Ministry of Environment and Food of Denmark
Environmental Protection Agency

Material Resource Productivity in Denmark

Past trends and outlook to 2030

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Sources must be acknowledged.

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Preface

This technical paper was developed for the Danish Environmental Protection Agency by Copenhagen Resource Institute in order to contribute to the evidence base on resource productivity in Denmark towards 2030.

Summary

In 2014, the Danish economy used 113.2 million tonnes of domestic material consumption (DMC), to produce a GDP of approximately 1837 billion DKK. This corresponds to a material productivity of 16.22 DKK/kg.

Resource productivity in Denmark has improved by 21.6 % in total in the period 2000-2014, or approximately 1.41 % improvement per annum, although the actual year on year change has been more volatile: from – 13% to +15 %. In comparison, the resource productivity in the EU improved by 34 % between 2000 to 2014. In a business as usual scenario, the resource productivity of the Danish economy is estimated to improve by approximately 16 % from 2014 to 2030. This estimate is associated with considerable uncertainty, primarily due to the high fluctuations in the use of non-metallic minerals.

The resource productivity figures are greatly dominated by resource use in a few sectors, and the productivity improvement is primarily caused by a slow-down in the construction sector from 2009 onwards – this is also true for the EU as a whole. The past and future development of resource use and productivity up to 2030 are primarily influenced by construction activity. Beyond the prominent role of the construction sector, the success of phasing out fossil fuels is crucial to boost resource productivity. However, reducing fossil fuel use in itself will not significantly increase resource productivity.

Approximately 65% of the direct material inputs (DMI) to the Danish economy are domestic material extraction, and around 35% from imports. At the other end, 25 % of DMI is exported and 75 % is used domestically (DMC). Use of non-metallic minerals, mainly construction materials such as sand and gravel, dominate material use. While the use of these materials has reduced somewhat, their application still seems strongly linked to the overall patterns of economic growth. The use of fossil energy carriers has decreased in absolute terms and has been decoupled from economic growth.

Using GHG emissions as a proxy, the environmental impacts associated with the extraction of the various raw materials in DMC do not reflect the quantities of these materials in DMC: while non-metallic minerals make up around half of total DMC, the environmental impacts of these materials are below 1 % of the total impacts. The impacts from DMC instead come mainly from the extraction of fossil fuel (57 %) and biomass (36 %).

Due to the dramatic price increase of raw materials (especially fossil fuel carriers) over the time period, the total value of raw materials in DMC (excl. '*other products*') has almost doubled, from 55.8 billion DKK in 2000 to 104 billion DKK in 2014. This corresponds to 3.3 % and 5.7 % of the GDP in the respective years. The value of raw materials as a share of GDP peaked in 2008 at 153 billion DKK, or 8.2% of GDP.

Sand and gravel, fossil fuels, cereals and fodder crops (and the industries that utilize them) could be specifically targeted as they have the potential to affect total DMC significantly and therefore increase resource productivity.

biomass

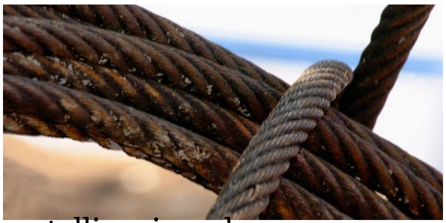
23 % of DMC

36 % of GHG emissions

non-metallic minerals

52 % of DMC

1 % of GHG emissions



metallic minerals

1 % of DMC

6 % of GHG emissions

fossil fuel

24 % of DMC

57 % of GHG emissions

Dansk sammenfatning

Denne tekniske rapport er udarbejdet af Copenhagen Resource Institute for Miljøstyrelsen. Formålet med rapporten er at præsentere viden om ressourceproduktiviteten i Danmark i perioden 2000-2014 samt give et bud på en fremskrivning i ressourceproduktiviteten i Danmark frem mod 2030.

I rapporten diskuteres udvalgte emner, som er knyttet til ressourceforbrug og produktivitet i Danmark. Emnerne er baseret på standardiserede såkaldte *Economy-Wide Material Flow Accounts* (MFA), som omfatter fossile brændsler, biomasse, mineraler og metaller. Mere generelle ressourcer som luft, jord, land, vand og biodiversitet er ikke omfattet af rapporten.

For at forstå de underliggende faktorer for den fremtidige udvikling, er der, med afsæt i materialestrømsdata for perioden 2000-2014, opbygget et basisscenarie for ressourceforbrug og produktivitet frem til 2030.

Rapporten har ydermere til formål at estimere de miljømæssige påvirkninger, som er forbundet med materialestrømme, samt at vurdere den økonomiske værdi af de materialer, som anvendes i den danske økonomi. Endelig bidrager rapporten til en bedre forståelse af materialestrømme set fra forskellige perspektiver ved at sammenligne materialestrømme, miljøpåvirkninger og priser på råmaterialer.

I 2014 forbrugte den danske økonomi 113,2 millioner tons materialer på hjemmemarkedet, såsom biomasse, fossile brændsler, metalliske og ikke-metalliske mineraler. Dette forbrug genererede et BNP på omkring 1.837 milliarder kr., hvilket svarer til en ressourceproduktivitet på 16,22 kr./kg materiale.

Den danske ressourceproduktivitet er samlet set forbedret med 21.6 % i perioden 2000-2014, hvilket svarer til en gennemsnitlig, årlig forbedring på ca. 1,41 %. Dette tal dækker over udsving på mellem -13 % og +15 % over årene. Til sammenligning er ressourceproduktiviteten i EU forbedret med 34 % i perioden 2000-2014. Med udgangspunkt i et business-as-usual scenarie, forventes den danske ressourceproduktivitet samlet set at forbedres med i størrelsesordenen 16 % i perioden 2014-2030. Det skal bemærkes at fremskrivningen er behæftet med stor usikkerhed, hvilket primært skyldes høje fluktuationer i brugen af ikke-metalliske mineraler.

Tallene for ressourceproduktivitet er domineret af ressourceforbruget i nogle få sektorer og forbedringen i produktiviteten er hovedsageligt forårsaget af et fald i aktiviteterne i bygge- og anlægssektoren siden 2009. Dette gør sig også gældende for EU samlet set. Den hidtidige og fremtidige udvikling i ressourceforbrug og produktivitet frem til 2030 er således hovedsagelig påvirket af aktiviteter i bygge- og anlægssektoren.

En succesfuld udfasning af fossile brændsler spiller ligeledes en afgørende rolle – omend mindre prominent end bygge- og anlægssektoren – i forbindelse med en forbedring af ressource-produktiviteten. En reduktion i brugen af fossile brændsler vil dog ikke i sig selv være nok til at forbedre ressourceproduktiviteten med en væsentlig højere faktor end tidligere. Generelt har sektorer, der er tættest på materialeudvindingsstederne i værdikæden, tendens til en høj materialeintensitet og dermed en lav ressourceproduktivitet.

Med hensyn til brugen af det direkte materialeinput (DMI) til den danske økonomi, stammer ca. 65 % fra indenlandsk udvinding mens 35 % er fra import. I sidste ende eksporteres 25 % af det direkte materialeinput, mens 75 % anvendes på hjemmemarkedet. Anvendelse af ikke-metalliske mineraler, hovedsagelig byggematerialer som sand og grus, dominerer materialeforbruget og er ikke reduceret i absolutte tal, men ser ud til fortsat at følge den overordnede udvikling i den økonomiske vækst. Brugen af fossile brændsler er reduceret i absolutte tal og er afkoblet fra den økonomiske vækst.

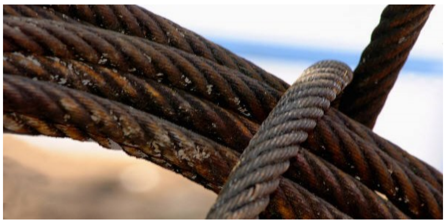
Ikke-metalliske mineraler, som udgør omkring halvdelen af DMC udgør blot under 1 % af de samlede miljøpåvirkninger (udregnet i form af klimagasudledninger). I stedet domineres miljøpåvirkningerne af udvinding af fossile brændstoffer (57 %) og biomasse (36 %). De miljøpåvirkninger, som er forbundet med udvinding af råstoffer i DMC følger således ikke mængden af udvundne materialer.

På grund af den drastiske prisstigning på råvarer (især fossile brændsler) i perioden 2000-2014, er den samlede værdi af råstoffer i DMC næsten fordoblet i perioden 2000 til 2014 fra 55,8 til 104 milliarder kr. årligt. Dette svarer til hhv. 3,3 % og 5,8 % af BNP i de to år. I 2008, da ressourcepriserne var på toppen, var dette tal helt oppe på 8,2 %.

For at reducere det danske DMC og øge ressourceproduktiviteten væsentligt anses der for værende potentialer inden for følgende materialegrupper: sand og grus, fossile brændsler samt korn og foderafgrøder.

Biomasse
23 % af DMC
36 % af klimagasudledninger

Ikke-metalliske mineraler
52 % af DMC
1 % af klimagasudledninger



Metalliske mineraler
1 % af DMC
6 % af klimagasudledninger

Fossile brændsler
24 % af DMC
57 % af klimagasudledninger

1. Introduction

This paper discusses issues related to resource use and productivity in Denmark. The analysis is based on standardised Economy-Wide Material Flow Accounts (MFA) covering fossil energy carriers, biomass, minerals, metals and other products. As such, it does not include the broader resources of air, soil, land, water and biodiversity.

Furthermore, this paper uses a combination of input-output analysis and material flow accounting to provide an exploratory analysis of the resource productivity of various sectors. An earlier working paper prepared by CRI experts (ETC/SCP, 2011) inspired the research methods used for this.

This paper also estimates the environmental impacts associated with material flows and the economic value of the materials used in the Danish economy. Ultimately, the paper also contributes to a better understanding of material resource flows by comparing material flows, environmental impacts and costs of raw materials. Data for the period of 2000-2014 is used to establish a baseline scenario on resource use and productivity up to 2030.

2. Methodology brief

2.1 Economy-Wide Material Flow Accounts (EW-MFA) and derived indicators

The information and analysis in this paper is based primarily on standardised Economy-wide Material Flow Accounts (EW-MFA) and derived indicators. To monitor economy-wide material flows, Eurostat has applied an accounting methodology and a number of indicators that describe the material throughput and material stock additions in a (national) economy.

The MFA-based assessment considers resource use in the most macroeconomic sense, focusing on physical flows of materials in the economy. Throughout the text, the term 'material resources' will be used to refer to MFA-based use of resources expressed in tonnes. EW-MFA accounts for all extraction of biomass, fossil fuels, metal ores and metals, and non-metallic minerals, and other products, and the imports and exports of all goods, but it excludes water and air.

Furthermore, MFA indicators account for the weight of used materials (tonnes) with an economic value. This is narrower than the broad definition of 'resources' used for example in the Roadmap to a Resource Efficient Europe, which covers not only 'material resources' but also water, soil, land, biodiversity, and ecosystem services.

The categories of materials available in material flow data are:

- Metallic minerals (gross ores, concentrates, and products mainly from metals),
- Fossil energy materials/carriers (i.e. crude oil for both energy use and plastic production, plus gasoline, coal, natural gas, etc.),
- Non-metallic minerals (cement, aggregates etc.)
- Biomass (agricultural products, food, timber, biomass for energy use etc.)
- Other products

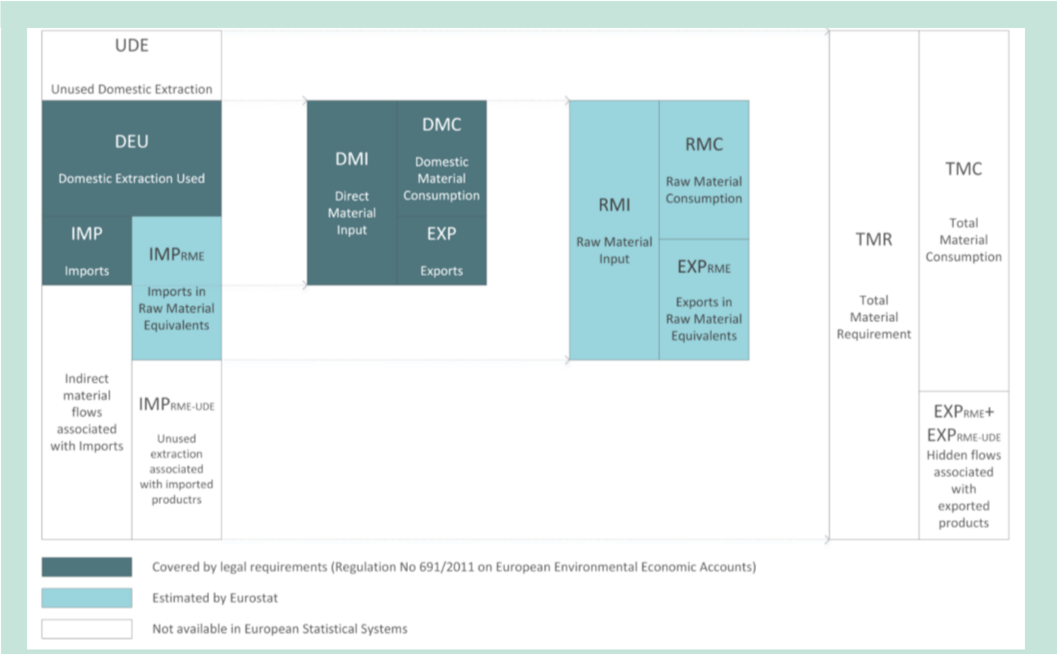
A common criticism of MFA is that the environmental implications of using a tonne of metal are very different from the use of a tonne of aggregates. While there are efforts to take environmental impacts into account, there is no widely accepted and robust methodology available to do so. In this paper, an attempt is made to quantify impacts based on data from life cycle assessments.

2.1.1 Main MFA indicators

The most important indicators illustrated in *Figure 1* used in this paper are the following:

- **Domestic Extraction Used (DEU)** that sums all natural resources that are domestically extracted in a given country and used in the economy.
- **Direct Material Input (DMI)** that measures all the direct input of materials into the economy, that is from domestic extraction (DEU) plus physical IMPORTS of goods (IMP).
- **Domestic Material Consumption (DMC)** is the most important throughput indicator that equals to DMI minus EXPORTS (EXP) and thus represents the material consumption of an economy domestically.
- **Resource Productivity**, a measure of how efficiently an economy uses resources to produce economic value, is generally defined as gross domestic product (GDP) per unit of resource use expressed in one of the indicators above. In this paper, in accordance with the European Commission's policy agenda, GDP/DMC expressed as DKK/tonne is used.

FIGURE 1 MAIN MATERIAL FLOWS ACCOUNTED AND INDICATORS DERIVED FROM ECONOMY-WIDE MATERIAL FLOW ACCOUNTS



Source: Eurostat, 2013

2.1.2 DMC vs RMC

The indicator Raw Material Consumption (RMC) measures all the material resources used in the economy, while also taking into account the resource use embedded in imports. In comparison, DMC only takes direct material flows from trade (IMP and EXP) into account on top of Domestic Extraction Used (DEU).

While RMC is the theoretically more suitable indicator to use for resource productivity calculations, the underlying data for RMC is currently far less robust than for DMC, and the overall trends in the two indicators are broadly the similar, with some divergences. The difference between DMC and RMC is primarily significant for fossil fuels and metals. In the EU-27 as a whole, RMC has been estimated by Eurostat (IFEU, 2012) to be approx. 5 % higher than DMC.

In absence of reliable data or estimates on RMC for Denmark, DMC is used as the main indicator in this paper. The choice of DMC is also acknowledged by the European Commission (EC, 2014), which urges countries to use DMC until the indicator RMC, the headline indicator defined by the European Commission, is made available.

When the analysis is focused on the *sectoral* resource productivity, where the entire direct resource use both for domestic consumption and for export are important, Direct Material Inputs (DMI) can be used to supplement DMC for some calculations. This is particularly relevant for Denmark, since many industrial sectors produce for export.

2.2 Resource demand along production chains using Input-Output Analysis

Most of the actual material extraction takes place in a few industries, i.e. mining and quarrying and agriculture and fishing. As such, using MFA itself does not directly provide information on material productivity of sectors and industries. In order to create a link between the material flows and the economy, input-output tables for Denmark can be used.

Environmentally extended input-output analysis (EE-IOA) can help describe the link between the final use of products and global resource extraction and use. The EE-IOA model is formed around an input-output table (IOT) in monetary units. The IOT is drawn from national accounts and shows the purchase and sale of raw materials and other products between all the industries in the economy. It also shows the sale of goods and services from industries and businesses to households and government, etc. The IOT also includes monetary flows of imports to and exports from industries, and shows imports for direct final use by government and households. The IOT is then further extended with environmental accounts (so-called environmental extensions) given in physical units e.g. the extraction of resources.

When attributing DMI to individual production sectors (i.e. agriculture, electricity, transport services, construction etc.), an individual sector includes the raw materials extracted domestically by that sector plus the raw materials and semi-finished products imported and used as intermediate products by that industry. Semi-finished or finished products produced domestically and used as intermediate input into industry are not considered in this economic-sector perspective. The material input and resource use of that industry can then be compared to its economic output and viewed over time to gauge whether the sector's material resource productivity have improved. However, there are few time series available to make this observation.

For the purposes of this paper the environmental extensions comprise material/resource flows derived from EW-MFA using a test version of a tool developed by the ETC/SCP for the EEA. The tool uses a well-defined algorithm to produce tables that follow the full production chains of products for final use, from the extraction of raw materials through the industries to the final use of products by households, by government, and for export. This process reallocates the direct resource use of industries to the final products according to the flow of money along the production chain of that final good, i.e. the resource use is assumed to follow the flow of money. In this way, the direct and indirect resource use caused by the purchase of different final product groups can be estimated and compared.

2.2.1 Limitations

The results of EE-IOA should be treated with some caution. There are two main sources of potential inaccuracy. Firstly, there is a reasonably high level of aggregation of industries and products in the IOT from Eurostat: The entire economy is represented by 60 industry and 60 product groups. Secondly, the model makes the assumption that the delivery of one Euro or DKK of products from, for example, the chemical industry to agriculture involves exactly the same economic activities and resource uses as the delivery of one Euro of products from the chemical industry to any other industry or final use category, e.g. the vehicle manufacturing industry or exports. This will often not completely reflect reality since, for instance, agriculture and the car industry use different chemicals with different characteristics. The indicator values should therefore be interpreted as material and resource flows induced by economic activities. The EE-IOA calculations for this paper have been carried out by the model developed by the ETC/SCP.

The data for conducting these calculations is only available for a few specific years and are typically rather outdated: i.e. the latest analysis is available for year 2005 and 2007. As such, they mainly provide a snapshot of the economy and do not help illuminate the development over time.

2.3 Forecasting trends up to 2030

A business as usual (BAU) scenario for the development of DMC and productivity has been developed based on various parameters:

- Economy-Wide Material Flow Accounts (2000-2014) from Statistics Denmark (DST) and Eurostat.
- Population and population forecasts from DST.
- Estimated future GDP growth rates from the Danish Ministry of Finance. These are the closest to a best-fit trend line for the period 1995-2015.
- The forecasts on development in future material flows and the DMC indicator are based on our expert judgement following an analysis of various forecasting methods, i.e. the combination of regression analysis between resource use and economic growth and best-fit trendlines observed in individual material groups as follows:
    - Non-metallic minerals: forecast based on the long-term trend observed for the DMC of sand and gravel. The DMC for this material group is very volatile, and this method provides a robust long-term projection. To account for likely future volatility, the forecast for this material group is presented as three scenarios: low, medium and high construction activity, using +/- 17.5% of the projected medium.
    - Metals and other products: forecasts based on a regression analysis between the DMC of these material groups and GDP.
    - Biomass: forecast constructed by correcting the linear extrapolation of past trends with a combination of the forecasted variation of solid biomass and bio fuels found in Danmark's Energifremskrivning (2012). The future impacts of existing policies are taken into account for the reduction of fossil fuel use by 2030 in Denmark and the partial substitution by biomass. The variation of solid biomass and bio fuels was given in PJ and was converted to tonnes based on conversion factors: 18 GJ/tonne biomass and 33.36 GJ/tonne biofuel.
    - Fossil energy carriers: forecast constructed by correcting the linear extrapolation of past tends with a combination of the 2014 levels of fossil energy carriers and the forecasted variation of coal, oil, nature gas and waste (fossil) found in Danmark's Energifremskrivning (2012).
- Estimates based on commodity prices from DST and the World Bank.

2.4 Estimating environmental impacts of material flows

Due to the complexity of the flows, there are no widely accepted methodologies to estimate environmental impacts of material flows, despite various attempts to account for the environmental aspects of every tonne of various material resources. As such, the figures presented here are based on selected life cycle assessment (LCA) derived results, and are based on a series of assumptions and mixture of methodologies and therefore should be understood as very speculative.

This report uses cradle-to-gate greenhouse gas (GHG) emissions as a proxy for all environmental impacts from resource extraction. GHG emissions are a reasonably robust proxy for most material groups (this is explored in more depth in section 3.3). The most important source of information was the GaBI professional database, where cradle-to-gate greenhouse gas (GHG) emissions were obtained for the most important material categories. Where the point of extraction is not providing the basic material, the primary process is taken into account, e.g. producing cast iron. Additional evidence was taken from an earlier CRI report[1] on resource use of buildings. The most important limitation of these methodologies is that they do not represent improvement over time, but a snapshot of technology.

[1] Resource efficiency in the building Sector (2014) http://cri.dk/publications/resource-efficiency-in-the-building-sector

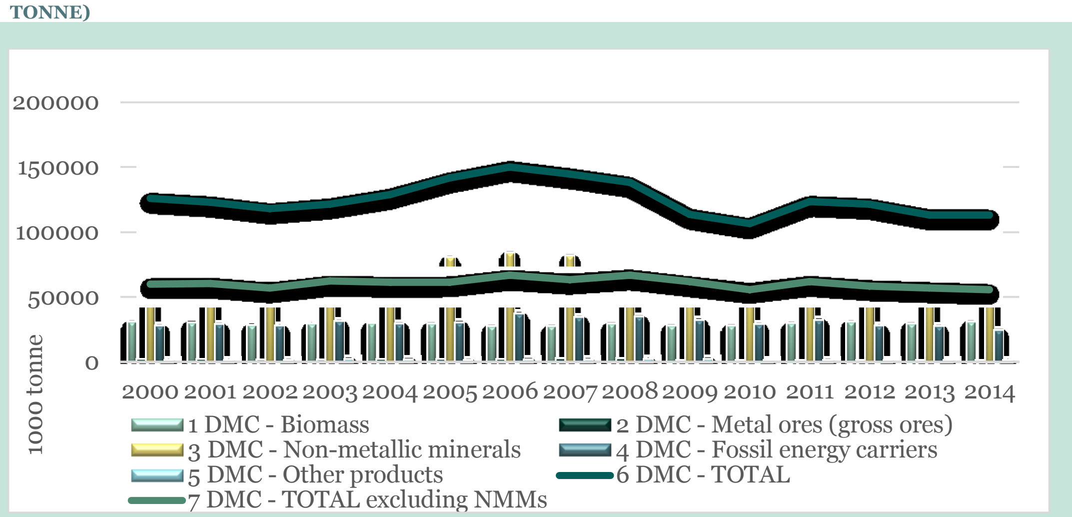
TABLE 1 MAIN DATA SOURCES

Institution	Data set
Eurostat	Material Flow Accounts (2000-2014)
Statistics Denmark (DST)	- Material Flow Accounts (2000-2014) - Population data and official forecasts (2000-2030) - GDP (1993-2015) - Construction activity (1939-2016)
Ministry of Finance	GDP real annual growth rate forecasts (2015-2030)
ETC/SCP-EEA online NAMEA Tool (non-public test version)	DMI in sectors (2005)
World Bank	Commodity Prices and Forecasts (2000-2025)
GaBI Professional Database	LCA impacts of various materials
Danish Energy Agency	- Danmarks Energifremskrivning, 2012 - Energy portfolio change (2012-2030) - Energy prices (2009-2016)

3. Resource use trends 2000-2014

As *Figure 2* shows, the DMC[2] of Denmark has reduced from 125.9 million tonnes in year 2000 to 113.2 million tonnes by 2014, with significant fluctuations over the period. In 2013[3], total DMC corresponded to approx. 20.2 tonnes/capita, putting Denmark in the top 9 of the EU in terms of resource use per capita following Finland, Estonia, Sweden, Ireland, Romania, Austria, Luxembourg and Latvia (*Figure 3*).

FIGURE 2 DEVELOPMENT OF DENMARK'S DMC AND ITS MAIN MATERIAL CATEGORIES (2000-2014, 1000 TONNE)



Source: CRI / Data source: DST

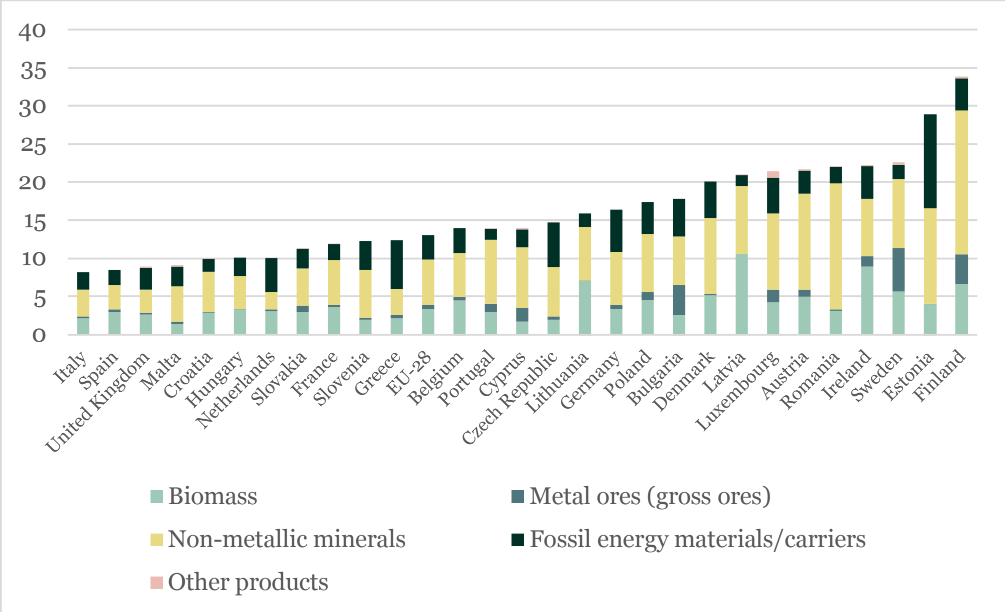
Few materials make up 80 % of the total DMC

Over the period of 2000-2014, seven materials were responsible for 80 % of the resource use (DMC). The materials used in highest amount are sand and gravel (45 %) followed by four sub-categories of fossil fuels (24 % in total). From biomass, the highest figures are reported for the group of cereals (6.5 %) and fodder crops (3.7 %). Metallic minerals make up a nearly insignificant (by weight) 1 % of total DMC, with iron itself accounting for 60 % of this.

Taking also indirect and unused material flows (raw material equivalent) into account using an estimate based on a Multi-Regional Input-Output Analysis, the raw material inputs (RMI) accounted for around 335.32 million tonnes in 2007, approximately 80 % more than the DMI itself (please see section 2.1.1 for more information on material flow definitions).

2 See Annex I for a detailed compilation of the DMC.
3 For this specific Eurostat dataset, 2013 is the most recent reliable data-point.

FIGURE 3 DMC (TONNES PER CAPITA) IN THE EU, YEAR 2013



Source: Eurostat

TABLE 2 MAIN MATERIAL CATEGORIES AND GROUPS OF DMC AND DMI. AVERAGE OF 2000-2014 (% OF DMC AND DMI) (ROUNDED FIGURES)

	% DMC	% DMI
Biomass	**22.9 %**	**23.4%**
Cereals	6.5 %	6.1 %
Fodder crops	3.7 %	2.7 %
Straw	2.7 %	2.0 %
Metals	**1.0 %**	**3.8 %**
Iron	0.6 %	1.8 %
Non-metallic minerals	**51.7 %**	**41.6 %**
Sand and gravel	45.1%	34.4%
Clays and kaolin	1.4 %	1.1 %
Chalk and dolomite	3.2%	2.7%
Fossil fuels	**23.7%**	**29.3%**
Crude oil and natural gas liquids	6 %	13.9 %
Fuel for water transport	7.8 %	5.8 %
Hard coal	5.2 %	3.9 %
Natural gas	3.0 %	4.1 %

Source: CRI /Data source: Eurostat

The DMC of Denmark is influenced mostly by use of sand and gravel

Total DMC of all material resources, with the exception of non-metallic minerals, has been reasonably stable over the period 2000-2014. DMC excluding non-metallic minerals has been approx. 70 million tonnes, subject to smaller fluctuations in a range of +/-10 % extremes.

The DMC of sand and gravel was 57.3 million tonnes on average over the period, but proved to be very volatile, i.e. 73.5 million tonnes in 2006 and only 42.3 million tonnes in 2010. In 2005-2006, during the peak of the last construction boom before the economic slow-down, as much as 49-50 % of Denmark's DMC was sand and gravel.

While in the EU-28 as a whole, sand and gravel account only for 30-33 % of the total DMC, it represented an average of 45 % of DMC in Denmark over the period. As such, this single material group, subject to very high fluctuations following mainly changing demand in the construction sector, has an enormous influence on the overall development of the total DMC and, as a consequence, resource productivity.

Use of crude oil and hard coal have decreased, but this trend was slowed by the increased use of fuel for water transport (including all Danish international shipping) while use of natural gas remained at a constant level.

Developing Amager Strandpark used around 2 million tonnes of sand in 2004-2005, which is equivalent to 1.5 % of the sand and gravel consumption

3.1 Physical trade balance

The amount of material from domestic extraction has fallen in Denmark over the period (*Figure 4*), and as *Figure 5* suggests, imports of all material groups have grown over the period, with biomass (23 %) and non-metallic minerals (34 %) experiencing the largest growth. Over the period of 2000-2014, the ratio of DMC and exports (EXP) remained relatively constant, with DMC accounting for 75 % of the DMI and EXP for approximately 25 % of the DMI.

FIGURE 4 DEU 2000-2014 (1000 TONNE)

Note: Zero value for metallic minerals and other products

FIGURE 5 IMPORTS 2000-2014 (1000 TONNE)

FIGURE 6 DMC 2000-2014 (1000 TONNE)

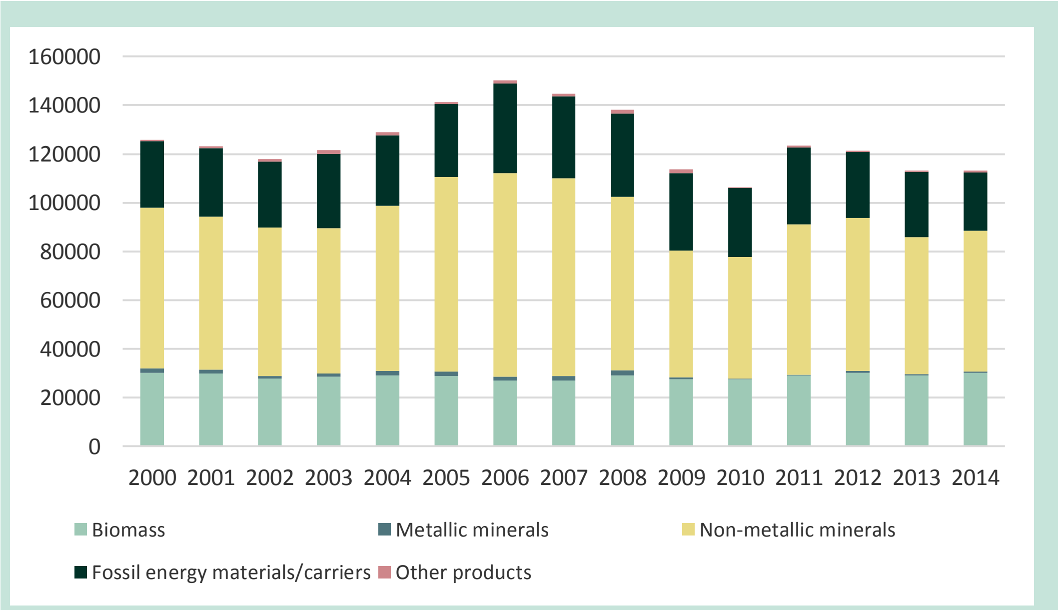


FIGURE 7 EXPORTS 2000-2014 (1000 TONNE)

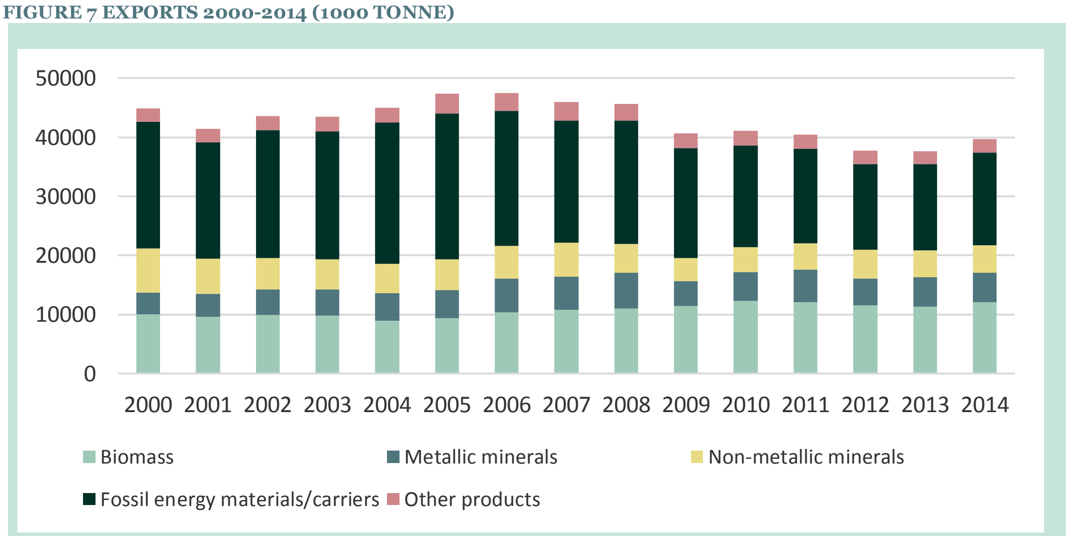
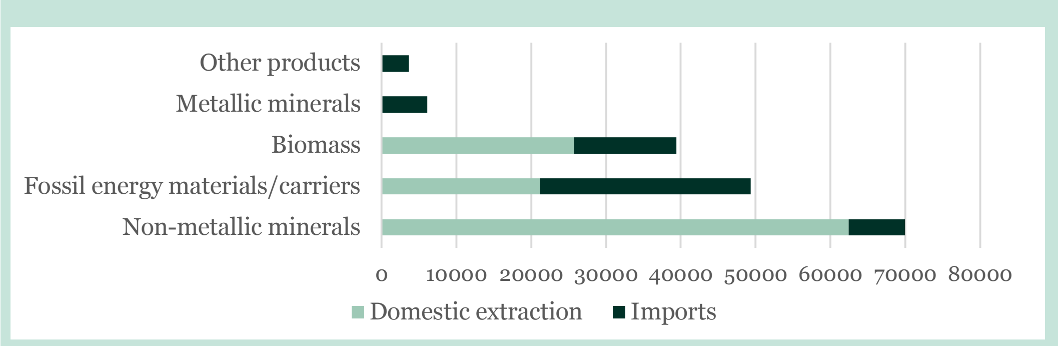


FIGURE 8 AVERAGE EXTRACTION AND IMPORTS 2000-2014



Data source: DST

3.2 Resource use in various industries

Most of the direct material inputs in the economy are limited to a few industries/products. Mining and quarrying, agriculture, forestry and food products, fossil fuels and energy supply and construction altogether account for some 90 % of the direct material inputs to the economy (*Figure 9*).

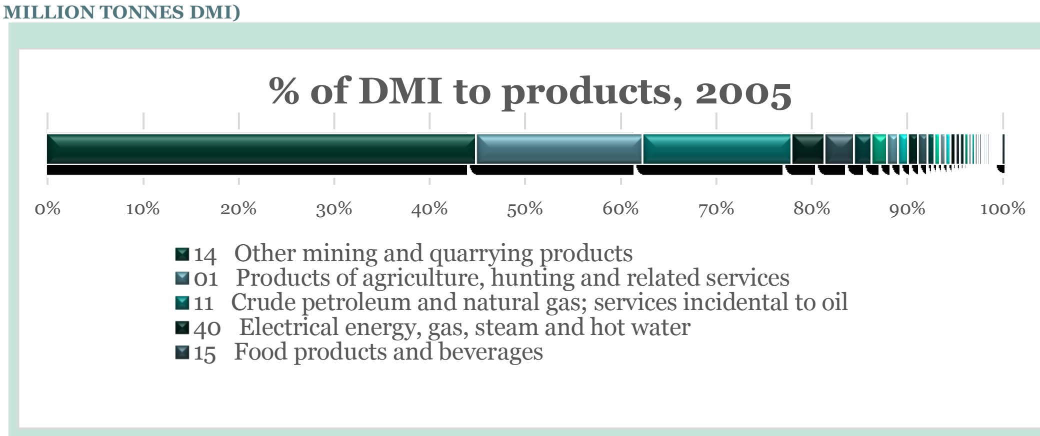
Taking indirect material use (raw material equivalent in addition to direct material flows) into account, using an estimate based on data from Multi-Regional Input-Output Analysis (BIO IS, 2013), the raw material inputs (RMI) accounted for around 335.32 million tonnes in 2007, approximately 80 % higher, than the DMI itself. *Figure 10* illustrates how these resources were divided between sectors.

In terms of the absolute volume of RMI, the construction industry uses by far the most raw materials, and two thirds of all minerals. The construction sector is followed by the agricultural sector and the food and drink industry as the next greatest material-consuming sectors using around 60 % of biomass.

Compared to the rest of Europe, Denmark also extracts a relatively large amount of oil, all of which comes from the North Sea. The RMI for the Danish fossil fuel mining industry is one of the largest in EU.

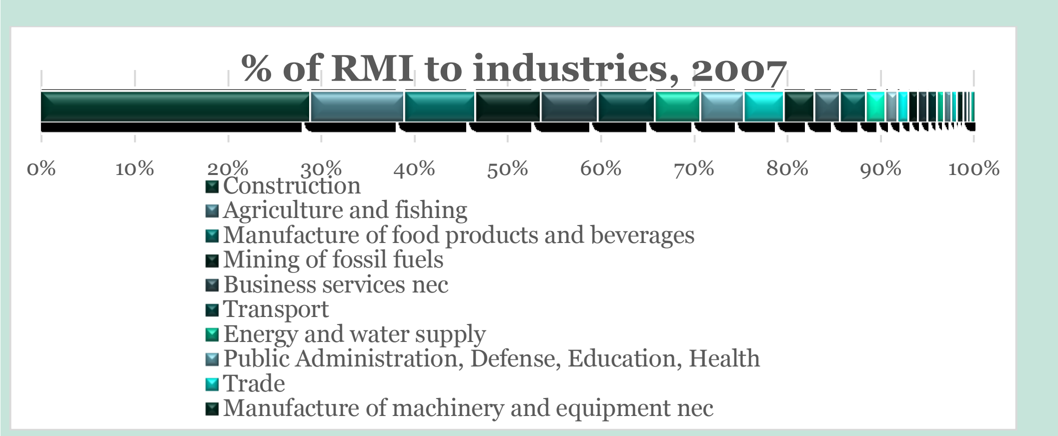
Use of fossil fuel is spread across several sectors (*Figure 11*). Mining of fossil fuels and production together are responsible for 30 % of raw material use of fossil fuels, followed by transport (16 %), energy and water supply (13.8 %), construction (5.3 %) and trade (5 %).

FIGURE 9 DIRECT MATERIAL INPUTS (DMI) TO PRODUCTS IN DENMARK, YEAR 2005 (AS % OF 174 MILLION TONNES DMI)



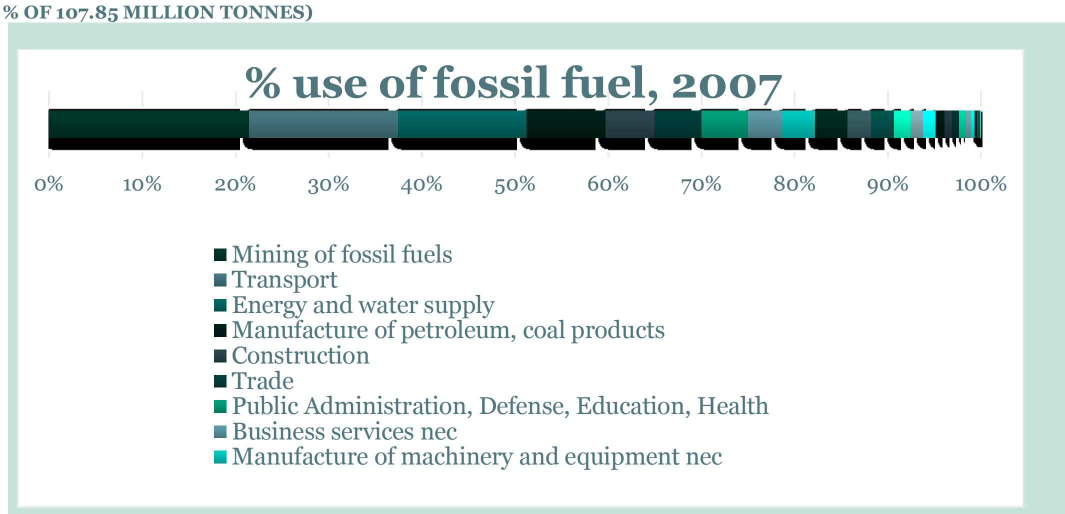
Source: Calculations by the ETC/SCP-EEA Online NAMEA Tool Test Version

FIGURE 10 RAW MATERIAL INPUTS* (RMI) TO INDUSTRIES IN DENMARK, YEAR 2007 (AS % OF 335.32 MILLION TONNES)



Source: Source: BIO IS and SERI, 2013

FIGURE 11 FOSSIL FUEL RAW MATERIAL INPUTS* TO ECONOMIC SECTORS IN DENMARK, YEAR 2007 (AS % OF 107.85 MILLION TONNES)



Source: BIO IS and SERI, 2013
*Note: this model uses total raw materials including indirect flows

According to DAMVAD, 2013, resource productivity (as defined by DAMVAD) of Danish industry has not improved at all between 2000 and 2010. According to the estimates, there is approximately 6.1 % savings potential for companies with lower efficiency compared to the average.

Regrettably, there are no long data series available in EE-IOT that would allow modelling of the change in resource intensity and productivity of individual sectors over time.

3.3 Environmental impacts of resource extraction

This report uses greenhouse gas (GHG) emissions measured in tonnes of CO_2 equivalents as a proxy for all environmental pressures of the extraction of the raw materials in DMC (*Figure 12*).

Accounting for GHG emissions is a reasonable proxy for total environmental impacts, but is not entirely representative for all environmental impacts. While information on all materials is incomplete, a regression between CO_2 emissions and LCA derived eco-points[4] a reasonably strong correlation for most material groups demonstrate (*Figure 13*). However, a number of other factors determine the overall environmental impacts of materials.

[4] The Eco-indicator ’99 is an LCA based methodology. The total environmental impacts are measured in milli-eco-points (mPt).

For example, while the extraction of non-metallic minerals, including sand and gravel, is relatively technologically simple, with extraction using mainly open-pit processes and the end products requiring little further processing, the mining and processing of metals or fossil fuel carriers require much more energy and create more waste materials. This is why iron is associated with a higher ratio of CO2 equivalent emissions to eco-points than most other materials. Similarly, the extraction of fodder crops also emits a very high ratio of CO2-equivalent emissions to eco points. This indicates that for these two material groups the overall environmental impacts, relative to those in the other material groups, will be overestimated by using CO2-equivalents as a proxy for total environmental impacts.

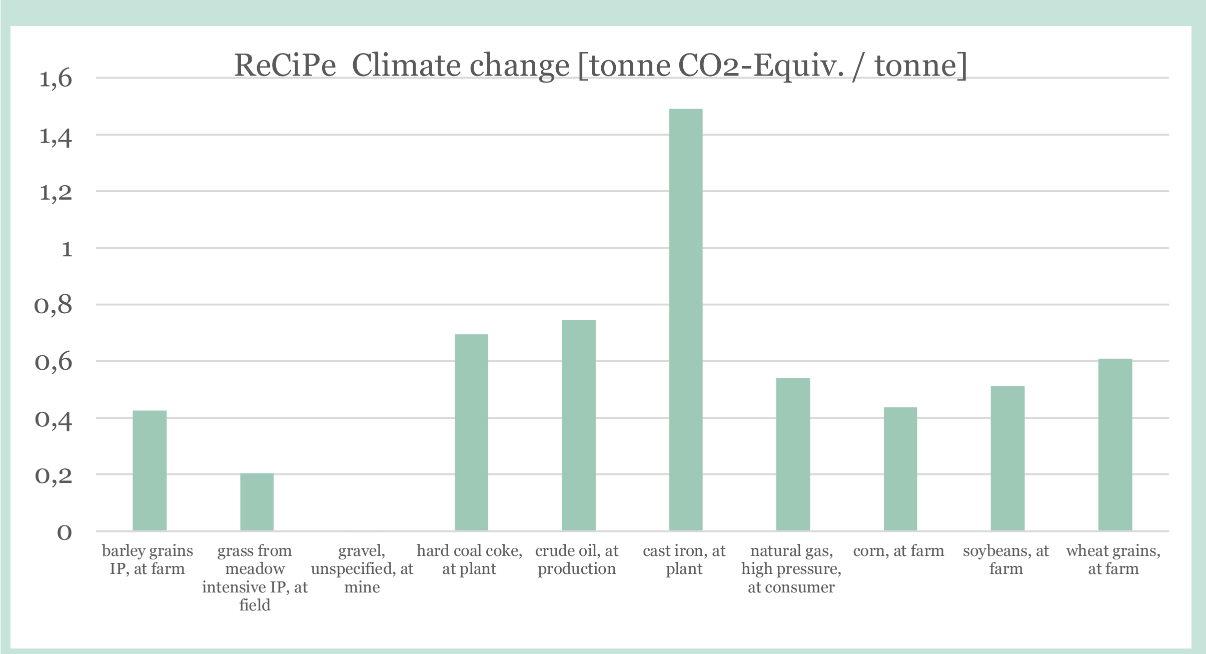
In terms of CO_2 emissions associated with the extraction of 1 tonne of the most important materials in DMC, iron[5] stands out (1.4 tCO_2/t) followed by fossil fuels (0.5-0.7 tCO_2/t) and biomass (0.2-0.6 tCO_2/t). The emissions for extraction of sand and gravel are as low as 0.003 tCO_2/t.

Total CO2 emissions from the extraction of non-metallic minerals is very low

Combining these impact figures with MFA data, allows the estimation of GHG emissions from extraction of the materials in total DMC and for each tonne of DMC. Unsurprisingly, the trend in the total emissions from extraction of the materials in DMC approximately correlates with the quantity of DMC extracted over time. The extraction of all of the material in Danish DMC causes the emission of approximately 30-35 million tonnes of CO_2 equivalents, and emissions peaked in the years 2006-2008, and were still below 2000 levels in 2014 (*Figure 14*). Over this period, the extraction of the average tonne of DMC resulted in the emission of 250kg CO_2 equivalents. While non-metallic minerals are by far the largest material group by weight, they are largely inconsequential in terms of GHG emissions: fossil fuels (57 %) and biomass (36 %) are most important, followed by metal flows (6 %) (*Figure 15*). This is in line with findings (Herczeg et al, 2014) on steel, copper and aluminium being dominant in the impacts stemming from all construction materials, although sand and gravel represent a much higher volume.

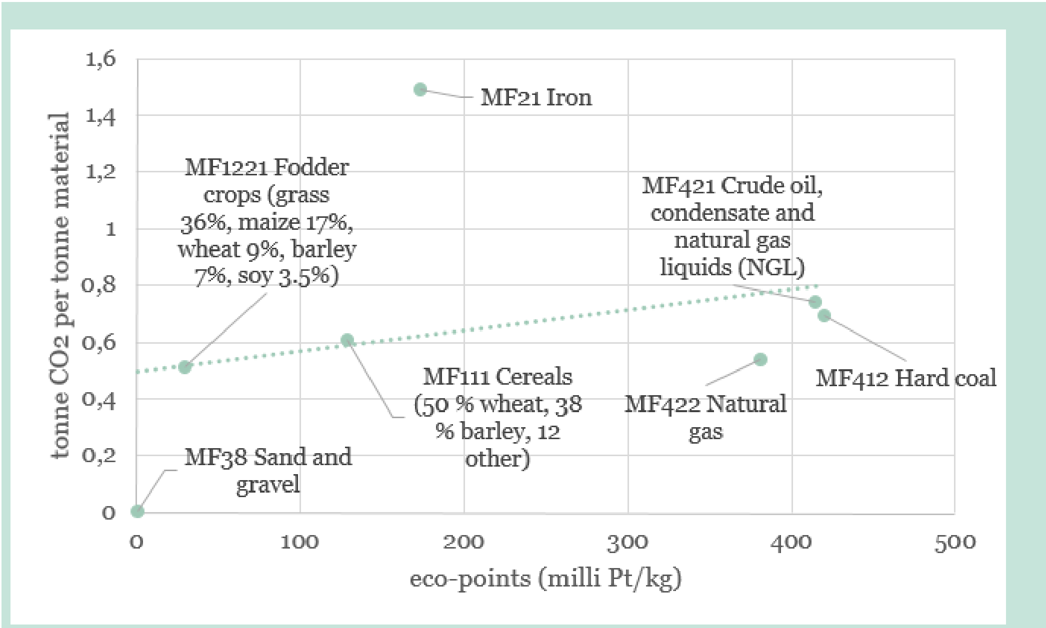
[5] Iron has been chosen rather than iron ore, as Denmark's material consumption within this category in MFA data is primarily iron rather than ore. This is used as a proxy for all metal types.

FIGURE 12 GREENHOUSE GAS EMISSION ASSOCIATED WITH EXTRACTION OF VARIOUS MATERIALS (TONNE CO_2-EQUIVALENT/TONNE)



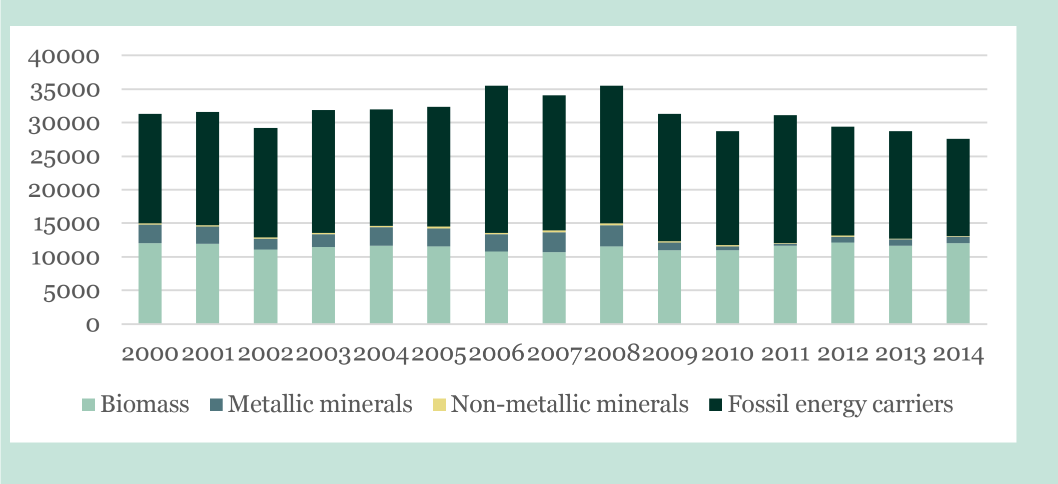
Source: GaBI

FIGURE 13 LCA DERIVED IMPACTS ASSOCIATED WITH EXTRACTION OF RAW MATERIALS – GHG EMISSIONS (TONNE CO_2 EQUIVALENT/TONNE) VS ECO-POINTS (ECO-POINTS/TONNE)



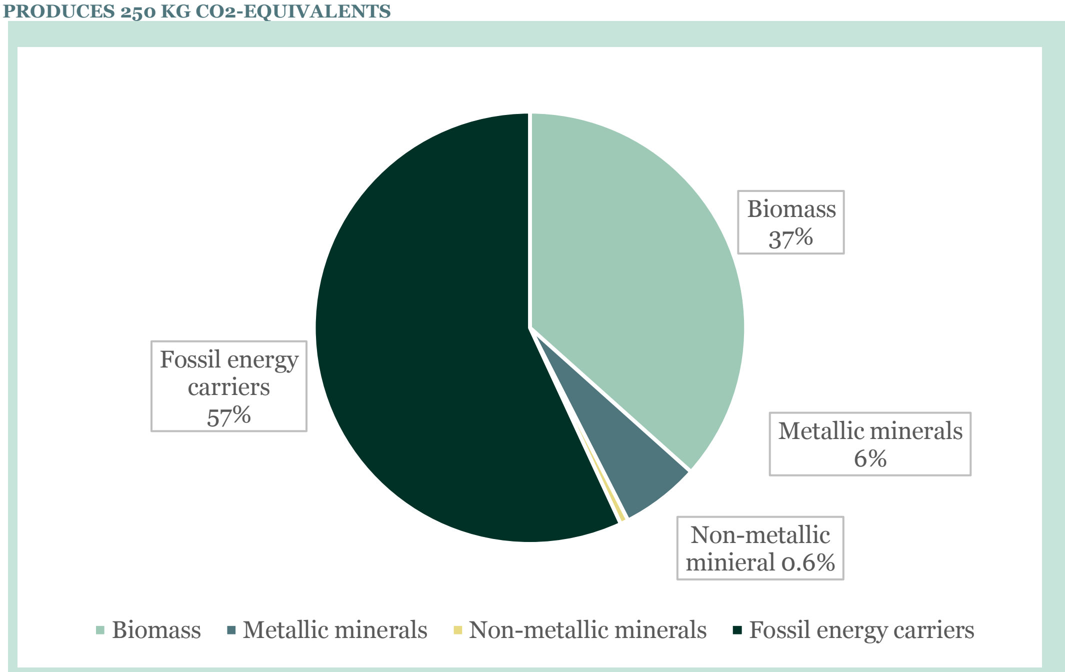
Source: CRI calculations / Data source: Eurostat, GaBI and Eco-indicator '99

FIGURE 14 GREENHOUSE GAS EMISSIONS ASSOCIATED WITH EXTRACTION OF RAW MATERIALS IN DMC (EXCL. OTHER PRODUCTS) (1000 T CO2-EQUIVALENTS)



Source: CRI calculations / Data source: DST and GaBI

FIGURE 15 EXTRACTION OF RAW MATERIALS IN 1 TONNE OF DMC (EXCL. OTHER PRODUCTS) PRODUCES 250 KG CO2-EQUIVALENTS



Source: CRI calculations / Data source: DST and GaBI

4. Resource productivity trend 2000-2014

4.1 Resource productivity of the total economy

In 2014, Denmark produced a GDP of 1837 billion DKK at 2010 prices, while the DMI of the Danish economy was 152.9 million tonnes and the DMC was 113.2 million tonnes.

Consequently, resource productivity (GDP/DMC) of the Danish economy was 16.22 DKK/ kg in 2014. Every DKK of GDP induced 61.6 grams (g) DMC in 2014, composed of 31.4 g non-metallic minerals, 16.4 g of biomass, 13.1 g fossil energy carriers, 0.3 g metal ores and 0.4 g other products and materials (*Figure 16*). This indicator shows the resource intensity of the economy.

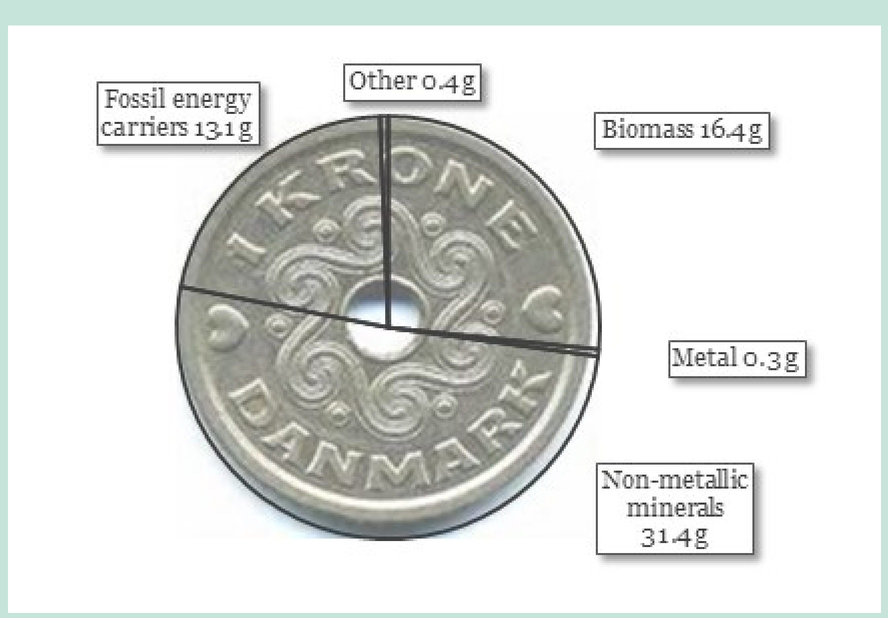
Resource productivity in Denmark is below the EU-28's average when the comparison is based on GDP values corrected for price levels (PPS) (*Figure 17*). However, this figure might say more about the difference in the structure of the economies across the EU Member States than the actual relative performance (productivity) of Danish industries. For example, the Danish agriculture's technical material efficiency improvement potential is greatly restricted by the high volume of livestock production. Furthermore, the relatively high price levels compared to countries with similarly high levels of GDP per capital also does not favour Denmark in this comparison.

If looking at a similar comparison but using chain-linked GDP at 2010 prices rather than in PPSs, Denmark is in the top ten EU countries for resource productivity, and above the EU average (*Figure 18*).

Material productivity of the economy as a whole is strongly influenced by material use of the construction sector

Resource productivity in Denmark has improved by 21.6 % from 2000 to 2014 (*Figure 19)*. This corresponds to approx. 1.41 % improvement per annum, but the actual change between years has varied from– 13 % to + 15 %. For example, just in 4 years, between 2006 and 2010 the apparent resource productivity grew by 30 %, mainly due to the decreased demand for construction materials caused by a slow-down in the construction sector.

FIGURE 16 PRODUCING 1 DKK OF GDP INDUCED 61.6 GRAMS DMC IN 2014



Source: CRI / Data source: DST

FIGURE 17 RESOURCE PRODUCTIVITY IN THE EU, 2013, GDP (EUR PPS)/KG DMC

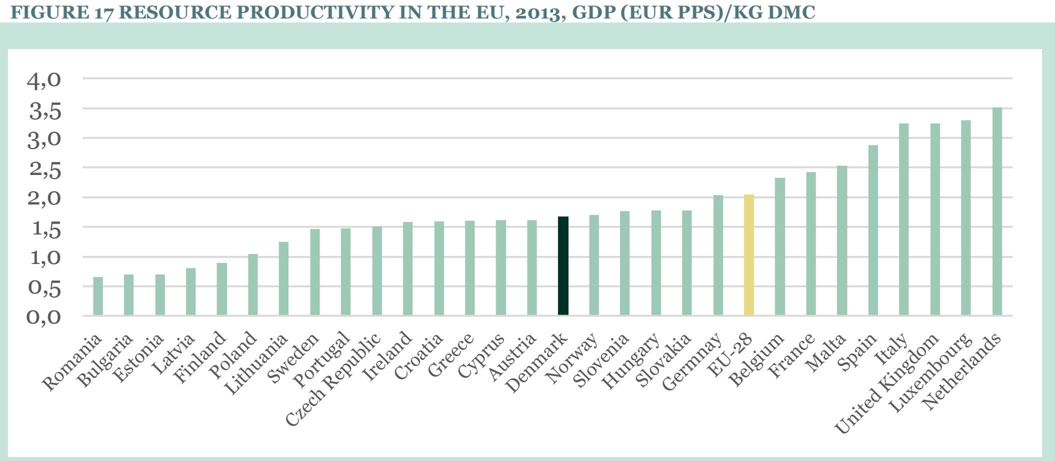
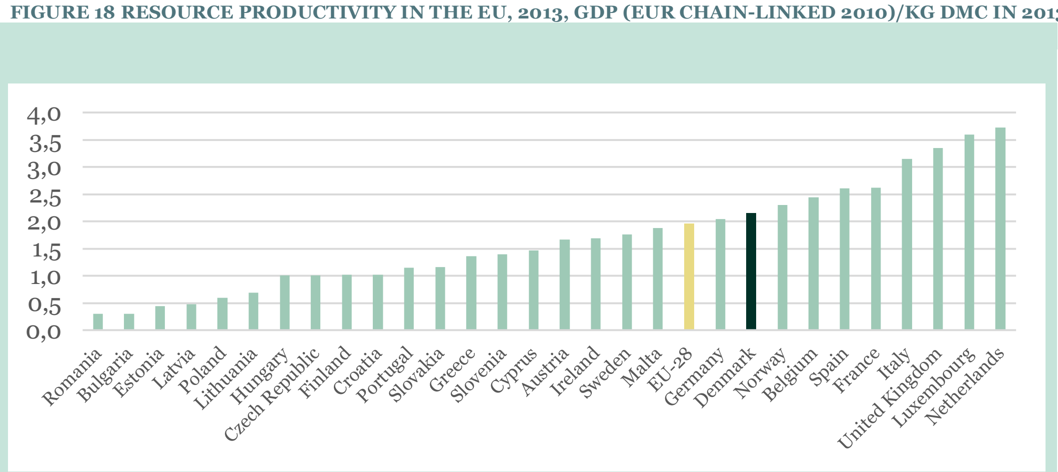


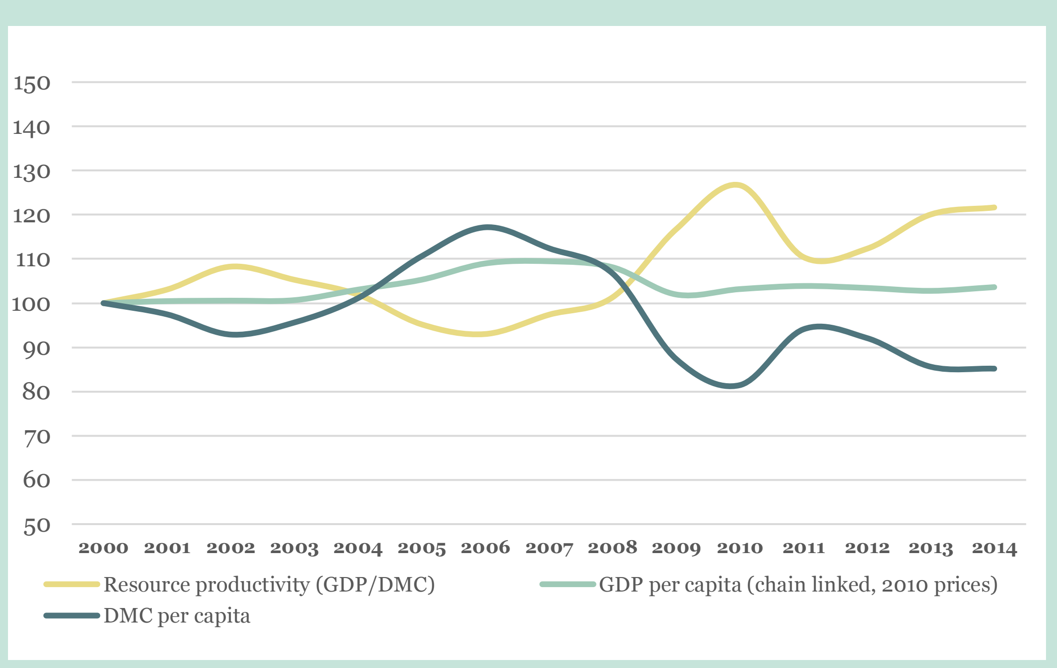
FIGURE 18 RESOURCE PRODUCTIVITY IN THE EU, 2013, GDP (EUR CHAIN-LINKED 2010)/KG DMC IN 2013



Source: CRI

Data source: Eurostat

FIGURE 19 DEVELOPMENT OF DENMARK'S RESOURCE PRODUCTIVITY, GDP (PER CAPITA) AND DMC (PER CAPITA) (YEAR 2000=100)



Source: DST

4.2 Sectoral resource productivity

Despite net economic growth over the period 2000-2014, the use of biomass and fossil fuels remained more or less stable, indicating that their consumption is decoupled, to a degree, from economic growth. The DMC of metals reduced dramatically after 2008, from 2.1 million tonnes in 2008 to 0.6 million tonnes in 2014. This is primarily due to using existing metal stocks in the technosphere for exports. The use of non-metallic minerals, mainly construction materials such as sand and gravel, not only dominate the material inputs, but their overall trends closely follow economic growth.

There is an approximately 1-year lag from the extraction of construction materials and the effect of the construction activities in the GDP growth. Consequently, resource productivity typically increases 1-2 year after a reduction in extraction of sand and gravel, and an increase in sand and gravel extraction results in a reduction of resource productivity (*Figure 20*).

It must be noted here, that sand and gravel are abundant and cheap materials with little or no price fluctuations (see next section). Furthermore, approximately 87 % of construction and demolition (C&D) waste is already being recycled (Regeringen, 2013). As such, they do not exhibit a major potential as substitute materials: theoretically, if all the construction and demolition waste was recycled to substitute raw materials, the DMC could only be reduced by 0.3 million tonnes.

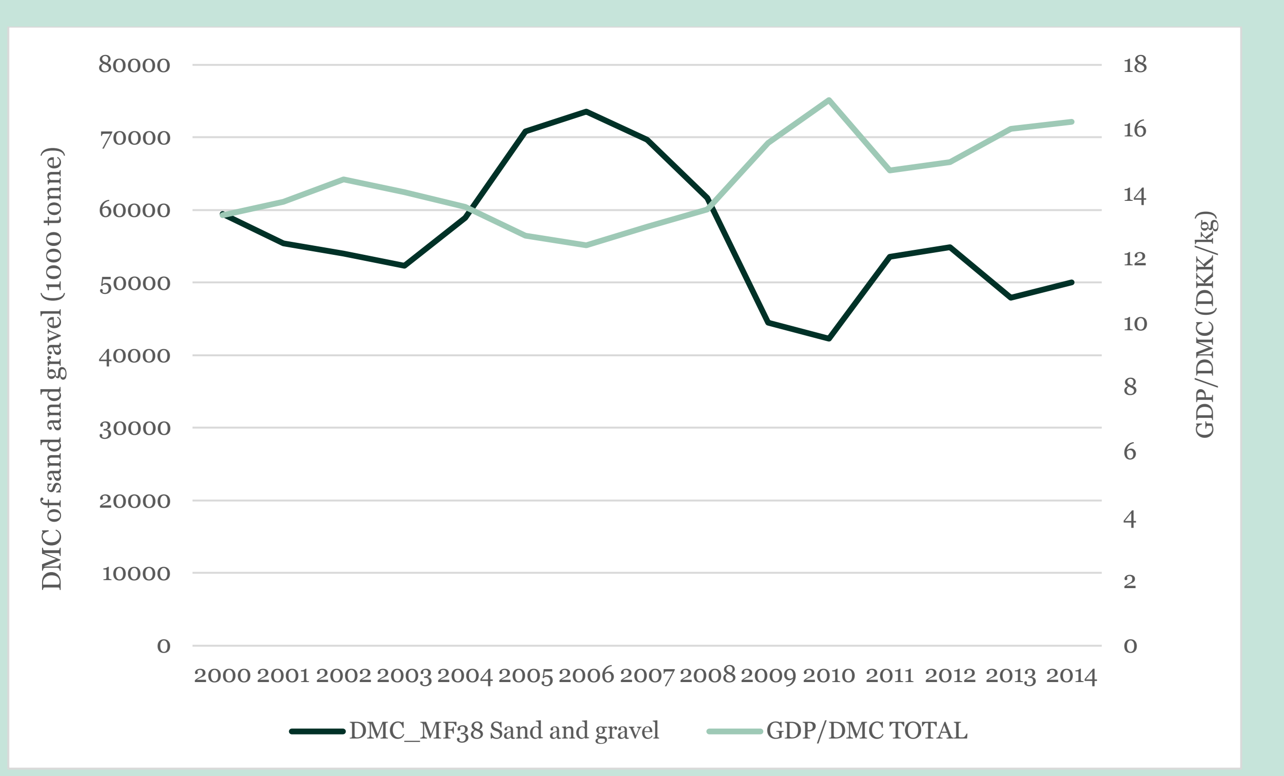
4.2.1 Value added versus resource inputs

One way to investigate the effects of different activities on resource productivity of the overall economy is to examine the resource productivity of sectors. This can be achieved by looking at the resource productivity, as measured by GVA[6]/DMI, of various sectors. Typically, economic activities closest to material extraction in the value chain, require more material per unit value added (*Table 3*). For example, mining activities and agriculture produces less than 1 DKK GVA from 1 kg inputs, while various service and knowledge-based sectors require hundred or thousand times less amount of materials in order to create added value.

[6] Gross value added (GVA) is a measure of the value of goods and services produced in an industry or sector.

Increased use of sand and gravel lowers the resource productivity - overall resource productivity is changed by 1 % with every 1 million tonnes of sand and gravel in DMC

FIGURE 20 DEVELOPMENT OF TOTAL RESOURCE PRODUCTIVITY (DKK/KG) AND DMC OF SAND AND GRAVEL (1000 TONNE)



Source: DST

TABLE 3 RESOURCE PRODUCTIVITY OF VARIOUS SECTORS IN DENMARK (GVA/DMI, DKK/KG) IN 2005

	Sectors	DKK GVA per kg DMI
J	Financial intermediation	1,086.95
K	Real estate, renting and business activities	574.25
M	Education	366.98
O	Other community, social, personal service activities	207.28
L	Public administration and defense; compulsory social security	193.72
G	Wholesale and retail trade; repair of motor vehicles, motorcycles	163.14
N	Health and social work	130.72
I	Transport, storage and communication	30.59
DK	Manufacture of machinery and equipment	20.87
DL	Manufacture of electrical and optical equipment	19.71
F	Construction	15.76
DE	Manufacture of pulp, paper and paper products; publishing and printing	15.06
DH	Manufacture of rubber and plastic products	11.93
DG	Manufacture of chemicals and chemical products	11.24
H	Hotels and restaurants	10.48
DJ	Manufacture of basic metals and metal products	9.65
DM	Manufacture of motor vehicles and other transport equipment	8.78
DB	Manufacture of textiles and textile products	7.93
DN	Manufacture of furniture and textile products	7.38
DD	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	4.68
DC	Tanning, dressing of leather; manufacture of luggage	4.56
DA	Manufacture of food products, beverages and tobacco products	3.94
DI	Manufacture of other non-metallic mineral products	3.31
E	Electricity, gas and water supply	3.26
CA	Mining and quarrying of energy producing materials	1.31
B	Fishing	1.29
A	Agriculture, hunting and forestry	0.38
DF	Manufacture of coke, refined petroleum products	0.08
CB	Mining and quarrying except energy producing materials	0.01

Source: CRI calculations with the ETC/SCP-EEA Online NAMEA Tool Test Version

4.3 Economic value of material resources in DMC

There is a significant price difference between materials present in DMC. It is difficult to approximate average prices for each of these material groups; they are composed of very many materials, the price of many of which cannot neatly be described by average commodity prices (i.e. exclude transaction costs, taxes, etc.). In the following section, commodity prices have been used for the major materials within each group where possible, and aggregated to produce a 'value' for each of the four main material groups: biomass, metallic minerals, non-metallic minerals, and fossil fuels. The 'other products' MFA category has been exempt from this analysis.

Of the key materials in these groups over the last decade, the price of natural gas and crude oil has been the highest, each peaking at around 600 EUR/t in 2008 and 2012 respectively. The price of biomass has been in the range of 50-500 EUR/t, and the price of iron ore and hard coal ranged between around 20 and 120 EUR/t, while sand and gravel costs only a fraction (6 EUR/t) of these materials (*Figure 21*).

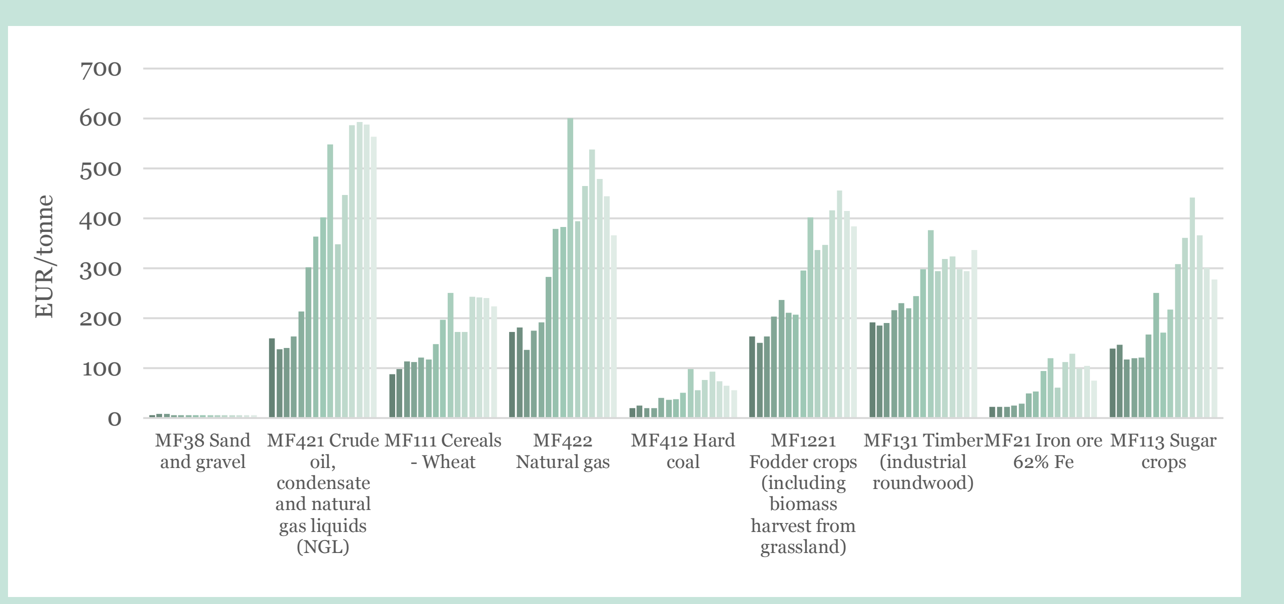
According to DAMVAD (2013) the price of raw materials used in manufacturing increased by 47 % between 2000 and 2010 in Denmark. The price increase was most significant for fossil fuels, the price of which doubled between 2000 and 2010. Over the same period, the price of metals has increased by about 50-60 %, while the price of biomass-derived materials has only increased about 20 %.

Due to the steep increase in commodity prices, the total value of the material flows has also increased dramatically between 2000 and 2014. The total value of material in DMC has peaked at 153 billion DKK in 2008 increasing from just 55.8 billion DKK in 2000 (*Figure 22*). In 2014, the value of raw materials in the DMC was 104 billion DKK. This means, every tonne of DMC in 2014 was worth approximately 751 DKK.

The value of DMC is dominated by fossil energy carriers (57 %) followed by biomass (39 %). Although non-metallic minerals are the most common material in DMC, its total value is minor (3 %). The low total value (1 %) of metals is due to the major export of older stocks in recent years virtually eliminating metal from DMC (*Figure 23*).

The increase in commodity prices has caused the total value of raw materials in DMC to jump from 3.3 % in 2000 to 5.7 % of GDP in 2014 (*Figure 24*). The value of resources in DMI (DMC plus exports) is of course even higher, approximately 13 % of GDP.

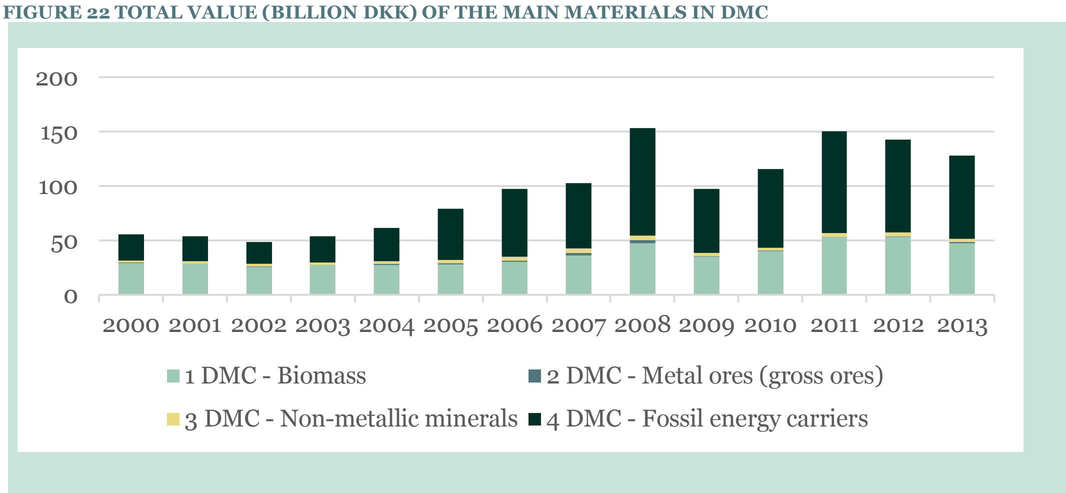
FIGURE 21 PRICE (EUR/TONNE) OF THE MATERIAL SUB-GROUPS WITH HIGHEST WEIGHT IN DMC (2000-2014)



Source: CRI estimates based on data from World Bank and DST

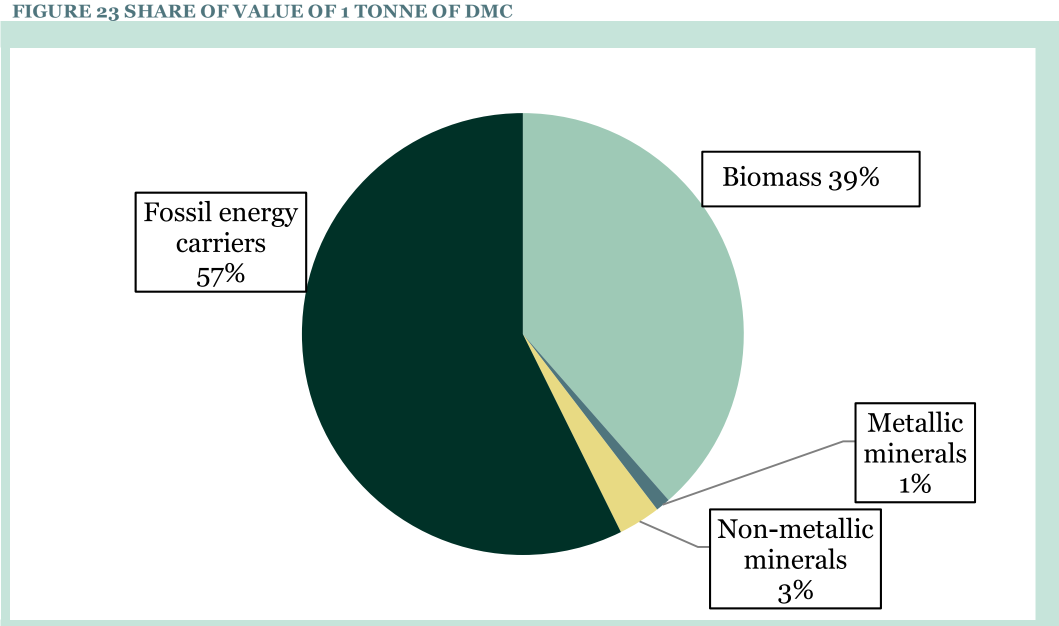
In 2014, every tonne of DMC had a total value of 751 DKK. The total value of materials in DMC was 104 billion DKK

FIGURE 22 TOTAL VALUE (BILLION DKK) OF THE MAIN MATERIALS IN DMC



Source: CRI
Data sources: World Bank and DST

FIGURE 23 SHARE OF VALUE OF 1 TONNE OF DMC



SOURCE: CRI
DATA SOURCES: WORLD BANK AND DST

FIGURE 24 TOTAL VALUE OF DMC AS % OF GDP

Source: CRI
Data sources: World Bank and DST

5. Outlook 2030

5.1 Economic growth and population

GDP growth is to remain between 1-2 %

Between 1995 and 2015 the real GDP of Denmark has grown by 1.3 % annually on average (*Figure 25*), but with significant fluctuations across the years: while in the 1990's, there were 3-5 % p.a. growth rates recorded, after 2000 the growth was modest, and the global financial crisis after 2008 caused GDP to fall.

Altogether, the GDP (calculated with constant 2010 prices) has grown by 28.4 % in the 20 years from 1995 to 2015, from 1447 to 1858 billion DKK. A best-fit linear extrapolation based on this trend forecasts a future annual real growth of just under 1 %.

Various predictions can be found that expect the real GDP growth rate to be between 1- 2 % with higher growth rates for the period of 2014-2020, and slightly lower rates for 2020-2030 (*Figure 26*). Predictions in the past tend to be slightly optimistic and to be closer to each other than actual growth rates achieved (*Figure 27)*.

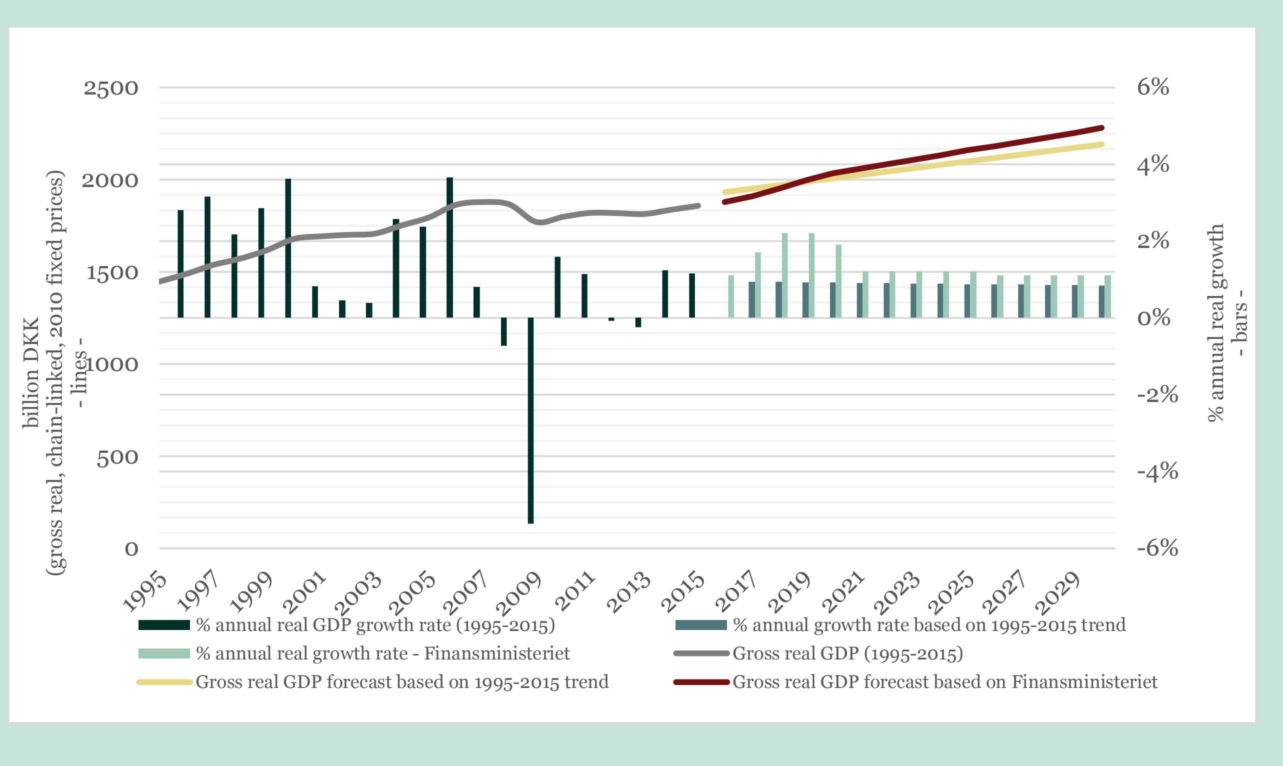
This paper uses the forecast from the Danish Ministry of Finance (*Table 4)*. This forecast is closest to the estimates based on historical real performance while establishing a baseline scenario for future resource productivity development.

TABLE 4 FORECASTED ANNUAL REAL GDP GROWTH RATE (%)

2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1.1	1.7	2.2	2.2	1.9	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1

Source: Danish Ministry of Finance

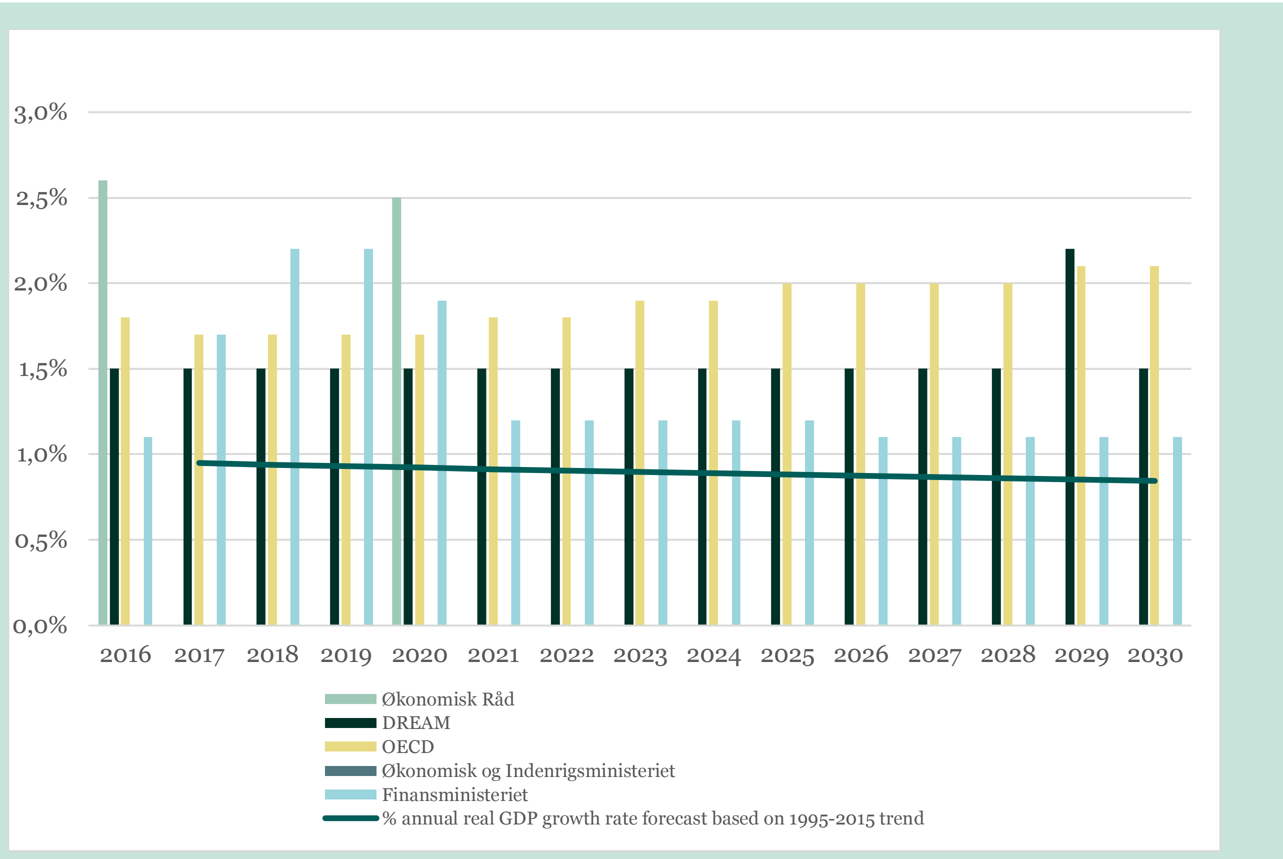
FIGURE 25 DEVELOPMENT OF DENMARK'S GDP (1995-2015) AND FUTURE FORECASTS (2016-2030)



NOTE: LEFT AXIS AND LINES: GROSS REAL VALUE IN DKK BILLION, CHAIN LINKED, AT 2010 PRICES.
Right axis and bars: annual growth rates (%)

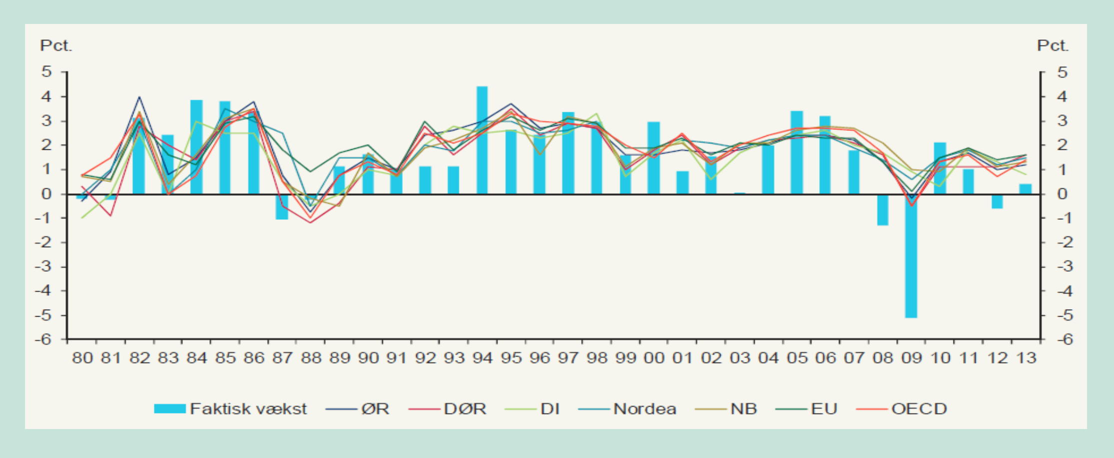
Source: CRI / Data source: DST and Ministry of Finance

FIGURE 26 GDP GROWTH RATE FORECASTS IN LITERATURE COMPARED TO LINEAR EXTRAPOLATION BASED ON ACTUAL TRENDS



Source: CRI

FIGURE 27 PAST PERFORMANCE OF GDP GROWTH RATE PREDICTIONS COMPARED TO ACTUAL GROWTH

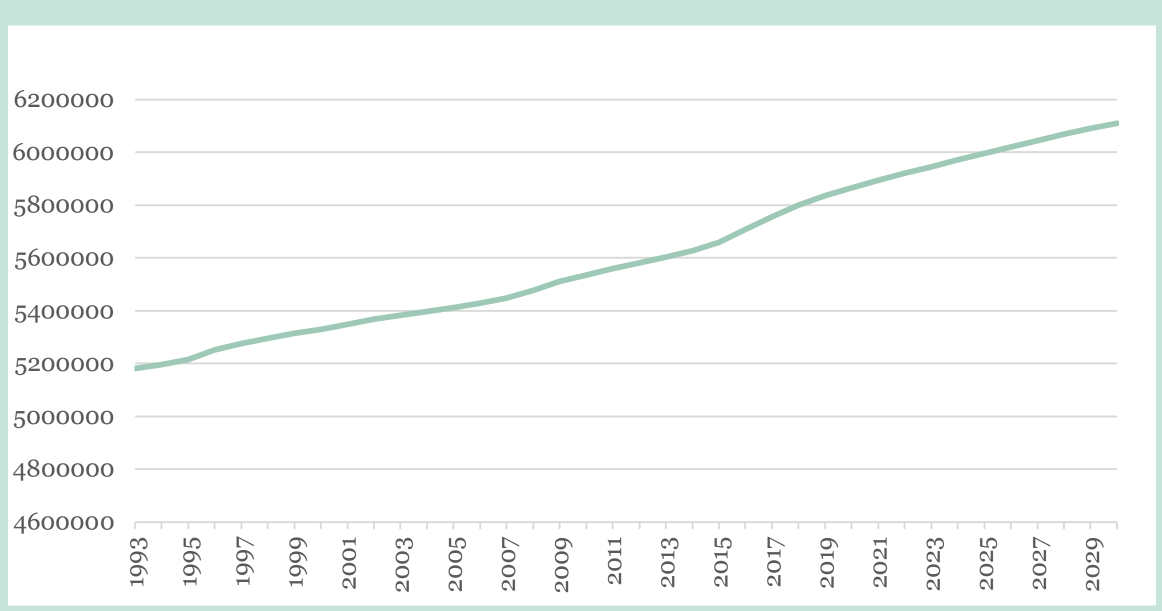


Source: Danish Ministry of Economic Affairs and the Interior, Økonomisk Redegørelse, May 2014

Population will continue to grow

According to forecasts from DST, the population of Denmark will increase from 5.660 million in 2015 to 6.110 million in 2030: a growth of around 0.35-0.4% per annum (*Figure 28*).

FIGURE 28 ACTUAL AND FORECASTED POPULATION OF DENMARK



Source: DST

5.2 Construction activities

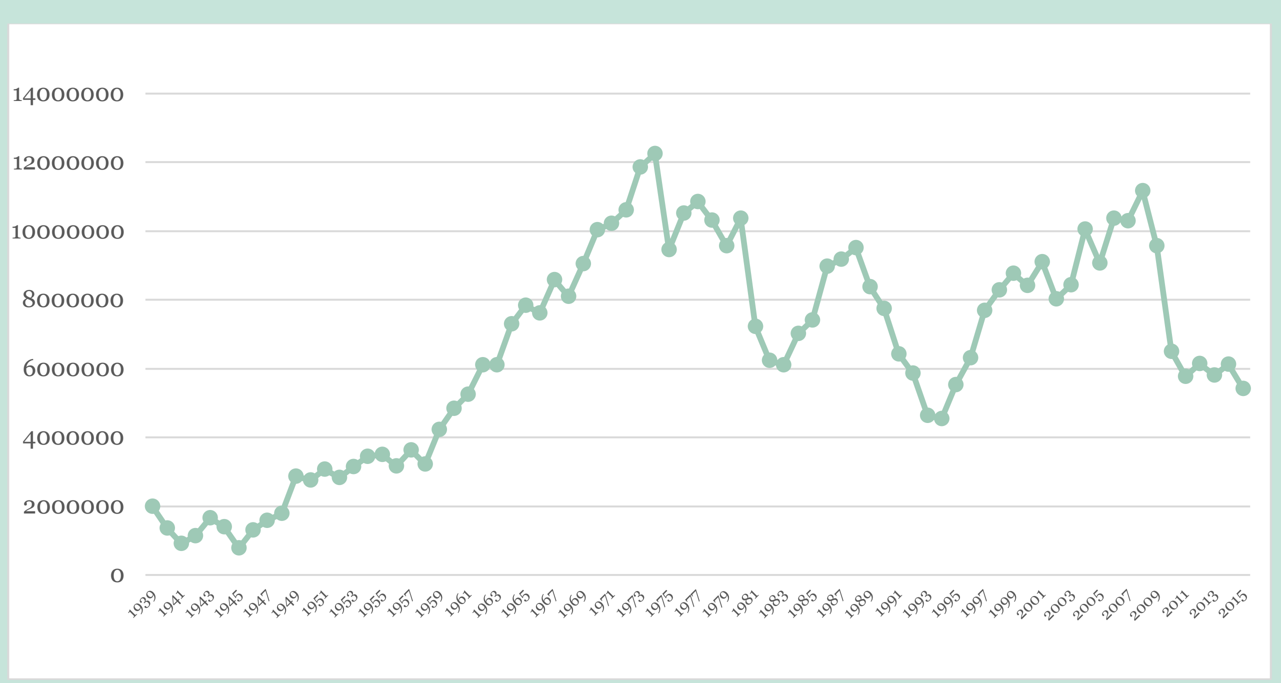
As already described, the DMC of non-metallic minerals is primarily driven by the construction sector. The following section presents the main drivers behind the demand for non-metallic minerals.

The Danish Geological Survey has confirmed that there are no official estimates of the future use of non-metallic minerals in Denmark. Forecasts of construction activity that do exist tend to be short term and insufficient for long-term forecasting.

The construction sector is sensitive to changes in the economy, so any economic slow-down or sudden future crisis is likely to substantially decrease the activity, at least in the short term.

Between 2009 and 2015, the sector has been in a depression, with output falling to levels not seen since the economic slowdowns in the early 1980's and the early-mid 1990's (*Figure 29*).

FIGURE 29 TOTAL CONSTRUCTION COMPLETED (M², 1939-2015)



Source: DST

However, there are a number of factors that have the potential to increase the need for non-metallic materials in the future:

- Government policy can use large-scale public infrastructure projects to level out market depressions. Examples of such infrastructure development projects include the Femern Link, highway developments, metro constructions and such like. These all contribute to increasing demand. Private investment companies, including pension schemes, also favour investments in infrastructure development.
- Climate adaptation strategies spur the construction of coastal protection systems to protect against a forecast rise in sea levels. If Danish municipalities adopted this approach on a large scale, this alone could drive an enormous rise in the use of sand and gravel.
- Both the population and number of single households are forecasted to grow in Denmark. According to estimates of The Danish Building Association (2013), there will be a demand for approx. 300.000 additional dwellings in 2030 compared to current levels.
- Floor space per capita in Denmark is the highest in Europe, and between 1996 and 2009, it grew further from 50 to 55 m²/capita (ODYSSEE).
- Denmark has the third oldest building stock in Europe (ETC/SCP, 2013) following Belgium and Luxembourg that may induce an increased need for refurbishment and/or renewal of building stock in the near future.
- A high rate of refurbishment is also spurred by both energy efficiency upgrades and the generally frequent maintenance in order to preserve market value of buildings.

5.3 Resource use forecast up to 2030

The forecasts for biomass (*Figure 30*), metallic minerals (*Figure 31*), fossil energy carriers (*Figure 32*) and other products (*Figure 33*) are presented on the following pages.

Energy policy increases demand for biomass

Use of biomass has stabilized over the period of 2000-2014, and in a business-as-usual scenario can be expected to remain stable for the foreseeable future. Although policy is in place to moderately increase the amount of biomass used in energy production, is it not possible to assess whether this will result in an increase in overall biomass consumption in Denmark.

Phasing out fossil fuels will help reduce resource use

The DMC of fossil energy carriers is expected to reduce in accordance with the plans of the Danish Energy Agency and Denmark's energy policy, which aims to reduce dependency on fossil energy carriers by 2050. This policy goal will contribute to a reduction of DMC of fossil fuels from 24 million tonnes in 2014 to around 19.7 million tonnes, in spite of the forecasted growth in the GDP.

DMC of metallic minerals and other products is likely to remain marginal in the total DMC

There have been some heavy fluctuations in the DMC of metals since 2008. This is can be explained by the growing export of iron scrap during the period. This is probably due to the closure of Stålvalseværket in 2002: after this closure much of secondary iron has been exported abroad (CRI, 2013). However, in the long run, the DMC of metal is expected to remain at the average level of earlier years, around 1.3-1.8 million tonnes based on calculations taking into account the regression between GDP and DMC.

The trend in the DMC of other products is highly unstable, but the quantity of other products is relatively insignificant compared to total DMC. It can be expected to remain between 1.1-1.7 million tonnes a year, although this category is very diverse.

FIGURE 30 DEVELOPMENT OF DMC OF BIOMAS AND FORECAST TO 2030 (1000 TONNE)

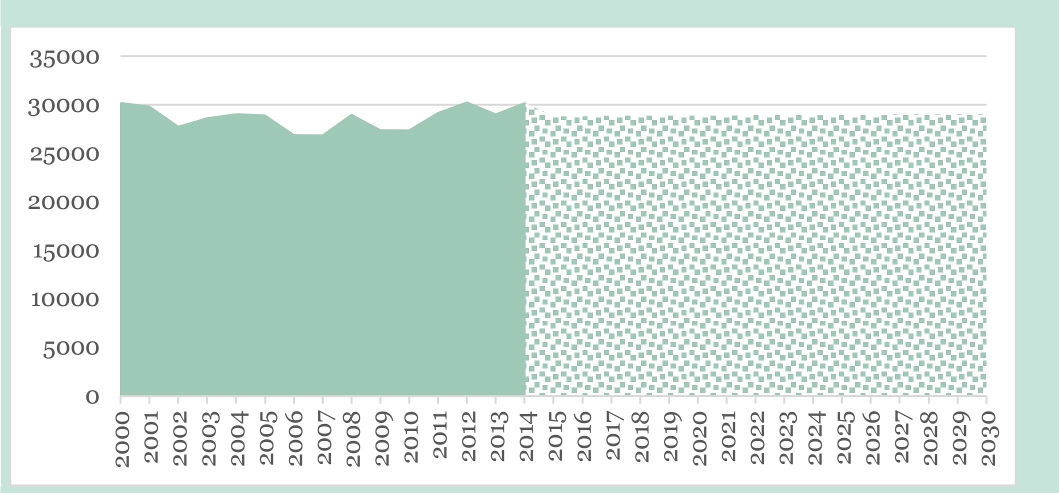


FIGURE 31 DEVELOPMENT OF DMC OF METALLIC MINERALS AND FORECAST TO 2030 (1000 TONNE)

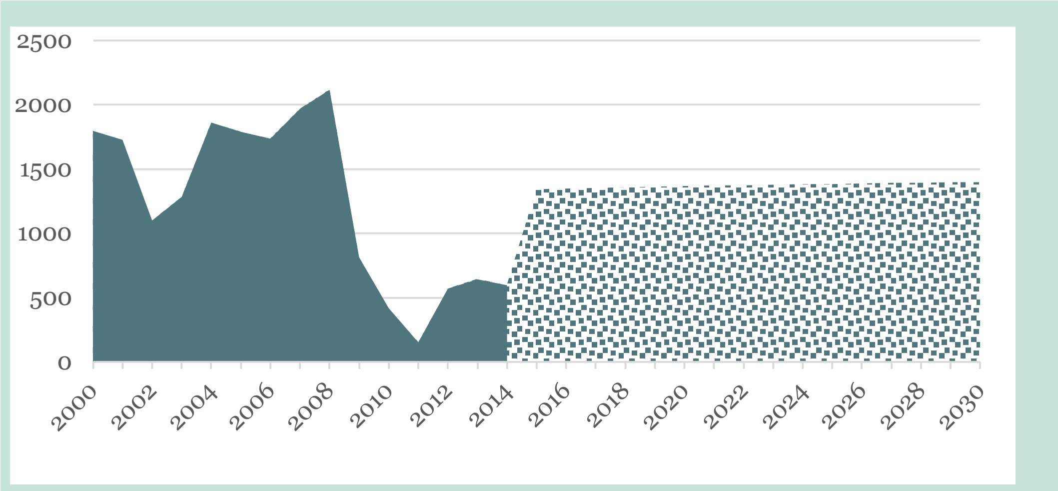


FIGURE 32 DEVELOPMENT OF DMC OF FOSSIL ENERGY CARRIERS AND FORECAST TO 2030 (1000 TONNE)

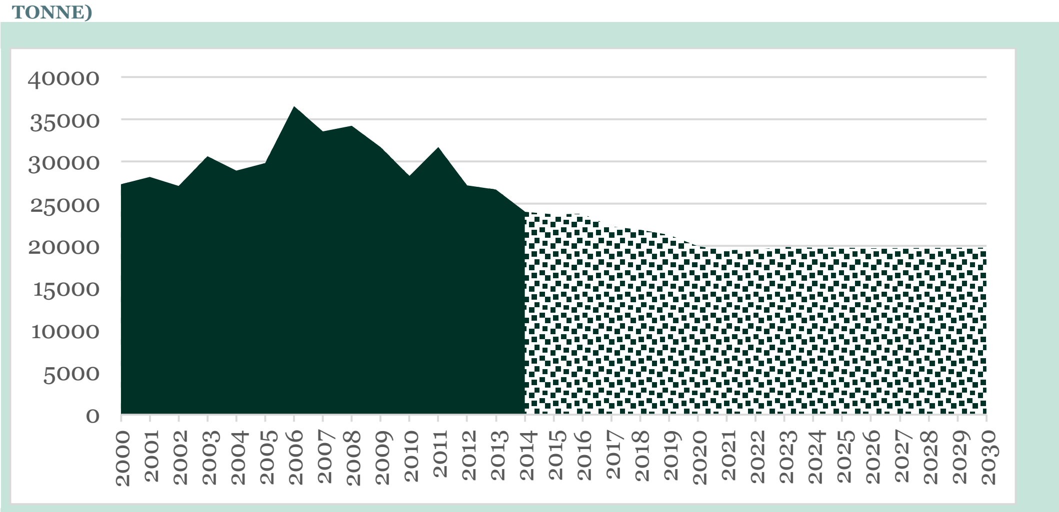
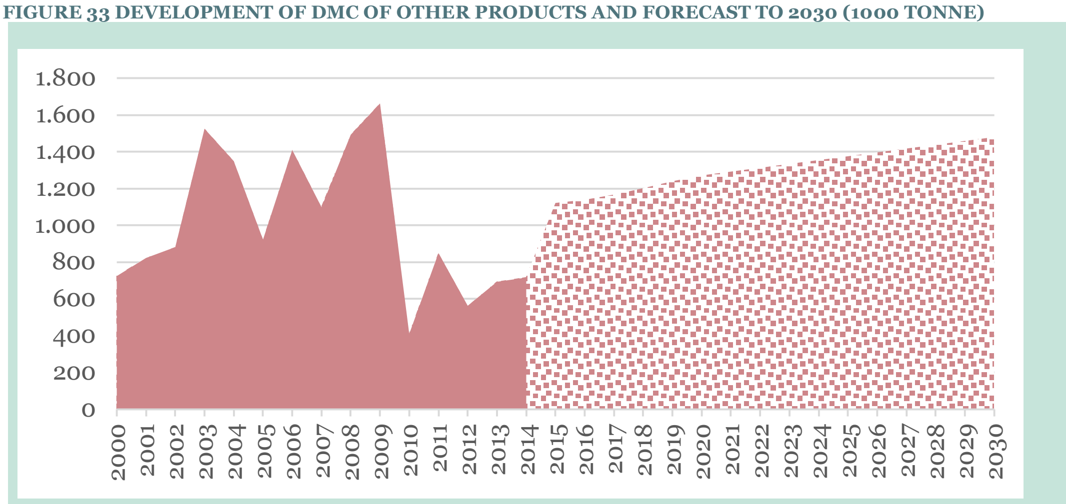


FIGURE 33 DEVELOPMENT OF DMC OF OTHER PRODUCTS AND FORECAST TO 2030 (1000 TONNE)

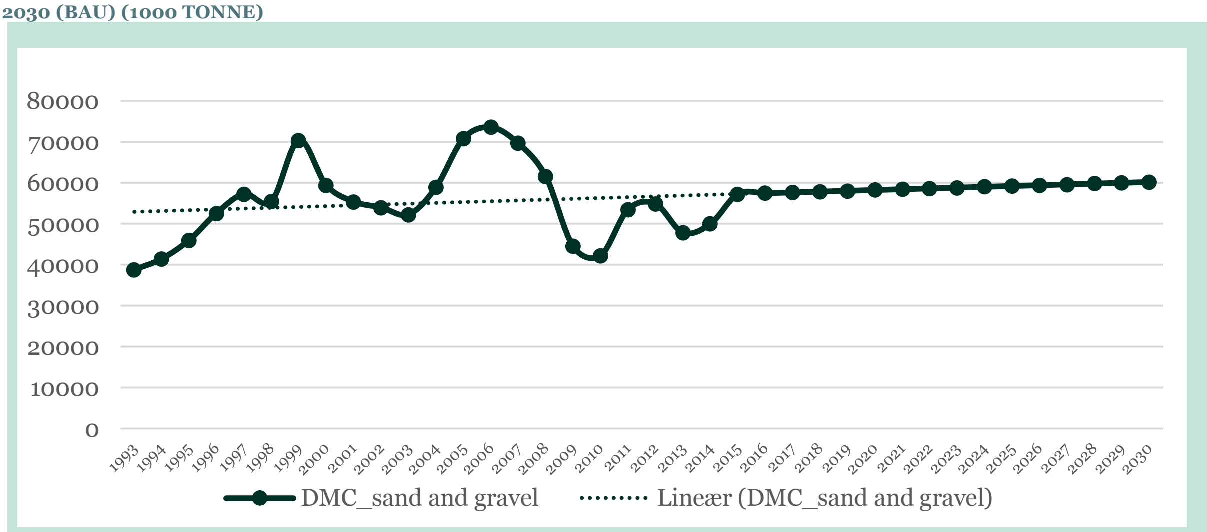


Source: CRI forecasts (2014-2030) and DST (2000-2013)

Rather high uncertainty for future use of non-metallic minerals

While for most material groups, the certainty of future forecasts in a BAU scenario seems rather high, there is a substantial uncertainty about the levels of future use of non-metallic minerals. This material group has the highest fluctuations and the strongest influence on development of DMC and resource productivity. To address this, this report takes the long-term development of the DMC of sand and gravel as a baseline for projecting toward 2030 (*Figure 34*). The volatility of the trend appears cyclic in nature, and these cycles are shorter than the projection period, indicating that projecting a long-term average is reasonably robust as the cycles are likely to push the DMC of non-metallic minerals above the average in some years and below the average in others.

FIGURE 34 DEVELOPMENT IN DMC OF SAND AND GRAVEL (1993-2014) AND EXTRAPOLATION UP TO 2030 (BAU) (1000 TONNE)



Source: CRI forecasts (2014-2030) and DST (2000-2013)

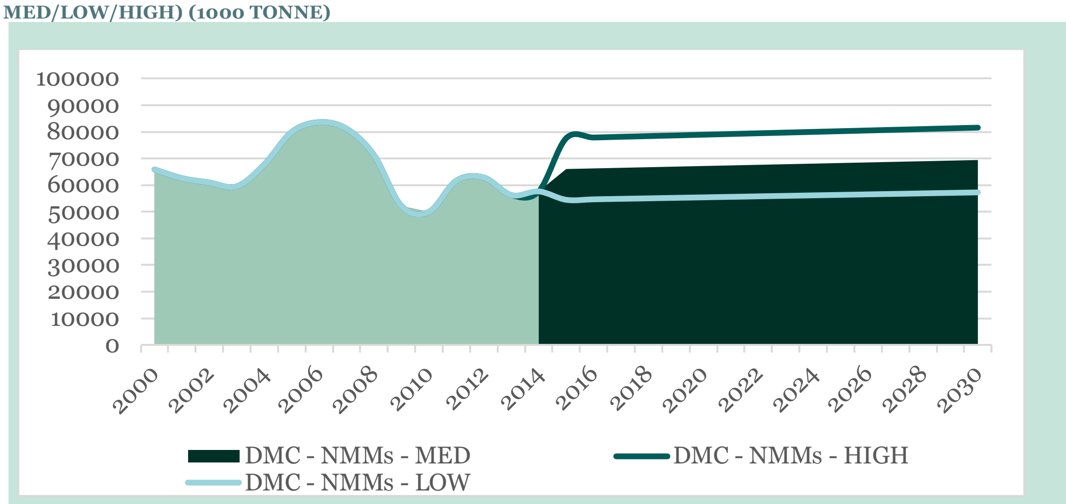
To account for potential divergence from the long-term average (from a prolonged extreme depression or above-forecast growth), three scenarios have been constructed:

- A *'medium'* scenario based on the best-fit trend line on a long-term data series (1993-2014) for the DMC of sand and gravel. This is used as a best predictor of the use of non-metallic minerals and refers to a policy-free scenario.
- a *'low'* growth scenario calculated as minus 17.5% of the '*medium*' scenario to accommodate an extreme of low growth or long-term depression of construction activity.

- a *'high'* growth scenario calculated as plus 17.5% of the '*medium*' scenario to accommodate unanticipated and prolonged economic growth.

Under the medium scenario, DMC of non-metallic minerals will climb to around 69.4 million tonnes in 2030: still some 14 million tonnes below the peak at 83.6 million tonnes in 2006 (*Figure 35*).

FIGURE 35 DEVELOPMENT IN DMC OF NON-METALLIC MINERALS AND FORECASTS UP TO 2030 (BAU MED/LOW/HIGH) (1000 TONNE)



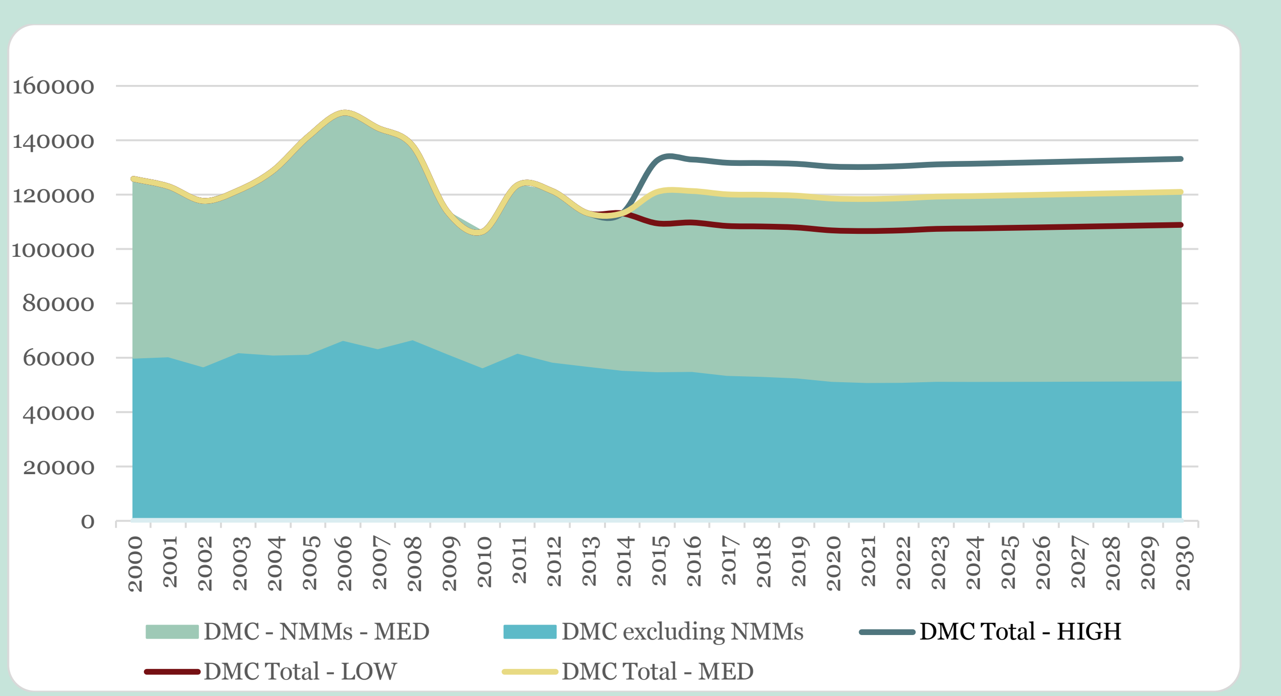
Source: CRI forecasts (2014-2030) and DST (2000-2014)

In the *medium* scenario, total DMC in 2030 will be approximately 121.1 million tonnes (*Figure 36*). The future activity of the construction sector will have the greatest influence on this number, and variations in the DMC of non-metallic minerals could reduce this figure to 108.9 million tonnes under the *low* growth scenario, or increase it to as high as 133.2 million tonnes in the *high* growth scenario. It is important to stress again that uncertainty is substantial regarding the future growth or otherwise of the use of non-metallic minerals.

The actual development of total DMC in the near future will primarily depend on a few trends:

- primarily the change in demand for non-metallic minerals, such as sand and gravel
- successful reduction in use of fossil energy carriers;
- use of biomass for energy utilisation;
- trends in Danish meat production.

FIGURE 36 DEVELOPMENT OF TOTAL DMC AND BAU FORECASTS UP TO 2030 IN LOW/MED/HIGH SCENARIOS (1000 TONNE)



Source: CRI forecasts (2014-2030) and DST (2000-2014)

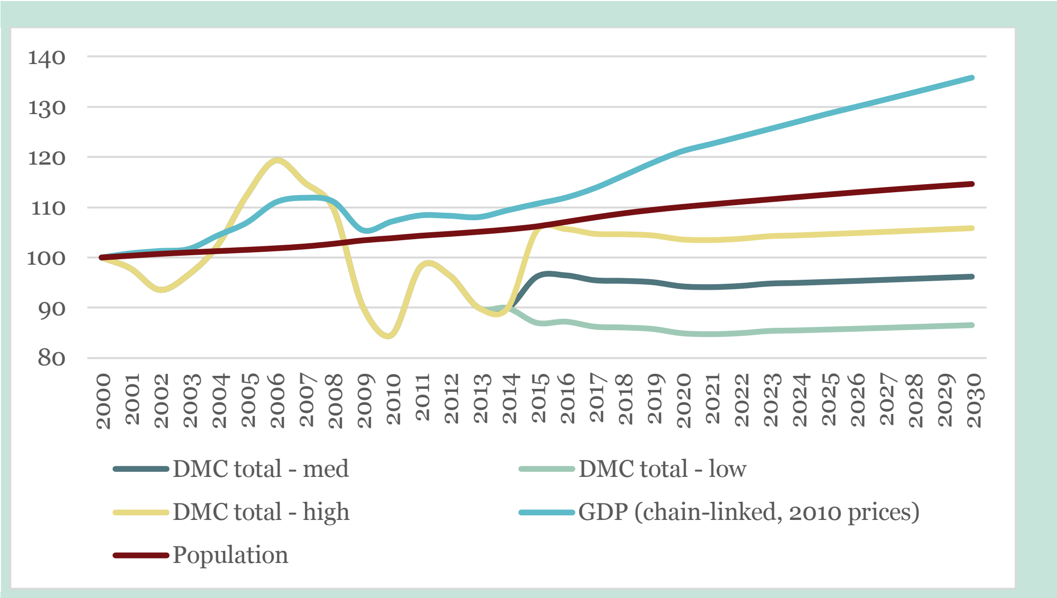
TABLE 5 FORECAST DEVELOPMENT OF DMC - MAIN MATERIAL GROUPS AND TOTAL (1000 TONNE)

Year	2014	2015	2020	2025	2030
Biomass	30 175	28 805	28 873	28 940	29 007
Metal ores (gross ores)	597	1 392	1 366	1 383	1 399
Non-metallic minerals (medium)	57 636	66 040	67 165	68 289	69 413
Fossil energy carriers	24 075	23 760	19 986	19 784	19 786
Other products	716	1 121	1 270	1 377	1 480
DMC (medium)	**113 198**	**121 070**	**118 660**	**119 772**	**121 085**
DMC (low)		**109 513**	**106 906**	**107 822**	**108 938**
DMC (high)		**132 185**	**130 414**	**131 723**	**133 233**

Source: CRI forecasts (2015-2030) and DST (2014, 2015)

Taking forecast GDP, population and data on DMC into account, a relative decoupling between growth of the population and material resource use might be expected (*Figure 37*): GDP and the population is likely to grow faster than material resource use.

FIGURE 37 FORECAST DEVELOPMENT OF GDP, POPULATION AND TOTAL DMC IN LOW/MED/HIGH SCENARIOS (YEAR 2000=100)



Source: CRI calculations and forecast
Data source: DST (DMC) and DST (GDP and population)

5.4 Resource productivity in 2030

Based on the forecasts, and the high level of uncertainty for use of non-metallic minerals in the future into account, all three scenarios indicate an increase in resource productivity under business as usual conditions (*Figure 38*).

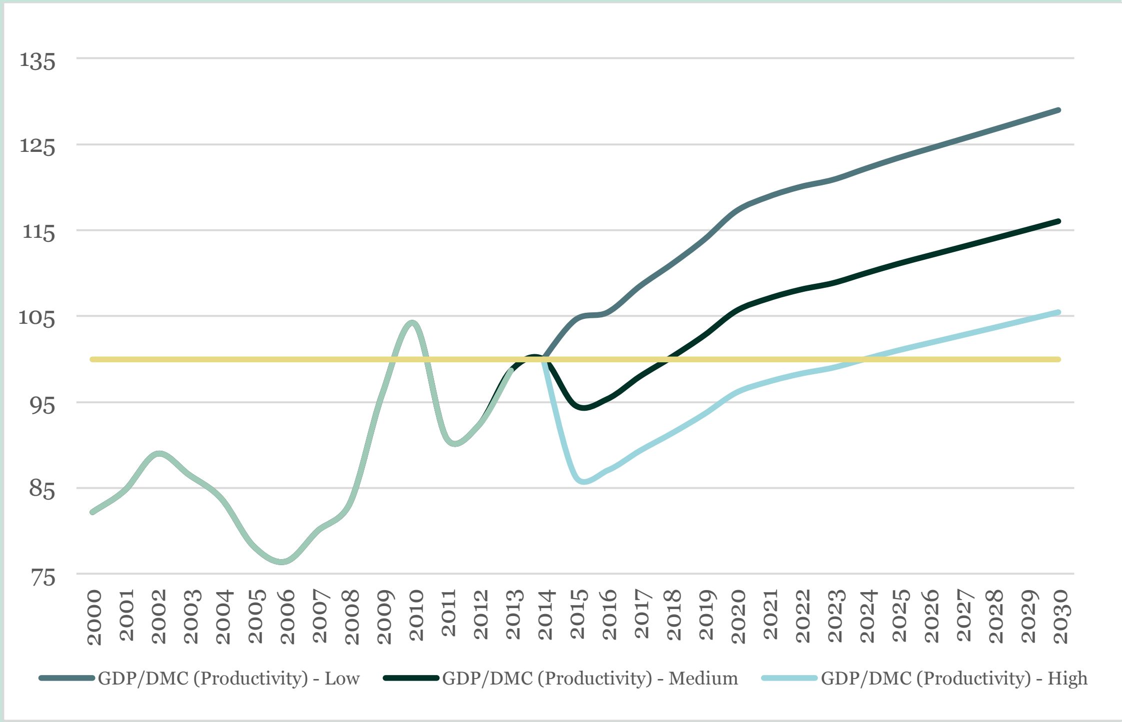
In the *medium* baseline scenario, the DMC would grow up to 121.1 million tonnes in 2030, and resource productivity would increase to 18.8 DKK/kg, a 16 % increase in resource productivity compared to 2014.

Resource productivity is estimated to improve by 16 % in total by 2030 – but depends on the construction sector and the figure is associated with significant uncertainty.

In the *low* construction activity scenario, the resource productivity would increase further, by 29 % compared to 2014, while with *high* level of material use in the construction sector, resource productivity would increase only by 45 %.

In the *medium* scenario, the 16 % increase in resource productivity by 2030 responds to 0.93 % improvement annually on average (*Table 6*). This is still slightly above the forecast from the European Commission (EC, 2014), which anticipates an absolute EU-wide improvement of 14 % by 2030 in a business as usual scenario.

FIGURE 38 DEVELOPMENT OF RESOURCE PRODUCTIVITY UP TO 2030 IN LOW/MED/HIGH SCENARIOS (YEAR 2014=100)



Source: CRI calculations and forecasts.
Data source: DST (MFA, 2000-2014) and DST (GDP, 2000-2015)

TABLE 6 FORECAST RESOURCE PRODUCTIVITY IMPROVEMENTS UNDER LOW/MED/HIGH SCENARIOS

RESOURCE PRODUCTIVITY IMPROVEMENT FORECASTED BY 2030		
	Total improvement (2014-2030)	**Annual average improvement (Compound annual growth rate)**
DMC low	5.5 %	0.33 %
DMC med	16.0 %	0.93 %
DMC high	29.0 %	1.60 %

Source: CRI calculations and forecasts

6. Conclusions

6.1 The baseline

In 2014, the Danish economy used 113.2 million tonnes of Domestic Material Consumption to produce a GDP of 1837 billion DKK. This corresponds to a resource productivity of 16.22 DKK/kg.

The resource productivity figures are greatly influenced by resource use in a few sectors and the apparent resource productivity improvement is primarily caused by a slow-down in the construction sector from 2009 onwards – this is also true for the EU as a whole.

Using GHG emissions as a proxy, the environmental impacts associated with the extraction of the various raw materials in DMC do not reflect the quantities of these materials in DMC: while non-metallic minerals make up around half of total DMC, the environmental impacts of these materials are below 1 % of the total impacts. The impacts from DMC instead come mainly from the extraction of fossil fuel (57 %) and biomass (36 %).

Resource productivity in Denmark has improved by 21.6 % in total in the period 2000-2014. This corresponds to approx. 1.41 % improvement per annum and, in a business as usual scenario, the resource productivity of the Danish economy is expected to improve by approximately 16 % by 2030 compared to 2014, although this estimate is associated with considerable uncertainty.

6.2 Seeking leverage points to improve resource productivity

This analysis suggests that when seeking to improve economy-wide resource productivity, the nature of the statistical base DMC limits potentially effective interventions to a limited number of materials and sectors - while of course recognizing the wider necessity to improve resource productivity across the entire economy.

There are some general leverage points that are relevant for all material streams and that can be addressed to help reduce DMC. These include:

- using more waste as resource to substitute virgin raw materials, and closing material circles by enhancing recycling and industrial symbiosis;
- looking for unused existing material stocks in the technosphere that could be used to substitute raw materials. For example, large stocks of metal scraps, or unused buildings from which materials can be recovered;
- substituting heavy materials with lighter materials, i.e. light alloys and high-strength steel;
- reducing material resource demand through:
    - structural change in the economy,
    - adapting product design to improve resource efficiency of final products,
    - ongoing process innovations to improve resource efficiency, and
    - targeting final consumption.

Sand and gravel, fossil fuels, cereals and fodder crops (and the industries that utilize them) could be specifically targeted as they have the potential to affect total DMC significantly and therefore increase resource productivity.

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Appendix 1 DMC detailed break-down

TABLE 7 DETAILED BREAK-DOWN OF DOMESTIC MATERIAL CONSUMPTION (1000 TONNE)
SOURCE: DST

MATERIAL	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
TOTAL	**125,887**	**123,130**	**117,776**	**121,585**	**128,919**	**141,383**	**150,206**	**144,642**	**138,038**	**113,705**	**106,457**	**123,548**	**121,380**	**113,276**	**113,198**
Biomass	**30,204**	**29,817**	**27,748**	**28,623**	**29,044**	**28,921**	**26,886**	**26,859**	**28,974**	**27,393**	**27,382**	**29,164**	**30,251**	**29,026**	**30,175**
MF111 Cereals	7,911	8,272	7,788	8,126	8,890	9,257	7,753	7,492	9,713	8,999	7,029	7,365	8,187	7,810	8,145
MF112 Roots, tubers	1,666	1,523	1,440	1,375	1,621	1,547	1,329	1,646	1,647	1,542	1,337	1,550	1,637	1,598	1,713
MF113 Sugar crops	3,294	3,097	3,328	2,887	2,809	2,645	2,236	2,342	2,227	1,813	2,204	2,656	2,508	1,844	2,102
MF114 Pulses	123	96	93	102	61	51	54	59	43	27	26	29	32	30	35
MF115 Nuts	12	14	12	14	13	12	13	14	13	12	11	14	14	13	11
MF116 Oil-bearing crops	598	633	606	800	952	660	891	944	1,076	924	1,008	712	814	1,028	1,028
MF117 Vegetables	453	456	431	464	537	531	522	516	537	559	558	551	520	519	557
MF118 Fruits	416	435	415	547	583	583	602	613	610	570	529	518	447	452	494

MF119 Fibres	3	3	2	2	2	2	1	2	3	1	1	1	1	1	1
MF1110 Other crops n.e.c.	**179**	**177**	**158**	**165**	**190**	**189**	**204**	**178**	**174**	**187**	**157**	**151**	**180**	**204**	**187**
MF1211 Straw	3,699	3,434	3,664	3,416	3,103	3,254	3,006	3,074	3,869	4,054	3,313	3,266	3,659	3,154	2,999
MF1212 Other crop residues (sugar and fodder beet leaves, other)	**244**	**182**	**59**	**41**	**27**	-	-	-	-	-	-	-	-	-	-
MF1221 Fodder crops (including biomass harvest from grassland)	4,481	4,532	4,529	4,319	4,114	3,911	4,162	4,328	4,510	4,778	5,048	5,202	4,975	4,948	5,322
MF1222 Grazed biomass	**718**	**764**	**739**	**740**	**693**	**715**	**811**	**884**	**856**	**858**	**1,155**	**1,089**	**1,101**	**936**	**998**
MF131 Timber (industrial roundwood)	3,349	2,354	2,307	2,842	2,809	2,922	2,690	2,468	1,897	1,470	3,183	4,272	4,101	4,252	4,418
MF132 Wood fuel and other extraction	444	433	465	611	600	802	721	684	636	855	1,081	1,107	1,364	1,588	1,500
MF141 Wild fish catch	-11	-30	-35	-16	-9	-9	-25	-36	-17	-27	-17	-8	-8	-14	-22
MF142 All other aquatic animals and plants	3	3	3	3	3	3	3	3	3	3	4	3	4	3	4
MF143 Hunting and gathering	3	3	3	3	3	3	3	3	3	3	4	3	4	3	4
MF151 Live animals other than in 1.4	-87	-88	-90	-93	-114	-169	-180	-246	-284	-405	-383	-347	-397	-400	-430
MF152 Meat and meat preparations	-1,389	-1,441	-1,500	-1,501	-1,561	-1,494	-1,499	-1,697	-1,493	-1,413	-1,510	-1,555	-1,391	-1,350	-1,465

MF153 Dairy products, birds' eggs, and honey	-341	-283	-307	-309	-261	-265	-320	-359	-421	-619	-482	-429	-492	-470	-474
MF154 Other products from animals (animal fibres, skins, furs, leather, etc.)	185	193	233	420	330	244	313	560	421	495	449	550	508	421	460
MF16 Products mainly from biomass	2,789	3,618	2,077	2,684	2,644	2,683	2,771	2,773	2,317	1,936	1,919	1,795	2,100	1,917	1,974
Metal ores	**1,797**	**1,727**	**1,100**	**1,283**	**1,861**	**1,789**	**1,736**	**1,968**	**2,116**	**813**	**418**	**152**	**570**	**642**	**596**
MF21 Iron	1,062	1,143	832	746	1,052	1,133	1,588	1,404	1,215	-83	-121	300	447	461	509
MF221 Copper	30	23	15	20	36	40	42	70	30	5	-55	-9	8	11	9
MF222 Nickel	0	0	0	0	0	0	1	1	0	0	-1	-1	-0	-0	0
MF223 Lead	6	5	5	5	4	2	3	4	2	-2	-3	-3	-1	-2	-2
MF224 Zinc	17	18	11	15	21	25	26	24	24	10	9	9	11	11	10
MF225 Tin	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	-0
MF226 Gold, silver, platinum and other precious metals	0	0	0	0	-1	0	1	-	4	2	1	-0	-1	-9	-2
MF227 Bauxite and other aluminium	90	220	109	105	117	120	112	117	127	37	56	72	60	70	46
MF228 Uranium and thorium	0	0	0	-0	-0	0	0	-0	0	1	0	0	0	0	0
MF229 Other metals n.e.c.	-33	-21	-24	-2	-1	-1	0	-4	-87	-28	34	-1	-47	-42	-60

MF23 Products mainly from metals	623	338	149	394	633	470	-37	353	800	870	499	-216	95	143	87
Non-metallic minerals	**65,852**	**62,588**	**60,940**	**59,523**	**67,742**	**79,930**	**83,601**	**81,140**	**71,210**	**52,120**	**49,957**	**61,670**	**62,825**	**56,240**	**57,636**
MF31 Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)	636	692	834	673	845	836	826	1,300	1,325	1,007	772	957	888	797	832
MF32 Chalk and dolomite	4,726	4,771	4,434	4,155	4,370	4,406	5,053	5,659	3,935	3,566	3,049	3,058	3,162	3,350	3,436
MF33 Slate	9	8	6	10	5	4	5	6	7	5	4	4	3	4	4
MF34 Chemical and fertiliser minerals	598	643	366	528	930	1,034	953	823	1,053	752	696	791	675	729	793
MF35 Salt	485	532	595	587	712	685	1,018	594	564	645	973	1,201	539	713	551
MF36 Limestone and gypsum	-849	-148	-76	113	163	183	177	241	390	94	107	159	173	230	214
MF37 Clays and kaolin	2,034	1,828	1,759	1,756	1,925	2,088	2,369	2,767	2,080	1,122	1,271	1,330	1,147	1,252	1,127
MF38 Sand and gravel	59,453	55,416	54,001	52,304	58,917	70,788	73,563	69,657	61,602	44,494	42,285	53,509	54,881	47,879	49,989
MF39 Other non-metallic minerals n.e.c.	224	-144	91	121	427	560	112	180	146	97	721	600	1,208	1,178	709
Fossil energy carriers	**27,310**	**28,176**	**27,106**	**30,631**	**28,923**	**29,820**	**36,574**	**33,576**	**34,245**	**31,716**	**28,291**	**31,713**	**27,172**	**26,676**	**24,075**
MF411 Lignite (brown coal)	1	0	1	-0	-0	-0	-0	-0	1	1	1	1	1	1	0

MF412 Hard coal	6,411	6,916	6,317	9,275	7,567	5,893	9,067	8,007	7,448	6,469	4,663	6,548	4,016	4,733	5,178
MF413 Oil shale and tar sands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MF414 Peat	215	231	256	252	284	254	284	233	181	168	146	181	184	209	222
MF421 Crude oil, condensate and natural gas liquids (NGL)	9,493	10,207	9,020	8,266	7,470	7,662	7,940	5,992	8,344	7,115	7,347	7,036	6,838	6,218	4,300
MF422 Natural gas	4,027	4,049	4,126	4,168	4,362	3,977	4,186	3,778	3,689	3,493	3,836	4,227	3,142	3,733	2,434
MF4231 Fuel for land transport	-	-	-	-	-	153	144	147	186	474	569	614	702	671	714
MF4232 Fuel for water transport	6,014	5,663	6,298	7,462	8,045	10,201	13,191	13,583	12,905	11,515	10,767	11,699	10,882	9,759	9,584
MF4233 Fuel for air transport	164	201	209	212	147	517	599	651	586	457	385	347	387	363	645
MF43 Products mainly from fossil energy products	985	908	878	995	1,048	1,163	1,163	1,184	905	2,025	576	1,060	1,020	989	997
MF5 Other products	724	822	881	1,526	1,349	922	1,410	1,099	1,493	1,663	409	849	562	693	716

Material Resource Productivity in Denmark

The report examines resource productivity in Denmark from 2000 to 2014 and gives an indication of a projection in resource productivity in Denmark towards 2030.

In 2014, the Danish economy used 113.2 million tonnes of material resources domestically (DMC), such as biomass, fossil energy carriers, metallic and non-metallic minerals to produce a GDP of approximately 1837 billion DKK. This corresponds to a productivity of 16.22 DKK/kg of material resources. Resource productivity in Denmark has improved by 21,6 % in total in the period 2000-2014. This corresponds to approx. 1.41 % improvement per annum. In comparison, the resource productivity in the EU improved by 34 % in the period of 2000 to 2014.

In the period 2014-2030, in a business as usual scenario, the resource productivity of the Danish economy is estimated to improve by approximately 15 % in total. This estimate is associated with considerable uncertainty, primarily due to the high fluctuations in the use of non-metallic minerals.
The resource productivity figures are greatly dominated by resource use in a few sectors and the productivity improvement is primarily caused by a slow-down in the construction sector from 2009 onwards – this is also true for the EU as a whole.

Environmental impacts associated with the extraction of raw materials in DMC do not closely follow the tonnage of materials: while non-metallic minerals make up around half of the DMC, the environmental impact (expressed as greenhouse gas emissions) is below 1 % of the total impacts.

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In the period 2014-2030, in a business as usual scenario, the resource productivity of the Danish economy is estimated to improve by approximately 15 % in total. This estimate is associated with considerable uncertainty, primarily due to the high fluctuations in the use of non-metallic minerals.

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