CIRCULAR ECONOMY

AND ENVIRONMENTAL PRIORITIES FOR BUSINESS

wbcsd

ECOFYS
A Navigant Company

Contents

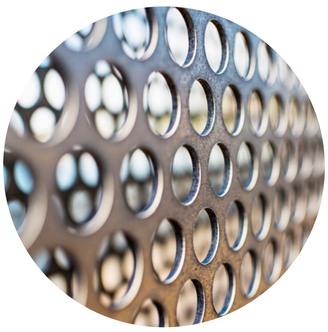
Summary

Companies start implementing the circular economy to improve the bottom line, mitigate risks in the supply chain and strengthen competitive advantage. Despite some companies already capitalizing on these business drivers, most find it difficult to identify and implement circular strategies and viable business cases.

This report helps companies to identify priorities for the circular economy from the environmental point of view, providing insight into the biggest circular economy opportunities for specific value chains. The report provides the global material flows and related carbon, water and land footprints for eight key materials for circular economy, as well as an inventory of available circular economy measures that can be applied to mitigate the impacts. The key findings of the report are listed below.

Key findings:

- We studied eight materials, which are responsible for 20% of global greenhouse gas (GHG) emissions, 95% of water use and 88% of land use. All circular economy measures related to these materials can therefore substantially reduce GHG emissions, water use and land use.
- Food and shelter supply chains have the greatest opportunities for carbon, water and land footprint reductions. The large footprint for food is related to primary crop production and cattle. The large footprint of shelter is mainly the result of the use of cement and steel, and to a lesser extent, wood. When accelerating the implementation of circular economy, the food and construction sector are the two big priorities. Food and shelter fulfil basic needs in society and can therefore not be circumvented. Circular economy can play a crucial role here.



- Circular value chains and digital platforms are CE measures with a high potential in all supply chains. Lifetime/shelf life extension is particularly important for food and construction. Advanced food packaging, early warning of approaching expiry date and food sharing are examples on how circular economy can prevent food losses. This may result in significant reductions in carbon, water and land footprint. Deconstruction of buildings with recovery and recycling of materials, refurbishments of buildings and new destinations of office buildings are examples on how circular economy can be implemented in the buildings supply chain, reducing the carbon footprint related to steel and cement.
- Environmental impacts often take place far upstream in the supply chain. For some products, the energy consumption in the use phase is dominant, e.g. for cars and electric appliances, leading to GHG emissions. For cars and electric appliances, it is important to consider the trade-off between the GHG emissions in the use phase (when increasing energy-efficiency) and the GHG emissions related to the material production (when extending product lifetime).
- Successful implementation of CE measures requires involvement of the complete value chain, including the consumer perspective. Consumers need to be aware of measures like sharing of products, and the recycling of materials.

Recommendations:

- If implementation of circular economy is to be successful, business must act now. Implementation of circular economy measures requires involvement of the complete value chain, from raw material extraction through manufacturing, consumer use and end of life. This asks for collaboration with value chain partners.
- Metrics for measuring circular economy are needed to monitor progress and report against financial, environmental and social goals. Such metrics can also help businesses choose measures wisely. Life Cycle Assessment (LCA) should be the starting-point, as it accounts for the function of the product and it avoids burden shifting across environmental impacts or supply chain stages.

1. **Introduction**

Companies face increasing commodity prices, price volatility and climate change risks. All of these highlight the risks associated with the linear economy.

Demand for resources is expected to increase because of population growth and movement into the middle class. The search for an industrial model that can decouple growth from natural resource consumption has generated interest in the circular economy. [1]

The Ellen MacArthur Foundation's 2012 *Towards the Circular Economy*, marked a turning-point - introducing the concept of circular economy, showing its potential benefits for businesses and presenting early successes. The report defines the concept of circular economy as follows:

"A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models."[2]

By applying circular economy principles, energy, labor and capital costs embedded in products are not lost, which could lead to large benefits if kept within the economy:

- Since over half of worldwide greenhouse gas emissions are associated with producing basic materials, there is a clear role for circular economy strategies in reducing this gap. Ecofys, a Navigant company, and Circle Economy estimate that circular economy strategies can reduce the emissions gap between the current national climate commitments and business-as-usual by about 50%.[3]
- There is a $4.5 trillion opportunity for implementing circular economy business models through 2030. This requires eliminating the concept of waste and recognizing that everything has a value.[4]
- The World Bank estimates an increase in the amount of municipal solid waste from 1.3 billion tons per year today to 2.2 billion tons by 2025. It is estimated that for the consumer goods sector alone, about 80 percent of the $3.2 trillion value is irrecoverably lost annually.[5]
- Another recent report outlines ten attractive circular innovation and investment themes, totaling €320 billion through to 2025 in Europe alone (€135 billion in the mobility system, €70 billion in the food system, €115 billion in the built environment).[6]

Although the benefits of the circular economy are widely accepted, companies are finding it difficult to identify and implement circular strategies and viable business cases.

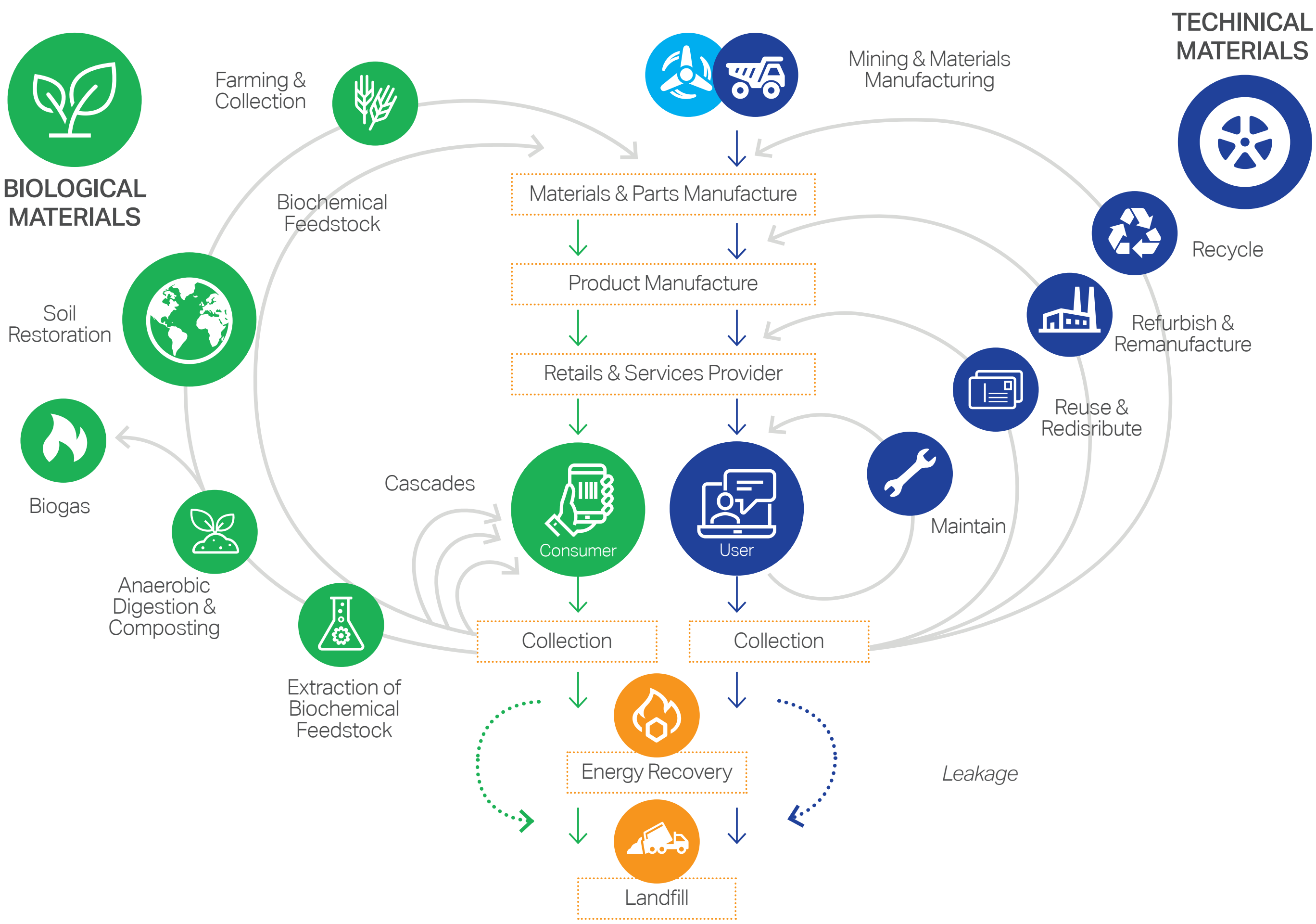
Ellen MacArthur Foundation, 2012. Towards the circular economy – Economic and business rationale for an accelerated transition.
[2] Ibid
[3] Ecofys and Circle Economy, 2016. Implementing circular economy globally makes Paris targets achievable.
[4] P. Lacy and J. Rutqvist, 2015. Waste to Wealth – The circular economy advantage. Palgrave Macmillan 2015.
[5] World Bank, 2012. What a waste - A Global Review of Solid Waste Management. Urban development series knowledge papers No. 15.
[6] Ellen MacArthur Foundation, SYSTEMIQ and McKinsey Center for Business and Environment, 2017. Achieving 'growth within'. A €320 billion circular economy investment opportunity available to Europe up to 2025.

This report helps companies identify environmental priorities for the circular economy, providing insight into the biggest circular economy opportunities for specific value chains. The report provides insight in the material flows in the global economy and the environmental impact related to the mining, material manufacturing or farming of eight key materials. It highlights the most resource-intensive sectors and product supply chains as well as where considerable environmental impacts occur.

This information provides insight into the environmental impact that can be avoided when implementing the concept of circular economy as illustrated in Figure 1.

Lastly, this report lists potential circular economy measures that can be implemented to mitigate the environmental impact of the eight materials studied.

Figure 1:
Outline of the circular economy[7]



[7] Adapted from EMF https://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram

2. Global material flows and their carbon, water and land footprints

Key materials for the circular economy

For this study, we have selected materials with high relevance for the circular economy, considering the amount (mass) used in the global economy and environmental impacts related to these materials. We have selected materials that cover different types of raw materials, including metal ores, crude oil, non-metallic minerals and biomass, to analyse various value chains. Based on available literature that provides information on the environmental impacts of materials over the value chain[8,9,] we selected the eight key materials for circular economy found in Table 1. Fossil fuels like coal, oil and natural gas, are also relevant for circular economy, but are excluded from the scope of this report. Fossil fuels and energy efficiency are extensively investigated in existing research. Our focus is on the use of materials.

Modeling approach

For the eight key materials, we have modeled the global material flows and carbon, water and land footprint of material production. This information provides insight into the embedded carbon, water and land footprint of materials that can be avoided when implementing circular economy measures like extension of the product life time, reuse of products and recycling of materials.[10] The analysis also shows the material and environmental hotspots in the economy. Companies will implement circular economy measures to save money and reduce environmental risks. These hotspots are points in the value chain where large amounts of materials are used and where large environmental impacts arise. These hotspots therefore provide valuable insight in where some of the largest opportunities are to move to a circular economy and reduce environmental impact. This study focuses on the carbon, water and land footprints because they are easy-to-understand metrics and they cover three important environmental impacts of material production.

Material flows and carbon, water and land footprints have been modeled by using Environmentally-Extended Input-Output analysis (EEIOA). This study was supported by the Norwegian University of Science and Technology (NTNU), which is a leading research institution on Input-Output analysis and is one of the co-founders of the Input-Output database EXIOBASE 3 used in this study.[11] NTNU assisted in data retrieval from Exiobase 3, and interpretation of the results. Moreover, NTNU reviewed this report.

For circular economy, the flows of manufactured materials through the economy as opposed to raw materials are the most interesting, because manufactured materials provide the functions that society is demanding and manufactured material flows reflect the actual mass that is flowing through the economy. Therefore, we have linked annual global production volumes of materials to the specific production sectors in EXIOBASE 3.[12] For primary crops and wood, we have used the raw materials volumes as included in EXIOBASE 3. Annex III includes all data used to obtain these materials flows.

Table 1:
Key materials for circular economy selected for this study

Type of raw material used	Selected material
Metal ores	1. Steel
	2. Aluminum
Crude oil	3. Plastic
Non-metallic minerals	4. Cement
	5. Glass
Biomass	6. Wood
	7. Primary crops*
	8. Cattle**

** Includes all primary crops. Excludes crop residues and fodder crops.*
*** Includes bovine cattle only which have the largest carbon, water and land footprint compared to other animal products.*

[8] UNEP (2010) Assessing the Environmental Impacts of Consumption and Production: Priority Products and Materials, A Report of the Working Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Management. Hertwich, E., van der Voet, E., Suh, S., Tukker, A., Huijbregts M., Kazmierczyk, P., Lenzen, M., McNeely, J., Moriguchi, Y.
[9] Esther van de Voet (2003). Dematerialisation: not just a matter of weight. Centre of Environmental Science (CML). Leiden University.
[10] When determining the net environmental benefit, it is necessary to not only calculate the avoided environmental impact of mining and material manufacturing, but also the environmental impact related to reversed logistics, remanufacturing, etc.
[11] Richard Wood, Konstantin Stadler, Tatyana Bulavskaya, Stephan Lutter, Stefan Giljum, Arjan de Koning, Jeroen Kuenen, Helmut Schütz, José Acosta-Fernández, Arkaitz Usubiaga, Moana Simas, Olga Ivanova. Jan Weinzettel, Jannick H. Schmidt, Stefano Merciai and Arnold Tukker, 2014. Global Sustainability Accounting—Developing EXIOBASE for Multi-Regional Footprint Analysis. Sustainability Vol 7, Issue 1): 138–163, doi:10.3390/su7010138.
[12] For example, we linked the global production of crude steel obtained from the World Steel Association, to the sector 'basic iron and steel and of ferro-alloys and first products thereof' in EXIOBASE 3.

The carbon, water and land footprints for the non-biomass materials were calculated including the footprint of the mining activities and the production processes required to obtain the manufactured material. The footprints of biomass-related products were calculated including the agricultural and forestry activities. Annex III includes the information used to obtain the footprints. The footprint of downstream activities, including all activities needed to produce specific products out of the manufactured materials, were not included in the analysis because we wanted to focus on the footprint of the manufactured materials. This information provides insight into the embedded carbon, water and land footprint of materials that can be avoided when extending the product life time, or when reusing and recycling products.

Description of the footprint concepts

Carbon footprint: GHGs of material production/agriculture, expressed in tons of CO_2-equivalents. Hence, this includes non-CO_2 greenhouse gases, such as CH_4 or N_2O, but does not cover greenhouse gases related to land use change.

Water footprint: Volume of blue water (surface and groundwater) consumed because of material production/agriculture; expressed in cubic metres of water consumption (withdrawals minus return flows).

Land footprint: Land used for material production/agriculture. Land use data underlying the land footprint calculations include cropland, pasture and forest and are expressed in km^2. Land use change is not included in the carbon footprint indicator used here.

Results

Global material flows

Figure 2 shows the material flows of the eight key materials through the economy. The left-hand side shows the amount of material produced by the production sectors for each of the eight key materials. The middle part shows the consumption sectors where the eight materials end up (see Annex I for an overview of the list of sectors). The right-hand side shows how the eight materials meet societal needs (see Annex II for an overview of the list of consumption categories).

The total weight of the eight selected materials is 17 Gton on an annual basis.

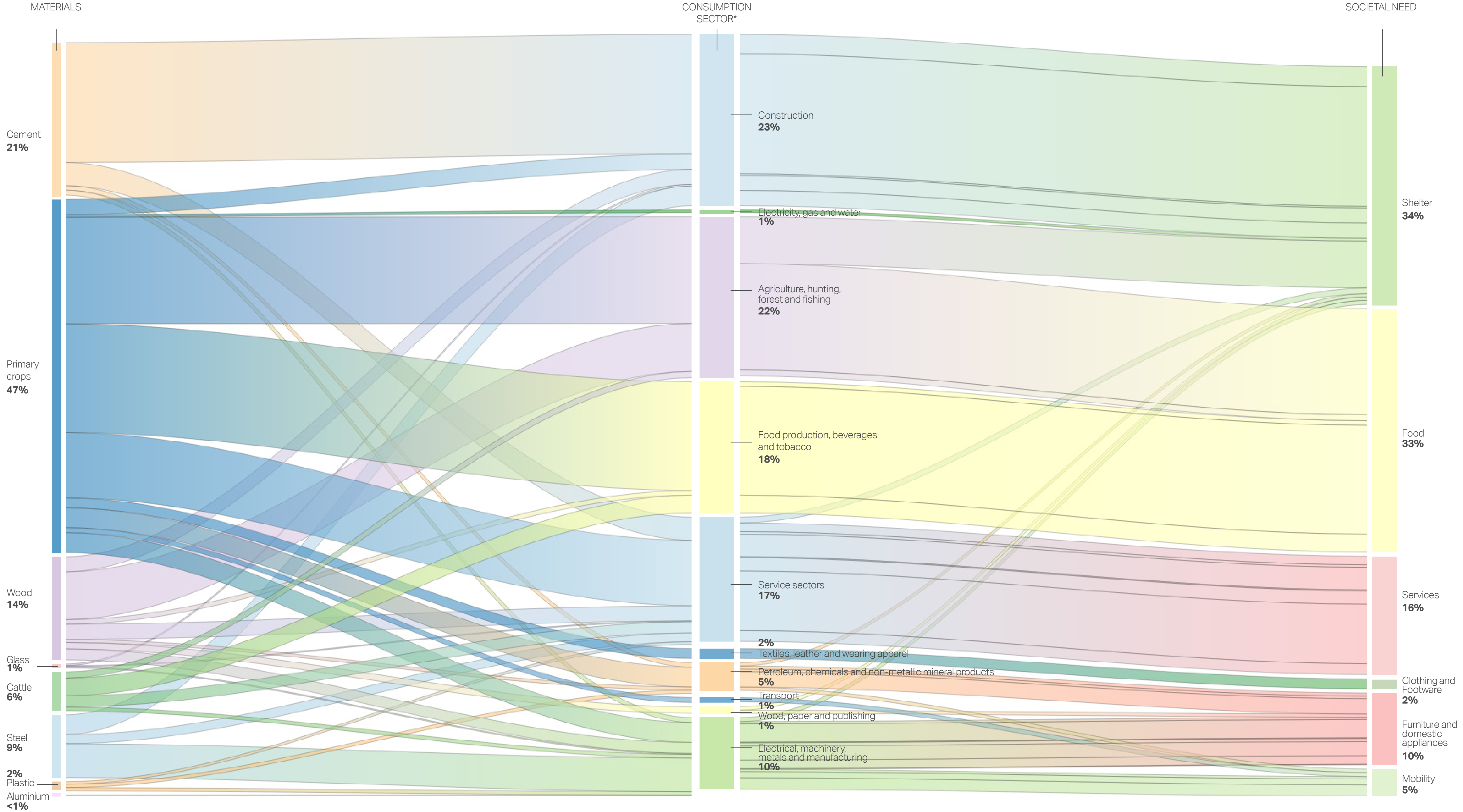
Figure 2 shows that the largest portion of the materials (93%), on a weight basis, is required to fulfil the following societal needs:

- Shelter (34%): cement is predominantly used, but also steel and wood.
- Food (33%): main input from primary crops and, to a lesser extent, cattle.
- Services (16%): main inputs from primary crops (for food), and cement, steel and wood (for buildings).
- Furniture and domestic appliances (10%): main inputs from primary crops, steel and wood.

The amount of materials used for mobility and clothing and footwear is relatively small, when focusing on the eight materials selected for this study.

In short, the supply chain of food and shelter use large amounts of materials on a weight basis, including cement, primary crops and, to lesser extent steel, wood and cattle. Accordingly, circular economy measures taken in these value chains can reduce material use upstream in the value chain.

Figure 2:
Flow diagram for weight (in tons) of key materials by consumption sector and societal need (threshold for including flows is 50 Mt for steel, plastic, cement, wood, primary crops, cattle and 10 Mt for aluminium and glass)



* Values may not add up to 100% due to rounding and/or excluding small flows

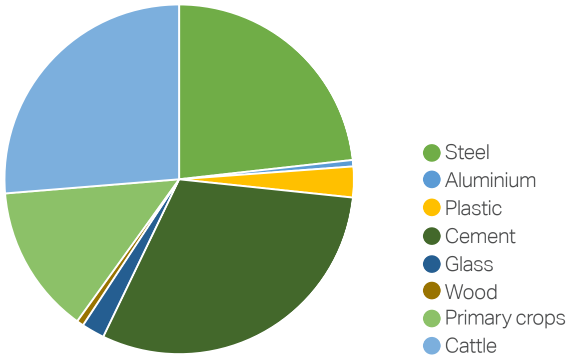
Carbon footprint

Figure 3 shows that the carbon footprint of the eight selected materials is 7,538 $MtCO_2e$ in total[13], which is 20% of the global GHG.[14] The largest portion of GHG emissions worldwide comes from combustion of fossil fuels for heat production and electricity generation. Figure 3 includes the GHG emissions related to the mining and manufacturing of materials, which includes energy use for producing the materials, but not the energy use for manufacturing the materials into intermediate and final products.

Figure 3 shows the percentage contribution of each material to this total carbon footprint. Cement (30%), cattle (26%), steel (23%) and primary crops (14%) are large contributors to the total carbon footprint. These materials are used in large quantities in the global economy (see Figure 2) but also lead to high GHG emissions per kg of material. The production of cement and steel lead to high GHG emissions because of the high temperatures needed for material production.

Figure 3: Contribution of materials to the carbon footprint

Total carbon footprint is 7538 $MtCO_2e$



Cattle farming leads to high GHG emissions per kg due to methane emissions from cows. For cattle, the carbon footprint of the cultivation of feed production is not included. When including feed in the analysis, the carbon footprint for cattle would even be larger. Primary crops lead to GHG emissions mainly from N_2O emissions from fertilizer applications.

To better understand which sectors and product supply chains GHG emissions come from, we have modeled the Sankey diagram for greenhouse gas emissions (Figure 4). Figure 4 shows how greenhouse gas emissions related to the production of the eight materials flow through the economy.[15] The left-hand side shows GHG emissions that arise from production of the eight selected materials. The middle shows how these GHG emissions end up in consumption sectors. The right-hand side shows how the GHG emissions of the production of materials are related to societal needs.

Large amounts of cement and steel are used in the buildings supply chain, including the construction sector and the product category shelter.

This means that the construction sector could reduce large amounts of GHG emissions when implementing circular economy measures around the production and use of cement and steel.

Steel is also used in the supply chain of furniture and domestic appliances. Circular economy measures taken by the "electrical, machinery, metals and manufacturing" sector or at the "furniture and domestic appliances" product category will reduce the amount of steel used and associated GHG emissions.

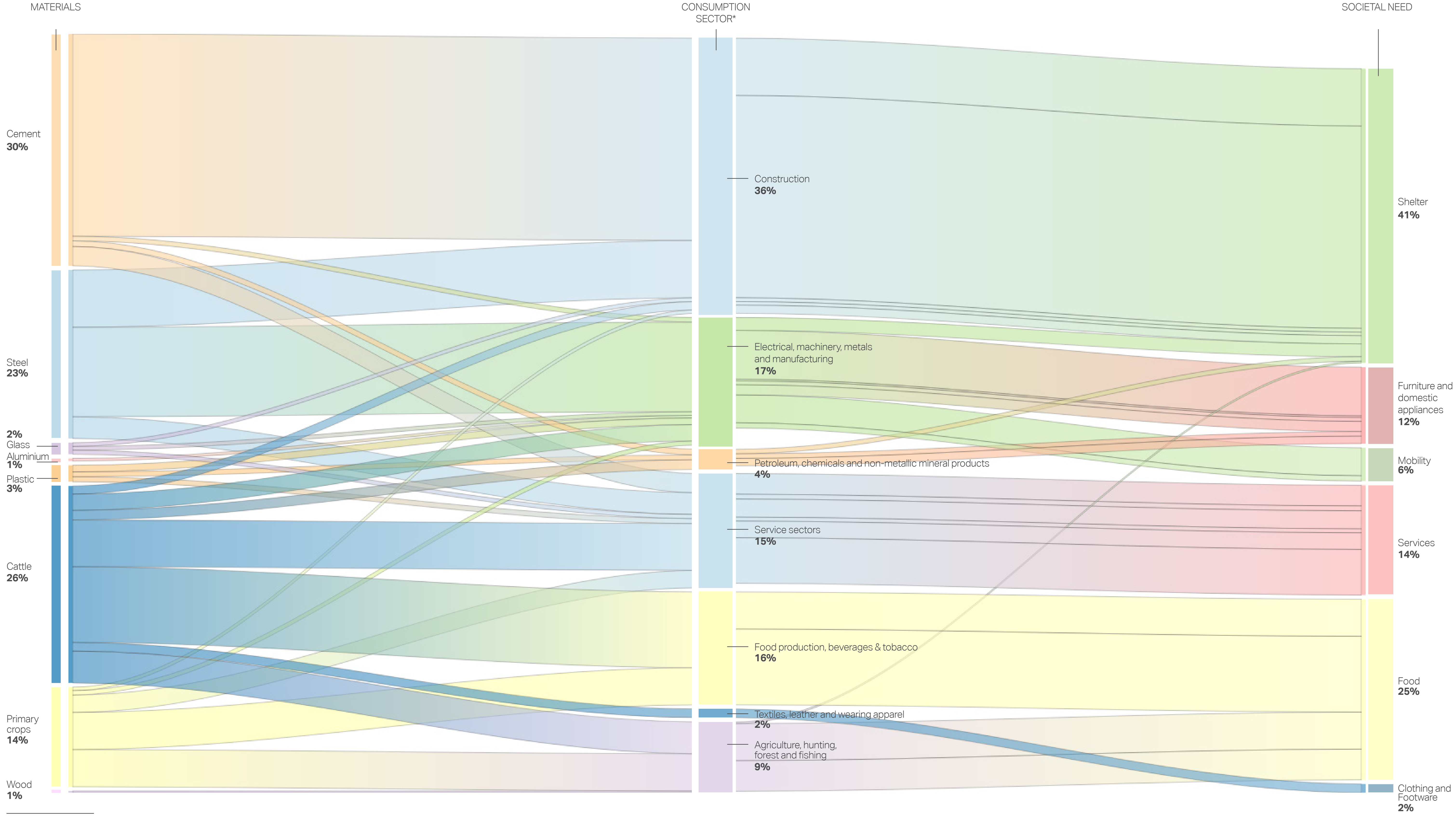
Cattle and primary crops are mainly used in the food supply chain, including the agriculture and food sector. A considerable amount is used by the services sector which includes public administration and defence, education, health and other services. The agriculture, food sector and services sector can reduce large amounts of GHG emissions related to cattle and the cultivation of primary crops by implementing circular economy measures like the reduction of food losses. Consumers can also have a big impact.

[13] The greenhouse gas emissions related to land use and land use change are not included in the carbon footprint, because this is not included in the Exiobase 3 database. The contribution of land use and land use change to total global GHG emissions is around 12% (IPCC, 2014: Agriculture, Forestry and Other Land Use (AFOLU). In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA; CEA 2014, Agricultural greenhouse gases - A review of agricultural emissions for the Climate and Land Use Alliance - Technical annex to "Strategies for Mitigating Climate Change in Agriculture: Recommendations for Philanthropy."

[14] This percentage is based by comparing the carbon footprint of the eight materials in scope of this study with the total carbon footprint of all products included in Exiobase 3.

[15] GHG emissions from the use and disposal of materials is not included.

Figure 4:
Flow diagram for GHG emissions of key manufactured products by consumption sectors and consumption categories (threshold for including flows is 30 $MtCO_2e$ for steel, plastic, cement, glass, primary crops, and cattle, and 10 $MtCO_2e$ for aluminium and wood)



* Values may not add up to 100% due to rounding and/or excluding small flows

Water footprint

Figure 5 shows that the total blue water footprint of the eight selected materials is 1248 Gm3 in total, which equates to 95% of the global blue water footprint.[16] The largest part of this blue water footprint comes from the cultivation of primary crops (91%). The blue water footprint relates to the irrigation of primary crops with surface water. Smaller amounts of surface water are used for the other materials.

Most primary crops are used in the food supply chain, including the agriculture and food sectors. A considerable amount is used by the services sector. Consumers as well as the agriculture, food and service sectors, can reduce the use of surface water by implementing circular economy measures like the reduction of food loss and the optimization of fertilizer and water use in agriculture by using smart sensors. This will especially be beneficial for regions with water stress.

Land footprint

Figure 6 shows that the total land footprint of the eight selected materials is 6,831 10^4 km^2 in total, which is 88% of the global land footprint.[17] Wood (52%), cattle (27%) and primary crops (22%) are the largest contributors to the total land footprint. For cattle, the land footprint needed for feed production is not included, so the land footprint would even be larger when including feed.

A large part of wood is used in the supply chain of shelter (see Figure 2), including the construction sector.

The construction sector can reduce land use by implementing circular economy measures at the level of construction products and buildings. Most cattle and primary crops are used in the food supply chain, including the agriculture and food sector. A considerable amount is used by the services sector. Consumers, as well as the agriculture, food and service sectors can reduce land use by implementing circular economy measures to reduce food loss.
Food loss can be reduced by selling food products that deviate in shape or otherwise. Food loss can also be reduced by extending shelf life through advanced packaging.

Detailed results can be found in Annex IV.

Figure 5:
Contribution of materials to the water footprint

Total blue water footprint is 1,248 Gm^3

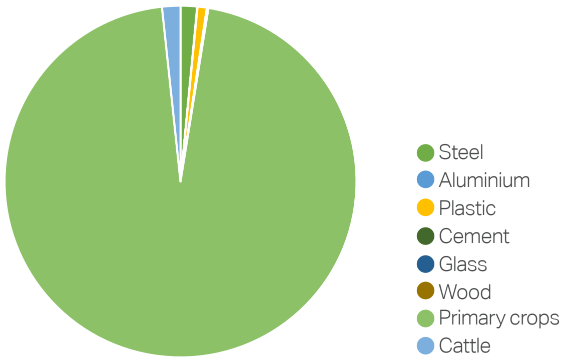
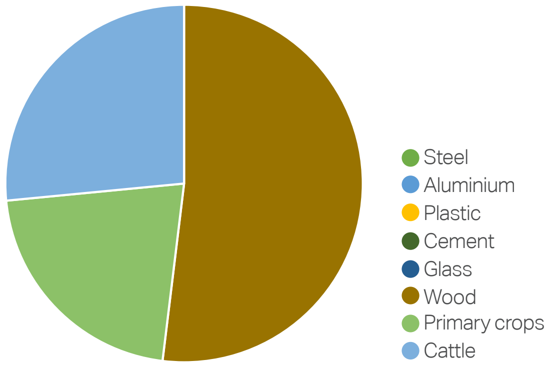


Figure 6:
Contribution of materials to land footprint

Total land footprint is 6,831 10^4 km^2



[16] This percentage is based by comparing the blue water footprint of the eight materials in scope of this study with the total blue water footprint of all products included in Exiobase 3.
[17] This percentage is based by comparing the land footprint of the eight materials in scope of this study with the total land footprint of all products included in Exiobase 3.

3. Inventory of circular economy measures

Based on outcomes of the material flow analysis and related carbon, water and land footprints in Chapter 2, we have made an inventory of available circular economy measures that can be applied to the supply chains for the six societal needs within the scope of this study. Table 2 shows a matrix, including potential for circular economy per societal need and type of measure. Food, shelter and services have a high impact on the environment and have therefore a large mitigation potential. The darker shaded cells reflect a larger potential for implementing circular economy measures, and reducing the embedded carbon, water and land footprints.

Table 2:
Inventory of circular economy measures related to the supply chain of six groups of societal needs

	Circular value chain	Lifetime extension/ shelf life extension	Recovery and reuse	Sharing and service models	Digital platform
Food	● (1)	● (2)	● (3)	● (4)	● (4)
Shelter	● (1)	● (1)	● (2)	● (3)	● (2)
Furniture and Appliances	● (2)	● (4)	● (2)	● (4)	● (2)
Mobility	● (2)	● (4)	● (4)	● (3)	● (2)
Clothing and footwear	● (4)	● (4)	● (4)	● (4)	● (2)
Services	● (2)	● (3)	● (3)	● (4)	● (2)

Legend:

● (1) ● (2) ● (3) ● (4)

Large potential … Smaller potential

Circular value chain Designing products and assets with low-footprint material selection and minimized resource use throughout the lifecycle in mind.

Lifetime extension Extending the lifetime of products and assets through a greater focus on maintenance, upgrade and repair, as well as reverse logistics, product takeback and remanufacturing. In the context of food, we speak of an extension of the shelf life.

Recovery and reuse Recovering and treating wastes and by-products for reuse as inputs or cascading for other uses.

Sharing and service models Offering products as a service through pay-per-use models and employing sharing and leasing platforms to maximize utilisation of products and assets.

Digital platforms Dematerialize by replacing physical services with online equivalents like Spotify and use the internet of things to optimize resource use and maximize value.

Potential and existing circular economy measures were identified for each societal need and are listed below:

To effectively reduce climate change impacts and to reduce the use of water and land, the circular economy should be targeted at food (beef, milk and vegetables) where circular value chain measures and reduced food losses seem to be the most promising, and shelter (cement and steel) where circular value chain measures and lifetime extension seem to be most promising. Moreover, we can conclude that digital platforms have a high potential for implementing circular economy for most societal needs. Consumer behavior is also an important factor for the implementation of circular economy, e.g. to share products, to repair products and to help in the recycling of materials.

Table 3:
Inventory of circular economy measures related to the supply chain of six groups of societal needs

	Circular value chain	Lifetime extension/ shelf life extension	Recovery & reuse	Sharing and service models	Digital platform
Food	• Optimized use of fertilizers and water in agriculture by using smart sensors • Prevent waste in the supply chain and at consumer level • Energy recovery from waste (biogas) • Energy efficiency improvements in the supply chain • Shift from meat and milk towards plant-based alternatives • Shift from beef to alternative meat like chicken and insects • Sell food products that deviate in shape or otherwise, without compromising minimum food conditions	• The shelf life of food can be extended by advanced packaging using different materials and different portion sizes	• Anaerobic digestion of vegetable and fruit waste • Increase recycling of packaging materials like plastic, metals and cartons by advancing recycling systems	• Sharing food products and meals via smart communication channels • Optimal use of food residues, e.g. via recipes or supermarket policy	• Early warning of approaching expiry date of food • Smart refrigerators
Shelter	• Different composition of cement • High-strength concrete • Increase recycled, reused and renewable materials • Use materials with a low environmental impact	• Refurbishment of buildings • Retrofitting • Designing for flexibility and adaptation	• Deconstruction of buildings, recovering and recycling materials • With Building Information Modelling (BIM) lower safety margins can be achieved, saving material use.		
Furniture and Appliances	• Material optimization • Design for disassembly	• 3D printing used to obtain spare parts	• Take back systems • Recycling systems for household waste	• Leasing appliances	• Website for advice on repair • Track and trace systems
Mobility	• Light-weight cars to save energy in the use phase	• Maintenance • Repair	• Remanufacturing of components • Refurbishment of car parts • Recycling of materials	• Car sharing (green wheels, Zip car, carpooling) • Public transport	
Clothing and footwear	• Design • Material optimization	• Maintenance • Repair	• Take-back system • Reuse • Recycling	• Reselling (second hand) • Leasing clothes and footwear	

4. Businesses taking circular economy forward

Companies start implementing the circular economy to improve the bottom line, mitigate risks in the supply chain and strengthen competitive advantage. Despite some companies already capitalizing on these business drivers, most find it difficult to identify and implement circular strategies and viable business cases.

This report identified priorities for the circular economy from the environmental point of view, which may provide starting-points for businesses to implement circular economy. This report provides the material flows and related carbon, water and land footprint for eight key materials for circular economy.

Priorities for circular economy

The eight key materials analyzed in this report are responsible for 20% of the global GHG emissions, 95% of global water use and 88% of global land use. Therefore, all circular economy measures related to these materials can substantially reduce GHG emissions, water use and land use.

Food and shelter supply chains have the greatest opportunities for carbon, water and land use reductions. This means that all businesses active in the food and shelter supply chains can potentially reduce environmental impacts significantly by implementing circular economy measures. Relevant areas in the food sector are the agricultural and food processing industries. Relevant sectors in the buildings supply chain are the cement and steel sectors, the forestry sector and the construction sector. When accelerating implementation of the circular economy, the food and construction sector are the two big priorities. In sum, food and shelter fulfil basic needs in society and must not be neglected. Circular economy can play a crucial role in making them better and more sustainable.

The footprint of the supply chain of furniture and domestic appliances is also substantial, mainly as a result of the carbon footprint of steel. Accordingly, the sector producing domestic appliances can also reduce environmental impact substantially by implementing circular economy measures. Aluminium, plastic and glass have lower carbon, water and land footprints compared to other materials in scope of this study. However, implementing circular economy measures related to these materials will definitely be beneficial for businesses and the environment as well. Circular economy can, for example, reduce the plastic litter in oceans.

Environmental impacts often take place far upstream in the supply chain, as in cement and steel production. For some products, energy use is dominant, e.g. for cars and electric appliances, which results in GHG emissions. For cars and electric appliances, it is important to consider the trade-off between GHG emissions in the use phase (when increasing energy-efficiency) and the GHG emissions related to the material production (when extending product lifetime). In general, it is recommended to calculate the net environmental benefit of circular economy measures by taking the complete product life cycle into account, including specific circular economy activities like reversed logistics, remanufacturing and recycling.

Implementation of circular economy measures

Various types of circular economy measures are available. Our inventory of measures shows that circular value chains and digital platforms are measures with high potential in all sector and product supply chains. Lifetime extension/shelf life extension is particularly important for shelter and food. Companies can start adopting circular economy measures by starting with the low-hanging fruit of operational efficiency through energy-efficiency, renewable energy and waste prevention. Eventually, companies can implement more advanced circular economy strategies by involving suppliers, consumers and the larger value chain. They can also change their business models from product supplier to service provider.

Worldwide, companies across various sectors are getting started implementing the circular economy. They see the potential to frame existing initiatives under the umbrella of circular economy and are considering adopting new initiatives. With a focused approach, companies operating in the sectors that have the most positive impact potential will make positive environmental impacts while reaping cost benefits and competitive advantages.

Annex I
List of consumption sectors

Sectors	Definition
Agriculture, hunting, forestry and fishing	Includes the exploitation of vegetal and animal natural resources, comprising the activities of growing crops, raising and breeding of animals, harvesting of timber and other plants, animal products from a farm of their natural habits.
Electricity, gas and water	Includes the activity of providing electric power, natural gas, steam, hot water and the like through a permanent infrastructure (network) of lines, mains and pipes. Also covers the distribution of electricity, gas, steam, hot water and the like in industrial parks or residential buildings.
Mining and quarrying	Includes the extraction of minerals occurring naturally as solids (coal and ores), liquids (petroleum) or gases (natural gas). Also covers supplementary activities aimed at preparing the crude materials for marketing, for example, crushing, grinding, cleaning, drying, sorting, concentrating ores, liquefaction of natural gas and agglomeration of solid fuels.
Petroleum, chemicals and non-metallic mineral products	Includes the transformation of crude petroleum and coal into usable products; the transformation of organic and inorganic raw materials by a chemical process and the formation of products and manufacturing activities related to a single substance of mineral origin.
Food production, beverages and tobacco	Includes processing agriculture, forestry and fishing products into food for humans or animals, and the production of various intermediate products that are not directly food products. Also covers the manufacture of beverages and the processing of agricultural products, like tobacco, into a form suitable for final consumption.
Textiles, leather and wearing apparel	Includes preparation and spinning of textile fibers as well as textile weaving, finishing of textiles and wearing apparel, manufacture of made-up textile articles. Also covers all tailoring in all materials of all items of clothing and accessories. Furthermore, it includes dressing and dyeing of fur and the transformation of hides into leather by tanning or curing and fabricating the leather into products for final consumption, and the manufacture of leather substitutes.
Wood, paper and publishing	Includes the manufacture of wood products, such as lumber, plywood, veneers, wood containers, wood flooring, wood trusses and prefabricated wood buildings. Also covers the manufacture of pulp, paper and converted paper products.
Electrical, machinery and metals	Includes the manufacture of products that generate, distribute and use electrical power. Also covers the manufacture of machinery and equipment that act independently from materials either mechanically or thermally or perform operations on materials. Furthermore, it includes the activities of smelting and/or refining ferrous and non-ferrous metals from ore, pig or scrap, using electro-metallurgic and other process metallurgic techniques.
Transport	Includes the manufacture of transportation equipment such as ship building and boat manufacturing, the manufacture of railroad rolling stock and locomotives, air and spacecraft and the manufacture of parts thereof. Also covers the provision of passenger or freight transport, whether scheduled or not, by rail, pipeline, road, water or air and associated activities such as terminal and parking facilities, cargo handling, storage etc.
Construction	Includes general construction and specialized construction activities for buildings and civil engineering works. It includes new work, repair, additions and alterations, the erection of prefabricated buildings or structures on the site and also construction of a temporary nature.
Service sectors	Includes public administration and defence, education, health, arts, entertainment and recreation, financial and insurance activities, real estate services, professional, scientific and technical activities and other services.

Annex II
List of consumption categories

Consumption category	Definition
Mobility	Includes passenger and freight transportation by various transport modes, including road transport, railway, air and sea transport. In contrast to other consumption categories, the majority of emissions occur in use-phase, e.g. driving a car on motor gasoline, diesel or liquefied petroleum gas. These use-phase emissions are also included in this category.
Food	Includes the consumption of final food products, comprising meat, fish, dairy products and other food products. Raw and intermediate food products are also included here, e.g. paddy rice, wheat, cattle and raw milk. The consumption of beverages and tobacco are moreover covered in this category.
Furniture and household appliances	Includes the use of machinery and equipment, office machinery and computers, electrical machinery, radio, television and communication equipment. Also includes raw and intermediate products such as pulp and plastics.
Clothing and footwear	Includes the use of all products related to wool, textiles, apparel and leather.
Shelter	Includes the construction of buildings and civil engineering works, as well as all materials used for construction, e.g. cement, lime and plaster, bricks and tiles, aluminium and glass. Also covers real estate services.
Services	Includes post and telecommunication, financial intermediation, insurance and pension funding, research and development, public administration and defence, education, health and social work services.

Annex III **Data used for calculation of material flows and footprints**

The material flows were created by linking global production volumes of manufactured materials, obtained from various sources, to the corresponding Exiobase production sectors (see the data included in Table 4).

The carbon, water and land footprints were retrieved from Exiobase, taking into account the footprint of the mining sector and the production sector (last two columns of Table 4). For wood, primary crops and cattle, only the footprint of the production sector itself is taken into account.

Table 4:
Data used to obtain the global material flows and footprints of the materials in scope of this study

Materials in scope of study	Global production volumes (kton)	Source of global production volumes	Name of EXIOBASE production sector to which production volume is linked	Corresponding raw material in EXIOBASE
Steel	1,527,000	https://www.worldsteel.org/media-centre/press-releases/2012/2011-world-crude-steel-production.html	Basic iron and steel and of ferro-alloys and first products thereof	Iron ores
Aluminium	46,275	http://www.world-aluminium.org/statistics/	Aluminium and aluminium products	Aluminium ores and concentrates
Plastic	279,000	http://www.plasticseurope.org/documents/document/20150227150049-final_plastics_the_facts_2014_2015_260215.pdf	Plastics, basic	Crude petroleum and services related to crude oil extraction, excluding surveying
Cement	3,600,000	https://www.statista.com/statistics/219343/cement-production-worldwide/	Cement, lime and plaster	Not applicable, lime is included in the production sector "Cement, lime and plaster"[18]
Glass	56,000 (flat glass) 45,710 (containerglass)	Flat glass: http://www.nsg.co.jp/~/media/NSG/Site%20Content/Temporary%20Downloads/Japanese/NSGF-GI_2011%20EN2.ashx Container glass: http://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/publication/wcms_442086.pdf	Glass and glass products	Sand and clay[19]
Wood	2,430,500	EXIOBASE 3[20]	Products of forestry, logging and related services	
Primary crops	8,164,689	EXIOBASE 3[21]	Paddy rice; wheat, cereal grains nec; vegetables, fruit, nuts; oil seeds; sugar cane, sugar beet; plant-based fibers; crops nec	
Cattle	1,051,877[22]	http://www.fao.org/faostat/en/#data/QA	Cattle	

[18] When determining the environmental impact for plastic we included the share of environmental impact from 'crude petroleum and services related to crude oil extraction, excluding surveying' assigned to 'plastics, basic'.
[19] For glass, we took a similar approach as for plastic. We included the share of environmental impact from 'sand and clay' assigned to 'glass and glass products'.
[20] EXIOBASE 3 contains the raw material 'wood' (in kilotons) as one of the environmental stressors. This raw material was used in our analysis directly.
[21] EXIOBASE 3 contains the raw material 'primary crops' (in kilotons) as one of the environmental stressors. This raw material was used in our analysis directly.
[22] For cattle we derived the amount of kton by multiplication of the number of cattle (in heads, obtained from http://www.fao.org/faostat/en/#data/QA) by the average weight of a cow (in kton per head, obtained from http://www.fao.org/wairdocs/ilri/x5522e/x5522e0b.htm).

Annex IV
Overview of results

Table 5:
Overview of eight key materials and their environmental impacts (absolute) compared to global totals

Material	Tonnages	GHG	Water	Land use
	Mt	$MtCO_2e$	Gm^3	10^4 km^2
Steel	1,527	1,751	19	0
Aluminium	46	45	0	0
Plastic	279	214	11	0
Cement	3,600	2,298	2	0
Glass	102	160	0	0
Wood	2,431	48	0	3,547
Primary crops	8,165	1,039	1,195	1,471
Cattle	1,052	1,982	21	1,812
Total from materials	17,202	7,538	1,248	6,831
Total from EXIOBASE 3 (all 200 products)		37,000	1,318	7,724
Share from total in EXIOBASE 3		20%	95%	88%

Table 6:
Overview of eight key materials and their environmental impacts (relative)

Material	Tonnages	GHG	Water	Land use
Steel	9%	23%	2%	0%
Aluminium	0%	1%	0%	0%
Plastic	2%	3%	1%	0%
Cement	21%	30%	0%	0%
Glass	1%	2%	0%	0%
Wood	14%	1%	0%	52%
Primary crops	47%	14%	96%	22%
Cattle	6%	26%	2%	27%

Annex IV
Overview of results

Table 7:
Overview of 11 consumption sectors and their environmental impacts (relative)

Consumption sectors	Tonnages	GHG	Water	Land use
Agriculture, hunting, forestry and fishing	22%	9%	37%	35%
Mining and quarrying	0%	0%	0%	1%
Food production, beverages and tobacco	18%	16%	28%	20%
Textiles, leather and wearing apparel	2%	2%	2%	2%
Wood, paper and publishing	1%	0%	0%	3%
Petroleum, chemicals and non-metallic mineral products	5%	4%	2%	3%
Transport	1%	1%	1%	1%
Service sectors	17%	15%	18%	17%
Electricity, gas and water	1%	1%	1%	1%
Construction	23%	36%	5%	9%
Electrical, machinery, metals and manufacturing	10%	17%	5%	8%

Table 8:
Overview of six key materials and their environmental impacts (relative)

Consumption sectors	Tonnages	GHG	Water	Land use
Shelter	34%	41%	7%	38%
Food	33%	25%	66%	30%
Clothing and footwear	2%	2%	2%	2%
Mobility	5%	6%	3%	3%
Furniture and domestic appliances	10%	12%	5%	10%
Services	16%	14%	17%	17%

Acknowledgements

This report was written by Annemarie Kerkhof, Maurice Quant, Preeti Srivastav, Maarten Neelis and Kornelis Blok (Ecofys, a Navigant company). Input was provided by Maria Mendiluce, Brendan Edgerton and Andrea Brown (WBCSD).

The authors would like to thank Richard Wood of the Norwegian University of Science and Technology (NTNU) for giving access to EXIOBASE 3, for his support in the data retrieval from the database, and for reviewing this report. NTNU is a leading research institution on Input-Output Analysis and is one of the co-founders of the Input-Output database EXIOBASE 3.

Project number: SISNL17428

About Ecofys, a Navigant company

Ecofys, a Navigant company, is a leading international energy and climate consultancy focused on sustainable energy for everyone. Founded in 1984, the company is a trusted advisor to governments, corporations, NGOs, and energy providers worldwide. The team delivers powerful results in the energy and climate transition sectors. Working across the entire energy value chain, Ecofys develops innovative solutions and strategies to support its clients in enabling the energy transition and working through the challenges of climate change.

Ecofys - A Navigant Company

Kanaalweg 15-G
3526 KL Utrecht
The Netherlands

www.ecofys.com

About the World Business Council for Sustainable Development (WBCSD)

WBCSD is a global, CEO-led organization of over 200 leading businesses working together to accelerate the transition to a sustainable world. We help make our member companies more successful and sustainable by focusing on the maximum positive impact for shareholders, the environment and societies.

Our member companies come from all business sectors and all major economies, representing a combined revenue of more than $8.5 trillion and 19 million employees. Our Global Network of almost 70 national business councils gives our members unparalleled reach across the globe. WBCSD is uniquely positioned to work with member companies along and across value chains to deliver impactful business solutions to the most challenging sustainability issues.

Together, we are the leading voice of business for sustainability: united by our vision of a world where more than nine billion people are all living well and within the boundaries of our planet, by 2050.

www.wbcsd.org

World Business Council
for Sustainable Development

Maison de la Paix
Chemin Eugène-Rigot 2B
CP 2075, 1211 Geneva 1
Switzerland
www.wbcsd.org