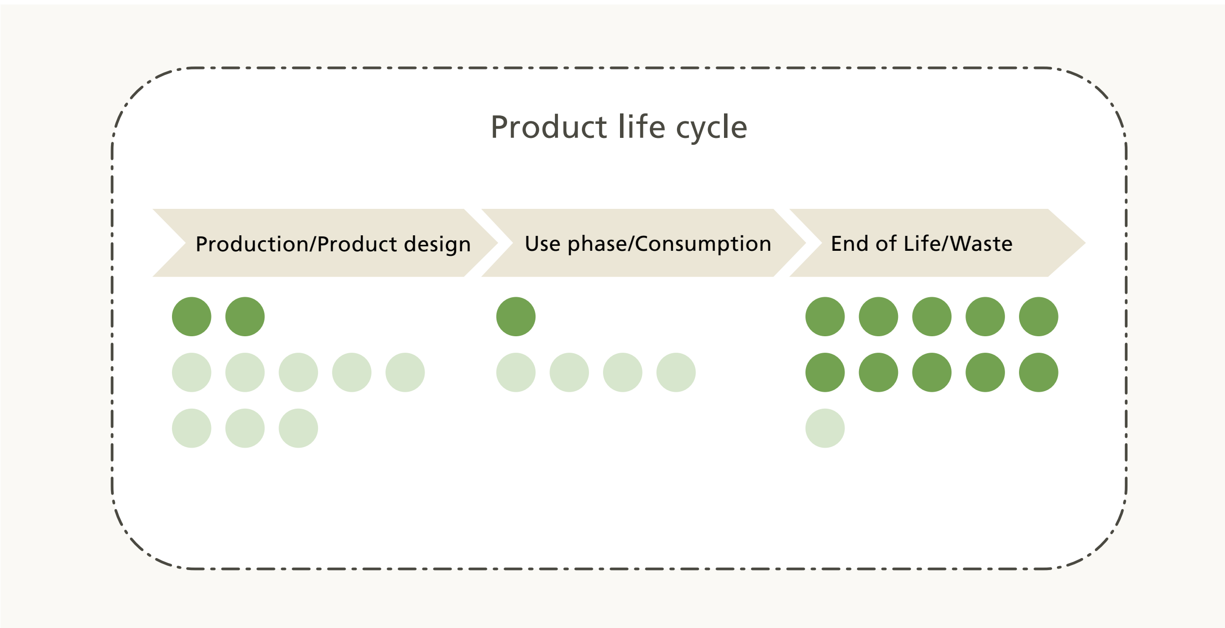


Figure 4.8. Indicative weighting of EU policy pre-2010.[29]

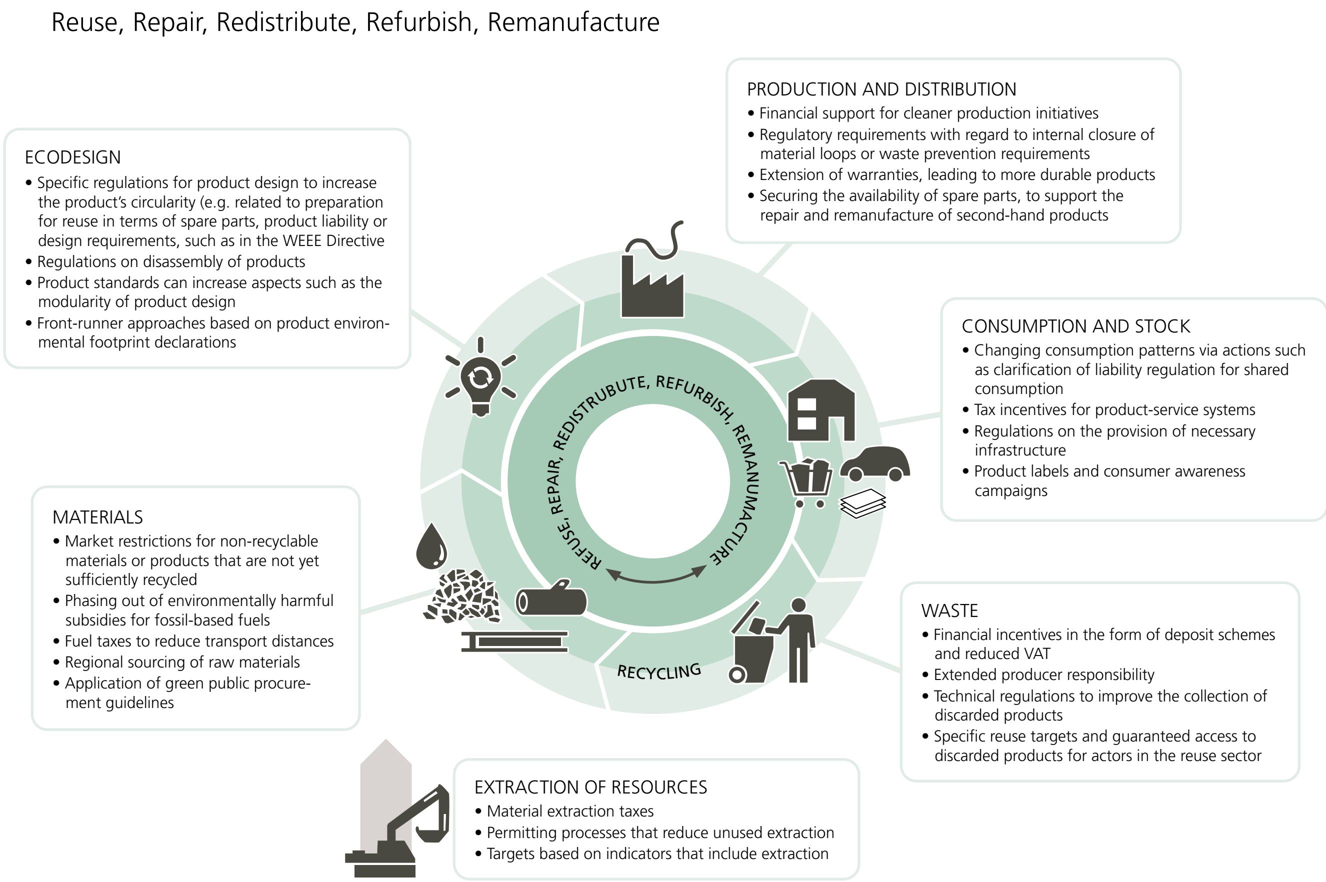


Figure 4.9. Overview of potential policy instruments affecting product circularity throughout the product life-cycle.[31]

ensure the alignment of policy measures throughout the life cycle, not only to avoid conflicting incentives for businesses and consumers, but also to capitalize on synergies resulting from concerted action aimed at different product circularity strategies. For example, the collection rate of end-of-life products from consumers could be increased if collection initiatives not only make use of recycling as an argument for consumers to hand in their old products, but also include the opportunity to reuse or repair. Another issue to be tackled is the aspect of liability when the repair of a product is undertaken through an informal sharing economy approach (such as repair cafés).

Streamlining policy measures is, however, a significant challenge. This is not only because different policy actors are responsible for different stages in a product´s life-cycle, but also because it is difficult to predict all the possible impacts of a policy before it is implemented.

To place these issues in context, a hypothetical example of negative side-effects related to conflicting incentives can be presented. In this example, a policy measure is to provide economic incentives to improve the recycling of a composite waste material (e.g. electronics). These have many different parts and materials. Logically, recyclers will respond with investment in, and development of, sorting and recycling technologies and infrastructure that will enable increased recycling. However, as it becomes easier to recycle, product designers and manufacturers may have less motivation to innovatively design products that are easier to recycle (a process that could be costlier), thinking that the advanced sorting technologies will take care of them anyway. Such situations can also happen in reverse. For example, a situation can also arise that when incentives are given for better product design, then there will be less incentive, motivation and need for recyclers to improve their sorting and recycling processes. This would then result in lower quality recycled materials despite the better product design.

Such examples highlight the need to use a monitoring framework allowing the identification of systemic impacts of policy action, and appropriate adaptations (Fig. 4.9).

4.3 EXTENDED PRODUCER RESPONSIBILITY

- Extended producer responsibility (EPR) is a policy principle that promotes efficient waste management and supports improved resource management by providing producers incentives to consider the end of life of their products when designing them.
- Products that contain metals are frequently part of EPR systems.
- A challenge for EPR implementation is that some end-of-life products are disguised as products for reuse in order to avoid more stringent and expensive recycling requirements in countries with more highly developed infrastructure.

The origins of Extended Producer Responsibility (EPR)
In Europe, the Extended Producer Responsibility (EPR) principle is often considered a key approach for the circular economy. The origins of EPR can be traced back to the late 1980s when many industrialized countries were struggling with their waste management, landfills were filling up and it was difficult to open new ones. Waste incineration was becoming more common, but it also met a lot of opposition. Household recycling had started, but the results of most initiatives were not very impressive. One reason for the limited success was that municipalities often lacked the money needed to build convenient and effective infrastructure for recycling. Municipalities are also normally reluctant to increase fees and taxes – and when they do so, there are competing issues for how to use the money. Actors in society also began to pay attention to the fact that products were typically designed and manufactured without any plan for how they should be treated as waste.

All this led to the development of a new strategy for how to approach the waste management and recycling of products. In 1990 the principle of *Extended Producer Responsibility* was formulated and gradually introduced in various countries.

The essence of the EPR principle is that producers are incentivized to consider the end of life of their products when designing them. This is achieved by making the producers responsible for the end-of-life management of their products. In addition to financial responsibility, producers are also often assigned responsibility for organising the collection of the discarded products. This makes it possible for them to control the costs for end-of-life product management. In practice, producers typically form collectives called *Producer Responsibility Organizations* and these organizations collect fees from producers and then hire waste management companies to collect and recycle the products. Producers, of course, seek to recover these costs when selling the products so in the end, it is the users of the product that pay. This means that the cost of taking care of the product at its end-of-life will be reflected in the price and will also influence the purchasing decisions.

Over the past 25 years or so, EPR has been introduced for a variety of products. The most notable product groups are packaging, cars, batteries, and electrical and electronic equipment. Most of these products are related to metal recycling.

WEEE as a central example
Waste Electrical and Electronic Equipment (WEEE), also called e-waste, is among the most common products addressed by extended producer responsibility. Since the first EPR systems for electronics started to appear in Asia and Europe in the late 1990s, EPR has spread to many countries on all continents. The scope of these systems differs among countries, but there are a number of common patterns. In most East Asian countries, the EPR systems started with a focus on a smaller set of bulky products that contribute more to waste volumes, such as refrigerators, air conditioners, washing machines and TVs, and their scope gradually expanded from there. In North America they also started on a smaller scale and then gradually expanded, but their EPR systems often started with products that contain lead and mercury, such as TVs and computers. In Europe, EPR systems covered a wide range of electrically powered products of various sizes, used both at home and in offices, and also some professional equipment like medical equipment and vending machines right from the start.

Many WEEE laws are introduced with requirements that restrict the use of toxic substances like mercury, cadmium, lead and hexavalent chromium. These laws also stipulate what costs should be covered by the producers, who should be responsible for collection, recycling and environmentally sound treatment. The laws also typically mandate how much (i.e. what proportion of the total amount of WEEE generated) electronic waste should be collected, reused or recycled, and

often include requirements on how various products should be handled or treated – for instance, if certain components have to be removed before further processing. The actual active engagement of producers varies across systems, but in general the engagement is rather limited in Europe. In other countries however, such as Japan, prominent producers run at least one recycling plant themselves.

WEEE legislation has led to a development of collection systems for discarded electronics in most OECD countries, but the existing systems are not always very convenient for the citizens. In many instances, this has resulted in low collection rates, especially for small appliances. In Europe, revised legislation now calls for easy-to-access collection systems for very small electronics, like mobile phones and light bulbs. The legislation mandates that large retailers have to accept very small electronics without consumers buying a new product. This is one way of reducing the likelihood that these products are thrown into the mixed residual waste and thus end up in landfills and waste incinerators.

Another challenge for the collection systems has been that many discarded products actually still work and there is a potential second-hand market. While continued use is preferable in most cases (as it extends the lifetime of a product), there is also a very real risk that these products end up in countries that don't have functioning recycling systems and that ultimately, they are discarded without any environmental controls.

Some discarded products containing valuable metals are also exported for recycling in other countries. They are often disguised as products for reuse in order to avoid more stringent and expensive recycling requirements at home. These products then often end up in recycling markets where the primitive recovery methods used only capture a limited portion of the useful metals and create devastating environmental and health hazards. This has seriously affected impoverished people around the world, mostly in Africa and Asia.

In most OECD countries there are state-of-the-art recycling facilities that are able to recover almost all metals, including minute amounts of so-called critical elements such as rare earth metals. Such facilities also emit extremely few, if any, hazardous elements to the environment.

The fate of phones. Mobile phones are clearly part of the challenge when it comes to collecting discarded products. This is a market that has grown extremely quickly, and many mobile phones are still very much fit for use after the first owner has upgraded to a newer model. The shift of owners may be repeated several times as the phone gets older. With repair and dedicated design adjustments it is technically feasible that the lifetime of a mobile phone could be extended even more. But due to so-called "style obsolescence", the cessation of software updates, and so forth, such older phones most often end up in markets that do not have good recycling systems or technologies. Another limiting factor is the cost of repair and varying quality of repair works, due partly to the limited availability of authorized repair parts.

Moving forward with EPR

The present EPR systems still face many challenges, but the development of collection and recycling systems has advanced a lot during the last decades. Many countries now collect and recycle the majority of discarded electronics, and we are witnessing a rapid development in the technology systems that treat or process the materials within them.

But, more progress is required. In particular, collection systems need to improve, especially for smaller electronic equipment, so even more products can be recycled. We also need better treatment systems and technologies for the collected items that allow for an effective use of the contained substances through well-working recycling systems.

The most difficult challenges for making EPR a central tool for obtaining a circular economy is in reformulating the laws to assure there are clear incentives for producers to redesign their products to have less environmental impact, and to ensure that the legislation is implemented with effective and honest monitoring. The reuse of products and the design for optimal life times also needs to improve – and this demands sound systems and good control.

Last but not least, although based on the same concept, the design and implementation of EPR programmes varies significantly. There are big differences between different products, and also between different countries. When discussing EPR programmes, it is very important to pay attention to the specifics of each program.

4.4 ECODESIGN POLICIES

- The Ecodesign Directive promotes product attributes such as longer product lifetimes and improved product reparability that align well with circular economy approaches.
- There are several options to regulate resource efficiency of products included within the Directive.
- Complexities related to product-related regulations dictate that, despite all planning, it is likely that society may still have to experiment with the policies to see what works best.

Policies for extending product lifetimes

One way to reduce material use is to encourage people to use products longer. The product lifetime is dependent both on the product design and the potential for repair of a damaged or otherwise non-functional product. Reparability is in turn dependent upon the availability of spare parts and access to reasonably priced repair services. Today, unfortunately, it often makes more economic sense to the consumer to buy a new product than to repair the old one.

So in order to promote longer product lifetimes, European governments have adopted different policies to provide incentives for manufacturers to increase the product lifetime. For instance, some EU countries have reduced the Value Added Tax for repair services in order to stimulate the repair sector and make repair a more attractive option for consumers. Several European countries have also recently changed the legal warranty time for many products. In some countries consumers can now claim a right to repair or replace a product for up to six years after the purchase.

France has adopted perhaps the most progressive policies; they have now criminalized planned obsolescence, sending a clear signal to the market. Further, France has also started to examine the practices of some corporations seeking evidence that planned obsolescence is actually taking place. In addition, France has introduced a scheme to provide incentives for manufacturers to ensure that spare parts are available to consumers for a number of years after the purchase of the product.

Policies for Ecodesign

There are many different initiatives in European countries seeking to provide incentives for the design of more durable products and to reuse, repair or remanufacture products. However, none of the national policies actually regulate product design. As the EU supports free trade of goods, it would be problematic if different European countries had their own rules for product design and composition. It would mean that products manufactured in one country could not be sold in another country. Therefore, rules related to product design are usually adopted by the European Union and are then applied equally in all member states.

The EU's main law related to product design is the Ecodesign Directive. The Ecodesign Directive is a framework law, and under this law, the European Union sets specific legislation for different product groups. These include products that are related to significant energy use, such as dishwashers, washing machines, refrigerators/freezers, water-boilers, TVs and electric motors. In most product groups the main focus in the legislation has been the energy efficiency of the products. However, now there are also ongoing discussions on how resource efficiency can also be considered within legal frameworks. For instance, the European Union's Circular Economy Action Plan promotes "the reparability, upgradability, durability, and recyclability of products" and new legislation is now being considered for such.

One approach among the strategies under consideration is to regulate *lifetime* or *durability*. Indeed, this has already been put in place for vacuum cleaners, where the motor lifetime and durability of the hose has been regulated. There have also been lifetime requirements set for lighting products such as lightbulbs.

While setting standards on lifetime may at first appear straightforward, in practice it can be very complex. For example, "lifetime" actually has several dimensions. Lighting products are a useful example to explain this term, as it includes not only the estimated useful length of life in hours but also how many switching cycles the lamp can endure and how the light output deteriorates over time. It is also necessary to test the legal requirements to ensure that manufacturers can comply with the laws. It is a challenge to ensure a product lasts for 15 years without actually testing it for 15 years!

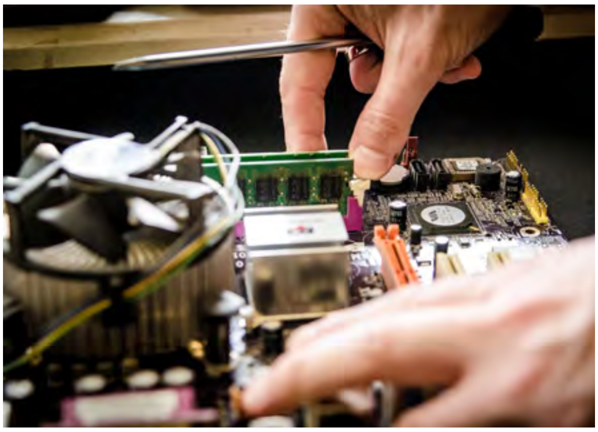
A second type of requirement that can also be posed is that manufacturers must promote *product reparability* and guarantee the provision of spare parts for several years. In addition to improving reparability, guaranteeing the availability of spare parts will also make repair a feasible, and potentially more attractive option to the consumer.

A third type of requirement is to promote *modular design*. Modular design is considered to be good for the environment if it increases the lifetime of consumer electronics. The most obvious case is that it becomes easier to change the battery, as it is often battery problems that makes a product less functional. But modular design is not easy to regulate, and there is always some risk that such rules can hinder desired design functions, and stand in the way of innovative design solutions. Nevertheless, some rules could be very feasible, such as rules that make it easier and cheaper for the consumer to change the battery!

A fourth type of requirement is related to *design for recycling*. One proposed example is that manufacturers must show that a product can be taken apart within a set time period, which makes recycling more cost-effective. Related to recycling, another category of rules could relate to declaration of content. If a manufacturer accounts for what materials are in a product and where they are situated, future recycling operations could be improved.

There are other options, too. In the light of this complexity, it is necessary to recognize that it is complicated to adopt such rules; and it is generally accepted that rules should not hinder desired innovations. A great challenge concerns the need to develop standards and test methods that help authorities ensure that manufacturers comply with the laws. Often, it is quite difficult to set requirements unless there are standards available to test them. If there are no such standards then they must be developed, and this is a time-consuming process.

Finally, one concern is that even if we make products durable, consumers may still change products before they have reached their useful lifetime. A prime reason for this is for reasons related to function or fashion, the latter which can be considered almost invariably to be a waste of resources. We must remember that reality is never straightforward. If we force manufacturers to develop more durable products, they may be incentivized to make them upgradeable and lease them to consumers instead of selling them, which could benefit its environmental performance. So, in some respects society may have to experiment with the policies to see what works and what doesn't.



Remember, too, that the Ecodesign Directive is not the only possible instrument to promote product resource efficiency. Another option is to stimulate longer product lifetimes and reparability through consumer labelling initiatives.

4.5 POLICY OUTLOOK

- The EU brings together private, public and academic stakeholders to provide guidance on addressing the challenges related to raw materials using the circular economy.
- The Netherlands in particular has initiated a progressive plan for its circular economy transition, with goal to have a fully circular economy by 2050.
- Implementing such policies at the EU would accelerate the circular economy transition across the world.

The EU European Innovation Partnership on Raw Materials and the role of Netherlands – an EU country perspective on circular policy

The European Union has its own circular economy policy framework, but it also encourages policy development at the member state level. The *European Innovation Partnerships*, EIPs, are a new approach to EU research and innovation. The EIPs cover a number of topics; the *EIP Raw Materials* topic has a direct relationship to the circular economy.

The *European Innovation Partnership on Raw Materials* (see text on page 66 and weblinks on page 74) is a stakeholder platform that brings together representatives from industry, government, academia and NGOs. Its mission is to provide high-level guidance to the European Commission and Members States on innovative approaches like the circular economy to address the challenges related to raw materials.

The EIP plays a central role in the EU's raw materials policy framework and a key output is a document called the Strategic Implementation Plan. It sets out specific objectives that target and support research, disseminate best practice and encourage cooperation between countries. A direct example is the production of this Compendium document.

As the European Union is made up of member states, the EIP needs to ensure alignment with their national policies. One member state, the Netherlands, has stated a progressive plan for a transition to a circular economy, setting ambitious objectives for 2030 and 2050. By 2030 the goal is a 50% reduction in the use of primary raw materials, including minerals, fossil fuels and metals. By 2050 the goal is to have a "fully circular economy" in the Netherlands.

The Netherlands has formulated strategic goals to achieve this policy. This includes ensuring that raw materials in existing chains are utilized at high quality. There is also a goal for fossil fuels and critical raw materials, which, where possible, are to be replaced by renewable and more widely available raw materials. There is also a goal to develop new production methods and promote new ways of designing and consuming products. This is all to be achieved within the frame of a circular economy.

However, there is explicit acknowledgement that current policies are insufficient to achieve the transition to a circular economy. This is largely because the focus is still aimed more at countering the damaging effects of waste and emissions, and not enough at utilising the value of raw materials. In order to address this, the government of the Netherlands propose instruments across five priorities:

- stimulating laws and regulations, such as developing circular product design guidelines;
- developing smart market incentives, such as circular public sector procurement;
- financing, such as support for circular entrepreneurs and startups;
- knowledge and innovation, such as monitoring material flows, across national and international value chains;
- international cooperation, such as forming strategic international coalitions.

The proposed guidelines for circular product design would include preventing the use of materials and components that are difficult to recycle in standard recycling processes, selecting materials that can be more easily reused, making the reuse of subcomponents possible, minimizing the different connections in a product and reducing the variety of materials used.

As part of circular product design thinking, guidelines for Design for Disassembly are also proposed. They include:

- ensure less manual force required to take the product apart;
- simplify connection mechanisms;
- increase use of identical parts so that recognition at disassembly is easier;
- make it easier to recognizable connection points;
- eliminate hazardous materials.

All of the above steps, if applied across all member states in the European Union, could accelerate the transition to a circular economy across the world.

4.6 NETWORKS AND INFORMATION SHARING

- Stimulating circular economy systems requires imagining new systems that reduce resource consumption and the amount of emissions in the environment.
- Innovation happens when people and companies meet to brainstorm, network and exchange knowledge.
- Governments and society are developing networks to connect people and cultivate synergies to support circular economy implementation.

Sharing information is important when attempting to foster a circular economy. The wave of circular economy policies initiated by governments has resulted in a need for these governments to develop tools to support their implementation.

Governments and society are developing networks as a tool to connect people and cultivate the necessary synergies, as the circular economy requires reorganizing the circulation of resource flows. This new circulation implies that different stakeholders collaborate to exchange energy or material flows based on their needs. For example, a company in the UK might have ceramics that they want to get rid of. At the same time, a company in France might need ceramics as a raw material for building, which would decrease the amount of virgin raw materials used. So, the organizations discarding and those demanding material and energy to be reused or recycled need to somehow get in touch.

Stimulating circular economy systems also implies thinking outside of the box and imagining new systems that reduce resource consumption and overall emissions in the environment. Innovation takes place when people and companies meet to brainstorm, network and exchange knowledge. This helps them identify what is needed, what is feasible (or not), and if an idea can actually contribute to creating a circular economy. Several initiatives around this topic have been launched by public authorities and independent organizations to promote the circular economy agenda.

One example of an initiative launched by public authorities is the European Circular Economy Stakeholder Platform (https://circulareconomy.europa.eu/platform/) launched by the European Commission in 2017. This platform aims to gather existing networks focusing on the circular economy in a "network of networks" to stimulate collaboration and knowledge sharing on opportunities and challenges. The platform gathers experts in the field of circular economy, organizes stakeholder discussions via conferences, and shares knowledge, strategies and best practices via a website. The European Commission is also funding a consortium of actors in the sector of raw materials in Europe called *EIT Raw Materials*, initiated by the European Institute of Innovation and Technology. EIT Raw Materials gathers more than 100 partners in academia, research institutes and businesses to find innovative solutions to secure and improve the supply of raw materials in Europe, including to a large extent the development of circular systems. This Compendium has been produced within such an EIT Raw Materials Initiative.

Yet another example is the initiative launched by the association ACR+, which was founded by a group of local authorities under the lead of the Brussels-Capital region. ACR+ launched the *Circular Europe Network* (https://www.circular-europe-network.eu) to share knowledge on efficient circular economy strategies implemented by cities and regions. One interesting output of the network is a map, which gathers successful circular economy initiatives from different regions in Europe (Fig. 4.10).

Besides initiatives launched by public authorities, other actors such as academia and businesses also participate in creating networks. This is the case of the Ellen MacArthur Foundation and its programme Circular Economy 100 (https://www.ellenmacarthurfoundation.org/our-work/activities/ce100). It aims to enable organizations around the world to innovate in the field of circular economy by bringing together companies, governments, cities, academia and emerging innovators. Members of the network have access to tools such as a matchmaking app, acceleration workshops and an Executive Education course. This initiative was recently extended with the creation of two specific programs for Brazil and the US.

Other types of initiatives gather specific technical information for social and environmental assessments of supply chains and resource management. The European Platform on Life Cycle Assessment was launched in 2014 by the European Commission to gather information and data for businesses and policy makers to make life cycle assessment studies. It hosts a registry called the Life Cycle Data Network (https://ec.europa.eu/jrc/en/network-bureau/life-cycle-data-network) for stakeholders to deposit life cycle inventory data and processes. It also frames the development of the European Life Cycle Database, which gathers life cycle inventory data for key products from EU business associations and others. For example, if seeking information on aluminium extrusion, a complete description of one specific process can be found on this website, including materials and energy consumption necessary for the process.

These examples stress the importance of information sharing in the development of a circular economy as intended by regional policies. Initiatives are already ongoing, from the creation of networks for matchmaking to the creation of new communication tools and technical

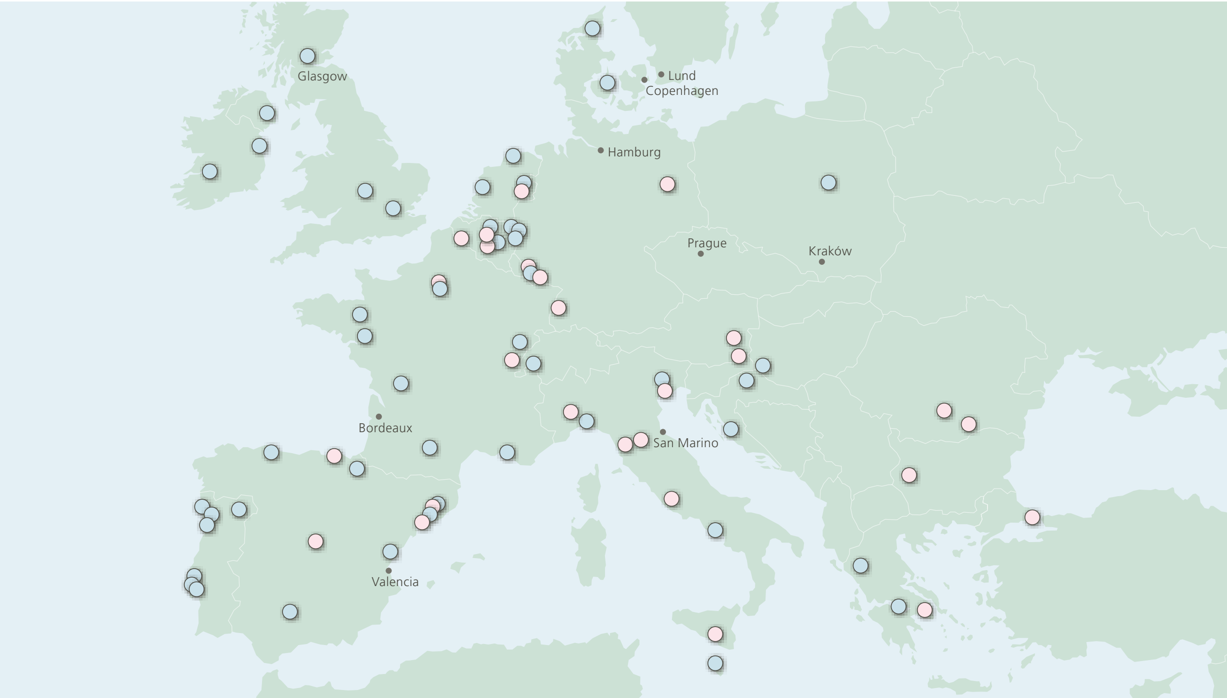


Figure 4.10. Circular Economy initiatives throughout Europe.[32]

databases that can support innovators in their efforts to create new circular systems. These networks rely on the participation of all actors involved to transition towards a circular economy.

Other examples of initiatives to stimulate circular economy via information sharing and networking

Many other initiatives aiming to stimulate circular economy via information sharing and networking are emerging around the world. They are led by a wide range of stakeholders, are implemented at different scales (from regional to worldwide levels) and have different levels of maturity. They can be a source of information and help project developers reach circular economy experts or future collaborators. A number of examples are introduced in the following paragraphs. Links to their websites are included at the end of this chapter.

The Circular Economy program of the WBCSD (global)

The *World Business Council for Sustainable Development* (WBCSD) has launched a circular economy program. Several outcomes of this program aim to inform businesses on circular economy practices and bring them together to create synergies. One example is the Circular Economy Practitioner Guide launched in 2017. It presents several circular economy practices as well as case studies, tools and publications from other organizations such as the Ellen MacArthur Foundation. Another output of the program is the MarketplaceHUB, an online platform that maps initiatives that promote the use of secondary resources around the world. The platform mainly maps marketplaces allowing businesses to publish their offers and demands for secondary materials (e.g., the North Carolina Waste Trader in the USA or the Belgian Waste Stock Exchange).

The Circular Economy Club (world)

The Circular Economy Club (CEC) is an international non-profit network of over 2600 professionals around the world. It aims to connect members to create synergies, for example via the voluntary activities of CEC local organizers who can organize networking events in their city, and to provide professionals with open tools and resources via their website. Resources and tools promoted include: information on funding opportunities; new publications on circular economy; guidelines to apply the circular economy principles, and examples of circular systems applied in different sectors.

The Raw Material Information System of the European Commission (EU)

In the EU, the Raw Material Information System (RMIS) was developed by the European Commission Joint Research Commission (JRC) as a web-based knowledge platform on non-fuel, non-agricultural raw materials from primary and secondary sources. The website aims to gather information on raw materials, including critical raw materials and secondary materials (e.g. definitions, policy and legislation, environmental and social sustainability, etc.). In terms of the circular economy, the RMIS will provide information for specific industrial sectors such as Electric and Electronic Equipment (for which product factsheets on product lifetime, recycling and ecodesign opportunities will be available) and Mobility.

The European Innovation Partnership on Raw Materials (EU)

As mentioned earlier (p. 63) the European Innovation Partnership on Raw Materials (EU) brings together representatives from industry, public services, academia and NGOs. Its mission is to provide high-level guidance to the European Commission, Member States and private actors on innovative approaches to raw materials challenges. The EIP plays a central role in the EU's raw materials policy framework. The EIP on Raw Materials has the aim to help raise industry's contribution to the EU GDP to around 20% by 2020. It will also play an important role in meeting the objectives of the European Commission flagship initiatives Innovation Union and Resource Efficient Europe. It will do this by ensuring the sustainable supply of raw materials to the European economy whilst increasing benefits for society as a whole.

The EIP targets non-energy, non-agricultural raw materials. Many of these are vital inputs for innovative technologies and offer environmentally-friendly, clean-technology applications. They are also essential for the manufacture of the new and innovative products required by our modern society, such as batteries for electric cars, photovoltaic systems and devices for wind turbines. With about 30 million EU jobs depending on the availability of raw materials, the EIP will have a clear, positive impact on European industrial competitiveness. The EIP's Strategic Implementation Plan (SIP) sets out specific objectives and targets. Actions to achieve these include research and development, addressing policy framework conditions, disseminating best practices, gathering knowledge and fostering international cooperation.

The circular economy platform of the Americas (American continent)

The Circular Economy Platform of the Americas (CEP-Americas) is an initiative of the Americas Sustainable Development Foundation (ASDF). It aims to facilitate the transition to a circular economy in the Americas, especially in South American countries. It functions through the involvement of professionals in the sector, networking events to connect people and ideas, as well as the sharing of information on the latest advancements of the American continent toward a circular economy.

The economiecirculaire.org platform (France, Switzerland and Belgium)

The economiecirculaire.org platform is a French initiative that aims to explain the concepts of circular economy, connect local circular economy platforms, and facilitate experience sharing in France, Belgium and Switzerland.

Links to various initiatives

The Circular Economy program of the WBCSD. More information on: https://www.wbcsd.org/Programs/Circular-Economy
The Circular Economy Club More information on: https://www.circulareconomyclub.com
The Raw Material Information System of the European Commission More information on: http://rmis.jrc.ec.europa.eu
The European Innovation Partnership on Raw Materials More information on:
https://ec.europa.eu/growth/sectors/raw-materials/eip_en
The circular economy platform of the Americas More information on: https://www.cep-americas.com
The economiecirculaire.org platform More information on: https://www.economiecirculaire.org

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4.4 ECODESIGN POLICIES Carl Dalhammar – IIIEE, Lund University, Sweden.

4.5 POLICY OUTLOOK David Peck – Delft University of Technology, The Netherlands

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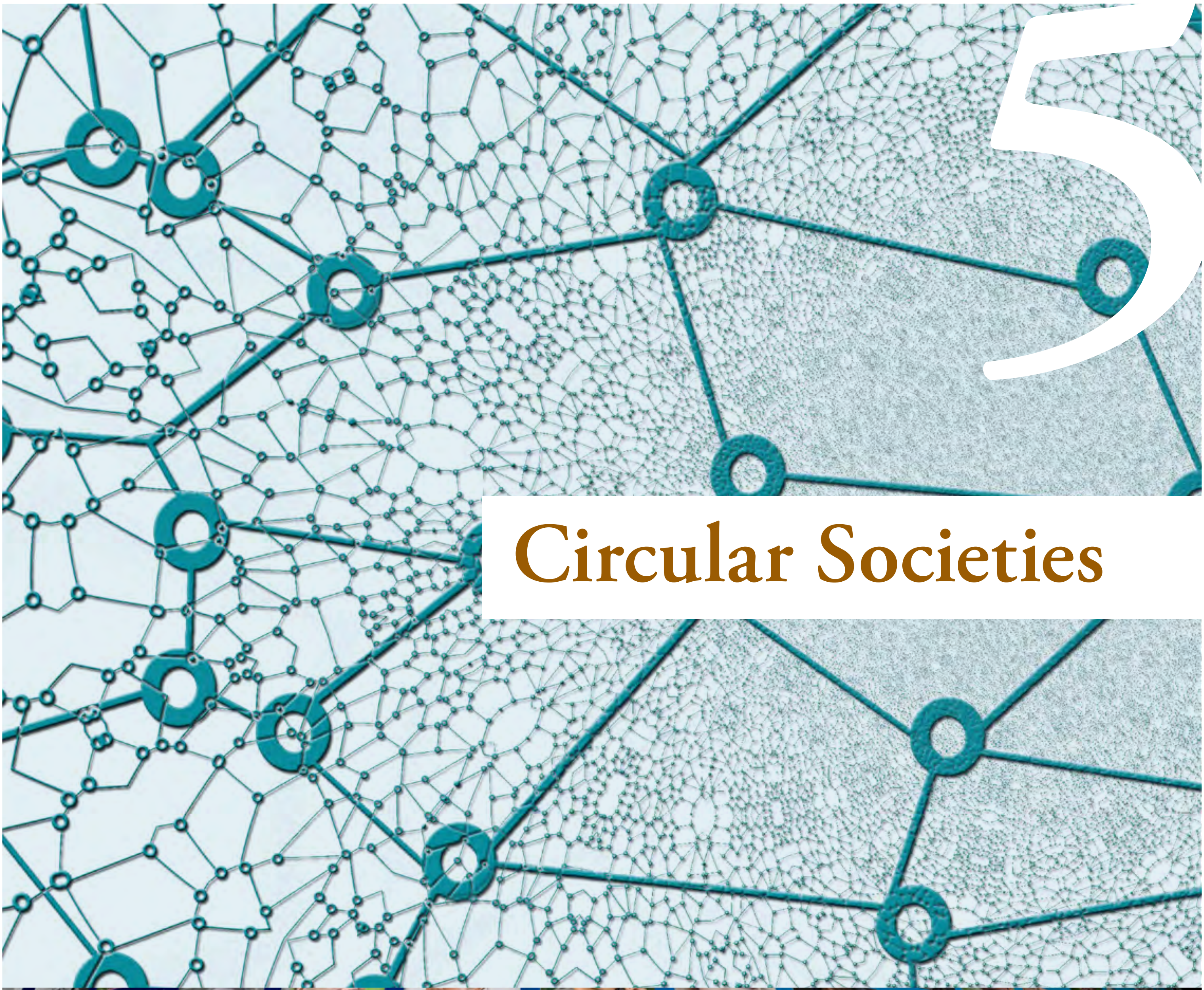


5

Circular Societies

This chapter examines new norms, forms of engagement, social systems, and institutions that are needed by the circular economy, and discusses how we can help society become more circular.

5.1 CIRCULARITY'S VALUE TO SOCIETY

- The circular economy can create value for society by securing global resources, preserving natural systems, and stimulating new norms and institutions that support our society.
- Large proportions of many economies rely on natural material or processes and services, this is a strong reason to transition to a circular economy and protect such resources.
- The circular economy transition will shift the way our modern society and institutions function, and the value of materials, services and skills and technologies.

Securing resources for social equity and development

The circular economy can create value for society in three major ways. The first is that it can help secure global resource availability. A second is how it can help preserve the ability of natural systems to deliver goods and services to society. A third way is related to the idea that we cannot achieve a circular economy without developing new technologies, norms and institutions, which can support and stimulate our society.

To start this discussion, we need to go back to a central argument supporting the need for circular economy: we must reduce burdens on the Earth's ecosystems. This is a very significant task. We face a future where by 2050 there may be 10 billion people that can afford a wealthy lifestyle with high levels of goods and services. A *business as usual approach* in this future – where we continue to use too many resources, too quickly, and don't reuse them – will exceed global resource availability. If we want to maintain the earth's ability to support humankind, we must provide these goods and services using only a fraction of the material and energy consumption per person of today's developed countries. This is a radical shift!

All societies must build their infrastructure in order to develop. There are many countries that are still developing – in all parts of the world – with Africa and South Asia as two regions that most people immediately recognize. Countries in such regions have yet to build all the factories, schools, hospitals, roads, railways, energy grids, and houses that are required to provide for a long healthy life.

Simply put, global society needs the circular economy to ensure that the resources required to support human development are available.

Preserving natural production systems

It must also be clearly understood that non-renewable resources like copper and iron are not the only resources that we deplete. The inefficiencies and wastes that are inherent with the current linear economy also endanger the supply of important resources from nature. Very large proportions of most of the world's economies actually rely on material things that we take from nature, or on the processes that natural systems provide when they can function normally.

Damage from pollution can drastically reduce the ability of natural systems to produce renewable resources, and taking too much, too fast, from natural systems can also damage them.

Reducing the dangers posed, and the damage caused, by waste and over-extraction is vital to preserving the ability of natural systems to support and supply society. One part of this is the danger pollution poses to health. Air pollution, for example, results in the loss of millions of human lives every year. Apart from the human tragedy within this, impacts on health along with lost productivity and the health care costs also impact our economies negatively.

Pollution also threatens environmental systems that produce renewable resources. Clean air and water, timber from forests, and fish from the sea are examples of these. We call these ecological goods. Sadly, pollution from today's linear, take-make-waste economy threatens many ecological goods. For example, crop yields are reduced – oftentimes quite drastically – when air and soil are contaminated. Forests that produce valuable timber are damaged by acid rain. Fisheries are damaged, or even destroyed, by the effects of pollution and overfishing. And all such systems are threatened by pests and diseases that flourish in a warming climate that has more extreme weather events.

Such productivity losses can also be very damaging to our economies. By reducing threats to the environment, a more circular economy can benefit our economies and our society.

In addition to providing society with ecological goods, we are deeply dependent upon ecosystems for the processes that they perform. The hydrological cycle delivers clean water, and photosynthesis in plants delivers the oxygen that we breathe. These processes are examples of *ecosystem services*. The ability of these natural systems to deliver such services are also threatened by our linear economy. Our oceans, rivers and landscapes, and their productive systems, are being clogged and poisoned by our wastes. Apart from taking away beautiful landscapes that we enjoy – in itself a service to society – such situations also reduce the ability of natural systems to deliver ecosystem services.

As an example, when a natural environment – producing clean water flowing in clean rivers – is polluted, then farms, towns and industry no longer have access to "clean" water for "free". There will probably still be water, but it must be must be subjected to more cleaning processes before it is suitable for use, a process that generally requires large investments in infrastructure. The process of purification then consumes energy, time and money. Further, other goods or services that the river provided such as fish, tourism, etc. may be lost. Such impacts constitute real costs and damage to a society and its economy.

Examples of ecosystem services:

- decomposition of wastes;
- generation of soil and vegetation;
- pollination of crops;
- seed dispersal;
- recharge of groundwater systems;
- greenhouse gas mitigation.

Taking too much from the environment, and releasing too much contaminated material back into it, threatens our very survival.

Creating a circular society

Broad social change, new ways of thinking, and lots of technological innovation are needed to make the circular economy work. These things can also support and stimulate modern society. Likewise, new social norms and aspirations must emerge to support reduced consumption, speed up the shift of products-to-services, stimulate the sharing of goods, and lengthen product lifetimes.

In supporting the circular economy, these social shifts will also demand that we invent, innovate, develop new technologies, and create new businesses.

The circular economy requires stimulation of society's research and development, and of the materials extraction and production industries. It demands the creation of new sectors to recover and process materials in circular ways, and it requires design innovation and the creation of new business models to operate everything that will make the circular economy function.

Nor can we lose sight of the fact that new policy processes must be put in place to support the emergence of the circular economy. Such work includes the design and negotiation of new policies and regulations to enable circularity. As well as supporting circularity, these policy frames must also impede value destruction and pollution in the first place. New institutional frameworks must be designed and implemented to support systems that share or remanufacture products.

There is also a general consensus among policy-makers and practitioners in the circular economy, that the creation of new systems to regulate both the linear economy and the emerging circular economy will create skills and knowledge that are vital to meet other global challenges, such as climate change adaptation. That is, the skills and knowledge that we build as we seek a more resource efficient circular economy are also directly applicable when seeking to work with a range of other sustainability challenges.

But we need to evolve more than just new processes and technologies. We must pursue new social norms and forms of engagement; and we need new social systems and institutions.

If we are truly serious about achieving a circular society then we must develop ourselves!

5.2 ENVIRONMENTAL IMPACTS OF CONSUMPTION

- Due to today's immense global supply chains, consumption in one part of the world can now trigger resource use and emissions in another part of the world much more than it did just a few decades ago.
- A national *environmental footprint* can be expressed by calculating the environmental impact from all goods and services produced within a country, minus the environmental impact from the production of exported products, plus the environmental impact from the production of imported products.
- In contrast to the environmental footprint, the *ecological footprint* is expressed by converting all environmental pressures to the global hectare, a unit that expresses the theoretical amount of land needed to absorb the exerted environmental pressure (e.g. to regrow resources, or to absorb CO_2 emissions). While easier to communicate, the ecological footprint concept is commonly criticized within the scientific community.

Our environmental footprint

Our demand for goods and services drives the extraction of resources across the globe. The production and transport of these goods cause the emission of greenhouse gases and other substances into our air, water and soil.

Our consumption patterns have become more and more globalized. Only decades ago, products were mostly produced in the same country where they were consumed, and they were made from materials and parts that were locally available. But today, in our global economy, products are made from materials from all over the world; supply chains have evolved into a complex and interconnected world-wide network of resource and money flows. For example, meat produced in Europe may be fed with soy produced in Brazil, and mobile phones sold in the US are very likely to be assembled in Asia using metals derived from ores mined in Africa and South America.

Because of these global supply chains, consumption in one part of the world now can trigger resource use and emissions in another part of the world much more than it did just a few decades ago. Take the example of a US-brand car sold in France: the emissions related to the burning of gasoline occur in France. However, the environmental impact of the extraction and refining of the gasoline was probably generated in the Middle East, and the impact of the car's assembly was generated in the US, while the impact of the extraction of the metals in the car's components was probably generated in South America, or Asia – depending on the material. All of these factors contribute to that which we call our *consumption related footprint*.

The notion of an *environmental footprint* allows us to estimate the environmental impact that our consumption habits exert on the natural environment. The footprint concept considers the environmental pressures that are associated with all the goods and services that are consumed by a person or a region. Like life cycle assessment, it takes the full life cycle of these goods and services into account, including the emissions generated along the world-wide value chain for resource extraction, production, transport and use. In this way, environmental emissions generated abroad are also taken into account.

Expressed in a formula, the environmental footprint is the environmental impact from all goods and services produced within a country (often called the *territorial flow*), minus the environmental impact from the production of exported products, plus the environmental impact from the production of imported products. Thorough knowledge of global value chains is needed in order to calculate the environmental footprint of a product, and by extension the consumption of a whole country (Fig. 5.1).

The most commonly used footprint in communication and policy-making is the *carbon footprint*. It expresses the amount of greenhouse gas emissions estimated to be emitted as a result of resource extraction, production, transport and use of all goods and services consumed. A carbon footprint can be calculated for specific goods or individual persons, but it's mostly used to estimate the impact of an average consumption pattern in a region or a country, and it's typically expressed in tonnes of CO_2-equivalents (CO_2-eq) per inhabitant. By taking a closer look at which goods and services are responsible for the largest contribution to the overall footprint, we gain insight in the way our consumption

National emissions accounting

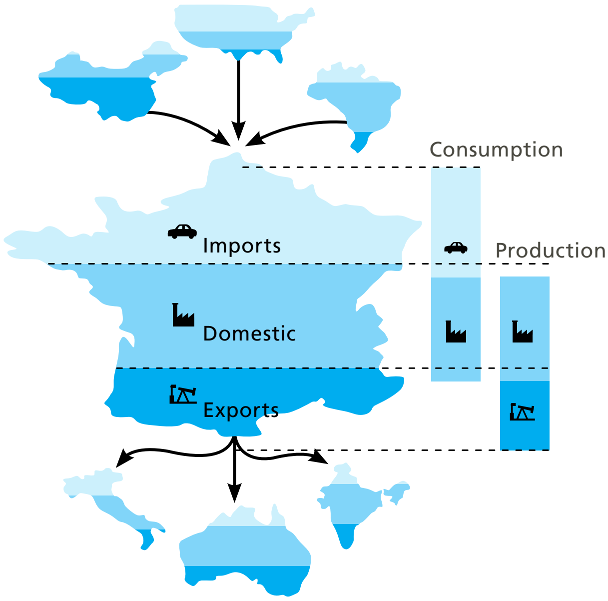


Figure 5.1. National emissions accounting for calculating the environmental footprint.[33]

habits affect the environment and which habits we should change in order to reduce our environmental impact.

Carbon is not the only measure used however, and environmental footprints are estimated for various environmental concerns. Well established footprint measures, including carbon, are summarised below.

- Carbon – presents the amount of embodied carbon dioxide and greenhouse gas emissions as a result of the consumption (and hence, the production) of goods and services, expressed in tonnes of CO_2-eq (hence, this includes non-CO_2 greenhouse gases, such as methane).
- Water – expresses the volume of freshwater consumed (or polluted) as a result of the consumption of goods and services, expressed in cubic metres of water. Distinction can be made between volumes of rainwater consumed (*green water*, e.g. by rain-fed agriculture or forests), surface and groundwater consumed (*blue water*, e.g. industrial process water or irrigation water) and volumes of water polluted (*grey water*, estimated as the amount of water needed for adequate assimilation of the pollutants).
- Land – tallies the amount of land use (cropland, pasture and forest) needed to produce the amount of final consumption, expressed in km².
- Material – calculates the consumption of raw materials (metal ores, fossil fuels, biomass, minerals) of final consumption, expressed in tonnes. Material footprints can be made on an aggregated level, or for individual materials.

In contrast with the footprints presented above, the concept of the *ecological footprint* was developed in the early 90s as an aggregated measure of the extent to which humanity used (or exceeded) the Earth's carrying capacity. In the ecological footprint, all environmental pressures are converted to the *global hectare*, a unit that expresses the theoretical amount of land needed to absorb the exerted environmental pressure (e.g. to regrow resources, or to absorb CO_2 emissions). Based on the ecological footprint concept, it was estimated that humanity used 1,5 times the carrying capacity of the Earth in 2010 (WWF, 2014). The ecological footprint is widely used in popular literature on sustainable consumption – in general it is found that the statement that "we currently need 1,5 Earths to sustain our global consumption" is a concept that is both attention-catching and relatively easy to grasp. Hence it helps communicate the seriousness of environmental concerns to broad audiences. This said, the concept is commonly criticized within the scientific community, not least because the methodology applied to calculate the ecological footprint very likely significantly underestimates the environmental impact of consumption. Further, it only encompasses available land area, while disregarding other very serious issues such as land degradation due to unsustainable land-use practices.

Case Study: The environmental footprint of Flanders

Carbon footprints are the most common footprints discussed in literature and used in policy making. The carbon footprint of a country or region is the total amount of greenhouse gases produced worldwide as a result of the consumption of its inhabitants.

As an example of how carbon footprints are applied for a country, it is useful to examine the carbon footprint of Flanders, a densely populated and highly industrialized region in Western Europe.

In 2010, the carbon footprint of Flanders amounted to about 20 tonnes per inhabitant. To limit the average global temperature rise to 2°C, global greenhouse gas emissions need to be reduced to an average of 2 tonnes per capita by 2050. The Flemish carbon footprint is therefore ten times higher than the nominal target. Important in the context of this discussion is that much of this footprint is linked to consumption.

Nearly three quarters of the Flemish carbon footprint, about 15 tonnes CO_2-eq per inhabitant, are linked to goods and services purchased by households. The majority of these greenhouse gas emissions, roughly 80%, result from the production, transport and use of goods and services linked to housing, food, and personal transport. In addition to the emissions related to direct consumption of households, roughly 5 tonnes CO_2-eq per inhabitant can be linked to investments by businesses and governments in buildings and infrastructure, machinery, ICT equipment, etc. (slightly over 3 tonnes CO_2-eq per inhabitant) and emissions linked to public services that are not directly paid for by consumers, such as education and defense (about 2 tonnes CO_2-eq per inhabitant) (Fig. 5.2).

When we dive deeper into the part of the footprint that is related to housing, we discover that energy use within homes is responsible for almost 80% of the carbon contribution. Most of the energy use is related to heating. Slightly over half of these emissions are generated during the production and distribution of heating fuel, natural gas and electricity, while the other half is caused during fuel combustion within the home itself. Based on this analysis, we can see that from an environmental point of view, reducing energy use in homes is an important part of reducing the carbon footprint of households.

When considering the global distribution of Flemish consumption emissions, over two-thirds of the carbon emissions originate from outside the region of Flanders.

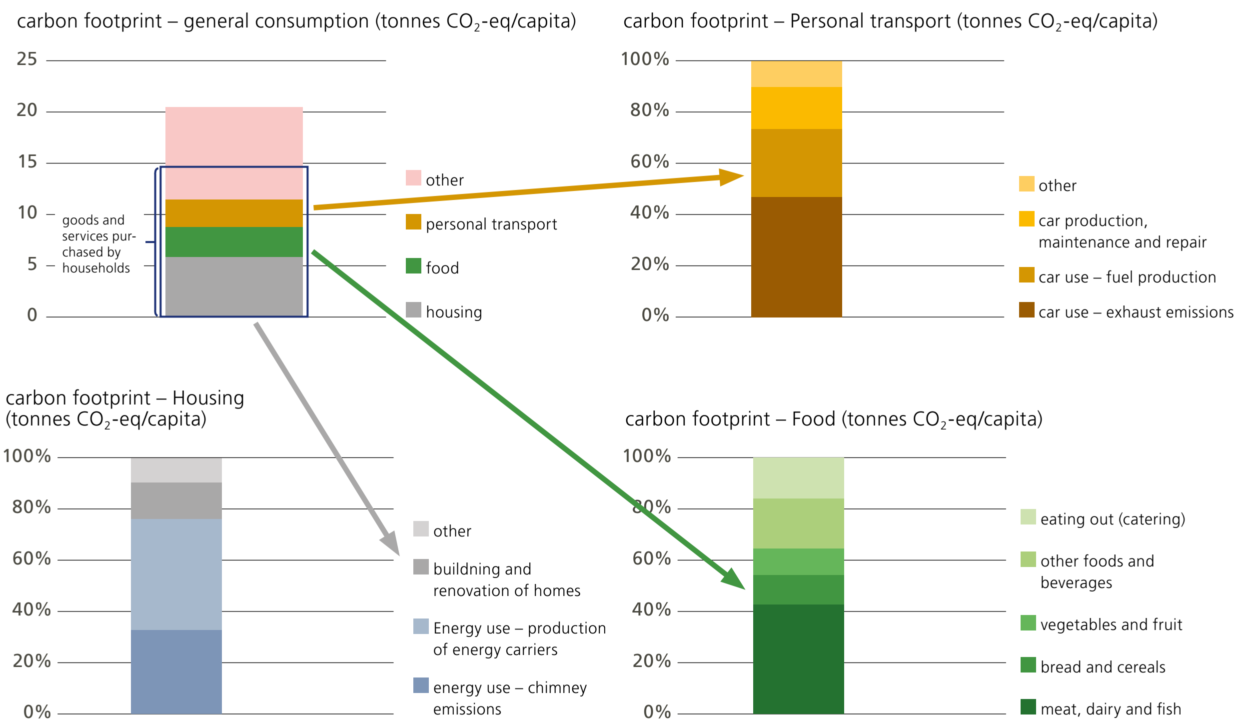


Figure 5.2. Carbon footprint for the region of Flanders, divided by consumption type.[34]

Further, a large share of this is generated outside Europe in regions where environmental standards are less strict. This "export" of carbon emissions explains partly why Flanders' carbon footprint increased between 2003 and 2010, while the carbon emissions within Flanders decreased slightly.

Material footprint

Metals are essential for society and the economy. The material footprint for metals for Flanders was calculated in 2007. When considering metal use across the whole production value chain, about 10 million tonnes (10 Mt) of primary metal ore was needed in order to fulfil the consumption demand in Flanders. The metal demand mainly consists of iron ore (3Mt), non-ferrous metal ores (5.7Mt), precious metal ores (0.97Mt) and special metal ores (0.275Mt). While steel is an important base material for a diverse range of applications, non-ferrous metals are essential for many sectors, such as electronics, renewable energy, energy efficient products, medical appliances, automotive, chemicals, etc.

The per capita consumption of primary non-ferrous metals and their ores is illustrated in the material footprint in Figure 5.3.

Sustainable consumption and circular economy

Our current resource use is unsustainable; we are consuming and extracting more raw materials than our planet can provide in the long term. The environmental footprint of modern middle-class lifestyles has steadily been increasing over the last century. And with business as usual, footprints are expected to increase even further during the coming decades: the size of the global middle-class will increase from slightly under 2 billion in 2009 to almost 5 billion by 2030.

Analysis shows that in order to reduce our footprint, shifting to a more vegetable based diet, reducing waste and saving energy at home and in transport are the most important actions we can undertake. Buying more local products also reduces environmental pressures abroad. The circular economy provides a way of using resources more efficiently. By using products longer, buying second-hand or recycled products, opting for dematerialized "services" rather than primary-material-based goods and by sharing products with more people, fewer new products need to be produced, resulting in a lower need for primary resource extraction activities such as mining. As such, circular economy strategies have the potential to contribute to a more efficient resource use and a reduction of primary resource needs. But, it is important to remember that it is not just a matter of making our consumption patterns more circular; we also need to think about the overall level of our resource use.

A vibrant social debate is going on about what level of consumption is needed for a good life and how much material, water, carbon, and land can be regarded as a "fair share" for each person on Earth, within the sustainability limits of our planet. For many regions of the world, especially in Europe and the US, this will require a significant reduction in footprint per capita and thus profound behavioural changes. In modern society, such behavioural changes are often difficult to achieve in reality, as the ownership of material goods is deeply ingrained in our psychological and social identity. In fact, we tend to use goods as extensions of our own self, reflecting our social status and who we are. As a result, in order to make our consumption behaviour more sustainable, it's vital to address the social logic of consumption as well.

Ores mined in one year to support the average consumption of one person

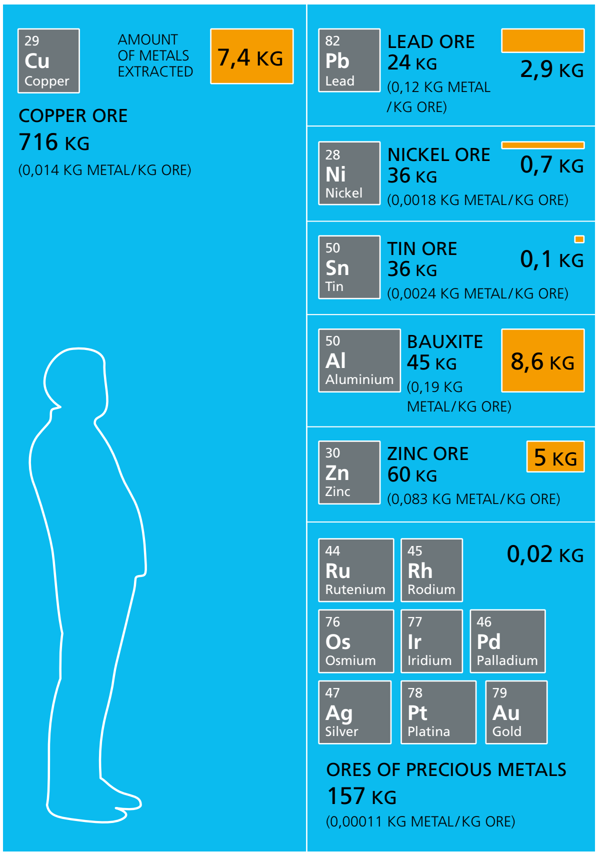


Figure 5.3. Material footprint of Flemish consumption, focused on non-ferrous metals.[6]

How can one define sustainable consumption?

Sustainable consumption means that the environmental footprint of consumption stays within the carrying capacity of the planet (the *planetary boundaries*), at global scale, and for some impacts at regional or local scale as well (e.g. water depletion). Unfortunately, the estimated maximum sustainable levels are difficult to estimate, highly uncertain, ambiguous and subjective. In 2014, a study estimated the global footprints and then compared them with their suggested maximum sustainable levels (Fig. 5.4, next page).[5] The inner green coloured circle represents the maximum sustainable footprint, while the red wedges represent estimates of the current global level of each footprint. From the figure it can be seen that the ecological footprint (expressed in global hectares) exceeds the estimated maximum sustainable level by about 50%, while the carbon footprint (expressed in CO_2-eq/year) exceeds its estimated maximum sustainable level by more than a factor of 2.

Sustainable consumption and well-being

The ultimate goal of society is to increase the well-being of its citizens. However, the question is whether a higher consumption pattern always leads to a higher well-being. As shown in Figure 5.5, well-being (expressed by the human development index of a country) levels off at a certain level of resource use (expressed by the material footprint of the country). This demonstrates that from a certain high level of well-being, additional resource consumption no longer improves the level of well-being.

Also, well-being encompasses much more than material concerns. As stated by Tim Jackson in the preface to his 2009 book *Prosperity Without Growth.*[35]

> *"It resides in the quality of our lives and in the health and happiness of our families. It is present in the strength of our relationships and our trust in the community. It is evidenced by our satisfaction at work and our sense of shared meaning and purpose. It hangs on our potential to participate fully in the life of society. Prosperity consists in our ability to flourish as human beings within the ecological limits of our planet. The challenge for our society is to create the conditions under which this is possible. It is the most urgent task of our times."*

5.3 THE GLOBAL VIEW

- Raw materials can have massive implications on a global scale, both for trade and for international diplomacy.
- There are a number of very problematic issues related to the mining, processing and later recycling of such materials in some countries with cheaper, but less developed, social systems.
- We must help develop raw materials production and recycling systems in less developed countries to become safe and beneficial. Equally important, however, is to work with countries that already can and do conduct operations responsibly.

Mining elsewhere and sending our wastes away

Today's material and product flows are truly global. Materials that make up complex products might be sourced from Africa, then shipped to Asia to be made into parts, and then moved on to Europe for assembly. As a single product can contain materials from all corners of the world, this means that products such as computers and phones are associated with environmental and social impacts – both good and bad – across the globe. With inputs from so many places, it can become very difficult to know where the materials we use in products come from, or how they were produced. And similarly, it is also very difficult to know where our products end up when we discard them. If we, as individuals and as societies, are concerned about sustainability, this means that

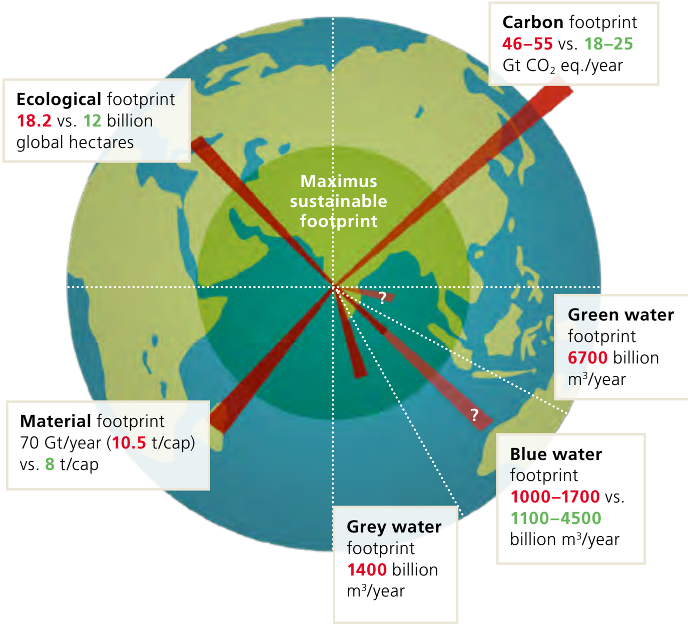


Figure 5.4. 2008 global footprints vs. the maximum sustainable footprint.[36]

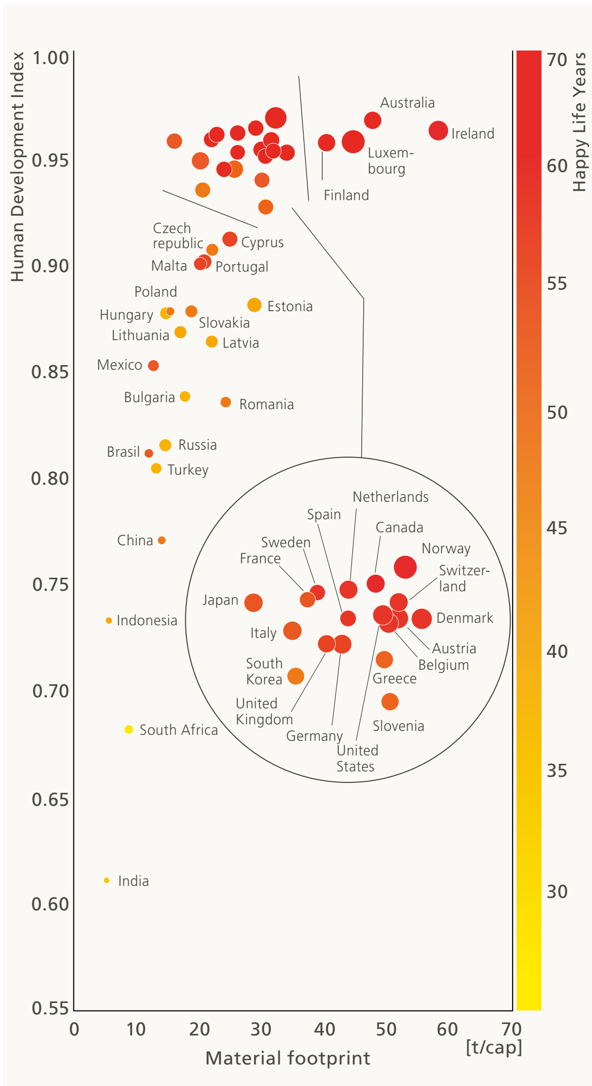


Figure 5.5 Human development index (HDI) as a measure of well-being versus the material footprint of consumption.[37]

we have to think more carefully about where we source our materials, and where we send our wastes.

Raw materials can have massive implications on a global scale, both for trade and for international diplomacy. For some particularly important materials, a few countries dominate the global supply. China for example, supplies the majority of *rare earth elements* (a set of seventeen chemical elements in the periodic table critical to many technological industries), magnesium, tungsten, antimony, gallium and germanium. Metals such as cobalt and tantalum are mostly sourced from the Democratic Republic of Congo and Nigeria. And other countries like Russia, South Africa and the US supply the majority of materials such as niobium, beryllium, and the platinum group metals.

Many of these materials are vital for a sustainable future, as they are used in products such as wind turbines, solar cells, communication devices, batteries and electric vehicles.

Supply situations where the sources of key materials are concentrated in a limited number of sourcing locations can be risky for companies and economies – if demand or supply changes quickly, then shortages or major price fluctuations can arise. Such risks become higher when the social, political or economic situations in source countries lack stability. Further, there are also some countries that have used their market dominance in ways that are damaging to other economies.

Such risks are made worse by our low recovery and recycling rates. We may depend on these materials, but instead of seeking to recover, reuse and recycle, often we discard large proportions in our wastes!

More circularity in our economies can help build resilience against supply restrictions. But that is not the whole story. We need to ensure that both the start and the end of raw material life cycles do not poison the environment or threaten society. However, this is exactly what is happening right now in a number of places that supply large proportions of critical materials to global markets. Serious environmental and health issues are also being caused in a number of countries that receive waste products that contain such materials – that have been sent there by other countries.

Rare earth elements and critical metals from countries with weak governance

There are a number of situations where global markets are dependent upon only one or two countries for the dominant proportion of supply for critical materials. Yet, we see a number of very problematic issues related to the mining and processing of such materials in some of the most important source countries. For example there has been significant international media attention for many years that has focused on human rights abuses, inhumane working conditions, and environmental degradation related to mining of metals in the Democratic Republic of Congo. There has also been similar attention given to catastrophic environmental degradation and human health impacts related to the extraction of rare earth elements in China's Inner Mongolia Autonomous Region.

Generally speaking, the underlying reasons are inadequate environmental regulation or enforcement of regulation, unsafe working conditions, or limited levels of technical development. Or indeed – all of these factors. In such governance contexts, the result can be that many operations will extract and process materials in ways that produce dangerous levels of pollution.

This all too often results in catastrophic damage from effluents, emissions, and residual wastes. These place society and environment at risk and will affect future generations. We even see examples where extraction of such materials in regions with poor governance has helped to finance wars, atrocities, or oppression.

A key issue in the context of this discussion, is that these are absolutely not the only places where such vital materials can be extracted! Many key materials are also present in countries that have effective regulations for work practices

and environmental protection, and that have advanced and environmentally safe systems for extraction, processing, and waste management.

A challenge for us all, however, is that many materials and products become more expensive when we take on the costs of good environmental and social practice. Avoiding the costs for clean and safe processes, waste management, and decent working conditions is one way to make materials cheaper, and hard to compete with. This is one part of why we see suppliers of cheap critical materials dominating world markets. However, the problems (and costs) have likely been shifted to the environment, to host communities, and to future generations.

If we are going to extract materials in a responsible manner, then we need to find ways to make sure that regulations are strengthened in all countries where we source materials, or we need to ensure that we only source materials from countries that have effective systems to protect society and the environment.

But sometimes achieving mining and mineral processing in countries with the more sustainable conditions described above is difficult. A contributing factor to this situation, is that stakeholders – particularly in wealthy developed countries – sometimes strongly oppose the presence of industries that they perceive as being "dirty".

As a result, we can end up with the apparently perverse situation where our societies demand the technologies and benefits that require special raw materials but our societies don't want them produced anywhere near home! Under such conditions, maintaining a strong and responsible raw materials sector can be difficult.

Process end of life products containing hazardous materials at home, or away?

Many of the products that we discard at the end of their useful life contain valuable rare earth elements and other critical raw materials. A particularly important product category is Waste Electrical and Electronic Equipment (WEEE), also called *e-waste*. Apart from potentially valuable materials, they can include hazardous substances like mercury, lead, cadmium and beryllium.

There are many good reasons to establish a good collection system for electronic waste, and to ensure that both valuable and hazardous materials, are captured and taken care of in the subsequent reuse and recycling process. In fact, many industrialized countries have developed systems to ensure that waste electronics are collected and recycled in an environmentally friendly manner.

We also have international rules to restrict the trade of hazardous waste. The most notable is the Basel Convention, on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (http://www.basel.int/). This global treaty came into force in 1992 and Basel mandates that hazardous waste should be taken care of as close to its origin as possible, and that when a country wishes to export hazardous waste, that country must obtain a written consent from the importing country. There are also regional conventions that go a step further and prohibit the exporting of hazardous waste from developed countries to developing countries.

But despite the existence of these national and international policy measures, electronic waste still flows to countries that lack good systems for recycling. The two main reasons for this is economic interests of actors and inadequate enforcement in both importing and exporting countries.

What makes the situation even more complex is that most of the electronic products are legally exported to developing countries as second-hand products. While the reuse of products is preferable in many ways, the problem is poor treatment of non-reusable parts and products in receiver countries.

When these products cannot be reused anymore and are finally discarded, many of these countries don't have the infrastructure and technical systems to take care of them in an environmentally responsible manner. And the recovery of the valuable resources is inefficient. This has resulted in serious environmental, health and social problems.

Taking responsibility for consumption of materials

Our common future requires large amounts of materials to build the infrastructure for equitable and clean development. But much of the pollution and damage that is caused by today's supply chains is a result of sourcing materials from unsustainable production systems – and then sending waste products that contain the materials away at their end of life.

Society needs more knowledge of the role of circularity in reducing resource dependencies, securing supply, and protecting communities. Sending our waste away to where it likely causes problems does not achieve this. In fact it causes multiple problems: human and animal health are put at risk, the environment is threatened, and significant proportions of valuable materials that could have been recovered are not. This last item in turn results in a situation that additional materials must be extracted to make up for those lost.

There is also a need for a range of societal actors to demand that all key materials are sourced from countries that have effective systems to protect their societies and the environment. Some of the stakeholders that need to be involved are companies working with their supply chains, policymakers and concerned consumers. We may have to reconsider our role as consumers and citizens as part of a society that demands new ways of production.

But it is clear that there are no simple solutions – for one thing, it seems these approaches may not result in raw materials that are the cheapest in the short term.

A key part of a sustainable solution must be to help develop systems in less developed countries, so that both their raw materials production systems and their recycling systems become safe and beneficial. However, a second and equally important part of a sustainable solution is to source from countries that already can and do conduct operations responsibly. The same can be said for the recovery of materials from end of life products. And this part of the solution very likely requires that wealthy industrialized countries – and their citizens – host more of these industries than they do today.

5.4 WHO OWNS IT?

- Remanufacturing can extend the lifetime of a product, but there are challenges involved.
- The challenges have to do with responsibility for the "new" product, liability, intellectual property rights, patents and trademarks, and market share.
- Our existing legal and market systems regarding these issues will have to evolve in order to facilitate a circular economy

Responsibility for a manufactured product

Remanufacturing can extend the lifetime of a product, but there are challenges involved; for example, when a third party remanufactures a product, who made the product? The original equipment manufacturer certainly designed the product, made the parts and assembled it together, but the third party company remanufactured it again. We see controversy in this area with hard drives that are extracted from used computers and put through a factory process that takes the hard drive apart, replaces worn or failed parts, reassembles and tests it, puts it in a box and sells it for new with warranty. The tensions between third party remanufacturers and original equipment manufacturers manifest in a variety of forms, described in the following paragraphs.

Liability – When this remanufacturing process is undertaken the product can be upgraded to improve performance. In that case who is liable for the product if it fails? Is the warranty of the original equipment manufacturer still valid? Might this situation have the potential to damage the brand name of the original equipment manufacturer? The original equipment manufacturer may not be responsible for the quality of the remanufactured product so it may have issues with the use of trademarks and brand name. This in turn leaves uncertainty about which logos can still be used on the product and packaging.

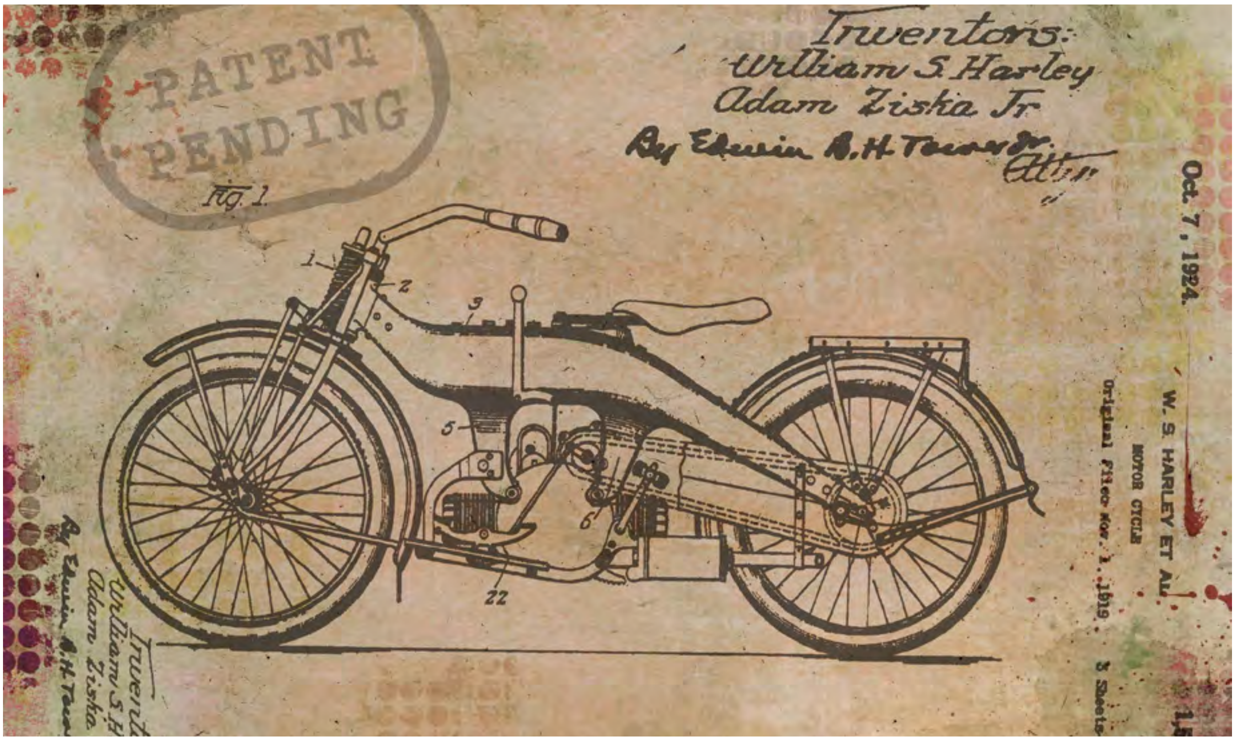
Intellectual Property Rights – Another challenge is that of intellectual property rights. This could be a barrier to the third party who needs information about the product or special tools in order to remanufacture

Market share – In some cases the third party develops a market that can be beneficial to the original equipment manufacturer, like opening up a new region. But in other cases the original equipment manufacturer sees the third party as stealing market share – what if people opt to buy the remanufactured products instead of new products?

Trademarks – As described in the paragraph about liability, the quality of the product can change after remanufacturing and there may be uncertainty about how brand logos and trademarks should be applied. It is generally advised that the remanufacturer places their trademark on the product itself and not only the packaging, so that it is clear that the product of the original equipment manufacturer has been remanufactured.

Patent infringement – In some countries, if a product is remanufactured, the original equipment manufacturer may have grounds for patent infringement. Therefore the remanufacturer is advised to check if a product is under patent protection. If a remanufactured product is defective the remanufacturer can face claims, therefore the remanufacturer is responsible for the product and for providing documents and support.

In the worst cases, these tensions can lead to legal disputes. But there is a better, circular, way forward. This can be pursued by setting up networks and alliances between original equipment manufacturers and third party remanufacturers. This can lead to business partnerships to the benefit of everyone in our circular economy.



Product user communities for repair

There can be tensions between original equipment manufacturers and product users when they repair and upgrade their own purchased products. To have more access to the knowledge and specialist tools they need, many users join online communities, and friction between these communities and original equipment manufacturers can develop. There are many such communities all over the world.

One example is the *Story of Stuff*, (www.storyofstuff.org) a worldwide movement about sharing information with the aim to reduce the number of products. It focuses on slowing consumption by sharing and serving the community. The movement also raises awareness about harmful products.

A second is *Hackerspace* (www.hackerspaces.org). This group set up creative spaces to co-create. It is a repairing community, and has its own philosophy on society and products. The Hacker Ethic is focused on freedom and open access of information. They embrace the concept of learning by doing and peer-to-peer learning.

A third is *Fablabs* (www.fablabs.io). This community focuses on empowerment through new technologies at the grassroots level and has a focus on the local community. Fablab is short for Fabrication Laboratory, and they are small-scale workshops offering digital fabrication, such as 3D printing.

Organizations such as *IFIXIT* (www.ifixit.com) provide support in the form of tools and knowledge, and support all communities in their repair activities.

We see an emerging and evolving topic in the tensions between people and companies. In a linear economy the situation is clearer, but the emergence of the circular economy is throwing up new challenges and tensions that we will need to resolve as we transition.

5.5 THE LOCAL VIEW

- Our lifestyles need to shift in support of sharing or repairing products, rather than each of us owning products we rarely use.
- Sharing is built around access-based consumption; we pay for access to the function, not necessarily ownership. Many resource intensive products, such as vehicles or washing machines, stand idle for most hours of the day, when multiple people could otherwise be accessing them.
- We need to make stronger efforts to repair or upcycle things that are broken, rather than replace them. In part, this relies on products being designed for easier repair.

The circularity principle has been applied at many different levels. It's important to remember that circularity (closing resource loops) and resource efficiency (narrowing resource loops) need to go hand in hand if we are to bring our consumption within global limits. This requires deep social shifts, such as re-organization of individual lifestyles by people joining, sharing and repairing communities. In this way, collaborative consumption and production are fast entering our everyday lives. Examining a number of the underlying issues associated with our consumption patterns can cast light on why this is so.

Sharing

Many goods stay idle for most of their lifetime. For example, the average European car is used for only 29 minutes per day. This means that over an average 12-year lifetime the car is used in total for only three months. Households own an increasing number of products and equipment, much of which is rarely used. In the UK and the US the items that people use less than once a month amount to 80% of all the items owned, and 30% of clothes bought by British households are never worn. Other developed countries show similar trends.

So if we know that many goods are already out there, and they have a large idling capacity, why do we need to produce more? Why not improve or optimize the use of goods that have already been produced instead? The whole idea of sharing is built around access-based consumption and functional thinking. Instead of viewing a product as a consumable, we can instead consider the function or value the product can deliver, and if we can get the same value by accessing the product instead of owning it.

This is nothing new! Libraries full of books for example, have existed for a very long time – in such a case, a central actor (the library) mediates the shared use of books. During a book's library lifetime it may be read by many individuals. What is now different is that we see more examples of sharing between strangers utilising new forms of mediation. Such new methods of sharing is generally mediated by digital technology and occurs in a variety of consumption domains including fashion, mobility and accommodation. Some examples of these are "swap shops" for clothes and accessories, car sharing organizations like Drivy (Now owned by Getaround: www.getaround.com) and Uber (www.uber.com), and home sharing platforms like BeWelcome (www.bewelcome.org) and AirBnB (www.airbnb.com).

Sharing's contribution to a circular society

Let's look at an example of how accessing goods instead of owning them can contribute to a reduced environmental impact from our consumption. In the European Union over the last two decades, the average specific electricity consumption of all large appliances (except TV-sets) has been decreasing steadily since 1990. This is because appliances that are more energy efficient are now offered on the market. Energy efficiency improvements have reached almost 40% for washing machines and dishwashers, and around 30% for freezers, refrigerators and dryers. (For TV-sets, the increase in energy consumption is due to the diffusion of larger TV-sets). Large appliances are on average 25% more efficient than in 1990, with countries like Germany, Sweden and the Netherlands registering very strong progress (Fig. 5.6).

At the same time, almost all energy efficiency gains have been offset by an increase in the equipment ownership (Fig. 5.7). In other words, even though people own appliances with higher energy efficiency, they also own more appliances overall. As a result, the electricity consumption per household of large appliances was only slightly lower in 2009 than 1997.

Environmental impacts occur not only in the production and the use phases of these appliances but also in their end-of-life, when the old appliances need to be recycled or disposed of. In addition, some appliances like washing machines and dryers often have considerable idling time – for example, standing idle for a week or so, waiting for a new batch of laundry to be loaded. We also see some

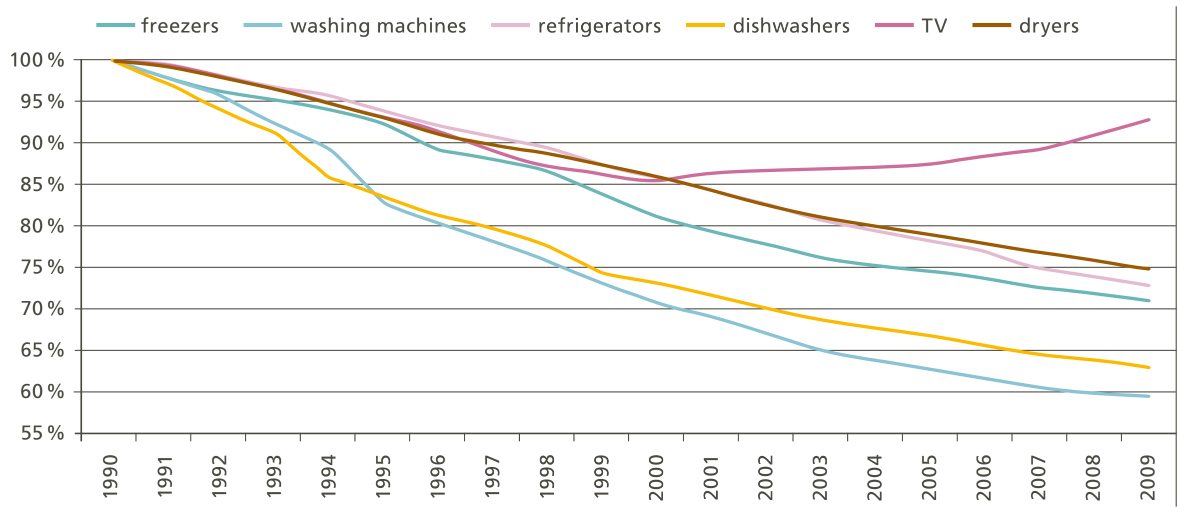


Figure 5.6. Evolution of specific energy consumption of large appliances (the base is 100% in 1990).[38]

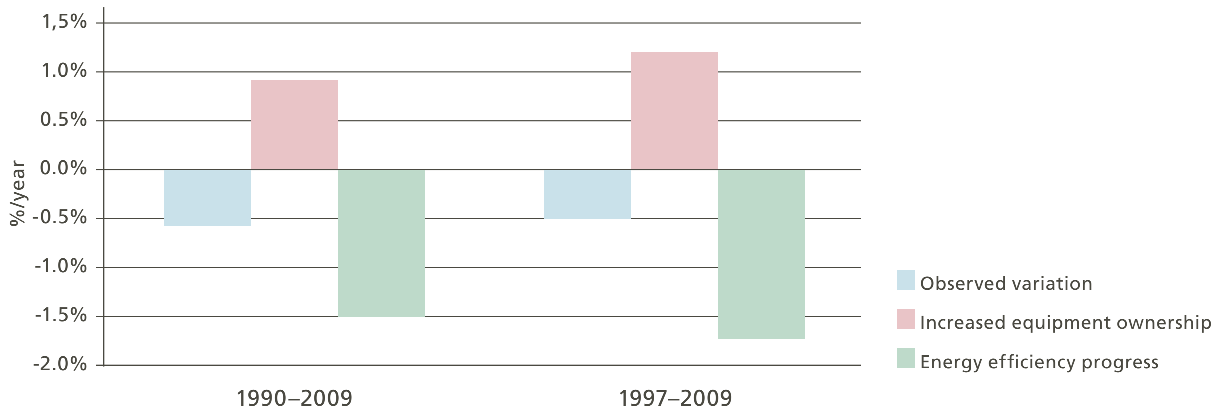


Figure 5.7. Decomposition of change in the use of large appliances.[38]

households owning an extra freezer, where people store frozen fruits and berries, pre-cooked food for parties etc. The net throughput, and thus effective use in this scenario is low, and thus equivalent to idling (Fig. 5.7).

If we owned fewer appliances instead, and could ensure that people get access to them when they need them, we could optimize the idling capacity of these appliances so that they are used more frequently. In addition, we could choose appliances of higher quality and efficiency, and the ones that have a longer lifetime. Having fewer, more efficient and more durable appliances would help keep production at lower levels. Such actions would save resources, and reduce environmental pollution and waste generation in the production phase. Since fewer appliances would be in use, this would also reduce the need for the end-of-life waste management and would decrease the associated environmental impacts. Overall, sharing appliances could help us contribute to a more circular society.

Sharing, *sharing economy*, the *peer to peer economy* and *collaborative consumption* are just some of the terms used to describe a variety of bottom-up initiatives, public-private-people partnerships, business start-ups and local government schemes, all of which seek to utilize more of the available idling capacity of our material world. Sharing is seen as one potential answer to the unsustainable patterns and levels of production and consumption. It can also be attractive for individual consumers as they can get easier access to products that are normally difficult to find or very expensive to buy, such as higher quality products, luxury goods and rarely used products.

Repairing

While some goods stay idle, others are thrown away too soon. Short product life cycles intensify the throughput of resources in the economy and aggravate environmental and social impacts. For every bin of waste that a household produces, many more bins of waste were made upstream. So even if we could recycle 100% of our household waste, it does not get us to the core of the problem.

One of the reasons that products are thrown away is because they physically fail in some way. Often the faults are minor but users are reluctant to consider repair options due the high cost of repair in relation to the low cost of a new good, or due to a desire to obtain the latest model of a product instead. Activities such as upcycling and repair offer valuable alternatives to the wasteful culture that mostly wealthy societies have created. In addition to being consumers, individuals can assume an active role in creating a circular society by repairing and upcycling products, from upgrading electric and electronic equipment to refurbishing houses and repairing bikes and cars. Examples of places where individuals do this collectively include repair cafes and bicycle kitchens.

Example: how repairing contributes to a circular society

The bicycle kitchen (Cykelköket) (www.cykelkoket.com) in Malmö, Sweden is a community-based workshop for servicing and repairing bicycles. Everyone is welcome to join the bicycle kitchen; registration is not required and there is no membership fee attached. The workshop does not offer services where customers can buy bicycles or leave their bikes for repair. Instead, the users may borrow tools to fix their own bikes. There are also staff members and volunteers to ask for advice, if one is unsure how to fix the fault or which tool to use. The bicycle kitchen also collects donations of old spare parts to be used by visitors (Fig. 5.8, next page).

How do the activities at an initiative such as a bicycle kitchen contribute to a circular society? Repairing items such as bikes, furniture, clothes and other personal belongings allows us to use them for longer, thus avoiding the purchase of new items and the production of new goods. This saves resources and energy, and waste is reduced both related to the production processes and by avoiding the premature disposal of still functional items.

The fashion of fixing things is being spurred by digital technology. Sharing knowledge and skills online is now easier than ever, through platforms like Youtube, Fixperts and Instructables. Individuals are actively co-creating new production-consumption systems with the help of diverse stakeholders like start-up businesses, municipalities or social innovation hubs. They reframe their everyday consumption practices to include serious leisure projects, repair services, and upcycling strategies. These often have a so-called pro-social purpose.

Figure 5.8. Spare wheels and wrenches for sharing in *The Bicycle Kitchen* (www.stpln.org/cykelkoket) in Malmo, Sweden.

Sharing and repairing more

Despite the potential of sharing and repairing to foster circular societal shifts, these activities are still marginal, and unsustainable lifestyles continue to dominate. To make sharing and repairing normal and embedded in our everyday lives, our perceptions need to change. People will also need to accept that it is perfectly okay to wear someone else's clothes or drive someone else's car, and this can be equally as fashionable and comfortable as wearing new clothes or driving your own car. People will also need to accept that it is quite normal to repair their smartphones, laptops or bikes. You can do it yourself or, even more fun, with some help from your neighbours, colleagues, friends or co-citizens.

But how do we go about achieving such a norms shift? As a starting point, it is generally agreed that there is a need to better understand the potential contribution of sharing and repairing to environmental sustainability, economic prosperity and social cohesion, as well as the socio-economic and environmental risks that these activities might bring. A balanced understanding provides proponents of the circular economy a basis for both action and communication.

From an economic perspective, by participating in sharing and repairing, individuals can save money since they don't have to buy as many new products. They can also earn money if they rent out their possessions, or help others with repairs. Since sharing systems are mainly local, they have real potential to contribute to local community development and economic growth. However, this is not without controversy, as uncertainties remain on how the profits should be distributed, and in what ways these new models affect established businesses. There is also no universally accepted practice on how to incorporate profits created from sharing into the formal tax system, which often places them in a "grey" legal area. Such areas remain works in progress in many countries, and resolving such issues is important to the future progress with the Circular Economy.

From a social perspective, by participating in sharing and repairing, individuals can build social connections, improve communal well-being and in this way build social capital. On the other hand, concerns have been raised about, for example, public safety, privacy and limited liability of sharing organizations. Again, such questions need to be resolved.

From an environmental perspective, we need to produce fewer goods. This would reduce the use of raw materials and energy, and generate less waste and emissions. But sharing could also stimulate consumption. If sharing does not substitute consumption, but rather adds to the consumption portfolio, there is always the possibility that society might end up with more consumption, and a higher demand for production. And there is also a risk that the money people save through sharing and repairing will be spent on environmentally detrimental things such as long-distance journeys or larger dwellings. Active consideration of such *rebound effects* is doubtless part of the learning process in the pursuit of a circular society.

Sharing and repairing activities can also foster circular societal shifts at individual and community levels. But to realize this potential, society need to be aware of associated risks, and find ways to circumvent those while maximising the benefits of sharing and repairing.

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5.1 CIRCULARITY'S VALUE TO SOCIETY David Peck – Delft University of Technology, The Netherlands and Karl Vrancken – Sustainable Materials Management, VITO, Belgium.

5.2 ENVIRONMENTAL IMPACTS OF CONSUMPTION Saskia Manshoven – Sustainable Materials Management, VITO, Belgium.

5.3 THE GLOBAL VIEW Philip Peck and Naoko Tojo – IIIEE, Lund University, Sweden.

5.4 WHO OWNS IT David Peck – Delft University of Technology, The Netherlands.

5.5 THE LOCAL VIEW Yuliya Voytenko Palgan – IIIEE, Lund University, Sweden.

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