Preface

SOME PEOPLE work with the Circular Economy every day. But many of us have lots of questions.

A simple question that we often hear is WHAT is the Circular Economy? We also consider other questions to be important. we shall be addressing many throughout this compendium... just as we do throughout the Massive Open Online Course: Circular Economy: Sustainable Materials Management. You can access the course at www.coursera.org/learn/circular-economy. This compendium directly supports that course.

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. Simply stated, not enough of our materials are derived from the resources that we’ve already extracted. This approach in turn demands that our materials are derived from the resources that we’ve not re-using nearly enough. Simply stated, not enough of the emerging circular economy. We choose to place knowledge so that many more of us can create a path forward.

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 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 billons 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 have. 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 a range of 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 eco-design; 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 help 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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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 MINING

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’.

But 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 sort 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 Avlyakan 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. 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
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 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 1.1)

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. Thus, a concentrate of the valuable recovered minerals is produced. This is generally a mineral powder that contains the mineral that we want at concentrations that are suitable for subsequent metallurgical processing.

The concentrate or metal is then transported to places where it is 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.

Mining 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 is material of little or no economic value that is left over when we have extracted the desirable mineral from the ore. It is 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/elements. 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. And then very importantly, to the use of the post-mine 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 potential negative impacts from 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 both the mining stages, and then also when processing operations have closed.

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 should therefore 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)
3. Ensure that environmental resources are not subject to

ground conditions:

[Image 14x515 to 581x828]

3. Mineral ore bodies are finite and all mines reach the end of mining.

stage it may be too late. Rather, planning for mine closure ideally should be done at the time of planning the start of mining.

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.

1. Rocks and ores are not at ‘equilibrium’ when brought to the surface and can become chemically and physically unstable when exposed to surface conditions. This bears with it that they can potentially release eco-toxic substances. Unless planned for, prevented, or contained, such processes can cause damage that lasts for very long periods of time.

2. 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 mine site can 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.

3. 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.

1.2 MINING AND SUSTAINABILITY

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 up to variable to achieve environmental performance that can be considered sustainable.

Boundary conditions for sustainable mining

Throughout the history of mining all the way up to 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:

1. Maximize socio-economic benefits.


3. Ensure that environmental resources are not subject to physical and chemical deterioration.

4. 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 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 planning should not be done close to the end of mining – at that stage it may be too late. Rather, planning for mine closure ideally should be done at the time of planning the start of mining.

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1.3 FROM MINING TO METAL – THE SUPPLY CHAIN

- 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)

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% 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 percent 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, 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

Generally 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 also impacts 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 can’t 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’.

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. Firstly, this information allows us to better understand the social circumstances related to the material flows, 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.
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 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.

1.5 CRITICALITY AND CIRCULARITY

- Raw material supply security has been central to economic systems since early civilization and the modern concept of ‘critical materials’ arose in the 1930s.
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- The material complexity of products, has drastically increased.

Understanding the complexity of material access

This global reach of so many different raw materials that supply industries, that in turn feed into segments of the Global Value Chain, has greatly increased complexity and makes it difficult to understand trade and how to access materials. 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 goes much further than just to 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 more challenging. And it makes accessing information about their trade more challenging too.

Knowing where and how to access materials – and being able to access them is important for our economies – this 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 U.S. government authorized stockpiling of materials for national defence 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.

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 high-tech metals. 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 horizontal axis and a measure of vulnerability and economic importance on the vertical axis.

Supply risk is defined as ‘the risk of a disruption in the EU supply of the material’. It’s derived from examining 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, as well as, to some degree, substitution, of the critical materials could contribute both to reducing supply risks and to shaping a circular economy.
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. Eurostat, the statistical database of the EU, is commonly used to derive this data.

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 the light and heavy rare earths 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 can provide insights from a global perspective on which countries have the largest supply share of a particular raw material. (Fig. 1.9)

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 the impacts related to the delivery of materials to global value chains. For each portion of materials value chains that have been addressed, an explicit link has been drawn to how working to address this issue can contribute to a systemic change towards a circular economy.

For each portion of materials value chains that have been addressed, an explicit link has been drawn to how working to 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 aluminum that went from ore to fabricated products with orders of magnitude increases in value along on the way.

Now let us relate this back to the very reason we are here – being a part of a broad social and economic transition to the circular economy – and as a scene setting for the chapters that follow, the concept of value and function preservation embodied in the Circular Economy, and the theme of transition are introduced.

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. (Fig. 1.10, 1.11)

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. Digitalization 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 an example of such.

The circular economy needs new business models in order to translate circular strategies into competitive advantage, resilient 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 use things.
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 are material losses in each step of the chain. We can minimize the losses through recycling, either back to the front of the cycle or 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 requires 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 inert 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 develop ‘inner circles’, where we manage the products and materials that we have in a different way, and dematerialize things.

The outer circles refer 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, but it can be reused, we can create a loop back to the distribution phase, and provide a second lifetime to the product. (Fig. 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.

AUTHORS and PRESENTERS CHAPTER 1: MATERIALS

1. MINING Konstantinos Modis and Daphne Sideris – Mining and Metallurgical Engineering, National Technical University of Athens, Greece.
2. MINING AND SUSTAINABILITY Philip Peck – EEE, Lund University, Sweden.
3. FROM MINING TO METAL Paragiosi Diamos – Mining and Metallurgical Engineering, National Technical University of Athens, Greece.
4. VALUE AND GOVERNANCE Erika Fager – GEUS, Denmark.
5. CRITICALITY AND CIRCULARITY Erika Fager – GEUS, Denmark.
In this chapter circular business models are explored in-depth and a range of ways for business to create economic and social value are discussed.

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 issues 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. Here, we present three key approaches applied as we seek to address this – strategies to narrow, slow, and close resource loops. The central 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.

Three key strategies

Narrowing Loops
In a business sense, ‘narrowing loops,’ is about reducing the amount of materials needed per product or service. Filling 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 save costs.

Narrowing loops is an essential strategy in a circular economy, but narrowing strategies may not account for what happens after the product 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.

First and foremost 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 – and 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.

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. 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 slowdown of the flow 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. 2.1)

Closing Loops
After many cycles of reuse we need to closed the loop and recycle. Central to successful loop closing is to avoid the mixing, or cross-contamination, of materials. Braunagel and McDonough in their seminal work on the Cradle to Cradle concept, already referred to separating technical materials from biological 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 ReBlending 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 and 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. British automotive start-up Riversimple’s prototype car only weighs 580 kilograms, 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 an access to a car, which also helps with slowing and closing loops. (Fig. 2.2, 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 ‘slowing loops’ example are businesses who 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, which experiments with business models to slow consumption. This project aims to incentivise 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. That which is really novel here is that this test project also seeks to change user behaviour by incentivising fewer and lower temperature washes. Customers only pay when they use the washing machine and they pay less if they wash at cold temperatures.

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. Outdoor company Patagonia’s Common Threads Initiative encourages people to consume less, and instead repair, reuse and recycle clothing. The company’s famous ad in the New York Times, “Don’t buy this jacket,” is an 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’, resulting in a circular flow of resources. In major industries like paper, metals and plastics, recycling rates 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 for example makes new sports fields out of old shoes and G-Star’s “Raw for the Oceans” turns ocean plastic into new garments. Interface Networks makes new carpets out of old fishing nets, and they also work with 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, Gunter Pauli is famous for his work on the “Blue Economy” and creating multiple ‘value cycles’. For instance, mushrooms can be grown using coffee waste and salad crops can be fertilized with 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, the first firm in the world to ‘lease jeans’ to customers, with 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 2.3)

To achieve this goal, the circular economy requires innovations at the technology, business model, design and value chain level with clear circular intent, followed by assessment of actual impact.

2.2 THE NUTS AND BOLTS OF A CIRCULAR BUSINESS MODEL

What is a 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.

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. (Fig 2.4)

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 Inc.’ can be used to help clarify how these fit together.

A value proposition dimension consists of three elements: customer segments; customer relationships; and the actual value proposition. The value proposition being the value that

Innovating business models

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 and secure partner networks or capabilities that are required to successfully preserve and utilize the embedded value in

Figure 2.2 The Riversimple Rasa prototype vehicle.

Figure 2.3 The ‘value hill’ in linear and circular economies.
resources. Business model innovation can help businesses devise an offer and value proposition that proactively embeds a circular strategy to prolong the useful life of products and parts or close material loops. By rethinking the three value dimensions; for example, how value is created, delivered, and captured (Table 2.1), business model innovation provides a more holistic approach when seeking to align the value creation logic of the company with principles of circularity.

The Business Model Canvas
When we design ‘circular’ business models, we seek specific changes in our economy’s resource flows. We want to move away from linear patterns and implement actions that narrow, slow, and close resource loops. This requires that companies innovate their business models. A key approach utilized in business model innovation has been the visualization of business models. Visual business model representations reduce complexity and reveal tacit structures. In turn, this helps actors to understand and communicate the current business model, generate and develop new business model ideas, and remove obstacles to innovation.

A framework for supporting work with business models that has been acknowledged for its practical relevance is the “business model canvas” by Osterwalder and Pigneur. The authors distinguish nine business model elements that describe three value dimensions (Table 2.1).

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 partnerships.

A note about value creation in circular business models
The processes and sources 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. To effectively implement these, and create a net positive environmental and economic outcome, business model elements need to be devised with the respective circular strategies and interventions in mind.

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 redefinition 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.

2.3 KEY STRATEGIES FOR CIRCULAR BUSINESS MODELS

- There are 3 key ingredients for a company applying circular business models: engage in circular value creation; use value propositions that enable circularity, and be embedded in circular value network.
- Success of a circular business model depends on intelligent combinations of circular value creation strategies, value proposition strategies, and value network strategies.
- Providing services to the customer instead of selling the product is a key strategy to create a circular economy.

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 will 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 business circular ‘business’.

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.

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 its leisure bags and purses: the design clearly emphasizes the origins of the waste materials they use. (Fig. 2.6 A)

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, as 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 to manage their copy machines like assets.

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 undeniably 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, 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

Though no official link exists, it is possible to connect the three ingredients to the Business Model Canvas components, helping 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.
- **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 highly valuable 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.

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 sending the phones to a recycler.

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. 2.7)

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

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**Circular Value Creation**

**Value Proposition enabling circularity**

**Circular Value Network**
The ‘Circular Business Model Planning Tool’ 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. The tool integrates the three value dimensions discussed earlier (‘value proposition’, ‘value creation and delivery’, and ‘value capture’) and their business model elements.

Further, it applies four lifecycle interventions:
1. collect and reintegrate;
2. first sale (enabling prolonged useful life);
3. additional sales of the product or parts;
4. material recovery. (Fig 2.9)

As the tool is built from the principles within the business model canvas of Osterwalder and Pigneur introduced earlier, the Circular Business Model Planning Tool, is also referred to as a ‘canvas’ – but it is now essentially a ‘circular business model canvas’.

It is important to note (see Figure 2.10) 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, and
- the management of value networks and partners.

As an aid to business model innovation, visualization tools that depict circular business models can be used to help plan product life cycles that can 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 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 her in addressing the customer’s need. In such a model, the consumer, and decides which product or products can help her in addressing the customer’s need. In such a model, the consumer is not the provider does not sell or lease products anymore, but provides the consumer with the tools to enable 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. It is up to the company to take advantage of these tools in setting up circular value chains.

The ‘Circular Business Model Planning Tool’ 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. The tool integrates the three value dimensions discussed earlier (‘value proposition’, ‘value creation and delivery’, and ‘value capture’) and their business model elements.

Further, it applies four lifecycle interventions:
1. collect and reintegrate;
2. first sale (enabling prolonged useful life);
3. additional sales of the product or parts;
4. material recovery. (Fig 2.9)

As the tool is built from the principles within the business model canvas of Osterwalder and Pigneur introduced earlier, the Circular Business Model Planning Tool, is also referred to as a ‘canvas’ – but it is now essentially a ‘circular business model canvas’.

It is important to note (see Figure 2.10) 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, and
- the management of value networks and partners.

As an aid to business model innovation, visualization tools that depict circular business models can be used to help plan product life cycles that can 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 Fairphone circular business model

Filling out the Circular Business Model Planning Tool using details from a mobile phone manufacturer and distributor named Fairphone, provides an example of how it can be applied in practice.

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. (Fig 2.10)

As part of their business model, Fairphone has an intertwined relationship with a collaboration partner named Teqcycle; 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.

Explore further – ‘The Circulator’

To help you with the design or analysis of a circular business model, the Circulator has been developed. This can be found at www.circulator.eu. This web-based tool allows you to explore circular strategies, and to combine them according to your own preferences. (Fig 2.11)

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2.5 MAPPING THE BUSINESS AND SOCIAL ENVIRONMENT:

- **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. For this change 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 6 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.

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Figure 2.11 The ‘Circulator’ – an example of a circular business model tool.
Examining today’s drivers and barriers for circular economy business.  

Drivers  

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 analysis provided in this chapter is a good springboard to 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 repairers. This is 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 systems. 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 multi-stakeholder initiatives 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 help 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. Stronger 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.  

Barriers  

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 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. There may not be established practices to fairly judge the value offerings. Or, they can be external, meaning 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 now when activities focused on reuse enter the market competition is set up between two systems.

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.

Technical barriers can also 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.

Circular business models must contribute to the cycling of products and materials and replace primary production in order to contribute to environmental sustainability but at present there remains uncertainty in some situations about whether there are actually environmental benefits associated with circular offerings under all circumstances. Even though it is expected, that environmental benefits dominate, studies have shown that this is not guaranteed. Such uncertainties have been observed to slow the adoption of circular business models.

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.
This chapter presents functional materials, eco-design and methods to assess environmental impacts.

3.1 DESIGNING MATERIALS FOR A CIRCULAR ECONOMY: OPPORTUNITIES AND CHALLENGES

- 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 stimulating new waves of innovation are many – 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 through time. 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.

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, but 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 such as ‘environmental friendliness’ or ‘recyclability’, 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, in particular 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. Later, that was reinforced by demands to reduce CO2 emissions. These factors spurred the replacement of some steel body components with lightweight 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 lightweight 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 lightweight materials. This has created more demands 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 ECO-DESIGN STRATEGIES

- There is an increasing demand for society and its decision-making systems to evaluate and design products to their potential as circular materials.
- Sustainability is seen as a product feature, and the circularity of a material is seen as an added value.
- One of the main tools in the circular design box is the eco-design.

Why eco-design? Eco-design is an umbrella term that incorporates several sub-strategies that companies can use to improve the environmental performance of their products. Eco-design 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 eco-design. One is to comply with present or upcoming regulations. Another is to save costs by being able to use recycled materials. Businesses might also attract customers willing to pay a premium price for environmentally superior products.

Building on the idea of eco-design, a product’s entire lifecycle must also be examined in the design phase when designing for circularity. To help ensure the reuse of products and their parts, products should 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 robust, 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.

Strategy 3: Design for standardization 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 requiring a unique charger or each.

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 and how parts are designed 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 modifications. 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 updating 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 it 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 material management. These are design for recycling and design for dematerialization.

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 dematerialization. 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 dematerialization, the product may actually be replaced by a service – and approach that typically consumes much significantly less resources. One example of this is the move toward streaming films instead of producing DVDs or Blu-ray disks.

### INTRODUCTION TO NANOTECHNOLOGY

The word “nanos” means “dwarf” in Greek, and many people associate nanotechnology with something that is small. In fact, no component of a nanoscale object is more than a nanometre in size. Yet, our 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. This is different from atomic physics, where the only 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 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 to the power of minus 3 metres (10^-3m)’, 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 mm, 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 ten to the power of minus 6 metres (10^-6m). 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 micrometres wide, but often micropores are required to study micron sized structures. Other examples of micrometre sized structures are red blood cells, around 8 micrometres wide and 2 micrometres thick, and bacteria, which often have a size of between half a micron to five 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 ten to the power of minus nine metres (10^-9m). 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, 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 can easily climb walls due to a large number of small nanostructures on their feet, each one giving rise to a tiny force, that when added together creates a force strong enough to carry the weight of the gecko. 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 or electricity or light is applied to them, a feature that is utilized in quantum dot
television – 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 contrast agents. So in addition to its size (very very small) 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 is the top-down approach, which 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. Innovative bottom-up approaches becoming established in the field are described here. Even at such tiny scales, and dealing with specialized substances, efforts are being pursued to create low waste, energy efficiency production techniques.

Semiconductor nanowires are rod-shaped, one-dimensional structures with a nanoscale diameter, and they have the potential to radically improve future electronic devices. In the production of nanoparticles and nanowires 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.

The nanowires are formed 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 way that can be even more 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. This makes it an extremely material efficient production route. (Fig 3.1)

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. 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.

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.

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

- Environmental life cycle assessment can be used to assess whether a new product or process can contribute to a more sustainable society.
- Circular systems do not by default lead to environmental improvements.
- 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 3.2)

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, it is necessary to 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 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). Instead of just considering the process of producing the circular product, it considers all processes throughout the entire life cycle of the product. The assessment starts from natural resource extraction and ends...
A life cycle assessment accounts for all the resources consumed and the substances emitted during the life cycle of the 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. 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 3.4)

The first step. Goal and scope. 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 includes:

- The selection of the product for assessment. In this instance, a product can be either a physical product, or a service.
- A functional unit is a certain ‘measure’ of the amount and the quality of service delivered by the studied product. Or in other words, the functional unit is a measure of product 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 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, an important issue is to make sure that the same steps in the life cycle are included for both products.

Second step. Inventory analysis. The second step of an LCA is an inventory analysis. This consists of inventorying all inputs that used along the product’s life cycle, and resulting outputs. These include inputs such as raw materials and energy, and outputs such as by-products and waste. This step is the most time-consuming and data intensive. Data can be collected based on measurements, information received from companies, literature, modelling, and more. As this data collection can be quite labor intensive, databases have been created to provide the life cycle inventory data of certain products. For example, if a product requires 1 kWh of electricity for its production, databases can provide the complete life cycle inventory for electricity from many possible sources. Such includes all steps from resource extraction via generation activities through to delivery of the electricity via power grids. Examples of databases are the Ecoinvent Database, the Agri-footprint Database and the European Reference Life Cycle Database. Data quality may vary rather significantly so it is important that an analyst always validate the data chosen by comparing it with literature, or similar studies.

Third step impact assessment: 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 emitted and consumed by a characterization factor. However, the various flows that have been inventoried do not have 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, characterization factors are defined for each contributing flow.

Last step: Interpretation & reflection. 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, sometimes even subjective choices have to be made. All of these influence the final outcome in some way and need to be clearly communicated.

How to deal with recycling and multi-functionality in LCA

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 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 can be recycled to fulfil the same function as in its previous life, which is called closed-loop recycling. It can also be recycled to fulfil another function – often at a lower quality. In this case we talk about 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 to 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 3.6)

The definition of the functional unit plays a role in determining the boundaries of recycling and in assessing the environmental impacts of recycling. The functional unit is therefore reduced to 25 kg CO₂ equivalent per functional unit. Hence, the recycling withdraws this impact from the phone 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.

Figure 3.6 Contributions to impact and net impact.

It can be seen that the impact of the phone’s production (extraction of raw materials, transport, and manufacturing) is 30 kg CO₂ equivalent per phone, the impact of the use phase is 2 kg CO₂ equivalent per functional unit and the recycling process is 3 kg CO₂ equivalent per functional unit (in total, 35 kg CO₂ equivalent 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 CO₂ equivalent per functional unit.

The use phase and the recycling process (in total, 35 kg CO₂ equivalent per functional unit) 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. 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.

Limitations of LCA

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 thereby 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 do have real value and support decision-making, the respective outcomes must be regarded as estimates and not as certain facts. 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 in mind the difficulties and uncertainties.

Software for LCA

Since conducting an LCA is a time-consuming task, software programs have been developed to help in this matter. Simapro and OpenLCA, which is freeware, are two examples. In these programs, databases and different impact assessment methods can be selected. 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...
Life cycle thinking

Life cycle assessment

only an informal consideration of the environmental stresses that occur over a product or process life cycle. This spectrum is illustrated in the figure above. (Fig 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.

3.6 ASSESSING RESOURCE EFFICIENCY

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

Many parts of the world face a huge challenge related to the supply and efficient use of resources. The global population is growing and market 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.

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 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”.

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 measure helps the management of such efforts, it is also a vital input to avoid “green-washing”, a practice that can create consumers doubt and distrust. It also helps prevent unexpected side-effects that could negatively affect 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. It begins with focus on “Resource Productivity”, which is the ratio between the Gross Domestic Product and the Domestic Material Consumption. 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. In Figure 3.8, below is the example of the Domestic Material Consumption of Denmark, 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 and those that are extracted within Denmark. They are represented here 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. (Fig 3.8)

Hence, the Domestic Material Consumption of Denmark is the amount of materials imported and extracted in Denmark, minus the amount of materials exported. However, when a research department or a company wants to develop an innovative circular product, resource efficiency indicators other than those defined at macro-level for Europe are necessary. Unfortunately, there can be confusion about the term “resource efficiency”, and unfortunately, 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.

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 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 used in industry and engineering, as resource consumption is the starting point for all economic production and consumption activities. (Fig 3.9)

As a developer of a new circular product, following the strict definition of resources makes more sense. Of course, even if it does not fall into the term of resource efficiency evaluation,
is becoming more and more scarce around the world, is land. This should 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 should 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 of the benefits obtained by Europeans from the use of resources (Gross Domestic Product) over 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 a production plant, an industrial sector or a 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 users, as you can see on figure 3.10. 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 it 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 consists of following a life cycle perspective. In this 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 3.11) 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.

A real study in the chemistry 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 3.12)

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

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, in recent times, it has been proposed that there should be a classification of methods to evaluate resource use in Life Cycle Analysis (LCA) according to two principles:

- 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\footnote{Exergy is the maximum theoretical work that can be obtained from a system brought to equilibrium with its surrounding environment. It is based on the second law of thermodynamics, which states that if an energy system is at thermal equilibrium with its surroundings, the maximum amount of energy that can be extracted from it is the exergy. While energy is never destroyed, exergy is always destroyed in irreversible processes. The impact of energy is instead related mainly to its impact on the environment, which can be measured by calculating the exergy embodied in a product.} 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. 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). On the contrary, non-renewable resources cannot be renewed in the natural environment, or can be renewed but not within a human lifetime (e.g., metals or natural gas). The methods used to quantify resources do not all consider these resource sub-categories in the same way.

Resource accounting method

Resource accounting methods can be used in both gate-to-gate and life cycle-based analyses. 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. Because not all resources have the same properties, 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, account for bio-productive land necessary to absorb CO2 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, especially only wind energy and electricity. Current energy-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 others 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 resources: 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 resources 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 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 2002+ method (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 one 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 termed ‘2002+’. For example, a recent study examined the sustainability of two ways of converting algae grown on aquaculture wastewater into a saleable product (also called valorization): valorization as shrimp feed and valorization 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 3.12).

These methods do not cover the same resources, and Table 3.1 illustrates that choosing one over the other changes the conclusion on which scenario is the most resource efficient. Therefore, you should consider one method or a 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, 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 valorization): valorization as shrimp feed and valorization 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 3.12).

The following table illustrates that choosing one over the other changes the conclusion on which scenario is the most resource efficient. Therefore, you should consider one method or a 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. Simple indicators, such as gate-to-gate analyses, can be conducted early as they require less time and data. An LCA approach, which doesn’t necessarily require quantification, should 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.

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**Table 3.1: Existing methods to quantify resource consumption and examples.**

<table>
<thead>
<tr>
<th>Method</th>
<th>Resource Coverage</th>
<th>Energy</th>
<th>Water</th>
<th>Land</th>
<th>Minerals and Substances</th>
<th>Energy Analysis</th>
<th>Exergy</th>
<th>Exergy Analysis</th>
<th>Material Flow Analysis</th>
<th>Surplus Energy or Surplus Costs Calculated to be Necessary to Extract the Same Amount of Resources in the Future as are Extracted Today</th>
<th>Future Consequences</th>
<th>Willingness-to-Pay</th>
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3.1 MATERIAL SCIENCE INNOVATIONS
Dmytro Orlov – Materials Engineering, Faculty of Engineering, LTH, Lund University, Sweden.

3.2 ECODESIGN STRATEGIES
Katherine Whalen – IIIEE, Lund University, Sweden.

3.3 NANOTECH DEVELOPMENTS
Maria Messing – Solid State Physics and Nanolund, Lund University, Sweden.

3.4 ASSESSING THE ENVIRONMENTAL SUSTAINABILITY OF CIRCULAR SYSTEMS: TOOLS AND METHODS
Sophie Sfez, Green Chemistry and Technology, Ghent University, Belgium.

3.5 ASSESSING CIRCULAR SYSTEMS
Sophie Sfez, Green Chemistry and Technology, Ghent University, Belgium.
This chapter explores the role of governments and networks and how policies and sharing best practices can enable the circular economy.

## 4.1 FROM WASTE TO MATERIALS

Over time, there has been a transition in governance from command & control approaches, through efforts to eliminate uncontrolled landfilling, and now towards a multi-stakeholder platform facilitation approach. Facilitation approaches include a range of different policy domains and a suite of new societal actors. A number of societal actors have also had to adopt new roles as governance of ‘waste’ has evolved towards governance of ‘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 4.1)

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 only as 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. In many cases this led to the closure of existing installations.

**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.**

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, 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. Collection could generally 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 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, and with the introduction of the waste hierarchy the focus of recycling activities shifted 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. At the same time, 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 cost.

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 of certain materials that will be harder to purchase or more expensive to get as the global economy grows and expands. 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 that primary producers, and larger service companies, also became more interested in waste management activities.

![Figure 4.1 Waves of waste policy in Europe.](image-url)
This led to 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 continues to become 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 PAST POLICY SOLUTIONS

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 problem of material availability stays the same. 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 during the Second World War (WWII), and they developed a variety of policies to help deal with the shortages. (Fig 4.2)

Of course, many of the critical materials and technologies we use today did not exist during the Second World War, 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 second-hand furniture prices were rapidly increasing. This fuelled 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 4.3 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! (Figure 4.4)

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

4.3 OVERVIEW OF 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 to 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 an appropriate 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.

Administrative or regulatory instruments can be, for example, bans, standards, licenses and voluntary agreements between government and industry. Economic instruments can be taxes, fees, subsidies and charges. Examples of informative instruments include 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 typically self-regulated among the participating organizations. (Table 4.1)

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 in a complementary way, the higher the effect can be towards catalysing change. The way policy instruments are used sparks change by enabling, engaging, encouraging and ultimately, enforcing. Policies can enable the circular economy by, for example, 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, for example, 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 the 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, including a comprehensive Action Plan (COM (2015) 614 final) and regulation amendments. The aim of the Circular Economy Package is to improve the competitiveness of EU businesses by shedding industries against potential resource scares 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 work force, 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 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, 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 mostly indirectly affect resource efficiency – a clear gap! While there is a plethora of 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 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-labeling so that material resource efficiency becomes more prominent. (Table 4.2)

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 existing EU policies. Table 4.3 summarizes a number of ambitious policies at Member State level, that aim to increase resource efficiency.

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

<table>
<thead>
<tr>
<th>Member State</th>
<th>Policy measure</th>
<th>Application</th>
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<tr>
<td>France</td>
<td>Act on consumption and preventing planned product obsolescence.</td>
<td>Mandatory</td>
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<tr>
<td>Spain</td>
<td>Reuse targets for Waste Electrical and Electronic Equipment (WEEE)</td>
<td>Mandatory</td>
</tr>
<tr>
<td>Sweden</td>
<td>Value Added Tax (VAT) reduction in repair services.</td>
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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 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 that consider:

1. the full range of available policy instruments targeting resource efficiency
2. the full cost of policies, including implementation costs, transaction costs and compliance costs
3. how to avoid negative interactions between single policies (i.e. instruments already in place vs. new ones), but also to ensure mutual benefits with existing policies
4. 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 eco-design rules for reusability, 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 might act synergistically. One addition may be public purchasing criteria that favour, or even require, the purchase of repairable 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 helping to 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 it. 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 an ambitious Circular Economy Package in 2015. This package includes legislative proposals on waste, and a detailed action plan. Apart from 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 eco-design, and extended producer responsibility policies, which aim to change the way products are designed. Other areas of intervention include standardization and certification for increased durability, reusability and recyclability of products. Public procurement is another policy approach that can significantly pull the uptake of circular solutions.

Figure 4.8 Indicative weighting of EU policy pre-2010.

Table 4.3: New policy approaches in EU Member States promoting the circular economy.
A broader perspective for future Circular Economy policy

The systemic nature of the transition towards a circular economy implies that policy measures targeting the waste phase, while necessary, are insufficient to achieve circular products. In this context, two elements are essential: (1) the focus of the policy should encompass more than just waste management; and (2) policy actions throughout the product’s life-cycle need to be aligned to avoid negative side-effects and lock-in situations.

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, systemic nature of the transition towards a circular economy approach. In this context, two elements are essential: (1) Better product design, and (2) policy actions throughout the 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 be provided with lesser motivation to innovatively design products that are easier to recycle (a process that may be costlier). The may follow a logic, that the advancing 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 then resulting in lower quality recycled materials despite the better product design.

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 that should be tackled is the aspect of liability when the repair of a product is undertaken through an informal circular economy approach (such as repair cafes).

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. For 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 be provided with lesser motivation to innovatively design products that are easier to recycle (a process that may be costlier). The may follow a logic, that the advancing 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 then resulting in lower quality recycled materials despite the better product design. Examples of such initiatives新三ples have been observed in practice, highlight the need to use a systematic monitoring framework allowing the identification of systemic impacts of policy action, and appropriate adaptations. (Fig 4.9)

**4.4 EXTENDED PRODUCER RESPONSIBILITY**

- Extended producer responsibility (EPR) is a policy principle that promotes efficient waste management and forward-designed 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, landfillfills 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. Society also began to pay attention to the fact that products were typically designed and used 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 organizing the collection of the discarded products. This is typically done by making the producers responsible for the end-of-life management of their products. 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 common 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 such as TVs and computers that contain lead and mercury. 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 primitive recovery methods are used, recovering only a limited portion of the useful metals and creating 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 little, if any, hazardous elements to the environment.

The fate of phones. Mobile phones are definitely 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 recycling systems 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 collection systems 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 achieve clear incentives for producers to manage 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 approaches, and between different countries. When discussing EPR programmes, it is very important to pay attention to the specifics of each program – the devil is in the detail!

### 4.5 THE ECODESIGN DIRECTIVE FOR CIRCULAR ECONOMY

- The ecodesign directive promotes product attributes such as longer product lifetimes and improved product reusability and repairability 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. Repairability is in turn dependent upon the availability of spare parts and access to reasonably priced repair services. Unfortunately today, 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 look at the practices of some corporations seeking evidence that planned obsolescence is actually taking place. France has also introduced a scheme to provide incentives for manufacturers to ensure spare parts are available 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. The EU’s product design legislation is to regulate lifetime or durability. Indeed, this has already been achieved, at least to some extent, by the EU’s 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 product design is usually adopted by 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 reusability, 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 achieved.
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 for lighting products. It includes the actual estimated useful lifetime 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, product reparability 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!

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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. But 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 enable authorities to 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.

We should also bear in mind 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.
of resource flows; this 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 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 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 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. 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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 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 popping up 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 subsections.

The Circular Economy program of the WBCSD (world)

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 Marketplace4UR, an online platform that maps initiatives that promote the use of secondary resources around the world. The platform mainly lists 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 fact sheets on product lifetime, recycling and eco-design opportunities will be available) and Mobility.

The Raw Material Information System of the European Commission (EU)
The European Innovation Partnership on Raw Materials (EU)
The European Innovation Partnership on Raw Materials (EU) is a stakeholder platform that 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.
This chapter presents an examination of new norms, forms of engagement, social systems, and institutions that are needed by the circular economy. It also discusses how we can help society become more circular.

5.1 SOCIETAL VALUE

Securing resources for social equity and development

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

To start, we need to go back to a central argument supporting the need for circular economy: we must reduce burdens on the earth’s ecosystems. However, 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 use too many resources, too fast, and don’t reuse them – will exceed global resource consumption per person of today’s developed countries.

Similarly, all societies must build their infrastructure in order 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.

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 should we lose sight of the fact that new policy provisions 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.

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 are functioning 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 factor of this, impacts on health along with lost productivity and the costs of health care 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 – often times 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, resources 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, it will also demand that we invent, innovate, develop new technologies, and create new businesses.
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 raw 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, rice may be produced in Vietnam, but is fed with soy produced in Brazil, and mobile phones sold in the US are very likely to be assembled in Asia using minerals that were 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 an American-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 America, while the impact of the tonnage of the metal in the car’s components was probably generated in South America, or Asia – depending on the material. All of these factors contribute to which we call our consumption related ‘footprint’.

The 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, transportation and use. In this way, environmental emissions generated abroad are also taken into account.

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 CO2 equivalents per inhabitant. By taking a closer look at which goods and services are responsible for the largest contribution to the overall footprint, we can gain insight in the way our consumption habits affect the environment and which habits we should change in order to reduce our environmental impact.

The environmental footprint of a country can be defined as the environmental impact caused by the consumption of goods and services by its inhabitants. These environmental impacts are generated during the entire life cycle of these goods and services, i.e. during resource extraction, production, transport and use. This is called the ‘life cycle impact’ of the product. Often LCA-like methods are used to estimate this impact.

Expressed in a formula, the environmental footprint is the environmental impact from all goods and services produced outside a country (often called the ‘terrestrial flows’), minus the environmental impact from the production of exported products, plus the environmental impact from the production of imported products. Good 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)

Carbon is not the only measure used however, and environmental footprints are estimated for various environmental concerns. Well established footprint measures, including carbon that has been presented, are listed 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 CO2-equivalents (hence, this includes non-CO2 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 environmental footprint, expressed in km². The Ecological Footprint is a measure of the amount of land needed to absorb the environmental pressure (e.g. to regrow resources, or to absorb CO2 emissions). Based on the ecological footprint concept, it was estimated that humanity used 1.5 times the carrying capacity of the Earth in 2015 (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-catchy 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 understimates the environmental impact of consumption; 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 by its inhabitants.

As an example of how carbon footprints are applied for a country (the total amount of greenhouse gases produced worldwide as a result of the consumption by its inhabitants) 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 CO2-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 two tonnes CO2 eq per inhabitant can be linked to investments by businesses and government in buildings and infrastructure, machinery, ICT equipment, etc. (slightly over 3 tonnes CO2 eq per inhabitant) and emissions linked to public services that are not directly paid for by consumers, such as education and defence (about 2 tonnes CO2 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 should be one of the priorities in order to reduce 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. 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 the carbon footprint of Flanders has increased between 2003 and 2010, while the carbon emissions within Flanders have decreased slightly.

**Material footprint**

Metals are essential for society and the economy. The material footprint for metals for the region of Flanders was calculated in 2007. When considering the metal use across the whole production value chain, about 10 million tonnes (10 Mt) of primary metal ore was needed in order to fulfill the consumption demand in Flanders. The metal demand mainly consists of iron ore (3 Mt), non-ferrous metal ores (5.7 Mt), precious metal ores (0.97 Mt) and special metal ores (0.275 Mt). 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 in a Circular Economy**

**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 depletions). Unfortunately, the estimated maximum sustainable levels are difficult to estimate, highly uncertain, ambiguous and subjective. In 2014, two European analysts Hoekstra and Wiedmann estimated the global footprints and then compared them with their suggested maximum sustainable levels (Figure 5.4). 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 sustainable level by far. However, the carbon footprint (expressed in CO2-equiv./year) exceeds its estimated maximum sustainable level by more than a factor of 2 (Fig 5.4.11).

**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 you can see 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), showing 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 his 2009 book ‘Prosperity without Growth’: “Well-being 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 A GLOBAL VIEW**

**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 move 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 are concerned about sustainability, this means that 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, 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 of source countries lack stability. Further, there are also some countries that have used their market dominance – apparently deliberately – in social, political or economic situations of source countries.

We need to ensure that both the start and the end of raw material life cycles do not poison the environment or threaten social impacts – both good and bad – across the globe.

**Material footprint**

Metals are essential for society and the economy. The material footprint for metals for the region of Flanders was calculated in 2007. When considering the metal use across the whole production value chain, about 10 million tonnes (10 Mt) of primary metal ore was needed in order to fulfill the consumption demand in Flanders. The metal demand mainly consists of iron ore (3 Mt), non-ferrous metal ores (5.7 Mt), precious metal ores (0.97 Mt) and special metal ores (0.275 Mt). 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 in a Circular Economy**

**How can one define ‘sustainable consumption’?**

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We need to ensure that both the start and the end of raw material life cycles do not poison the environment or threaten social impacts – both good and bad – across the globe.
Rare Earth Elements and critical metals from countries with weak governance

There are a number of situations where global markets are dependent upon 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 many operations that 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 are also expected to affect future generations. We even see examples where extraction and processing of such materials in some of the most problematic issues related to mining of metals in the Democratic Republic of Congo.

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 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.

A challenge for us all, however, is that many materials and products often 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.

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 in countries with the more sustainable conditions described above is hard to achieve. 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’.

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, a global treaty that came into force in 1992. The BASEL Convention 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.

Despite the existence of these national and international policy measures, electronic waste still flows to countries that don’t have good systems for recycling. The two main reasons for this is economic interests of actors and lack of good enforcement in both importing and exporting countries.

What makes the situation even more complex is that much of the electronic products discarded in developed countries are still working, and are 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 good infrastructure to take care of them in an environmentally friendly manner. And the recovery of the valuable resources is not done in an efficient way. This has resulted in serious environmental, health and social problems. Further, much less of the valuable material is recovered.

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 when they reach 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: first human and animal health are put at risk, second the environment is put at risk, and finally significant proportions of valuable materials that could have been recovered. 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 on 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 A LOCAL VIEW – CHANGE CLOSE TO HOME

The circularity principle has been applied at many different levels. We should 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 3 months. Households own an average of 10 things that are more energy efficient are now offered on the market. 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 (Figure 5.6). In other words, even though people own more appliances that are energy efficient they also own more appliances overall. As a result, the electricity consumption per household for large appliances was only slightly lower in 2009 than in 1997.

Environmental impacts occur not only in the production and 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 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”, ‘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. 99% of the material content of goods becomes waste within 6 weeks. 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, 70 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 the 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 ‘dump culture’ that mostly wealthy societies have created. In addition to being consumers, individuals can assume an active role in saving 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 novel production-consumption systems with the help of diverse stakeholders like start-up businesses, municipalities or social innovation hubs. They refrain their everyday consumption practices to include serious leisure projects, repair services, and upcycling strategies. These often have a so-called pro-social purpose.

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 along. 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 areas need to be resolved.

Despite these challenges, there are also advantages. 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 living areas. Active consideration of such ‘rebounds 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, key actors need to be aware of associated risks, and find ways to circumvent those while maximising the benefits of sharing and repairing.

5.5 WHO OWNS IT?

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.

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 might also have issues with the use of trademarks and brand name. This in turn leaves uncertainty about which logos or information can still be used on the product and packaging.

Example: how repairing contributes to a circular society

The bicycle kitchen in Malmö, Sweden (Figure 5.8) 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)

Figure 5.8 Spare wheels and wrenches for sharing in the bicycle kitchen in Malmo, Sweden.
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 it. Issues concerning liability, quality and warranty are also connected to the original equipment manufacturer and this is possibly extends to third party remanufacturers.

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 buying new products?

Trademarks
Concerning trademarks, it is advised that the remanufacturer places their trademark on the product itself and not only the packaging. It should be 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 should provide documents and support.

So there are tensions between third party remanufacturers and original equipment manufacturers, and in the worst cases this 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, 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 example is Hackerspace. 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 example is Fablab, 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 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 sort out as we transition.