DYNAMIX

Decoupling growth from resource use
and environmental impacts

The underlying reasons for resource (in)efficiencies

Final version of Deliverable 2.2

July 2013

European Commission

SEVENTH FRAMEWORK PROGRAMME

DYNAMIX is a project funded
under the European Union
Seventh Framework Programme

AUTHOR(S)

BIO Intelligence Service

Adrian R. Tan

Polina Dekhtyar

Marion Sarteel

Mary Ann Kong

Thibault Faninger

Sarah Lockwood

Shailendra Mudgal

Policy Studies Institute

Roger Salmons

Ecologic Institute

Martin Hirschnitz-Garbers

Albrecht Gradmann

Tanja Srebotnjak

IVL Swedish Environmental Research Institute

David Palm

Ida Adolfsson

Anna Fråne

Lena Dahlgren

Hanna Ljungkvist

With contributions by:

Lidia Wisniewska, BIO Intelligence Service

Alvaro de Prado Trigo, BIO Intelligence Service

ACKNOWLEDGEMENT & DISCLAIMER

The research leading to these results has received funding from the European Union FP7 ENV.2010.4.2.3-1 grant agreement n° 308674.

Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of the following information. The views expressed in this publication are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

Cover photo credit: Creative Commons Public License (Highways Agency, Steven Depolo and La Citta Vita)

DYNAMIX PROJECT PARTNERS

Table of Contents

List of Tables

List of Figures

List of Boxes

1 Executive summary

While progress has been made in increasing the economic benefits of resource use in the EU, there is still significant potential to increase resource efficiency and hence to decouple economic development from resource use and environmental degradation. These aims can be achieved by:

1. **Using fewer resources** to fulfil the same needs
2. **Increasing the (socio-economic) value and benefits** from the use of (the same amount of) resources
3. **Reducing the environmental impacts and damage** associated with the use of resources

This report documents the work performed in Work Package 2 (WP2) of the EU funded FP7 project DYNAMIX. The objective of the DYNAMIX project is to identify policy pathways to absolute decoupling of economic growth from resource use and its environmental impacts. This report identifies the main inefficiencies of resource use in the EU and investigates their drivers and underlying causes. This research will serve as a basis for identifying key policy areas to focus on later in the DYNAMIX research project and support the European Commission in the development of policy mixes that will achieve absolute decoupling. A thorough understanding of the drivers and causes of inefficient resource use is vital when designing appropriate and effective policy mixes.

Based on an extensive review of existing literature and data, the main areas of inefficient resource use were identified and analysed using qualitative and quantitative methods. Resource use in the EU was examined from the perspective of individual types of resources such as materials, energy, water, land and ecosystems, but also from a production and consumption perspective, with a particular focus on food, transport and buildings. In both cases a life cycle approach was used following the resources from their extraction to outputs and returns back to the natural environment in the form of waste and emissions to air, water and soil. Material (and substance) flow analysis was used to demonstrate how resources such as iron, cobalt, phosphorus and water are used in the EU or globally.

The drivers of inefficient resource use were examined qualitatively and quantitatively using meta-analysis of literature. Based on this analysis, six broad groups of factors that directly or indirectly influence resource use were identified: behavioural and informational; institutional and organisational; policy and regulatory; economic and demographic; technological and infrastructural; and bio-physical.

1.1 Global and macro-economic overview of inefficiency

A review of the global and macro-economic flows of resources and their uses provided a first indication on which resources are used most inefficiently and where in the life cycle this occurs. The resources that are used the most in the economy are not necessarily the same as those that are used most inefficiently, but the total flow of resources in the economy provide an idea of which types of resource use are most important to improve.

- The EU food system is particularly resource intensive in terms of biomass extracted, freshwater withdrawals, land use, application of fertilizers and wild fish catches. While there is significant potential to improve resource efficiency related to agriculture, fisheries and food production, the greatest potential seems to lie in addressing food consumption: diets, overconsumption and food waste.
- Over 75% of EU's primary energy consumption is based on fossil fuels. Renewables represent about 10% of current energy consumption, but could potentially cover all EU energy demand. In addition to being a finite resource, the burning of fossil fuels is the main source of human induced GHG emissions that lead to climate change. While renewable energy sources could reduce GHG emissions significantly, this involves large investments and might even put a even greater strain on the use of other resources, e.g. land and water to produce bioenergy, critical raw materials to produce photovoltaics and wind turbines. It would be less costly to increase energy efficiency in power generation, buildings, transport and industry, even though this also requires significant investments.
- Compared to other resources, metals are generally the most valued within the economy. Despite being inherently recyclable, they are often sent to landfills at their end-of-life. Besides reducing the demand for metal through better design and longer product lifetimes, closing material loops seems to have the greatest potential for increasing resource efficiency of metals.
- Minerals also have the potential to be more efficiently reused and recycled, however the greatest potential for improving the resource efficiency of construction minerals is through better design and planning of buildings and infrastructure. It also holds the potential for more efficient use of land, energy and water related to buildings and urban areas. Other minerals, phosphorus in particular, are used very inefficiently with losses occurring throughout the life cycle.
- The greatest users of freshwater in the EU are the energy sector (for cooling purposes), the agricultural sector, public water supply and industry. The greatest inefficiencies identified were related to irrigation technologies and practices; leakages in the public supply system and evaporation in (energy production) cooling systems. There is also scope for significant improvements in the water efficiency of water-using products (e.g. toilets, showers, dishwashers, washing machines, etc.) and buildings as well as the potential for reusing wastewater and harvesting rainwater.
- The main inefficiencies identified related to land use is land conversion from natural land to agricultural or built-up land (particularly, urban sprawl and transport infrastructures). Due to large remediation costs, abandoned contaminated sites in particular represent inefficient use of land, which is a finite and scarce resource.
- From a general perspective of resource use, the extraction of all natural resources and the generation of environmentally harmful emissions and waste along all life cycle stages are often the cause to severely degraded ecosystems and their ability to provide the services that the economy is dependent on. In most cases ecosystems provide these benefits in a much more efficient manner than humans are capable of.

1.2 The main drivers of resource inefficiency

A variety of factors that influence resource inefficiency were identified through both the qualitative literature review and meta-analysis. These factors affect resource efficiency in various ways, e.g. positive or negative, as well as directly or in combination with other drivers (conjoint or moderator effects).

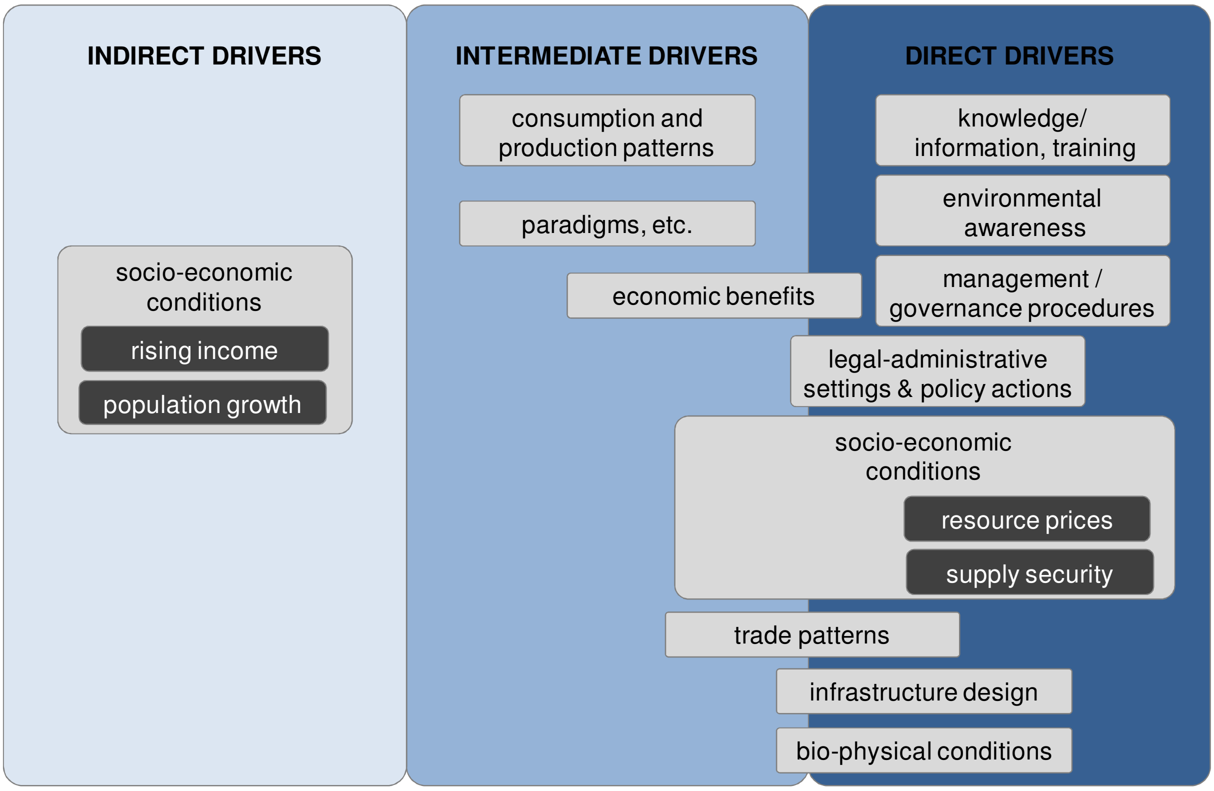
In most of the existing literature on resource efficiency, population growth and rising income (affluence) are identified as two of the main root causes of existing unsustainable patterns of resource use – regardless of the resource type (energy, materials, water, land). However, rising income and population growth are mainly indirect drivers – there are other factors with more direct influence on resource inefficiency. Our analysis points to drivers that constitute part of the complex interplay of factors: in particular consumption and production patterns that translate the increasing affluence of ever more people (emerging middle-class consumers) into lifestyles and habits associated with high resource use. This was observed in relation to areas such as:

- dietary choices (high meat and dairy consumption),
- choice of transport modes and distance travelled (more use of individual transport modes, increasing air travel), and
- housing preferences (larger living spaces per person, increasing number of appliances in use, more efficient heating systems which in the context of the rebound effect might even lead to an increase in excessive energy use).

All the above mentioned drivers appear to be directly affected – or at least indirectly influenced – by either resource efficiency fostering or impeding legal frameworks, administrative settings and political actions. The meta-analysis showed that legal-administrative settings and political actions and legal/political frameworks/actions were most often mentioned of among the drivers identified. While the focus of the study was on factors affecting resource inefficiency, several factors were identified that contribute to improving resource efficiency. The most commonly mentioned are environmental concerns (mainly in relation to water pollution), resource prices, and supply insecurity. While it can be discussed whether environmental concerns as such are sufficiently powerful drivers for more efficient resource use, resource prices and supply insecurity were shown to be considered powerful drivers that case studies demonstrated to have already led to improvements in resource efficiency. Both have direct economic impacts on business, trade and competitiveness.

In an attempt to classify drivers according to the way they influence the improvement of resource efficiency, the following figure (based on the effect type allocation) of indirect, intermediate and direct drivers was created.

Figure 1 Conceptualisation of indirect, intermediate and direct drivers for improving resource efficiency

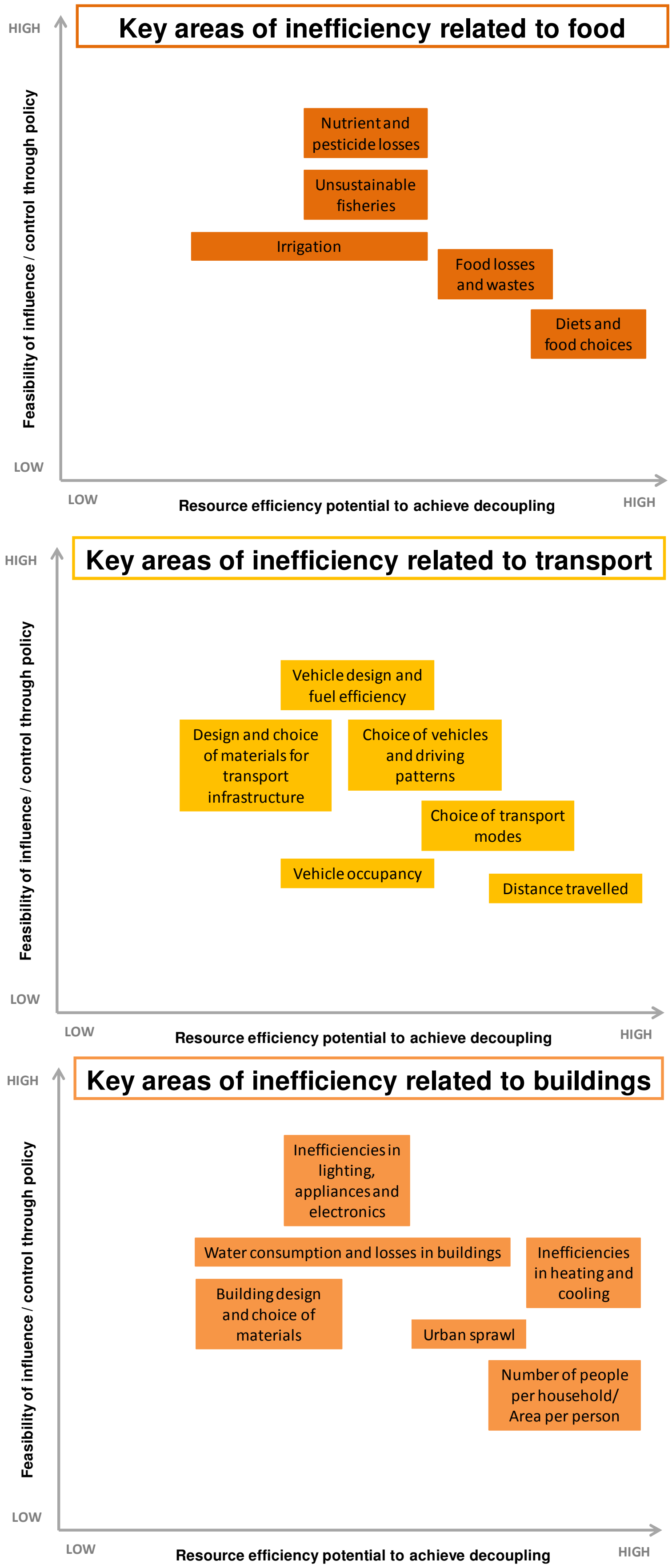


1.3 The key areas to address to achieve absolute decoupling

The review and analysis of resource inefficiency uncovered areas which could potentially be addressed by policy intervention to achieve absolute decoupling in the EU by 2050. Besides some general aspects of EU production and consumption patterns, the key areas of resource inefficiency were related to food, transport and buildings. These represent the areas that contribute the most to environmental pressures in the EU.

Figure 2 presents the areas with significant potential to improve resource efficiency and possibly achieve absolute decoupling. The areas identified in this study are ranked according to two dimensions: in relation to the potential for resource efficiency improvement, and in relation to the feasibility or ease for EU policy to influence resource efficiency improvements (Bringezu and Bleischwitz 2009). The ranking and comparison of key areas of inefficiency are based on the authors' opinion and not on thorough assessments.

Figure 2 A preliminary assessment of key areas of inefficiency in relation to potential for decoupling and policy intervention



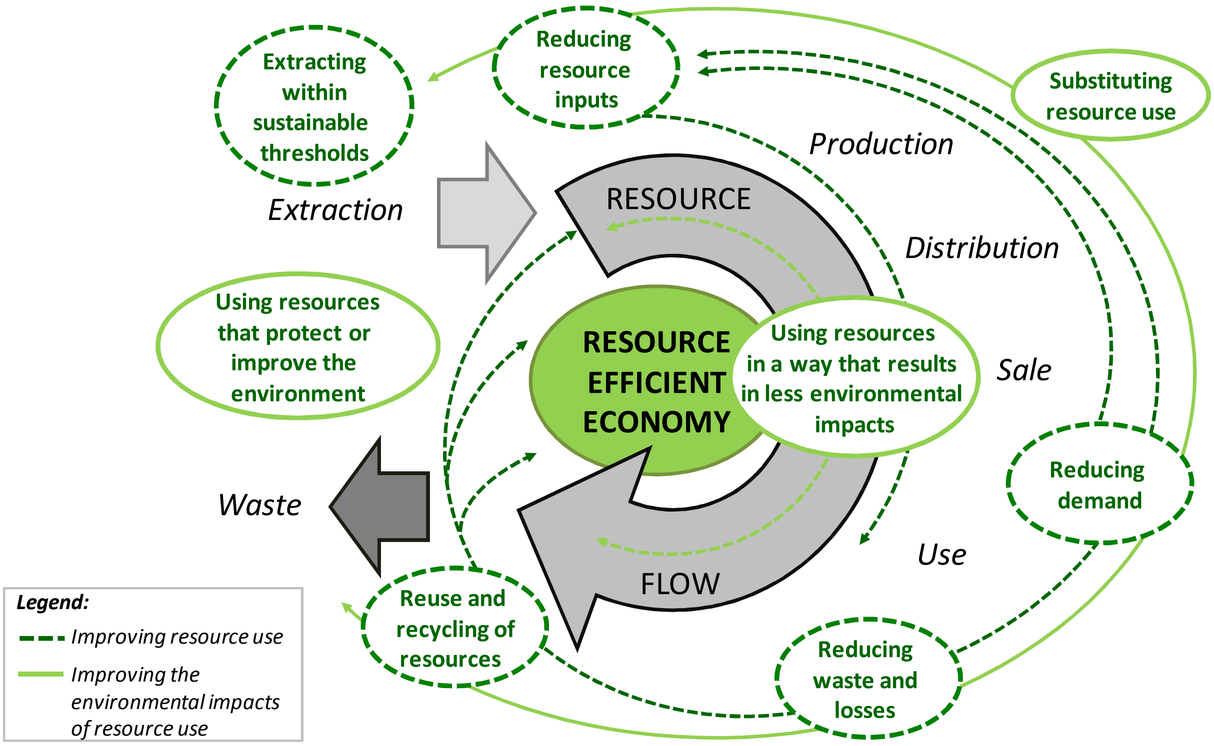
1.4 Approaches to improving resource efficiency

The review and analysis of inefficient resource use showed that there are many different approaches to improving resource efficiency, e.g. reducing waste and losses, reducing demand (e.g. resource sufficiency), sustainable raw material extraction, substituting resources with others that cause less harm to the environment, reuse and recycling, etc. One of the most common strategies to improving resource efficiency is to reduce waste and losses. This can contribute to other resource efficiency strategies upstream in the life cycle of resource use such as reducing the overall demand for resources, reducing the need for resource inputs and ultimately leading to a more sustainable level of natural resource extraction. The reuse and recycling of resources can also reduce the need for virgin resources by closing material loops and reducing the demand for resources.

A set of resource efficiency strategies focus more on reducing the environmental impacts associated with resource use rather than the amounts of resources used. These are substituting specific resources with other types of resources that are less harmful to the environment (e.g. using wood instead of metal), using resources in a way that results in less environmental damage (e.g. applying fertilisers only in certain times of the year) and using resources that actually protect or improve the environment (e.g. establishing green areas to reduce heat islands in urban areas).

The following figure summarises the main strategies to improving resource efficiency.

Figure 3 The identified main strategies to improve resource efficiency



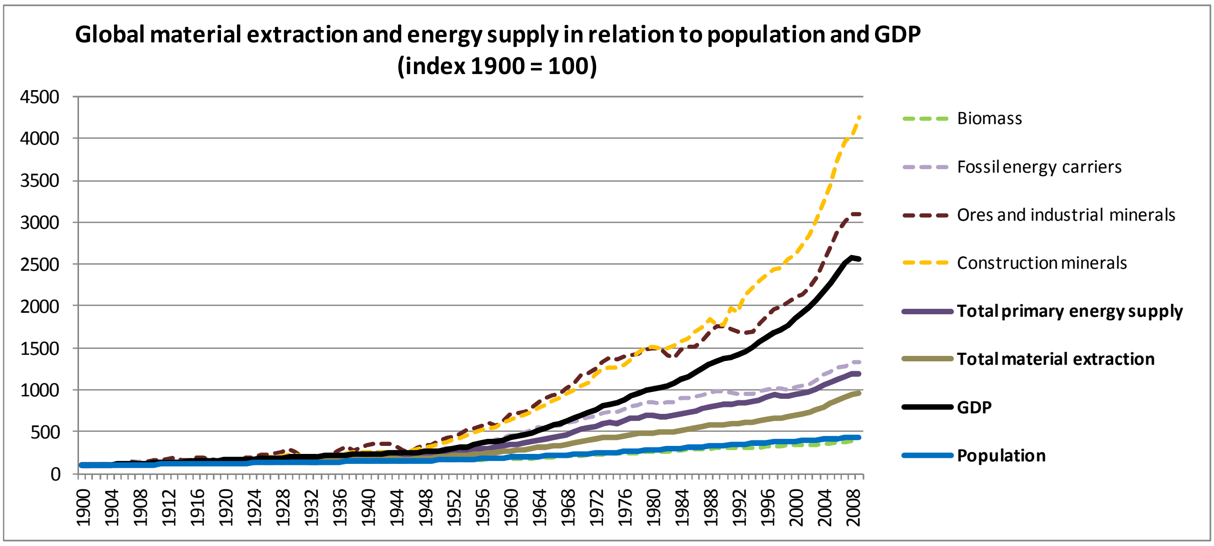
Overall, the findings from the literature review and the meta-analysis contribute to an improved and more comprehensive picture of relevant drivers affecting resource inefficiency. This will serve as a guide for the other work packages of the DYNAMIX project, which aims is to identify policy pathways to absolute decoupling of economic growth from resource use and its environmental impacts.

2 Introduction

Natural resources are fundamental for our society and its prosperity. They are needed in all human activities, and their use forms the basis of our economy. Resources such as raw materials, energy, food, water and land are directly extracted from nature to produce products and services that create economic value. In addition to the resources that are directly valued by the economy, other natural resources, such as ecosystems, provide environmental and social services that humans greatly depend on.

While humankind continues to develop and improve the quality of life, this has been based on the ever increasing use of natural resources over time (Figure 4). History has shown that the main drivers of resource use and environmental impacts are population, affluence (per capita consumption) and technology (Ehrlich and Holdren 1970). In economies today, resource use increases with population and affluence, while advances in technology typically increase resource efficiency (e.g. products become more efficient over time).

Figure 4 Global material extraction and energy production from 1900 to 2008



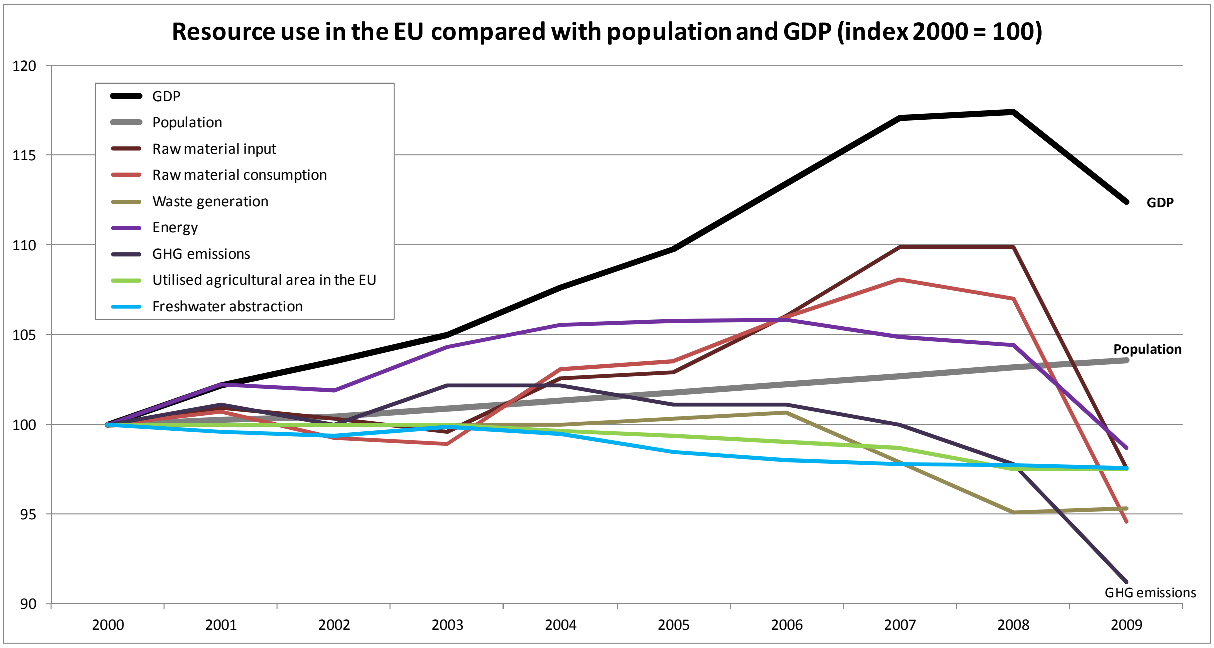
Source: (Krausmann, et al. 2009)

Based on current projections of population growth and income and even with the most optimistic expectations of technological development, we will not be able to avoid irreversible damage to the planet's natural environment and jeopardise its very ability to provide the resources and the ecosystem services that are essential to meeting some of the world's basic needs. According to WWF, the planet's biocapacity - the area of land and productive oceans actually available to produce renewable resources and absorb CO_2 emissions – have already been exceeded by more than 50% (WWF 2012). Global population and income forecasts will only put additional pressure on the planet's carrying capacity. This is why the concept of absolute decoupling is so important. Absolute decoupling aims to modify the drivers of resource use and environmental impacts, so that they are no longer linked to population or economic growth.

2.1 Decoupling

The EU is a long way from absolute decoupling of the consumption of resources from economic growth, despite examples of success in improving the resource efficiency of its economy. Since the year 2000, relative decoupling can be observed for materials, waste, energy and GHG emissions, which have all followed the development of GDP but at a reduced rate (see Figure 5). Absolute decoupling can be observed for water abstraction and agricultural land in the EU, but this does not take into account the increase of resource use outside the EU due to EU demand. The imports of agricultural products from countries outside the EU have increased over the past decades. This has not only increased land use in other countries, but has also shifted the environmental (and social burden) of EU consumption (SERI 2011).

Figure 5 EU consumption of different resources in relation to population and GDP



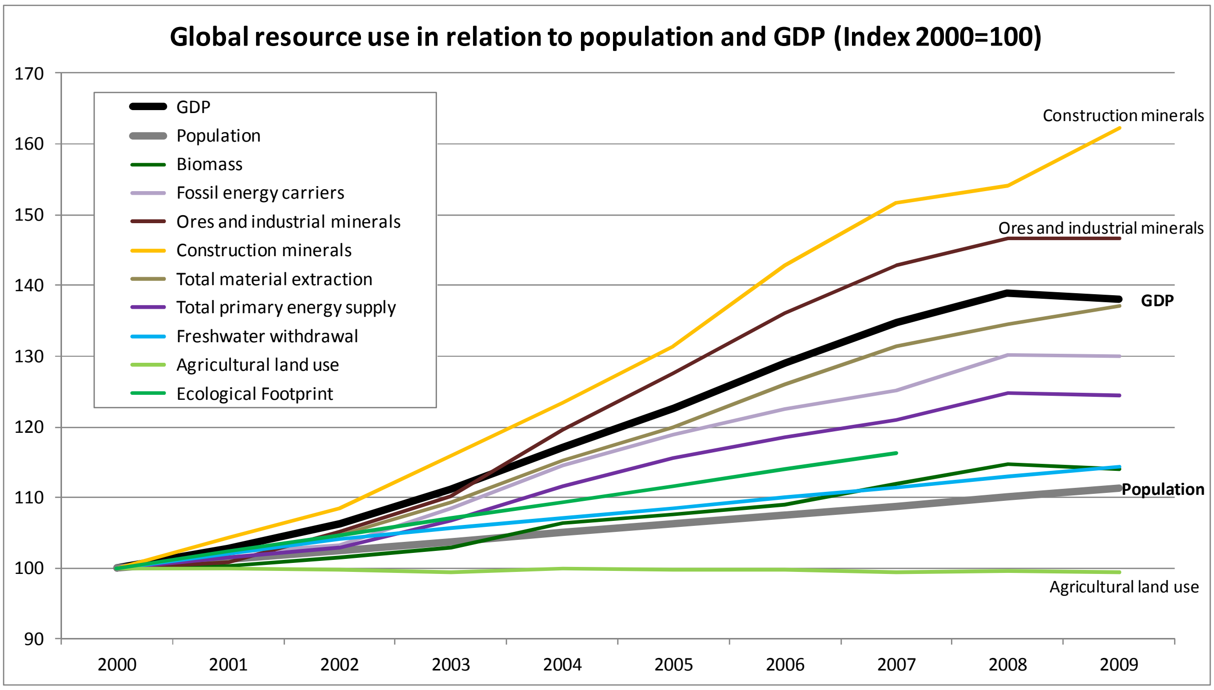
Source: Eurostat

Notes:

- Waste data only available for 2004, 2006, 2008 and 2010 (extrapolation was used to fill data gaps)
- Energy is measured as Gross Inland Energy Consumption
- Data gaps in freshwater abstraction were filled by using data from the latest year available and using per capita abstraction data from neighbouring countries
- Data gaps in utilised agricultural area were filled by using data from the latest year available

On a global scale, most resources indicate some level of relative decoupling from GDP growth (see Figure 6) - with the exception of the rate of extraction of metal and mineral ores. Only agricultural land seems to be fully decoupled from GDP growth. This may be an example of an increase in land use efficiency, but could also be an expression of the limited availability of land. Besides agricultural land, the consumption of all other resources remains coupled with population growth.

Figure 6 Global consumption of different resources in relation to population and GDP



Source:

- GDP, population, energy and material extraction data from (Krausmann, et al. 2009).
- Freshwater withdrawal data from Food and Agriculture Organization, AQUASTAT data. Data available only for 1997, 2002, 2007, 2011. Intermediate years estimated through extrapolation.
- Agricultural land data from Food and Agriculture Organization, FAOSTAT data;
- Ecological Footprint from the Global Footprint Network (National Footprint Accounts 2010 edition). Data available only for 2000, 2005 and 2007. Intermediate years estimated through extrapolation.

While global trade has brought wealth to more people on the planet, it has a major impact on the environment. The level of resource use within the EU (and other industrialized and emerging economies) cannot be maintained without seriously threatening the functioning of various ecosystems with crucial provisioning and supporting services for human society and endangering climate stability (Millennium Ecosystem Assessment 2005). This high (and growing) demand for resources together with the on-going degradation of ecosystems lead to increasing scarcity of natural resources. This in turn results in rising global commodity prices. Resource scarcity also creates substantial economic dependencies with respect to resource-exporting countries. Finally, current levels of resource use in industrialized countries have a disproportionately negative impact on populations in developing countries, ultimately limiting their possibility to reach higher standards of living, while at the same time threatening future generations' well-being (Wuppertal Institute 2010).

2.2 Resource efficiency

In order for the EU to continue to develop and flourish sustainably within planetary boundaries (Rockström, et al. 2009), it has to increase its resource efficiency until absolute decoupling[1] is achieved. In general, improvements in resource efficiency can be achieved through any of the following approaches (or combination of approaches):

1. **Using fewer resources** to fulfil the same needs
2. **Increasing the (socio-economic) value and benefits** from the use of (the same amount of) resources
3. **Reducing the environmental impacts and damage** associated with the use of resources

In order to achieve absolute decoupling, resource efficiency must consider the entire life cycle of resources (e.g. extraction, production of products and services, distribution, sales, use and end-of-life phases). This can include diverse strategies such as sustainable resource extraction (e.g. water abstraction, mining, fishing, forestry, etc.), increasing agricultural yields without degrading ecosystems, applying ecodesign, substituting more damaging resources with those that are less harmful to the environment, using the best environmental technologies and practices, preventing waste, reducing demand through better consumption and increasing recycling and reuse.

While there seems to be considerable scope for increasing resource efficiency, it is not clear what the possible pathways are to absolute decoupling in the EU. To determine how the EU can achieve absolute decoupling, the areas with greatest potential for improving resource efficiency must be identified, and the manner in which they can be exploited must be understood.

This report documents the work performed in Work Package 2 (WP2) of the EU funded FP7 project DYNAMIX. The objective of DYNAMIX is to identify policy mixes and pathways to absolute decoupling of economic growth from resource use and its environmental impacts. The identification of any meaningful policy mix towards absolute decoupling must therefore build on an analysis of the drivers underlying existing patterns of resource use. Only then can the policy mix be tailored to best tackle prevailing inefficiencies in relation to resource use and to avoid, as much as possible, associated environmental impacts of resource use (double decoupling, encompassing resource and impact decoupling).

2.3 Document structure

This report has six parts:

- Chapter 1 provides an introduction to DYNAMIX, decoupling and resource efficiency.
- Chapter 2 presents the objectives of this research and describes the methodology behind the research.
- Chapter 3 presents the findings of inefficient resource use from a macro-economic and global perspective.
- Chapter 4 investigates the drivers and underlying causes of inefficiency in general, as well as from three specific sectoral views: food, transport and buildings.
- Chapter 5 presents the findings from the meta-analysis.
- Chapter 6 summarises the main findings in the context of the DYNAMIX project.

[1] For renewable resources, absolute decoupling is achieved when resource extraction does not exceed a sustainable level, i.e. the level of extraction of resources is equal to or less than the rate of resource regeneration.

3 Methodology

3.1 Objectives of this study

The main aim of this study is to identify the main inefficiencies of resource use in the EU and to investigate their drivers and underlying causes. The study was broken down into three steps, each with its own objective:

1. To map efficient and inefficient uses of resources over their life cycle.
2. To determine the magnitude of inefficient resource use.
3. To analyse the main drivers and underlying reasons for inefficiency.

This study will serve as a basis for identifying key policy areas to focus on later in the DYNAMIX research project and support the European Commission in the development of policy mixes that will help achieve absolute decoupling. A thorough understanding of the drivers and causes of inefficient resource use is fundamental when designing appropriate and effective policy mixes.

3.2 Research approaches and analytical framework

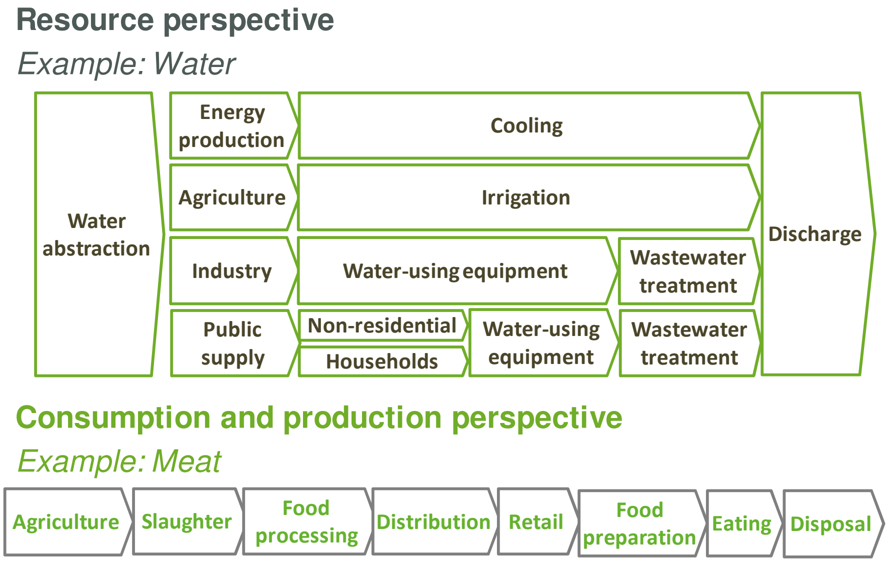
The research in this study is based on a review of existing literature and data using qualitative and quantitative methods. A broad search was conducted for relevant literature and data on resource use in the EU, as well as resource use outside of the EU that is driven by EU production and consumption. Initially all types of resources, economic sectors, and products and services were considered, but after a first preliminary screening of literature, two major perspectives emerged:

1. A **resource perspective,** with the main resource types being materials, energy, water and land
2. A **consumption and production perspective,** with the main sectors being food, transport and buildings

These perspectives were then used to categorise the identified literature and focus the search for other relevant literature. The identified literature that did not specifically address any of the main resource types or sectors was still considered in the study, but no further search was performed to cover individual resources, sectors, products or services that were not already included in the scope of the perspectives listed above.

Although there may be specific resources and sectors that might not be covered in this analysis, in the context of EU economy-wide decoupling of resource use and environmental impacts, all major areas of resource use are accounted for (EEA 2013a)(SERI 2009). In both perspectives of resource use a life cycle approach is applied (Figure 7). In the resource perspective, resources are tracked from the transformation of their natural state to raw inputs to the economy, their ‘flow’ through or ‘use’ in economic sectors and finally as outputs of the economy, as waste and emissions to the natural environment. The consumption and production perspective considers the life cycle of products and services and their flow through the economy, including resource inputs and outputs and environmental impacts at each stage.

Figure 7 Illustration of the two life cycle perspectives used to analyse resource use in this study



Both perspectives of resource use are overlapping and complementary. They both allow for the identification of the main uses of resources in relation to specific (economic) activities. This can then be used to determine the associated environmental impacts of resource use at each stage in the life cycle. The amount of resources used and the associated environmental impacts in relation to each economic activity provide a first indication of whether a resource is used efficiently (or, at least, where an inefficient use of the resource is important to rectify). Furthermore both these perspectives provide an analytical framework for identifying the main actors at each stage of the life cycle and the drivers of inefficient use of resources. In particular, the life cycle approach makes it clear that the drivers of inefficient resource use may be found at other life cycle stages than where the resources are actually used. For example, meat consumption drives the production of crops for feed, which in turn drive land, water and fertiliser use.

Although not illustrated in Figure 7, the analysis of inefficient resource use and its drivers are also seen in the context of global trade. Production and consumption in the EU may drive the extraction and use of natural resources, as well as the associated environmental impacts outside the EU. This aspect is also considered in the analysis.

Following the objectives of this research a two-step approach is applied for determining the reasons for inefficient use of resources:

1. Identification and prioritisation of the main inefficiencies of resource use through the literature review and existing data.
2. Analysis of the drivers of the main inefficiencies identified.

The following sections describe in greater detail what is meant by efficient / inefficient use of resources and drivers.

3.2.1 Defining efficient and inefficient use of resources

There are many ways to define efficiency. From a physical or technical perspective, efficiency is the relationship between inputs and outputs of a physical process or transformation, e.g. the useful electric power, mechanical work or heat (output) in relation to the input energy (OECD 2008). Efficiency could also be defined in terms of the minimisation of waste and/or losses. An efficient system is one that requires a minimum amount of resources to provide a certain functional unit (i.e. the level of service or benefit that is provided – typically in the form of products and services), e.g. a nutritious and healthy diet for one person for one year, transport of a person over 100 km, or a 50 m^2 living space.

The terms 'resource efficiency' and 'resource productivity' are often used interchangeably[2]. However, in economics there is a difference between the concepts of efficiency and productivity. Efficiency is a measure of optimality (i.e. how close a system is to its optimum state, or a particular system variable to its optimal value); while productivity is a measure of the relationship between a particular output and a particular input such as labour, materials, energy, etc. Productivity, or its inverse intensity, are only meaningful as comparative measures – i.e. comparing one firm / sector / country with another, or one time period with another (trends over time). It is, for example, not meaningful to talk about a sector being productive in absolute terms. In contrast, it is meaningful to say whether it is efficient or not, but it is difficult to determine what is the optimal efficient state.

While there are clearly links between changes in efficiency and changes in productivity, one does not necessarily imply the other. For example, an efficient level of resource use does not necessarily mean that resource use is minimized, and, conversely, the minimum technically possible level of resource use is unlikely to be economically efficient. Furthermore reductions in resource use that improve resource efficiency (i.e. move resource use closer to its optimal value) may not necessarily improve resource productivity (e.g. if they also lead to a reduction in output).

From a sustainability point of view, the World Business Council on Sustainable Development (WBCSD) defined eco-efficiency as *"the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impact and resource intensity throughout the life cycle, to a level at least in line with the Earth's estimated carrying capacity"* (WBCSD 2000). Building on this, the European Commission in its communication "Thematic Strategy on the Sustainable Use of Natural Resources" (EC 2005) made it clear that resource efficiency meant both reducing the environmental impact of resource use and at the same time improving resource productivity, i.e. the value added per unit of resource input, overall across the economy. For renewable resources this meant also staying below the threshold of overexploitation.

It is difficult to say how much of the current rates of resource extraction could be seen as inefficient. One way of attempting to define how much of current resource use is inefficient is by asking to what extent it is possible to reduce current resource use and environmental impacts without compromising economic development and well-being of current and future generations all around the world[3]. Based on the principles of the Natural Step (Robèrt 2002), one could say that it is inefficient to:

---

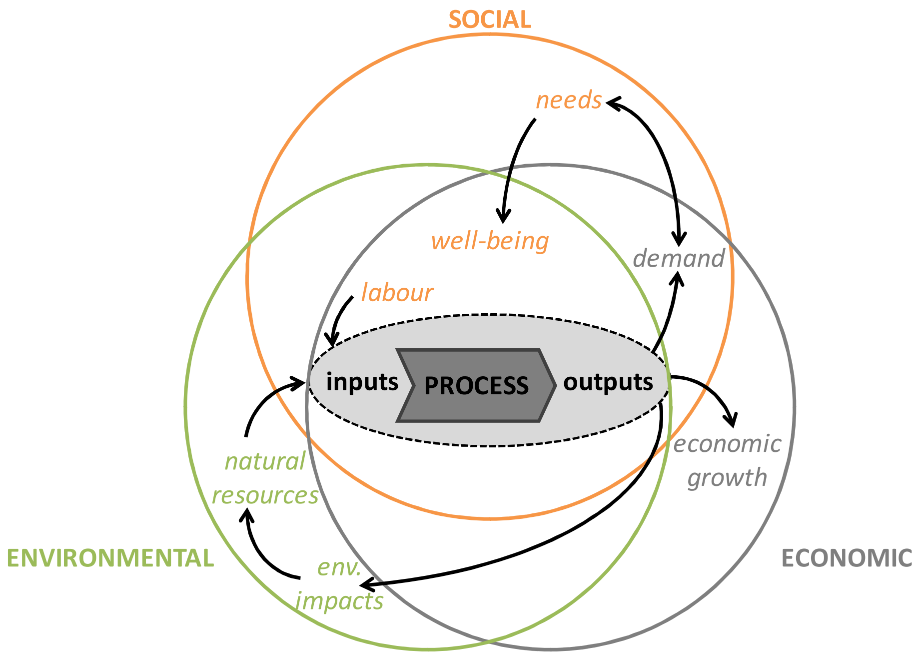
[2] From a business management point of view, efficiency is generally understood as the ratio of the time needed to perform a task, e.g. the number of units produced per hour. A distinction is made in the management literature between efficiency and effectiveness: efficiency is often defined as "doing things right", while effectiveness is "doing the right things". While efficiency relates outputs to inputs, effectiveness relates the outcomes with set objectives.

[3] Similar to the definition: *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (UN World Commission on Environment and Development 1987)

- Extract renewable resources at a faster rate than the regenerative capacities of ecosystems.
- Lose or waste any non-renewable resources or toxic substances.
- Generate emissions at a faster rate than ecosystem services can manage without degrading their capability.

In this perspective, the capability of ecosystems to provide resources and ecosystem services should be included in the understanding of resource efficiency;

Figure 8 Resource efficiency relates to different perspectives of the relationship between inputs and outputs



As presented, there are many definitions and dimensions of efficiency (Figure 8). Resource efficiency depends on the perspective taken. For example, the packaging of bottled water can be seen as resource efficient if it uses a minimum of resources and causes a minimum of environmental impacts to adequately transport and protect the mineral water. But from a perspective of providing clean drinkable water, a public water supply system may be a more efficient use of resources as it does away with the bottle and packaging.

In this research, improvements in resource efficiency are understood to encompass:

- reductions in the amount of resources needed in an economy; and/or,
- increases of the economic value of the resources used in the economy; and/or,
- reductions in the environmental impacts of resource use; and,
- ultimately leads to absolute decoupling.

One can only identify inefficient use of resources when comparing resource use to a known technically feasible and socially acceptable approach that is more resource efficient. The scope for increasing resource efficiency is therefore relative in relation to the feasibility of existing technologies and what is considered socially acceptable. Policy can encourage resource efficiency directly by increasing the uptake of existing technologies, or by changing paradigms for what is socially acceptable. Included in this perspective is also the scope for 'resource sufficiency', i.e. influencing consumers to only consume a quantity of a resource that is just necessary and sufficient for optimal health, well-being and happiness (Boulanger 2010).

3.2.2 Drivers of inefficient use of resources

Understanding the fundamental factors that lead to inefficient use of resources is essential to the identification of interventions and strategies for reducing resource use and environmental impacts. The extent to which resources are used efficiently (or inefficiently) depends on a multitude of complex interacting factors and causes. In this research it is assumed that it is possible to identify various cause and effect principles that determine how efficiently or inefficiently a resource is used. Inspired by the environmental indicator DPSIR framework[4] developed by the European Environment Agency (EEA 2003), this research sets out to determine what are the main drivers of inefficient resource use.

A driver is any natural or human-induced factor that directly or indirectly influences the efficient (or inefficient) use of resources (Millennium Ecosystem Assessment 2005). A driver can either help improve resource efficiency performance or actually be an obstacle for improvement. It can have various degrees of impact or strength. Direct drivers affect the efficient (or inefficient) use of resources in a direct causal way. Indirect drivers affect the efficient (or inefficient) use of resources indirectly through direct drivers. While causality between direct drivers and resource use is clear, it is not always possible to determine the causality between indirect drivers and resource use. Each driver of inefficiency resource use may have multiple causes or explanations for why the resource is not used more efficiently.

For example, the direct drivers of the low uptake of energy efficient appliances could be low awareness of the saving potential among consumers, lack of information to identify the most energy efficient products, lack of availability of energy efficient products on the market, low energy costs and higher investment costs / sales prices of energy efficient equipment. Indirect drivers could be lack of education and awareness of environmental issues and actions, no clear labelling or mandatory energy performance information of products, manufacturers who do not have the skills or see the market potential of producing energy efficient products, energy subsidies and higher prices of energy efficient equipment on the market.

It is not always straightforward to identify or assess drivers of inefficiency as they affect the use of resources on different spatial and temporal scales. Using the same example as above, energy costs may depend on the national or global context, while inappropriate consumer behaviour patterns may only be relevant for some consumer groups. Some drivers have greater 'inertia' than others, meaning that they do not change much and continue influencing inefficient resource use over the long term, while other drivers change more

[4] DPSIR stands for Drivers-Pressures-State-Impact-Response. The framework is useful in describing the relationships between the use of natural resources and its impacts on the natural environment. It starts by identifying the key drivers of resource use (e.g. economic growth, technological changes, etc.); the type of pressures exerted on the natural resources and the natural environment throughout its life cycle stages (e.g. energy or water consumption in extraction, production, use, etc.); the state of the ecosystem providing or sustaining the resource (e.g. depletion, degradation, etc.); the actual or expected impact of these pressures on stocks of natural resources and the natural environment (e.g. climate change, loss of biodiversity, etc.); and finally the policy actions (e.g. energy efficiency standards, recycling targets) that are the responses to the challenges.

rapidly, e.g. energy efficiency of computers, which seems to develop faster than other products. Finally, drivers may affect inefficient resource use across the life cycle of products and services. An example of this is high meat consumption in the EU driving land use change in other countries which leads to deforestation.

While the interactions between the multitude of direct and indirect drivers is complex, this research tries to identify the most influential drivers of inefficient resource use and explain their main underlying reasons. Given the scope of the project, and for pragmatic reasons, this will result in a presentation of only a limited set of drivers for each main inefficiency identified, as well as simplified descriptions.

3.2.3 Research strategy

Three different research strategies were applied to perform the research in this study:

- Qualitative analysis of relevant literature
- Quantitative analysis of resource use
- Meta-analysis of the drivers of inefficient resource use

The three approaches were conducted in parallel and were treated as complementary in analysing the inefficiencies of resource use and their drivers.

The literature review revealed many different dimensions of efficient and inefficient use of resources. When existing data or quantitative evidence was found, this was subject to a quantitative analysis to demonstrate the magnitude and relative extent of inefficiency. The quantitative analysis provided an overview of current resource use, which helped uncover areas where significant inefficiencies such as waste and losses in the life cycle of resources occur. Using these findings as a starting point, existing literature was consulted during the qualitative analysis in order to better understand the drivers behind the identified inefficiencies.

The literature review also revealed findings and evidence of inefficiencies that were not easily quantified or for which data was unavailable. The findings and evidence were summarised and categorised in an attempt to figure out how they fit with the overall findings of inefficient resource use. This was done in a traditional qualitative manner, as well as via a more structured quantitative analysis by means of a meta-analysis.

The following sections describe in more detail the methodological approach of each of the research strategies.

3.3 Literature review

The literature review aimed to identify, interpret and summarise the most recent literature currently available on resource efficiency and examples of inefficient use of resources. The literature was classified according to resource type and economic sector. The evidence and findings of inefficient resource use and drivers were compared and structured in an attempt to create a comprehensive picture of the most significant examples of inefficient resource use and drivers.

3.3.1 Literature search strategy

The search strategy for literature was developed by identifying relevant data sources, time frame and key words. The sources of literature were academic (peer-reviewed) journal papers, conference papers, theses and books, as well as reports and other forms of publications from the so-called 'grey literature'. A large majority of the grey literature was from governmental organisations such as UNEP, the European Commission, the European Environment Agency and national agencies - either produced by the organisations themselves or commissioned work. Some of the grey literature also originated from business associations and NGOs (also either produced by the organisations themselves or commissioned work). In all cases, the evidence and findings of the literature were scrutinised for reliability and validity. The literature review covers published work from the year 2000. Occasionally, if any older literature was found relevant to the study, this was also included in the literature review.

Academic literature was identified through various search criteria in the Web of Science (Thomson Reuters) and Science Direct (Elsevier) online databases and complemented with a search using Google Scholar.

The following combination of key words was used in the database research:

- ("resource" OR "material" OR "energy" OR "water" OR "land") AND
- ("efficiency" OR "productivity")

In each case the search results were scanned to check for their relevance. If the search results were not found to be relevant or resulted in a large number of results, the search was refined to focus specifically on the policy dimension by using the following key words:

- ("policy" OR "behaviour" OR "consumption")
- ("driver" OR "cause" OR "reason" OR "case study")

For the grey literature, a web search was conducted using Google applying the same approach as above.

3.4 Quantitative analysis

In this study an MFA-based approach is used for the quantitative analysis. The approach follows the general principles of Material Flow Analysis (MFA) (Bringezu and Moriguchi, 2002) and Substance Flow Analysis (SFA) (Van der Voet, 2002) (Brunner and Rechberger, 2003). The principles of MFA and SFA are the same and can be applied to materials and substances, including water. Material flow analysis is used for various purposes, for instance to estimate the loss of materials and the environmental impacts related to processes of the studied materials life cycle. It is also used to track the fate of materials by applying the mass conservation principle (Yellishetty, Ranjith and Tharumarajah 2010).

An MFA provides a systemic analysis of processes and flows in support of strategies and policies as management measures. With regards to policy, MFAs have in recent years been used to, for example:

- Support policy debate on resource and efficiency goals and targets
- Provide economy-wide material flow accounts for official statistics
- Create indicators for sustainability

In MFA, a process is defined as the transformation, transport, or storage of materials. Transformation processes take place in primary production processes, such as in the mining and metal industry, where metals are extracted from mineral ores. Consumption processes, such as private households, transform goods into wastes and emissions. Transformation processes are not restricted to anthropogenic processes and could also be relevant for natural systems, e.g. when forests transform carbon into biomass and oxygen.

Another important term in MFA is transportation processes, in which the materials or goods are not transformed, but rather relocated over a certain distance. Both transformation and transport processes are usually symbolised by rectangular boxes. The processes are defined as “black box” processes, which mean that the processes within the box are not taken into account, only the inputs and the outputs are of interest. There is also a third type of process, the stock of materials, describing the quantity of materials within a process. Both the quantity of the stock and the rate of change of the stock per unit time are important parameters for describing a process. Examples of storage processes are households storing goods like electronic appliances or materials stored in buildings. A “final sink” is a process where materials have very long residence times, usually over 1000 years.

In MFA the terms flow and flux are commonly used, sometimes inconsistently. A flow is defined as a mass flow rate, given in units, e.g. tonne per year. A flux, on the other hand, is defined as a flow per cross section. Taking a water pipe as an example the flux might be given in units of kilo per second and m^2. According to (Chen and Graedel 2012), it is important to observe the conservation of mass at each stage of the system, i.e. the input flows should equal the output flows. Failure to achieve conservation of mass indicate that a deficiency exists in the description of the cycle or in the quantification. Many MFA studies do not succeed in fully respecting the conservation of mass, but can in any case contribute to valuable insights about the system studied.

A material flow analysis is usually either static or dynamic. In the static case a “snapshot” of flows in a certain time is studied, unlike the dynamic case, where changes over time are considered. It is often more difficult to perform dynamic MFAs than static ones. In this study, in-depth flow analysis was performed for four types of resources:

- Iron and steel
- Cobalt
- Phosphorus
- Water

3.5 Meta-analysis

While the qualitative analysis of the literature review provides a narrative of and supporting context to the arguments that have been used in the on-going discourse on the reasons and means to address resource use inefficiency, the quantitative meta-analysis tries to compare and, as much as possible, combine the available quantitative evidence to gain a better understanding of the relationships between different resource use patterns, their underlying drivers, and their effects on resource efficiency.

3.5.1 Quantitative meta-analysis and caveats for application

Despite being a well developed and widely practiced method in the statistical sciences, the application of meta-analysis to resource policy questions has yet to mature. A quantitative meta-analysis is described by Egger et al. (1997, p. 1553) as:

> *"[…] a statistical procedure that integrates the results of several independent studies considered to be "combinable." Well conducted meta-analyses allow a more objective appraisal of the evidence than traditional narrative reviews, provide a more precise estimate of a treatment effect, and may explain heterogeneity between the results of individual studies. Ill conducted meta-analyses, on the other hand, may be biased owing to exclusion of relevant studies or inclusion of inadequate studies. Misleading analyses can generally be avoided if a few basic principles are observed."*

When conducting a meta-analysis the analyst has to carefully and in full transparency develop the protocol for identifying and selecting the studies, assessing the heterogeneity of results and analysing the data. Study selection can become biased by three main bias types: publication bias (i.e., the tendency of scientific journals to publish positive findings over inconclusive findings), search bias in the identification phase (i.e., missing relevant publications due to choice of database and/or search phrases), and selection bias in the selection phase (i.e., exclusion of legitimate studies). There exist tools, including graphical techniques, to assess the presence of these types of bias.

Heterogeneity in the context of meta-analysis is used to describe the degree of dissimilarity in the results across the individual studies. These differences might be due to variations in study design, but in some cases the reasons are not so easily discernible. As a general rule of thumb, the greater the heterogeneity of the studies' findings, the less defensible it becomes to integrate/combine them into a single estimate. A meta-analysis that adheres to common quality standards can provide valuable as well as additional information for researchers and policy-makers. Conducted poorly, however, meta-analyses can be misleading or misinterpreted. As over the past years and decades environmental policy has become more data-driven and statistical methods are now routinely applied even to complex problems, this evolution has also led to the further development and adaptation of data analytical methods to the types of problems encountered in the environmental policy arena (e.g., the combination of quantitative and qualitative methods to study social impacts of environmental degradation). Nelson and Kennedy (2009) have conducted a critical review of the usage of meta-analysis in the field of environmental economics and social science, highlighting that: *"Implicit in any meta-analysis is the assumption that the primary studies are similar enough that they can be usefully combined or analyzed."* (p. 359)

In the context of the DYNAMIX project, the quantitative meta-analysis envisioned aims to review and combine the available literature for the purpose of identifying the drivers of resource use inefficiency – primarily in Europe, but also globally if relevant aspects would transfer to the European context. To arrive at a quantitative meta-analysis it was necessary to screen for articles dealing with one of more of the resources selected for this study and examine what societal, individual and economy processes influence their extraction, use, and after-use management, and how they can be made more efficient. In the majority of studies identified, the analysis does not yet include a rigorous quantitative treatment of the driver-resource use efficiency nexus. The following meta-analysis, therefore, has a number of limitations. First, typically applied statistical tools to aggregate individual effect estimates fail because most of the identified and selected studies do not provide such estimates. In addition, the scope of the articles with respect to the choice and definition of resources varies widely from specific compounds, such as in phosphorus fertilizer and CO_2 as a greenhouse gas, to broad examination of anthropogenic land use efficiency for economic production, living and waste absorption purposes. The question of sample size is also challenging to answer in a meta-analysis of the drivers of resource use efficiency. Often, the sample is a single geographic area selected on the basis of political or topographic, physical or hydrological boundaries (e.g., a city, country or watershed), which cannot be aggregated or compared with other such areas. The description of the sample population therefore leads to nearly unanimous individual cases, which have little in common and therefore do not lend themselves to “pooling”. Lastly, the drivers identified from the selected studies are not always rigorously defined. For example, policy and legal frameworks are not always explained further, and in some cases, the drivers are so inherently context-dependent that other studies focusing on the same driver could not be found.

The following sections explain how we addressed these limitations to arrive at meaningful, aggregated results regarding the types and directions of drivers of resource use efficiency.

3.5.2 Development of a multi-tier conceptual map

The first analytical step consisted of developing a multi-tier conceptual map of the key drivers that are considered to affect the efficiency of resource use. A conceptual map is a multi-level, hierarchical display that is generally used to structure the relationships that exist between different concepts. In the present context, the conceptual map was applied to structure and organize the key drivers of resource use efficiency (including drivers for both efficient and inefficient resource use). The hierarchical structure of the conceptual map depicts the cause-and-effect chains at different levels of detail. Furthermore, it helps structure existing relationships between different drivers.

An initial conceptual map was developed based on a review of the two reference reports UNEP (2011a) and McKinsey Global Institute (2011) that represent extensive reviews and amalgamations of the existing knowledge base on resource use.

Figure 9 Conceptual map of high-level (Tier 1) drivers for inefficiency

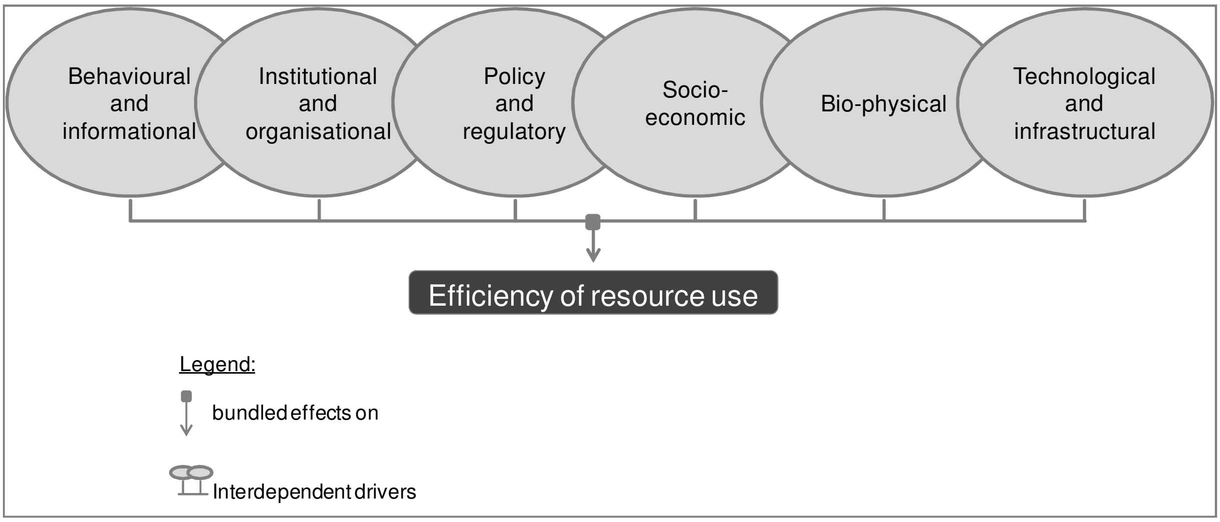


Figure 9 shows the high-level drivers we have identified. We refer to them as Tier 1 drivers. They are interdependent aggregates or abstracts of more narrowly defined drivers affecting the efficiency of resource use. While (1) behavioural and informational and (2) institutional and organizational drivers link to characteristics (e.g., mental models, knowledge) of and relations (e.g., governance modes, discourses) between the different resource policy actors (such as policy-makers, civil society organizations, industry and business and academia), policy and regulatory drivers span factors which relate to political decisions and legal frameworks. Socio-economic and bio-physical drivers encompass socio-economic factors (such as population growth and density, economic performance, global trade patterns and resource prices) and bio-physical factors (such as climate, resource endowments, available land area), while technological and infrastructural drivers relate to technological factors having an influence on resource use efficiency (available technologies and associated infrastructure, resource requirements for certain technologies). Annex A provides a list of the Tier 2 and 3 drivers of the Tier 1 categories.

3.5.3 Search and selection of relevant articles

The second step of the analytical framework encompasses searching for and selecting relevant case studies for the meta-analysis. A literature search was performed using ScienceDirect (http://www.sciencedirect.com/) and Google Scholar (http://scholar.google.com/). This procedure returned 220 different articles. A four-stage selection procedure was applied to identify and select relevant articles. This finally led to a total of 34 articles for further analysis. For more detail on the search and selection process see Annex A.

3.5.4 Coding of articles

For coding of the selected articles, a coding scheme was developed and tested by three scientists independently coding the same two articles. After exchange between the three scientists the coding scheme was refined and finalised for use for the remaining articles (see Annex A).

The coding scheme helped ensure that all relevant findings were considered. The level of driver was also taken into consideration by looking at its context-specific or overarching nature (e.g. a driver for increasing the efficiency of the use of bottled water will be very different from a driver explaining the efficiency of the use of drinking water, which could do away with bottled water altogether).

While the articles were generally coded by different scientists, a total of three articles were, at varying intervals, exchanged for joint coding to test intercoder reliability. Upon finalisation of the codings, a joint discussion on the main findings in terms of key drivers was held. During the discussion, six of the 34 articles coded were found to not yield relevant information – these were excluded from further analyses.

3.5.5 Characterisation of the key findings of each article in a comparable matrix

In the last analytical step, the remaining 28 articles were revisited and a questionnaire was developed to quantitatively summarise the key findings per article in a comparable matrix:

Table 1 Questionnaire matrix applied to the selected articles

Article identifier	Coding variables
Driver	- *Tier 1 driver: Highest level driver category (Tier 1), to which Tier 2 and Tier 3 drivers are allocated* - *Tier 2 driver: Higher level driver category (Tier 2), to which Tier 3 driver is allocated* - *Tier 3 driver: Name of Tier 3 driver found*
Direction	- *Positive* - *Negative* - *Undetermined*
Effect Type	- *Direct Effect* - *Undetermined Effect* - *Differential Effect* - *Conjoint Effect* - *Moderator Effect* - *Mediator Effect*
Resource	- *Energy* - *Materials/Waste* - *Water* - *Land/Soil* - *Air* - *N/A*
Sector	- *Energy* - *Food* - *Transport* - *Buildings* - *N/A*
Explanation	*textual explanation of driver*
NA_Comment	*comment on any NA chosen*

The characteristics have been coded as nominal variables with value domains as described in Table 1. The questionnaire was then filled in for all 28 articles, listing the relevant drivers identified from each of the coded articles, their direction in relation to increasing or hindering efficient resource use, the effect type identified, as well as the resource and sectoral focus of each article analysed. In order to facilitate completion of the questionnaire and subsequent analysis, a textual explanation of the driver was provided and a comment given in case of selecting any ‘not applicable’ (NA) entry in the questionnaire.

4 Global and macro-economic perspectives of resource efficiency

This chapter provides an overview of the use of the main types of resources at a global and EU level. Based on the literature review and analysis of resource flows, the main areas of inefficiency are highlighted. By analysing how resources are used, e.g. tracking the flows of resources, waste and environmental emissions, or considering what purposes they are used for, e.g. to provide food, feed or fuel, it is possible to determine whether resources could be used more efficiently. To the extent that data is available, the share of global resource use due to EU demand is also presented.

The chapter is structured by type of resource: materials, energy, water, land and ecosystem services. The analysis is often constrained by the indicator used to measure resource use and the data available. For example the indicator to measure material use is based on weight, so the materials that weigh the most are most apparent. Important materials for the economy which are used in small quantities, such as rare earths and plants for pharmaceutical purposes, are not distinguished, when total material use is discussed or quantified.

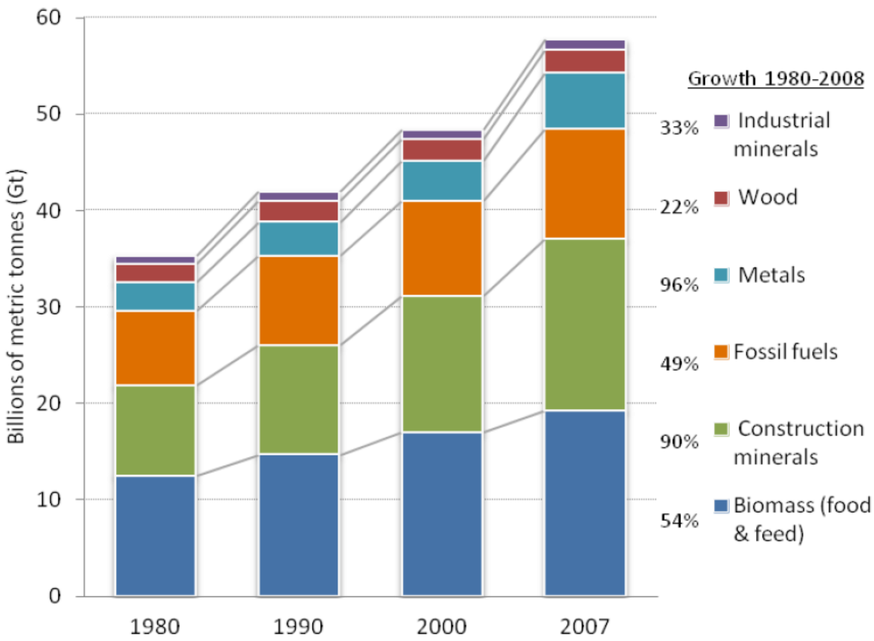
The uses of resources (and the indicators to measure resource use) are interlinked. For example, material use includes materials such as fossil fuels, uranium and wood fuel, which are used for energy production. Under each section, if there is data available, an overview of some of the outputs of resource use, such as waste, wastewater and environmental impacts, are also presented.

4.1 Materials

Global material extraction has increased, but so has economic development. The main drivers of material extraction are population growth and affluence (UNEP 2011a). While it is clear that material consumption would increase to satisfy the basic needs of more people, economic growth in itself has led to greater affluence and higher consumption per person. Gross Domestic Product (GDP) has grown more than material consumption/extraction due to improvements in extraction and production processes, as well as changes in the composition of global extraction (OECD 2011).

According to data used by Krausmann et al. (2009), around 68 billion metric tonnes of materials were extracted globally in 2009, including unused and used extraction (Figure 10). This represents a doubling in material extraction over the past 30 years. At the same time, GDP has more than doubled, from below 20 to approximately 50 trillion dollars. Thus, resource use grew at a slower rate than economic activity, implying relative decoupling. However, as total material use continues to grow and associated environmental impacts often remain unresolved, relative decoupling will not be sufficient to avoid irreversible damage to the planet’s natural environment and jeopardise its very ability to provide the resources and the ecosystem services that we are so dependent upon.

Figure 10 Global extraction of material resources



Source: (OECD 2011)

Despite the increases in material productivity, the literature review revealed that it is possible to use resources much more efficiently. The following are the main inefficiencies related to material resource use:

- When it comes to **biomass** extraction, agriculture is the most important activity. The majority of biomass in agriculture is used for food and animal feed (including grazing), but significant quantities of agricultural crops are also used to produce biofuel and fibres. Forestry is another important activity involving the harvesting of wood for wood products (e.g. construction materials, furniture and packaging), paper and pulp products and bioenergy. Finally, fishing and hunting also consume natural biomass resources.
    - **Meat production:** Food production and consumption is resource intensive (BIO Intelligence Service 2012a). This is particularly true for the production of meat (Weidema, et al. 2008). As a means to provide protein, meat production is inefficient compared to protein from plant sources. Fish reared by aquaculture require 1.5 – 2 kg of feed to produce 1 kg of fish product, chickens require about 2-3 kg of feed to produce 1 kg of meat, whereas cattle can require up to 16 kg of feed to produce 1 kg of beef (Gold 2004). In the EU on average 1 kg of feed produces 30 grams of meat and 270 grams of milk (Westhoek, et al. 2011). Besides providing health benefits (Gold 2004), a reduction in meat consumption would lead to a significant decrease in biomass extraction, as about one third of global cropland is used for the production of feed (Wirsenius, Azar and Berndes 2010).
    - **Food waste:** Global food losses and waste are estimated at roughly 30%percent for cereals; 40–50% for root crops, fruits and vegetables; 20 percent for oil seeds; and 30%for fish (Gustavsson, et al. 2011). In the EU, about 89 Mt of food waste is generated each year across the food chain (BIO Intelligence Service 2010a). The largest fraction of food waste is generated by

private households in the EU – about 76 kg of food waste per person each year. About two thirds of this is thought to be avoidable (WRAP 2009).

  - **Overconsumption:** Based on the number of overweight and obese people, it seems that overconsumption in the form of excessive food energy intake is prevalent. Over 20% of the world population is either overweight or obese (Moomaw, et al. 2012). In the EU, 30-70% of adults are overweight and 10-30% are considered obese (DG for Health & Consumers 2010).
  - **Depletion of fish stocks**: Over 80% of fish populations are either fully fished (57% of stocks) or overfished (30% of stocks) (FAO 2012). Overfishing reduces the productivity of fish stocks and reduces the capacity of the oceans to provide for the future (Crilly and Esteban 2012).

- **Fossil fuels** are predominantly used to produce energy, e.g. electricity, heating and transport fuel. A small amount of fossil materials go towards non-energy uses, i.e. plastics and chemicals.
  - As fossil fuels are a finite resource and the greatest contributor to climate change, burning fossil fuels is generally not considered to be an environmentally efficient use (MacKay 2008). It is technically possible to phase out the use of fossil fuels for energy purposes and substitute them with renewable energy sources in a sustainable way (Greenpeace and EREC 2010)(WWF, Ecofys and OMA 2011). Even though this would increase biomass extraction, it has the potential to reduce overall environmental impacts. The inefficiency of fossil fuels is also discussed in the next section on energy.
  - While it might not be possible to substitute the use of fossil fuel for plastics and chemicals (GUA 2005), there is considerable scope to both reduce the consumption of plastics and chemicals as well as use alternative feedstocks (BIO IS, AEA and IEEP 2011).
- The majority of **metal ores** extracted and used are iron ores to produce iron and steel products (see Box 1 for more about iron and steel flows). Copper and bauxite (to produce aluminium) are the next largest group of metals used in the economy. Other metals are used in much smaller quantities, but some of them are extremely valuable (e.g. gold, platinum, etc.) or important for certain types of products (e.g. lithium, rare earths, etc.). Metals are used in a variety of products, such as vehicles, construction materials, industrial equipment, appliances and packaging.
  - Metals are inherently **recyclable** (UNEP 2011b). Therefore, it may be possible to reduce waste of metals significantly. In general, fewer resources are used to recycle metals than to extract them. Recycling rates vary considerably. Some metals such as lead, aluminium and iron and steel are commonly recycled, but they all still have significant potential for improved recycling. The majority of metals have recycling rates of below 50% (or are simply not recycled at all).
  - According to Allwood and Cullen (2012), it would technically be possible to reduce global metal production by 30% without loss of final service through **better design**. McKinsey (2011) estimates that steel demand in 2030 could be reduced by 13% even when taking into consideration the increased global demand for steel for products, transport, buildings and infrastructure.

Metal ores are a finite resource, but, as they are elements, the greater issue with the use of metals is resource dispersion rather than resource depletion. The main concern related to metal extraction is the **scarcity and supply security** of some types of metals (DG Enterprise and Industry 2010).

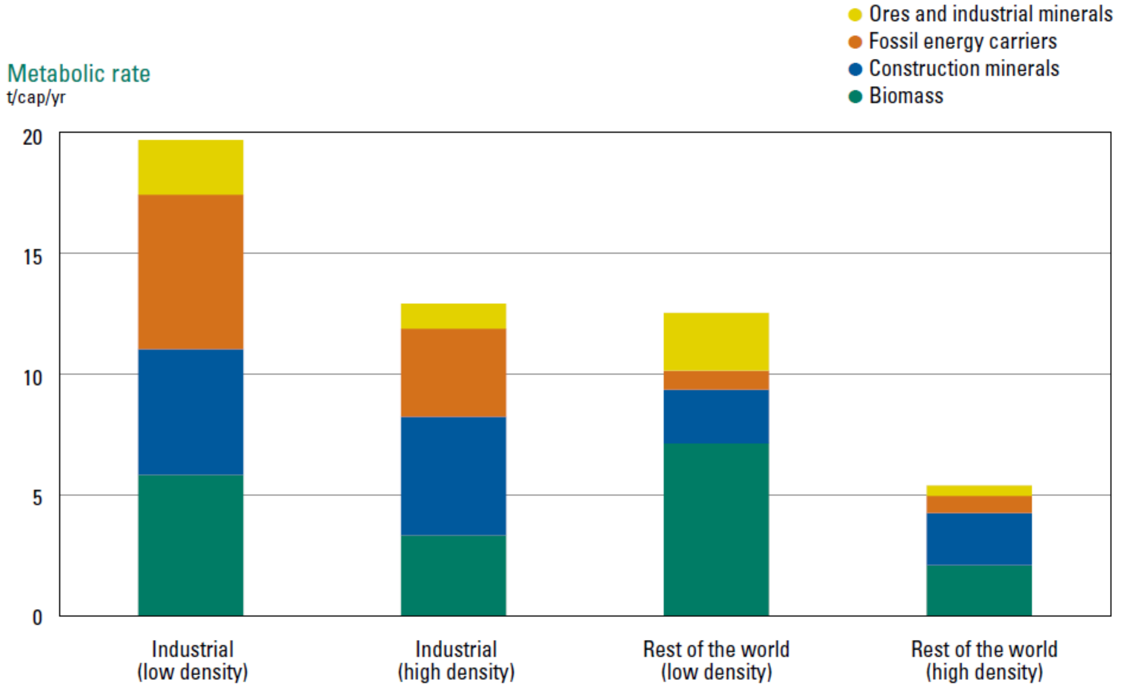
    - Box 2 provides the example of cobalt, which has been identified as a critical raw material.

- Most **minerals** extracted are used as construction materials (e.g. sand, gravel, marble, granite, etc.). Compared to the total amount of minerals extracted, a small amount of minerals have dedicated uses, such as quartz for the optical industry, feldspar for glass and ceramic manufacture, precious and semi-precious stones, phosphorus for fertilisers and salt for human consumption, use in the chemical industry and for salting icy roads.
    - While substantial quantities of construction materials are needed for efficient buildings and infrastructure (both new construction, and repair and maintenance), there is significant potential for using fewer mineral construction materials (Wuppertal Institute 2010). Reductions in construction mineral use could be achieved through **optimised construction standards, better design and production techniques**; for example, Allwood and Cullen (2012) mention that up to 40% less cement would be needed as a result of such approaches. Other studies suggest that modular homes can reduce waste by 70 to 90% through better material management, and houses can be made using on average 10% less material tonnage (WRAP 2007)(BRE 2009)(Barrett et Wiedmann 2004)(Bringezu and Bleischwitz 2009).
    - **Low density housing and buildings** represent an inefficient use of construction materials, as well as also land and energy use (UNEP 2012).
    - It is often cheaper to **demolish an existing building** and construct a new one in its place than to renovate it. Approximately two thirds of the material used during the construction and use phases could be saved when converting an existing building to new uses (Eco-Innovation Obervatory 2011).
    - There also seems to be substantial potential to increase **recycling of construction and demolition waste**. At present less than 50% of construction minerals are recycled (BIO IS, Arcadis and IEEP 2011), while certain Member States in the EU have shown that this rate could be as high as 90% (ETC/SCP 2011). Furthermore, while most recycled construction materials tend to be downcycled, i.e. used as lower grade materials that do not replace the use of virgin materials, there is great potential to also increase reuse and high quality recycling of building materials (US EPA 2009).

Less than 20% of the phosphorus extracted is actually taken up by crops and finally consumed by humans (Smit, et al. 2009). Losses occur throughout the life cycle of phosphorus use, but the main losses happen when phosphorus is applied as a fertiliser on fields (D. Cordell 2010). Besides the loss of a finite resource, this causes severe environmental impacts such as eutrophication (Schröder, Cordell, et al. 2010). For more on flows of phosphorus see Box 3.

One of the first clues to identifying inefficient use of resources is by comparing the material consumption of different countries. Although basic human needs such as food and shelter are thought to be the same throughout the world (UN World Commission on Environment and Development 1987), they manifest themselves materially in different ways. Two major factors determine the per capita material consumption: development status and population density (UNEP 2011a). Fully industrialised or developed countries have a higher material consumption than developing or emergent countries (see Figure 11), but it is not possible to say which is more resource efficient. Densely populated areas tend to require fewer resources per capita, particularly in terms of biomass, fossil fuels, and ores and industrial minerals, but this is probably due to the fact that agricultural production and industrial facilities are placed in sparsely populated areas.

Figure 11 Differences in material resource consumption per capita

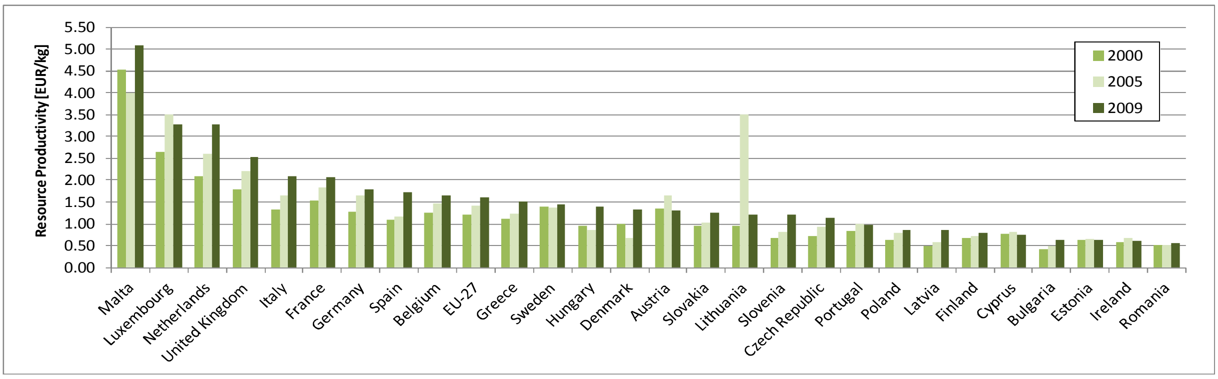


High-density means a population density of 50 people/km² or higher. Share in world population: 13% industrial, high density, 6% industrial, low density, 62% rest of the world, high density, 6% rest of the world, low density.
Source: Krausmann *et al.*, 2008

Source: (UNEP 2011a)

Even in developed countries, material productivity varies considerably. Material consumption and productivity depend on the structure of the economy and the main sectors. For example, countries with large trade and service sectors tend to have higher material productivity levels than countries that have a large agriculture, manufacturing or construction sector (see Figure 12).

Figure 12 Changes in material resource productivity in EU Member States



Source: (BIO Intelligence Service 2011b) based on Eurostat

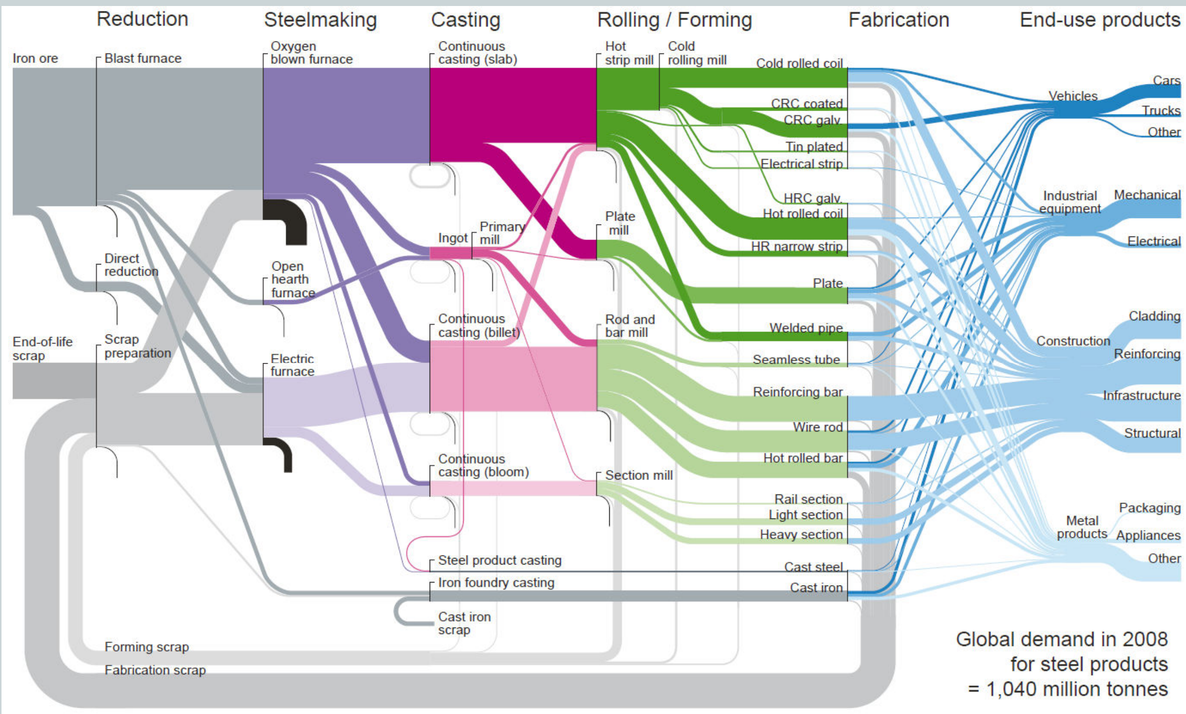
Across material resources on a product level, Scott et al. (2009) identified that the material requirement of packaging, structural metal products, buildings, electrical products, household goods such as furniture and transport vehicles could be reduced by 50% by 2050 by using best practices – and possibly even 75% (i.e. using only 25% of materials compared to products to day to deliver the same functionality. Furthermore Scott et al. (2009) also estimated that it could be possible to reduce consumption of clothes, household appliances, glassware, tableware, household utensils and equipment, vehicles, communication products, photo and information processing equipment and cultural and recreational durables by 40% by increasing the durability of products and extending their life spans.

Box 1 Iron and steel

Iron is the fourth most abundant element in the earth's crust (Yellishetty, Ranjith and Tharumarajah 2010) and the second most abundant metal. The iron content in the crust ranges from 2-3% in sedimentary rocks, to 8.5% in basalt and gabbro. Due to its relatively high availability, iron is in comparison to many other elements of low value and a deposit must generally contain at least 25% of iron to be considered economically recoverable. The most important use of iron is in steelmaking where the iron is processed and the properties, such as strength, tension, ductability and resistance, are optimized for different end-use sectors. Sectors where iron and steel are used the most include, among others, construction, automotive, packaging, and electric and electronic appliances ((Yellishetty, Ranjith and Tharumarajah 2010).

The raw material market of iron and steel comprises hundreds of billions of dollars per year. It is the second largest raw material market after oil. However, the extraction of iron ore and production of steel do also have disadvantages imposing considerable environmental consequences and high energy demand. The iron and steel industry, the mining of iron ore excluded, is responsible for over 10 percent of the global energy consumption and around 20% of the industrial waste emissions of the manufacturing sector (Allwood and Cullen 2012). The wide use of iron and steel in modern society, together with the industry's significant environmental impact makes the flows of iron and steel interesting to look into deeper. Iron and steel production involves a chain of complex processes and sub-processes and Figure 13 shows the flows on a global scale.

Figure 13 Global flows and uses of iron and steel



Source: (Allwood and Cullen 2012).

We have identified the following five main inefficiencies in the iron and steel processes:

- **Iron in tailings and residual flows as a result of iron ore production**. Approximately 1.84 million tonnes of iron was landfilled or put into storages close to the mining site in year 2010. Presumably, depending on the economic circumstances, the iron present in the old landfills can be subject to mining activities in the future. This is already a reality at some sites.
- **Iron present in blast oxygen furnace slag, secondary steel slag, and electric arc furnace slag**. Four million tonnes of slag from different steel processes was produced in year 2010. The slag is used in applications, such as in road construction, the iron content in the slags does not add any important properties to the applications and could consequently be regarded as unnecessary.
- **Iron and steel in construction and demolition waste not subject to recycling**. A large amount of C&D waste is disposed in landfills.
- **Iron and steel disposed in landfills**. Data on iron and steel present in end-of-life waste streams is limited but approximately 2.1 million tonnes was disposed on landfills.
- **Low collections rates for WEEE**. Current collection rates are in the majority of EU Member States far below the amount of goods sold many years ago.

For more information about iron and steel, see Annex B.

Box 2 Cobalt

Cobalt (Co) is a bluish-white, lustrous, hard and brittle metal. It has fairly low thermal and electrical conductivity, is ferromagnetic and chemically very active. Cobalt and its compounds are considered to be slightly toxic (British Environmental Agency 2011).

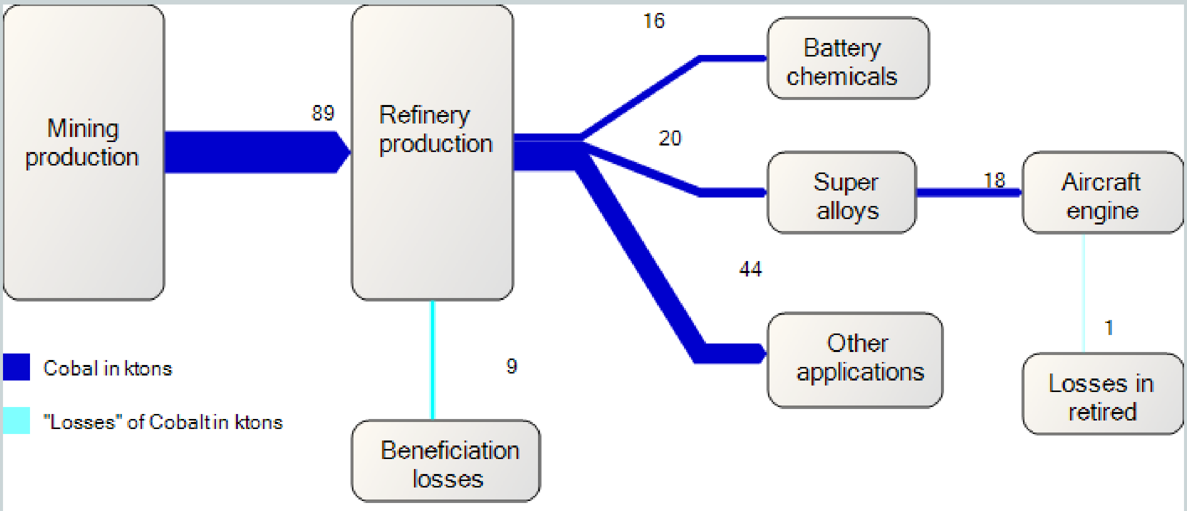
The extraction of cobalt has increased in recent years, partly driven by increasing demand from emerging technologies such as batteries for electric vehicles and other electric devices. At the same time, the discussion about resource supply and efficiency has increased in society, using terminology such as footprints and planetary boundaries (Rockström, et al. 2009). Several political incentives identify cobalt as a critical raw material for the future, both in Europe and worldwide.

The European Union names cobalt as one of 41 "critical raw materials" in a report from 2010, identifying materials of economic and strategic importance for the union (European Commission 2010) . It has relatively large economic importance, but the supply risk is not very high because of large resources and production capacity. The share of demand from emerging technologies in relation to production was 21% in 2006 and estimated to 43% for 2030 given the current level of production(European Commission 2010). Other economies have also identified cobalt as an important metal for the future. In December 2010, the U.S. Department of Energy (DOE) outlined its "Critical Materials Strategy". Cobalt is one of 14 elements defined as a critical metal to enable clean energy production over the next 5-15 years. The DOE sees cobalt as such a critical metal because of its use in lithium ion batteries, and predicts that each electric-powered vehicle (PHEVs and EVs) will demand 9.4 kg of cobalt. The rest of the list is dominated by rare-earth elements (Dove 2011). All this justifies a closer look at the efficiency of current cobalt use in society.

Cobalt is a by-product of copper and nickel metallurgy and 89 000 tonnes of cobalt were mined in 2010.

Figure 14 shows the flow chart of cobalt for the EU-27. The turquoise arrows are losses from the technological system.

Figure 14 Flows and uses of cobalt in the EU



We identified three main inefficiencies identified for cobalt:

- **Beneficiation losses**. Cobalt losses to tailings and slags can be roughly estimated to 9500 tonnes globally in 2010.
- **Alloys in scrap aircraft**. An aircraft engine can contain up to 1.5 metric tonnes of cobalt and in 2010 over 1100 metric tonnes of cobalt were found in retired aircrafts without being recycled.
- **Automotive battery**. The growing market for lithium ion batteries in electric vehicles indicates that this sector will be increasingly important for an efficient use of cobalt in the future. The current mandatory recycling rate of (only) 50% for automotive batteries in electric vehicles entered into force in late 2011.

A possible way to decrease the inefficiencies is to recycle more of aircraft and automotive batteries. In 2010, Aircraft Fleet Recycling Association (AFRA) treated around 150 aircrafts, recycling 70% of their materials (mainly frames and engines). The recyclability goal for 2016 is set to 90% (by weight). This goal is comparable to the regulated targets for vehicles, which are set to 85% reuse and recycling and 95% reuse and recovery (by weight) for the year 2015. However, the industry acceptance and participation in AFRA is promising, and will hopefully lead to a strong increase in aircraft recycling for the future.

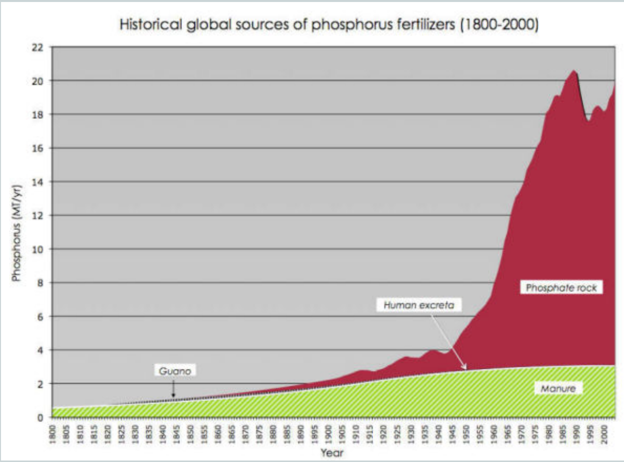
In Belgium, one of the large battery producers has established recycling plants to recover rechargeable batteries, such as Li-Ion and Li-Metal hydride from electric vehicles and other applications, using a pyrometallurgical process (Umicore 2013). After dismantling, the EV batteries are put through a smelter and granulated before going through a number of refining steps. The metals, including cobalt, are then shipped to Asia, where they are transformed into battery chemicals such as $Ni(OH)_2$ and $LiMeO_2$. Rare earths are treated separately, and slags are used as construction material. Total recycling efficiency of the process is not reported.

For more information about the production and inefficiency for cobalt see Annex B.

Box 3 Phosphorous

The use of phosphate rock as a fertilizer has since the end of the Second World War been the major source of phosphorus, in magnitudes larger than manure, guano and human excreta together, see Figure 15.

Figure 15 Historical global sources of phosphorus fertilizers

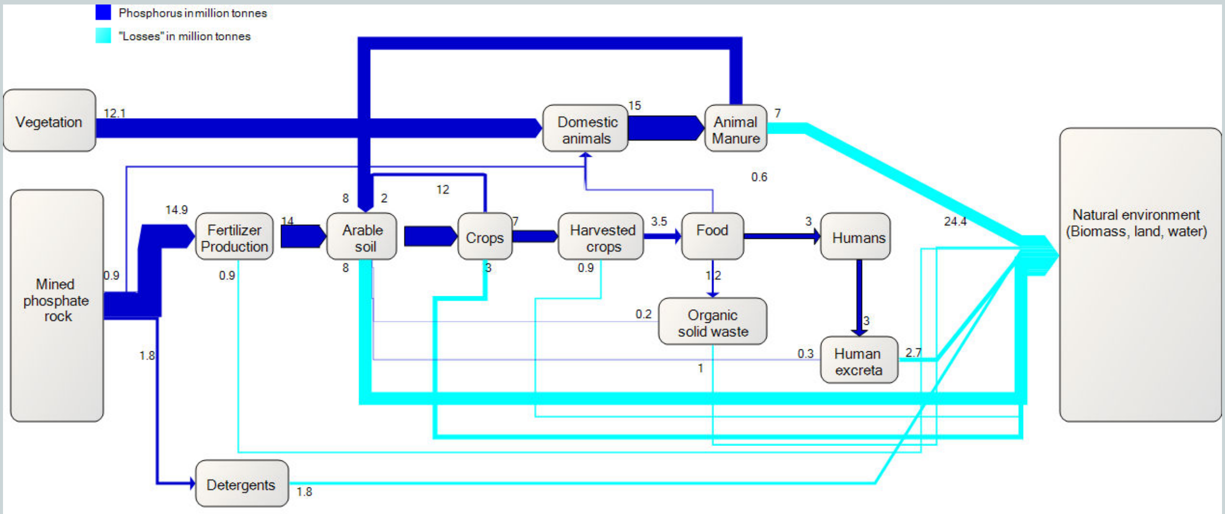


Source: (Cordell, 2010, p. 86)

The reserves of phosphorus are diminishing at a rapid rate and Peak phosphorus is likely to occur around 2035 (Cordell D 2009). The available phosphate rock reserves[5] for all countries but Morocco have been reduced significantly over the last years. There are significant uncertainties in the statistics on phosphorus resources, but among the top 20 countries listed in Jasinski (2012), which together cover more than 99% of available phosphorus, no European countries are listed. In 2050, it is most likely that all phosphate rock used in the EU will come from Morocco (D. Cordell 2010).

Globally the flows of phosphorus have been modelled by (D. Cordell 2010) as is redrawn in Figure 16. Inefficiencies where phosphorus is lost in some way are marked in turquoise. There are other inefficiencies which cannot be as clearly shown, excessive consumption of meat is one example. Roughly 80% of the phosphorus from phosphate rock never reaches the fork but is lost in different parts of the supply chain (Cordell D 2009) (Schröder, Cordell, et al. 2010).

Figure 16 Global phosphorus flows in 2000 [million tonnes]

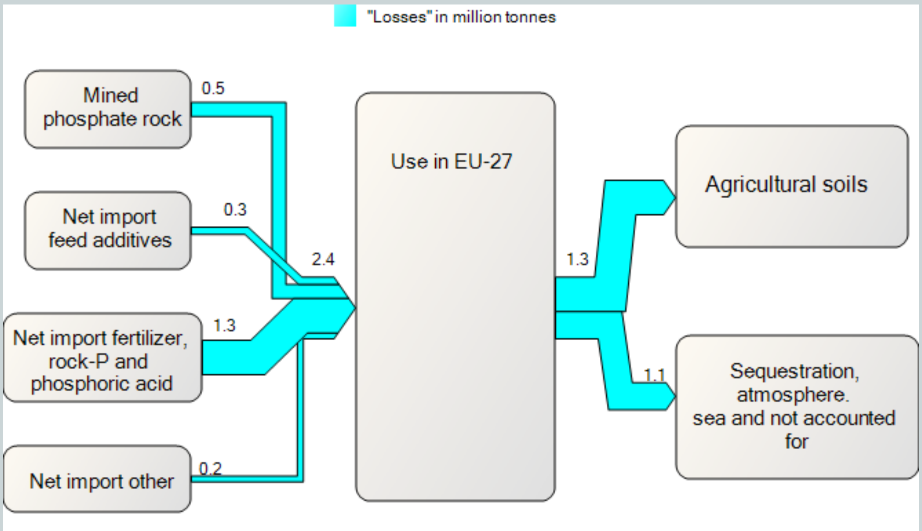


Source: (Cordell, 2010)

5 Note that it is phosphate rock reserves and not phosphorus reserves. Phosphorus content of phosphate rock is about 13% in average.

Richards and Dawson mapped phosphorus flows in EU-27 in 2008 (Richards and Dawson 2008) with large uncertainties. Uncertainties are mainly due to two factors: mapping flows in a limited region has the added complexity of imports and exports of products with embedded phosphorus, and the general lack of phosphorus statistics for EU-27. Major flows are shown in Figure 17[6].

Figure 17 EU-27 Phosphorus flows [million tonnes]



Source: based on (Richards and Dawson 2008)

Inefficiencies of phosphorus occur both in the European Union and globally and it is important to consider both the global and the EU P management practices since the EU is largely dependent on import of phosphorus.

We identified four main inefficiencies of phosphorus:

- **Meat and diets**. Meat production represents 65-70% of all dietary phosphorus use while providing a considerably lower part of the food consumed. If the global trend goes toward western diets, the phosphorus use would increase by 50%, while a reduction is possible if meat is substituted with other sources of protein.
- **Eutrophication and field leakage**. Lack of proper soil management with soil erosion and resulting leakage of nutrients are a major cause for eutrophication. Globally one third of all phosphorus put into soils is lost in this way
- **Lack of manure and humanure** (human excrements that is recycled for agricultural purposes). Globally there is a lack of reuse of manure in agriculture and almost half of the produced manure does not return to crop production, which in turn only provides one third of the phosphorus put into arable soils. In the EU-27, manure provides about two thirds of the phosphorus to soils which is higher but there is still potential for improvement. The reuse of human excreta from waste water treatment plants and untreated sewage are almost negligible both globally and within the EU.
- **Detergents**. Detergents represent 3% of the EU-27 phosphorus use and 6% globally. For laundry detergents phosphorus is not needed and it has been banned for consumer use in many countries. Bans on dishwasher detergents are less frequent but several brands offer phosphate free products (Maskindiskmedel 2008)

In the food sector, there are different ways to reduce the use of phosphorus. For instance, by having a

[6] Note: Figures are taken from (Schröder, Cordell, et al. 2010) since (Richards and Dawson 2008) was only available by regular post and did not arrive in time for this study.

meat free day every week, the need of phosphors can be reduced up to 9%. Another way to reduce the use of phosphorus is to decrease the food waste which has a reduction potential of 22%. A third way is to have proper fertilizer management. It can increase the efficiency of applied phosphorus to soils and would then decrease the P put into soils at 24 Mt globally and 3.3 Mt in the EU27.

Better integration of animal manure in crop production can substitute mined phosphorus and thus reduce total inputs. This is especially true for the United States of America which stores manure in lagoons, but according to Berg (2011). it would lead to reductions of up to 12% of phosphorus use in the EU as well.

Using human excreta as a fertilizer was previously natural and common but is today principally not done anywhere. Source separating toilets are however available and can deliver phosphorus rich urine for fields. There is also technology available for producing Struvite in WWTP's corresponding to 1.6% of annual mined phosphorus (Shu, et al. 2006). With technological improvement this figure can of course increase. Berg (2011) estimates a possible phosphorus reduction of 18% with efficient recycling of human excreta.

The European Union has from July 2013 banned phosphorus in laundry detergents for household use and preliminary banned phosphorus in dishwasher detergents for household use from 2017. Several Western European countries (Austria, Belgium, Germany, Ireland, Italy, Luxemburg, the Netherlands, Sweden) have successfully implemented such legislation.

For more information about phosphorus see Annex B.

4.1.1 Waste

A clear sign of inefficiency is waste[7]. Over 12 billion tonnes (of the 68 billion tonnes of all materials extracted globally and used in the economy) end up as waste (OECD 2011). In the EU more than 30% of all resources used end up as solid waste – and this does not take into consideration all the fossil and biofuels that end up as air emissions. From an economic point of view, waste may not always be considered to be inefficient, but when considering the environmental impacts and external costs associated, most forms of waste can be considered inefficient (Ellen MacArthur Foundation 2012).

As production and consumption increase with economic growth, there is a risk of increased waste as a result. For example, current data shows that municipal solid waste (MSW) generation and composition varies widely across countries as a function of affluence and economic development, and is generally greater in areas with higher levels of development and urbanization (World Bank 2012). Based on current population and growth trends, the World Bank predicts that global MSW generation levels will nearly double by 2025 (World Bank 2012).

However, there is potential for reducing waste and its impacts despite economic growth. For example, according to a 2011 study on waste prevention, average waste generation could decrease between 12 to 62 kg per capita in 2020 and total waste generation could decrease 6 to 32 million tonnes compared to the baseline (ARCADIS 2011). The study also posits that all production and end-of-life waste is preventable[8]. When it comes to industrial and commercial waste, Scott et al. (2009) estimated that 10% of this kind of waste in the economy is avoidable.

[7] Note that while waste streams may be considered inefficiencies under a general definition (e.g. wasteful use of resources), they are not necessarily economically inefficient. In general, it is unlikely to be economically efficient to eliminate all wastes.

[8] The study did not estimate what the costs would be to achieve this.

If it is not possible to prevent waste, there are still ways to substantially increase resource efficiency though preparing for reuse and refurbishing, recycling and energy recovery (e.g. anaerobic digestion and incineration with co-generation of heat and power). The EU's Waste Framework Directive and existing recycling, reuse and recovery targets demonstrate that the potential for increasing the resource efficiency related to waste is high (BiPRO 2012). For example, the EU has set reuse, recycling and/or recovery targets for a variety of waste streams, including MSW, construction and demolition (C&D) waste, packaging waste, WEEE, batteries and end-of-life vehicles. For MSW a minimum reuse and recycling target by 2015 has been set at 50%, while the target for C&D waste is at 70%.

Reducing waste would have a dual positive effect, by reducing resource demand and decreasing negative environmental impacts, such as GHG emissions or pollution. Waste prevention must be targeted by various actions throughout the life cycle phases, with the greatest impact coming from prevention measures taken higher up in the material chain (e.g. ecodesign) (ARCADIS 2011).

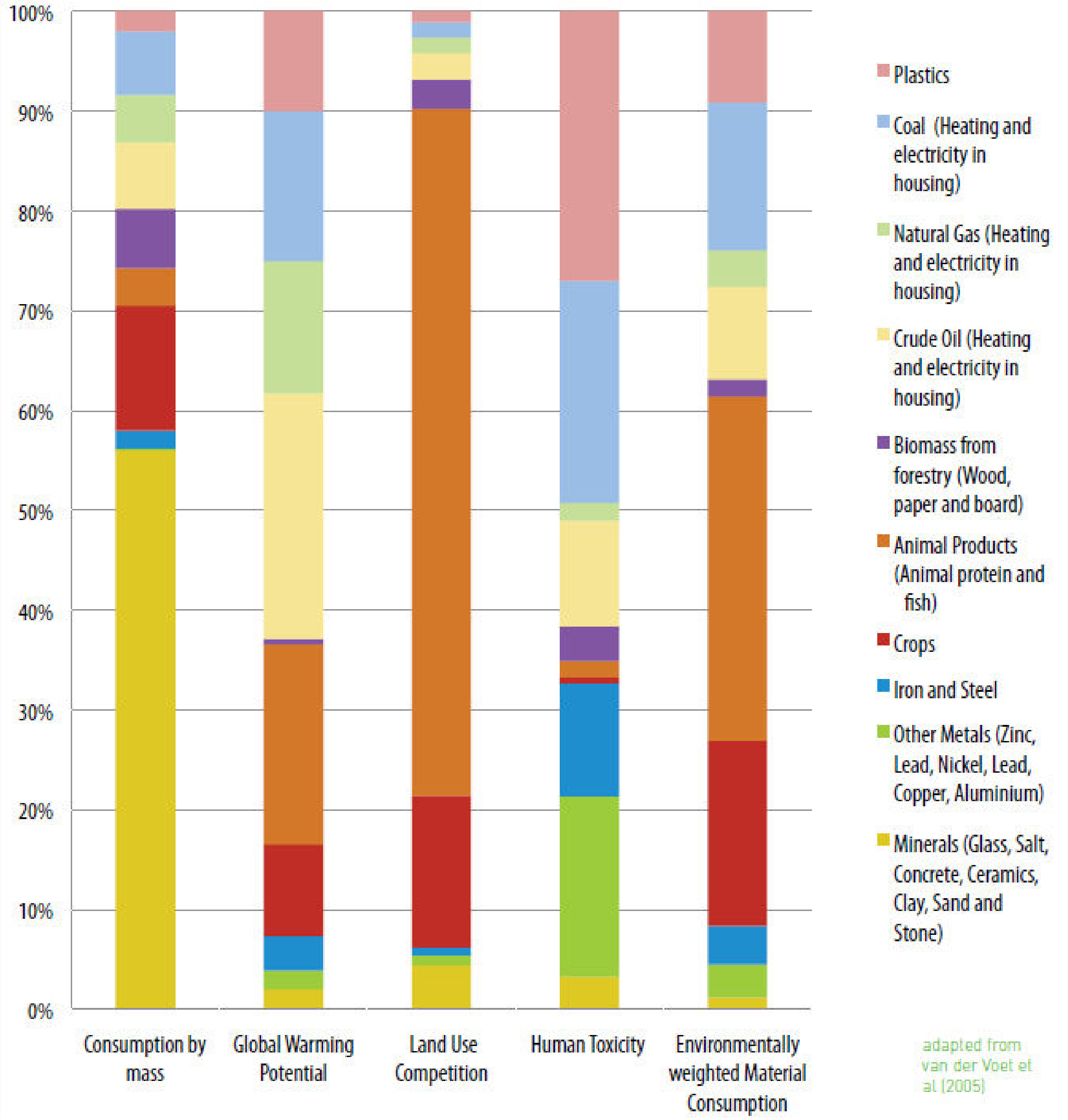
4.1.2 Environmental impacts of material consumption

The environmental impacts of material resources are very different depending on the type of material and the environmental impact category considered (UNEP 2010). For example, although minerals might represent more than half of the total EU consumption of materials (measured in weight), they contribute to less than 5% of any of the environmental impact categories. On the other hand, coal and animal products represent relatively high environmental impacts in relation to the amounts consumed (see Figure 18).

- In terms of greenhouse gas (GHG) emissions, fossil fuels, animal products, crops, metals and cement contribute most to global warming.
- Acidification is caused through the combustion of fuels (particularly those that contain sulphur) and emissions of ammonia from fertilisers and livestock (EEA 2013a).
- Ground (photochemical) ozone formation or smog is predominantly caused by volatile organic compounds (VOCs) from road vehicles and the use of organic solvents in paint.
- Eutrophication is typically caused by excessive use of fertilisers (e.g. nitrogen and phosphorus) in agriculture, but also from nitrogen oxides from combustion processes (EEA 2010a).
- Plastic and metals contribute the most to toxicity, but the combustion of coal and oil also lead to hazardous substances (UNEP 2010).

One strategy for improving eco-efficiency is by substituting materials with high environmental impacts with materials that cause less harm to the environment, e.g. using bioenergy instead of fossil fuels (UNEP 2009), vegetable protein instead of animal protein (Westhoek, et al. 2011) and biomaterials instead of metals and cement (Allwood and Cullen 2012). If it is not possible to substitute materials, there is often still scope for improving the processes where resources are used, e.g. more sustainable fishing practices (Crilly and Esteban 2012), resource efficient production (Greenovate! Europe 2012) or reuse and recycling instead of landfilling (Ellen MacArthur Foundation 2012).

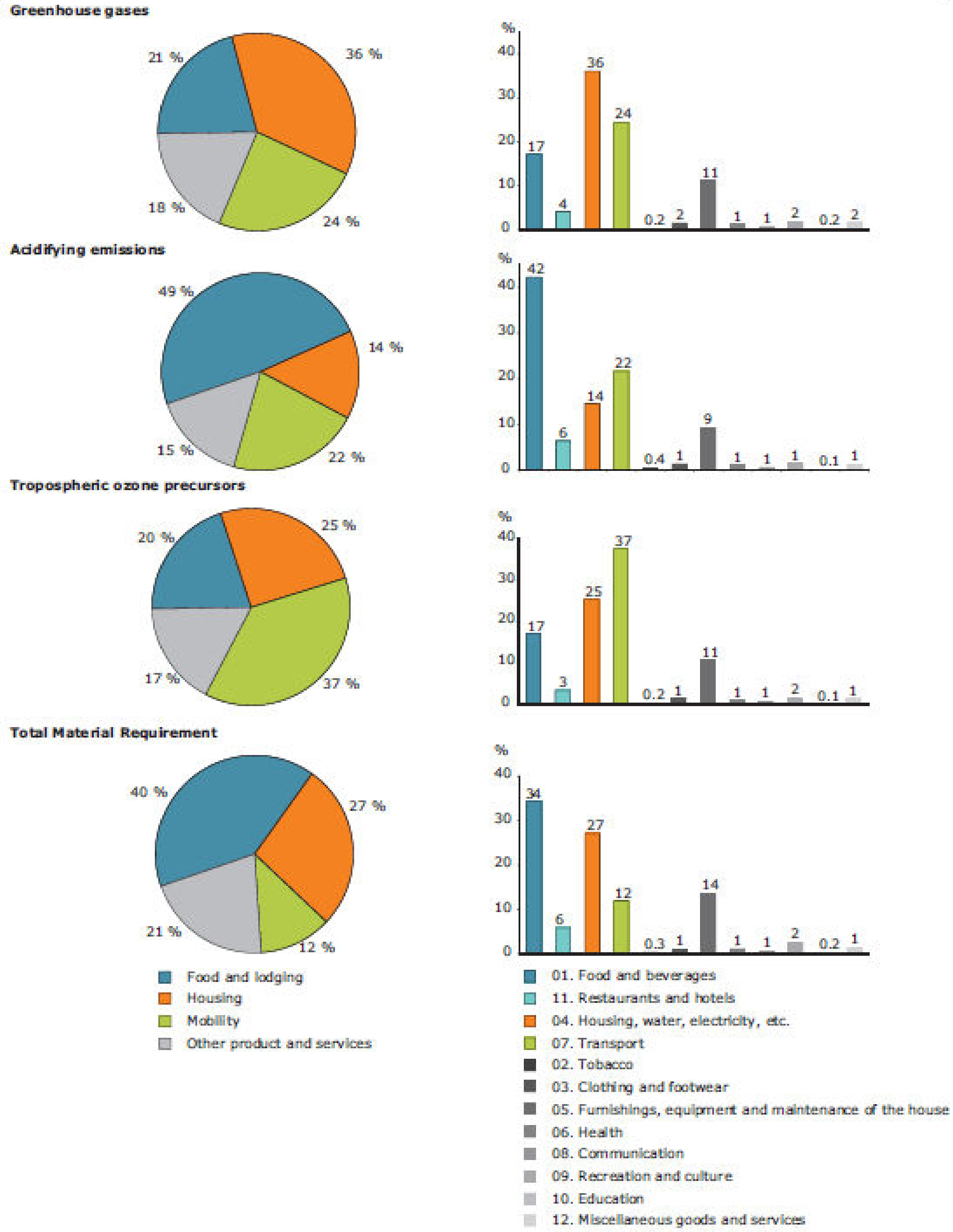
Figure 18 The total environmental impacts of different material resources in the EU and Turkey



Source: (UNEP 2010)

In terms of areas of production and consumption, the sectors that represent the largest environmental pressures are food, transport and buildings (see Figure 19). The greatest flows of materials in food are crops and animal products, but also significant amounts of packaging (paper and board, plastic, glass, wood and metal). In transport, fossil fuels represent the greatest use of resources, but large amounts of metals are also used to produce vehicles. Buildings and infrastructure require large amounts of metals and construction minerals, but also consume significant amounts of energy for heating and electricity use.

Figure 19 Three areas of consumption cause the majority of total environmental pressures



Note: The results for DMI look very similar to TMR and are not reproduced here.

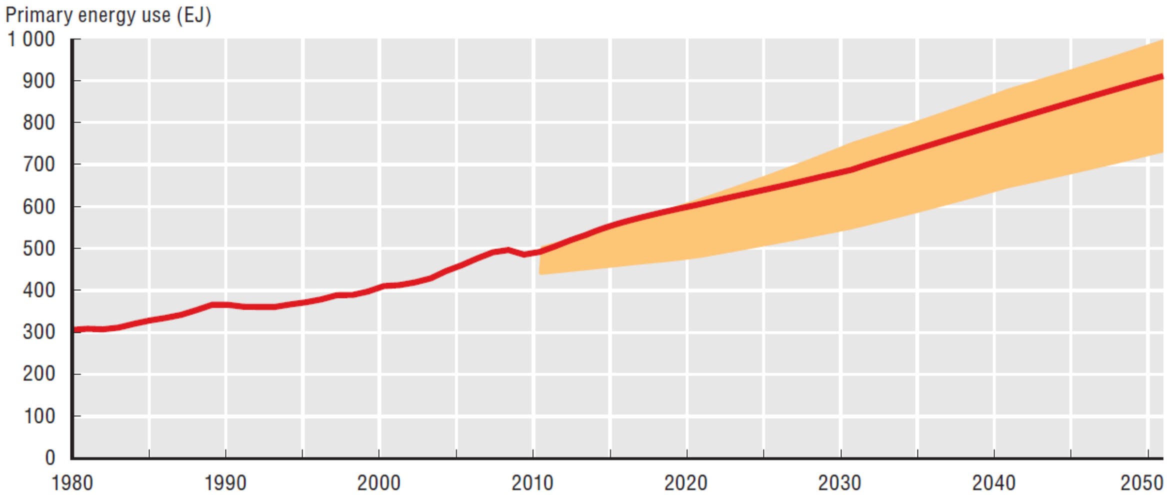
Source: (EEA 2013a)

4.2 Energy

Energy is one of the world's key resources, and faces high demand across a variety of sectors. Energy demand is set to continue increasing to accompany economic growth. For example, the IEA New Policies scenario predicts that global energy demand will increase by over one-third by 2035, and the OECD estimates that it may almost double by 2050 (see Figure 20).

In recent years, all major energy-consuming countries have introduced new legislation to promote energy efficiency (IEA 2012a) and many countries are exploring the potential for a shift towards cleaner and renewable energy sources. For instance, the EU has developed the 20-20-20 targets (20% reduction of GHG emissions, 20% reduction of energy consumption and 20% renewable energy by 2020) to transition towards an increasingly energy-efficient and low carbon economy.

Figure 20 Global primary energy use: baseline, 1980-2050



Notes: A widely accepted method for the accounting of primary energy use from different energy sources does not exist. Here, the methodology proposed by the IEA is used, which assumes a 33% efficiency for nuclear power and 100% for renewable power. Alternative methods may lead to slightly different contributions of nuclear power and renewables to the energy mix. The shaded area indicates the 10-90th percentile literature range.

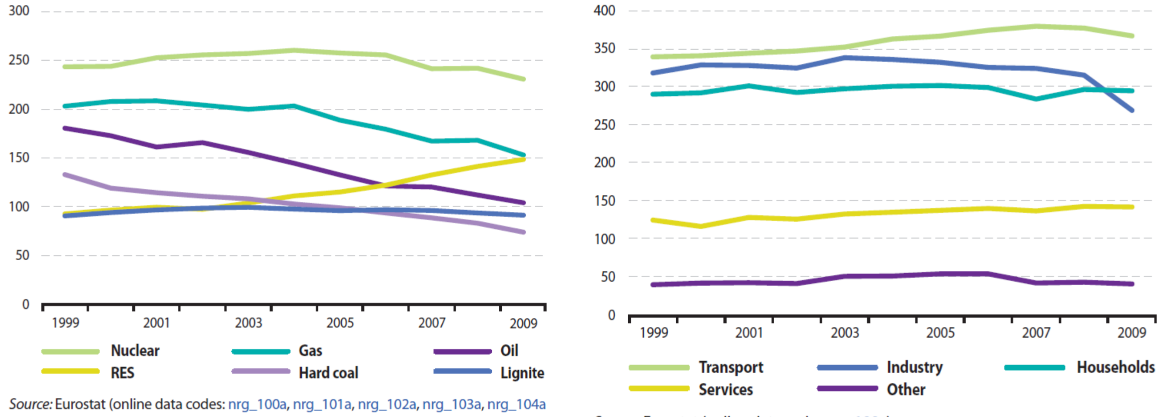
Source: OECD Environmental Outlook Baseline; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932570259

Source: (OECD 2012)

Nonetheless, inefficient energy use persists, particularly in certain heavily energy-consumptive sectors, such as buildings (representing about 41% of total energy consumption in the EU, between households and services), transport (about 32%) and industry (about 25%) (ADEME 2012). While the industry and buildings sectors consume a mix made mostly of electricity, coal, natural gas, and biomass, the transportation sector is mainly fuelled by oil products. Energy for transport will increase as the number of passenger cars doubles to 1.7 billion and demand for road freight rises quickly – especially because fuel-economy standards for trucks are much less widely adopted than for personal cars (IEA 2012a).

Figure 21 Primary energy production in the EU-27 by fuel (in Mtoe, left) and final energy consumption by sector (in Mtoe, right) in the EU-27



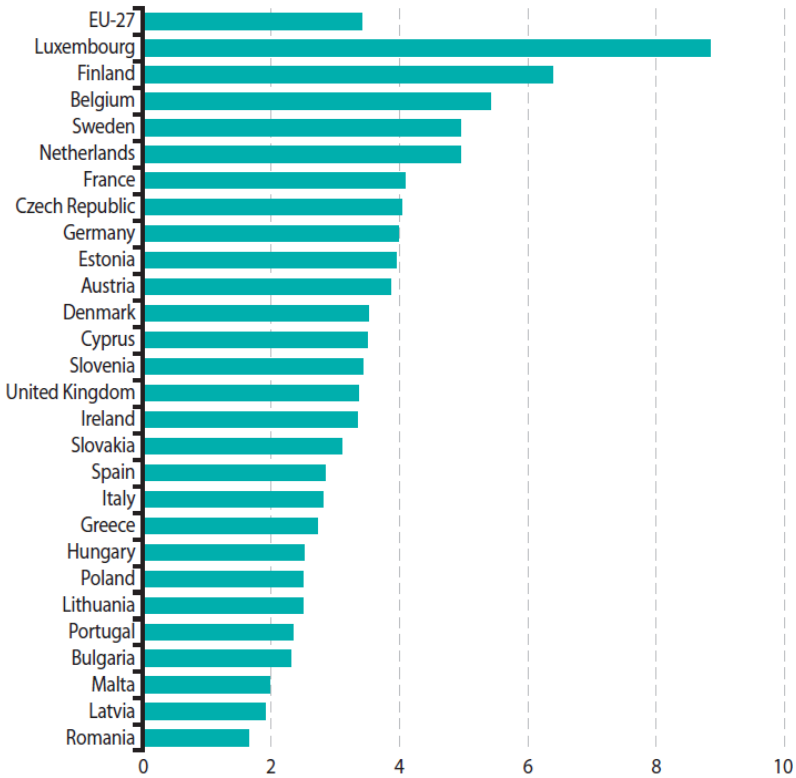
Source: Eurostat (online data codes: nrg_100a, nrg_101a, nrg_102a, nrg_103a, nrg_104a and nrg_1071a)

Source: Eurostat (online data code: nrg_100a)

Source: (Eurostat 2011)

According to the World Bank, per-capita energy consumption varies widely by country, with developing nations generally consuming less energy than developed nations. Variation exists even across developed nations, as can be seen in Figure 22 below. There are several factors influencing energy consumption across the EU countries, e.g. differences in industry structure, or differences in climates and building standards affect energy use for heating.

Figure 22 Per capita gross inland consumption in 2009 in EU Member States (tonnes of oil equivalent (toe) per capita)



Source: Eurostat (online data codes: nrg_100a and demo_pjan)

Source: (Eurostat 2011)

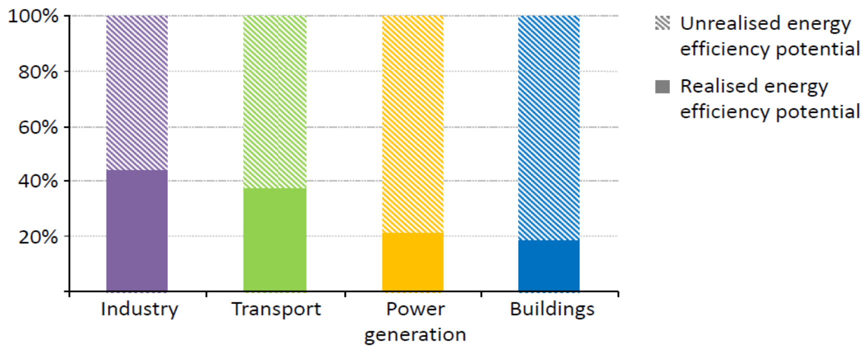
4.2.1 Energy efficiency potential

More than half of the electricity in the EU is produced by thermal power stations (Eurostat 2011). The average thermal efficiency of the power stations was 49.5% in 2009. There is significant potential to increase efficiency as the most efficient power stations in the EU are able to achieve thermal efficiencies over 80%. Besides electricity production, losses also occur in transmission (between 1.0% and 2.6%) and distribution (between 2.3% and 11.8%) networks (Ecofys 2013), but the greatest losses occur in transformers. The European Commission's Joint Research Centre estimated that as much as 40% of losses could be reduced through optimization of the electricity transmission and distribution (JRC 2012).

For the three main energy consuming sectors, significant potential exists for energy savings via greater efficiency. For example, the IEA's New Policies Scenario, which assumes a certain level of implementation of national efficiency policies which have recently been adopted or are under development, would result in annual improvements in energy intensity of 1.8% over 2010-2035. A McKinsey analysis estimates that productivity improvement opportunities could reduce the demand for global primary energy demand by 22% by 2030 (McKinsey Global Institute 2011).

According to the IEA, the key energy-consumptive sectors all have substantial unrealised energy efficiency potential in a baseline scenario (IEA 2012a), which are illustrated in Figure 23. In particular, it is estimated that two-thirds of the economic potential to improve energy efficiency remains untapped in the period to 2035. Buildings and transport are the two sectors with the most important saving potentials on the consumption side. The potential savings in the industry sectors are also linked to considerations of material efficiency in the manufacturing processes.

Figure 23 Energy efficiency potential used by sector in an IEA scenario



Source: (IEA 2012a)

McKinsey's analysis of resource productivity potential (McKinsey Global Institute 2011) is in line with the fact that buildings and transport represent some of the main area of energy consumption inefficiency, and identifies specific areas of savings potential within these two sectors. The most important opportunities for global energy savings identified are: building energy efficiency (696 US$ billion), urban densification (155 US $ billion), iron and steel energy efficiency (145 US $ billion), transport efficiency (138 US $ billion), electric and hybrid vehicles (138 US $ billion) and road freight shift (108 US $ billion)[9].

In the EU, estimates of the potential for efficiency to reduce energy demand by 2050 are about 30 – 40% (Greenpeace and EREC 2010). The most important energy saving options are improved heat insulation and building design, super efficient equipment, replacement of old style electrical heating systems by renewable heat production (such as solar collectors) and a reduction in energy consumption by vehicles used for goods and passenger traffic. These estimates are based on their feasibility without loss of comfort or level of service.

4.2.2 Renewable energy sources

Increased deployment of renewable energy sources, particularly in energy-intensive sectors, can be a key contributor to more efficient energy use. In Europe, the *Roadmap for moving to a competitive low-carbon economy in 2050* (European Commission 2011) includes a significant shift away from fossil fuels and towards renewable energy sources as an essential component of its transition towards a low-carbon economy. Opinions differ, however, on the potential share of renewables in the energy mix. On the more ambitious end, Greenpeace and the European Renewable Energy Council (2010) suggest a scenario in which, by 2050, 97% of EU-27 electricity generation and 92% of its final energy demand are covered by renewable sources. The Impact Assessment to the *Roadmap for moving to a competitive low-carbon economy in 2050* (European Commission 2011) notes, however, that business associations tend to set less ambitious targets for final energy consumption, and when it comes to electricity generation, the European Climate Foundation found that an 80% renewable share by 2050 would be feasible without significantly increasing prices.

Increasing the share of renewable energy sources in the energy mix will help decrease demand for traditional fossil fuels, although it may increase the use of other resources, such as biomass, land and water (UNEP 2009). However, given the renewable nature of these resources, as well as their potential lower environmental impacts in areas such as GHG emissions, substitution of fossil fuels for renewable sources could represent an overall improvement in resource efficiency.

4.2.3 Greenhouse gas emissions

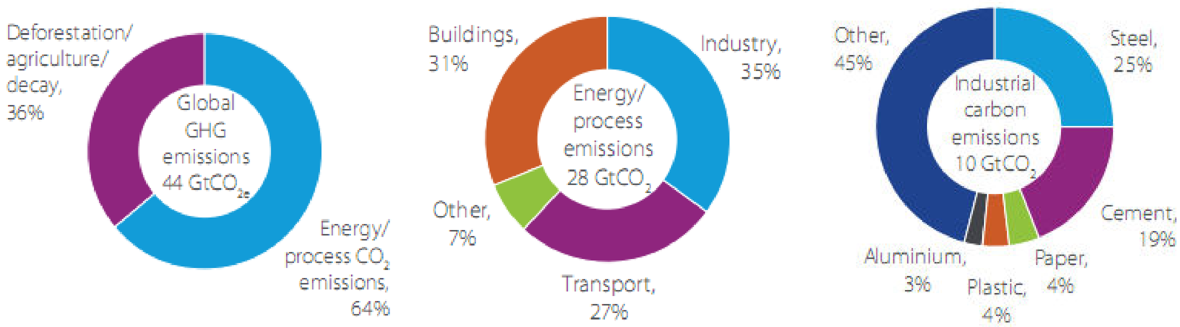
Global GHG emissions are high and on the rise. According to the IPCC, the greatest contributors to GHG emissions are the energy supply sector, industry, the agricultural sector and deforestation (IPCC 2007). In order to contain global warming within 2°C above pre-industrial times, all countries, particularly developed nations, need to participate in GHG emissions reduction, for which there is significant potential.

The trends for the GHG emissions are very similar to the ones previously presented for energy consumption(OECD 2012). The IEA has identified that end-use efficiencies in buildings, industry and transport have the largest potential for CO_2 emission abatements, but improving the efficiency of power plants and increasing the share of renewable energies could also reduce emissions (IEA 2012a). Within specific industry sectors, the chemicals and petrochemical industries, iron and steel industry and the cement industry have the greatest

[9] The analysis is based on a large number of assumptions. Furthermore, it should be noted that the size and cost efficiency of opportunities are highly dependent on the future evolution of resource prices.

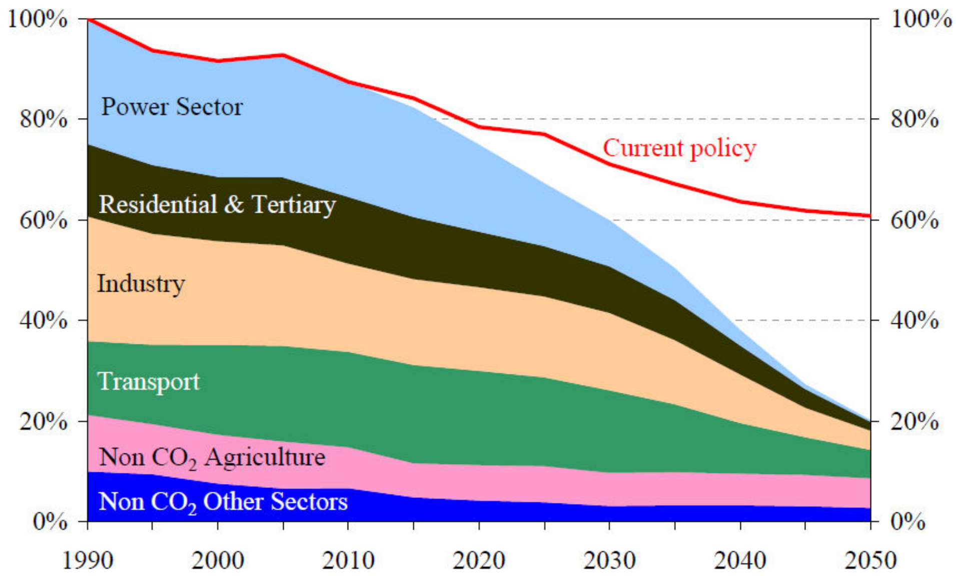
potential for reducing GHG emissions through energy efficiency and best available technologies (IEA 2013). Regarding the industry shares, the production of just five materials results in 55% of all industrial emissions (Allwood and Cullen 2012), with steel and cement, widely used in the construction sectors (including transport infrastructures) making the most important contributions (Figure 24). It should be noted that while energy consumption and CO_2 can in most cases be considered as closely related, this is not the case for cement manufacturing, where half of the CO_2 emissions result from a chemical reaction.

Figure 24 Sources of global CO_2 emissions (Allwood and Cullen 2012)



To tackle climate change, the EU has passed legislation to reduce GHG emissions to 20% below 1990 levels by 2020, and the *Roadmap for moving to a competitive low-carbon economy in 2050* (European Commission 2011) sets out a pathway for achieving cuts of 80% below 1990 levels by 2050 (see Figure 25). For industry, the Roadmap sets a target of 83 to 87% below 1990 levels by 2050, 88 to 91% for the residential and services sector and 54 to 67% for transport.

Figure 25 The EU roadmap to reducing domestic GHG emissions by 80% by 2050 (compared with 1990)



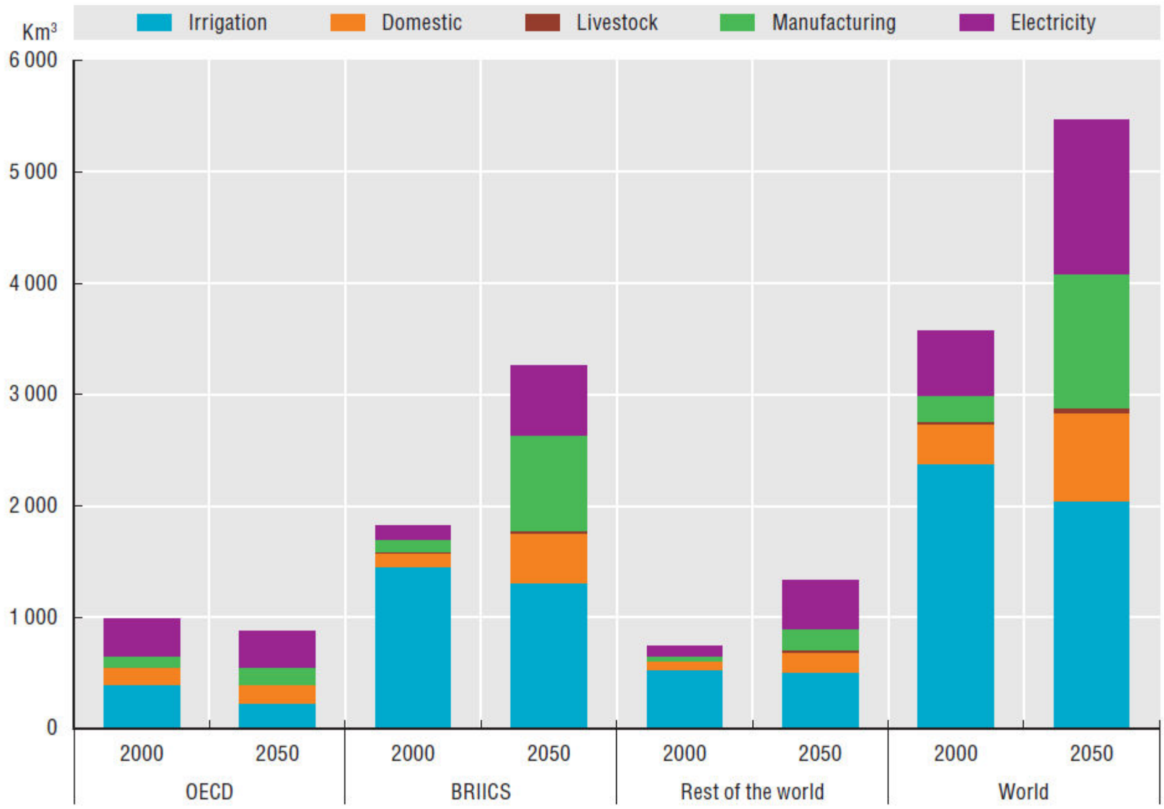
Source: (European Commission 2011)

Although there is significant potential to reduce GHG emissions in industry, there is greater potential for consumption to address inefficiency than production (Scott, et al. 2009). Energy use in residential buildings represents approximately 25% of end-use GHG emissions from energy use in EU-27 in 2009, around half of which come directly from fuel burning and the other half indirectly from electricity and district heating (EEA 2011). Behavioural changes can have a considerable impact on GHG emissions reduction. A recent study for the European Commission identified 36 behavioural changes that would help cut emissions, of which 11 were assessed for reduction potential (Faber, et al. 2012). At maximum realistic implementation, the total reduction potential of the 11 behavioural changes reaches about 600 Mt CO_2 in 2020, or about a quarter of projected emissions not covered by the EU Emissions Trading Scheme (ETS). Some of the greatest reduction potential was found in the food sector.

4.3 Water

Water is a prerequisite for all life. In addition to meeting demand for clean drinking water, water is used in agriculture for growing crops and rearing animals, as a cooling medium for energy production, for cleaning and washing, etc. Water is in this way linked with the use of other resources, such as biomass and energy production, as well as many economic activities. Water demand is expected to increase with growing population and demand for food, energy, products and services (see Figure 26).

Figure 26 Global water demand



Notes: This graph only measures "blue water" demand (see Box 5.1) and does not consider rainfed agriculture.
Source: *OECD Environmental Outlook Baseline*; output from IMAGE.
StatLink http://dx.doi.org/10.1787/888932571171

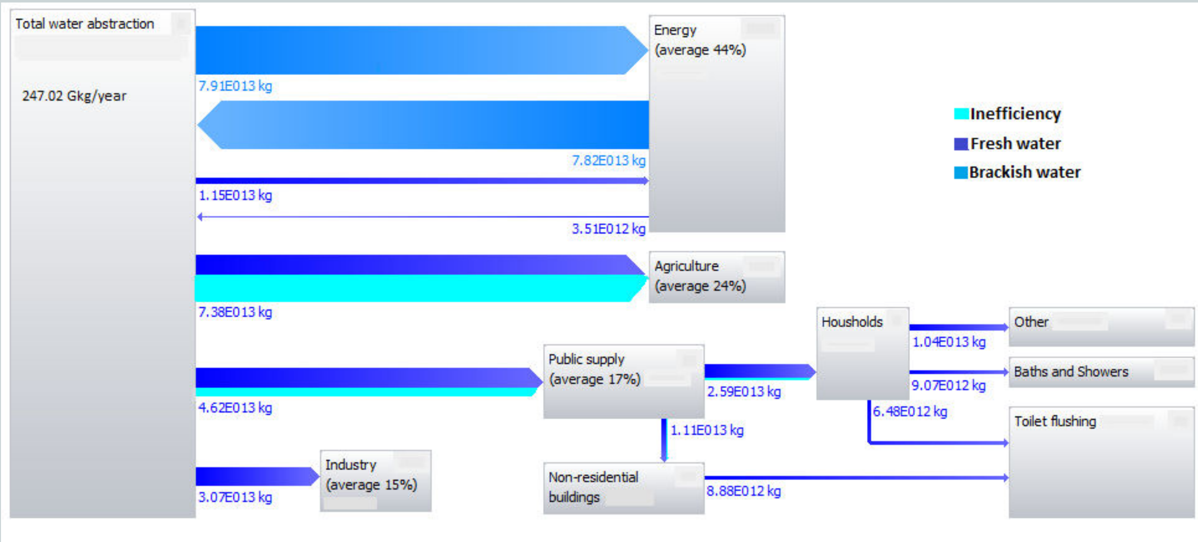
Source: (OECD 2012)

The total water abstraction in EU-27 is on average 247 020 million m^3 per year (Dworak, et al. 2007). Usage of this water can be divided into four main sectors; energy, agriculture, public sector and industry (see Box 4).

Box 4 Water flow analysis in the EU

The energy sector appears to be the largest water user. Here water is mainly used for cooling purposes in thermoelectric power plants. However, most of the water is brackish, (light blue arrows in Figure 27), and almost all of this water is normally returned to the local environment (Dworak, et al. 2007).

Figure 27 Sectoral use of water in Europe (EU-27), the flowchart doesn't illustrate losses



Source: (Dworak, et al. 2007)

After energy, agriculture and the public sector are the largest consumers of freshwater in Europe. For the public sector, abstracted water first passes a treatment plant system before it is distributed to consumers. It is then discharged to the wastewater treatment plant, from which it is returned to the recipient. In agriculture, on the other hand, most of the water abstracted is consumed by evapotranspiration or bound in the plant; therefore 70% of the abstracted water is not returned to a recipient (EEA 2012b)

Water withdrawal differs from country to country. For instance, in Sweden the largest volume is used in industry, whereas in Greece it is primarily for agriculture (Dworak, et al. 2007). Finland, France, Germany, Sweden, Spain and Italy are the largest consumers of water for industrial purposes. Finland and Sweden use 71% and 42%, respectively, of their total industrial consumption in the pulp and paper industry. The water consumption in the chemical sector is largest in Germany and Italy, where it constitutes 38% and 36%, respectively, of domestic industrial water consumption.

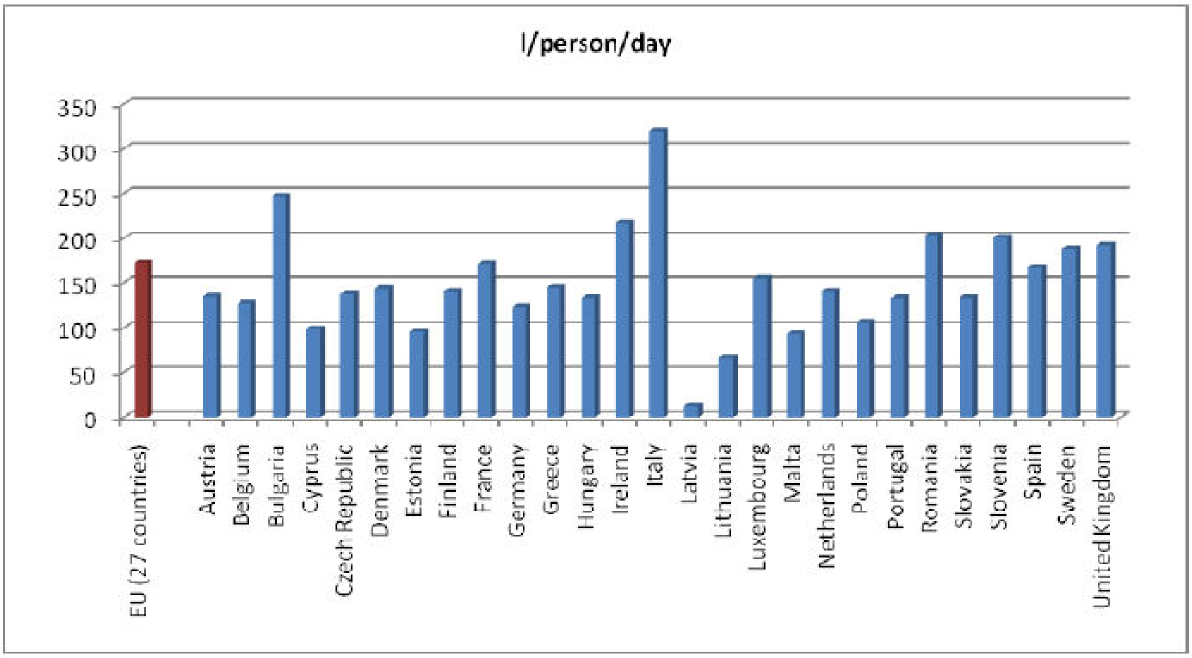
In the last 30 years water abstraction has decreased in industrialized countries due to closures in water-intensive industries and introduction of cleaning technology. In Central and Eastern Europe water abstraction has decreased by 70%. However, in some industries water abstraction has increased due to higher demand of better-quality products, which require greater amounts of water. This has been shown in the textile, paper and chemical industries, in Denmark, Ireland and the UK.

One of the largest pressures on water resources in the EU is agriculture, which accounts for approximately 33% of total water use in EU (EEA 2012b). Within this sector, irrigation is the largest water consumer, whereas livestock farming and aquaculture (e.g. fish-farming) are considered marginal (Dworak, et al. 2007). The southern parts of Europe are the main consumers of water for agricultural purposes, with nearly all of this water used for irrigation (EEA 2012b). About 85% of the total irrigated area in EU is situated mainly in Greece, France, Italy, Spain and Portugal. These countries also experiences some of the most significant levels of water stress (Kinner, et al. 1999).

The need for irrigation is basically the difference between the total water requirement of plants and the effective rainfall (Dworak, et al. 2007). The amount of water used for irrigation depends on different factors, such as: crop type, climate, soil characteristics, cultivation practices and methods of application(Kinner, et al. 1999) (Agriculture and rural development 2012)

Figure 28 presents the residential water usage per person per day in EU Member States (Ecotapware 2011). This amount varies, of course, by living standards, age, environmental education, etc. (Dworak, et al. 2007), and some differences can probably be explained by statistical inconsistencies. The high consumption in Italy, according to BIO Intelligence Service (2012b), can partly be explained by the low price elasticity of water demand.

Figure 28 Residential water use in EU-27

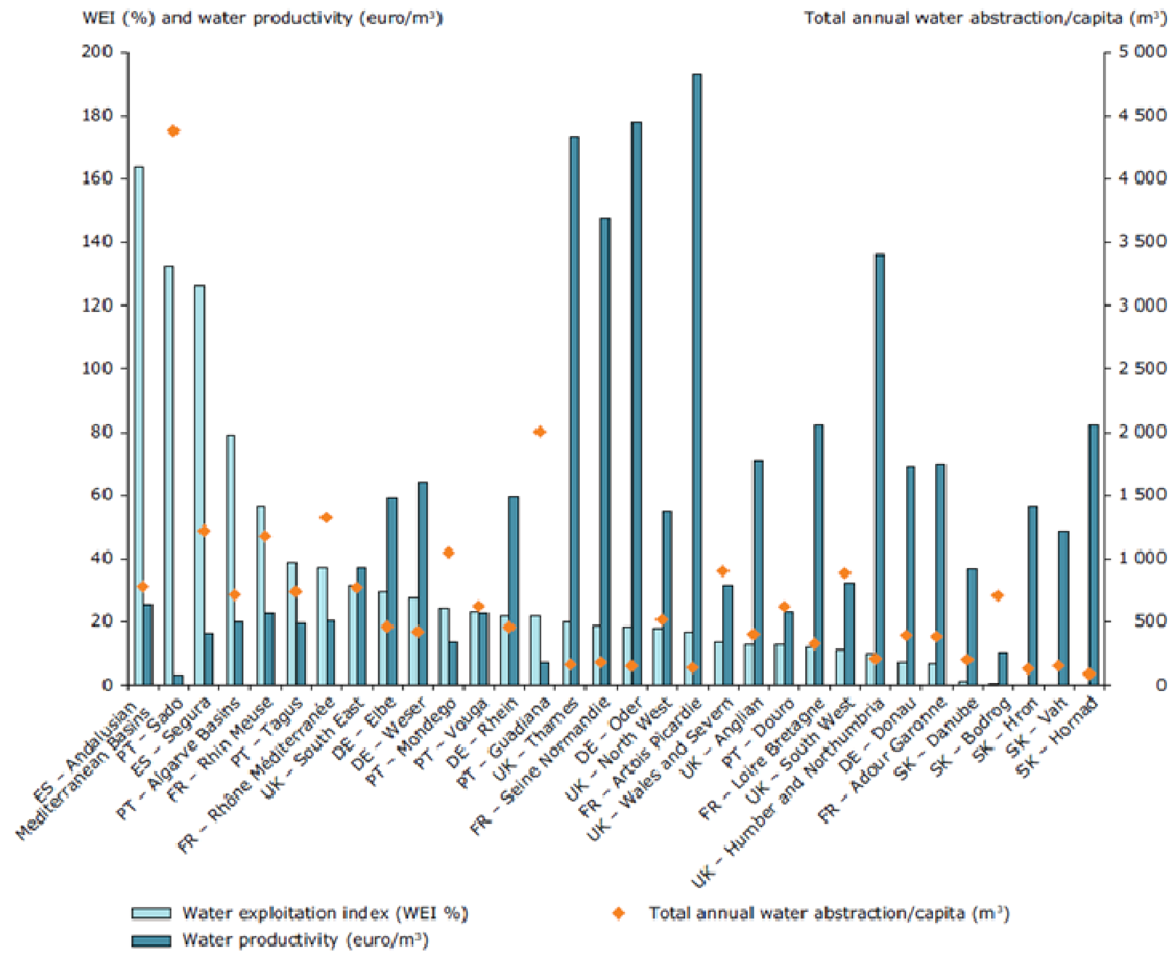


Source: (Ecotapware 2011)

Although freshwater is a renewable resource, if water is abstracted at a faster rate than the available resources are replenished, then water scarcity can easily occur in many locations at different times of the year (EEA 2012). The pressure on freshwater resources in a country can be measured by the water exploitation index (WEI), which is the annual ratio of total freshwater withdrawal to the total renewable resources. A number over 20% indicates that water resources are under stress, and, above 40%, severe water stress (McGlade and Werner 2012).

There are considerable differences in the per-inhabitant amounts of freshwater abstracted and productivity within each of the EU Member States (Figure 29), in part reflecting the resources available, but also abstraction practices depending on climate as well as on the industrial and agricultural structure of the country.

Figure 29 Water abstraction per capita, water productivity and water exploitation index (water stress)



Source: ETC/ICM. The water exploitation index was calculated by the EEA (2009) based on data submitted to the European Commission. Total annual water abstraction per capita was calculated based on the same data, while GDP data (current euro) are from Eurostat.

Source: (EEA 2012b)

According to McKinsey (2011), productivity improvements could reduce the demand for global freshwater by 18-21%. The main inefficiencies in water use are:

- **Ineffective irrigation technology.** Significant losses (evaporation and leakages) can occur in irrigation between abstraction and field application. Table 2 presents the differences in efficiency of different irrigation methods. Improvement in conveyance efficiency for the irrigation method alone is estimated to save up to 25% of water in Europe. Estimates show that savings of up to 43% in total can be made in the agricultural sector via measures such as making the irrigation technology more efficient, shifting to drought resistant crops, reusing wastewater and changing agricultural practices (EEA 2012b).

Table 2 Water efficiency of the different irrigation methods

Distribution and irrigation system	Water conveyance efficiency	Field application efficiency	Global gross efficiency
Open channel main network + furrow etc.	70%	55%	39%
Pressurized + Sprinkler	90%	75%	68%
Pressurized + Drip	90%	90%	81%

Source: (Dworak et al. 2007, 45)

- **Evaporation in cooling systems.** Significant differences can be observed in water withdrawals of different cooling systems used in the production of energy. The type of system used is largely dependent on the location of the power plant. It is difficult to find obvious measures for the energy sector; however, some examples given in literature are: utilizing water with low quality, reusing and recycling cooling water and changing to other coolants. Table 3 shows water withdrawal and water consumption for different cooling systems. Clearly, pond cooling and cooling towers have high percentages of water consumption. The distribution is the same for other fuels like nuclear and natural gas (Dworak et al. 2007).

Table 3 Water withdrawal and water consumption for different cooling systems

Plant and cooling system type	Water withdrawal [l/MWh]	Typical water consumption [l/MWh]	Water consumption as % of withdrawal
Fossil/biomass/waste-fuelled steam, once-through	75 800 – 189 500	1 137	1%
Fossil/biomass/waste-fuelled steam, pond cooling	1 137 – 2 274	1 137 – 1 819	87%
Fossil/biomass/waste-fuels steam, cooling towers	1 895 – 2 274	1 819	87%

Source: (Dworak et al. 2007)

- **Leakage in the public supply system.** The leakage in the public supply system varies between 2% in France to 61% in Bulgaria and the average for EU-27 is 21% (Pöyry 2012). The large variation between the Member States is due to the differences in technical performance of the supply system networks, but could also be due to the incorrect estimates due to lacking data and assumptions made. However, it is clear that leakages in the network system are of great importance for an efficient water supply.
- **Inefficient water-using devices in buildings.** The majority of water use (70 - 95%) in buildings is for showers, baths, toilets and household appliances such as washing machines and dishwashers (BIO Intelligence Service 2012b). The efficiency of households technology differs between EU Member States. For example, a shower in Finland may use 3.75 times more water per shower than one in France (Ecotapware

2011). Installation of water-saving technologies can help reduce water consumption for toilets, showers and baths. For instance, water savings of up to 70% can be achieved by installing taps which are regulated by sensors (European Environment Agency 2012a).

- **Reuse of wastewater and rainwater harvesting.** Besides the quantity of water used, water quality is also an important dimension when considering resource efficiency. There are several opportunities to reduce the demand of high quality potable water by reusing wastewater – either directly or after some form of treatment (EEA 2012b). In areas where water is scarce, treated wastewater may provide a cost-efficient alternative source of water for irrigating crops, e.g. more than 20% of the water in some areas is supplied from treated wastewater. Similarly, used household water and rainwater harvesting could be used to reduce the use of freshwater.

Water efficiency within the public, energy and industry sector is likely to be achieved through improved urban planning, ecological design, innovations and process design. A reduction in water use also decreases energy consumption for wastewater treatment and achieves more efficient chemical use, hence lowering other environmental burdens. In the industry and energy sectors it is probably more difficult, costly and time consuming to exchange existing technology than, for instance, in the public sector, where methods such as installation of water reducing taps and toilets can be used.

4.4 Land

Land is a finite resource. Land use corresponds to the socio-economic description (functional dimension) of areas: areas used for residential, industrial or commercial purposes, for farming or forestry, for recreational or conservation purposes, etc. The three largest land types in Europe are forests (35%), arable land and permanent crops (25%), and pastures and mixed mosaics (17%). About 4% of Europe is covered by artificial surfaces.

The main inefficiencies related to land use that were identified are:

- **Land use change** from natural land to agriculture land can have severe impacts on climate change and ecosystems services (EEA 2010a). Although land use change is driven by the demand for other uses of land, it is responsible for a large share of global GHG emissions and also causes degradation and pollution of water, soil and air.

- A specific case of land use change is the **loss of productive land** which occurs when land that could be used to produce natural resources and provide ecosystem services is lost to urban sprawl and transport infrastructures (JRC 2012a) through land[10] take and soil sealing[11] (Didier and Thomson 2007). Overall, about 1 000 km² is lost each year in the EU due to land uptake by urban and other artificial land development (Prokop, Jobstmann and Schönbauer 2011). Between 2000 and 2006,

[10] Loss of agriculture, forest and other semi-natural and natural land taken by urban and other artificial land development. It includes areas where soil is sealed by construction and urban infrastructure as well as urban green areas and sport and leisure facilities.

[11] Sealed soils can be defined as the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.). It is the most intense form of land take and is essentially an irreversible process (JRC 2012a).

the EU average loss of land increased by 3%. The formation of new artificial surfaces is greater than the formation of new agricultural land (EEA 2010).

Although cities may impact the environment and biodiversity on a much bigger scale than their actual area, urbanisation itself is not necessarily inefficient. It is often necessary to fulfil human needs for transportation and dwelling. Associated with urban living, the proximity of people, businesses and services may actually provide greater opportunities and benefits, especially in terms of sustainability and resource use. Urban dwellers on average consume less energy and land for living per capita than rural residents and have fewer requirements for transport (EEA 2010b).

- Soil compaction, erosion, loss of organic carbon and contamination are examples of **degradation of land and soil**. Common for all types of land degradation is the fact that the soil loses its ability to provide vital ecosystem services such as crop growing, water retention and carbon sink. Over 30% of subsoil in Europe has been severely affected by soil compaction, mainly due to the use of heavy machinery in agriculture (JRC 2012a). About 16% of Europe's total land area is prone to water erosion. About 45% of the soil in Europe is considered to have low or very low soil organic carbon content. About 3 million sites in Europe are contaminated by heavy metals and mineral oil. Many of the contaminated sites in the EU are **abandoned** and have potential to be remediated and reused productively.

- **Inefficient land use management and agricultural practices** are still prevalent. For example, the United Nations Food and Agriculture Organization estimates that there is still significant potential to increase crop yields economically (FAO 2012). Western and Central European countries have on average only achieved 65% of their economic potential yield. However, these estimates do not take into consideration whether it is possible to close these 'yield gaps' in a sustainable manner (Foley, et al. 2011).

4.5 Ecosystem services

Ecosystem services are *"the benefits people obtain from ecosystems"* (Millennium Ecosystem Assessment 2005). They encompass all the resources that nature provides directly and indirectly to the economy and human well-being. Ecosystem services are classified into four areas:

- Provisioning services such as crops, fish, timber and water. These are the services that underlie most of the resources discussed in the previous sections.
- Regulating services such as climate regulation, water filtration, flood protection, etc.
- Cultural services which provide recreational, spiritual and educational experiences
- Supporting services such as soil formation, photosynthesis and nutrient cycling.

The state and proper functioning of ecosystem services are in decline due to environmental pressures caused by human production and consumption. The Millennium Ecosystem Assessment (2005) found that approximately 60% (15 out of 24) of the ecosystem services examined in their study are being degraded or used unsustainably As the economy is dependent on ecosystem services, their degradation can be seen as an inefficient use of resources. It is only recently that the value of ecosystem services has been attempted to be quantified (TEEB 2009). Monetary valuations of ecosystem services often make it clear that decisions on resource use are not optimal and that more benefits could be gained from sustainable management approaches (Naumann, et al. 2011).

4.6 Summary

This chapter has identified the major areas of inefficient resource use in terms of materials, energy, water, land and ecosystems by considering their resource efficiency potential. In general there seems to be significant potential to increase resource efficiency for all resources considered. However, the resource efficiency potentials mentioned in this chapter are often theoretical (technical) estimates that do not always consider whether it would be economically feasible and socially acceptable to achieve such efficiencies.

Many of the inefficiencies identified can be seen as ‘classical’ examples of technical inefficiencies where a comparison is made between the amount of resources needed as inputs per unit of output. This could be improvements in crop yields, electricity transmission, irrigation, etc. Here the focus is on the potential for improving productivity and it is related to available technologies, knowledge of best practices and costs. These types of inefficiencies typically relate to production or supply side perspectives, and they do not question how the resource outputs are actually used.

In contrast, some of the other identified areas of inefficiency relate to use and consumption behaviours such as choice of diets, use of products and overconsumption in general. These types of inefficiencies typically lead to increased demand for natural resources even though the supply of the resource, product or service in itself may be very efficient. For example, even if we imagine that the production of beef was optimised in relation to breed, feed, rearing methods, slaughtering, transport, etc. so that this was resource efficient, but the total global demand for beef would not be sustainable in the long term due to limited land, freshwater resources and climate change. To improve this perspective of inefficiency, one would have to address preferences and the question of ‘sufficiency’, i.e. when can something be considered excessive or too much.

A third type of inefficiency relates to resources that typically are considered waste - meaning that it has little or no value to the person who discards it. Here the inefficiency is considered from the perspective that the waste has a potential to be reused, recycled or transformed to another useful resource. This eliminates the need for extracting other (virgin) resources and is often less harmful to the environment.

A fourth type of inefficiency identified is the potential to substitute the use of one resource with another resource that is less harmful to the environment. Using coal for heat and power production could be seen as inefficient in relation to renewable energy sources such as wind power. Another example could be to rely on red meat instead of white meat to fulfil the nutritional requirements for protein.

Finally the last type of inefficient resource use identified is unsustainable resource extraction or use. The inefficiencies are seen as the rate of extraction in relation to the natural stocks and the rates of replenishment such as fish stocks, available freshwater and high value conservation areas. The potential for increasing resource efficiency is related to how well the resources are managed and planned to ensure a secure supply in the future.

The different types of inefficiencies listed here should not be considered individually. In effect, they are often interlinked and depend on how the problem is framed. For example, food waste is a mixture of production inefficiencies (e.g. bakers make more bread than they can sell); consumption inefficiencies (e.g. consumers buy more than they can eat); waste inefficiencies (e.g. leftovers are thrown away); and, substitution inefficiencies (e.g. fresh milk does not keep as well as long life milk). One should rather see the list of inefficiencies as different dimensions of inefficiency than separate categories.

5 Analysis of drivers of inefficiency and the underlying reasons

This chapter builds on the previous chapter and examines the drivers behind the identified inefficiencies. First a presentation of the general factors influencing inefficiency is provided. Then the inefficient use of resources and their drivers in the three consumption areas (food, transport and buildings) that contribute most to environmental pressures in the EU are analysed. The reasons for inefficiency are many and interact with each other in a complex manner. In the following sections only the most significant drivers of inefficiency are presented.

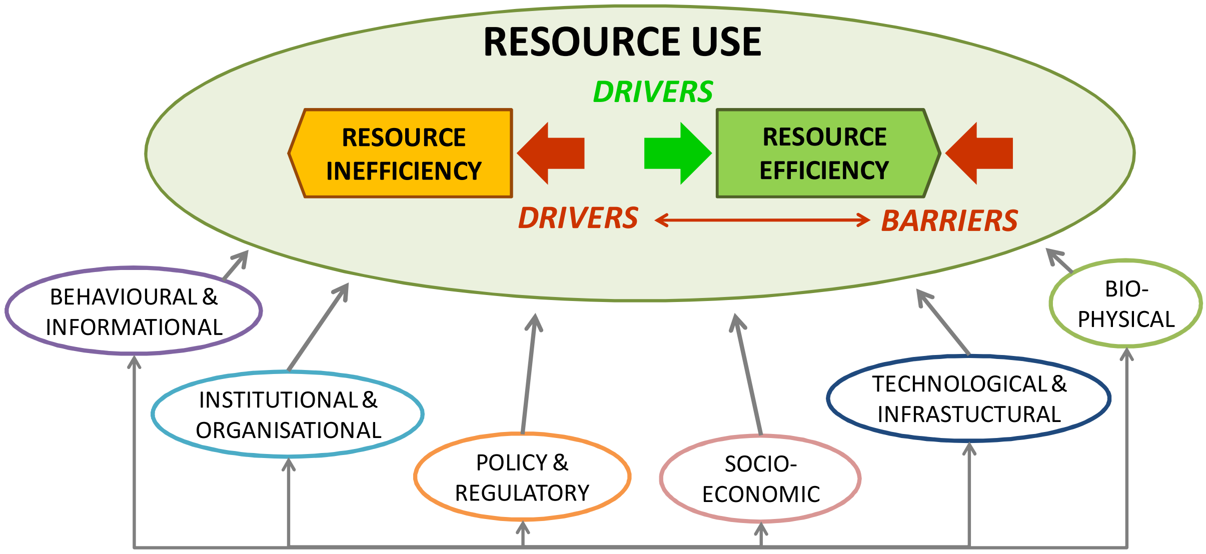
5.1 General categories of drivers of (in)efficiency

There are many factors that influence the inefficient (or efficient) use of resources. As barriers are the opposite of drivers, the drivers of inefficiency are the same as the barriers to resource efficiency, i.e. a driver of inefficiency is a factor that restrains resource efficiency from improving. Based on the literature review, six main categories of driving forces were identified that explain and encourage inefficient resource use (same categories as the Tier 1 drivers used for the meta-analysis – see Figure 9 in section 3.5.2):

- **Behavioural and informational drivers** regroup factors related to personal and cultural values, preferences and paradigms; cultural and societal trends; as well as issues with information, communication and awareness.
- **Institutional and organisational drivers** can refer to macro-level social and economic structures and processes, including governance, business management, decision making, supply chain structure, interaction between actors (e.g. producers, retailers, consumers, policy-makers, etc.).
- **Policy and regulatory drivers** involve factors stemming from policy, regulation or the legal framework**.**
- **Socioeconomic drivers** include demographic and social trends, as well as economic factors such as high costs, lack of funding, distorted pricing, lack of economic incentives for efficient behaviour and other market failures.
- **Bio-physical drivers** refer to the environmental context and factors, as well as resource endowments.
- **Technological and infrastructural drivers** refer to inherent technical inefficiencies and limitations of materials, technologies, systems and processes, as well as of surrounding infrastructure.

These six categories of drivers are relevant for all sectors and can impact efficiency throughout the life cycle of a resource or sector. There is rarely only one driver of resource inefficiency. Typically several factors are in play and often the factors influence each other (see Figure 30).

Figure 30 Factors influencing resource efficiency



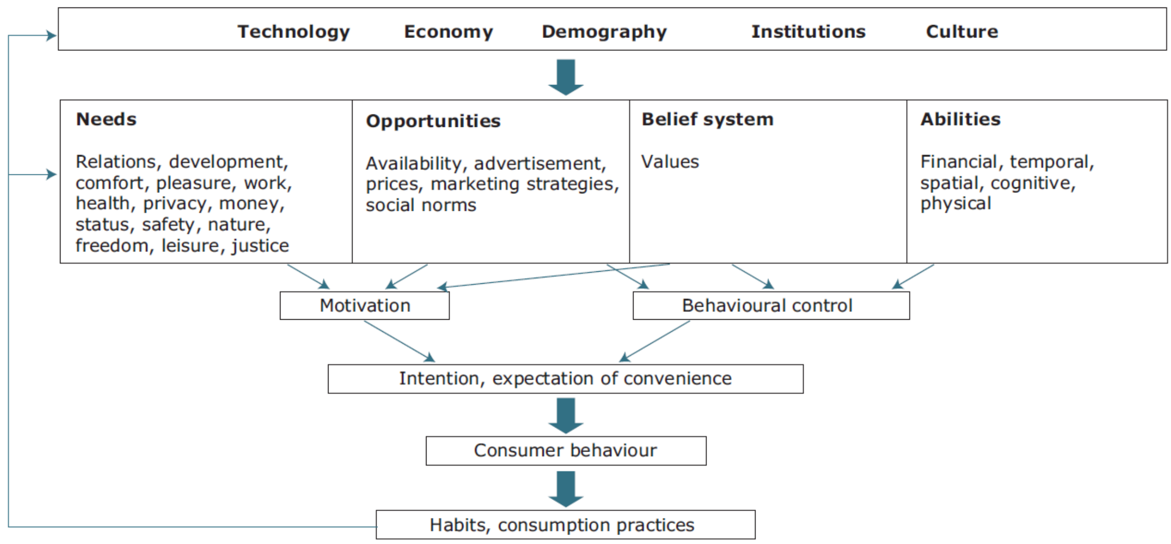
For example regarding energy efficiency, experts from across the EU-27 were asked in a recent survey what were the major barriers in their countries (Energy Efficiency Watch Project 2012). For 47% of them, financing of energy efficiency investments was the most important barrier. The lack of legislation or its implementation was mentioned by 28%. The experts also stressed that many other barriers to energy efficiency remain to be addressed (e.g. legal, institutional, in the fields of information, awareness raising and training).

5.1.1 Behavioural and informational drivers

Human behaviour ultimately drives resource use. It determines what resources we use and how we use them. Behaviour is determined by personal values and attitudes, but is also influenced by incentives, norms and institutional constraints (Jackson 2005). Policy development generally assumes 'rational' behaviour, i.e. people will make decisions by calculating the individual costs and benefits of different courses of action and choosing the option that maximises their expected net benefits. But reality shows that this is not always the case.

Several models have been proposed to understand behaviour and how it is influenced (Jackson 2005). An example of a simplified model for individual consumer behaviour is presented in Figure 30. Consumer behaviour is a result of motivation and behavioural control (Vlek 2000) – both factors must be present. Motivation is first and foremost determined by needs and desires (e.g. a comfortable home), but also depends on individual belief systems and values (e.g. that protecting the environment is important). The opportunities that exist and are present for the individual are however key to both motivation and behavioural control. Opportunities are to be understood as external facilitating conditions such as the availability and accessibility of the means that allow an individual to act. This could be resource efficient technology, products and services; information on consumption; or prices and rewards. Besides opportunities and values, behavioural control is dependent on the individual's abilities. These are the internal capacities of an individual (or an organisation) to act in a certain way, which could include financial ability (e.g. it is affordable), temporal abilities (e.g. there is enough time), spatial (e.g. in close proximity), cognitive (e.g. awareness and appropriate knowledge) and physical (e.g. able to perform the action). For example, household energy use depends on the need for energy to heat a home, what is believed to be a comfortable temperature, the heating system and how well the house is insulated. If consumers are to adopt more energy efficient behaviours, they should not only be motivated, but also be able to choose and buy energy efficient equipment (depends on the availability and affordability), be able to install it and know how to use it correctly.

Figure 31 A model for influencing individual consumer behaviour



Source: (EEA 2013)

This model for influencing consumer behaviour explains that it is not sufficient to just be aware or motivated to use resources more efficiently, but one must also have the opportunities and abilities to change behaviour. Studies show that there is a gap between consumer attitudes and behaviour. People do not always act on their environmental and social concerns. Despite a general increase in levels of awareness and concern about environmental and social issues, many consumers have not made the same shifts in general behaviours, lifestyles and purchasing decisions. Consumers are more likely to adopt environmentally responsible behaviours, if both cost-efficient and convenient (WBCSD 2008).

In general, individuals and organisations make reasoned choices in relation to behaviour. However behaviour is often habitual and guided by automated cognitive processes instead of elaborate reasoning (Steg and Abrahamse 2010). The existence of habitual actions of consumers creates a large barrier to changing 'routine' behaviour. Habits, or 'inertia', are formed in a process of continuous reinforcement. Once people are satisfied with their choice and situation, their behaviour becomes routine and they do not tend to search for new solutions until new signals and influences arrive that can trigger the search for a better alternative. Alternatives to a specific product or brand are rarely sought out because of transaction costs in terms of time, trials, and errors (Power and Mont 2010).

Social norms are believed to also influence behaviour either through injunctive norms (i.e. the extent that the behaviour is generally considered as good or bad in a social group) or descriptive norms (i.e. the extent to which the behaviour is perceived as common) (Steg and Abrahamse 2010). Although, there are differences between individual behaviour and organisational behaviour (such as a government organisation or a company), many of the dynamics are similar (Oakdene Hollins 2011), e.g. social pressure can also influence the decisions and behaviour of companies (Montalvo Corral 2003).

A general driver of overconsumption of resources is consumerism. Consumerism in modern society is characterised by an underlying sentiment that is more competitive than co-operative, and members of the community strive to be materially better off than others. Individual freedom to own property and to consume is considered a fundamental right of all human beings. The natural world is viewed as a source of commodities, which provide the basis for consumption (Michaelis 2000). The definition of what people ‘need’ in order to be a ‘normal’ member of society is continually increasing in terms of material consumption (Power and Mont 2010). A culture of high and continuously growing levels of consumption, generally associated with well-being and success, has become the norm in western European countries (EEA 2010a). Conspicuous consumption, where there is heavy societal pressure to maintain high consumption patterns and where competitive spending and displays of wealth are encouraged by society, is becoming common place around the world (WBCSD 2008).

The activities of business and marketers are closely linked to the above mentioned principles of today’s consumer culture. The link between perceived needs and consumption levels is complex: the ways in which we choose to satisfy our needs and wants are influenced by cultural and institutional factors, and do not always contribute to our overall well-being — consumption of junk food or alcohol are examples. An obvious explanation is the role of advertising and marketing in creating ‘false’ needs, although there are many other social and psychological drivers of consumption, which the following sections aim to explain. The advertising industry plays a key role in continually creating new needs to ensure that we keep on buying new products (see section 5.1.4 on socio-economic drivers and the ‘engine of growth’).

When individuals make poor choices about resource use, it is often due to misinformation or lack of information. In many cases consumers and companies do not have adequate information about the efficiency, resource use and environmental performance of products and services. Without comprehensible, reliable and comparable information about resource use and efficiency, individuals and organisations are not able to make the right choices (Koos 2011). Furthermore, without information on resource use and environmental impacts, actions to improve resource efficiency cannot be effectively communicated and implemented.

Even if information on resource use and environmental performance is available (e.g. energy labels, water metering, environmental product declarations, etc.), people rarely search out, read or properly digest all of the information available to them when making a decision. The type, complexity and amount of information provided, and the way in which it is presented, all have a significant impact on the likelihood of people reading and understanding (Borin, Cerf and Krishnan 2011). This is even sometimes misused when companies market products with misleading environmental claims (TerraChoice 2010). Furthermore, selective exposure to information means people seek out only information that they are interested in (based on social and personal norms) (Borgstede and Andersson 2010). Nonetheless, information and feedback on the use of resources is a prerequisite for resource efficiency. Results of studies show that frequent measuring of resource use and feedback is effective in reducing resource use (Steg and Abrahamse 2010). In many cases, the perception of the size of the resource efficiency savings and the ease of implementation do not correspond to reality (Oakdene Hollins 2011). Actual data and objective information can alleviate this.

Finally, the lack of knowledge and skills of best practices among producers as well as consumers is a major factor for why resources are used inefficiently (UNEP 2011).

Insufficient or outdated education and training are often the causes for the lack of knowledge and skills, but it is also related to the diffusion of knowledge and information.

5.1.2 Institutional and organisational drivers

Social structures in society influence behaviour by imposing systems, hierarchies, procedures and norms on individuals. For example, the manner in which we organise ourselves and our economy puts formal and informal constraints on resource efficiency. Globalisation and the separation of production and consumption make it less clear how our consumption is affecting (inefficient) resource use in other parts of the world (UNEP 2011). Related to this is how some business models are structured, which incentivise inefficient use of resources (Tukker and Tischner 2006)(Ellen MacArthur Foundation 2012). For example, the aim of most manufacturing firms and retailers is to sell as many products as possible rather than ensure that their clients' needs are satisfied.

Differences in power may also result in inefficient resource use, e.g. large multi-national corporations can influence other actors in the supply chain to produce or consume resources in a certain manner that is not optimised (Moomaw, et al. 2012). For example, major retail chains offer fresh strawberries throughout the year, encouraging the production and consumption of off-season produce. In relation to businesses, the lack of leadership and management support is often mentioned as a barrier to resource efficiency (Oakdene Hollins 2011). The presence of corruption and weak systems of regulation and accountability can also lead to inefficient use of resources (UNEP 2011)(EEA 2012b). Inefficient resource use may also be due to how resources are managed, e.g. spatial planning (BIO Intelligence Service 2011a).

5.1.3 Policy and regulatory drivers

Although there are many policies and regulations that aim to encourage resource efficiency and reduce the environmental impacts of resources, there are areas where policy and regulation actually drive resource inefficiency (IEA, OPEC, OECD and World Bank 2010)(WWF 2013)(Crilly and Esteban 2012). Some of the policies are conscious decisions to directly support the consumption of certain resources to protect a certain social group or industry, e.g. environmentally harmful subsidies, or indirectly by support research and development for a certain technology. Even though policy aims to encourage resource efficiency, perverse effects can actually result from policy intervention – as has been seen with biofuel policies (UNEP 2009).

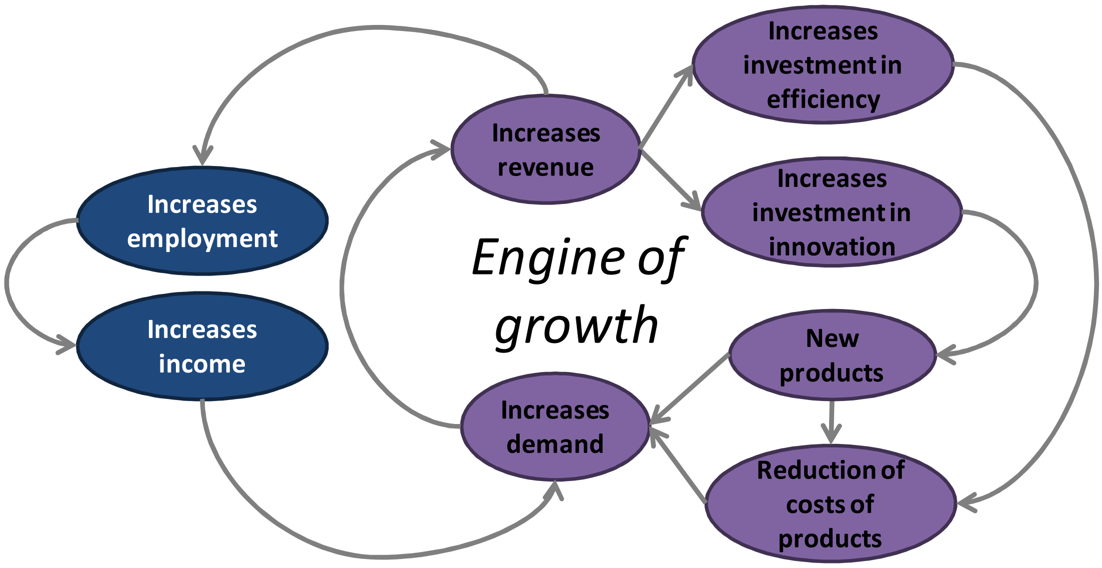
5.1.4 Socio-economic drivers

Demographic changes such as growth in population (including population density), an ageing population, increased migration to urban areas and changes in family sizes (e.g. increasing number of single households) have led to the construction of new dwellings, road construction and urban sprawl (EEA 2010). These demographic changes affect consumer preferences and demands, and lead to lifestyle changes (Power and Mont 2010). Two key factors that influence direct resource use are the level of development (given by GDP per capita) and population density (UNEP 2011a). Each factor seems to double the per-capita consumption of resources. When comparing the rates of resource use per capita of regions and areas with the same level of development, it appears that densely populated areas, such as urban areas, need fewer resources per capita for the same standard of living.

Urbanisation is strongly linked with income levels. Cities tend to attract people because incomes are higher, and in turn consumption levels are higher in urban areas because of higher incomes (UNEP 2012).

Most economies strive to grow. Economic growth increases welfare and reduces poverty in society. However, the current model for economic growth is based on constantly increasing the demand for products and services (Jackson 2009). Put simply, an increase in demand increases the revenue of firms, which again allows firms to employ more people and/or invest in capital such as buildings and production equipment (Figure 32). When employment increases, households' income also tend to increase, and consumers can buy more products and services. To encourage consumers to spend more money, firms may invest money to be able to increase the efficiency of their production, which leads to cheaper products that stimulates demand; or, they may invest in innovation, which leads to new products that also can stimulate demand. In this (oversimplified) manner, increases in efficiency seem to actually drive resource consumption.

Figure 32 Economic growth is built on the constant increase in demand



Source: After (Jackson 2009)

High income consumers account for by far the greatest per-capita share of consumption expenditure and environmental footprint (UNEP 2010). Besides economic growth and wealth driving consumption - and perhaps also overconsumption - inefficient resource use can be explained by market failures such as:

- **Externalities**, i.e. costs or benefits of a product or process which affects a third party. The classical example of this is environmental impacts of production that are not included in the price of production and products resulting in relatively low resource costs (von Weizsäcker, et al. 2009). Resource losses during production are often because of the relatively low costs of materials compared to the (often perceived) effort of reducing losses, in particular labour costs (Allwood and Cullen 2012).
- **Public goods**, i.e. when property rights of natural resources are incompletely defined and/or enforced, individuals in a group will tend to continue to exploit common resources in accordance with self-interest - even to the extent that this reduces the entire group's ability to exploit the resource in the future. This behaviour leads to

degradation of ecosystems and overexploitation of natural resources. This problem is typically known as the “tragedy of the commons” (Hardin 1968).

- **Imperfect competition** relates to the market structure, where there is only one or a few sellers of products and services that can influence the supply or price, e.g. in a monopoly.
- **Imperfect information**, i.e. buyers and sellers on a market do not both have full information on the consequences of their purchasing and selling decisions. An example of this is when consumers purchase products without knowing how long they will last or what their real life energy performance is (related to the informational drivers described in section 5.1.1).

Another economic barrier is the lack of capital to invest in resource efficient technology and equipment (IEA 2007). High investment costs and low resource use costs result in low or no returns on investment. Related to this are split incentives, also called principal-agent problems, which refer to the potential difficulties that arise when two parties engaged in a contract have different goals and different levels of information. Such failure is common in the building sector, e.g. the tenant-landlord scenario, where economic incentives are not aligned.

5.1.5 Bio-physical drivers

Resource efficiency can be constrained by bio-physical factors that are only indirectly a result of human activities. Crop yields are for example dependent on climate, soil quality and water ability (FAO 2012). The degradation of ecosystems can be a major factor that contributes to inefficient use of resources (Millennium Ecosystem Assessment 2005). For example, the location of cities and agricultural activities in certain areas might require more freshwater than is naturally available and therefore water either has to be transported, treated and/or desalinated to satisfy demand (EEA 2012b). Besides depleting local water supplies and putting a pressure on ecosystems, the transportation, treatment and/or desalination of water requires additional energy.

5.1.6 Technological and infrastructural drivers

Resource efficiency could be improved dramatically by retrofitting or replacing existing equipment with more efficient technology (IEA 2008) and designing or planning more efficient infrastructure (UNEP 2012). Besides the investment costs, the diffusion and availability of tested technology limits improvements in resource efficiency.

Often technologies and infrastructures ‘lock’ us into a certain way of using resources (OECD 2012). This is particularly true for technologies (which may refer to systems, appliances, equipment, processes, vehicles, infrastructures, etc.) that demand or consume resources themselves, e.g. energy-using technologies. Overall efficiency of these technologies depends both on the choice of technology and the user’s behaviour during its subsequent use.

Further, with respect to the choice of technology, it is important to note that a comprehensive analysis of the drivers of inefficiency must take into account the interaction between technology supply and demand. More specifically, on the one hand, use of technologies beneficial to resource efficiency is often constrained by limited availability, whether due to inexistence of these technologies (due to lack of R&D, etc.) or to insufficient supply by producers or authorities. On the other hand, development and supply of these technologies is in turn affected by demand, with low user/consumer demand lowering the attractiveness of the supply of these technologies (particularly given often-high initial investment costs by suppliers). Choice of technology is therefore driven by a cyclical interaction between supply and demand. Here market failures occur between lack of availability of resource efficient products and services on the market, and consumer demand for such products and services.

In some cases, yield losses are inherent in the existing technologies and manufacturing techniques (Allwood and Cullen 2012). For example, machining results in shavings, whilst 3D printing has no material losses. Developments in technologies and production processes have generally led to new products and services using less materials[12], but not necessarily because of environmental concerns (Steger and Bleischwitz 2011)(Hertwich 2005). Environmental gains made through technical efficiency are often partially or wholly offset by resulting increases in consumption due to lower costs of production and/or use and more money thereby becoming available for spending on other/more goods and services — the so–called rebound effect (Hertwich 2005).

In addition, the concept of planned obsolescence or built-in obsolescence is also worth mentioning here (Ellen MacArthur Foundation 2012). Planned obsolescence refers to the planning or designing of a product with a limited useful life, so that it eventually becomes obsolete i.e. no longer functional after a certain period of time. This has several negative environmental implications including resource depletion because the quicker a product fails, the quicker a new replacement is needed, and the more resources are required. Planned obsolescence also further perpetuates the consumer disposable mentality that something can be used, abused and thrown away.

[12] The lightweighting of products is often beneficial for transport and use phases, but it can come at a price of increased resource (e.g. materials, energy, water) consumption and environmental burden during the extraction and production phases (Morley, et al. 2007)

5.2 Food

While there are significant inefficiencies of resource use in the production of food, the key inefficiencies in the EU are actually driven by food consumption. The following presents the main areas to improve resource efficiency significantly and their drivers.

Table 4 The main areas of inefficient use of resources related to food

Area of inefficiency	Life cycle stage	Key actor(s)	Main drivers	Key relevant resource
Diets and food choices (in particular meat consumption and overconsumption)	Consumption	Consumers	Food prices, income, consumerism, lack of knowledge, year round availability	Biomass materials (agricultural products and fish), but also land, water and energy
Food losses and food waste	All life cycle phases	Farmers Retailers Consumers	Production exceeds demand, planning and purchasing behaviour, low food prices, regulations, retail quality standards, poor storage and processing	Biomass materials (agricultural products and fish), but also land, water and energy
Unsustainable fishing	Fishing	Fishermen	Regulation failure, consumer demand, retail standards, fishing equipment	Biomass materials (fish)
Inefficient irrigation	Agriculture (farming)	Farmers	Intensive agriculture, water price, irrigation systems, lack of best practices / training, illegal water abstraction,	Water
Nutrient and pesticides losses from crop production	Agriculture (farming)	Farmers	Agricultural practices, excessive amounts used depleted soils, soil erosion, resistant pests	Materials (phosphorus) Degradation of soil and water

Please note that for all illustrations of inefficiencies in this section, the six main categories of driving forces are colour coded as per the legend in Figure 30.

5.2.1 Diets and food choices

High meat (animal protein) consumption in diets, overconsumption and non-seasonal food could be seen as inefficient uses of food resources.

More resources are required to produce 1 g of animal protein compared to 1 g of vegetable protein. While chicken production is relatively efficient with a feed conversion ratio of less than 2 (i.e. chickens need less than 2 kg of feed to produce 1 kg of meat), beef can have a feed conversion ratio up to 16(Williams, Audsley and Sandars 2006) (Gold 2004). Fish tend to have the highest feed conversion ratio. For example, depending on species and literature sources, 1.4 to 2.0 kg of wild-caught feed is generally required to produce 1 kg of farmed fish (FAO 2012). The World Health Organization recommends an intake of 58 g of protein per day for a 70-kg-adult (World Health Organization 2007). Most people in industrialised countries consume more protein – in particular meat - than necessary (Westhoek, et al. 2011): the average protein intake is over 100 grams per person per day (FAO 2011). Changing from a typical western high meat diet to a nutritionally adequate diet with less meat could reduce animal protein consumption by 63% (Erb, Haberl and Krausman 2009). A vegetarian diet with dairy and eggs could reduce livestock products by 66% and only lead to a 29% increase in other food products (Audsley, et al. 2009).

In addition to a high share of animal products in western diets, average caloric intake is well beyond dietary guidelines (FAO 2011): people in industrialised countries consume 3,430 kcal per person per day. The recommendations of the World Health Organization are between 2250 and 2700 (for men) kcal per day per 70-kg adult (FAO 2001) depending on age and physical activity. Over 20% of the world population is either overweight or obese (Moomaw, et al. 2012). In the EU, 30-70% of adults are overweight and 10-30% are considered obese (DG for Health & Consumers 2010).

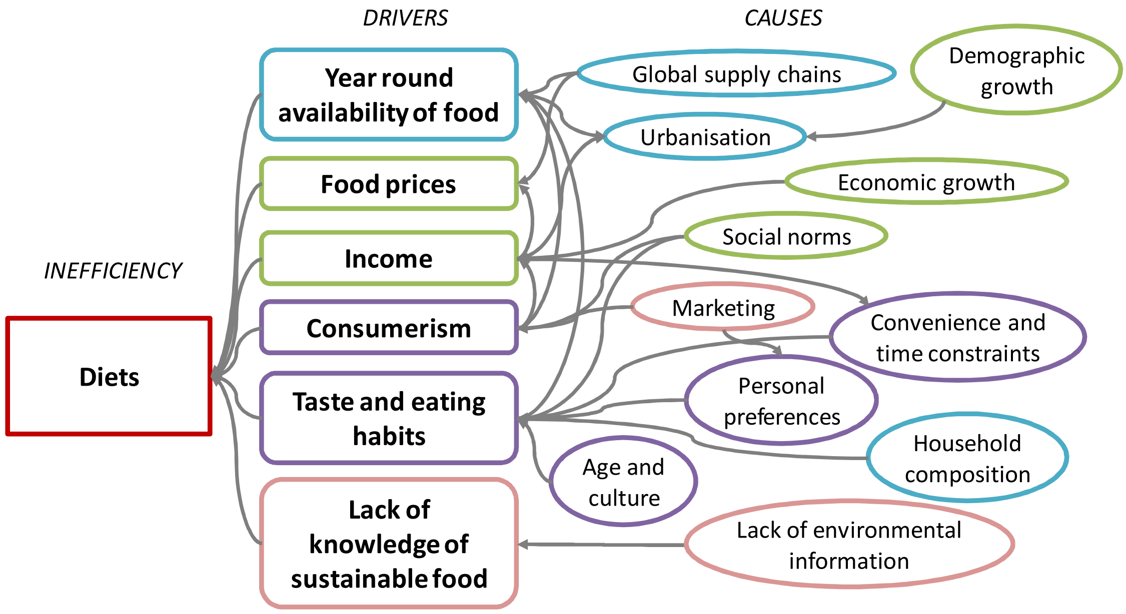
Out-of-season products typically require more energy to produce (e.g. crops are grown in heated greenhouses) or transport (e.g. food must be shipped from other parts of the world) than locally sourced seasonal production. In order to extend the growing season, farmers often have to provide additional energy and/or nutrients to compensate the lack of adequate conditions for plant growth. For example, off-season tomato production can take place in greenhouses, the majority of them being heated and ventilated to provide an optimum climate for fruit growth (Bressoud 2010). About 97% of the energy used in greenhouse tomato production is for heating and lighting (Williams, Audsley and Sandars 2006). Out-of-season products also lead to 'food miles' – products have to be transported from places in the world where the product is in season. This does not mean that seasonal production is systematically resource efficient - some local and seasonal crops and vegetables can be produced in a very resource intensive. While the demand for out-of-season products is ultimately driven by consumer preferences and choice, retailers and caterers influence these choices through decisions on what to stock and serve. Not providing more sustainable food choices is one of the reasons consumers do not make the more resource efficient purchasing decisions.

Food related behaviour patterns are complex, habitual and strongly influenced by marketing, budgetary and socio-cultural pressures (BIO Intelligence Service 2012a). Unsustainable diets and resource inefficient food choices are due to several factors:

- ***Urbanisation*** - due to increasing urbanisation and the growth of household incomes, people have access to more diversified food and to imported food (Lundqvist, de Fraiture and Molden 2008). Thus, they get accustomed to non-seasonal food being available. A convergence has been observed toward urban diets high in resource-intensive saturated fats, sugar and refined food ('western diet') with high animal content and carnivorous fishes.

- ***Income*** - linked with urbanisation, higher income induces a decline in consumption of starchy food staples, in favour of nutrient-dense food. Although the link between income and the quantity of meat and fish consumed is not clear, higher income households consume higher shares of beef and lower income households tend to chose white meats such as chicken and pork (Omann, et al. 2007).
- ***Convenience and time constraints*** - Also linked to income, households tend to eat out more and have less time to prepare meals. The consumption of fruit, meat, and vegetables increases with age due to the time required to prepare these types of food (e.g. potatoes) (Omann, et al. 2007).
- ***Food offering and marketing strategies*** – Many supermarket and food service chains have optimised their processes to be able to offer food at low costs. To increase revenue and profits, they are motivated to sell as much food as possible and therefore often advertise aggressively with special offers and discounts. Although, this can save consumers money, it leads to overconsumption – particularly, with "buy one, get one free" promotions. Another example of retailers and food service providers encouraging overconsumption is packaging sizes and portion sizes that are bigger than some consumer's needs.
- ***Preferences*** - Food choice is ultimately determined by preferences related to taste and eating habits. This is driven by factors such as personal preferences, culture, religion, social norms and convenience. For example, women have a greater tendency to buy organic food (Power and Mont 2010).
- ***Lack of knowledge about sustainable food*** - Although environmental labelling has been developed in Europe, consumers have little information about the environmental impacts of their diets and sustainable food consumption. The demand for food with high environmental impacts, such as beef, cheese or predator fishes are the main causes of their high production and their associated impacts. In addition, people are increasingly getting used to eating all types of food regardless of whether it is in season.

Figure 33 Drivers and causes to unsustainable diets and resource inefficient food choices



5.2.2 Food losses and waste

Food losses refer to the losses at the beginning of the supply chain (crop and livestock production, processing and transport), while food waste refers to losses due to retailer and consumer behaviour (Parfitt, Barthel and Macnaughton 2010)[13]. One quarter of the food supply in terms of kcal and one third in terms of weight is lost in the food supply chain due to losses and waste (Kummu, et al. 2012). In Europe, the global food loss represented 280-300 kg/year/capita in 2007(Gustavsson, et al. 2011). The main losses and waste are at the agricultural stage and the consumption stage (see Table 1). A study by Kummu et al. (2012) estimates that agricultural losses could be reduced globally by 47% (varying regionally between 25% and 59%) compared to baseline, and consumption waste could be reduced by 86% (varying regionally between 0% and 94%).

Table 1 Estimated/assumed waste and losses for each commodity group at each step of the life cycle in Europe, including Russia

	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarket Retail	Consumption
Cereals	2%	4%	0.5%, 10%	2%	25%
Roots & Tubers	20%	9%	15%	7%	17%
Oilseeds & Pulses	10%	1%	5%	1%	4%
Fruit & Vegetables	20%	5%	2%	10%	19%
Meat	3.1%	0.7%	5%	4%	11%
Fish & Seafood	9.4%	0.5%	6%	9%	11%
Milk	3.5%	0.5%	1.2%	0.5%	7%

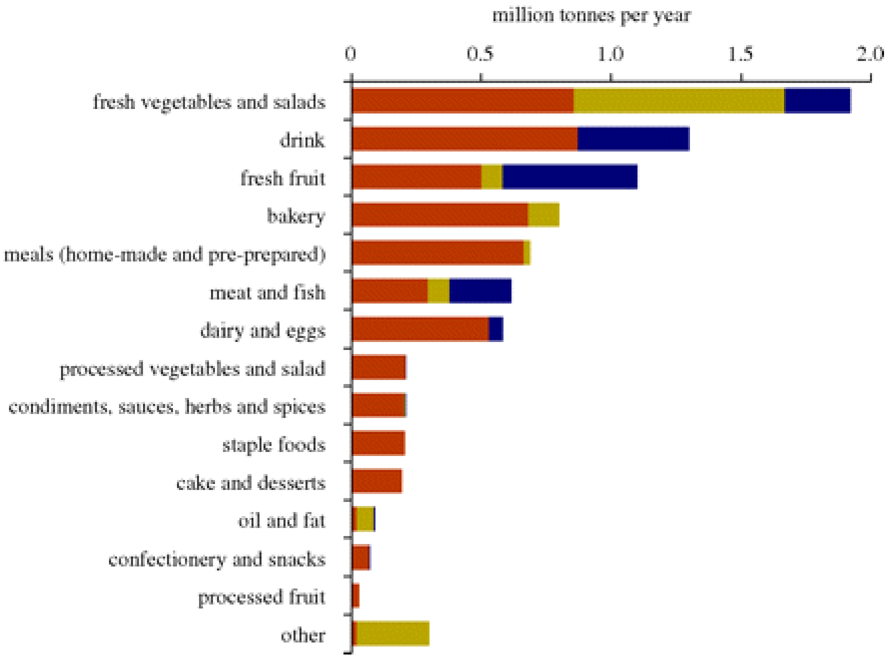
Source: (Gustavsson, et al. 2011)

[13] For this part, global food loss refers to both food losses and food waste

Food losses and waste represent a loss of resources: crops, livestock, fishes, but also indirectly the resources necessary for the production of these resources such as land, water, energy, fertilizers and other inputs (Kummu, et al. 2012). In addition to saving resources, reducing food losses and waste avoids unnecessary pollution related to the entire food supply chain.

Food waste constitutes the main source of losses for medium- and high-income countries, especially regarding cereals (Gustavsson, et al. 2011). They are mainly due to social norms and consumer behaviour (Kummu, et al. 2012) (Gustavsson, et al. 2011)(McKinsey Global Institute 2011). Of the estimated total 52 Mt of EU food waste, households produce the largest fraction (38 Mt; 71% of the total), representing 109 kg per capita (BIO Intelligence Service 2010a), with evidence showing that over 60% of it may be avoidable (WRAP 2009). Food waste also occurs in the wholesale/retail (4 Mt; 7%) and food service sector (12 Mt; 22%).

Figure 34 Food and drink waste by food group, split by 'avoidability'



Note: Brown bars - avoidable; yellow bars - possibly avoidable; dark blue bars - unavoidable

Source: (Parfitt, Barthel and Macnaughton 2010) (WRAP 2009).

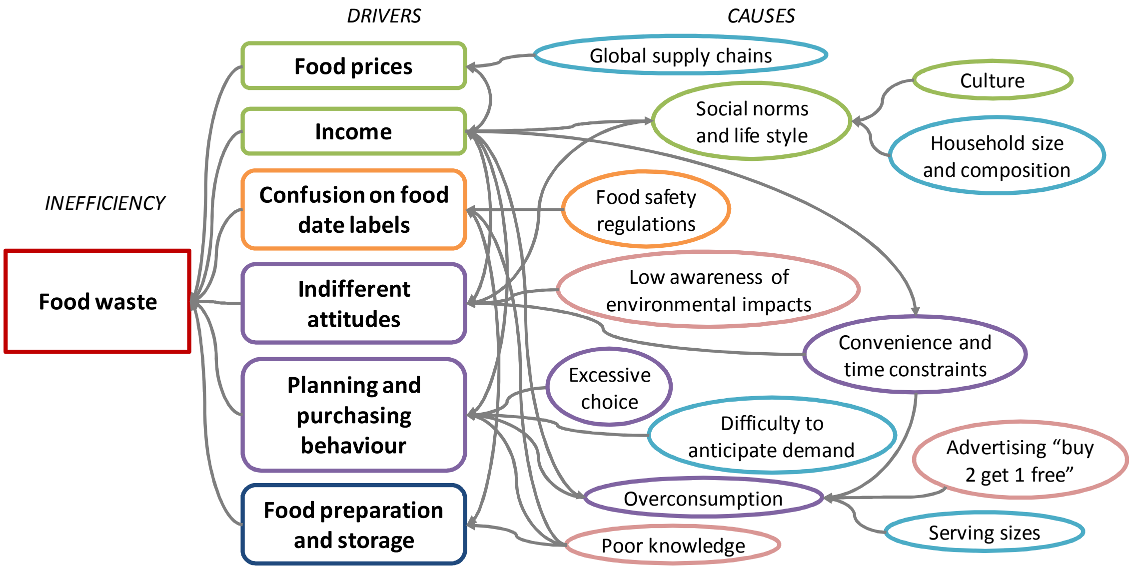
At the **consumption stage**, behaviour and lack of information are the main drivers regarding food waste:

- ***Indifferent consumer attitudes*** – indifferent attitudes to food waste is caused by demographics, education and income:
  - Single-person households tend to throw away more food per capita. Households with children tend to waste more than households without children, although rates vary with the children's age (WRAP 2009a).
  - Education, related to environmental awareness, positively influences attitudes regarding food waste.
  - Income can induce an indifferent attitude among consumers, who think that they can afford to waste food (Moomaw, et al. 2012). The correlation between food waste and income is not proved however; according to some studies low

income households generate less waste than high income households (WRAP 2007a).

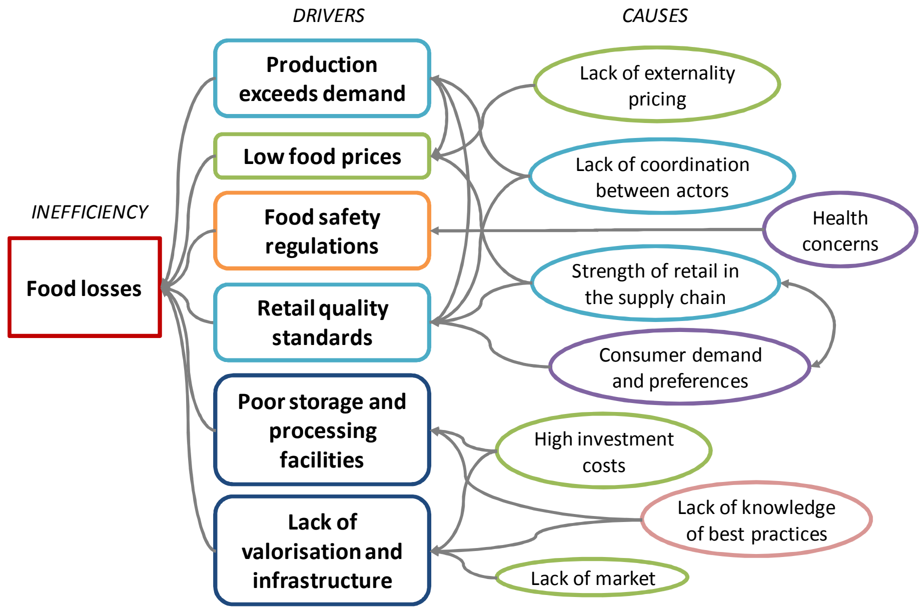
- ***Insufficient planning*** - caused by insufficient organisation, overconsumption and confusion over food date labels.
    - Insufficient organisation is due to the difficulty of anticipating numbers of clients that leads to overstocking in the retail and food service sector (BIO Intelligence Service 2010a).
    - Overconsumption results from excessive choice due to the social environment and lifestyle, income, advertising, big portion size (at home and in the food service sector), etc. In particular, advertising and promotional events for perishables items can encourage bulk purchasing which can lead to waste, if the food is not managed properly (Moomaw, et al. 2012).
    - Confusion in food date labels: misinterpretation or confusion over date labels leads to the discard of still edible food (Moomaw, et al. 2012)(BIO Intelligence Service 2010a). Moreover, hygiene laws do not permit the use of perishable but still edible food after the expiry date.
- ***Lack of knowledge in food preparation*** - Food waste here is mainly due to surplus food preparation. Otherwise losses due to food preparation are: unavoidable food waste such as bones, and possibly avoidable waste such as vegetable peelings.

Figure 35 Drivers and causes to food waste during retail and consumption



Food losses can be discards, degradation during harvest, handling, storage or transportation, surplus, crops sorted out due to quality requirements, or losses during processing (washing, peeling, slicing, etc.). Food losses are a function of the technology available; plant and animal diseases; and, the quality and quantity standards of retailers and food service providers, e.g. perfectly edible food being rejected because of imperfect shape or size (Parfitt, Barthel and Macnaughton 2010).

Figure 36 Drivers and causes to food losses during farming and food production



5.2.3 Unsustainable fishing

Over 80% of fish populations are either fully fished (57% of stocks) or overfished (30% of stocks) (FAO 2012). Overfishing reduces the productivity of fish stocks and reduces the capacity of the oceans to provide for the future (Crilly and Esteban 2012). Furthermore, fisheries are one of the sectors that results in the most losses related to the fish consumed. The discard of unwanted by-catch produces 20 million tonnes of waste annually. The protein loss from fish by-catches and discards could provide enough fish meal to increase current aquaculture by 50% (Moomaw, et al. 2012). Global by-catch discards from fishing represented between 20-60% of the catch for the period 2003-2005 (STECF 2012). The unwanted by-catch can be non-edible fish; fish unwanted by consumers (due to esthetical quality standards); poor quality fish; fish with too low market value; juvenile and undersized fish of the species targeted that cannot be landed.

Losses are due to:

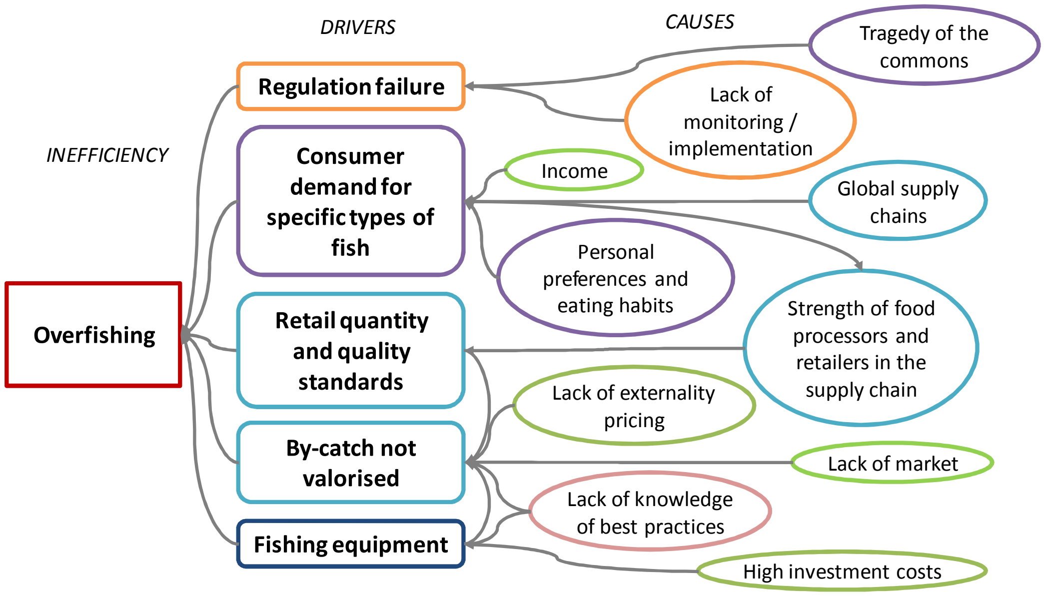
- ***Quantity and quality standards*** - Fishermen (and more broadly producers) often fish larger quantities than required in order to ensure delivery of agreed quantities to clients and to avoid potential contract penalties for partial delivery of order volumes (Moomaw, et al. 2012). Thus, losses are also linked to market factors underlining a lack of co-ordination between actors and their different strengths.

- ***Inappropriate equipment*** - Losses are especially significant in trawl and gillnet fisheries where the proportion of species caught incidentally can reach 95% of the total material taken on board (FAO 2012). Moreover, post-harvest losses, in particular in small-scale fisheries are generally regarded as being the highest for all commodities in the entire food production system.

- ***Lack of valorisation*** - By-catch is mostly discarded into the sea, often dead but they can potentially be kept on board and used in feed, pharmaceuticals, etc. (European Commission 2011a). Nonetheless, recovery of fish discards is currently insufficient due to the lack of market and appropriate infrastructure.

- ***Lack of appropriate legislation*** - There is currently no EU-wide policy aiming at reducing discards. The European Commission is currently considering the implementation of quotas in consultation with fisheries stakeholders to reduce unwanted by-catches (European Commission 2011a).

Figure 37 Drivers and causes to unsustainable fishing



5.2.4 Inefficient irrigation

Within the life cycle of food, the most water-consuming sector is agriculture (EEA 2012b). Over 90% of the water footprint of food production is from farming, with irrigation as the main driver of water consumption (Vanham and Bidoglio 2013). Water availability is very heterogeneous within the EU, since natural supply and storage of freshwater is unevenly distributed and may be difficult to access. Climate and soil characteristics influence irrigation requirements by conditioning the capacity of soil to absorb and store water as well as make it available for plants. For instance, the need for irrigation is particularly high in water-stressed areas, where evaporation is high and where rainwater and water stored in soil is not sufficient to meet crop water requirements and become limiting factors for yields (EEA 2012b). In water-scarce areas, water withdrawals for irrigation are likely to exceed sustainable thresholds of abstraction, therefore increasing the risk of water shortages or scarcity, especially for downstream uses, and impacting ecosystems through the reduction of environmental flows (Keys, Barron and Lannerstad 2012). Water withdrawals may have significant impacts on the status of water bodies and water ecosystems, should they exceed environmental flows. Furthermore, infrastructures developed for irrigation purposes (e.g. concrete lined canals) disturb hydrological flows by modifying the volume of water that is infiltrated into surrounding soils, in some cases by as much as 50% (Keys, Barron and Lannerstad 2012). The main inefficiency in the use of water for irrigation is the occurrence of water stress and lies in the facts that:

- Demand for irrigation exceeds water availability.
- Water withdrawal for irrigation exceeds water irrigation requirements.

The present section discusses possible reasons underlying these inefficiencies.

From a demand perspective, the overall demand for irrigation is driven by the increasing demand in food, feed and fibre and the intensification of production. The cultivation of water-intensive crops such as maize, wheat, sugarcane, rice and cotton increases water requirements for irrigation and contributes to 49% of global water scarcity (Pfister, et al. 2011). The high protein diet (see section 0), relying on products with high water virtual content such as meat and dairy products, further contributes to the water footprint of agriculture by boosting the production of feed. Irrigation allows increasing and/or securing yields in the context of a changing climate, which is likely to exacerbate seasonal water stress in some areas. This results in the expansion of cultivation of irrigated crops at the expense of rain-fed agriculture (Keys, Barron and Lannerstad 2012).

Despite the development of more sustainable agricultural practices, irrigation is driven by the culture of maximising agricultural productivity, which encourages increasing the use of inputs as long as marginal gains can be achieved (water productivity increases significantly at low yields and tends to stabilise at high yields (Keys, Barron and Lannerstad 2012). Soil degradation through intensive agricultural practices may also contribute to reducing the capacity of soil to naturally store water.

The expansion of irrigated areas may be further driven in certain Member States by the rebound effects of technological improvements, such as increased irrigation efficiency, which may cause either no change or an increase in water consumption. There does not seem to be a consensus in the literature on this issue. For example, EEA (2012b) highlighted that García Mollá (2002) reported that subsidised drip irrigation technologies in the Valencia region of Spain did not lead to reduced application rates, while Candela et al. (2008) reported a tripling of irrigation area following efficiency improvements.

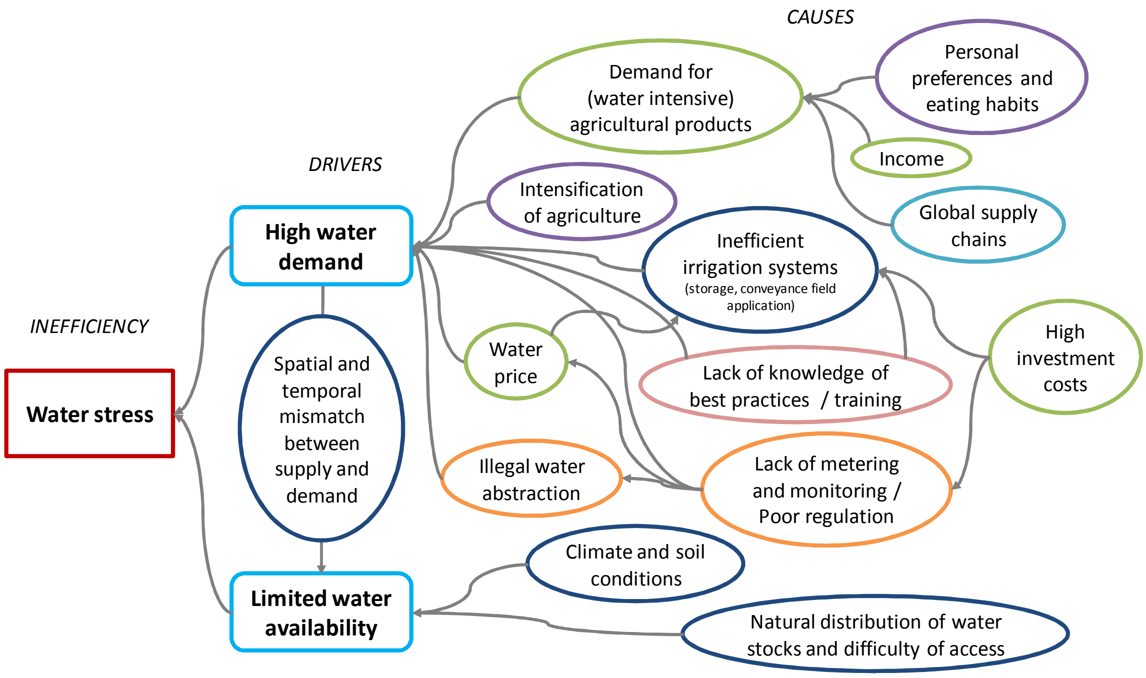
Beyond behavioural, political and market drivers, the high demand of water for irrigation purposes can also be explained by the significant volumes of water that can be lost between the abstraction stage and the delivery to the crops, because of technological shortcomings and lack of knowledge (EEA 2012b). Water losses depend on the performance of technologies in irrigation conveyance on the one hand and in application on the other hand, as well as human factors, such as the correct implementation of such technologies and type of access to water for irrigation. Irrigation conveyance reflects how well an irrigation system performs in transporting water to the plant roots. The types of pipes used significantly influence water losses, through infiltration or evaporation.

Besides irrigation performance, the main limitations of the implementation of such systems seem to be the lack of knowledge about such enhanced techniques and the lack of training to maximise the benefits of such techniques. For instance, geographical areas dominated by smallholder farming systems with little access to enhanced techniques generally experience low water productivity (Keys, Barron and Lannerstad 2012). Research in Crete has also revealed that the technical efficiency of some farmers using drip irrigation systems is low, and that any installation of improved irrigation systems needs to be accompanied by advice to farmers (EEA 2012b). The timing of supply for example can also significantly impact losses (BIO Intelligence Service 2012).

From a supply perspective, overabstraction of water for agricultural purposes can first be explained by shortcomings of water withdrawal licensing or permit procedures in some Member States. The implementation of such permits may be impeded by a lack of implementation of metering - although some EU Member States reported increasing implementation in agriculture (EEA 2012b) - or by metering uncertainties. Combined with the insufficient control of abstraction, this may lead to illegal abstractions.

Water prices may also have a significant influence on water consumption, because they do not reflect water scarcity or other environmental and resource costs (Dworak, et al. 2010)(EEA 2012b). However, water prices would not be a major driver of water inefficiencies in agriculture because of the low price elasticity of the demand. Inefficiencies could be rather linked to water policies and management plans as well as mode of governance (complex and multilayered institutional and governance arrangements for water resources (OECD 2010)).

Figure 38 Drivers and causes of water stress and inefficient irrigation



5.2.5 Nutrient and pesticides losses from crop production

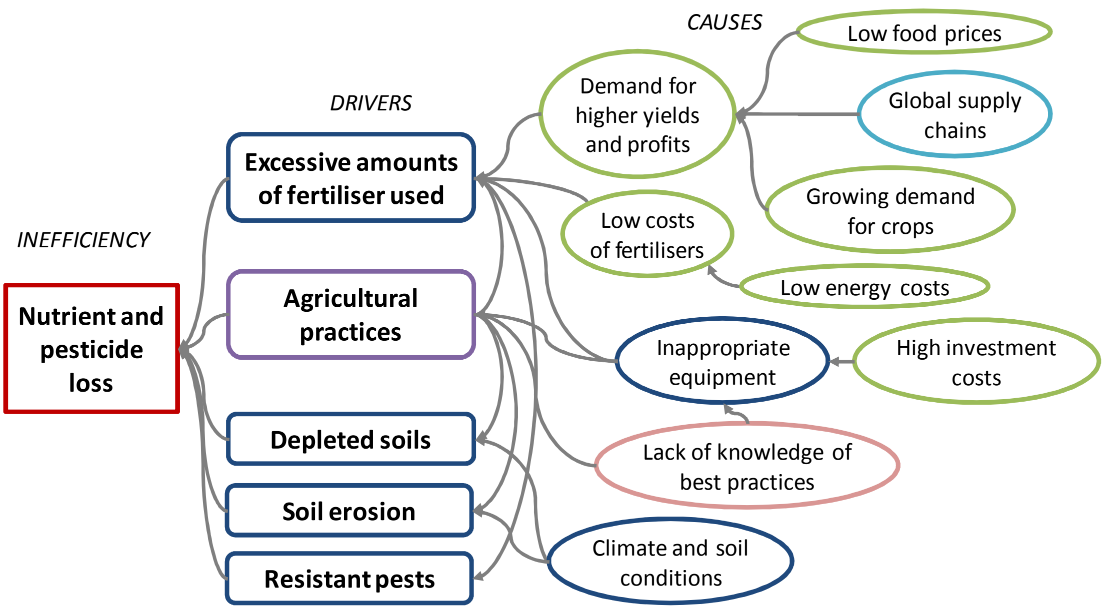
Both fertilizers and plant protection products are used to increase yields (and profits), but often excessive amounts are applied to crops and fields. Fertilizers supply nutrients such as nitrogen (N), phosphorus (P) and potassium (K) that are essential for crops to grow. However, if too much fertilizer is used - or if it is applied incorrectly – the nutrients are either washed away or leached through soil into waterways. Fertilizer runoff causes eutrophication and oxygen depletion in rivers, lakes and oceans. Pesticides are used to protect crops from pests and diseases, but if they are over-applied or incorrectly applied they can result in toxic air, water and soil pollution, which degrades ecosystems and causes biodiversity loss. The inefficient uses of fertilizers and pesticides have similar drivers.

The use of fertilizers in excess is mainly caused by the low cost of energy and fertilizers (especially phosphorus). It is also linked to the lack of knowledge of best practices to obtain the desired yield while optimising the quantity of fertilizers used. Many farmers do not believe that it is possible to reduce nitrogen input without decreasing yields. Applying high rates of fertilizers can also induce an adverse effect. The application of fertilizers can result in a decrease of soil fertility due to high losses of soil elements, inducing a decrease of the yield. Hence, this creates a vicious circle since the depleted soil requires more fertilizers. Similarly, the excessive use of pesticides can result in pests becoming resistance, which decreases the efficiency of the pesticides used.

Agricultural practices, in relation to climatic and soil conditions (Moncrief and Bloom 1999), determine the efficient use of fertilizers since it influences the magnitude of nutrient losses and the associated environmental impacts (Basset-Mens 2005). There are many practices that cause nutrient losses. In addition to the quantity of fertilizer used, which can increase the risk of leaching in case of excess (Czymmek, et al. 2005), the quality of fertilizers and in particular its C:N ratio, must be chosen carefully in order to avoid excess of nitrogen and leaching (Basset-Mens 2005). Tillage techniques drive soil aeration and thus will influence GHG emissions (in the case of saturated soil) or ammonia emissions that cause acidification (in the case of well-ventilated soil) (INRA 2012)(Alterra 2012). The spraying of pesticides also increases the risk of pesticides drifting beyond the targeted crop area.

Inappropriate equipment is another factor contributing to inefficient fertilizer and pesticide application and management. The high investment costs of equipment are the main cause for use of inappropriate equipment.

Figure 39 Drivers and causes of nutrient and pesticides losses



5.2.6 Other inefficiencies

While the inefficiencies discussed above represent some of the key areas for improving resource efficiency related to food, there are many other areas of inefficiency that can be mentioned:

- Other agricultural practices that lead to inefficient use of resources:
    - **Inefficient livestock management** - livestock production represents 9% of total GHG emissions in Europe (Leip, et al. 2010) mainly due to enteric fermentation (i.e. methane emissions from cattle, sheep and goats) and manure. Furthermore, livestock production is responsible for a third of the nutrient loads of nitrogen and phosphorus in freshwater resources (Steinfeld, et al. 2006). The magnitude of the impacts is linked to rearing management, in particular inappropriate manure storage and management, feed choice and excessive use of veterinary products (Audsley, et al. 2009). Regarding feed choice, livestock retain between 23 to 45% of the nitrogen intake. Hence,

adjusting feed according to growth stage or physiological condition could help decrease excretions like nitrogen and thus emissions (Dourmad, Rigolot and Jondreville 2009) by reducing protein content, increasing the digestibility of nutrients, encouraging multiphase feeding and decreasing heavy metals supplementation. Some of the reasons for these inefficiencies are lack of knowledge of best practices, costs of special feed, and inappropriate equipment and facilities for collecting and storing excrements. Intensive livestock production may be efficient, but the concentration of animals can put a severe load on local ecosystems.

- **Land management** – there is on-going debate regarding sustainable land management, which of the two competing approaches is the more resource efficient: 'land sparing' or 'land sharing' (Phalan, et al. 2011). 'Land sparing' focuses on compact urbanisation and intensification of agriculture (increasing yields per hectare), with a view to reduce the area needed for housing and agricultural production. This is in principle beneficial for energy efficiency and carbon storage, and leaves space for natural ecosystems and nature development. On the other hand it may increase local pressures on soil, water and air and affect human health in urban areas. 'Land sharing' does the opposite: it tries to accommodate multi-functional land use, by supporting extensive agriculture in marginal areas and attempting to achieve biodiversity goals on farmland. In a European context, this approach applies to the conservation of high nature value farmland and the adoption of agri-environment measures. The choice between the two involves complex trade-offs with regard to ecosystem resilience and resource efficiency that require careful consideration. For example, where low-input, extensive farming appears essential to tackle environmental impacts, it results in lower yields. There will not be enough land for this type of farming to supply sufficient food if current production and consumption patterns continue. Dietary shifts, more effective distribution chains and food waste prevention would potentially have to compensate for lower yields.

- Manure is also insufficiently valued, for example as a fertilizer or to produce energy. This is mainly due to low demand, a lack of appropriate knowledge and technology. Globally there is a lack of reuse of manure in agriculture and almost half of the produced manure does not return to crop production which in turn only provides one third of the phosphorus put into arable soils. In the EU-27, manure provides about two thirds of the phosphorus to soils which is higher but there is still a potential for improvement. The reuse of humanure from waste water treatment plants and untreated sewage are almost negligible both globally and in the EU. These inefficiencies are related to the use, reuse and recycling of phosphorus.

5.2.7 Summary

The reasons for inefficiencies related to food consumption are mostly behavioural and informational. Food-related behaviour patterns are complex, habitual and strongly influenced by marketing, economic and socio-cultural pressures. In general, all actors of the food life cycle have low awareness on environmental impacts and good practices due to the lack of information.

Key inefficiencies of food production are related to agricultural practices such as food losses, inefficient irrigation and nutrient and pesticide losses, and fishing such as overfishing and discards. These inefficiencies are magnified by behaviour at the retail and consumption stage. Inappropriate diet and food choice increases the demand for food with high environmental impacts such as beef, cheese and predator fishes. This induces a permanent quest for increased productivity that can lead to unsustainable agricultural practices. Food waste, which represents one third of the food produced within the supply chain, is also a strong factor of resource efficiency since it cumulates all the upstream inefficiencies

5.3 Transport

While a range of inefficiencies can be observed within the transportation sector, the key inefficiencies have been grouped into several main areas, which reflect a combination of issues and for which there may be potential for efficiency improvement via effective policy mixes.

Table 5 The main areas of inefficient use of resources related to transport

Area of inefficiency	Life cycle stage	Key actor(s)	Main drivers	Key relevant resource
Vehicle design and fuel efficiency	Production and construction; impact on use and maintenance	Auto industry	Technological barriers, path-dependencies, existing business models, low regulatory ambition	Energy
Driving inefficient road vehicles and driving behaviour	Use and maintenance	Consumers / users	Low fuel costs, user behaviour, travel patterns, lack of information	Energy
Choice of transport modes (freight and passenger)	Use and maintenance	Users, private sector, public authorities	Limited availability and high costs of high-efficiency vehicles, low fuel costs, lock-in effect	Energy
Non-optimization of vehicle occupancy (volume / weight)	Use and maintenance	Users	Varying demand for transport, standard business practices, personal preferences, availability of vehicle sharing	Energy
Distance travelled	Use and maintenance	Users	Urban planning, long commute, holiday culture	Energy
Material intensive transport infrastructure	Production and construction	Public authorities	Standards and regulations, infrastructure planning, maintenance, low use of recycled materials	Materials

Please note that for all illustrations of inefficiencies in this section, the six main categories of driving forces are colour coded as per the legend in Figure 30.

Inefficiencies in energy use in transport can be found in any of the three parameters which contribute to energy consumption in transport (IEA 2010):

- The transportation needs (societal/structural aspect), which may be reduced or optimised.
- The user through the choice of transport mode/vehicle and driving (behavioural aspect).
- The intrinsic technical properties of the vehicle (technical aspect).

5.3.1 Vehicle design and fuel efficiency

A vehicle's fuel efficiency is to a large extent determined in its conception and design phases and limited by the choice of engine technology. For traditional petrol and diesel cars, for instance, only about 14-26% of the vehicle's fuel intake is used to move it, while the rest is lost to engine and other inefficiencies (US Department of Energy, www.fueleconomy.gov). Fuel economy therefore has significant potential for improvement, notably via improved vehicle design and different power-train technologies (e.g. electric and hydrogen/fuel cell).

Some recommended principles of vehicle design include reducing the frontal area per person; reducing the vehicle's weight per person; making the energy chain more efficient; improving the engine or power-train; and using regenerative braking(JRC 2008) (MacKay 2008). Despite availability of relatively efficient vehicles on the market, consumers do not consistently make optimal vehicle choices (for example, by choosing clean vehicles over internal combustion engines (ICEs) or by making relatively efficient choices within the range of available ICEs). For instance, today's car fleet is still heavily dominated by ICEs, though McKinsey (2011) estimates that electric and hybrid vehicles could represent over 60% of new light-duty vehicle sales in 2030.

A study which performed a total life cycle[14] comparison of ICEs versus fuel cell vehicles (FCVs) in the US and Canada confirmed that FCVs were generally the better choice in terms of energy consumption and emissions (except when hydrogen is produced using coal as the primary energy source) (Zamel and Li 2006). For example, in the US, total life cycle energy consumption of FCVs with hydrogen production from steam[15] was about 709 GJ, compared to 1379 GJ for ICEs, indicating potential efficiency gains in the transition to cleaner vehicles. Besides, MacKay estimates that electric vehicles (using 15 kWh per 100 km) can be five times more efficient than a baseline fossil fuel car.

Potential for fuel efficiency improvements exists for all vehicle sizes, e.g. lightweighting strategy. For light-duty vehicles, McKinsey estimates that by 2030 automakers could reduce fuel consumption by 40% compared to today's levels (4.3 litres/100 km vs. 7 litres/100 km today) (McKinsey Global Institute 2011). According to the IEA, there is an even more ambitious potential of up to 50% for cost-effective technical improvement in new vehicle fuel economy by 2030, provided strong policies that maximise technology uptake and minimise fuel economy losses due to increases in vehicle size, weight and power are implemented (IEA 2009a). Car manufacturers already appear ready to commit to substantial improvements in fuel efficiency over the next decades, and current policy paths could capture as much as 80% of this potential. For medium-duty and heavy-duty trucks, potential for fuel consumption reduction is at 11% and 13%, respectively.

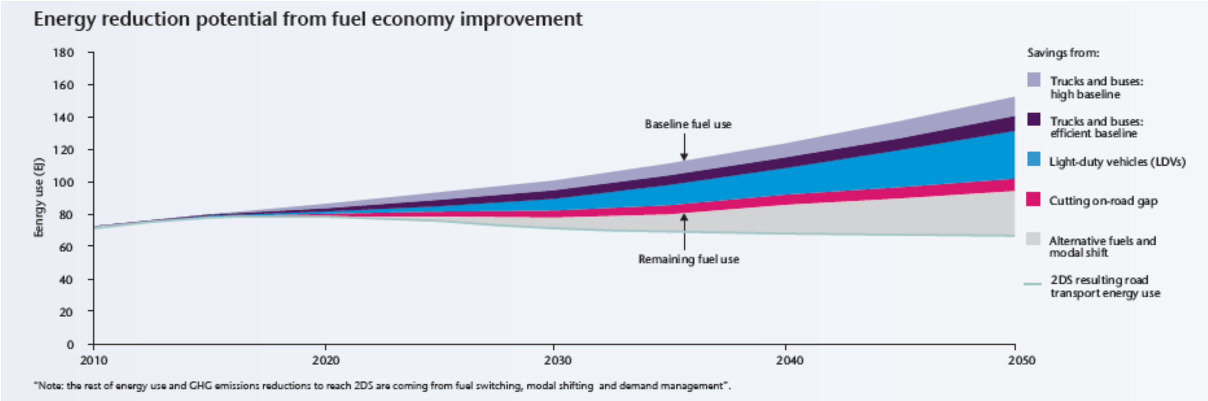
---

[14] Total life cycle is defined here as the sum of the vehicle life cycle and the fuel life cycle

[15] Hydrogen from the steam reforming of natural gas in a central plant

According to MacKay (2008), there is limited scope of improving the fuel efficiency of individual planes and ships. The potential for efficiency lies in replacing the older planes and ships in operation with the latest models and operating them more efficiently (McCollum, Gould and Greene 2009) – see the next section.

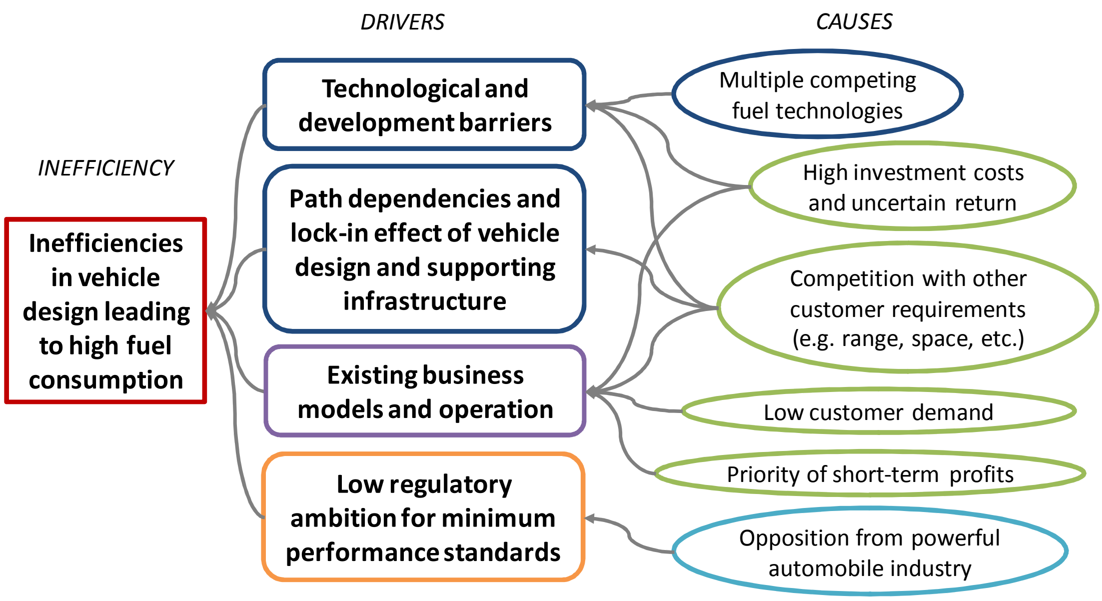
Figure 40 Energy reduction potential from fuel economy improvement



Source: (IEA 2012).

High R&D investment costs can impede further voluntary efficiency improvements amongst vehicle manufacturers. Legal considerations such as a lack of ambitious regulatory technology performance standards (e.g. fuel efficiency standards for vehicles, vehicle accessories performance standards) can also contribute to the non-optimal performance of vehicles put on the market and purchased (IEA 2010).

Figure 41 Drivers and causes of inefficient vehicle design and fuel consumption



-

5.3.2 Driving inefficient road vehicles and driving behaviour

The use of inefficient vehicles is a key contributor to high energy use in the transportation sector. The continued use of inefficient vehicles is driven by a combination of different factors. Even through manufacturers have increased the fuel efficiency of their vehicles, the rate of uptake of new technologies is sometimes slow (e.g. electric cars), or the increase in efficiency is offset by an increase in engine power (IEA 2012). According to the IEA, most key technologies for improving the efficiency of various sized vehicles already exist and are often cost-effective. However, their market penetration remains low due to a variety of barriers, including market failures such as relatively low fuel prices, high discount rates, high investment costs and lack of information; behavioural concerns such as anxiety over the range of electric cars, and the lack of infrastructure such as fuelling stations for hydrogen cars (IEA 2012). Further, market failures such as principal-agent situations (e.g. subsidized company cars), create split economic incentives which lead to inefficient choices or uses of vehicles. Of all passenger cars in the Netherlands, 11% are classified as company cars, which consume 21% of the total energy consumption by passenger cars (Graus and Worrell 2008). As company cars are newer, operate more diesel engines, but are also larger, the fuel efficiency is slightly worse than that of private cars. Company cars seem to drive longer distances for commuting than the national average of private cars. Together, this might result in a net 1–7% increase of all fuel use of passenger cars in the Netherlands. Economic reasons are highly significant, especially for private users who are less sensitive to these parameters than commercial vehicle operators. Specific for the trucking industry, around 91% of trucking fuel consumption in the US (i.e. 18% of total fuel consumption) is exposed to driver-usage principal-agent problems (Vernon 2012).

In addition, efficient choices may in some cases be prohibitively expensive resulting in lengthy payback periods. Hybrid and electric vehicles remain more costly today than ICEs, due largely to high costs of batteries. High battery costs are partially offset by lower transport or operational costs of hybrid and electric vehicles, which currently benefit from lower taxes on electricity compared with fuel (McKinsey Global Institute 2011). However, the remaining price difference between traditional and alternative vehicles, or between the most fuel efficient cars and the others, lowers the attractiveness of clean vehicles in the absence of financial incentives (e.g. tax deduction, fee based on fuel efficiency performance).

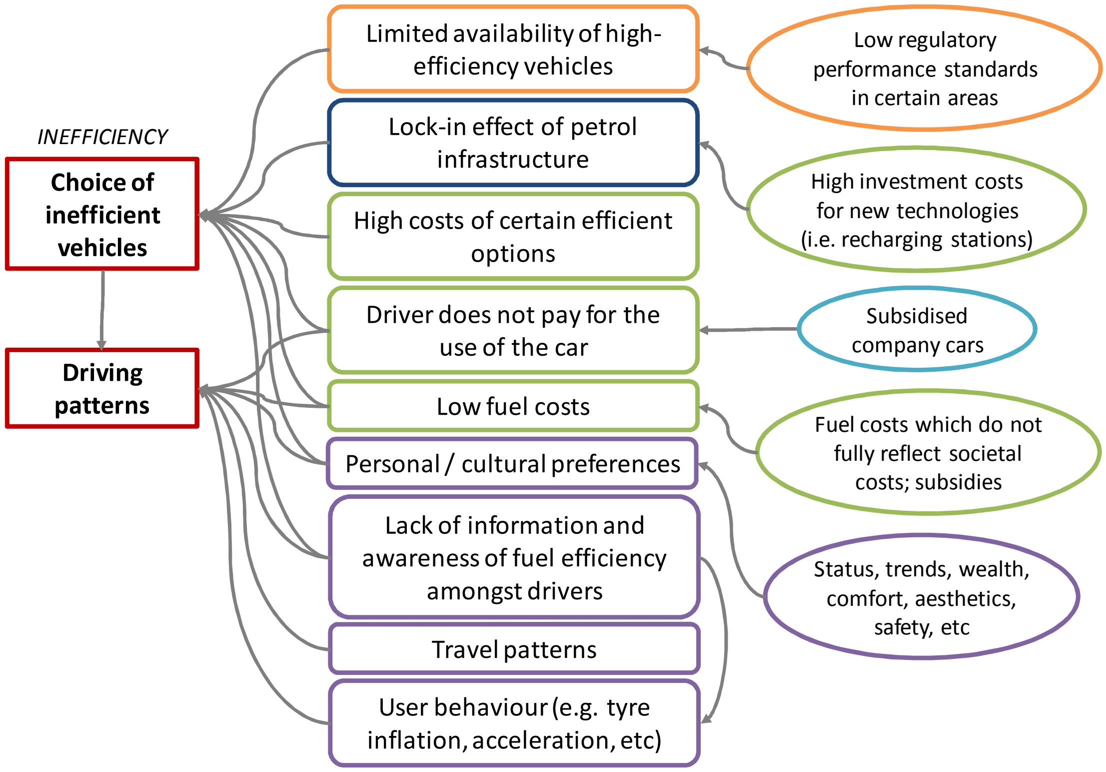
Development of infrastructure to support the uptake of new more fuel efficient technologies is in turn impeded by the need for substantial upfront investments.

At the consumer level, information asymmetry and lack of awareness or information about relative efficiency of different vehicles or accessories (like low rolling resistance tyres) can also help account for inefficient choices (Defra 2008). Consumers may face a lack of clear and consistent communication throughout the value chain (e.g. EU/international labelling schemes) and clear and consumer-friendly labelling systems which would facilitate comparison between vehicles. The lack of ambitious legal requirements for fuel efficiency standards in vehicles also play a role, as consumers are not limited in their choices of vehicles.

Finally, personal and cultural preferences, values and paradigms can play a significant role in vehicle choice. Car purchasers may have a variety of selection criteria besides fuel efficiency, including such personal considerations as comfort, aesthetics, brand loyalty, habit, etc. Further, fashion, social identity and cultural values can impact choices significantly, and even those motivated to engage in sustainable behaviour may find themselves pitted against dominant societal structures and values (Jackson 2009). Vehicles in particular can serve as status symbols, with larger, often inefficient vehicles reflecting affluence or position in society. It should be noted, however, that societal paradigms can also work in favour of efficient vehicles, whether due to fashion trends or lasting evolution of values (for example, the rise in popularity of the hybrid cars (e.g. the Toyota Prius) as reflective of a particular ideology).

Inefficiencies may also result from the non-optimal use of the vehicles by users, not familiar with eco-driving best practices or proper maintenance of their vehicle for instance. Eco-driving is estimated to represent a 5%-10% energy savings potential, through optimised gear changing, avoided vehicle idling, avoided rapid acceleration and deceleration, efficient speeds, etc. (IEA 2010), while MacKay mentions a 20% reduction in fuel consumption. Lack of information and training are underlying causes of this behavioural driver. One example of improper maintenance is the common under-inflation of tyres resulting in higher fuel consumption, as roughly 20% of a motor vehicle's fuel consumption is used to overcome rolling resistance of the tyres (IEA 2005).

Figure 42 Drivers and causes of driving inefficient vehicles and driving behaviour



5.3.3 Choice of transport modes (passenger and freight)

Choice of transport mode for transporting both passengers and freight is a key determinant of overall efficiency of the transportation sector. It is driven by several factors including economic ones such as income and prices; demographic such as family size and structure; spatial and infrastructural such as population density, distance between home and work place; and, cultural factors such as image and status (EEA 2008).

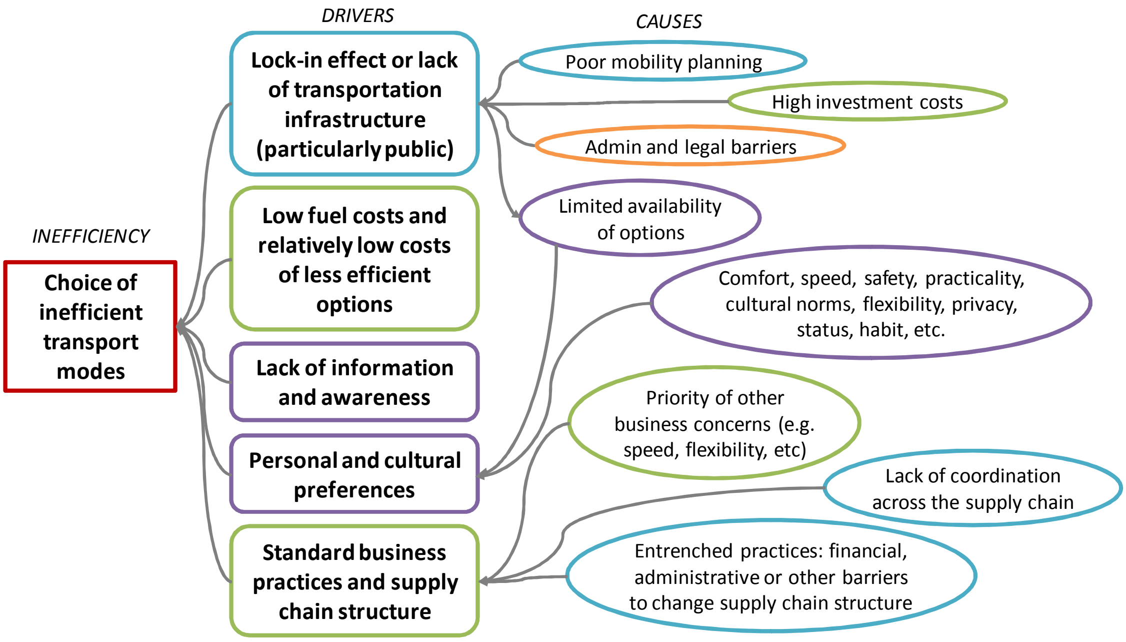
Significant discrepancies exist between the fuel efficiency of different transport modes. For example, according to McKinsey (2011), freight transport (including air) accounts for over one-third of oil consumption in the transportation sector, but efficiency measures could tangibly lower this demand, notably by transitioning greater volumes towards shipping and rail, which are significantly more energy-efficient than road or air. Rail requires around 6.8 litres of fuel per 1000 revenue tonne-kilometres, and shipping requires about 20 litres, compared to about 50 litres for trucking (McKinsey Global Institute 2011). Choice of transport mode is also a key efficiency factor in passenger transport, where air and private road transport is less efficient than rail, public transportation or non-motorized modes (at full occupancy – see the next section). Nonetheless, use of inefficient modes such as road freight or private vehicles remains widespread, whether or not substitutes exist. A combination of factors influences the choice of transport mode both in freight and passenger transport.

Infrastructure limitations are an important obstacle to a generalized shift towards higher-efficiency modes. Poor urban mobility planning, inadequate public transportation systems, lack of adapted infrastructure for non-motorized modes, lack of green corridors for freights and insufficient connections between efficient modes of freight and passenger transport all reduce transportation options. Urban mobility planning plays a paramount role (at a very high level) in the organisation of transport: for instance, it may contribute to the reduction of traffic jams which waste substantial amounts of energy as most drivers do not turn off their engines. To illustrate the effect of a switch from cars to coaches, vacuuming up 40 people using individual cars into a single coach frees up two kilometres of road (MacKay 2008). Inefficient freight transport may also be due to organizational issues such as a lack of effective freight distribution centres and intelligent transport systems. It should be noted that developing adequate infrastructure and overcoming inertia in structures requires significant up-front investment, which limits its feasibility and attractiveness. Economic constraints are therefore fundamental to transportation mode choice. The development of adequate multimodal infrastructure may also in some cases be limited by administrative or legal obstacles. Simplifying and standardizing processes for building and using cross-border infrastructure could help boost infrastructure development.

Economic considerations are also relevant on the part of the individual making the choice between different modes. Fuel prices are often too low (due in part to fuel subsidies), thus providing little economic incentive for shifts towards energy-efficient modes of transport. In passenger travel, relatively efficient modes of travel may not always be the most economically attractive, for example in areas with high public transportation costs, costly park-and-ride schemes or low road tolls; or in the case of budget airlines which make air travel more affordable than rail alternatives. Similar economic considerations apply in freight transport. Thus, market failures result in a higher than optimal level of road transport use (IEA 2010), also highlighting a lack of positive economic incentives. In addition, many supply chains today are based primarily on road freight, and revamping them to shift to other modes may represent a significant sunk cost for businesses (McKinsey Global Institute 2011).

On the user side, entrenched behaviour and lack of information about alternatives further drive inefficient choices. Disseminating information about availability of efficient transportation options could therefore help change behaviour. Finally, personal and cultural preferences and values contribute substantially to transportation choice. A variety of considerations such as comfort, safety, flexibility, need for privacy, speed of travel, status or habit play into passenger transportation mode choice. For freight travel, energy efficiency considerations may be secondary to other business-related concerns, such as speed of delivery. Optimizing the energy efficiency of supply chains may be further complicated by the need for cooperation between a variety of functions within the business (supply chain, sales, product development, etc), each of which has its own priorities (McKinsey Global Institute 2011).

Figure 43 Drivers and causes of choosing inefficient modes of transport



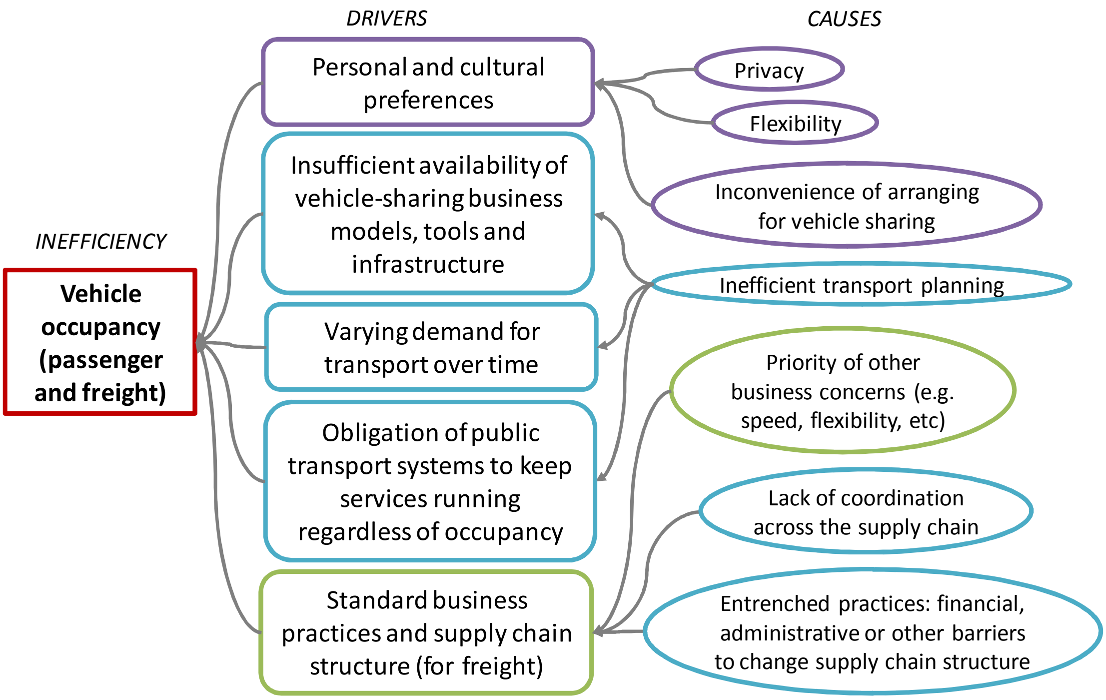
5.3.4 Non-optimization of vehicle occupancy (volume / weight)

Both for passenger travel and freight transport, energy efficiency is determined not only by vehicle fuel efficiency, but also by occupancy and distance travelled (see the next section). Losses in efficiency therefore occur when vehicles are not utilized to their full volume or weight capacity. Sharing vehicles between multiple passengers or optimizing freight volumes could help gain in energy efficiency. While adding passengers or more freight increases fuel consumption due to the added weight, this effect is minimal (Sivak 2013). A recent US study (Sivak 2013) illustrated the dampening effect of reduced vehicle occupancy on efficiency gains. The study found that in the US, overall vehicle fuel economy of the entire vehicle fleet improved by about 40% between 1970 and 2010. However, as vehicle load decreased from 1.9 to 1.38 occupants in the same timeframe, *occupant* fuel economy improved by only 17%.

Behavioural reasons are largely responsible for occupancy inefficiencies in low-volume passenger travel. Low occupancy may be more convenient or more comfortable, or passengers may simply prefer to have some alone time in their vehicles.

For high-volume passenger travel (public transportation, rail, air, etc), sub-optimal volumes may be due to low use, which in turn is linked to the various drivers of choice of transport mode discussed in section 5.3.3. They may also be linked to organizational issues such as poor planning or structural inflexibility, as transportation systems (number and frequency of vehicles) may not be properly adapted to volume demand, and as public transportation must run regardless of whether the vehicles are empty or not. Sub-optimal volume optimization may also be due in part to a lack of supporting systems and structures (for example, car sharing or car pool lanes). For freight, organizational and business considerations (deadlines for delivery, etc) may lead to sub-optimal volume distribution (Oakdene Hollins 2011). Businesses could optimize their freight volumes by, for instance, using consolidators to avoid half loads, and minimizing volume size and mass via better material selection and design

Figure 44 Drivers and causes of non-optimal vehicle occupancy



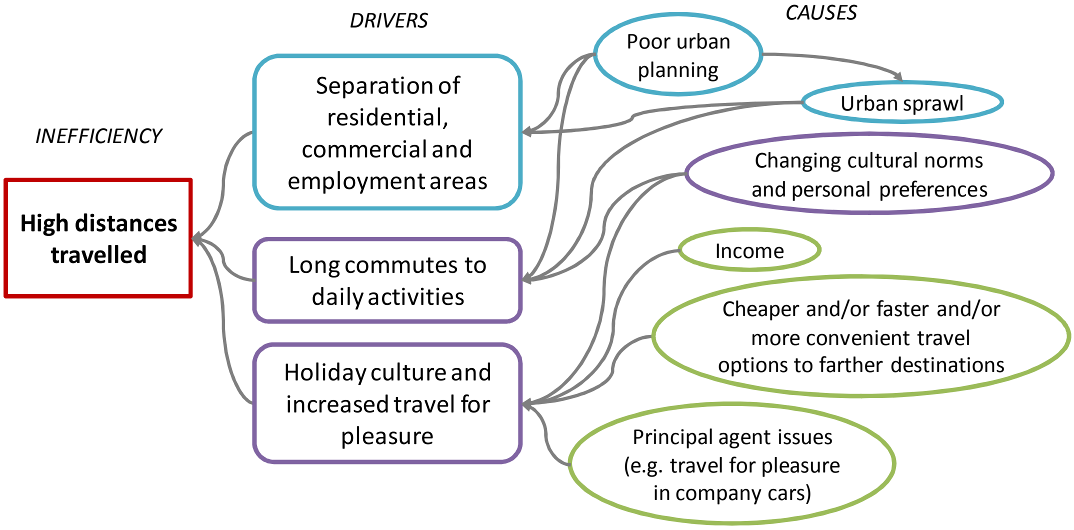
5.3.5 Distance travelled

Reducing travel distances is identified as one of the principles for more efficient transport (MacKay 2008). Excessive and/or avoidable travel increases fuel demand unnecessarily and could be reduced. Reducing overall transport demand by intelligent urban and regional design (compact cities and a polycentric regional development) has an important role to play in reducing inefficiencies. Integrating sustainable mobility concepts into urban planning is thus crucial. A recent study on fuel economy in the US between 1970 and 2010 found that an upward trend in distance travelled, along with falling vehicle occupancy for the same time period, led to an increase of 53% in total amount of fuel used, despite a 40% improvement in fuel efficiency (Sivak 2013). This has also been visible in the low-cost air transport sector, which has been an important driver of airplane fuel efficiency, but also the growth in the number of trips and the trend towards more frequent and shorter stays (EEA 2012a).

Several factors contribute to increased travel distances. Organizational issues such as urban sprawl (e.g. relocation of retailing / office space out of town) and lack of nearby amenities (stores, pharmacies, hospitals, schools, post offices, etc.) have increased commuting distances. Commuter subsidies and company car taxation also contribute to increased travel (Graus and Worrell 2008). The development of home-working or e-commerce may contribute to reduced energy consumption for transport though trade-offs are possible (e.g. increased delivery, or building energy use for heating).

Principal-agent problems factor in, for example in the case of favourable taxation rules or otherwise favourable pricing schemes for company cars, which may lead to excessive use (Copenhagen Economics 2010). Inefficient price signals, such as low fuel costs, low road tolls or cheap car parks, can also induce inefficient behaviour. Behavioural reasons, such as increased travel for pleasure and holiday culture, have also made longer travel distances the norm.

Figure 45 Drivers and causes of increased travel distance



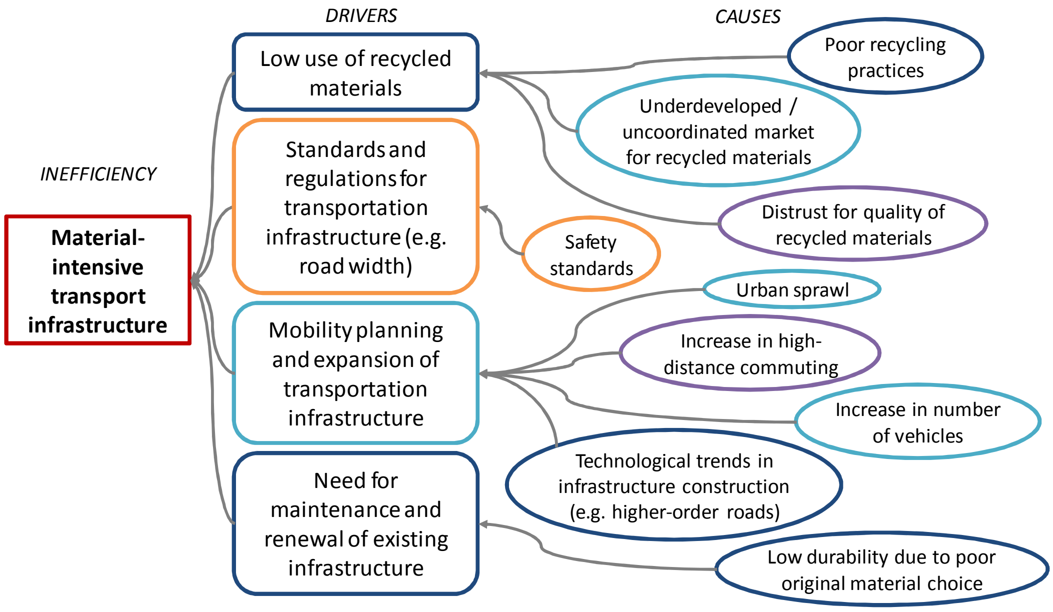
5.3.6 Material intensive transport infrastructure

The Wuppertal Institute analyzed material flows in German transport infrastructures (including streets, railways, waterways and related civil engineering structures), looking at the material stock and annual material flows for maintenance and expansion (Wuppertal Institute 2010). The project found that mineral material stock in the road network was significantly higher than for other infrastructure systems. Further, in contrast with other infrastructure systems, annual material flows in transport networks in Germany result mainly from maintenance rather than expansion, due in part to a slowdown in expansion of certain kinds of transport infrastructure (e.g. rail). Overall, material use in transport systems is significant, particularly for certain types of infrastructure (e.g. motorways, which were found to be the most material-intensive road type).

Excessive material use in transport infrastructure may result partly from poor choice of materials, which could be optimized both via increased use of substitute materials (for example, to improve durability and reduce frequency of repair) and via increased use of recycled materials and secondary raw materials in construction and maintenance, coupled with improved recycling practices at end-of-life. LCAs can help determine the material demand reduction potential resulting from the use of alternative and recycled materials. High material use can also sometimes result from constraining safety regulations, for example in the case of guidelines mandating wider driving lanes.

Material use trends are strongly shaped by past and present infrastructure and planning decisions. The maintenance and renewal of existing roads and railway lines leads to a dependency on high inputs of construction minerals and metals just to maintain present levels of infrastructure provision (BIO Intelligence Service 2011a). Further, increases in material stocks increase material demand for future maintenance and repair. Ongoing expansion of transportation infrastructure in most EU countries, as well as trends towards higher-order roads, electrified two-track railway lines and expanding cities, are contributing towards increased material consumption (BIO Intelligence Service 2011a).

Figure 46 Drivers and causes of material intensive transport infrastructure



5.3.7 Other inefficiencies

While the inefficiencies discussed above represent some of the key areas of potential resource productivity gains in the transport sector, additional areas of secondary significance should be kept in mind. These inefficiencies can include, among others:

- **Energy use during vehicle assembly and materials production:** Together, vehicle materials production and component manufacturing and assembly can account for a significant proportion of an electric vehicle's total energy use (Sullivan, Burnham and Wang 2010). A recent study found that while electric vehicles offer significant GHG emissions reduction potential during the use phase, their other environmental impacts (eco-toxicity, metal depletion, etc) are high during production (Hawkins, et al. 2012). The vehicle production supply chain must therefore be taken into account to assess the full impacts of the vehicle.

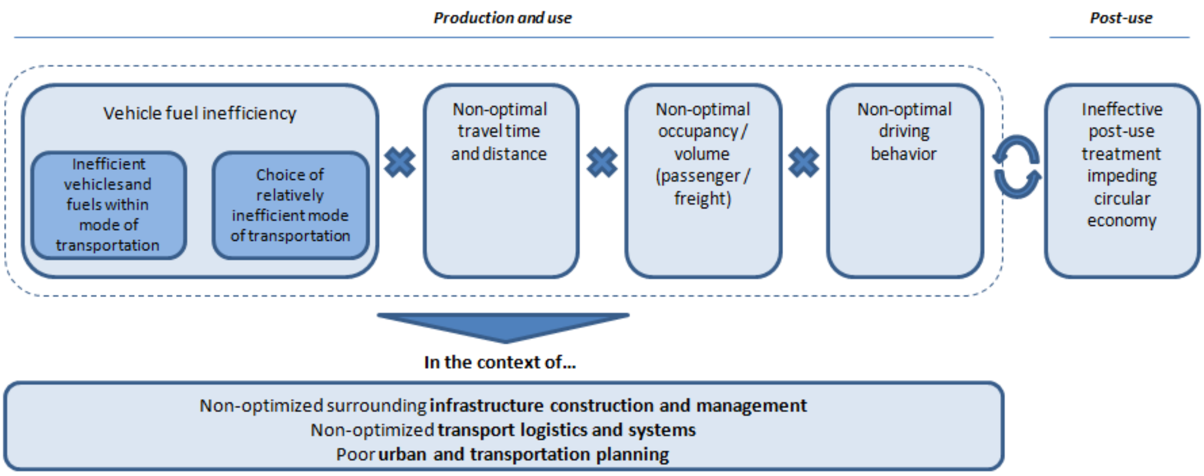
- **Inefficiencies in the end-of-life phase:** The end-of-life phase holds potential for improving resource productivity by closing the material loop. Recycling and especially refurbishment can help increase vehicle lifetimes (although this might limit the uptake of newer more fuel efficient vehicles), significantly reduce material demand and help lower energy use and GHG emissions throughout the vehicle life cycle (Ellen MacArthur Foundation 2012). Lack of effective collection systems and professional refurbishment systems, as well as coordination problems in end-of-life, can account for inefficiencies in vehicle collection and treatment.

5.3.8 Summary

Key inefficiencies in the transportation sector are most often related to energy use, and are largely concentrated in the use and maintenance phase.

Key inefficiencies in energy demand can be observed both within the technical properties of vehicles and the choices and behaviour of users – notably with respect to choice of vehicle and transport mode, distance travelled, occupancy and driving behaviour. The figure below maps the interaction between some of the key components that contribute to energy inefficiency in the transportation sector. Vehicle fuel inefficiency, as well as non-optimal travel distance, occupancy and driving behaviour together help create excessive overall energy demand of a vehicle in use. At the same time, inefficiencies in the post-use phase can impede the development of a circular economy for vehicles. Surrounding infrastructure and systems display further inefficiencies of their own, while also impacting user-related inefficiencies. Acting on any of these components can help generate efficiency gains.

Figure 47 The main components for increasing resource efficiency in transport



Inefficiencies in the transportation sector are driven by a combination of drivers across the broad categories discussed in section 5.1. While technical issues impose certain baseline constraints on resource efficiency in the sector, further inefficiencies are driven to a significant extent by behavioural, socio-economic and institutional/organisational issues.

5.4 Buildings

Several key areas of inefficiency can be observed in the building sector, which are concentrated in the construction and use life cycle phases.

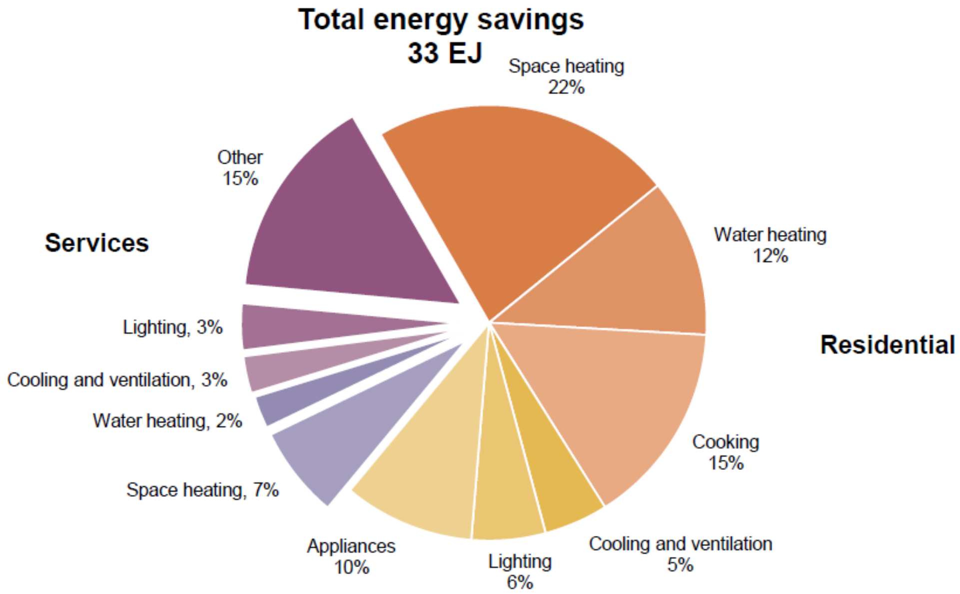
Table 6 The main areas of inefficient use of resources related to buildings

Area of inefficiency	Life cycle stage	Key actor(s)	Main drivers	Key relevant resource
Building design and choice of materials	Production and construction; use and maintenance / refurbishment	Construction, architecture and design professionals	High investment costs, low demand, low regulatory ambition, lack of knowledge, fractured decision making	Energy
Inefficiencies in heating and cooling	Use and maintenance	Producers, users	Poor building design, inefficient heating and cooling systems, user behaviour	Energy
Inefficiencies in lighting, appliances and electronics	Use and maintenance	Producers, users	Ownership of equipment and appliances, lock-in effect, low uptake of efficient technologies, user behaviour	Energy
Number of people per household / area per person	Use and maintenance	Users, developers, public authorities	Income, urban sprawl, comfort, changing social and cultural norms, demographic trends	Energy
Urban sprawl	Production and construction	Public (local) authorities construction, architecture and design professionals,	Demand for housing, subsidies for home ownership, urban planning, transport networks, price of agricultural land	Land
Water consumption and losses in buildings	Use and maintenance	Construction professionals, users	Income, urbanisation, household size, low uptake of water saving equipment, water prices, low reuse of water	Water

Please note that for all illustrations of inefficiencies in this section, the six main categories of driving forces are colour coded as per the legend in Figure 30.

Some of the most significant resource inefficiencies in the building sector concern energy use, which has substantial potential for improvement (JRC 2008a). According to IEA scenarios, some of the greatest potential for building energy savings lies in the residential sector (70%), and particularly in residential heating. In terms of actual energy consumption, space heating accounts for 68% of household energy consumption in the EU-27, followed by water heating and appliances/lighting (Odyssée Database 2011). The majority of impacts are caused by energy use while the houses are in use, while around one fifth are caused during their construction (EEA 2012a).

Figure 48 Buildings sector potential energy savings by sector and end-use



Source: (IEA 2013)

5.4.1 Building design and choice of materials (original construction and subsequent retrofitting)

Building design and choice of materials both play a role in shaping a building's energy performance. Various aspects of building design, such as level of insulation and envelope structure, air flows, ventilation, use of passive heating and cooling or day lighting, help determine the building's artificial heating, cooling and lighting energy needs (von Weizsäcker, et al. 2009) (IEA 2011).

Building materials also have a significant impact on a building's life cycle energy use via their embodied energy (the energy associated with extracting, processing, manufacturing and delivering materials) and their contribution to the operational energy demand of the building.

According to the JRC, on average about 20% of a building's energy consumption throughout its lifecycle lies in the embodied energy of its materials and components (Van Holm, et al. 2011). As building operational energy performance increases, this share grows, and may reach 50% for passive houses. The contribution of embodied energy occurs primarily via three categories of materials: 1) materials with low embodied energy but which are used in large quantities (ex: concrete, brick); 2) highly processed materials used in lower quantities (ex: steel, aluminium); 3) layers that need to be frequently replaced (ex: plastics, ceramic tiles).

Further, materials have an impact on buildings' operational energy demand. According to the JRC, buildings' operational energy use is largely determined by two elements: the passive performance of building insulation and materials, and the active influence of technical systems together with user behaviour (Van Holm, et al. 2011). The technical properties and combinations of materials used in construction therefore play an important role in determining overall building energy performance during its lifetime, particularly given that almost 35% of building energy use is directly connected with losses through the envelope or infiltration (for well-insulated buildings; higher for most existing buildings) (Van Holm, et al. 2011). A variety of materials can play a role, including structural materials, insulation materials, glazings, coatings, adhesives, finishes and materials for passive solar heat collection.

Significant potential exists for improving building energy efficiency via improved design and material use. For example, today it is possible to construct new buildings which use less than 10% of the energy of typical designs, and in some cases net zero-energy or even net-positive designs are possible. For existing building stock, effective retrofitting can save up to 90% of their thermal energy use (IEA 2012a).

The design and material choices made in construction are driven by a variety of constraints and considerations:

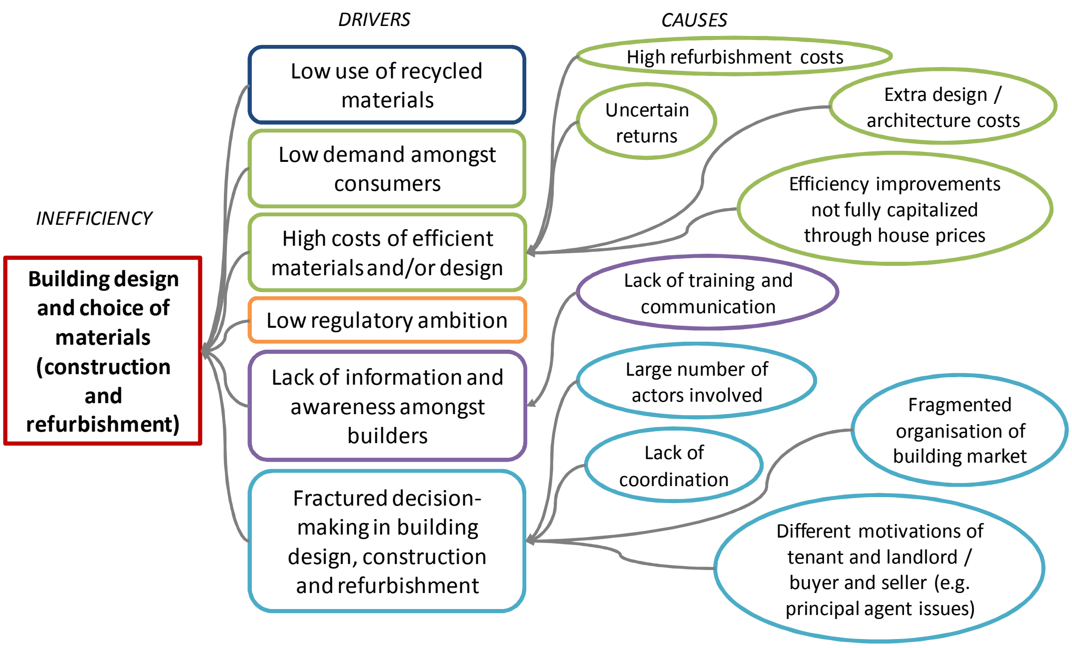
- **Technical properties** of materials limit their basic energy efficiency potential. These technical limitations may be due in part to insufficient investment in R&D aiming to develop new technologies, such as nanotechnologies or hybrid materials, which could help boost energy efficiency of materials without compromising structural reliability (Van Holm, et al. 2011).
- In making certain design or materials choices, construction sector professionals are also driven by **economic considerations.** For example, since energy efficiency improvements are not fully capitalized through house prices, sellers do not adequately invest in energy efficiency (Amecke 2012). Further, prices of materials or design choices must be taken into account during the design and construction phases.
- Economic considerations aside, building designers have a variety of **additional considerations** in mind when making choices about design and materials, which may play a more significant role in decision making than energy efficiency. For example, energy performance of building materials must be considered alongside structural, durability and aesthetic characteristics to determine the best choices for a particular building.
- Inadequate **regulatory measures** (such as building codes or minimum energy performance standards) can also help explain inefficient choices in building construction and retrofitting. The Energy Performance Building Directive (2010/31/EU) requires Member States to apply minimum requirements on the energy performance of new and existing buildings when undergoing major renovation and technical building systems. At the same time, legal requirements such as historic preservation stipulations may also hamper efficient refurbishments initiatives (Weiss 2012).
- **Behavioural reasons** also play a role. For example, old buildings may not necessarily be retrofitted to high-performing standards for reasons that may include

loss of storage space, as well as concerns about disruption and construction mess (Caird 2008)(Weiss 2012). Lack of **awareness or training** amongst building professionals about sustainable construction creates further obstacles to efficient construction.

- At an **organizational level**, fractured decision-making which examines components separately, rather than taking a whole-system approach, can impede efficiency. This can be due largely to the organizational set-up of the building sector, which is a fragmented market in which several actors may be making decisions in parallel with limited communication, and which typically doesn't involve end-users. Holistic design solutions, which keep in mind the linkages between different systems and technologies, and which involve various actors at the design, construction and refurbishment stages, can offer some of the greatest potential for efficiency (von Weizsäcker, et al. 2009).

A holistic approach is also important for optimizing choice of materials, as it is important to consider the trade-off between embodied and operational energy. For example, while substituting certain materials for others may reduce the embodied energy of the building, it may also increase the building's operational energy requirements, offsetting gains in efficiency. A life cycle approach is necessary to choose materials whose properties will optimize both embodied and operational energy (IPCC 2007).

Figure 49 Drivers and causes to inefficiencies related to building design and choice of materials



5.4.2 Inefficiencies in heating and cooling

Heating and cooling are major sources of building energy demand. The McKinsey Global Institute (2011) found that improving building heating and cooling performance (including installing efficient water heaters) accounts for 30% of the overall opportunity for improving energy productivity specifically. Due to the provision of hot water, which can be an important share of the energy consumption in a residential building, energy efficiency is also linked to water efficiency.

The energy consumed to heat a building is determined by the average temperature difference (between indoors and outdoors); the leakiness of the building (i.e. insulation of the building); and, the efficiency of its heating and/or cooling system (MacKay 2008). Thus, a building's heating and cooling demand is partly determined by its insulation and other design properties, already discussed above. Insulation optimisation concerns both old buildings that can be refurbished and new buildings. Key best practices for insulation of new buildings include: better insulation in floors, walls, and roofs; ensuring that the building is completely sealed and using active ventilation to introduce fresh air and remove stale and humid air, with heat exchangers passively recovering much of the heat from the removed air; and designing the building to exploit sunshine and natural air flows as much as possible (MacKay 2008) (Allwood and Cullen 2012). Inefficiencies in heating and cooling demand can results from problems with any of these design practices, or other design issues. However, the properties and use of the building's heating and cooling systems themselves also play a significant role, and have a tangible savings potential (Department for Business Innovation & Skills 2009).

On the supply side, technical limitations and availability of existing technology limit consumers' choices, e.g. space to install a renewable energy heating system. In parallel, user choice and behaviour (choice and use of heating and cooling systems), is an important determinant of overall efficiency of these systems. A combination of factors drives inefficient user behaviour.

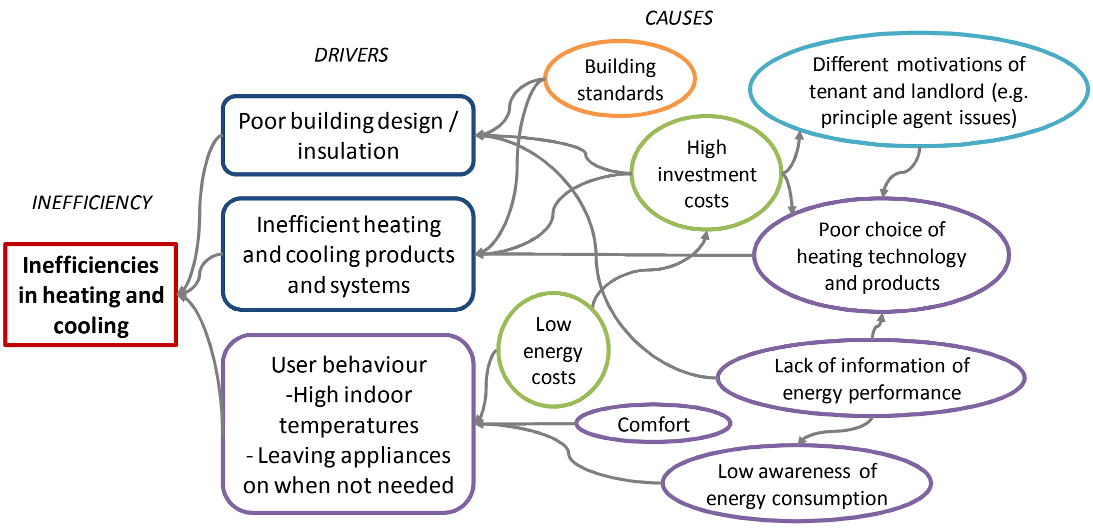
- High costs of investment into efficient systems (e.g. condensing boilers, combined heat and power system, waste heat recovery systems) or renewable energy systems (e.g. solar thermal water heating, solar photovoltaic, micro wind turbines, wood-burning stoves), coupled with doubts about the reliability of returns or long payback time, limit the economic attractiveness of these technologies (Jarnehammar 2010), (Caird 2008). At the same time, market failures, such as principal-agent issues (e.g. tenants and landlords have different motivations), as well as low energy costs (sometimes due to energy subsidies (IEA, OPEC, OECD and World Bank 2010)), create inefficient incentives for the actors involved (IEA 2011); (Jarnehammar 2010) and contribute to a lack of interest in efficiency measures (Weiss 2012). Lack of financial incentives from the government (tax breaks, subsidies, grants) or the energy supplier (e.g. financial packages to install systems with repayment via fuel bills) can contribute to these inefficiencies. Users can also be reluctant because of hassle and disruption, or problems with connecting to existing heating systems(Caird 2008).

- Informational obstacles specifically related to renewable energy systems include difficulties in finding trusted installers, scepticism about performance and worries about noise and vibration (Caird 2008). Lack of information regarding maintenance of heating and cooling systems can also be the cause of avoidable inefficiencies (Department for Business Innovation & Skills 2009).

- Personal and social preferences also contribute to inefficient use of heating and cooling. For example, standards of comfort with respect to room temperature may drive excessive use of heating and cooling technologies (MacKay 2008).

- Finally, organizational issues also play a role. For example, central heating and cooling technologies may limit the user's ability to regulate use, and may result in energy use that even surpasses the user's needs (in some cases, for example, residents open windows because the heat is on too high and they cannot adjust it). In addition, end users do not always participate in the choice of heating and cooling technologies.

Figure 50 Drivers and causes to inefficiencies related to heating and cooling



5.4.3 Inefficiencies in lighting, appliances and electronics

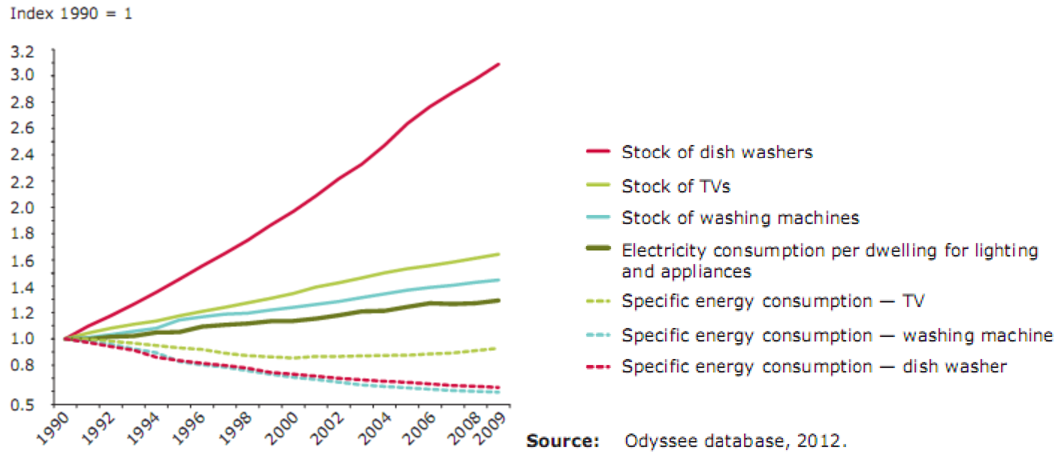
McKinsey estimates that there is potential to reduce energy consumption of lighting, appliances and electronics significantly, with more than half of this potential reduction coming from increased adoption of energy-efficient appliances in residential buildings (McKinsey Global Institute 2011). Continued use of inefficient appliances versus efficient alternatives (particularly those certified by energy labelling schemes) thus has a tangible impact on overall buildings energy use. Technical inefficiencies inherent to the appliances themselves, as well as inefficient choices and behaviour on the part of consumers of these appliances, both play a role.

Important progress has been made over the last decade regarding the energy efficiency of lamps. Some obstacles to the adoption of the best performing products (more efficient fittings, bulbs and light sensors) include incompatibility with existing fittings and dimmers, light quality or lack of brightness (Caird 2008).

The implementation of sensors allows users to reduce the inefficiencies that can be caused by inappropriate user behaviour, due to low energy costs and other factors. For example, in professional buildings (e.g. offices), lighting inefficiencies can occur at night when lights are not switched off, despite the possibility to apply such a policy with the help of security teams (Department for Business Innovation & Skills 2009).

Standby power consumption accounts for roughly 8% of residential electricity demand according to the IEA, and 6% according to the JRC (2009). This is partly due to the fast increase of the ownership levels of ICT equipment and consumer electronics, which are still expected to increase and are due to the increasing number of households and disposable income (see Figure 51 illustrating the rebound effect). For this equipment, the largest proportion of savings result from ensuring that products can modulate their power requirements according to the services they provide to users (IEA 2009). According to the IEA, energy use by these devices will double by 2022 and increase threefold by 2030. Switching to the best available technologies would save at least 40% of residential electricity consumption in most appliance categories (IEA 2009). Timer switches also represent a technical option for reducing the energy wasted when appliances are not actually used (Department for Business Innovation & Skills 2009).

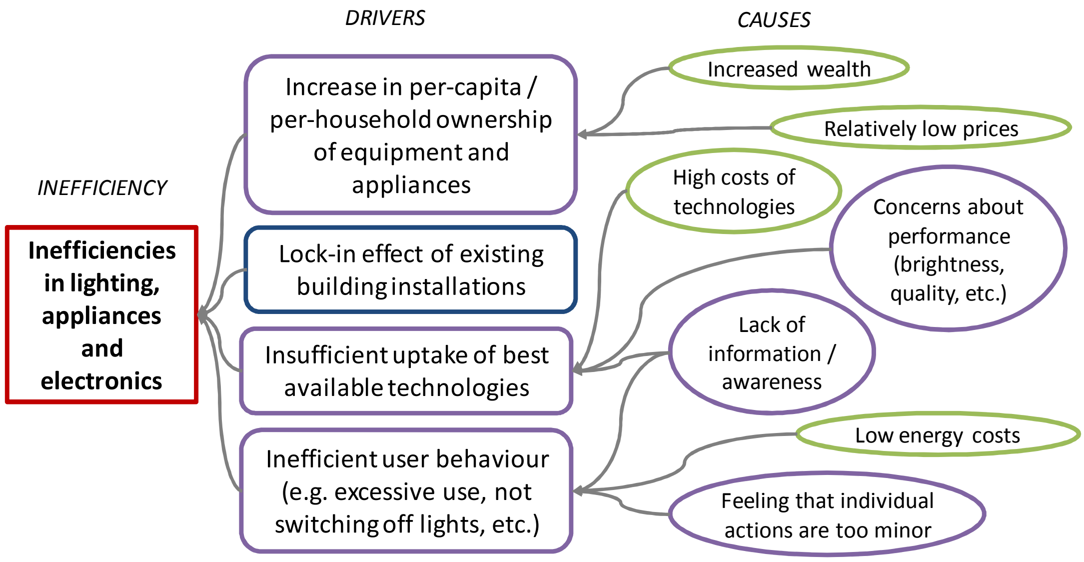
Figure 51 Trends in appliance energy efficiency and ownership in the EU-27



Source: (EEA 2012a)

Given the fragmented aspect of the potential savings in appliances and electronics (high number of device types, high number of households), individual user behaviour plays an important role in achieving these potential energy savings. However, because of relative low energy costs, savings often appear low to consumers at the individual level, which may lead them to poor consumption choices.

Figure 52 Drivers and causes to inefficiencies related to lighting, appliances and electronics



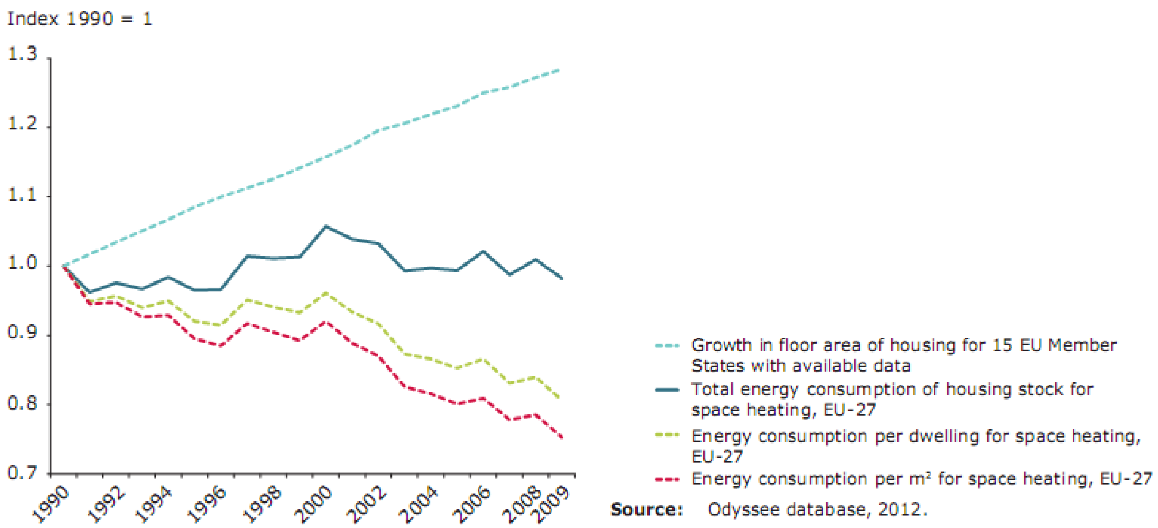
Other generic drivers already introduced also contribute to these choices, e.g. lack of information or principal-agent problems in cases with larger white goods. The IEA also highlights regulatory inefficiencies, as many implemented programmes are missing the opportunity to deliver 20% to 50% more savings due to poor attention to implementation.

5.4.4 Number of people per household / Area per person

Per-capita energy consumption is influenced by the number of people per household, as smaller households tend to have higher per-capita consumption. As some of the key energy-demanding residential technologies (heating, lighting and some appliances), are usually shared between household members, overall demand increases if larger households are replaced by greater numbers of smaller households. Overall, wealthier countries tend to have smaller households, and in Europe population growth has been accompanied by an increase in the number of small households (Bertoldi, Hirl and Labanca 2012). This trend is contributing to overall inefficiency in energy consumption.

Average household size in square meters also makes a difference, as larger homes generally require more energy for heating, cooling and lighting. When economic growth drives up the average size of dwellings, greater demand due to the extra space may offset some of the efficiency gains achieved via improved technology or behaviour. Thus, the EEA underlines that energy efficiency of dwellings has clearly improved since 2000, but this trend has been largely offset by an increase in housing space per person (EEA 2012a).

Figure 53 Trends in heating energy consumption and energy efficiency of housing in the EU-27

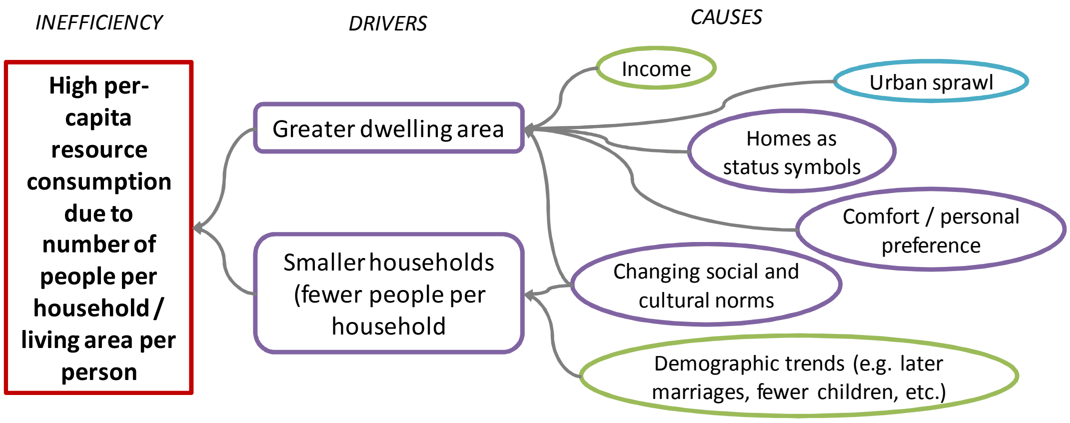


Source: (EEA 2012a)

The type of dwelling also plays a role. For example, single family houses typically use 1.5 to 2 times more energy per m^2 than multi-family buildings(EEA 2012a).

Household and dwelling size are both impacted by cultural, demographic and economic trends. Demographic factors, such as marriage age or average numbers of children, as well as lifestyle changes, impact household size and the numbers of single households. Increases in wealth may also make it easier for single or small households to afford their own dwellings. Larger homes may become more culturally standard in countries with stronger economic growth, whose consumers may also have higher income to dispose on dwellings. Larger homes are also seen as status symbols in many societies.

Figure 54 Drivers and causes to the inefficiencies related to the use of space



5.4.5 Urban sprawl

Several factors drive urban sprawl, at different scales (global, regional or local). Top drivers of urban development include demand for housing, development of industrial and commercial sites, services recreation and to a lesser extent transport networks and related infrastructures (EEA 2012a).

Although increased demographics partly explains the increasing development of infrastructures and housing nearby urban areas (Eurostat, 2011), it is only one of the several factors at stake, since European cities expanded by 78%, whereas population grew by 33% since mid-50s, which means that the amount of space consumed per person in the cities of Europe has more than doubled over the past 50 years (EEA 2012a). Both economic context and behavioural factors play a role in urban sprawl.

Overall, in the EU, the development of economic activities nearby cities, along with the abandonment of less dynamic rural regions, mostly explains current land take since conversions for residential purposes have been decreasing for the last decade (EEA 2010). However, this may vary depending on countries. For instance, in Luxembourg and Ireland, the demand for housing, services and recreation was responsible for 70% of the land take. In countries like Belgium (48%), Greece (43%) and Hungary (32%), urban development remains mainly driven by industrial and commercial activities (BIO Intelligence Service 2011a).

For economic activities, urban areas seem particularly attractive because of their e.g. employment opportunities and competitiveness, privileged access to services, trade and communication. They can cause great impact since they have a great degree of imperviousness compared to residential areas (80% to 100% of water impermeability) (Haase 2008). At the local level, housing still seems to be the top driver for urban sprawl nearby cities. There, the individual decisions and housing preferences of dwellers, which seek an improved quality of life, further shapes European inner cities and suburbs (density, green spaces, etc.) (EEA 2006). Urban sprawl can be driven for instance by a poor social and environmental quality (in particular air quality and noise levels, lower influence of green spaces comparatively) in inner cities where dwellers may have to deal with pressures such as overcrowding, social inequity, pollution and traffic, which can encourage people to move to suburbia (EEA 2006)(EEA 2010b). It is interesting to note that perception of the quality of the environment may weight more than the actual observations: perceived poor environmental quality in cities can lead to movements to the suburbs without necessarily a correlation with reported air quality and noise levels[16]. At the regional and local levels, prices of land, real estate market and rising living standards (which have impacts on social equity) also contribute to urban sprawl by favouring the development of settlements in the suburbs, where housing and services remain more accessible for low-income population(European Commission 2010). Likewise, the price difference between areas allocated to agricultural activities and constructible areas may encourage farmers to sell their properties to urban investors. Furthermore, in some countries public subsidies for home ownership may encourage the acquisition of single properties (EEA 2012a).

At the regional scale, a driver of urban sprawl is spatial planning, which entails organising the distribution of activities across a territory, structuring a territory and the players in it around a vision of the desired development (EEA 2006). Currently it strongly promotes land specialization into urbanisation, agricultural intensification and abandonment plus natural afforestation. More policy emphasis could be put on the complementarity of territorial assets and possible multi-functionality taking into account ecosystem and natural resource management objectives (EEA 2010b).

At the local scale, an important driver is urban planning, which rules on the density of structures, the development or conservation of green spaces, etc., i.e. the quality of life in inner cities and the availability of settlements compared to the number of inhabitants.

Today, the trend is however towards new low-density structures, since over the past 20 years, the extent of built-up areas has increased faster than population (EEA 2010). By 2035 and in the context of European population decline, many more cities will have to cope with the problems of low density settlements, although the trend is not uniform across Europe (EEA 2010b). However, the European Spatial Development Perspective (1999) already advocated the development of compact cities. Lower population densities (see section 5.4.4) demand more energy for transport and housing, and more built-up area per person, and result in less or more-fragmented open space for biodiversity and ecosystem services (EEA 2012). On the other hand, lower densities are likely to result in relief from some environmental pressures and create opportunities for green space whereas increased population density may increase the pressures described earlier (EEA 2012).

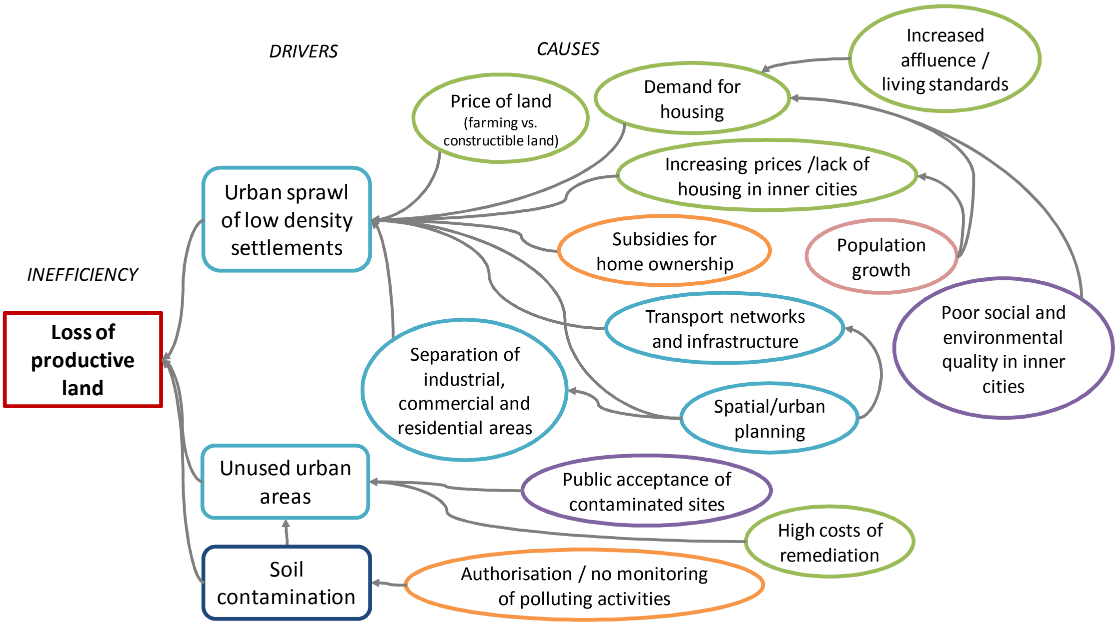
The fact that some urban areas with potential remain unused may be explained by the lack of rehabilitation of these areas and/or their contamination due to industrial or landfilling activities. Soil contamination may be one of the main drivers of urban land abandonment. It results from deliberate or accidental release or disposal of substances (such as trace elements, organic compounds, or even plant nutrients like nitrogen or phosphorous) in, on or under the land. Most frequent contaminations include heavy metals and mineral oil. To our knowledge, there is no indication of the area contaminated in the EU, but soil contamination is a widespread problem in the EU. Estimates of the number of contaminated sites in the EU range from 300,000 to 3 million (JRC 2012a). This is mostly due to the operation of some polluting activities.

From an economic perspective, the high costs of remediation may also impede the remediation of contaminated sites. They can amount one million Euro per ha for the most polluted areas. In the end of the day, another main reason behind these issues seems to be legislative and regulatory shortcomings, which authorize some polluting activities and do not

[16] Results of the 2004 Urban Audit Perception Survey (European Commission 2005) with the population movements between core cities and their surrounding Larger Urban Zones indicates that nearly all cities with perceived bad air quality and major noise problems are de-concentrating.

necessarily require remediation after contamination. Lastly, public acceptance might impede the rehabilitation of such areas into for example recreational areas, although several attempts to valorise such land uses could be successful.

Figure 55 Drivers and causes to the inefficiencies related to urban sprawl



5.4.6 Water consumption and losses in buildings

Approximately 20% of water abstraction across Europe supplies public water systems, including households but also small businesses, hotels, offices, hospitals, schools and some industries (see Box 4). The key drivers influencing public water demand are population and household size, income, consumer behaviour and tourist activities (EEA 2012b)(OECD 2002). For instance, higher household income is linked to greater water consumption and ownership of more water consuming appliances (e.g. showers, toilets, water heater, dishwaters, washing machines, swimming pools, etc.)(OECD 2002).

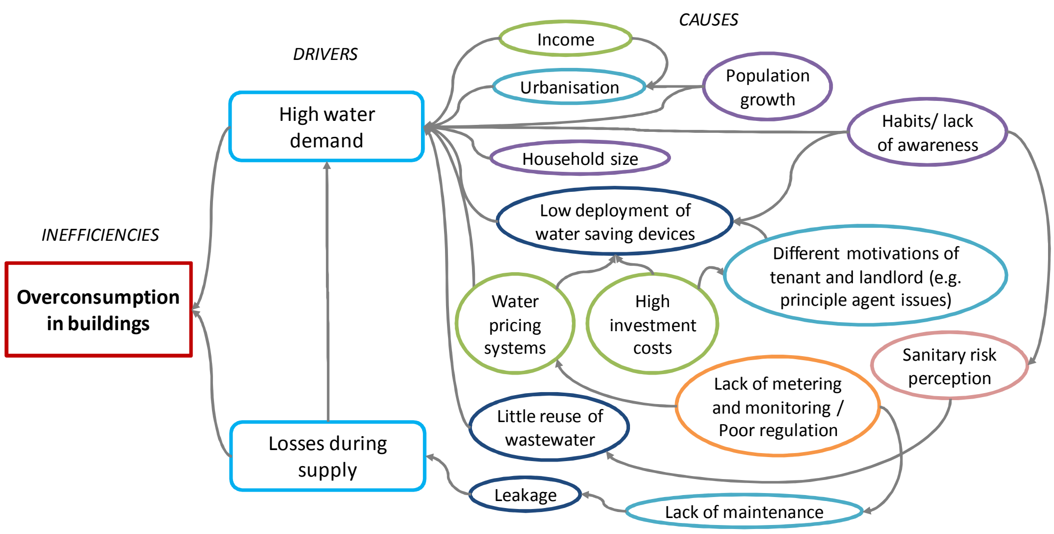
From a demand perspective, the main inefficiency related to water use in building is the overconsumption of water. This concept can be understood in absolute terms, i.e. consumers consume too much water, e.g. for cultural reasons, lack of awareness, inadequate water prices, etc., and should reduce their overall demand, although this could mean decreasing their well-being. For instance, taking long showers, cleaning cars with drinking water in summer or filling up pools may be discussable from the perspective of sustainable use of water resources especially in water-stressed areas. Overconsumption can also be understood in relative terms, in the sense that a certain amount of water could be saved while bringing the same services to the consumer. In this case, increasing water efficiency can relate to behavioural factors, such as turning off the tap while cleaning your hands, but also to technological developments, such as the installation of water saving devices (BIO Intelligence Service 2012b). It is usually considered that 60 to 80% of the public water supply system is used by residential households, with personal hygiene and toilet flushing accounting for about 60% of this proportion (BIO Intelligence Service 2012b). Ten to fifteen percent of water consumption could be saved in 10 years in the EU through the deployment of water-saving devices, such as dual flush systems (BIO Intelligence Service 2012b). Furthermore, the reuse of grey water (i.e. waste water), which could decrease the pressure on drinking water resources, still faces reluctance from residents, because of the perceived sanitary risks (Bio Intelligence Service 2011).

From a supply perspective, technological measures to address leakage in public water supply systems play an important role in increasing water efficiency in buildings. Leakage in public water systems is a common problem in the EU, undermining water efficiency (EEA 2012b). It is usually the largest component of distribution loss, according to the European Benchmarking Co-operation (EBC 2011), which reports distribution losses of about 5 m^3/day/km of mains in the supply network. Currently leakage rates are not subject to regulation other than management decisions by utilities and reasoning based on economic return periods for infrastructures investment. Beyond the loss of drinking water, leakages also result in energy losses as well as losses of materials used in the extraction and water treatment.

Furthermore, water pricing systems combined to adequate metering may significantly influence water consumption. For instance, a ten-country household survey has found that households subject to volumetric pricing (based on metering) use 25% less water (Grafton 2011). In the United Kingdom, water metering is estimated to be able to achieve average water savings of around 13% per household (Environment Agency 2008). Developing adequate pricing strategies and metering could contribute saving 10% of water consumption in the EU(BIO Intelligence Service 2012b). So far, technical challenges have been limiting the deployment and use of meters in apartments, unlike their increasing development in single houses throughout the EU.

Overall, the move towards more water efficient buildings or products remains very slow considering the evidence pushing for the implementation of water savings in this sector and the technical solution already available (BIO Intelligence Service 2012b). This may be explained by difficulties in implementing such solutions, e.g. responsibilities sharing between actual users and owners/investors (e.g. principal-agent issue).

Figure 56 Drivers and causes to the inefficiencies related water consumption in buildings



5.4.7 Other inefficiencies

Other building related areas of inefficiency remain, which are not explored in detail, but which can also be optimized to contribute to greater resource productivity.

- **Inefficiencies in the end-of-life phase (EOL):** The significant material flows generated by the buildings sector could potentially be reduced via targeted approaches, such as recycling or down-cycling, as well as design of durable and long-lasting structures to achieve a reduction in future material flows even if higher initial investment in monetary and material terms may be necessary (BIO Intelligence Service 2011a). Non-optimal choice of materials may also lead to greater overall material demand. Inefficiencies in demand for materials in construction and refurbishment may be due to a variety of drivers, including ineffective recycling practices, lack of awareness of priority amongst professionals, poor design or poor choice of materials. The EOL phase is critical to developing more resource efficient construction. Construction and demolition (C&D) waste has tangible environmental impacts, and EOL practices (e.g. demolition vs. dismantlement) impact the level of material recovery in the EOL phase. Inefficiencies in EOL may result from lack of awareness or training, or from underdeveloped systems for proper dismantlement. Economic considerations are also important, for example if dismantlement is found to be more expensive than demolition, or when certain materials are considered too low-value to recover for recycling. Building design without the EOL phase in mind may also impede dismantlement or recovery of individual materials.

5.4.8 Summary

Key inefficiencies in the building sector span several resource types, with energy inefficiencies being particularly significant. Inefficiencies in the building sector stem both from the choices of building designers and developers and from the choices and behaviour of end-users of the buildings and its systems, appliances and equipment. The building life cycle phases are highly interconnected, with choices made in the construction phase (or, later, in refurbishment), playing a key role in determining the efficiency potential of both the use phase and the end-of-life phase. User behaviour in the use phase can also either contribute to or detract from the efficiency of technologies selected in the construction or refurbishment phases. While acting on specific areas of inefficiency can help generate productivity gains, a holistic approach that considers the entirety of the building life cycle could be most successful in improving resource efficiency.

5.5 Findings of the quantitative meta-analysis

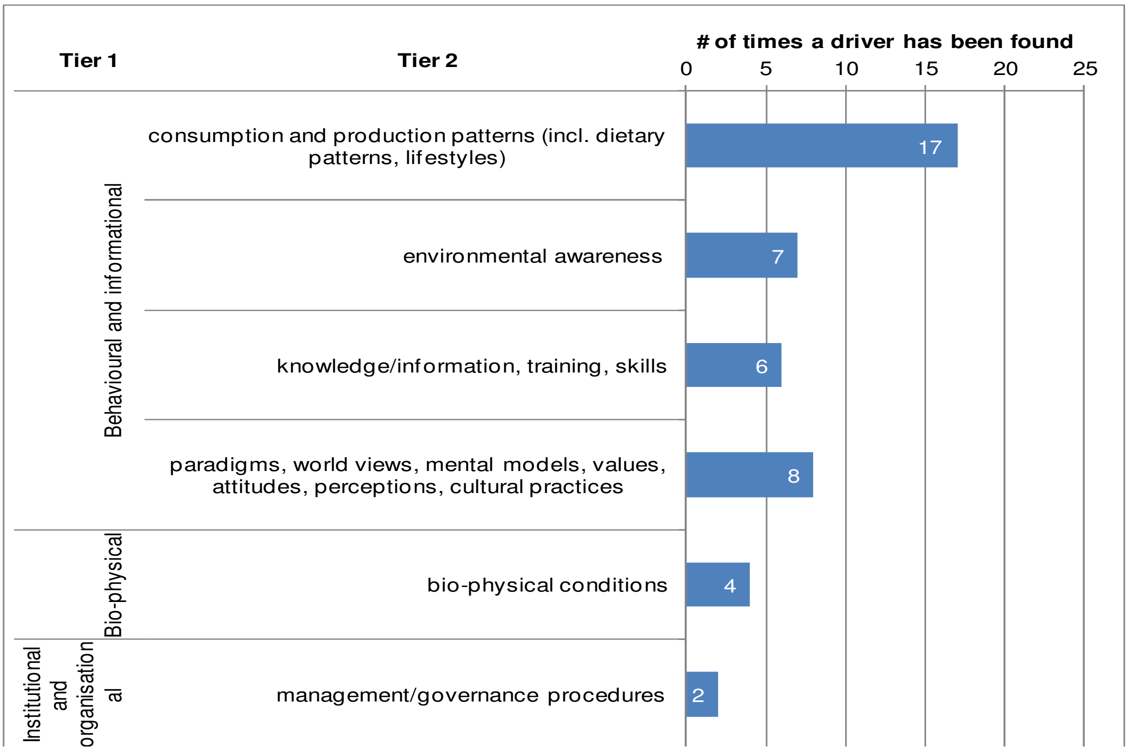
The following results are based on the procedure outlined above in section 3.5. Specifically, we allocated the drivers named in the selected articles on our conceptual map into the three nested driver tiers (cf. section 5.5.1). We also determined the direction of each effect in a normative framework, i.e., a driver was judged to have a positive effect if it improves resource efficiency, whereas any driver reducing resource efficiency was defined to have a negative effect (cf. section 5.5.2). If the driver's effect direction was shown to be both positive and negative, depending on context, circumstance or the size or direction of other drivers, then its effect direction was labelled undetermined. Effect type descriptions were developed for the Tier 3 drivers and are presented in section 5.5.3, while the drivers' resource and sectoral focus was identified as much as the article allowed in order to gain further insight into how, where and when the driver exerts the identified impact on resource efficiency (cf. section 5.5.4).

The following sections provide descriptive details of the findings of the meta-analysis. The evaluation tables in the following sections have been prepared by cross-tabulating several of the qualitative variables against the driver categories. Depending on the scope of the section, the drivers have been displayed at all three or only at the first two levels of the conceptual map. The total number of drivers identified in the 28 coded articles is 128 – the latter number is greater than the former as for most articles multiple drivers were identified.

5.5.1 Frequency of mention of Tier 1 and 2 drivers

In the first step of our analysis we simply counted how many times we allocated the drivers named in the selected articles to the Tier 1 and 2 categories. A given article can include more than one Tier 1 and 2 driver, which means that the total count shown in the table exceeds the number of articles analysed.

Figure 57 Frequency of Tier 1 and 2 drivers found through the meta-analysis



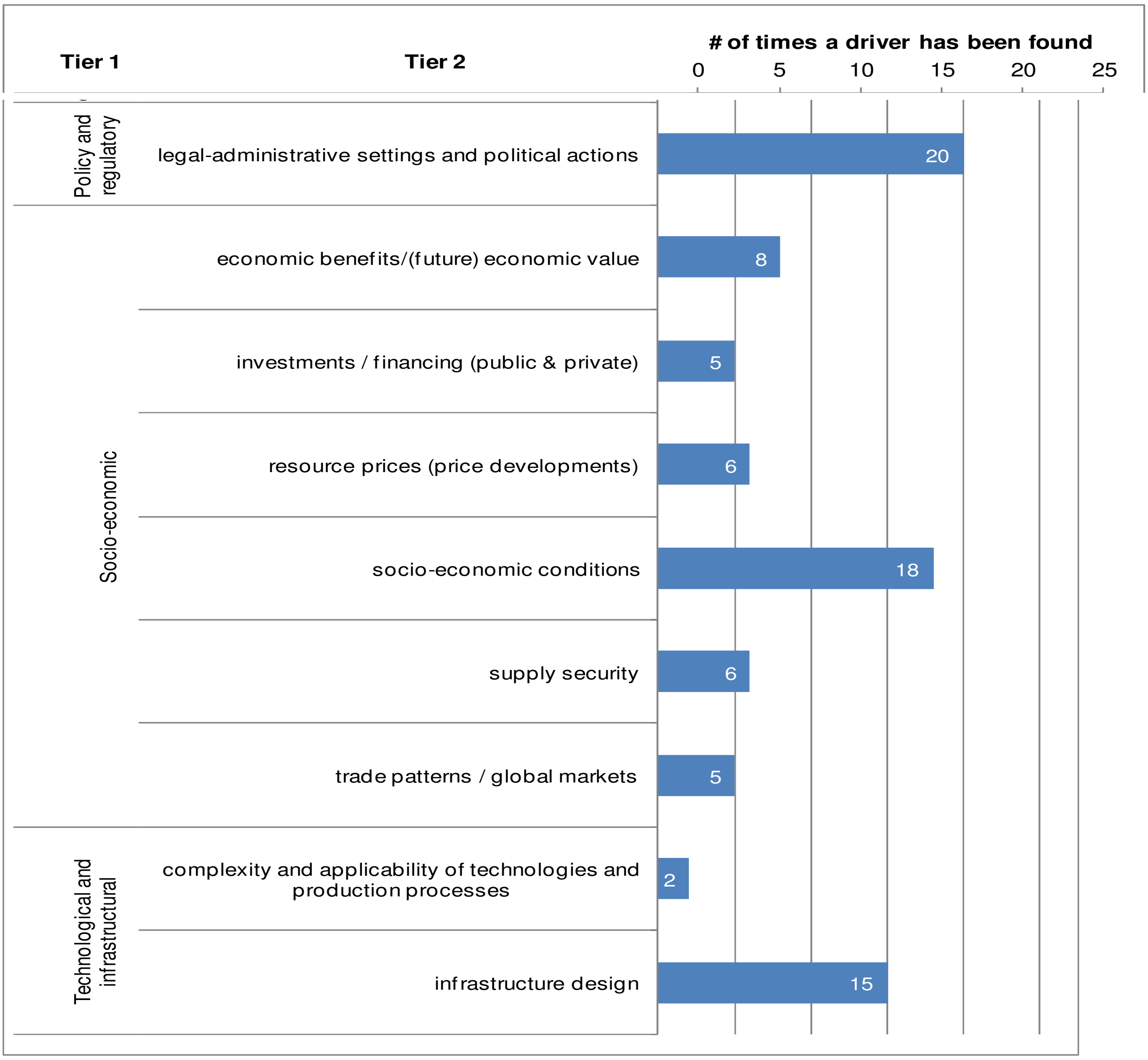


Figure 57 shows the absolute frequency of Tier 1 and Tier 2 drivers found through the meta-analysis. The length of each bar corresponds to the number of times the respective Tier 2 driver has been identified. The Tier 1 driver categories encompassing the Tier 2 drivers are shown on the left-hand side of the figure.

The four most frequently cited Tier 2 drivers are **legal-administrative settings and political actions** (20 mentions), **socio-economic conditions** (18 mentions), **consumption and production patterns**, including dietary patterns and lifestyles (17 mentions) and **infrastructure design** (15 mentions).

The first of these probably reflects the empirical findings of many of the articles that resource use is influenced, controlled or manipulated through **policies, laws and/or regulation**, both positively and negatively. In some cases the goal is to improve a perceived or demonstrated resource use inefficiency, while in other articles existing policies, legal or regulatory frameworks were found to be obstacles to efficient resource use (cf. section 5.5.2 on direction of the effect).

The second most frequently cited Tier 2 driver refers to the broad class of characteristics describing the prevailing **social and economic system**, including rising income, population density and growth, degree of urbanization, composition of the economy, etc. Many articles investigate how these characteristics affect resource use, how they interact with one another, and how their influences change over time, e.g., how rising incomes change resource consumption, dietary patterns, etc. Steinberger et al. (2010), for example, find rising income in many cases correlated with the physical efficiency of an economy as a measure of material productivity - high income countries in this context typically display a higher material productivity than low income ones. For instance, Ezeah and Roberts (2012) find that the socio-economic realities of many people living in Abuja, Nigeria act as a barrier against more expensive, but more sustainable municipal solid waste management options, because people are struggling for economic survival and therefore can assign only low priority and low spending to considering more efficient waste management.

The latter aspect of living standards is captured in the third most often cited Tier 2 driver, namely **consumption and production patterns**. This Tier 2 driver encompasses different dimensions of consumption and production found to be affecting resource use efficiency: inter alia, aspirations in relation to living standards, dietary choices, conventional models of agrarian production or business models internalizing external costs of production processes. In several cases the Tier 3 drivers under allocated to consumption and production patterns are interlinked with rising income as a Tier 3 driver allocated to socio-economic conditions. For instance, Schandl and West (2010) find that rising income in urban households in the Asia-Pacific region led to the emergence of an affluent class of consumers, to massive infrastructure development, lifestyle changes and new consumption and mobility patterns which are seen as an explanation of the decreasing resource efficiency in the Asia-Pacific region, both in early 1990s and from 2000 onwards. In addition, as regards the use of phosphorus in agricultural production Schröder et al. (2011) find that changing diets towards more meat and dairy products – frequently associated with rising income – drive increasing phosphorus use, which in turn is based on inefficient production and consumption chains leading to huge dissipative losses.

Infrastructure design is the fourth most often cited Tier 2 driver (15 times). Its driver effects are seen as both positive and negative (or undetermined in some articles). This broadly defined driver category includes for example building design, materials and processes; city design; lock-in of old, capital-intensive infrastructure; EU energy grid integration; and, the location of production sites/processes. In the regression analyses run by Steger and Bleischwitz (2011), the length of motorways, for example, is found to increase total domestic material consumption (DMC), while Zaman and Lehmann (2011) identify intelligent city design as a driver for reducing material use.

In contrast, the least often named Tier 2 drivers are **bio-physical conditions** (4 mentions), **management and governance procedures** (2 mentions), **complexity and applicability of technologies and production processes** (also 2 mentions).

Bio-physical conditions refer to climatic conditions as well as topography and resource endowments. While these factors certainly play a role, they are largely viewed as given constraints on resource use management, i.e. something that needs to be accepted as is and be considered with respect to the solutions that can be successfully applied. They are thus drivers that are without immediate control by society, policy-makers, and business-owners. An argument supported by Steger and Bleischwitz (2011), who say that climatic and topographic conditions (as shaped by geographic conditions) cannot - or can only marginally – be influenced by policy to address consumption patterns of economies.

Management and governance procedures were cited only twice, one time each in two articles: Ezeah and Roberts (2012) who focus on factors affecting the adoption of sustainable management of municipal solid waste in Nigeria, and Pajunen et al. (2012) who analyse drivers and barriers of effective industrial material use. In both cases, insufficient or lacking involvement of relevant actors (trained waste managers in decision making in Nigeria's municipal solid waste management, and local plant managers to make decisions on using residues in production) in relevant decision-making processes hampers a more efficient use of resources or management of municipal solid waste.

The **complexity and applicability of technologies and production processes** was also only named twice in our set of articles, also one instance each in two articles: Ezeah and Roberts (Ezeah and Roberts 2012), and Trianni et al. (2013) who investigate barriers to industrial energy efficiency in foundries across Europe. While Ezeah and Roberts find that many efficient waste management technologies are not applicable in Nigeria due to high waste density and moisture content, Trianni et al. identify the complexity of production processes to decrease the acceptance of energy efficiency as an investment goal.

Looking at the different brief descriptions of relevant Tier 3 and Tier 2 drivers above, it becomes obvious that the different drivers can foster or impede resource efficiency, or both. Whether the drivers identified through the meta-analysis are considered to have a positive, negative or undetermined effect on resource efficiency is analysed in the following section.

5.5.2 Direction of effects of Tier 3 drivers on resource efficiency

Table 7 below shows the direction of the effects of Tier 3 drivers on resource efficiency. For each Tier 3 driver the table shows if the identified effect is considered positive (fostering resource efficiency), negative (impeding resource efficiency) or undetermined (the direction of the effect could not be identified unambiguously). This usage of terminology corresponds to the normative notion that increases in resource efficiency are perceived to be positive, while increasing inefficiency is perceived to be negative. Owing to the large number of Tier 3 drivers (129), the information was split into three tables to facilitate reading. The nested structure of the 3 tiers is illustrated through indentation with Tier 3 being the most indented.

Table 7 Direction of effects of Tier 3 drivers on resource efficiency

	Direction			
Drivers (Tier 1-3)	negative	positive	undetermined	total
Behavioural and informational				
consumption and production patterns (incl. dietary patterns, lifestyles)	13	3	1	17
(rising aspirations for) standard of living	5		1	6
application of equality principle & cost internalization		1		1
consumption patterns (incl. dietary patterns)	5			5
conventional model of agrarian production	1			1
dietary practices (--> towards vegetarian diet)		1		1
existing practices/habits	2			2
holistic inter-generation resource recovery and product stewardship		1		1
knowledge/information, training, skills	5		1	6
environmental uncertainty	1			1
information			1	1
insufficient/lacking knowledge	3			3
insufficient/lacking public education and training/skills	1			1
paradigms, world views, mental models, values, attitudes, perceptions, cul	4	3	1	8
existing cultures		1		1
paradigm shifts (world views, mental models, values, beliefs, attitudes)	3	2		5
psychological barrier, cultural barriers, perceived contamination concerns	1			1
values, and personal behavior			1	1
environmental awareness		7		7
environmental concerns		6		6
stakeholder pressure		1		1
[…] continued in next table				

Drivers (Tier 1-3)	Direction negative	positive	undetermined	total
Bio-physical				
bio-physical conditions	1	1	2	4
climatic conditions	1	1	1	3
natural factors (topography, climate, resource endowment)			1	1
Institutional and organisational				
management/governance procedures	2			2
lacking involvement and participation	2			2
Policy and regulatory				
legal-administrative settings and political actions	9	10	1	20
energy subsidization	1			1
labelling		1		1
land use planning		1		1
legal/political frameworks/actions	8	1		9
legal/political frameworks/targets		1		1
policies (R&D investment, demonstration support, subsidies)		1		1
policies and regulation		1		1
political agenda			1	1
public policy (carbon price, support schemes)		2		2
streamlining administrative procedures (grid access)		2		2
Socio-economic				
economic benefits/(future) economic value	2	5	1	8
„need to be competitive“		1		1
development potentials for RES			1	1
economic benefits/(future) economic value	1	2		3
economic benefits/(future) economic value (of recycled fertilizers)		1		1
economic benefits/(future) economic value (of recycled products)		1		1
low economic potential	1			1
investments / financing (public & private)	3	2		5
allowances and public finance		1		1
cost of innovations	1			1
lacking basic materials for waste collection	1			1
lacking investment in phosphorus recovery technologies in developing co	1			1
R&D investments		1		1
resource prices (price developments)	1	4	1	6
energy prices		1		1
prices of goods and services, especially of energy, electricity and energy-intensiv			1	1
resource prices (price developments)	1	3		4
socio-economic conditions	13	2	3	18
country size and population density			1	1
employment in construction sector	1			1
energy consumption per capita	1			1
labour productivity	1			1
population density		1		1
population growth and economic growth	1		1	2
rising income	3	1	1	5
share of imports in GDP	1			1
share of industry in GDP	1			1
socio-economic realities (e.g. people struggling for economic survival)	1			1
urbanisation	3			3
supply security	1	5		6
scarcity of energy resources		1		1
scarcity of resources to implement efficient behvaiour	1			1
supply insecurity		3		3
supply security of recycled fertilizers		1		1
trade patterns / global markets	5			5
trade patterns	3			3
trade patterns (internationalisation of agricultural production)	1			1
trade patterns (shifting production)	1			1
Technological and infrastructural				
complexity and applicability of technologies and production processes	1		1	2
complexity of production processes			1	1
physio-chemical / technical issues	1			1

[...] continued in next table

Drivers (Tier 1-3)	Direction: negative	positive	undetermined	total
infrastructure design	8	5	2	15
building design, materials and processes	1			1
city design, material flow			1	1
eu grid integration		1		1
infrastructure / design	3	2		5
length of motorways	1			1
location/nationality (of production processes)			1	1
lock-in of old, capital-intensive infrastructure	1			1
man-made barriers (e.g., buildings)	1			1
number of completed dwellings	1			1
switch in building materials		1		1
technological innovation		1		1
Grand Total	**68**	**47**	**14**	**129**

Of the 129 Tier 3 drivers listed in Table 7 above, 68 (53%) were found to have negative impacts on resource efficiency, 47 (36%) were assessed to have positive effects and for 14 drivers the effect direction could not be conclusively determined (hence termed undetermined, i.e. the effect varies depending on context).

The Tier 3 driver most commonly associated with positive effects on resource efficiency are **environmental concerns** (mentioned 6 times to be positive). Interestingly, of all Tier 2 driver categories, environmental concerns is the only category whose allocated Tier 3 drivers are associated with only having one effect – positive in this case. Based on the six articles specifying environmental concerns as a positive driver, the positive effect is explained by external or internal motivation (outside stakeholder pressure, but also employee and managers/farmers' concerns for the environment), which causes actors to improve resource efficiency in order to reduce environmental harm, mainly in relation to water pollution. Lehtoranta et al. (2011) identify increasing consumer and public interest in environmental protection as a driver for the establishment of more industrial symbiosis set-ups and Eco-Industrial Parks, which due to the cascading use of resources and waste can be considered as a more efficient use of resources compared with conventional industrial set-ups. As regards water pollution, Hu et al. (2010) find that concerns about environmental problems through leaching and soil erosion, and associated water pollution encouraged agricultural water-saving measures in Shijiazhuang Irrigation District, China. In a similar context, Cordell et al.(2011) find that *"[s]ustainable phosphorus use has been largely driven by pollution concerns over the past few decades […]"* (ibid, p. 756).

Other Tier 3 drivers most often associated with positive effects are **resource prices** (3 times) and **supply insecurity** (also 3 times). The articles identifying resource prices as positive drivers refer mainly to high raw material prices (e.g. for phosphorus) as encouraging more efficient resource use in production processes in order to save costs. Cordell et al. (2011) find that the price and price developments for phosphorus drive increasing efforts for phosphorus recovery – to the extent that the recovery in wastewater treatment plants could be economically attractive at a certain phosphorus price. Verbruggen et al. (2010) argue that low energy prices generally encourages more inefficient uses, while higher energy prices lead to energy conservation, energy efficiency increases and technological innovation. However, resource prices were also found to negatively affect resource efficiency. As Schröder et al. (2011) argue, the prices at which phosphorus is sold on commodity markets do not reflect the true (external) cost of production and use, but are significantly below this, so there is no financial rationale for using phosphorus more efficiently.

The findings in relation to supply insecurity are similar in that the articles citing this as a positive driver relate to insecure supply conditions and import dependencies. When supply is insecure, more efficient resource use helps to reduce import dependencies and time lags in production processes. A prominent example found in the articles is phosphorus, whose supply is mainly provided by a few countries (e.g. Morocco, China and the USA) and where large-scale import dependencies play an important role. Therefore, both Clift and Shaw (2012) and Cordell et al. (2011) view supply insecurity as a driver for improving resource efficiency in order to reduce import dependencies.

The drivers seen as negative most often are **legal-administrative settings and political actions** (8 times); **consumption patterns** (5 times); and, (**rising aspirations for) standard of living** (5 times). With respect to **legal/political frameworks/actions**, the negative effect encompasses legal regulations counteracting resource efficiency improvements and political actions encouraging or unintentionally causing inefficient resource use. As regards regulations, Pajunen et al. (2012) identify increasingly strict environmental regulation that considers residues as wastes instead of reusable materials to legally complicate their use in Eco-Industrial Parks – hence, where end-of-waste criteria are not sufficiently decided, efficient use of resources is complicated. Schröder et al. (2011) find in relation to the agri-food sector that existing regulations concerning organic farming precludes human excreta or wastewater as important sources for phosphorus recovery from the list of permitted fertilizers (due to potential heavy metal or pathogenic content). Thus, reusing organic waste for phosphorus recovery is limited.

Looking at political actions, Lehtoranta et al. (2011) find subsidies, in particular energy tax concessions, exemptions and paybacks, encouraging inefficient energy use in Finland. According to Lifset et al. (2012), inefficient use of copper in the form of dissipative losses has been fostered by environmental policies which phased-out the use of tributyltin as marine paints for boat hulls. This in turn caused an increase in the application of copper-based marine paints and results in copper being dissipated to the marine environment.

Interestingly, although the Tier 3 driver legal/political frameworks/actions driver was seen as negative in 8:1 cases, the more aggregated Tier 2 driver that also includes other policy aspects swings 10:9 in the positive direction. Positive effects are cited for instance by Pajunen et al. (2012), who find environmental legislation, in particular the Waste Framework Directive 2008/98/EC, as a major driver for improving material efficiency. Furthermore, Cordell et al. (2011) find that existing EU legislation (Water Framework Directive 2000/60/EC) helped to create legally obligatory environmental protection concerns, which in turn increased efforts to recover phosphorus from sewage and prevent the nutrient from entering waterways, and thus reduce nutrient pollution.

Thirteen articles viewed the role of **consumption and production patterns** (incl. dietary patterns and lifestyles) as negative for improving resource efficiency, three found positive effects and one was undetermined. Stenis and Hogland (2011) found that the application of the “equality principle” in the mining industry can lead to waste reduction and hence a more efficient use of the resource land/soil, while Zaman and Lehmann (2011) found rising living standards to be a negative pressure on resource consumption in urban contexts in their two city case study of Adelaide and Stockholm.

Tier 3 driver (**rising aspirations for) standard of living** was found to have negative effects in five of six references in the reviewed literature. In one reference its effect was undetermined. The five mentions as a negative effect relate to rising demands and aspirations, which frequently in combination with rising income lead to emerging middle class consumption patterns and associated (inefficient) resource use. Zaman and Lehmann (2011) state that *"most cities in China and India are using the developed, industrialized world's model of high consumption [and inefficient resource use] to drive their GDP growth"* (ibid, p. 182). In addition, Weinzettel et al. (2013) identify land demand in combination with affluence to be driving inefficient land use in the form of ever increasing land footprint, including displacement of land use to other geographic regions.

Tier 3 drivers cited next most often as negatively affecting resource efficiency encompass **infrastructure design**, **insufficient/lacking knowledge**, **rising income**, **trade patterns** and **urbanisation**. Eight articles found negative impacts of **infrastructure design** drivers, five are considered positive and two are undetermined. The negative effects are associated with building design; infrastructure design; length of motorways; number of completed dwellings; lock-in of old, capital-intensive infrastructure and technologies; and, man-made barriers such as buildings. For example, del Rio (2011) state that infrastructure tied up in fossil fuel electricity generation contributes to the lock-in time for these infrastructure projects, which blocks the adoption of more resource-efficient systems. And Ezeah and Roberts (2012) find that infrastructure, in the form of easily available dumping grounds and access constraints for collection vehicles due to narrow and unsurfaced streets contributes to inefficient municipal waste management in Abuja, Nigeria.

According to three articles, **insufficient/lacking knowledge** leads to inefficient resource use in that more efficient solutions are not known or the respective information is not available. Hu et al. (2010), for instance, find that a lack of knowledge as regards the timing, frequency and rate of irrigation drives inefficient irrigation water use in Shijiazhuang Irrigation District, China, as a substantial amount of the irrigation water is wasted to direct evaporation. Espinola-Arredondo et al. (2011) analyse the role of information in resource extracting agents using a game theory approach. They find that information has a direct effect on resource efficiency, but the direction (i.e., positive or negative) depends on (1) the information extent – full or partial – available to the extracting agents, (2) whether market entrance for competitors is open or deterred by the incumbent agent, and (3) the size of the available stock of the resource.

Three articles identify (global) **trade patterns** to adversely affect resource efficiency, mainly in combination with affluence (and partially also consumption patterns). For instance, Weinzettel et al. (2013) argue that international trade and affluence leads to land displacement in other geographic areas in that higher-income countries tend to set aside more space as protected areas and hence trigger burden shifting to other countries by requiring land use for domestic demands.

Urbanisation is considered as a negative driver by three articles, which see the negative effect in relation to increasing resource demands and inefficiency through urban areas increasing in size and density. Ezeah and Roberts (2012), for example, find rapid urbanization in Nigeria to be one driver behind growing municipal waste generation and linked needs for inefficient management practices, such as dumping.

5.5.3 Tier 3 drivers and effect types in relation to resource efficiency

Table 8 provides an overview of the effect types identified in the meta-analysis. It is a cross tabulation of the driver categories of the first two tiers against the expected effect types. The effect types are described in Annex A. Not all of the expected effect types could be identified in the selected literature, so that only four out of the six listed types are present in the evaluation table.

Following the effect type classification (see Table 1 in section 3.5.5) we identified 92 direct effects, 29 conjoint effects, five moderator effects and three undetermined effects. It is remarkable that there is a strong concentration of effect types in the first two categories. Overall, 94% of all identified drivers fall into these direct and conjoint effect types.

Table 8 Tier 2 drivers and identified effect types on resource efficiency

	Effect type				
Drivers (Tier 1-2)	direct Effect	conjoint Effect	moderator Effect	undetermined Effect	Total
Behavioural and informational	27	9	2		38
consumption and production patterns (incl. dietary patterns, lifestyles)	8	8	1		17
knowledge/information, training, skills	6				6
paradigms, world views, mental models, values, attitudes, perceptions, cultural practices	6	1	1		8
environmental awareness	7				7
Bio-physical	3	1			4
bio-physical conditions	3	1			4
Institutional and organisational	2				2
management/governance procedures	2				2
Policy and regulatory	16	1	2	1	20
legal-administrative settings and political actions	16	1	2	1	20
Socio-economic	33	13	2		48
economic benefits/(future) economic value	6	2			8
investments / financing (public & private)	4	1			5
resource prices (price developments)	6				6
socio-economic conditions	9	7	2		18
supply security	6				6
trade patterns / global markets	2	3			5
Technological and infrastructural	12	3		2	17
complexity and applicability of technologies and production processes	1			1	2
infrastructure design	11	3		1	15
Grand Total	**93**	**27**	**6**	**3**	**129**

Overall, direct effects constitute the effect most often identified: 93 (72%) of the 129 Tier 3 drivers are considered to have a **direct effect**. In comparison, a **conjoint effect** was identified only for 27 (21%) Tier 3 drivers, while six drivers (5%) were seen as having a **moderator effect** and three drivers (2%) with **undetermined effect**. Except for the behaviour & information and the socio-economic context Tier 1 categories, the direct effects significantly outnumber the conjoint and moderator effects.

All Tier 3 drivers that the respective literature considered as directly affecting (positively, negatively or undetermined) resource efficiency were allocated to **direct effects**. Examples for direct effects include:

- Increasing consumption of animal products, especially meat and milk of ruminant animals (e.g. (Schandl and West 2010) and (Clift and Shaw 2012)).
- Perceptions that the use of recycled phosphorus recovered from human excreta will lead to contamination of agricultural products (Cordell, et al. 2011).
- Stakeholder pressure (from NGOs and the general public) driving companies to increase material efficiency and applying ISO 14001 Environmental Management System standards (Pajunen, et al. 2012).
- Aridity of the region and low groundwater per capita availability driving farmers to apply water saving measures (Hu, et al. 2010).

- Lacking involvement of trained staff in decision-making processes concerning sustainable municipal waste management (Ezeah and Roberts 2012).
- Policies to set the carbon price (del Río 2011).
- Technological innovation in the transition of energy systems to fully renewable systems (Verbruggen, et al. 2010).

The highest number of **conjoint effects** (27 altogether) were specified for the Tier 2 driver categories **consumption and production patterns** (8 drivers, or 30%); **socio-economic conditions** (where 7 drivers, or 26%, belong to the conjoint effect category, and 9 to the direct effect category); **trade patterns;** and, **infrastructure design** (3 drivers each, or 11% each). Some of the examples given above in relation to the number of driver mentions (section 5.5.1) and the direction of drivers (section 5.5.2) already pointed to conjoint effects between rising income and rising demands/living standards as drivers, mostly for inefficient resource use:

- Schandl and West (2010) argue that rising income in the Asia-Pacific region yield an emergent affluent class of consumers with new consumption and mobility patterns, which in turn explain massive infrastructure developments and decreasing resource efficiency in the Asia-Pacific region in the last decade.
- Schröder et al. (2011) see increasing consumption of meat and dairy products, in turn frequently associated with rising income as one important driver for increasing phosphorus use and associated dissipative losses due to inefficient production and consumption chains.
- Zaman and Lehmann (2011) find rising living standards in relation to affluence to be a negative pressure on resource consumption in urban contexts in their two city case study of Adelaide and Stockholm. In addition, they find than many urban centres in China and India are increasingly pursuing the developed, industrialized world's model of high consumption in order to drive GDP growth.

As some of the analysed articles show, existing driver linkages need to be expanded to also embrace trade patterns:

- Infante Amate and de Molina (2013) find the conventional model of agrarian production (fuel and nitrogen-fertilizer intensive, and requiring large transportation networks) in combination with meat related consumption patterns and the globalisation of agricultural production as key drivers both for high dissipative phosphorus losses and for energy inefficiency through small, road-based transport vehicles (lorries, cars of consumers) in Spanish agri-food systems.
- Weinzettel et al. (2013) argue that international trade patterns in combination with affluence and consumption patterns are driving increasing land footprint in other countries by requiring land use for domestic consumption demands.

Other conjoint effects occur between Tier 3 drivers from Tier 2 driver categories **economic benefits/(future) economic value** and **infrastructure design**. For instance, Lehtoranta et al. (2011) find that the infrastructure and design of Eco-Industrial Parks (EIPs) requires certain features (such as co-located enterprises, short distances between cascading used) in order to realize the economic benefits associated with EIPs.

Moderator effects are identified for drivers that influence how other drivers affect resource use efficiency. For instance, streamlining administrative procedures (del Río 2011) are considered to have a moderator effect on the applicability of technologies, because streamlined procedures can increase the adoption of more resource efficient renewable electricity technologies and projects. As regards phosphorus recovery, Cordell et al. (2011) find existing infrastructure as a moderating effect for urbanization. While urbanization creates hot-spots of human phosphorus sources as a potential pool for recycled phosphorus, many existing urban sanitation systems are water-based, so that phosphorus is diluted and therefore much more difficult to recover technologically. In relation to land use, Weinzettel et al. (2013) identify country size and population density, in combination with affluence, as moderating drivers in relation to land demand. Larger, less densely populated and lower-income countries are subject to more foreign land demand than other countries.

5.5.4 Tier 2 drivers and resource / sectoral focus

Similar to the display in the preceding section we can also look at other aspects of the drivers identified in the analysis, namely the types of resources and economic sectors they affect. The following two tables show cross tabulations of resource type and sector, respectively, against the first and second Tier drivers.

Table 9 Tier 2 drivers and resource focus

	Resources					
Drivers (Tier 1-2)	materials/Waste	energy	NA	land / soil	water	Total
Behavioural and informational	30	3	2	1	2	38
consumption and production patterns (incl. dietary patterns, lifestyles)	13	3		1		17
knowledge/information, training, skills	3		2		1	6
paradigms, world views, mental models, values, attitudes, perceptions, cultural practices	8					8
environmental awareness	6				1	7
Bio-physical	1	1	1		1	4
bio-physical conditions	1	1	1		1	4
Institutional and organisational	2					2
management/governance procedures	2					2
Policy and regulatory	12	7		1		20
legal-administrative settings and political actions	12	7		1		20
Socio-economic	32	7	6	3		48
economic benefits/(future) economic value	6	2				8
investments / financing (public & private)	4	1				5
resource prices (price developments)	4	2				6
socio-economic conditions	10		6	2		18
supply security	5	1				6
trade patterns / global markets	3	1		1		5
Technological and infrastructural	9	6	2			17
complexity and applicability of technologies and production processes	1	1				2
infrastructure design	8	5	2			15
Grand Total	**86**	**24**	**11**	**5**	**3**	**129**

Table 9 presents which resources the identified drivers are associated to. The resources most frequently addressed by the identified drivers are materials/waste (86 mentions) and energy (24 mentions). Taken together these two categories cover 85% of all identified drivers. Eleven drivers were identified either in relation to no clear single resource or to several resources – labelled as NA.[17] Five drivers are associated with land/soil and three drivers with water.

For **materials/waste**, consumption and production patterns was the Tier 2 driver category most often associated (13 times), followed by legal-administrative settings and political actions (12 times), and socio-economic conditions (10 times). As discussed above in section 5.5.3, the Tier 3 drivers consumption and production patterns and socio-economic conditions are frequently found as having conjoint effects on resource efficiency. This is also a finding in relation to materials/waste, where for instance rising income and aspirations drive inefficient use of phosphorus through increasing meat consumption and conventional models of agrarian production (Clift and Shaw 2012)(Cordell, et al. 2011)(Ott and Rechberger 2012)(Schröder, Smit, et al. 2011), as well as the use of industrial minerals and metals (Pajunen, et al. 2012)(Steger and Bleischwitz 2011)(Steinberger, Krausmann and Eisenmenger 2010)(Tiess 2010). Several cases identify legal-administrative settings and political actions as affecting waste management (Ezeah and Roberts 2012) and efficient use of waste as a secondary resource in Eco-Industrial Parks (Lehtoranta, et al. 2011)(Pajunen, et al. 2012).

For **energy**, legal-administrative settings and political actions were found to be important drivers seven times, followed by infrastructure design with five mentions. In their analysis of the drivers and barriers to the efficiency and uptake of renewable electricity, del Río (2011) specifically focused on legal-administrative settings and political actions. For this particular type of energy, they identify drivers ranging from carbon pricing, support schemes and removal of administrative barriers and provision of grid access as being relevant. In addition, Alotaibi (2011) finds the subsidization of energy as one key driver encouraging inefficient use of energy in Kuwait, while Verbruggen et al. (2010) identify R&D investments to have direct effects on the development, cost-efficacy and potential use of renewable electricity as a driver for more efficient energy use. In relation to infrastructure design, del Río (2011) see infrastructure tied up in fossil fuel electricity generation as causing a lock-in against more efficient (renewable) energy production. For instance, the ability of renewable electricity generators to feed their output into the grid strongly depends on the grid design.

Land/soil were most often (two times) found in the context of socio-economic conditions. Here, Weinzettel et al. (2013) argue that country size, population density and affluence, in combination with consumption patterns lead to increasing land demand and displacement of land use to other countries to fulfil domestic consumption demands.

Water was mentioned only once in relation to several Tier 2 drivers, e.g. environmental concerns and bio-physical conditions. According to the findings of Hu et al. (2010), both the farmers' concerns for water pollution through leaching and soil erosion, and low groundwater per capita availability act as drivers for water saving measures in Shijiazhuang Irrigation District, China.

As there are large overlaps between resources and the sectors, in which the resources play important roles in relation to resource efficiency (e.g. phosphorus and the food sector; energy for the energy sector, such as electricity generation; or, minerals in the building sector), the findings of the sectoral focus of many Tier 2 and Tier 3 drivers are very similar to the resource focus analysis above. The following Table 10 describes the sectoral focus of the identified drivers.

---

[17] This term is common in descriptive tables and refers to information that is either not available or to categories that are not applicable.

Table 10 Tier 2 drivers and sectoral focus

Drivers (Tier 1-2)	Sectors: NA	food	energy	buildings	Total
Behavioural and informational	19	17	1	1	38
consumption and production patterns (incl. dietary patterns, lifestyles)	8	7	1	1	17
knowledge/information, training, skills	4	2			6
paradigms, world views, mental models, values, attitudes, perceptions, cultural practices	4	4			8
environmental awareness	3	4			7
Bio-physical	1	1	1	1	4
bio-physical conditions	1	1	1	1	4
Institutional and organisational	2				2
management/governance procedures	2				2
Policy and regulatory	10	3	7		20
legal-administrative settings and political actions	10	3	7		20
Socio-economic	27	14	5	2	48
economic benefits/(future) economic value	4	2	2		8
investments / financing (public & private)	3	1	1		5
resource prices (price developments)	3	2	1		6
socio-economic conditions	13	3		2	18
supply security	2	3	1		6
trade patterns / global markets	2	3			5
Technological and infrastructural	12		4	1	17
complexity and applicability of technologies and production processes	2				2
infrastructure design	10		4	1	15
Grand Total	**71**	**35**	**18**	**5**	**129**

In most (71 out of 129, or 56%) cases, the sector was not specifically identified in the literature (**NA**). **Food** and **energy** with 35 (27%) and 18 (14%) cases, respectively, are the most important sectoral categories. Taken together, they make up 41% of the total. The **building** sector was the focus of only five drivers (4%).

For the **food** sector, the Tier 2 drivers most often mentioned are consumption and production patterns (seven times or 20%), environmental concerns and paradigms, world views, mental models, etc. (four times each or 11%). These findings can be explained in relation to the phosphorus use in agriculture, where inefficient use is driven by increasing meat consumption and conventional models of agrarian production as well as by perceived fears of contaminated agricultural products from applying recycled phosphorus from human excreta, while environmental concerns for water pollution help drive efforts to recycle phosphorus and thus prevent losses to waterways (Clift and Shaw 2012)(Cordell, et al. 2011)(Schröder, Smit, et al. 2011).

As regards the **energy** sector, legal-administrative settings and political actions (seven mentions, or 39%) and infrastructure design (four times, or 22%) are the Tier 2 drivers most often found. This relates to subsidization of energy which encourages inefficient energy use in Kuwait (Alotaibi 2011), or to administrative procedures setting incentives and framework conditions that influence investors' decisions concerning renewable electricity (del Río 2011). It also encompasses infrastructure tied up in fossil fuel electricity generation that leads to a lock-in against more efficient (renewable) energy production (ibid.).

The Tier 2 driver most often identified in relation to the **building** sector is socio-economic conditions. Here, it is again a combination of rising income and demands for more floor space, which according to Güneralp and Seto (2012) drives concrete demand and greater resource inefficiency as the floor space per person increases.

6 Summary and findings

The aim of this report was to identify the main inefficiencies of resource use in the EU (production and consumption) and investigate their drivers and underlying causes. This was done by reviewing existing literature and analysing available data on various types of resource use (materials, energy, water, land and ecosystems) and their environmental impacts in the EU and global economy.

6.1 Overview of the main resource inefficiencies

A review of the global and macro-economic flows of resources and their uses provided a first indication on which resources are used most inefficiently and where in the life cycle this occurs. The resources that are used the most in the economy are not necessarily the same as those that are used most inefficiently, but the total flow of resources in the economy provide an idea of which types of resource use are most important to improve.

- The EU food system is particularly resource intensive in terms of biomass extracted, freshwater withdrawals, land use, application of fertilizers and wild fish catches. While there is significant potential to improve resource efficiency related to agriculture, fisheries and food production, the greatest potential seems to lie in addressing food consumption: diets, overconsumption and food waste.
- Over 75% of EU's primary energy consumption is based on fossil fuels. Renewables represent about 10% of current energy consumption, but could potentially cover all EU energy demand. In addition to being a finite resource, the burning of fossil fuels is the main source of human induced GHG emissions that lead to climate change. While renewable energy sources could reduce GHG emissions significantly, this involves large investments and might even put a even greater strain on the use of other resources, e.g. land and water to produce bioenergy, critical raw materials to produce photovoltaics and wind turbines. It would be less costly to increase energy efficiency in power generation, buildings, transport and industry, even though this also requires significant investments.
- Compared to other resources, metals are generally the most valued within the economy. Despite being inherently recyclable, they are often sent to landfills at their end-of-life. Besides reducing the demand for metal through better design and longer product lifetimes, closing material loops seems to have the greatest potential for increasing resource efficiency of metals.
- Minerals also have the potential to be more efficiently reused and recycled, however the greatest potential for improving the resource efficiency of construction minerals is through better design and planning of buildings and infrastructure. It also holds the potential for more efficient use of land, energy and water related to buildings and urban areas. Other minerals, phosphorus in particular, are used very inefficiently with losses occurring throughout the life cycle.
- The greatest users of freshwater in the EU are the energy sector (for cooling purposes), the agricultural sector, public water supply and industry. The greatest

inefficiencies identified were related to irrigation technologies and practices; leakages in the public supply system and evaporation in (energy production) cooling systems. There is also scope for significant improvements in the water efficiency of water-using products (e.g. toilets, showers, dishwashers, washing machines, etc.) and buildings as well as the potential for reusing wastewater and harvesting rainwater.

- The main inefficiencies identified related to land use is land conversion from natural land to agricultural or built-up land (particularly, urban sprawl and transport infrastructures). Due to large remediation costs, abandoned contaminated sites in particular represent inefficient use of land, which is a finite and scarce resource.
- From a general perspective of resource use, the extraction of all natural resources and the generation of environmentally harmful emissions and waste along all life cycle stages are often the cause to severely degraded ecosystems and their ability to provide the services that the economy is dependent on. In most cases ecosystems provide these benefits in a much more efficient manner than humans are capable of.

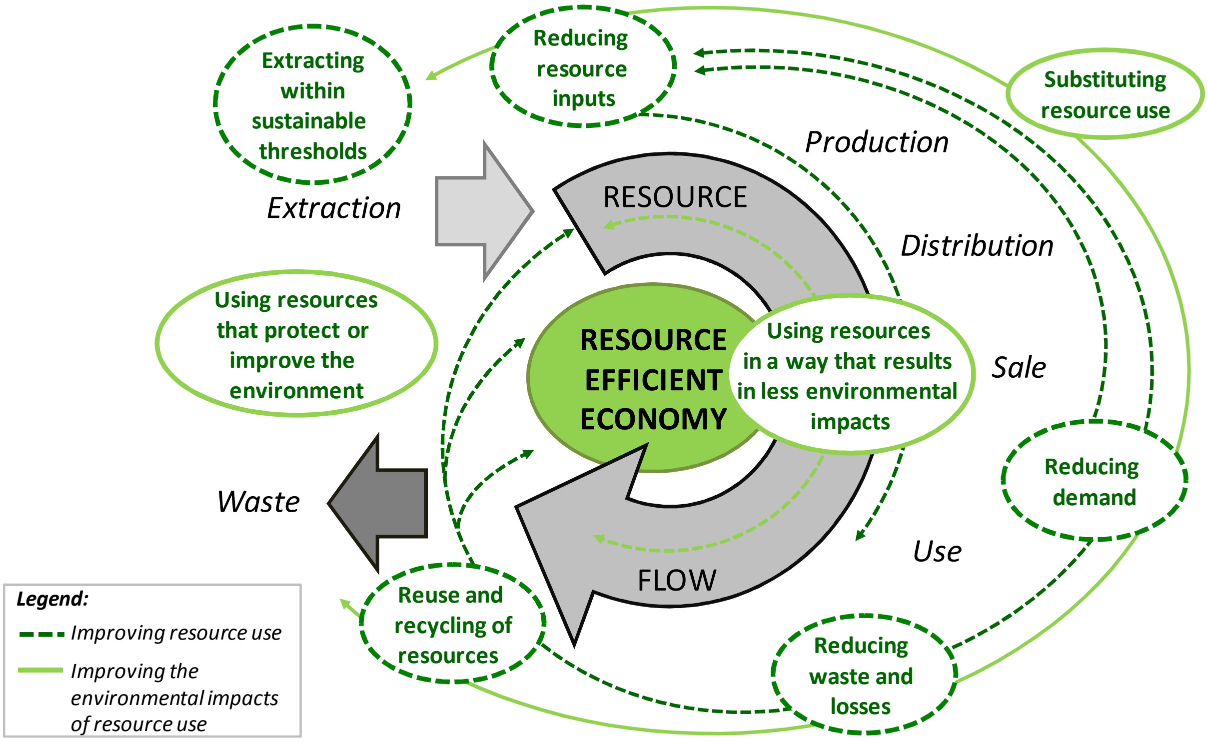
The review and analysis of inefficient resource use showed that there are many different approaches to improving resource efficiency:

- Reducing waste and losses is the most common strategy. Besides reducing the environmental impacts associated with waste treatment, it also contributes to reducing the demand of resources, which in turn also reduces the amount of resources that are extracted.
- Reducing demand is in itself a resource efficiency strategy, which can be achieved by changing user behaviour and using more efficient technologies and products, but could also be achieved by simply ensuring that consumers' needs are fulfilled (resource sufficiency). Reducing demand indirectly reduces the amount of resources that need to be extracted.
- Directly reducing resource inputs is another option for improving resource efficiency. This relates to actions such as improving the yield during the extraction of raw materials and production, e.g. optimising fertiliser and pesticide application in agriculture; minimising losses in metal production; or, designing products in a way that require less resources.
- Another design related approach is substituting specific resources with other types of resources that are less harmful to the environment. Human needs can be fulfilled by different means, e.g. wood can be used instead of fossil fuels and vegetable proteins can replace meat. This approach does not necessarily result in less resources used, but can shift towards more sustainable resource use.
- For renewable resources, ensuring that the extraction respects sustainable thresholds is another approach to improving resource efficiency. This allows the ecosystem to continuously provide the desired resource (e.g. wild fish catches).
- It is also possible in some cases to use resources in a way that results in less environmental damage. This does not necessarily reduce the amount of resources used, but reduces the emissions to the environment and disruptions to ecosystems.

- In special cases, it is even possible to use resources in a manner that is beneficial to the environment. Examples of this are creating green spaces in urban areas or cleaning contaminated soils.
- Finally, if waste is unavoidable, it can still be transformed into a useful resource through (energy) recovery, reuse and recycling.

The following figure summarises the main strategies to improving resource efficiency.

Figure 58 The identified main strategies to improve resource efficiency

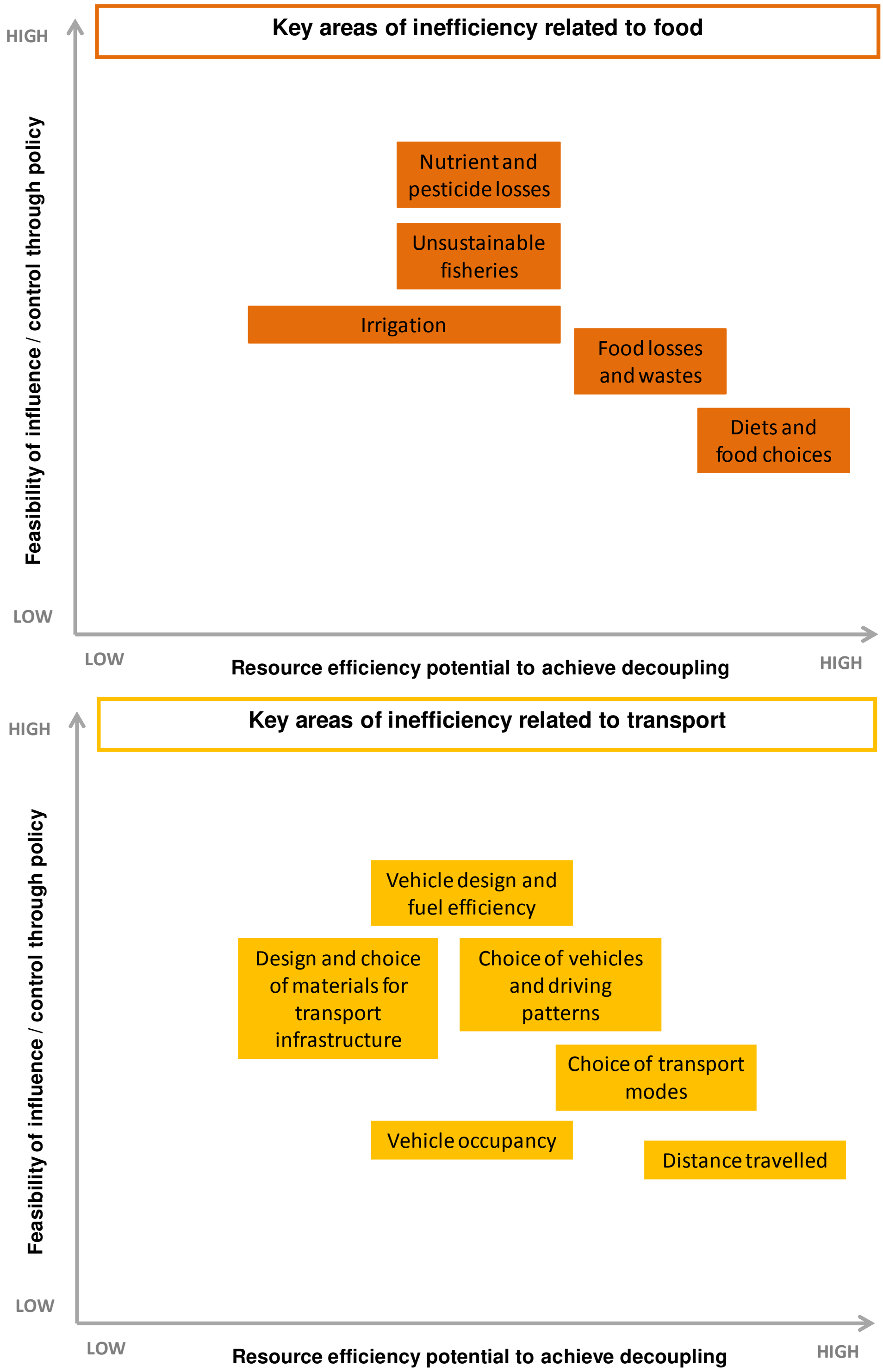


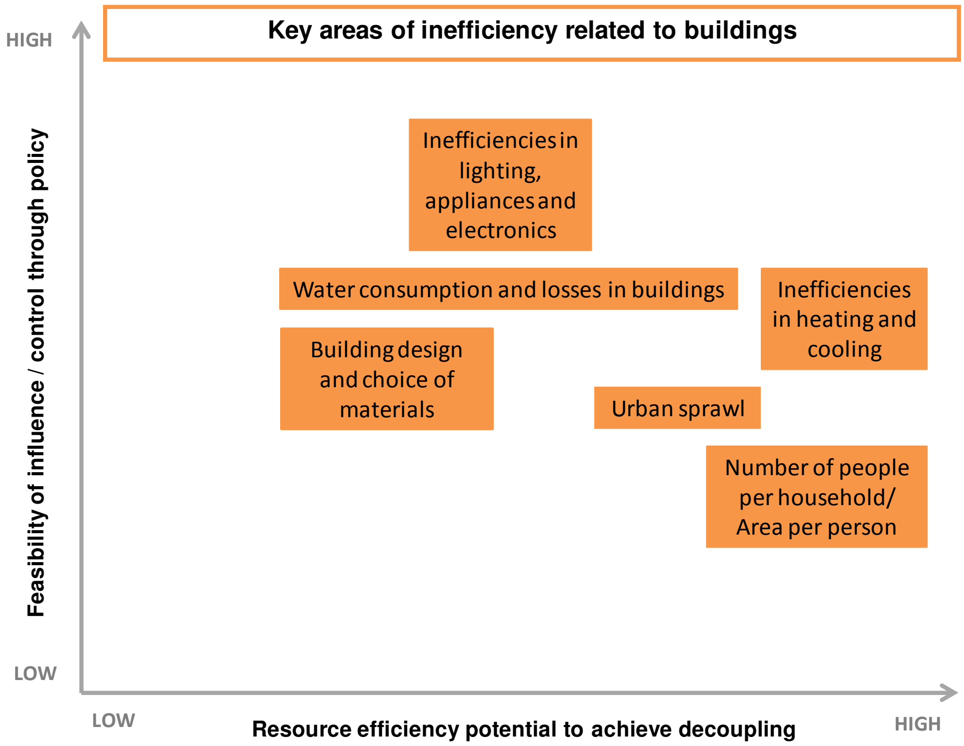
6.2 The key areas to address to achieve absolute decoupling

The review and analysis of resource inefficiency uncovered areas which could potentially be addressed by policy intervention to achieve absolute decoupling in the EU by 2050. Besides some general aspects of EU production and consumption patterns, the key areas of resource inefficiency were related to food, transport and buildings. These represent the areas that contribute the most to environmental pressures in the EU.

Figure 59 presents the areas with significant potential to improve resource efficiency and possibly achieve absolute decoupling. The areas identified in this study are ranked according to two dimensions: in relation to the potential for resource efficiency improvement, and in relation to the feasibility or ease for policy to influence resource efficiency improvements (Bringezu and Bleischwitz 2009). The ranking and comparison of key areas of inefficiency are based on the authors' opinion and not on thorough assessments.

Figure 59 A preliminary assessment of key areas of inefficiency in relation to potential for decoupling and policy intervention





6.3 The main drivers of resource inefficiency

A variety of factors that influence resource inefficiency were identified through both the qualitative literature review and meta-analysis. These factors affect resource efficiency in various ways, e.g. positive or negative, as well as directly or in combination with other drivers (conjoint or moderator effects).

In most of the existing literature on resource efficiency, population growth and rising income (affluence) are identified as two of the main root causes of existing unsustainable patterns of resource use – regardless of the resource type (energy, materials, water, land). However, rising income and population growth are mainly indirect drivers – there are other factors with more direct influence on resource inefficiency. Our analysis points to drivers that constitute part of the complex interplay of factors: in particular consumption and production patterns that translate the increasing affluence of ever more people (emerging middle-class consumers) into lifestyles and habits associated with high resource use. This was observed in relation to areas such as:

- dietary choices (high meat and dairy consumption),
- choice of transport modes and distance travelled (more use of individual transport modes, increasing air travel), and
- housing preferences (larger living spaces per person, increasing number of appliances in use, more efficient heating systems which in the context of the rebound effect might even lead to an increase in excessive energy use).

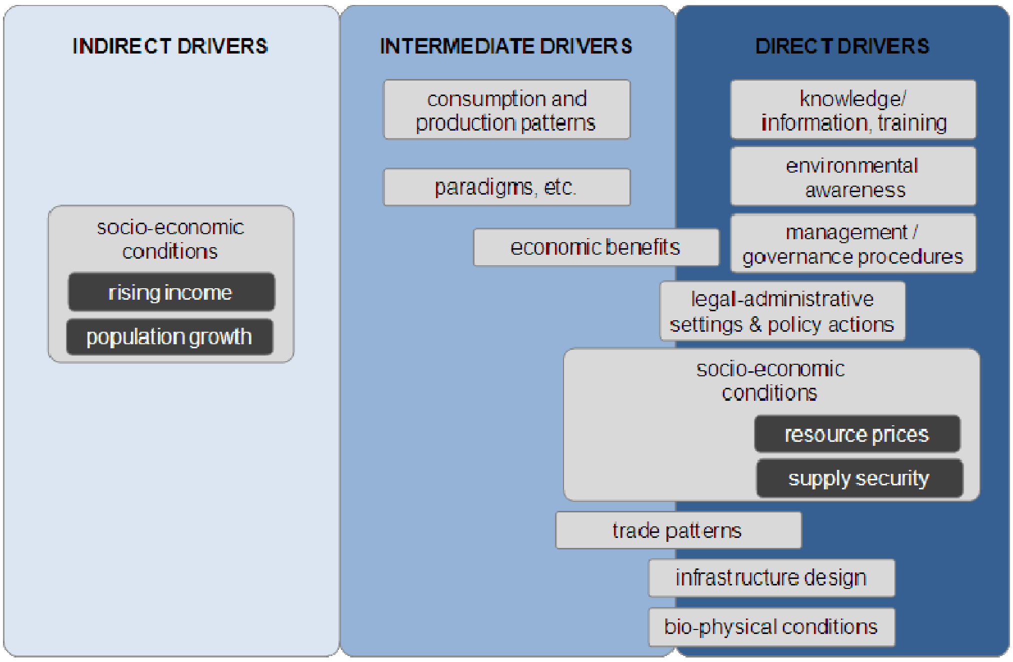
These consumption and production patterns might manifest themselves in, or in turn are encouraged by:

- Resource-intensive global trade patterns satisfying emerging needs of more affluent people through globalisation of production and consumption, with associated land displacement and environmental impacts abroad.
- Infrastructure development that could lead to lock-ins (e.g. waste incineration plants, fossil fuel based energy infrastructures, urban sprawl).

All the above mentioned drivers appear to be directly affected – or at least indirectly influenced – by either resource efficiency fostering or impeding legal frameworks, administrative settings and political actions. The meta-analysis showed that legal-administrative settings and political actions and legal/political frameworks/actions were most often mentioned of among the drivers identified. While the focus of the study was on factors affecting resource inefficiency, several factors were identified that contribute to improving resource efficiency. The most commonly mentioned are environmental concerns (mainly in relation to water pollution), resource prices and supply insecurity. While it can be discussed whether environmental concerns as such are sufficiently powerful drivers for more efficient resource use, resource prices and supply insecurity were shown to be considered powerful drivers that case studies demonstrated to have already led to improvements in resource efficiency. Both have direct economic impacts on business, trade and competitiveness.

In an attempt to classify drivers according to the way they influence the improvement of resource efficiency, the following figure (based on the effect type allocation) of indirect, intermediate and direct drivers was created.

Figure 60 Conceptualisation of indirect, intermediate and direct drivers for improving resource efficiency



The light grey boxes are Tier 2 driver categories, while the dark grey boxes are Tier 3 drivers. The light blue area to the left indicates indirect drivers, while the darker blue are in the middle represents intermediate drivers. The dark blue area to the right shows direct drivers. The location of the Tier 2 and 3 drivers within each blue area is based on an indicative visualization of the share of direct to conjoint and moderator effects the different drivers were found to have (see Table 8, section 5.5.3).

Overall, the findings from the literature review and the meta-analysis contribute to an improved and more comprehensive picture of relevant drivers affecting resource inefficiency. This will serve as a guide for the other work packages of the DYNAMIX project, which aims is to identify policy pathways to absolute decoupling of economic growth from resource use and its environmental impacts.

7 References

ADEME. “Energy Efficiency Trends in Buildings in the EU. Lessons from the ODYSSEE MURE project.” Prepared by Enerdata. Managed by ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie), the French Environment and Energy Management Agency. Financed under the Intelligent Enegry Europe Programme , 2012.

Agriculture and rural development. "Agriculture and Water." *Agriculture and rural development.* 2012. http://ec.europa.eu/agriculture/envir/water/index_en.htm.

Allwood, J, and J Cullen. *Sustainable Materials with both eyes open.* UIT Cambridge, 2012.

Alotaibi, Sorour. “Energy consumption in Kuwait: Prospects and future approaches.” *Energy Policy*, 39 (2) 2011: 637-643.

Alterra. “Emissions from agriculture and their control potential.” 2012.

Amecke, H. “The impact of energy performance certificates: A survey of German home owners.” *Energy Policy*, 2012.

ARCADIS. “Analysis of the evolution of waste reduction and the scope of waste prevention.” Study commissioned by the European Commision, DG Environment, 2011.

Audsley, E, M Brander, J Chatterton, D Murphy-Bokern, C Webster, and A Williams. *How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050.* WWF-UK and the Food Climate Research Network, 2009.

Barrett, J, et T Wiedmann. *A comparative carbon footprint analysis of on-site construction and an off-site manufactured house.* Stockholm Environment Institute (SEI) and ISAUK research report 07-04, 2004.

Basset-Mens, Cluadine. “Proposition pour une adaptation de l'Analyse de Cycle de Vie aux systèmes de production agricol. Mise en oeuvre pour l'évaluation environementale de la production porcine.” 2005.

Bennett, Merril K. “International contrasts in food consumption.” *Geographical Review*, 1941.

Berg, M van den. *EU Resource Efficiency Perspectives in a Global Context.* The Hague: PBL Netherlands: Environmental Assessment Agency, 2011.

Bertoldi, Paolo, Bettina Hirl, and Nicola Labanca. “Energy Efficiency Status Report: Electricity consumption and efficiency trends in the EU-27.” JRC Scientific and Policy Reports, 2012.

BIO Intelligence Service. *Assessment of resource efficiency in the food cycle.* Final report, prepared in collaboration with AEA, DR Donal Murphy-Bokern, Institute of Social Ecology Vienna and Institute for Environmental studies, European Commission (DG ENV), 2012a.

BIO Intelligence Service. "Large Scale Planning and Design of Resource Use." Study commissioned by the European Commission, DG Environment, 2011a.

BIO Intelligence Service. *Preparatory study on food waste across EU 27.* Paris, France: BIO Intelligence Service, 2010a.

BIO Intelligence Service. “Update of analyses of DMC accounts.” Study performed for DG Eurostat based on Eurostat data, 2011b.

BIO Intelligence Service. “Water Performance of Buildings.” Final report prepared for the European Commission, DG Environment, 2012b.

BIO Intelligence Service. “Water saving potential in agriculture in Europe: findings from the existing studies and application to case studies.” Final report prepared for the European Commission, DG Environment, 2012.

BIO IS, AEA and IEEP. *Plastic waste in the environment.* BIO Intelligence Service, AEA Energy and Environment and the Institute for European Environmental Policy for the European Commission, 2011.

BIO IS, Arcadis and IEEP. *Study on the management of construction and demolition waste in the EU.* BIO Intelligence Service, Arcadis and the Institute for European Environment Policy for the European Commission, DG Environment, 2011.

BiPRO. *Screening of waste management performance of EU Member States.* Study commissioned by the European Commission, DG Environment, 2012.

Borgstede, C, and K Andersson. “Environmental Information—Explanatory Factors for Information Behavior.” *Sustainability*, 2 (9) 2010: 2785-2798.

Borin, Norm, Douglas C Cerf, and R Krishnan. “Consumer effects of environmental impact in product labelling.” *Journal of Consumer Marketing*, 28 (1) 2011: 76-86.

Boulanger, Paul-Marie. “Three strategies for sustainable consumption.” *SAPIENS (Survey And Perspectives Integrating ENvironment & Society)*, No. 2 Vol. 3 2010.

BRE. "BeAware Supply Chain Resource Efficiency Sector Report, Modern Methods of Construction." 2009.

Bressoud, F. “Système de culture et qualité de la tomate.” *Innovations Agronomiques*, 2010: 107-114.

Bringezu, S, and R Bleischwitz. *Sustainable Resource Management.* (eds), Greenleaf Publishing, 2009.

British Environmental Agency. *Study into the Feasibility of Protecting and Recovering Critical Raw Materials Through Infrastructure Development in the South East of England.* European Pathway to Zero Waste Protecting and Recovering Critical Raw Materials, 2011.

Caird, S., Roy, R. et al. “Improving the energy performance of UK households: Results from surveys of consumer adoption and use of low- and zero-carbon technologies.” *Energy Efficiency*, 2008.

Candela, L, F Dominga, J Berbel, and J J Alarcon. *An overview of the main water conflicts in Spain: Proposals for problem-solving.* Options Méditerranéennes A n°83 Water Culture and Water Conflict in the Mediterranean Area, 2008.

Chen, W-Q, and T E Graedel. “Anthropogenic Cycles of the Elements: A Critical Review.” *Environmental Science and Technology*, 46 2012: 8574–8586.

Clift, Roland, and Heather Shaw. “An Industrial Ecology Approach to the Use of Phosphorus.” *Procedia Engineering*, 2012: 39-44.

Copenhagen Economics. “Company Car Taxation.” Taxation Papers prepared for the European Commission, DG Taxation and Customs Union, 2010.

Cordell D, Drangert J., White S. «The story of phosphorus: Global food security and food for thought.» *Global Environmental Change* (Global Environmental Change 2009;19:292–305), 2009: 292–305.

Cordell, D, A Rosemarin, J J Schröder, and A L Smit. “Towards global phosphorus security: A systems framework for phosphorus recovery and reuse options.” *Chemosphere*, 84 (6) 2011: 747-758.

Cordell, Dana. *The story of phosphorus: sustainability implications of global phosphorus scarcity for food security.* Linkoping: Linkoping University, 2010.

Crilly, R, and A Esteban. *No Catch Investment. Investing to restore European fish stocks.* nef (the new economics foundation), 2012.

Czymmek, Karl, Larry Geohring, Quirine Ketterings, Peter Wright, and Angus Eaton. “Supplemental Manure Spreading Guidelines to Reduce Water Contamination Risk During Adverse Weather Conditions.” 2005: 1-3.

Defra. “Progress Report on Sustainable Products and Materials.” London, 2008.

del Río, Pablo. “Analysing future trends of renewable electricity in the EU in a low-carbon context.” *Renewable and Sustainable Energy Reviews*, 15 (5) 2011: 2520-2533.

Department for Business Innovation & Skills. “Practical Resource Efficiency Savings - Case Studies.” 2009.

DG Enterprise and Industry. *Critical raw materials for the EU. Report of the Ad-hoc Working Group on defining critical raw materials.* European Commission, 2010.

DG for Health & Consumers . *Strategy for Europe on nutrition, overweight and obesity related health issues.* Implementation progress report, European Commission, 2010.

Didier, K, and J Thomson. “Habitat Fragmentation and Connectivity.” In *CBD Technical Series 32: Sourcebook on Remote Sensing and Biodiversity Indicators*. Prepared by the NASA-NGO Biodiversity Working Group and UNEP-WCMC for the Convention on Biological Diversity, 2007.

Dourmad, J.-Y., C Rigolot, and C Jondreville. “Influence de la nutrition sur l'excrétion d'azote, de phosphore, de cuivre et de zinc des porcs, et sur les émissions d'ammoniac, de gaz à effet de serre et d'odeurs.” 2009: 41-48.

Dove, Justin. "Cobalt: A Critical Metal to Clean Energy." 2011. http://www.investmentu.com/2011/September/cobalt-critical-metal-clean-energy.html.

Dworak, T, et al. *Assessment of agriculture measures included in the draft River Basin Management Plans.* Berlin/Vienna: Ecologic, 2010.

Dworak, Thomas, et al. *EU Water Saving Potential (Part 1-Report).* Report prepared for the European Commission, Ecologic- Institute for International and European Environmental Policy, 2007.

EBC. *2010 Water and Wastewater Benchmark — Learning from international best practices.* European Benchmarking Co-operation, 2011.

EC. *Thematic Strategy on the Sustainable Use of Natural Resources.* European Commission, 2005.

Ecofys. *Incentives to improve energy efficiency in EU grids.* Commissioned by the European Copper Institute, 2013.

Eco-Innovation Obervatory. “Resource-efficient construction. The role of eco-innovation for the construction sector in Europe.” EIO Thematic Report, 2011.

Ecotapware. "Task 2: Economic and Market Analysis Task 3: User Behaviour." 2011.

EEA. *Achieving energy efficiency through behaviour change: what does it take?* European Environment Agency, 2013.

EEA. “Beyond transport policy - exploring and managing the external drivers of transport demand.” 2008.

EEA. “End-user GHG emissions from energy. Reallocation of emissions from energy industries to end users 2005-2009.” 2011.

EEA. *Environmental Indicator Report 2012. Ecosystem resilience and resource efficiency in a green economy in Europe.* European Environment Agency, 2012.

EEA. *Environmental indicators: typology and use in reporting.* EEA internal working paper, European Environment Agency, 2003.

EEA. *Environmental pressures from European consumption and production. A study in integrated environmental and economic analysis.* EEA Technical report No 2/2013, European Environment Agency, 2013a.

EEA. *Land use — SOER 2010 thematic assessment.* European Environment Agency, 2010.

EEA. “The European environment - State and outlook 2010 - Consumption and the environment 2012 update.” 2012a.

EEA. *The European environment — State and outlook 2010: synthesis.* Copenhagen: European Environment Agency, 2010a.

EEA. *Towards Efficient Use of Water Resources in Europe.* European Environment Agency, 2012b.

EEA. *Urban environment - SOER 2010 thematic assessment.* European Environment Agency, 2010b.

EEA. *Urban sprawl in Europe – The ignored challenge.* EEA Report No 10/2006, European Environment Agency, 2006.

Egger, M, G D Smith, and A N Phillips. “Meta-analysis: principles and procedures. BMJ. 1997 Dec 6;:.” *British Medical Journal*, 7121 315 1997: 1533–1537.

Ehrlich, P., and J Holdren. “The people problem.” *Saturday Review*, 4 1970: 42-43.

Ellen MacArthur Foundation. *Towards the Circular Economy.* 2012.

Energy Efficiency Watch Project. “Survey report - Progress in energy efficiency policies in the EU Member States - the experts perspective.” 2012.

Environment Agency. *Water resources for England and Wales – current status, future pressures.* UK, 2008.

Erb, Karl-Heinz, Helmut Haberl, and Fridolin Krausman. *Eating the Planet: Feeding and fuelling the world sustainably, fairly and humanely – a scoping study.* Institute of Social Ecology, Alpen-Adria Universität Klagenfurt – Graz – Wien and Potsdam Institute for Climate Impact Research, PIK Potsdam, 2009.

Espínola-Arredondo, Ana, and Félix Muñoz-García. “Can incomplete information lead to under-exploitation in the commons?” *Journal of Environmental Economics and Management*, 62 (3) 2011: 402-413.

ETC/SCP. *Europe as a Recycling Society. European Recycling Policies in relation to the actual recyling achieved.* ETC/SCP working paper 2/2011, European Topic Centre on Sustainable Consumption and Production, European Environment Agency (EEA), 2011.

European Commission. “A Roadmap for moving to a competitive low carbon economy in 2050.” 2011.

European Commission. *Impact Assessment of Discard Reducing Policies.* Studies in the Field of the Common Fisheries Policy and Maritime Affairs, Lot 4: Impact assessment studies related to the CFP, Brussels: European Commission, 2011a.

European Commission. "Impact Assessment. Roadmap for moving to a competitive low carbon economy in 2050." 2011.

European Commission. *Land in Europe: prices, taxes and use patterns.* Technical report, n°4, 2010.

European Commission. “Urban Audit.” Flash Eurobarometer, 2005.

Eurostat. «Energy, transport and environment indicators.» 2011.

Ezeah, Chukwunonye, and Clive L Roberts. “Analysis of barriers and success factors affecting the adoption of sustainable management of municipal solid waste in Nigeria.” *Journal of Environmental Management*, 103 2012: 109-119.

Faber, Jasper, Arno Schroten, Mart Bles, Maartje Sevenster, Agnieszka Markowska, and Martine Smit. *Behavioural Climate Change Mitigation Options and Their Appropriate Inclusion in Quantitative Longer Term Policy Scenarios.* Delft, 2012.

FAO. “Food consumption: energy, protein and fat.” *Food and Agriculture Organization of the United Nations.* Food and Agriculture Organization of the United Nations. 2011. http://www.fao.org/fileadmin/templates/ess/documents/food_security_statistics/FoodConsumptionNutrients_en.xls (accessed 03 2013).

FAO. *Human energy requirements: reports of a joint FAO/WHO/ONU expert consultation.* Rome, Italy: FAO, 2001.

FAO. *The State of World Fisheries and Aquaculture 2012.* Rome: Food and Agriculture Organisation (FAO), 2012.

Foley, Jonathan A, Navin Ramankutty, Kate A Brauman, Emily S Cassidy, James S Gerber, and Matt Johnston. “Solutions for a cultivated planet.” *Nature*, 478 2011: 337-342.

García Mollá, M. *Análisis de la influencia de los costes en el consumo de agua en la agricultura valenciana. Caracterización de las entidades asociativas para riego.* PhD thesis, Departamento de Economía y Ciencias Sociales. Universidad Politécnica de Valencia, Valencia., 2002.

Gold, Mark. *The global benefits of eating less meat.* A report for Compassion in World Farming Trust, 2004.

Grafton, R. Q. et al. “Determinants of residential water consumption: evidence and analysis from a 10-country household survey.” *Water Resources Research*, 47 (no W08537) 2011.

Graus, Wina, and Ernst Worrell. “The principal–agent problem and transport energy use: Case study of company lease cars in the Netherlands.” *Energy Policy* , 2008: 3745–3753.

Greenovate! Europe. *Guide to resource efficiency in manufacturing. Experiences from improving resource efficiency in manufacturing companies.* REMake project, 2012.

Greenpeace and EREC. *Energy [r]evolution. Towards a fully renewable energy supply in the EU 27.* Greenpeace and the European Renewable Energy Council, 2010.

GUA. *The Contribution of Plastics Products to Resource Efficiency.* Gesellschaft für umfassende Analysen GUA) for PlasticsEurope, 2005.

Güneralp, Burak, and Karen C Seto. “Can gains in efficiency offset the resource demands and CO2 emissions from constructing and operating the built environment?” *Applied Geography*, 32 (1) 2012: 40-50.

Gustavsson, Jenny, Christel Cederberg, Ulf Sonesson, Robert van Otterdijk, and Alexandre Meybeck. *Global food losses and food waste.* Food and Agriculture Organisation of the United Nations, 2011.

Haase, D. “Modelling the effects of long-term urban land use change on the water balance.” *AGD Landscape & Environment*, 2 (2) 2008: 143-159.

Hardin, G. “The Tragedy of the Commons.” *Science*, 3859 162 1968: 1243-1248.

Hawkins, Troy, Bhawna Singh, Guillaume Majeau-Bettez, and Anders Stromman. "Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles." *Journal of Industrial Ecology 17 (1)*, 2012: 53-64.

Hertwich, Edgar. “Consumption and the Rebound Effect: An Industrial Ecology Perspective.” *Journal of Industrial Ecology*, 9 (1-2) 2005: 85-98.

Hu, Yukun, Juana Paul Moiwo, Yonghui Yang, Shumin Han, and Yanmin Yang. “Agricultural water-saving and sustainable groundwater management in Shijiazhuang Irrigation District, North China Plain.” *Journal of Hydrology*, 393 (3–4) 2010: 219-232.

IEA. “Assessing measures of energy efficiency performance and their application in industry.” 2008.

IEA. “Buildings Technology Roadmap. Energy-efficient Buildings: Heating and Cooling Equipment.” Paris, 2011.

IEA. “Energy Efficient Tyres: Improving the On-Road Performance of Motor Vehicles.” 2005.

IEA. “Energy Technology Perspectives 2012.” 2013.

IEA. “Gadgets and Gigawatts: Policies for Energy Efficient Electronics.” 2009.

IEA. “Mind the Gap - Quantifying Principal-Agent Problems in Energy Efficiency.” 2007.

IEA. “Technology Roadmap: Fuel Economy of Road Vehicles.” Paris, 2012.

IEA. “Transport Energy efficiency - Implementation of IEA Recommendations since 2009 and next steps.” 2010.

IEA. “Transport, Energy and CO2: Moving Toward Sustainability.” 2009a.

IEA. “World Energy Outlook 2012.” 2012a.

IEA, OPEC, OECD and World Bank. *Analysis of the scope of energy subsidies and suggestions for the G-20 initiative.* Joint Report prepared for submission to the G-20 Summit Meeting Toronto (Canada), 26-27 June 2010, International Energy Agency, Organization of the Petroleum Exporting Countries, Organisation for Economic Co-operation and Development and the World Bank, 2010.

Infante Amate, Juan, and Manuel González de Molina. “‘Sustainable de-growth’ in agriculture and food: an agro-ecological perspective on Spain’s agri-food system (year 2000).” *Journal of Cleaner Production*, 2013: 27-35.

INRA. *Les flux d'azote liés aux élevages. Réduire les pertes, rétablir les équilibres.* Institut National de la Recherche Agronomique (INRA) / the French National Institute for Agricultural Research, 2012.

IPCC. “IPCC Fourth Assessment Report: Climate Change 2007.” 2007.

Jackson, Tim. *Motivating Sustainable Consumption. A review of evidence on consumer behaviour and behavioural change.* A report to the Sustainable Development Research Network, 2005.

Jackson, Tim. *Prosperity Without Growth? The transition to a sustainable economy.* Sustainable Development Commission, 2009.

Jarnehammar. “Barriers and possibilities for a more energy efficient construction sector.” 2010.

Jasinski, SM. «Phosphate Rock, Mineral Commodity Summaries.» *US Geological Survey.* 2012. http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mcs-2012-phosp.pdf.

JRC. *Electricity Consumption and Efficiency Trends in the European Union.* European Commission, Joint Research Centre (JRC), Institute for Energy (IE), 2009.

JRC. *Environmental Improvement of Passenger Cars (IMPRO-car).* European Commission, Joint Reseach Centre (JRC), Institute for Prospective Technological Studies (IPTS), 2008.

JRC. *Environmental Improvement Potential of Residential Buildings.* European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTS), 2008a.

JRC. *Report on saving potentials in energy transmission and distribution.* European Commission, Joint Research Centre, Institute for Energy and Transport, 2012.

JRC. *State of soil in Europe. A contribution of the JRC to the EEA's Environment State and Outlook Report (SOER 2010).* European Commission, Joint Research Centre, 2012a.

Keys, P, J Barron, and M Lannerstad. *Releasing the Pressure: Water Resource Efficiencies and Gains forEcosystem Services.* Nairobi; Stockholm: United Nations Environment Programme; Stockholm Environment Institute, 2012.

Kinner, W, C, et al. *Sustainable Water Use in Europe Part 1: Sectoral Use of Water.* European Environment Agency, 1999.

Koos, Sebastian. "Varieties of environmental labelling, market structures, and sustainable consumption across Europe: A comparative analysis of organizational and market supply determinants of environmental-labelled goods ." *Journal of Consumer Policy*, 34 (1) 2011: 127-151.

Krausmann, Fridolin, Simone Gingrich, Nina Eisenmenger, Karl-Heinz Erb, and Marina Fischer-Kowalski. "Growth in global materials use, GDP and population during the 20th century." *Ecological Economics*, 68 2009: 2696-2705.

Kummu, M., H. de Moel, M. Siebert, S. Porkka, O. Varis, and P.J. Ward. "Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use." *Sciences of the totla environment*, 2012: 477-489.

Lehtoranta, Suvi, Ari Nissinen, Tuomas Mattila, and Matti Melanen. "Industrial symbiosis and the policy instruments of sustainable consumption and production." *Journal of Cleaner Production*, 19 (16) 2011: 1865-1875.

Leip, Adrian, et al. *Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS).* European Commission, Joint Research Centre, 2010.

Lifset, Reid J, Matthew J Eckelman, E M Harper, Zeke Hausfather, and Gonzalo Urbina. "Metal lost and found: Dissipative uses and releases of copper in the United States 1975–2000." *Science of the Total Environment*, 2012: 138-147.

Lundqvist, J., C. de Fraiture, and D. Molden. *Saving Water: From Field to Fork – Curbing Losses and Wastage in the Food Chain.* Stockholm International Water Institute (SIWI), 2008.

MacKay, David JC. *Sustainable Energy — without the hot air.* UIT Cambridge, 2008.

Maskindiskmedel. "Testfakta." 2008.

McCollum, David, Gregory Gould, and David Greene. *Greenhouse gas emissions from aviation and marine transportation: mitigation potential and policies.* Prepared for the Pew Center on Global Climate Change, 2009.

McKinsey Global Institute. "Resource revolution: meeting the world's energy, materials, food and water needs." 2011.

Michaelis, Laurie. *Ethics of Consumption.* Oxford Centre for the Environment, Ethics, and Society (OCEES), 2000.

Millennium Ecosystem Assessment. «Ecosystems and Human Well-being: Synthesis.» 2005.

Moncrief, John F., and Paul R. Bloom. "Generic Environmental Impact Statement for Animal Agriculture in Minnesota." 1999.

Montalvo Corral, C. "Sustainable production and consumption systems-cooperation for change: assessing and simulating the willingness of the firm to adopt/develop cleaner technologies. The case of the In-Bond industry in northern Mexico." *Journal of Cleaner Production*, 4 11 2003: 411-426.

Moomaw, W., T. Griffin, K. Kurczak, and J. Lomax. *The Critical Role of Global Food Consumption Patterns in Achieving Sustainable Food Systems and Food for All, A UNEP Discussion Paper.* Paris, France: United Nations Environment Programme, 2012.

Morley, Nicholas, David Parker, Peter Lee, Paul Vaughan, Phil Longhurst, and Matthew Cook. *Product Lightweighting. A strategy to deliver a sustainable economy?* Report prepared by Oakdene Hollins and Cranfield University for the UK Resource Efficiency Knowledge Transfer Network (RE-KTN), Published by C-Tech Innovation Ltd , 2007.

Naumann, S, et al. *Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe.* Ecologic Institute and the Environmental Change Institute (ECI), Oxford University Centre for the Environment for the European Commission, DG Environment, 2011.

Nelson, Jon, and Peter Kennedy. "The Use (and Abuse) of Meta-Analysis in Environmental and Natural Resource Economics: An Assessment." *Environmental & Resource Economics, European Association of Environmental and Resource Economists*, 42 (3) 2009: 345-377.

Oakdene Hollins. *The Further Benefits of Business Resource Efficiency.* A research report completed for the Department for Environment, Food and Rural Affairs, UK, 2011.

Odyssée Database. 2011.

OECD. *Household energy and water consumption and waste generation: Trends, environmental impacts and policy responses.* Organisation for Economic Co-operation and Development (OECD), 2002.

OECD. *Measuring material flows and resource productivity. Synthesis report.* Organisation for Economic Co-operation and Development, 2008.

OECD. "OECD Environmental Outlook to 2050." 2012.

OECD. *Pricing water resources and water and sanitation services.* Paris: Organisation for Economic Co-operation and Development, 2010.

OECD. *Resource Productivity in the G8 and the OECD – A Report in the Framework of the Kobe 3R Action Plan, Paris.* Paris: Organisation of Economic Co-operation and Development, 2011.

Omann, I., B. Friedl, M. Hammer, and A. Pack. *The environmental effects of food consumption for different household categories in Austria.* Sustainable Europe Research Institute (SERI), Department of Economics and Wegener Center for Climate and Global Change (University of Graz, Austria), 2007.

Ott, Christian, and Helmut Rechberger. "The European phosphorus balance." *Resources, Conservation and Recycling*, 2012: 159-172.

Pajunen, Nani, Gary Watkins, Maaria Wierink, and Kari Heiskanen. "Drivers and barriers of effective industrial material use." *Minerals Engineering*, 2012: 39-46.

Parfitt, Julian, Mark Barthel, and Sarah Macnaughton. "Food waste within food supply chains: quantification and potential for change to 2050." *Philisophical transactions of the Royal society- Biological sciences*, 2010: 3065-3081.

Pfister, S, P Bayer, A Koehler, and S Hellweg. "Environmental impacts of water use in global crop production: hotspots and trade-offs with land use." *Environmental Science & Technology*, 45 (13) 2011: 5761–5768.

Phalan, Ben, Malvika Onial, Andrew Balmford, and Rhys E Green. "Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared." *Science*, 2011: 1289-1291.

Power, K, and O Mont. "The role of formal and informal forces in shaping consumption and implications for sustainable society." *Sustainability*, 2010: 2573-2592.

Prokop, G, H Jobstmann, and A Schönbauer. *Overview of best practices for limiting soil sealing or mitigating its effects in EU-27.* Study for the European Commission, DG Environment, 2011.

Richards, IR, and CJ Dawson. *Phosphorus imports, exports, fluxes and sinks in Europe.* York: International Fertiliser Society., 2008.

Robèrt, Karl-Henrik. *The Natural Step Story: Seeding a Quiet Revolution.* Gabriola Island, BC: New Society Publishers, 2002.

Rockström, Johan, Will Steffen, Kevin Noone, Åsa Persson, F Stuart Chapin, and E F Lambin. "A safe operating space for humanity." *Nature*, September Vol 461 2009: 472-475.

Schandl, Heinz, and Jim West. "Resource use and resource efficiency in the Asia–Pacific region." *Global Environmental Change*, 20 (4) 2010: 636-647.

Schröder, J J, A L Smit, D Cordell, et A Rosemarin. «Improved phosphorus use efficiency in agriculture: A key requirement for its sustainable use.» *Chemosphere*, 84 (6) 2011: 822–831.

Schröder, J J, D Cordell, A L Smit, and A Rosemarin. *Sustainable Use of Phosphorus.* Wageningen University and Research Centre & Stockholm Environment Institute (SEI) for the European Commission, DG Environment , 2010.

Scott, Kate, John Barrett, Giovanni Baiocchi, and Jan Minx. *Meeting the UK climate change challenge: The contribution of resource efficiency. WRAP Project EVA128.* Stockholm Environment Institute and University of Durham Business School, 2009.

SERI. *Europe's Global Land Demand. A study on the actual land embodied in European imports and exports of agricultural and forestry products.* Sustainable Europe Research Institute (SERI), 2011.

SERI. *How to measure Europe's resource use. An analysis for Friends of the Earth Europe.* Sustainable Europe Research Institute (SERI), 2009.

Shu, L, P Schneider, V Jegatheesan, and J. Johnson. "An economic evaluation of phosphorus recovery as struvite from digester supernatant." *Bioresource Technology*, Nov 2006: 97(17):2211–2216.

Sivak, Michael. *Effects of vehicle fuel economy, distance travelled, and vehicle load on the amount of fuel used for personal transportation in the U.S.: 1970-2010.* Ann Arbor: University of Michigan Transportation Research Institute, 2013.

Smit, A L, P S Bindraban, J J Schröder, J G Conijn, and H G van der Meer. *Phosphorus in agriculture: global resources, trends and developments.* Plant Research International, Wageningen UR, 2009.

STECF. "Reducing discards and by-catches." *Summaries of EU legislation.* Scientific, Technical and Economic Committee for Fisheries (STECF), European Commission. 2012. europa.eu/legislation_summaries/maritime_affairs_and_fisheries/fisheries_resources_and_environment/l66048_en.htm (accessed 03 2013).

Steg, Linda, and Wokje Abrahamse. "How to promote energy savings among households: Theoretical and practical approaches." In *Psychology approaches to sustainability: Current trends in theory, research and applications*, by V Corral-Verdugo, C H Garcia-Cadena and M Frias-Armenta. New York: Nova Science Publisher, 2010.

Steger, Sören, and Raimund Bleischwitz. "Drivers for the use of materials across countries." *Journal of Cleaner Production*, 19 (8) 2011: 816–826.

Steinberger, Julia K, Fridolin Krausmann, and Nina Eisenmenger. "Global patterns of materials use: A socioeconomic and geophysical analysis." *Ecological Economics*, 69 (5) 2010: 1148-1158.

Steinfeld, Henning, Pierre Gerber, Tom Wassenaar, Vincent Castel, Mauricio Rosales, and Cees de Hann. *Livestock's long shadow - environmental issues and options.* Food and Agriculture Organisation of the United Nations, 2006.

Stenis, Jan, and William Hogland. "Optimization of mining by application of the equality principle." *Resources Policy*, 36 (3) 2011: 285-292.

Sullivan, J.L., A. Burnham, and M. Wang. *Energy-Consumption and Carbon-Emission Analysis of Vehicle and Component Manufacturing.* Argonne National Laboratory, 2010.

TEEB. *TEEB for Policy Makers — Summary: Responding to the Value of Nature 2009.* The Economics of Ecosystems and Biodiversity (TEEB), 2009.

TerraChoice. *The Sins of Greenwashing. Home and Family Edition. A report on environmental claims in the North American Consumer Market.* Terrachoice and Underwriters Laboratories, 2010.

Tiess, Guenter. "Minerals policy in Europe: Some recent developments." *Resources Policy*, 35 (3) 2010: 190-198.

Trianni, Andrea, Enrico Cagno, Patrik Thollander, and Sandra Backlund. "Barriers to industrial energy efficiency in foundries: a European comparison." *Journal of Cleaner Production*, 2013: 161-176.

Tukker, Arnold, and Ursula Tischner. *New Business for Old Europe. Product-Service Development, Competitiveness and Sustainability.* Greenleaf Publishing, 2006.

Umicore. «Battery Recycling Process.» 2013. http://www.batteryrecycling.umicore.com/UBR/process/.

UN World Commission on Environment and Development. *Our Common Future.* Report of the United Nations World Commission on Environment and Development (Brundtland Report), Oxford University Press, 1987.

UNEP. *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, United Nations Environmental Programme, 2010.

UNEP. *Decoupling natural resource use and environmental impacts from economic growth.* A Report of the Working Group on Decoupling to the International Resource Panel. Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., et al., United Nations Environmental Programme, 2011a.

UNEP. *Recycling Rates of Metals - A Status Report. A report of the Working Group of Global Metal Flows to the International Resource Panel.* United Nations Environmental Programme (UNEP), 2011b.

UNEP. *Sustainable, resource efficient cities – Making it happen!* United Nations Environmental Programme, 2012.

UNEP. "Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication." 2011.

UNEP. *Towards sustainable production and use of resources: Assessing Biofuels.* United Nations Environmental Programme, 2009.

US EPA. *"Green Servicizing" for a More Sustainable US Economy:Key concepts, tools and analyses to inform policy engagement.* US Environmental Protection Agency, 2009.

Van Holm, Marlies, Luis Simões da Silva, Gian Marco Revel, Michael Sansom, Heli Koukkari, and Hans Eek. "Scientific Assessment in support of the Materials Roadmap enabling Low Carbon Energy Technologies: Energy efficient materials for buildings." JRC Scientific and Technical Reports, 2011.

Vanham, D, and G Bidoglio. "A review on the indicator water footprint for the EU28." *Ecological Indicators*, 2013: 61–75.

Verbruggen, Aviel, et al. "Renewable energy costs, potentials, barriers: Conceptual issues." *Energy Policy*, 38 (2) 2010: 850-861.

Vernon, D. and Meier, A. "Identification and quantification of principal-agent problems affecting energy efficiency investments and use decisions in the trucking industry." *Energy Policy*, 2012.

Vlek, Charles. "Essential Psychology for Environmental Policy Making." *International Journal of Psychology for Environmental Policy Making*, 2 35 2000: 153-167.

von Weizsäcker, Ernst, Karlson Hargroves, Michael H. Smith, Cheryl Desha, and Peter Stasinopoulos. *Factor Five: Transforming the Global Economy through 80% Improvements in Resource Productivity.* Malta: Gutenberg Press, 2009.

WBCSD. *Eco-efficiency. Creating more value with less impact.* World Business Council for Sustainable Development, 2000.

WBCSD. *Sustainable Consumption Facts and Trends. From a business perspective.* World Business Council for Sustainable Development, 2008.

Weidema, B P, M Wesnæs, J Hermansen, T Kristensen, and N Halberg. *Environmental Improvement Potentials of Meat and Dairy Products.* Editors: Peter Eder and Luis Delgado, European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTS), 2008.

Weinzettel, Jan, Edgar G Hertwich, Glen P Peters, Kjartan Steen-Olsen, and Alessandro Galli. "Affluence drives the global displacement of land use." *Global Environmental Change*, 23 (2) 2013: 433-438.

Weiss, J., Dunkelberg, E. et al. "Improving policy instruments to better tap into homeowner refurbishment potential: Lessons learned from a case study in Germany." *Energy Policy*, 2012.

Westhoek, H, T Rood, M van de Berg, and J Janse. *The Protein Puzzle.* The Hague: PBL Netherlands Environmental, 2011.

Williams, A.G., E. Audsley, and D.L. Sandars. *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Bedford: Cranfield University and Defra, 2006.

Wirsenius, S, C Azar, and G Berndes. "How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030?" *Agricultural Systems*, Issue 9 Vol. 103 2010: 621-638.

World Bank. "What a Waste: A Global Review of Solid Waste Management." 2012.

World Health Organization. *Protein and amino acid requirements in human nutrition: report of a joint FAO/WHO/ONU expert consultation.* Geneva, Switzerland: WHO Library Cataloguing-In-Publication, 2007.

WRAP. *Current Practices and Future Potential in Modern Methods of Construction.* Waste & Resources Action Plan, UK, 2007.

WRAP. "Down the drain: quantification and exploration of food and drink waste disposed of to the sewer by households in the UK." Banbury, UK, 2009a.

WRAP. "Food Behaviour Consumer Research: quantitative phase." 2007a.

WRAP. "Household food and drink waste in the UK." 2009.

Wuppertal Institute. *Final Report on the Material Efficiency and Resource Conservation (MaRess) Project.* Wuppertal Institute for Climate, Environment and Energy, 2010.

WWF. *Agri-Myths. Facts behind Europe's Common Agricultural Policy reform .* World Wide Fund For Nature, 2013.

WWF. *Living Planet Report 2012. Biodiversity, biocapacity and better choices.* WWF in collaboration with the Zoological Society of London (ZSL) and the Global Footprint Network (GFN), 2012.

WWF, Ecofys and OMA. *The Energy Report. 100% renewable energy by 2050.* World Wildlife Foundation (WWF) International, 2011.

Yellishetty, M., P. G. Ranjith, and A. Tharumarajah. “Iron and ore steel production trends and material flows in the world: Is this really sustainable?” *Resources, Conservation and Recycling*, 54 2010: 1084-1094.

Zaman, Atiq Uz, and Steffen Lehmann. “Urban growth and waste management optimization towards ‘zero waste city’.” *City, Culture and Society*, 2 (4) 2011: 177-187.

Zamel, Nada, and Xianguo Li. "Life cycle comparison of fuel cell vehicles and internal combustion engine vehicles for Canada and the United States." *Journal of Power Sources 162*, 2006: 1241-1253.

Annex A: Meta-analysis

The highest level of the conceptual map, Tier 1, (see section 3.5) provides topical clusters that combine related concepts. These high-level categories not considered to be drivers themselves but rather a classification scheme that bundles and organizes the underlying drivers according to the features described by the Tier 1 labels. The second tier of the conceptual map represents a second classification, but of drivers. We found it necessary to develop this Tier because of the large diversity of individual, detailed drivers specified in the literature. Working only at this "high-resolution" level would essentially preclude any meta-analysis because it would not be possible to aggregate the sample of studies to arrive at broader, substantiated conclusions on the drivers of resource efficiency. The third tier in this nested classification structure, hence, provides the most fine-grained description of the individual drivers.

Based on the review of the above literature sources, the conceptual map encompasses the following main clusters of drivers:

Table 11 Relevant component Tier 2 and 3 drivers for efficiency of resource use

Tier	Cluster of drivers
1	Behavioural and informational
2	Behaviour (consumption patterns, production patterns)
2	Mental models (mind-sets, beliefs, values, paradigms, consumption aspirations, lifestyles, development aspirations, cognitive routines)
2	Information & Capacities
3	Level of knowledge, skills and information (e.g. insufficient information and awareness of environmental impacts)
3	Learning capacities
3	Innovation capacity (e.g. for leapfrogging)
1	Institutional and organisational
2	Structures of institutions and organisations (enabling / hampering innovation and learning)
2	Governance and power relations (multi-level, top-down, bottom-up, coordination, networks and partnerships, etc.)
3	Participation and involvement
3	Property rights (regimes)
2	Political and societal resource efficiency discourses (securing access; competitiveness/ecological modernisation; planetary boundaries; sufficiency & beyond GDP/ending poverty & overcoming social inequality)
3	Competitiveness (incl. competitiveness concerns)
1	Policy and regulatory
2	Policy and regulatory frameworks, responses and failures
2	Geopolitics (securing access to resources, land-take, etc.)
2	Transparency of political systems
2	Windows of opportunity (supportive contextual / situational factors, e.g. an ecological catastrophe, shifting power relations, public support, etc. which may help

Tier	Cluster of drivers
	fostering efficient resource use)
1	Socio-economic
2	Demographics
3	Population growth
3	Population structure (age and gender distribution, ethnics)
3	Migration
2	Population density (cities vs. rural)
2	Development level, paths (i.e., GDP growth over time → perhaps important regarding efficiency-cum-Kuznets curves, but acknowledging the critique of the Kuznets curves in relation to decoupling by maturation will not be enough for the transition needed) and poverty
2	Urbanisation and urban sprawl
2	Economic
3	Resource prices (market price level and volatilities)
3	Economic resource scarcities
3	Subsidies
3	Financial markets and access to credit
3	Global trade patterns and trade exposition
3	Costs associated with introducing and applying technologies
2	Issues of access/property rights
3	Access to information and knowledge for different actors (e.g. insufficient access to or sharing of knowledge, technology and best practices)
3	Access to technologies for different actors
1	Bio-physical
2	Environment
3	Resource availability (resource endowments)
3	Ecological impacts (and catastrophes)
1	Technological and infrastructural
2	Technologies and Innovation infrastructure
3	Level/Degree of innovation (technological, organisational, institutional, relational), including R&D
3	Resource requirements of certain technologies actors
2	Infrastructure
3	Infrastructure design (path dependencies and lock-ins)

Drivers of resource use efficiency can either be operate adversely, i.e., by reducing resource use efficiency, or positively, i.e., by improving resource use efficiency. In addition, drivers can interact with one another to enhance, diminish or neutralize their effects on resource use efficiency.

The concept of driver is integrated in several important sustainability and environmental management measurement framework, including the Driving force-Pressure-State-Impact-Response framework developed by the European Environment Agency (EEA 2003) and the Millennium Ecosystem Assessment (2005). The latter defines a driver as any natural or human-induced factor that directly or indirectly causes a change in an ecosystem. It distinguishes global driving forces as being of demographic, economic, socio-political, cultural and religious, scientific and technological, physical and biological origin.

In the context of this study, we understand a driver as an underlying cause of an existing level of efficiency of resource use in a causal relationship (Nelson et al. 2006):

1. A change in < Driver > leads to an existing level, or a change thereof, in efficiency of resource use.
2. The <Driver>, or its intensification, leads to an increase in resource efficiency
3. The <Driver>, or its intensification, leads to a decrease in resource efficiency

Thus the analyses aim to identify drivers and their effects on the most meaningful level, allowing for a characterization of the effects en detail.

In order to identify the effect of the different drivers and tiers of drivers, and the resulting (in)efficient resource uses, the following conceptualizations will be used:

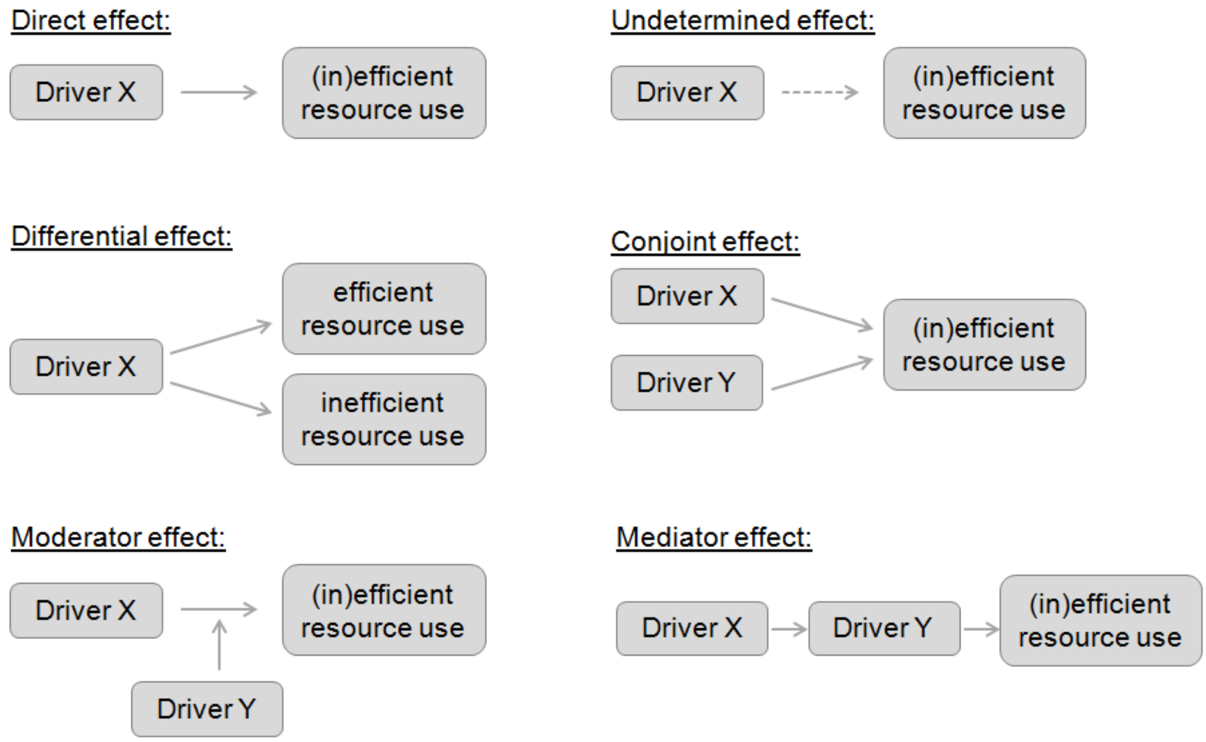


Figure 61 Types of effects of drivers for (in)efficient resource use (adapted from Oberlack 2010, p. 10)

Drivers having a direct effect are considered affecting the efficiency of resource use in a direct causal way. In contrast, in case of undetermined effects there is no clear proof of the respective driver directly determining resource efficiency. Differential effects encompass drivers which both affect efficient and inefficient resource use, while in the case of conjoint effects it is the interplay of two different drivers affecting resource use efficiency. A moderator effect occurs if one driver influences (amplifies or weakens) the effect of another driver, while a mediator effect, in contrast, assumes that one driver affects resource use efficiency only through another driver.

Search and Selection Procedure

The second step of the analytical framework encompasses searching for and selecting relevant case studies for the meta-analysis. A literature search was performed using ScienceDirect (http://www.sciencedirect.com/) and google scholar (http://scholar.google.com/) applying the following to key word search approach:

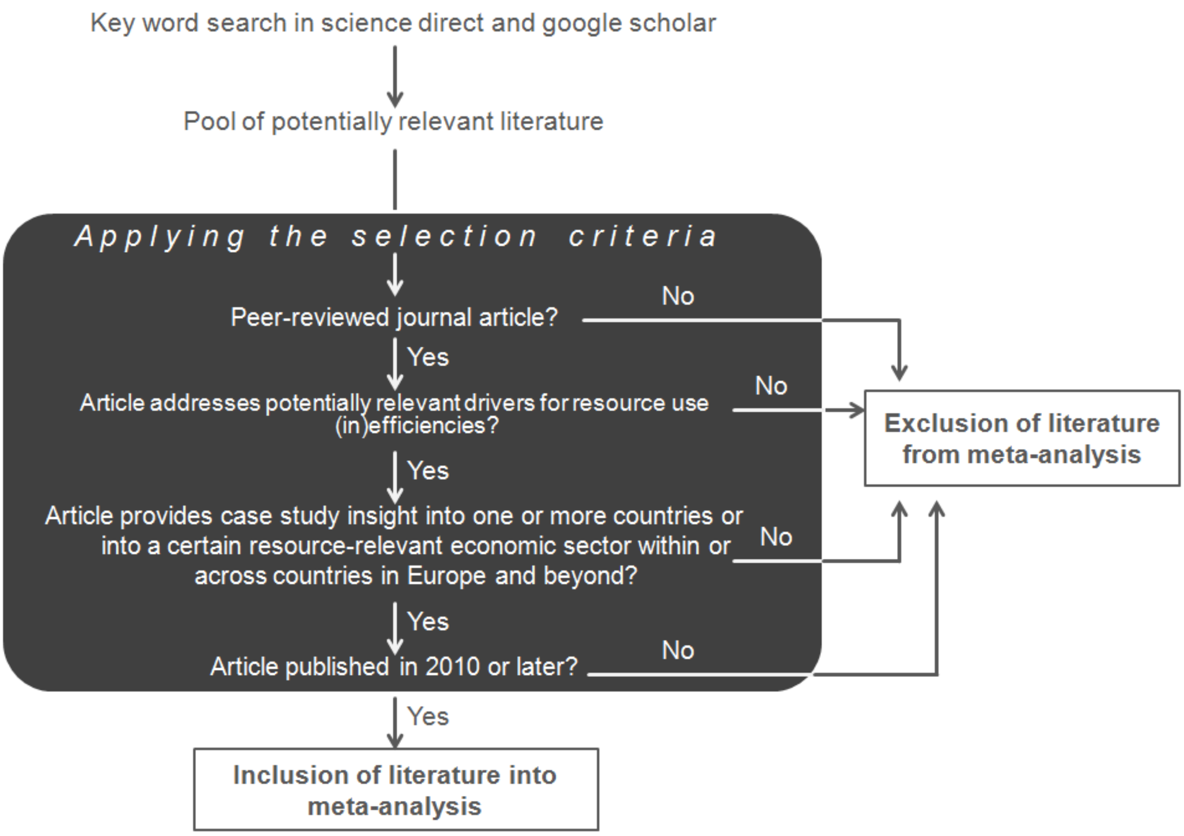
a) The search was undertaken in the search fields key words, title, abstract. Only journals were searched, spanning the time-period from 2010 to present.

b) Key words used in a levered search procedure included:

- resource use AND efficiency driver
- resource efficiency AND drivers
- resource use AND inefficiency
- efficient resource use AND driver
- inefficient resource use AND driver
- efficient resource use AND Europe
- inefficient resource use AND Europe
- resource use Europe AND driver
- resource use Europe AND efficiency

This procedure returned 261 articles altogether, of which 41 were found more than once with the different key word combinations used. For identification and selection of relevant articles out of the remaining 220, a four-stage selection procedure was applied, see Figure 62.

Figure 62 Four-stage selection procedure for inclusion into meta-analysis



Selection criteria included:

1. Is the literature a peer-reviewed journal article (excluding book reviews)?
2. Does the article address potentially relevant drivers (assessed according to the abstracts), including those already elaborated in the conceptual map?
3. Does the article provide case study insight into one or more countries or into a certain resource-relevant economic sector within or across countries in Europe and beyond?
4. Was the article published in March 2010 or later? This criterion was used in order to cover articles relating to the EU's main policies and strategies on resource efficiency (including the Europe 2020 strategy, adopted in March 2010; the Flagship Initiative "A resource-efficient Europe, adopted in January 2011; the Communication Tackling the Challenges in Commodity Markets and on Raw Materials, adopted in February 2011; the Roadmap to a resource efficient Europe, adopted in September 2011).

Using the selection criteria outlined to analyse titles and abstracts of the 220 hits led to the identification of 63 potentially relevant articles. The abstracts for the 63 articles were then analysed in parallel by the three scientists authoring this study and ranked according to their relevance for the meta-analysis. The ranking was conducted using a 1 for articles considered relevant for inclusion, a 2 for articles considered irrelevant and therefore to be excluded, and a 3 for articles where the authors considered joint discussions necessary to arrive at a final decision.

Thus, 30 articles of the 63 were considered relevant for inclusion (based on at least two of the three scientists assigning a 1 and one assigning a 3), 10 articles were considered needing joint discussions (based on either all scientists assigning a 3 or one assigning a 1, one a 2 and one a 3) and 23 articles were considered irrelevant (based on at least one scientist assigning a 2 and the others assigning a 3).

In the course of jointly discussing the 10 articles considered in need for discussions, 3 were considered relevant for inclusion upon exchanging arguments and perspectives, while 7 were considered irrelevant.

Altogether, the outlined selection procedure yielded 33 articles for inclusion, which constitute the empirical basis of this paper's meta-analytical procedures.

In a final selection step, using a snow-ball system approach the 33 articles were scrutinised for further relevant articles cited therein, which were then in turn checked against the selection criteria. This led to selecting another additional article, so that altogether 34 articles were included.

Coding of Articles

Coding scheme

For coding of the selected articles, a coding scheme was developed and tested by three scientists independently coding the same two articles. After exchange between the three scientists the coding scheme was refined and finalised for use for the remaining articles. Its final form encompasses the following codes:

Table 12 Coding scheme for case study coding and analysis

Code	Brief description
Resource type	Which resource(s) are in the study's focus? Based on the wide resource understanding of the DYNAMIX project

Code	**Brief description**
Country	A clear link to a case study investigation within a region of one country or completely covering one country
Sector	A clear link to a case study investigation within a certain sector (according to NACE)
Efficiency	Any section explaining the context specific empirical findings on efficient resource use
Key driver	A factor contributing to or explaining (completely or partially, in combination with others) empirical findings on (in)efficient resource use; to be used in combination with any one or more of the below Tier 1 drivers
Behavioural and informational	For example: - *Behaviour (consumption patterns, production patterns)* - *Mental models (mind-sets, beliefs, values, paradigms, consumption aspirations, lifestyles, development aspirations, cognitive routines)* - *Information & Capacities*
Institutional and organisational	For example: - *Structures of institutions and organisations (enabling / hampering innovation and learning)* - *Governance and power relations (multi-level, top-down, bottom-up, coordination, networks and partnerships, etc.)*
Policy and regulatory	For example: - *Policy and regulatory frameworks, responses and failures* - *Geopolitics (securing access to resources, land-take, etc.)* - *Transparency of political systems* - *Windows of opportunity (supportive contextual / situational factors, e.g. an ecological catastrophe, shifting power relations, public support, etc. which may help fostering efficient resource use)*
Socio-economic	For example: - *Demographics* - *Population density (cities vs. rural)* - *Development level, paths (i.e., GDP growth over time) and poverty* - *Urbanisation and urban sprawl* - *Economic* - *Issues of access/property rights*
Bio-physical	Environment
Technological and infrastructural	For example: - *Technologies and Innovation infrastructure* - *Infrastructure*
Context specific driver	Any driver relating to the specific country / sector or resource type context
Overarching driver	Any driver found as relevant for efficient use of other resource types, for other countries or sectors from previously coded articles

The coding scheme helped ensure that all relevant findings are considered. Here, also the aspect of the level of driver was taken into consideration by looking at its context specific or overarching nature (e.g. a driver for increasing the efficiency of the use of bottled water will be very different from a driver explaining the efficiency of the use of drinking water, which could do away with bottled water altogether).

After finalisation of the coding scheme, all remaining 32 articles were coded. While the articles in general were coded by different scientists, at varying intervals altogether three articles were exchanged for joint coding to test intercoder reliability. Upon finalisation of the codings, a joint discussion on the main findings in terms of key drivers were held and thus both context specific drivers (applying to specific country or sectoral cases or resource types) and overarching drivers (applying across several country or sectoral cases or resource types) were identified. This discussion led to the identification of relevant Tier 3 and Tier 2 drivers, with all Tier 3 drivers having been jointly allocated to Tier 2 driver categories.

Coding questionnaire

During the above discussion, six of the 34 articles coded were found not yielding relevant information – these were excluded from further analyses. In the last analytical step, the remaining 28 articles were revisited and a questionnaire was developed in order to quantitatively summarise the key findings per article in a comparable matrix:

Table 13 Questionnaire matrix applied to the selected articles

Article identifier	
Tier 1 driver	*Highest level driver category (Tier 1), to which Tier 2 and Tier 3 drivers are allocated*
Tier 2 driver	*Higher level driver category (Tier 2), to which Tier 3 driver is allocated*
Tier 3 driver	*Name of Tier 3 driver found*
Direction	*To be chosen from:* *Positive* *Negative* *Undetermined*
Effect Type	*To be chosen from:* *Direct Effect* *Undetermined Effect* *Differential Effect* *Conjoint Effect* *Moderator Effect* *Mediator Effect*
Resource	*To be chosen from the following list:* *Energy* *Materials/Waste* *Water* *Land/soil* *Air*

	NA
Sector	*To be chosen from:* *Energy* *Food* *Transport* *Buildings* *NA*
Explanation	*textual explanation of driver*
NA_Comment	*comment on any NA chosen*

The characteristics have been coded as nominal variables with value domains as described in Table 13. The questionnaire was then filled in for all 28 articles, listing the relevant drivers identified from each coded articles, their direction in relation to increasing or hindering efficient resource use, the effect type identified, as well as the resource and sectoral focus of each article analysed. In order to facilitate filling-in of the questionnaire and subsequent analysis, a textual explanation of the driver was provided and a comment given in case of selecting any NA entry in the questionnaire.

Annex B: Quantitative assessments of inefficiencies

Material- and Substance Flow Analysis case studies

This annex is a summary of four case studies in Material- and Substance Flow Analysis carried out to identify inefficiencies in the DYNAMIX project. The case studies addressed the following materials and substances:

- Phosphorus
- Iron and Steel
- Cobalt
- Water

The annex starts with a common section on methodology and data availability, followed by the case study chapters. Each study follows the same pattern of flow mapping and quantification, identification of inefficiencies and their drivers, examples of best practices and implications for policy.

AUTHORS

Ms Ida Adolfsson, IVL Swedish Environmental Research Institute

Ms Lena Dahlgren, IVL Swedish Environmental Research Institute

Ms Anna Fråne, IVL Swedish Environmental Research Institute

Ms Hanna Ljungkvist, IVL Swedish Environmental Research Institute

Mr David Palm, IVL Swedish Environmental Research Institute

Project coordination and editing provided by Ecologic Institute.

Manuscript completed in May, 2013

LIST OF ABBREVIATIONS

ABS	Air cooled Blast furnace Slag
AFRA	Aircraft Fleet Recycling Association
ASR	Automotive Shredder Residue
ARN	Auto Recycling Nederland
BAT	Best Available Technology
BF	Blast Furnace
BOF	Basic Oxygen Furnace
BOS	Basic Oxygen Furnace slag
C&D waste	Construction and Demolition waste
CiP	Cleaning in Place
DOE	Department Of Energy (US)
EAF	Electric Arc Furnace
ELV	End-of-Life Vehicle
EOL	End Of Life
EV	Electric Vehicle
FAO	The UN Food and Agriculture Organisation
GBS	Granulated Blast furnace Slag
HEV	Hybrid Electric Vehicle
LCO	Lithium Cobalt Oxide
LMO	Lithium Manganese Oxide
LNCMO	Lithium Nickel Cobalt Manganese Oxide
LNCAO	Lithium Nickel Cobalt Aluminum Oxide
MFA	Material Flow Analysis
MSW	Municipal Solid Waste
PHEV	Plug-in Hybrid Electric Vehicle
SFA	Substance Flow Analysis
USGS	US Geological Services
WEEE	Waste Electrical and Electronic Equipment
WEI	Water Exploitation Index
WFD	Waste Framework Directive
WWTP	Waste Water Treatment Plant

1 Material- and substance flow analysis

The substance flow analysis herein follows the general principles from *A handbook of industrial ecology* (Ayres and Ayres, 2002) chapters eight *Material flow analysis* (Bringezu and Moriguchi, 2002) and nine *Substance flow analysis* (Van der Voet, 2002). A similar methodology is also found in *Practical handbook of material flow analysis* (Brunner and Rechberger, 2003). Material flow analysis (MFA) is placed in the field of Industrial Ecology and Substance flow analysis (SFA) is a specific brand of material flow analysis.

Material flow analysis is divided into two types of analyses:

- Type I Specific environmental problems related to certain impacts per unit flow of
- Substances
- Materials
- Products
- within certain firms, sectors, regions

- Type II Problems of environmental concern related to the throughput of
- Firms
- Sectors
- Regions
- associated with substances, materials, products.

Material flow analysis (MFA) and substance flow analysis (SFA) provides a systemic analysis of processes and flows in support of strategies and policies as management measures. The use and policy relevance of type II analysis have in recent years been used for example to:

- Support policy debate on resource and efficiency goals and targets
- Provide economy wide material flow accounts for official statistics
- Create indicators for sustainability

1.1 Methodology

The methodology for SFA is briefly described below.

Goal and systems definition

The goal and purpose of the SFA are crucial for setting the system definition. Target questions are defined to clarify the primary objective of the study. The scope defines the boundaries for the study in time, geography and possibly functions of flows. The system boundaries define the start and end of accounted material flows. The system boundary is not necessarily the same as the scope of the study.

Process chain analysis, Accounting and balancing

The process chain analysis defines the processes, inputs and outputs relevant for quantification in accounting and balancing. A mass balance is created to check consistency and accuracy of data and to fill in missing data.

Modeling and evaluation

Modeling can be accounting, static or dynamic depending on the purpose of the model. Accounting modeling keeps track of flows and stocks by registering them, static modeling specifies the steady state relations between stocks and flows and dynamic modeling include time as a parameter. Evaluation is done both with regard to the goal and purpose of the study and assumptions made.

Interpretation of results for policy makers

SFA is designed to support environmental decision making but the implications for policy is not always clear. The basic principles of SFA; the terminology and the complexity of results need to be addressed when communicating results.

- The basic principles that the knowledge of extraction and emissions does not accurately describe a system.
- Translating the terminology into policy language since words can have different meaning.
- Decreasing the complexity into for example indicators not to run the risk getting misinterpreted data presentations.

1.2 Data availability and quality

Using the accounting type modeling mainly applied for this project, van der Voet suggests to use data from trade and production statistics, and if necessary also data regarding the content of specific substances in those goods and materials (van der Voet 2002). The data may however not be available, or not available in the needed format. One particular challenge is the assessment of stocks and flows in infrastructure and products, for which data may be unavailable or different to generalize. National material accounts, following the Eurostat guidelines (Eurostat 2012), are useful for some materials, but too aggregated for others. Not all materials are mandatory in the reporting (for example certain metal ores), making the statistics incomplete.

Indeed, van der Voet also acknowledge the fact that accounting MFA/SFA can be used to identify missing or inaccurate data, and suggests that the mass balance principle should be used to estimate missing flows.

For metals, global data is available from US Geological Services, USGS. This data is updated on a regular basis, but does not cover details about product content… For Europe, similar data is compiled by British Geological Survey. Both these sources generally use metal content as reporting unit. If comparing metal data from sources using different units, it is important to use the correct conversion factors (Eurostat 2012).

Data regarding water resources are reported in separate databases, such as the Aquastat database of FAO Land and Water division, and various national and regional databases. Since the nomenclature around water quality and water use is quite complex, it is important to establish the comparability of data when using different sources.

2 Phosphorus in the European Union and globally

2.1 Introduction

There are a large number of areas to investigate when looking at resource (in)efficiency in the EU. The use of phosphorus, although a major pollutant with regard to eutrophication, can be seen to be within the planetary boundaries(Rockström, Steffen, et al., 2009). This however considers the environmental effects and fails to encompass the fact that phosphorus in the form of phosphate rock is a finite resource that will become very expensive in the medium term (Cordell, 2010).

As seen in Figure 63, use of phosphate rock as a fertilizer has since the end of the Second World War been the major source of phosphorus, magnitudes larger than manure, guano and human excreta.

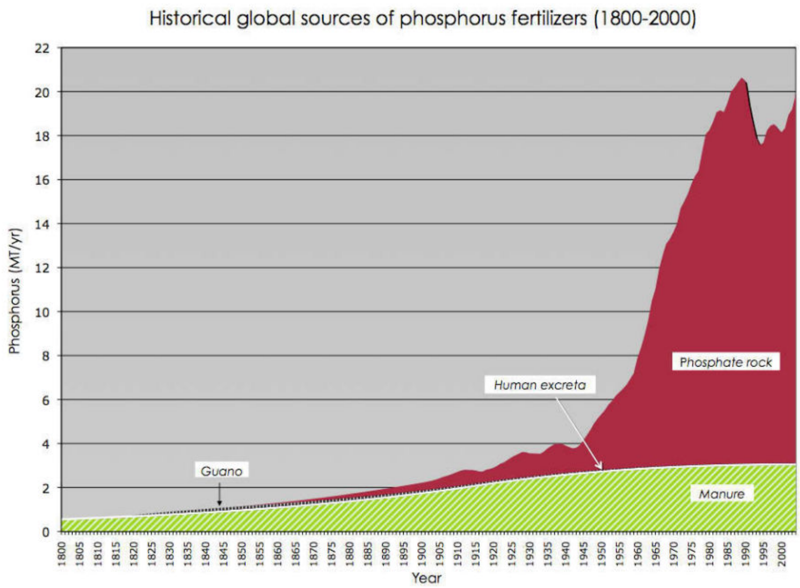


Figure 63 Historical global sources of phosphorus fertilizers (Cordell, 2010, p. 86)

The reserves of phosphorus are diminishing at a rapid rate and Peak phosphorus is likely to occur around 2035 (Cordell, et al., 2009). Figure 64 shows available phosphate rock reserves[18] based on USGS data (Jasinski, 2006, 2008, 2010, 2012) and for all countries but Morocco estimates have been reduced significantly over the last years. There are large uncertainties in the statistics but among the top 20 countries, covering more than 99 % of available phosphorus, listed in Jasinski (2012) there are no European countries. In 2050, it is most likely that all phosphate rock used in the EU will come from Morocco (Cordell, 2010).

[18] Note that it is phosphate rock reserves and not phosphorus reserves. Phosphorus content is about 13 % in average.

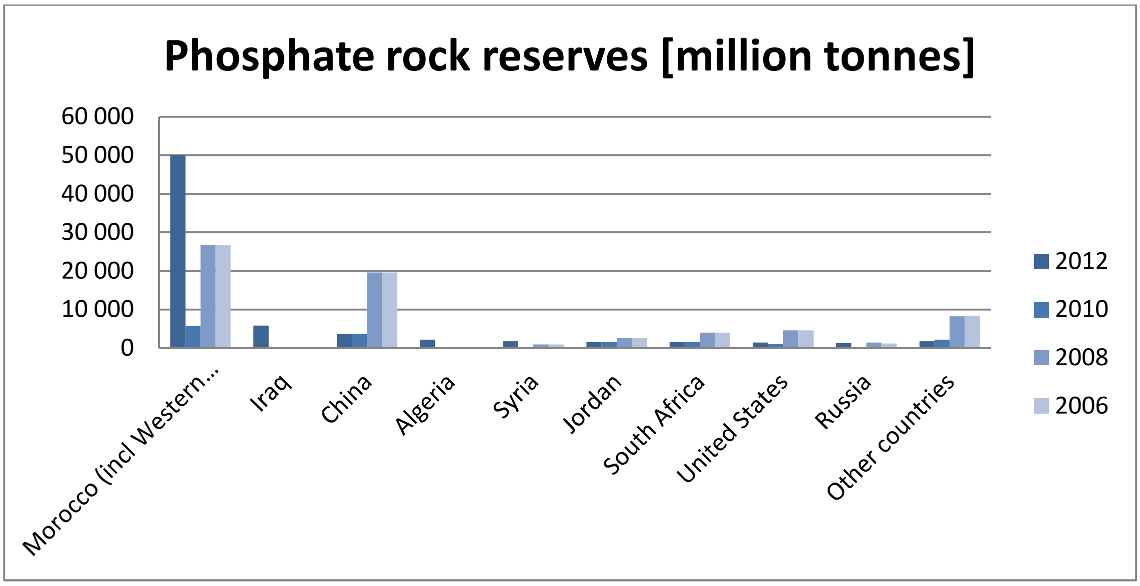


Figure 64 Phosphate rock reserves 2006-2012 (Jasinski, 2006, 2008, 2010, 2012)

Effects of increased prices for phosphorus will not come over night in the EU but since phosphorus cannot be substituted in crop production, the medium and long term effects are problematic. There was a spike in the price for fertilizer in 2008 as seen in Figure 65 due to a mismatch between supply and demand. This led to farmers not fertilizing their land although strongly encouraged by their political leaders (Cordell, 2010). China overnight put a 135 % export tariff on phosphate to ensure domestic supply for food production clearly exemplifying the risk of not having domestic production.

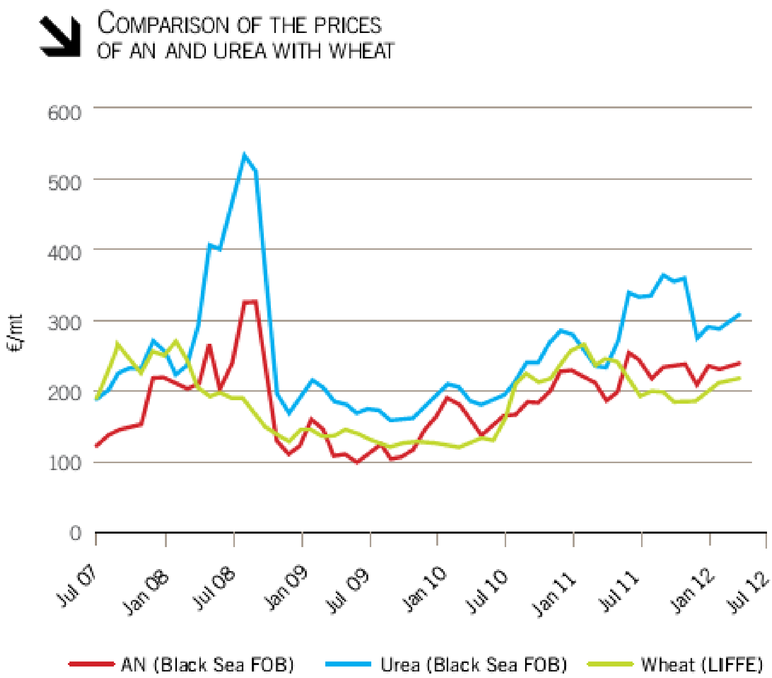


Figure 65 Price of fertilizer and wheat (Fertilizers Europe, 2012)

Cordell (Cordell, 2010, p. 117) describes five different dimensions of phosphorus scarcity: physical-; economic-; managerial-; institutional- and (geo)political scarcity. These are stated in Table 14 and can easily be translated to five dimensions of (in)efficiencies for phosphorus.

Table 14 Five dimensions of phosphorus scarcity. Source: (Cordell, 2010, p. 117)

Dimension of scarcity	Relevance to phosphorus
Physical scarcity	Physical *availability* of phosphorus is constrained, such as the lowering availability of the world's high quality phosphate rock reserves.
Economic scarcity	Lack of *access* to phosphorus, due to constraints in financial capacity (e.g. farmer purchasing power, investments in new resources) or constraints in labor and time capacity to source phosphorus.
Managerial scarcity	Improper management or maintenance of phosphorus, resulting in substantial system *inefficiencies* that limit the ability of available phosphorus to meet demand (such as phosphorus losses in the food production and consumption chain).
Institutional scarcity	Scarcity resulting from a lack of appropriate and effective institutional structures to ensure phosphorus supply will meet demand both in the short and long term, for all users.
(Geo)political scarcity	Availability or access to phosphorus resources is restricted due to political or geopolitical circumstances such as monopolies or oligopolies controlled by governments or corporations.

Regarding EU policies aimed at phosphorus scarcity Schröder, Cordell, et al. (2010, p. 97) summarized: *"So far, none of the policies and regulations is based on or includes the awareness that phosphorus is a finite resource for which there is no substitute."*

This report uses substance flow analysis to investigate the inefficiencies related to phosphorus both on a global and European level.

2.2 Goal and systems definition

This study is classified as Type IIc since the substance phosphorus is studied in regard to total throughput within the EU rather than impacts per unit flow of phosphorus.

This study aims at:

- Finding inefficiencies in the phosphorus life cycle affecting the EU
- Finding key drivers for these inefficiencies
- Find best practice that reduce the inefficiencies
- Investigate connections between policy and efficiency for phosphorus

The scope is phosphorus use with a focus on food security in the European Union. Models will describe use within one year but the total use over many years is included in the interpretation. The geographical boundary includes both the EU and the world to ensure inclusion of critical issues both in the primary area: the EU and the supporting area: the world. To a large extent due to very limited data availability, existing substance flow analyses will be used.

2.3 Phosphorus globally

Globally the flows of phosphorus have been modeled by (Cordell, 2010) as is redrawn in Figure 66. Inefficiencies where phosphorus is lost in some way are marked in turquoise. There are other inefficiencies which cannot be as clearly showed, excessive consumption of meat is one example. Roughly 80% of the phosphorus from phosphate rock never reaches the fork but is lost in different parts of the supply chain (Cordell, et al., 2009; Schröder, et al., 2010). As seen in Figure 66, the major losses of phosphorus occur in fertilizer application with 8Mt lost annually and from manure (7Mt) which is not effectively returned to soils as fertilizer. The phosphorus applied to arable soils remains to an extent in the soil and may become available over time as a phosphorus stock. The production of meat is the single largest user of phosphorus with over 12 Mt from vegetation used annually combined with 40% of the useful Phosphorus from harvested crops. Combining the share of total phosphorus in fertilizer used for crop production, meat production accounts for 65% of all phosphorus consumption while only representing 15% of Phosphorus in food delivered.

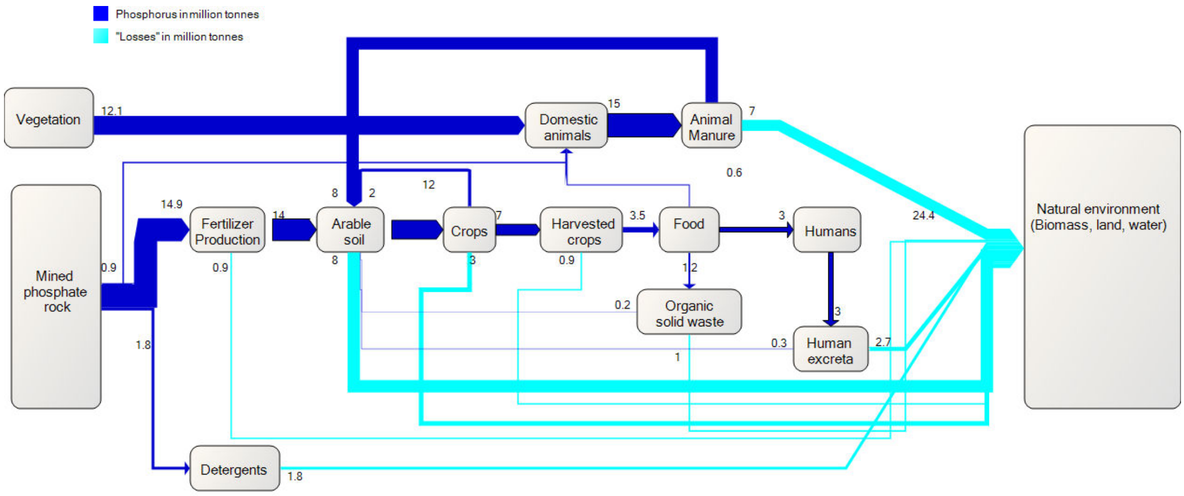


Figure 66 Global phosphorus flows in 2000 according to Cordell [million tonnes] (Cordell, 2010)

Phosphorus flows are very different in different regions and countries according to (Cordell, 2010). Metson, Bennett, et al. (2012) performed a study on how diets affect the use of phosphorus which supports this. There is however a close relation between diet and phosphorus use where a meat based diet requires substantially more phosphorus than a vegetarian diet. (Metson, Bennett, et al., 2012) found that over 70% of the average dietary phosphorus footprint between 1961 and 2007 was due to animal based food groups worldwide. Dietary influence ranges from a potential 50% per capita increase in phosphorus use by 2050 with predicted increased meat consumption to a 20% reduction if protein comes from pulses instead of meat. (Cordell, 2010) had a more modest reduction estimation but this could be due to different methodologies and the fact that (Cordell, 2010) included all phosphorus while (Metson, Bennett, et al., 2012) only included mined phosphorus.

Detergents stand for a smaller part of the phosphorus use with 1.8 Mt annually.

For a more comprehensive view of phosphorus losses, see (Cordell, 2010, pp. 91–93).

2.4 Phosphorus in the European Union

Richards and Dawson mapped phosphorus flows in EU-27 in 2008 (Richards and Dawson, 2008) with 2008) with large uncertainties. Uncertainties are mainly due to two factors: Mapping flows in a limited a limited region has the added complexity of imports and exports of products with embedded phosphorus and the general lack of phosphorus statistics for EU-27. Major flows are shown in Figure in Figure 67[19].

Figure 17 is highly simplified and does not show internal flows of phosphorus in EU-27. Agriculture, for example, also uses roughly 2 Mt phosphorus from manure. The net demand for phosphorus is however clear from this figure. Fertilizers Europe has a lower figure for EU-27 import of phosphorus in fertilizer with roughly 1 Mt (Fertilizers Europe, 2012).

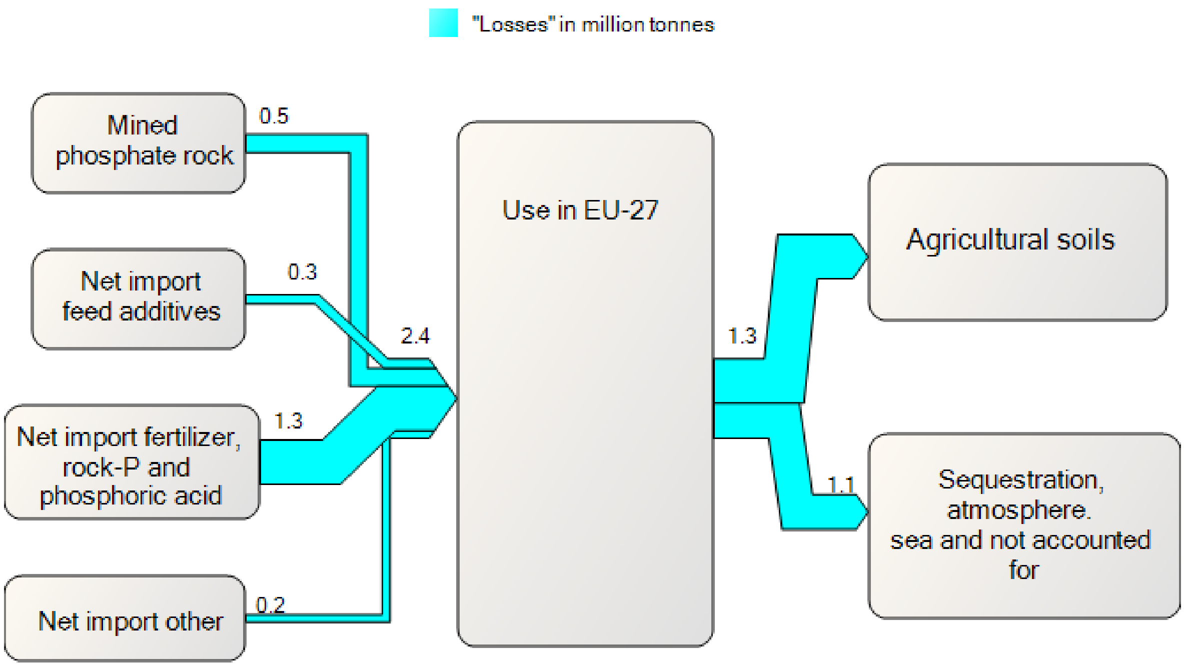


Figure 67 EU-27 Phosphorus flows based on (Richards and Dawson, 2008) [million tonnes]

Consumer detergents are not included but total use in 2004 where around 0.0615 Mt according to a CEEP-INIA study (Madariaga, et al., 2007) representing less than 3% of the imported and mined phosphorus. Comparing this with Figure 66, global use of phosphorus in detergents are larger than the net import to all EU-27 agriculture.

Phosphorus from households are around 0.154 Mt which would amount to 0.09 Mt from human excreta when detergents are subtracted. This gives a phosphorus efficiency for food

[19] Note: Figures are taken from (Schröder, et al., 2010, p. 22) since (Richards and Dawson, 2008) was only available by regular post and did not arrive in time for this study.

production of 3% (human consumption divided by net import). The uncertainty of this figure is high and it could well be 2-3 times higher.

2.5 (In)efficiency

Inefficiencies occur both in the European Union and globally and consist of both process inefficiencies (e.g. agricultural practices, food waste, benefication losses) and system inefficiencies (e.g. diets, lack of circular flows). System inefficiencies are more complex and often include several process inefficiencies.

Phosphorus cannot be considered only for use within EU but must include global use and practices since the EU is largely dependent on import of phosphorus.

2.5.1 Identification

Meat and diets

Producing meat requires substantially more phosphorus than production of food crops. Meat production represents 65-70% of all dietary phosphorus use while providing a considerably lower part of the food consumed. If the global trend goes towards western diets the phosphorus use would increase by 50% while a reduction is possible if meat is changed for other sources of protein.

Low phosphorus conversion efficiency in livestock production due to low feed conversion and feed additives represent a major part of the inefficiency of meat. This inefficiency is related to the demand of phosphorus.

Eutrophication and field leakage

Lack of proper soil management with soil erosion and leakage of nutrients as a result are a major cause for eutrophication. Globally one third of all phosphorus put into soils is lost in this way. Usually measures against leakage of nutrients are only implemented where effects of eutrophication are damaging. Measures are almost always end-of-pipe solutions and do not consider the resource.

Proper fertilizer management can increase the efficiency of applied phosphorus to soils and would then decrease the 24 Mt globally and 3.3 MT in EU27 put into soils. This inefficiency is related to waste and losses and demand of phosphorus.

Lack of reuse of manure and humanure (human excreta)

Globally there is a lack of reuse of manure in agriculture and almost half of the produced manure does not return to crop production which in turn only provides one third of the phosphorus put into arable soils. In EU27, manure provides about two thirds of the phosphorus to soils which is higher but there is still a potential for improvement. The reuse of humanure from waste water treatment plants and untreated sewage are almost negligible both globally and in the EU. These inefficiencies are related to the use, reuse and recycling of phosphorus.

Detergents

Detergents represent 3% of the EU27 phosphorus use and 6% globally. For laundry detergents phosphorus is not needed and it has been banned for consumer use in many countries. Bans on dishwasher detergents are less frequent but several brands offer phosphate free products(Testfakta 2008). This inefficiency is related to reducing the demand.

2.5.2 Drivers

The largest driver for phosphorus inefficiencies and use overall is related to meat in diets and the aspiration of many to have this diet rather than a vegetarian or low meat diet. The choice of diet relates to almost all inefficiencies in the phosphorus flows both globally and in the EU. World meat production has risen from 64 Mt to 279 Mt during the last 50 years (Brown, 2012).

Short term markets for fertilizer give a low price of fertilizer that reduces the incentives for better soil management and feed conversion. This also gives little incentive to recycle phosphorus recovered in WWTPs.

Globally the idea of fertilizing with manure is to some extent considered dirty and bad for business. In the EU, this is more closely connected to fertilizing with humanure. The sanitary revolution where removing excreta stopped spreading of disease broke the return flow of excreta to soils although proper management can deal with this.

2.5.3 Best practice

There are several measures that can be implemented to reduce the use and inefficiencies connected to phosphorus. In general, measures taken in the end of the supply chain have the largest overall impact since they affect losses in many steps of the supply chain.

Vegetarians and meat free day

Eating less meat is likely the most efficient way to reduce dependence on phosphorus. There is little doubt that a vegetarian or low meat diet is sufficient. A meat free day every week could reduce phosphorus needed by up to 9%.

Food waste reduction

Around 24% of the phosphorus in food is lost due to food waste globally. Successful measures to reduce food waste have the potential of reducing overall phosphorus use by 22%. Clearing the plate, cooking left overs and better food management are low hanging fruits.

Phosphorus recycling of excreta

Using human excreta as fertilizer was previously natural and common but is today practically not done anywhere. Source separating toilets are however available and can deliver urine for fields at low cost. There is also technology available for producing Struvite in WWTPs corresponding to 1.6% of annual mined phosphorus(Shu, et al., 2006). With technological improvement this figure can of course increase. (Berg, 2011) estimates a possible phosphorus reduction of 18% with efficient recycling of human excreta.

Better use of animal manure

Better integration of animal manure in crop production can substitute mined phosphorus and thus reduce total inputs. This is especially the case for the United States which store manure in lagoons but according to (Berg, 2011) it would lead to reductions of up to 12% of phosphorus use also in the EU.

Ban on phosphorus in detergents

The European Union have from July 2013 banned phosphorus in laundry detergents for household use and preliminary banned phosphorus in dishwasher detergents for household use from 2017. Several western European countries countries (Austria, Belgium, Germany, Ireland, Italy, Luxemburg, the Netherlands, Sweden) have successfully implemented such legislation.

2.5.4 Policy impacts

There are some policy related to phosphorus in the EU, mostly in the EU Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy, n.d.). There are however no policy related to phosphorus as a resource as stated in (Schröder, et al., 2010): ”So far, none of the policies and regulations is based on or includes the awareness that phosphorus is a finite resource for which there is no substitute.”

The Swedish environmental goals (“Miljömål.se - Den svenska miljömålsportalen,” 2013) had a goal of 60% recycling of phosphorus in WWTP to soils but this was later dropped due to the risk of hazardous substances.

The Swedish board of agriculture recently proposed a meat tax as one of many possible measures to reduce the environmental impacts of meat which resulted in a public storm which made them retract the measure as an alternative (“För en hållbar livsmedelskonsumtion behöver vi äta mindre kött och välja kött med omsorg,” 2013).

2.6 Conclusions

Phosphorus is a substance that is invaluable for agriculture; has no substitute for food production; is likely to become very expensive in the near future and is hardly available as phosphate rock in the European Union. There is no policy related to phosphorus as a resource and few affecting phosphorus resource efficiency at all.

The largest driver for phosphorus use is consumption of meat which drives all inefficiencies except for detergents. To reach sustainable levels of phosphorus use the European Union needed to:

- drastically reduce the amount of meat consumed
- recycle both manure and human excreta into soils
- reduce food waste to a minimum, and
- ban use of phosphorus in detergents, both in households and in business.

It is also necessary to attempt to govern the use of phosphorus on a global level since many issues related to phosphorus scarcity take place outside of the European Union.

3 Iron and steel flows in the European Union

3.1 Introduction

Iron is the fourth most abundant element in the earth's crust (Yellishetty et al., 2010) and the second most abundant metal. The iron content in the crust ranges from 2-3 percent in sedimentary rocks to 8.5 percent in basalt and gabbro. Due to its relatively high availability iron is in comparison to many other elements of low value and a deposit must generally contain at least 25 percent of iron to be considered economically recoverable. The most important use of iron is in steelmaking where the iron is processed and the properties, such as strength, tension, ductability and resistance, are optimised for different end-use sectors. Sectors where iron and steel are used the most is among others in construction, automotive, packaging and electric and electronic appliances (Yellishetty et al., 2010).

The raw material market of iron and steel comprises hundreds of billions dollars per year and is the second largest raw material market after oil. However, the extraction of iron ore and production of steel do also have disadvantages imposing considerable environmental consequences and high energy demands. The iron and steel industry, the mining of iron ore excluded, is responsible for over 10 percent of the global energy consumption and around 20 percent of the industrial waste emissions of the manufacturing sector (Allwood and Cullen, 2012). The wide use of iron and steel in modern society, together with the industry's significant environmental impact makes the flows of iron and steel interesting to look into deeper.

This study contains five parts, the introduction included. In the second part a brief overview is given of the methodology this study's approach is inspired of, followed by the goal and scope of the study. In chapter 4, which is about data collection, the flows related to the processes are quantified. In chapter 5 the identified inefficiencies are discussed.

3.2 Material flow analysis

3.2.1 Methodology

In MFA, a process is defined as the transformation, transport, or storage of materials. Transformation processes take place in primary production processes such as in the mining and metal industry, where metals are extracted from mineral ores. Consumption processes, such as private households, transform goods into wastes and emissions. Transformation processes are not restricted to anthropogenic processes and could also be relevant for natural systems e.g. forests transform carbon into biomass and oxygen.

Another important term in MFA is transportation processes where the material or goods are not transformed, but relocated over a certain distance. Both transformation and transport processes are usually symbolised by rectangular boxes. The processes are defined as "black box" processes, which mean that the processes within the box are not taken into account, only the inputs and the outputs are of interest. There is also a third type of process, the stock of materials, describing the quantity of materials within a process. Both the quantity of the stock and the rate of change of the stock per unit time are important parameters for describing a process. Examples of storage processes are households storing goods like electronic appliances or materials stored in buildings. A “final sink” is a process where materials have very long residence times, usually over 1000 years.

In MFA the terms flow and flux are commonly used, sometimes inconsistently. A flow is defined as a *mass flow rate,* given in units e.g. ton per year. A flux, on the other hand, is defined as a flow per *cross section*. Taking a water pipe as an example the flux might be given in units of kilo per second and m^2. Examples of symbols for the different terms used in MFA are presented in Figure 68.

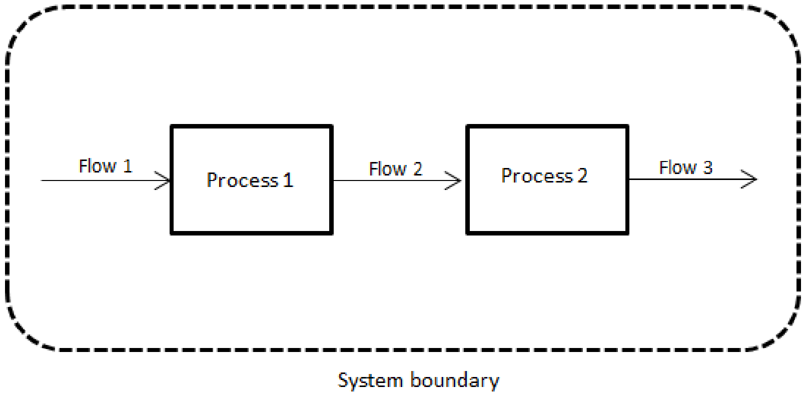


Figure 68 Examples of terms symbolized in MFA.

According to Chen and Graedel (2012) it is important to observe the conservation of mass at each stage of the system i.e. the input flows should equal the output flows. Failure to achieve conservation of mass indicate that a deficiency exists in the description of the cycle or in the quantification. Many MFA studies do not succeed in fully respecting the conservation of mass, but can in any case contribute to valuable insights about the system studied.

A material flow analysis is usually either static or dynamic. In the static case a “snapshot” of flows in a certain time is studied unlike the dynamic case where changes over time are considered. It is often more difficult to perform dynamic MFAs in comparison with static ones.

3.2.2 Goal and system definition

By using a static MFA-based approach this study aims at:

- Finding the major inefficiencies in the iron and steel anthropogenic life cycles within the EU27
- Finding key drivers for these inefficiencies

Iron and steel are in this study defined as all economic iron and steel qualities, why all alloying elements present in the metal matrix are considered. Another possibility would be to track the iron content of the material flows, but as practically all iron and steel qualities, including carbon steel, consists of alloying elements, this approach is considered more practically manageable in order to fulfill the aim of this study. A similar approach was made in Geyer et al. (2007). For the processes iron ore production and steel production it has not been possible to account for finished iron and steel qualities why the content of iron instead has been subject for evaluation. Otherwise, it would not be possible to quantify losses of iron that potentially could have been used in further iron and steel production.

The system boundaries of the study are the geographical borders of the European Union (EU27). Trade of iron and steel and products containing iron and steel are therefore part of the study where these flows have been considered possible to include. For finished goods, as well as for end-of-life flows containing iron the trade balance is not taken into account. Losses of iron and steel refer to corrosion or iron and steel leaving “the cycle” i.e. ending up in flows where the iron and steel no longer is subject to material recycling or reuse.

In this study the accounting period is one year, specifically 2010, meaning that the study is of static nature. The year 2010 was chosen on the basis that some sources of data was not available for 2011 and 2012.

The stocks of iron and steels in the EU27 are not quantified in the study, as well as the change of stock during 2010. This means that material entering a process is assumed to leave the process during the same year

3.2.3 Data collection

In this chapter the iron and steel flows in the defined processes are quantified. For the processes iron ore production and pig iron production the iron content of the flows are tracked. Once crude steel is produced flows are tracked as the steel content present in the flows. No distinction is made between magnetic steel and non-magnetic steel even if the fate in reality could be different due to the separation processes in the recycling chain.

3.3 Iron ore production

For the relevance of the scope of the study the balance between production, import and export of iron ore concentrates in the EU27 is important i.e. the consumption of iron ore in 2010. British Geological Survey gathers this type of information in their *European Mineral statistics* where data on the production, import and export, by country level are presented. LKAB in Sweden is the largest producer of iron ore in EU27, counting for over 90 percent of the total iron ore production within the union. Other iron ore producing countries in EU27 are Austria, Germany, Romania, Slovakia and the United Kingdom. The total iron ore[20] production in EU27 2010 was 27.75 million tonnes. Statistics on imports and exports of iron ore are not available on EU27 level why data for imports and exports of all the member states were gathered. By adding up the total exports and imports of each member state the difference must come from imports or exports from third countries. The exports and imports of iron ore[21] in EU27 in 2010 were 21.37 and 138.9 million tonnes respectively. This leads to a total consumption of iron ore in EU27 of 145.3 million tonnes.

It is difficult to determine the amount of iron present in the iron ore imported and exported to and from the EU27. It is assumed that the import and export of iron ore is in the form of iron ore concentrates e.g. pellets, fines, beneficiated iron ore etc. The average iron content of the pellets and fines produced by LKAB is 67 percent. The iron ore mined in Sweden has an average iron content of 60 percent. By a number of dry and wet beneficiation steps the content of iron is raised to 67 percent in the finished products of pellets and fines (LKAB, 2013). On the basis of this fact it is assumed that the imports and exports as well as the produced iron ore in the EU27 has the same iron content, 67 percent, when sold to steelworks. Furthermore, it is assumed that the total amount of iron ore produced in the

[20] including micaceous iron oxide and manganiferous iron oxide

[21] including burned pyrite

EU27 is produced in similar ways as the iron production of LKAB (representing 90 percent of the iron ore production in the EU27).

When mining, the iron ore is followed by gauge and impurities present in the tailings. Some of the gauge with remains of iron, is left at the mine. In the beneficiation steps a number of residual flows containing iron are generated. In total, nine percent of the iron present in the mined iron ore ends up in residual flows and is currently disposed of in landfills or in interim storages (LKAB, 2013). In practical terms it means that if 1000 kg of iron ore is mined with an average content of 600 kg iron, 54 kilos of the iron ends in the residual flows and 546 kilos continues into the pellet production. The losses in the pelletization of iron ore are excluded. Some of the iron in the old landfills have been mined and reused in the production.

The production of iron ore in other iron ore producing member countries are assumed to result in the same amount of iron losses to landfills and interim storages. In total the production of iron ore in the EU27 results in 1.84 million tons of iron not being put into beneficial use. Some of this amount is related to the iron ore production being exported from the EU27, but as the iron is disposed of in the EU27 the amounts are accounted for. The amounts of iron in the residual flows related to the imported amounts of iron ore are not considered as the process occurs outside of the system boundaries. Due to this the conservation of mass is not respected for this process, Figure 69. Another reason that the conservation of mass is not respected is that the change of stock has not been considered. It is likely that an amount of concentrated iron ore is put into stock and not consumed during 2010, which the figure suggests.

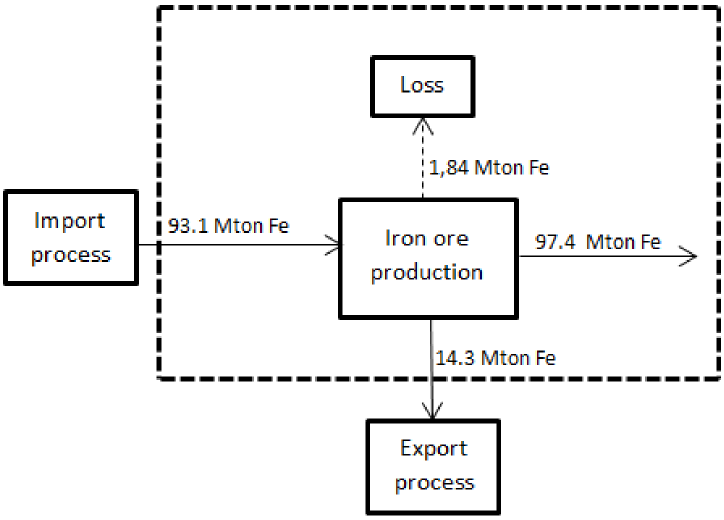


Figure 69 Iron content in iron ore production in EU27 in 2010, import and export of iron in iron ore and losses of iron in the iron ore production.

3.4 Steel production

The share between the BOF-BF route and the EAF route has been stable during the last years. In 2010, 59 percent of the crude steel produced within EU27 came from the BF-BOF route and the remaining 41 percent from the EAF route. The total amount of crude steel produced was in 2010 172.5 million tonnes. Germany represents the largest amounts of crude steel produced (25%) followed by Italy (15%), Spain and France, both representing approximately 9 percent of the total amount of crude steel produced (Eurofer, 2012). In terms of quality 80.1 percent of the total amount of crude steel was non alloy, 15.6 percent other alloy and 4.3 percent stainless in 2010. Within steel production the terms apparent consumption and real consumption are often used. The apparent consumption is the production plus imports minus exports not considering change in stock, although the real consumption takes changes in stock levels into account. According to Eurofer the apparent consumption was 148.5 million tonnes in 2010 and the real consumption 147.8 million tonnes. This means that the stock levels in EU27 in 2010 increased by slightly less than 700 000 tonnes. The figures refer to all steel qualities.

3.4.1 BF-BOF

Blast furnace

The production of pig iron from blast furnaces in the EU27 in 2010 was 93.8 million tonnes. 0.96 million tonnes of pig iron was exported outside of the EU and 3 million tonnes were imported (British geological survey, 2012). Taking this into account the consumption of pig iron in the EU27 was counted to 95.8 million tonnes. The majority of pig iron was used in blast oxygen furnaces, but was also to a limited extent used in iron foundries and in electric arc furnaces. The amount of pig iron used outside of blast oxygen furnaces are excluded in the study.

The blast furnace generates a number of material flows apart from pig iron.

The iron content in blast furnace slag is typically below 0.5 percent of weight (Euroslag, 2012) or between 0.2-0.6 percent (EIPPCB and IPTS, 2010). The BF slag can be divided into BF granulated slag (GBS), BF foam or air-cooled BF slag (ABS). ABS is a suitable material for use as a construction aggregate replacing natural rock. GBS exhibits cementitious properties and is used as hydraulic binder in cement and concrete applications. According to a survey conducted every two years by Euroslag among its members (European steelworks and processing companies) the BF slags produced in EU27 in 2010 were dominated by granulated blast furnace slag (82 percent). Air-cooled blast furnace slag represented the remaining 18 percent. The same year the amount of BF slag was primarily used for cement production and concrete addition (66%), road construction (23%), interim storage (10%) and others (1%), Figure 70. According to Euroslag they cover 100 percent of the blast furnace slag produced in EU27 and 80 percent of the steel slags (Euroslag, 2013). This information shows that the iron present in the blast furnace slag produced was not recycled within the steelworks and that the iron present was not put into use, in this context therefore seen as losses. Assuming an iron content of 0.5 weight percent the total amount of 2.48 million tonnes of blast furnace slag (Euroslag, 2012) resulted in 12 500 tonnes of iron not recycled within the steelworks.

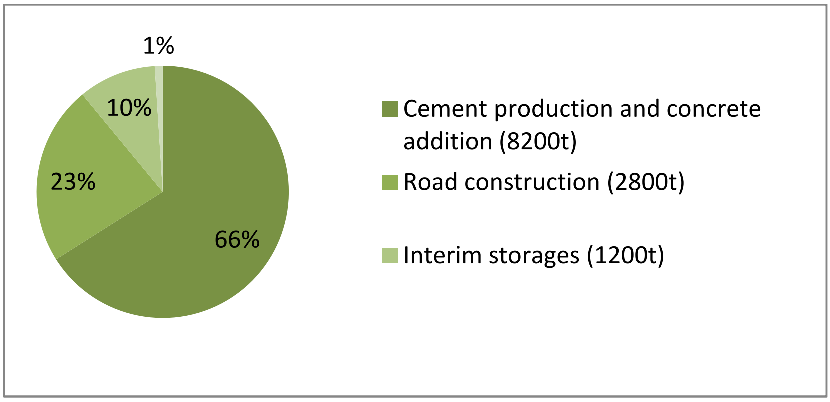


Figure 70 The use of blast furnace slag in 2010 (Euroslag, 2010).

Another material flow produced caused by pig iron production is dust, both coarse and fine dust. The BF coarse dust is assumed to be recirculated through a sinter plant or a briquette plant (EIPPCB and IPTS, 2010) Other residual flows such as sludge from blast furnace gas cleaning and ladle slurry have due to difficulties with finding reliable data been excluded from the study. A small amount of scrap is also used in the blast furnace for cooling purposes. The potential amount of scrap used in blast furnaces in the EU27 is not considered in the study.

Steel production from basic oxygen furnace

In 2010, 101.7 million tonnes of crude steel was produced from the BF-BOF route (Eurofer, 2012). In contrast to blast furnace slag, basic oxygen furnace slag (BOS) and electric arc furnace (EAF) slag are generated in an oxidizing process and therefore have iron contents that are significantly higher than blast furnace slag. Euroslag defines steel slags as BOF slag, slag from secondary metallurgy, EAF high alloy slag and EAF low alloy slag. The average content of iron in steel slags is 16-26 wt% (FeO). An average value of 20 wt% iron content in the steel slags are assumed representative for both secondary steel slag, all EAF slags and the BOF slag. According to figures from Euroslag 10.46 million tonnes of BOF slag were generated in 2010 resulting in an iron amount of 2.20 million tonnes. 2.83 million tonnes of secondary steel slags representing 580 000 tonnes of iron were also produced. Ten percent of the generated steel slags were recycled within the steelworks, whereas 90 percent was used in road construction, in cement production, finally disposed or put in interim storages. 2.39 million tonnes of iron present in the steel slags (BOF slag and secondary steel slag) were consequently not recycled.

Other output flows from the basic oxygen furnace are spittings, dust, rubble, mill scale and slag from desulphurisation. Spittings generally have a relatively high content of iron why the iron is separated and internally recycled through the sinter plant. The remaining part from the separation, with decreased iron content, is normally landfilled (EIPPCB and IPTS, 2010). The potential iron content is not considered further.

According to BAT the generation of desulphurisation slag is between 3 and 21 kilos per ton produced crude steel. The average content of iron (total Fe) is 20 percent. 40 percent is assumed to be recycled within the steelworks and 60 percent landfilled or sold. As a result approximately 150 000 tonnes of iron present in the desulphurisation slag was not recycled or put into beneficial use i.e. in this context regarded as losses.

The BF-BOF route also generates dust, both coarse and fine, as well as sludge. Coarse dust is usually returned to the BOF or recycled through the sinter plant. An amount of coarse dust is disposed of in landfills. No data for 2010 was found, but in 2007 around 12 percent of the dust was landfilled within the EU. Assuming an iron content of 50 percent in BOF dust and that 12 percent is sent to landfill, whereas the remaining part is internally recycled, approximately 8000 tonnes of iron from dust ended up in landfills in 2010 (EIPPCB and IPTS, 2010).

Neither average iron content in rubble and mill scale, nor the use of these fractions, could be found. The generation of rubble and mill scale was, however, approximated to 10.21 million tonnes (EIPPCB and IPTS, 2010).

Sludge is produced from gas cleaning in scrubbers or hydrocyclonage and is assumed recycled within the iron and steelmaking process. Spittings are a by-product from the converter during blowing. The spittings have a high content of iron which is separated and recycled to the sinter plant (EIPPCB and IPTS, 2010).

Steel production from electric arc furnace

Main material flows coming out from the EAF route are crude steel, slag, dust and refractory materials. In 2010, 70.7 million tonnes of crude steel was produced from the EAF route (Eurofer, 2012). The main raw material is different sources of scrap, but also a quantity of pig iron. Depending on the intended steel quality (carbon steel or stainless/high alloy steel) different types of EAF slag are produced: EAF low alloy slag or EAF high alloy slag. The carbon steel production uses non-alloyed steel scrap as input material in contrast to stainless steel production or production of other high alloy steels where high alloyed steel scrap and addition of alloys are used. The alloy materials are optionally added to give the crude steel the required chemical composition for certain qualities.

The EAF high-alloy steel slag represents around 8 percent of the total amount of steel slags produced and EAF low-alloy steel slag 31 percent (Euroslag, 2012). If an average iron content of 20 wt% is assumed and that 10 percent was recycled internally, 1.78 million tonnes of EAF slag was not recycled and regarded as “losses”.

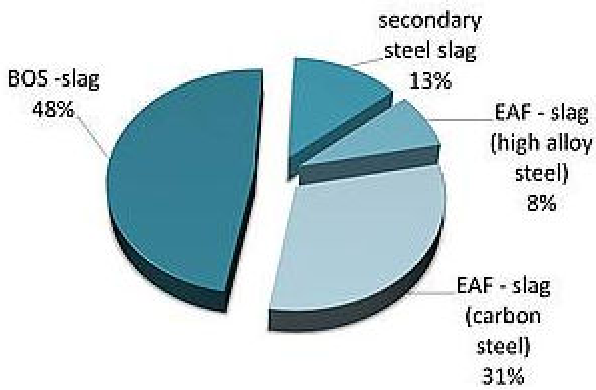


Figure 71 Generation of steel slags in 2010 (Euroslag, 2013).

Manufacturing of finished steel products

The semi-finished steel products are formed into steel parts of different shapes by rolling mills, thereafter sold to a variety of end-use sectors. There are different ways of talking the diverse group of finished steel products into account. Eurofer divides these products into flat and long products of steel. The long products can further be divided into wire rod, rebars, merchant bars and heavy sections. The flat products are instead divided into hot rolled wide strip and quarto plates. Furthermore, there are cold rolled flat products, hot dipped metal coated and organic coated fractions. Due to the fact that cold rolled flat production for instance is used in part of the hot rolled wide strip, the hot dipped metal coated is part of hot rolled wide strip and cold rolled, it is not possible to make a crude steel balance of the statistics of the finished steel products.

According to Eurofer annual report (Eurofer, 2012) the total production of carbon steels was 123.1 million tonnes in 2010, 20.5 million tonnes were exported to third countries. The deliveries of steel (all qualities) to the EU27 market were 147.8 million tonnes in 2010 including imports and exports and change of stock.

Manufacturing and use of final goods

The flat and long products delivered to the market could, as explained in 5.3, be divided further into bars, rods, quarto plates etc. The different steel products and steel qualities have different end-use sectors, but due to the complex pattern it is chosen not to go into detail of which steel product entering which sector of final goods. As an example, quarto plates are mostly used in tubes and buildings. Detailed coordinated information on end-use businesses of steel products have not been found, but there are a number of attempts to map the most important end-use sectors of finished steel products.

Inspired by Allwood and Cullen (2012) Eurofer's sector shares can be aggregated according to the following:

- Construction (infrastructure + structural steelworks + tubes) (51%)
- Automotive (16%)
- Mechanical engineering (14%)
- Miscellaneous (3%)
- Metal products (including consumer packaging and domestic appliances) (15%)
- Shipyard (1%)

Construction represents the top consuming end-sector of finished steel products. According to global estimates in Allwood and Cullen (2012), the most used finished steel products in the construction sector is reinforcement bars (49%), steel structural sections (25%) and sheet products (16%).

Flows relevant to the use phase are production of final goods as well as imports and exports of final goods. The final goods, when produced, are exported and similar products are also entering the EU27 by import. Looking deeply into trade of final goods containing steel has not been possible within this study. According to Chen and Graedel (2012) it is common that MFA studies do not consider trade of final goods containing steel, which is also a draw-back of this study. To avoid the uncertainties surrounded by estimating the iron and steel content in final goods it is assumed that the in-flow of iron and steel in the manufacturing of final goods is equal to the outflow from the manufacturing of final goods the same year i.e. change of stock is not accounted for.

Manufacturing of final goods result in production of prompt scrap when the finished steel products are cut, welded and transformed in various ways. The scrap generation rate can be expected to between 5 and 15 percent depending on the sector of final goods and is assumed to experience very high material recycled rates (Davis et al., (2007b).

Davis et al., (2007b) suggests that the iron and steel content in different final goods categories varies from 30 percent to 100 percent, Figure 72:

Goods category	Iron and steel content [%]
Mechanical engineering	71
Electrical engineering	30
Shipbuilding	70
Vehicles	58
Structural steelwork and building and civil engineering	100
Metal goods	85
Cans and metal boxes	100
Boilers, drums and other vessels	100
Other industries	60

Figure 72 Iron and steel content in different categories of final goods (David et al., 2007).

Trade of final goods is, as already mentioned, not included in the study.

3.5 End–of-life

It is difficult to estimate the availability of post-consumer scrap as many steel products have very long circulation times before they are available for recycling. Allwood and Cullen (2012) estimates the average life time expectancy for a steel product to 34 years. The circular times are not only long, but are very dependent on the end-use sector. Steel packaging has a very short lifetime in comparison to vehicles or large equipment and machinery. The availability of scrap a certain year is therefore depending both on the steel-containing products being scrapped during the actual year and the accumulated flows from previous years, which have not yet been discarded (Söderholm, 2012).

The end-of-life scrap accounted for in the study is presented in Figure 73. As seen in the figure, it has not been possible to include generated scrap amounts from all the identified final goods sectors, neither all products groups from the sectors. For instance, in the final goods category *Automotive*, only vehicles covered by the end-of-life vehicle directive (Directive 2000/53/EC) are taken into account. Busses and heavy trucks are not included. Apart from the waste streams presented in Figure 73, iron and steel also end up in unsorted residual waste flows subject to landfill or incineration. Iron and steel are therefore present in incineration bottom ash as well as in mixed waste volumes.

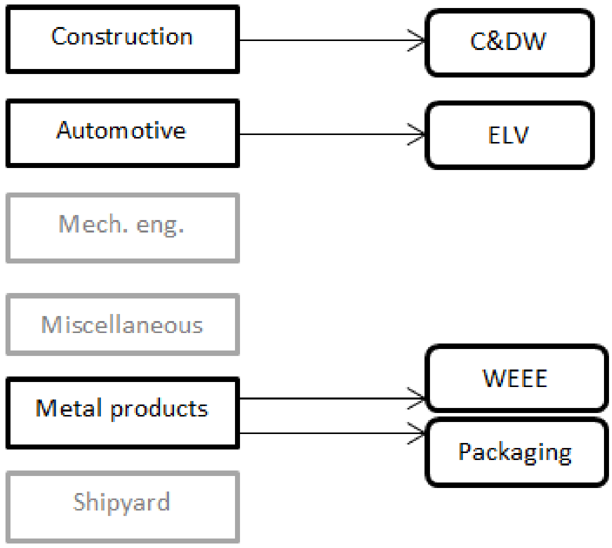


Figure 73 Final goods categories and related end-of-life waste streams.

There are three ways of quantifying post-consumer scrap arisings. One method is to empirically measure or estimate the flow of the arising scrap. This could be done by analysing samples of waste fractions to be disposed of in landfills and waste fractions subject to incineration. To empirically assess the end-of-life scrap contained in all final goods generated by households and industrial sectors is a very arduous task, if not impossible.

Another possibility to estimate scrap arisings would be to survey waste companies in charge of landfills and waste-to-energy plants. A third method would be to theoretically model the scrap generation based on the application of the *mass balance principle* using life time distributions of final goods. This method has been used in the Davis et al. (2007).

The approach in this study is to use the bottom-up approach by quantifying the scrap arisings from a number of selected key sectors of final goods as well as quantifying the amounts of iron and steel being disposed of in landfills. Life time assumptions of various final goods are therefore not relevant. The quantification of scrap generation is specific for the year 2010. Trade of post-consumer scrap as well as change in stock was not possible to quantify in the study.

End-of-life vehicles

The end of life vehicle directive (Directive 2000/53/EC) states how end of life vehicles (vehicles that has become waste) should be treated within the EU. According to the directive end of life vehicles refer to "vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat" and "vehicles designed and constructed for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes". The directive is not applied on commercial vehicles over 5 tons or busses and coaches.

The ELV directive is still not fully implemented in some member states resulting in inconsistency in the reporting of data and problems in terms of comparability of the reported data from different member states. One important reason is the question when a used car ceases to be product and becomes waste according to the Waste Framework Directive (2008/98/EC). The absence of reliable statistics can be demonstrated by the fact that the estimated the number of end-of-life vehicles arising in the EU-25 to be about 14 million in

2010 (Schneider et al., 2010). According to the reporting to Eurostat in 2010, based on data reported by 25 member states, the figure for 2010 is about 9 million vehicles. The amount of de-registered vehicles exported outside of EU as used cars are also uncertain. According to data from the COMEXT database the number of exported vehicles out of the EU was 893 000 in 2008. There is also strong evidence suggesting that a considerable number of ELVs are exported illegally out of the EU, mostly to the Middle Eastern countries and Africa (Schneider et al., 2010). Kanari et al., (2000) suggests that this phenomenon could partly be explained by assuming that higher profits are gained when selling intact ELVs as second-hand cars rather than spare parts and materials.

Data for the number of scrapped vehicles in Germany and Italy were not available for 2010 why data for 2009 for the two countries were used and added to the total amount for 2010.

According to ARN, the Dutch centre of expertise for recycling in the mobility sector, the average ELV contains 75 percent metals and 25 percent other materials. The metal consists of 41 percent steel sheet, 18 percent plain steel and 6 percent cast iron. That counts for an average content of 589 kg of iron and steel in an average ELV. At end-of-life, vehicles are sent to dismantlers for removal of reusable parts and hazardous components guided by the ELV-directive. According to Eurostat it is suggested that around 21 percent (195 kg) of a vehicle were dismantled by European dismantling companies in 2010.

The dismantled vehicles are sold to shredding plants where a heavy fast-turning rotor crashes the vehicle fed into the rotor house. The shredding results in general in three major fractions: a ferrous fraction, a non-ferrous fraction and an automobile shredder residue (ASR). The ferrous fraction is separated by magnetic separation leaving non-ferrous metals and non-metallic materials to pass to further stages such as dense media separation and eddy current separators. The separated ferrous fraction may contain as much as 98 % iron and steel (JRC and IPTS, 2010).

About 20- 25 percent of the weight of an ELV ends up in the shredder residue (ASR) with a main content of plastics, rubber, textiles and fibrous materials and wood, which are contaminated with metals. It is estimated that 1.93 to 2.34 million tonnes of ASR are generated in the EU each year (JRC and IPTS, 2010). This type of waste represents up to 10 percent of the whole amount of hazardous wastes produced per year in the EU and about 60 percent of the EU's total shredding wastes. Even though the ASR mainly consists of non-metal fractions iron and steel involuntarily end up in this fraction. The average content of metals are 8 percent (Simic and Dimitrijevic, 2012), or 8 percent of iron (Kanari, 2000). Another study suggests that the average composition of ASR is 0.8 percent steel and almost 4 percent iron scrap (Passarini et al., 2012). Assuming a content of 5 percent iron and steel in the ASR results in a total amount of 100 000 tons of iron and steel in the generated ASR within the EU. 70 percent of the weight of the ELV is sorted out as ferrous containing up to 98 percent of ferrous material. ASR is commonly disposed of in landfills, which is also the destiny of iron and steel present in the ASR (Passarini et al., 2012; Kanari, 2000). There are post-shredder treatment techniques available in some member states including sorting of iron and steel in the ASR and separating the ASR into a heavy fraction and a lighter fraction. For instance six VW Sicon process plants exist in Europe. In this study it is however assumed, in line with Kanari (2000) and Passarini et al., (2012), that the majority of ASR is still being put in landfills or used as construction materials where the iron and steel is not used. The treatment of ASR strongly depends on landfill legislation and landfill costs in the member country. In some countries landfilling of ASR is still the most economical choice (Moakley et al., 2010).

Packaging

EU member states are according to the packaging directive (Directive 94/62/EC) obliged to provide the Commission with data on the total quantity of packaging placed on the market and on the quantities of recovered and recycled packaging waste. The member states are not obliged to make a distinction between steel packaging and aluminum packaging, although a number of member countries have chosen to make this distinction and report the quantities of steel and aluminum packaging separately.

In 2010, 4.54 million tonnes of metal packaging waste were generated within the EU27 according to Eurostat. 3.25 million tonnes were estimated recycled leading to a recycling rate, based on generated waste quantities and recycled waste quantities, of almost 72 percent. Data for Germany, Italy and the UK from 1999 and onwards and for France, Sweden and Greece from 2003 and onwards indicate that aluminum has a share of 10-13 percent of the total metal packaging waste. Since 1999 a small increase has been observed.

In this study it is assumed that 90 percent of the metal packaging waste generated in 2010 consists of steel packaging i.e. 4.09 million tonnes, and that the same percentage can be applied on the quantities recycled resulting in a total amount of 2.94 million tonnes of steel packaging waste going to material recycling in 2010. The generated amounts of packaging waste are assumed to equal the amounts put on the market due to the short life time expectancy of packaging. The generated amounts are therefore the quantities of packaging waste put on the market reported by the member countries. There are no statistics on the collected amounts of packaging waste why the destiny of the packaging waste not being recycled is unknown. The remaining quantities can either be stored up adding to the stock or disposed of in waste fractions subject to landfill or incineration. There is in any case around one million tonnes of steel packaging waste not being put to recycling. Even though, a part of this amount is likely incinerated together with residual waste and sorted out by slag separation the iron and steel recycled that way is not covered by statistics.

Considering imports and exports of steel packaging waste, only Greece had reported an import of steel packaging for material recycling, 1000 tonnes. Exports of steel packaging for material recycling counted for 250 840 tonnes which are minor amounts in this context.

Construction

The use of iron and steel in the construction sector is widely spread representing over half of the consumption of finished steel products. Even so, the share of steel in a building represents slightly less than one percent of the total mass of a residential building. Steel parts in construction and demolition waste are generally recycled and some parts are also reused. Metal scrap is for economic reasons often separated from the rest of generated waste fractions along the dismantling processes and sold to traders or treatment plants. Separation is often performed at site, but the steel elements inside concrete may first be sent to recovery centres for crushing and separation with magnets before being used as raw material to in electric arc furnaces (JRC and IPTS, 2010). Process losses of iron and steel in the separation are not considered.

The official statistics on construction and demolition waste from Eurostat include all waste generated under NACE code F (construction sector). This means that the reported quantities include non-C&D waste generated by the construction sector and excludes C&D waste generated by other economic activities, such as other industries and households. However, it is likely that these two waste streams, which are not accounted for in the official C&D waste statistics, represent a minor part of the total generated C&D waste (Bio Intelligence Service, 2011). According to the official statistics from Eurostat the construction sector generated 875 000 000 tonnes of waste. A problem is that some member countries include excavated material, such as soil and vegetation, in the reported C&D waste quantities whereas others do not. This fact results in a difference in reported data not to be foreseen (Bio Intelligence Service, 2011).

Bio Intelligence Service (2011) has estimated the total amount of generated C&D waste, excluding the aforementioned excavated materials, and filled in data gaps for certain member states. Their estimate is that 461 million tonnes of construction and demolition waste was generated in 2005. The content of metal in C&D waste was estimated to between one and 18 million tonnes (not counting Estonia and Finland) indicating the difficulty of estimating the content of metal. According to the official statistics 2010, 12.93 million tonnes of metallic waste were generated in 2010 by the construction sector. The potential content of metal in the reported generation of mixed ordinary waste (12.78 million tonnes) and mixed and undifferentiated waste (8.4 million tonnes) is not known. Adding up to the already problematic situation is the fact that there is not reliable data on recycling rates of C&D waste in the EU. The member states do not report recycled C&D waste to Eurostat, only the generated amount, as it is not needed according to Waste Statistics Regulation. Data about composition, recycling and even generation of construction and demolition waste are therefore limited (ETC/SCP, 2009; Bio Intelligence Service, 2011).

ETC/SCP (2009) concluded in a study on recycling levels of C&D waste in the EU, that it is only possible (in 2009) to obtain data of recycled C&D waste in 17 member states and that the recycling is over 50 percent for most of these 17 countries. In the countries where recycling of C&D waste is registered, the registration mostly concerns recycling of concrete, bricks, tiles and asphalt. Recycling of soil and track ballast represented a large part of the recycled quantities.

Waste Electrical and Electronic Equipment (WEEE)

Steel in electric and electronic equipment (part of the final goods category metal products) represents in average almost half of the content on a weight basis in electrical equipment (Bogaert et al., 2008). When discarded, the waste stream of electrical and electronic equipment becomes waste electrical and electronic equipment (WEEE) covered by the WEEE-directive (Directive 2002/96/EC). The WEEE directive covers a wide variety of end-of-life products, mainly from households and offices, and identifies producers as responsible for recycling and waste prevention of WEEE. The WEEE directive requires depollution by stating that hazardous components of WEEE, such as batteries, must be removed. After depollution, WEEE consists of a mixture of metals, plastics and glass. Those three fractions make up the majority of the weight of average WEEE. The further treatment may vary, but usually includes shredding, magnetic separation and eddy current separation. Different kinds of density separations are also quite common. Shredding plants normally process mixture of ELVs, mixed light iron items and large household appliances. The major fractions coming out of the shredder is a ferrous fraction for recycling at steelworks, a non-ferrous fraction and a residual fraction similar to the automotive light fraction.

Data on generated amounts of WEEE are poor, but estimated to 8.3-9.1 million tonnes in 2005. This number is based on estimations from extending the known data to EU-wide coverage. The level of implementation of the WEEE directive varies among the member states why the data on collection of WEEE is varying. Current collection rates are in the majority of member states far below the amount of goods sold many years ago why increasing collection rates are seen as a key issue to increase the effectiveness of WEEE handling. The differences in collection performance among member states are believed, among others, to be due to differences in collection points and availability of collection infrastructure, that smaller items more likely are disposed of in the residual household waste than larger parts of WEEE, reporting effectiveness, developed second hand markets which could lower the reported quantities and exports (sometimes illegal) outside the EU lowering the collected amounts. In Figure 74 the collection rates of WEEE are estimated for different WEEE treatment categories.

#	Treatment category	Current % collected of WEEE Arising
1A	Large Household Appliances	16.3%
1B	Cooling and freezing	27.3%
1C	Large Household Appliances (smaller items)	40.0%
2,5A,8	Small Household Appliances, Lighting equipment – Luminaires and 'domestic' Medical devices	26.6%
3A	IT and Telecom excl. CRT's	27.8%
3B	CRT monitors	35.3%
3C	LCD monitors	40.5%
4A	Consumer Electronics excl. CRT's	40.1%
4B	CRT TV's	29.9%
4C	Flat Panel TV's	40.5%
5B	Lighting equipment – Lamps	27.9%
6	Electrical and electronic tools	20.8%
7	Toys, leisure and sports equipment	24.3%
8	Medical devices	49.7%
9	Monitoring and control instruments	65.2%
10	Automatic dispensers	59.4%

Figure 74 Estimated collection rates of WEEE of different categories (Huisman et al., 2008).

According to Eurostat approximately 2.5 million tonnes of WEEE were collected and treated within EU27 in 2010. With a total estimation of 8.7 million tonnes of WEEE generated this suggests that 6.2 million tonnes of WEEE, and 3.1 million tonnes of iron and steel, are ending up elsewhere, possibly into other waste flows or adding up to the stock. In Bigum (2012) 30 percent of the weight of WEEE (category 4 and 5, according to the WEEE-directive) was estimated to be dismantled before shredding where 60 percent consisted of metallic parts. If a rough estimation is made saying that 50 percent of the dismantled parts consist of steel, nearly 400 000 tonnes of steel are dismantled and subject to material recycling. In Bigum (2012) it was estimated that 54 kilos out of 1000 kilos of WEEE (category 4 and 5) ended up in the shredder light fraction, but as large appliances are often shredded together with end-of-life vehicles it is here assumed that a higher percent of the average WEEE weight ends up in the shredder light fraction, assuming 10 percent of the total weight of collected WEEE. With this assumption and an assumed content of iron of 8 percent as in ASR, approximately 200 000 tonnes of iron and steel end up in the shredder light fraction, with the same assumed destiny as ASR, landfilling. The rest of the iron and steel in the WEEE, 650 000 tonnes, are presumed sorted out and sent to recycling at the shredder facilities.

Iron and steel in bottom ash

There are 49 waste-to-energy plants within the EU where waste is incinerated for energy production. Both household and industrial waste streams, mostly mixed waste streams are accepted. Residual household waste contains to a certain extent iron and steel, which have not been sorted out to material recycling. The composition of the waste streams sent to incineration is difficult to estimate and could vary considerably between member states and between different waste streams. For this reason an easier way of finding out how much iron and steel that go to incineration is by evaluating how much iron and steel the bottom ash from incineration contain.

In 2009 it is estimated that 16 million tonnes of bottom ash were produced from the Waste-to-Energy plants in the EU (CEWEP, 2009). In reprocessing steps ferrous materials are sorted out by magnets and sold as raw materials in electric arc furnaces. According to CEWEP, bottom ash contains 6-10 percent of ferrous material leading to a total content of ferrous material in bottom ash of 0.96 – 1.6 million tonnes. However, the efficiency of the sorting process is unclear. If it is assumed that 90 percent of the iron and steel is sorted out, a total amount of 1.2 million tonnes of ferrous material go to material recycling (if 1.3 million tonnes of bottom ash is assumed generated). In that case, around 100 000 tonnes of iron and steel follows the bottom ash in its common usage as construction material, as a foundation material, in noise barriers, as a capping layer on landfill sites and in some countries as an aggregate in asphalt and concrete.

Iron and steel disposed of in landfills

There are reasons to believe that relevant amounts of iron and steel are disposed of in landfills in the EU27. In many member countries the counterpart of the generated municipal solid waste is landfilled. Nine new member states[22] have reported to Eurostat that over 55 percent of the treated amounts of MSW were landfilled in 2010, some countries have even reported 100 percent landfilling of MSW in 2010. Looking at Estonia, Lithuania and Latvia national surveys show that around three percent of the MSW disposed of in landfills consist of metals. Scaling up the share to the total reported quantities of landfilled MSW from these nine member states, assuming that the share of metals in landfilled MSW is representable, results in around 600 000 tonnes of iron and steel (assuming a 90 percent share of iron and steel of the content of metals) ending up in landfills.

By including the treated amounts of MSW in Spain, Italy, Germany, the UK and France above 80 percent of the treated amounts of MSW in EU27 is covered. Over half of the treated amounts of MSW in Spain and Italy are disposed of in landfills according to Eurostat statistics. In the UK, 49 percent of the treated amounts of MSW are reported disposed of in landfills and 31 percent in France. MSW is not sent to landfill in Germany.

It is challenging to find analysis of MSW disposed of in landfills, but by assuming that the MSW quantities disposed of in landfills are landfilled without prior sorting and that the same content of metals and share between ferrous and non-ferrous as in the nine member states can be applied on these waste quantities an addition amount of 1.5 million tonnes of iron and steel end up in landfills. It has to be notified that these figures do not include industrial waste

[22] Bulgaria, Poland, Estonia, Lithuania, Latvia, Romania, Slovenia, Slovakia and Czech Republic.

and that only 80 percent of the total amounts of treated MSW in the EU27 are represented. It is thus likely that the total amounts of iron and steel subject to disposal at landfill sites are significantly higher than 2.1 million tonnes per year.

3.6 Identification of inefficiencies

By applying an approach based on material flow analysis, a number of inefficiencies related to the life-cycle of iron and steel in the European Union are identified. It has to be noted and emphasised that the figures often are based on rough estimations and assumptions, why interpretations should be made with precaution.

The top five inefficiencies identified in the study are:

- Iron in tailings and residual flows as a result of iron ore production
- Iron present in blast oxygen furnace slag, secondary steel slag and electric arc furnace slag
- Iron and steel in construction and demolition waste not subject to recycling
- Iron and steel disposed of in landfills
- Low collections rates for WEEE

The flows of iron and steel identified as "losses" in this study i.e. flows where the iron and steel is not put into beneficial use or recycled, are presented below divided into process categories. The flows are incomplete and uncertain, but provides, however, with an idea of where the major losses of iron and steel occurs.

Iron ore production:

- 1.84 million tonnes of iron landfilled or put into interim storages

Steel production:

- 2.39 million tonnes of iron in basic oxygen furnace slag and secondary steel slag
- 150 000 tonnes of iron in desulphurisation slag
- 1.78 million tonnes of iron in electric arc furnace slag

End-of-life:

- 100 000 tonnes of iron in automotive residual fraction
- 200 000 tonnes of iron and steel in shredder light fraction from WEEE treatment
- million tonnes of iron and steel disposed of in landfill
- 100 000 tonnes of iron and steel in bottom ash from incineration

The inefficiencies related to the iron and steel flows in the EU27 are illustrated in Figure 75. The flows regarded as inefficiencies are marked in turquoise. Neither imports and exports, nor home scrap and prompt scrap, are included in the flow chart. "Unknown losses" refer to difference between generation and collection of a certain waste flows. The flow from "iron and steel in other waste flows not accounted for" is the amount of iron and steel in landfilled MSW identified in the study.

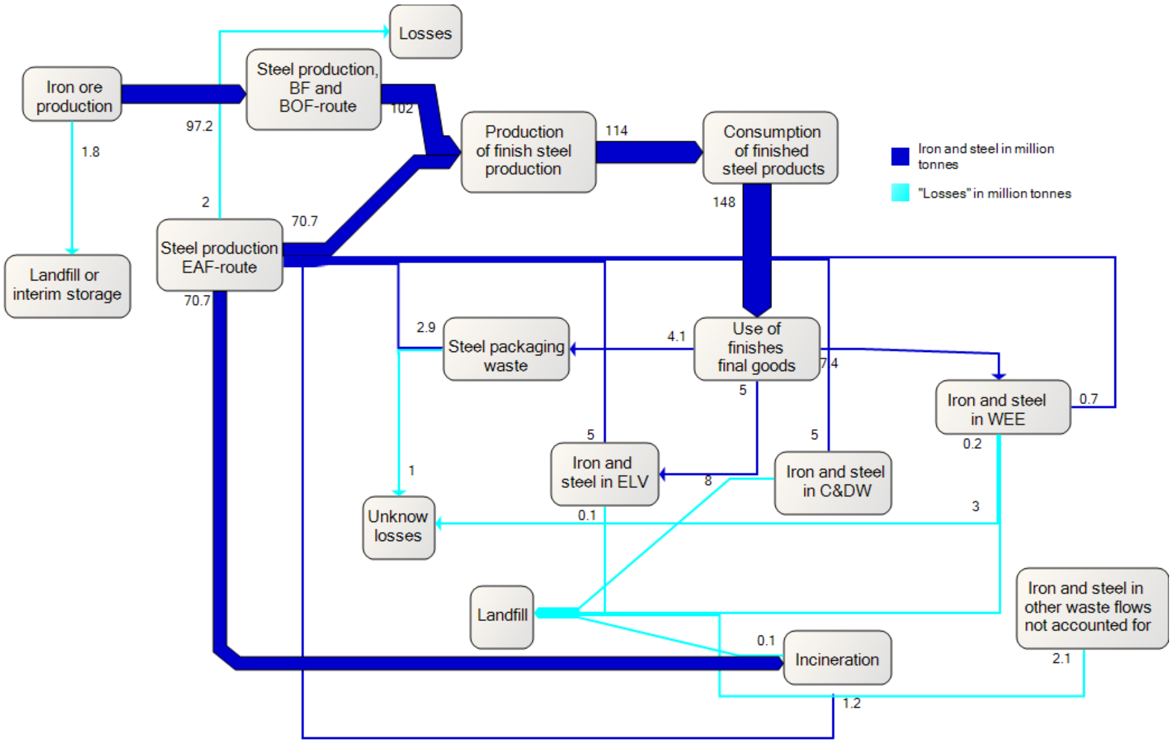


Figure 75 Illustration of inefficiencies in the cycles of iron and steel in the EU27.

Starting with the production of iron ore in the EU27 there is a relevant quantity of iron ending up in the tailings of the mining activities and in residual flows as result of beneficiation of the iron ore. This amount, estimated to nearly 2 million tonnes of iron in 2010, is currently being disposed of in landfills and in interim storages close to the mining sites. Presumably, depending on the economic circumstances, the iron present in the old landfills can be subject to mining activities in the future, which is already reality at some sites. The EU27 is a net importer of iron ore why this inefficiency would be even greater if a larger share of the iron ore consumed in the EU27 was produced within the union.

The steel production results in a number of different residual flows with varying iron and steel content. Estimations of iron present in the majority of the identified residual flows suggest that over 4 million tonnes of iron present in different steel slags, notably BOF slag and EAF low-alloy steel slag, are not put into beneficial use. Even though, the 4 million tonnes of slag is used in applications, such as in road construction, the iron content in the slags does not add any important properties to the applications and could consequently be regarded as unnecessary.

In this study it is projected that one of the major inefficiencies for iron and steel flows in the EU27 is iron and steel disposed of in landfills every year. The quantity of iron and steel ending up in landfills is estimated to 2.1 million tonnes in 2010, only counting for municipal solid waste and 80 percent of the total treated amounts. There are therefore strong reasons to believe that the amounts are significantly larger.

Construction is the end-sector where most of the finished steel products are consumed. The construction sector generates vast amounts of waste in the EU and consists of a significant quantity of iron and steel. However, due to absence of reliable and consistent data both on generation and treated amounts of C&D waste on the EU-level, which in fact can be regarded as an inefficiency itself, it is very difficult to evaluate and quantify possible inefficiencies. There are reasons to believe that a substantial amount of iron and steel present in the mixed and undifferentiated waste streams are likely to end up in landfills due to the fact that a large amount of C&D waste is disposed of in landfills without prior separation. Previous studies suggest that the metal content in C&D waste is somewhere between one and 18 million tonnes (Bio Intelligence Service, 2011). According to the official statistics from Eurostat 12.9 million tonnes of metallic waste were generated in 2010 as part of waste from the construction sector suggesting that a significant amount is disposed of in landfills.

Data on iron and steel present in end-of-life waste streams is limited, much more limited than data on production of iron and steel. The absence of reliable data and different reporting efficiency among member states is important to emphasise since data coverage is essential for the follow-up and evaluation of material waste flows within the EU. The fact that EU directives and regulations have not yet fully been implemented in all EU member states makes official statistics less comprehensive and identification of inefficiencies aggravated. Illegal waste streams not covered by official statistics add up to the overall uncertainty.

A key issue in recycling of iron and steel is the availability of scrap. Scrap from the iron and steel production and manufacturing are more readily available than post-consumer scrap. Home scrap can be recycled at site whereas new scrap can either be recycled internally or delivered to the steelworks by scrap dealers. Post-consumer scrap from long-lived products is not as available and dependent on collection and sorting schemes as well as the public’s awareness. For some EOL waste streams the collection rates are identified as extraordinary low e.g. the collection rates for WEEE. Current collection rates are in the majority of member states far below the amount of goods sold many years ago why increasing collection rates are, also by other studies, seen as a key issue to increase the effectiveness of recycling of WEEE handling, thereby also iron and steel present in WEEE.

An inefficiency not considered in this study, which also is challenging to quantify, is dilution losses in the recycling of ferrous materials. This phenomenon has, among others, been observed by Nakamura et al., (2012). In the best of worlds metals can be recycled an infinite number of times without any degradation in quality. In reality, close-loop recycling is not typical for ferrous scrap due to mixing of different qualities of steel in the end-of-life chain. When products composed of iron and steel is discarded and available for recycling the secondary materials have no longer equal quality as steel produced from raw material and is therefore subject to a quality loss. The quality requirements of the target products do not meet the quality of the scrap why the secondary material needs to be diluted with high purity material. Tin and copper are for example undesired constituents in steelmaking processes. When the contaminants occurring in secondary materials exceed the maximum content allowed for the target product to be produced out of the secondary material, additional high purity materials must be added to dilute the contaminant to an acceptable level. For instance, if a given mass of IS scrap with 0.60% copper is to be used to produce section steel, it has to be diluted with primary iron of equal mass to achieve the requirement of 0.3% copper.

Reduction in dilution- and quality losses could be achieved by, among others, an improvement in sorting technology, implementation of design for recycling/disassembly, and the introduction of an easier way to identify the chemical properties of secondary materials. Improvement in the quality of recovered secondary materials results in a shift in their use from an open cycle loop to a closed loop cycle. Associated with this shift, however, is the fact that a lesser amount of secondary materials will be available for the original users that were participating in the open loop (Nakamura et al., 2012).

Steel enhances unique properties of stiffness, strength, thermal expansion and corrosion ductility. The availability of iron ore in the earth's crust is vast and the iron ore can be mined at relatively low cost. All this adds up to the reason why iron and steel is so widely used in the society. A possible inefficiency would be if our use of iron and steel could be partly substituted by use of other materials such as wood, concrete or stone. Allwood and Cullen (2012) means that the advantages of using other materials before steel are not evident. For instance one tonne of steel could not be substituted by one tonne of wood. Wood is also less stable than steel and less resistant to fire. The strength to weight ratio is relatively good, but to reach the same strength as steel there is need of a high amount of wood. The major disadvantage of concrete and stone compared to steel is that the tension is very low in comparison. On the other hand concrete is very easy to use and can easily be poured and moulded. Allwood and Cullen (2012) concludes that we do not have any clear substitutes for iron and steel.

3.6.1 Drivers

There are strong incentives to use scrap for steel production. Scrap-based steel production using EAF has both economic and environmental advantages over iron ore-based production. The process chain from scrap to steel involves fewer steps, and less costs, compared to iron ore-based production. Due to the positive value of scrap and the fact that involved scrap dealers gain money from selling scrap to steelworks, collection of scrap is driven by economic incentives. An example of this is sorting of metals from incineration slags (Gyllenram et al., 2008).

Drivers to increase collection rates for selected waste streams are for example focused campaigns where the public are economically motivated to hand in end-of-life items for recycling. This has been done in Sweden for used equipment in the farming sector and for end-of-life vehicles.

For construction, material cost is often far lower than labor cost which drives time optimized construction rather than material optimized.

3.6.2 Best practice

Steel is the world's most recycled material (Yellishetty et al., 2011). In 2010 over 40 percent of the crude steel production was produced by the electric arc furnace route (Eurofer, 2012).

Besides, steel packaging is the most recycled packaging material. The fact that most steel is magnetic makes it relatively easy to sort out from other materials (APEAL, 2013).

Home scrap produced at steel mills experience very high recycling rates due to its known composition. The home scrap recycling is managed within the steel mills why contaminants from other waste fractions are avoided. The recycling of prompt scrap, generated from the production of finished steel products, is also rather straight-forward. In general, this scrap is of high quality and can be sold back to the steel mills either directly by the manufacturers or through scrap dealers.

3.6.3 Policy impacts

There exists no legislation on the EU level concerning the recycling of iron and steel specifically, although there are many examples of encouraging policy measures for increasing the recycling of iron and steel, both directly and indirectly. Landfill taxes and fees diverting waste from landfill encourage other waste treatment options, as one example.

Member states in the EU have reached different levels in this encouragement why the majority of generated waste still is disposed of in landfills. The Landfill Directive sets targets for progressively reducing the amount of biodegradable municipal waste landfilled to 2016, but there are no specific targets for iron and steel disposed of in landfills. However, in the Waste Framework Directive the Waste hierarchy prioritises how waste should be treated within the European Union where disposal is the stated as the least attractive way of treating waste.

There is also EU legislation encouraging recycling of iron and steel. An example is the Waste Framework Directive (WFD) which requires Member States to take any necessary measures to achieve a minimum target of 70 percent (by weight) of construction and demolition waste by 2020 for preparation for re-use, recycling and other material recovery, including backfilling operations using non hazardous C&D waste to substitute other materials. The target is valid for the total amount of C&D waste and no distinction is made dependent of the actual fraction. This means that the target itself does not necessarily represent an incentive for the appropriate treatment of the smaller fractions of C&D waste, such as metals, due to the fact that fractions representing the largest shares (weight basis) are likely to be focus in reaching the target. Unlike many other waste streams e.g. end-of-life vehicles, WEEE and packaging, construction products are not covered by producer responsibility obligations.

In the WEEE directive (Directive 2012/19/EC on waste electrical and electronic equipment (WEEE)) the collection target is that 4 kilos of WEEE on average per inhabitant per year should be collected from private households. From 2016 the minimum collection rate will be sharpened to 45 percent calculated on the basis of the total weight of WEEE collected in a given year in the member state expressed as a percentage of the average weight of electrical and electronic equipment placed on the market the three preceding years in the member state. The collection rate shall increase gradually and in 2019 be 65 percent of the average weight of EEE placed on the market in the three preceding years in the member state or 85 percent of the WEEE generated in the member state. The collection targets for WEEE do only apply for WEEE coming from private households including commercial, industrial, institutional and other sources which, because of its nature and quantity, is similar to that from private households. This means that no target on WEEE generating from industries are not covered.

The recycling of metal packaging, including steel packaging, is regulated by the Packaging Directive (Directive 2004/12/EC on packaging and packaging waste). According to the directive the minimum recycling target for metal packaging waste is 50 percent by weight.

3.7 Conclusions

A number of inefficiencies related to the life-cycle of iron and steel in the European Union have been identified in this MFA-based study. Quantity estimations are subject to large uncertainties. The top five inefficiencies identified in the study are:

- Iron in tailings and residual flows as a result of iron ore production
- Iron present in blast oxygen furnace slag, secondary steel slag and electric arc furnace slag
- Iron and steel in construction and demolition waste not subject to recycling
- Iron and steel disposed of in landfills
- Low collections rates for WEEE

The inefficiencies or “losses” listed above are flows of iron and steel where the iron and steel is not put into beneficial use or recycled. Data on iron and steel present in end-of-life waste streams is limited, much more limited than data on production of iron and steel, which is also regarded as an important inefficiency making it hard to draw conclusions of inefficiencies in the post-consumer phase.

4 Cobalt in the European Union and globally

4.1 Introduction

This study, using material- and substance flow analysis (hereinafter MFA and SFA) methodology, aims at identifying inefficiencies in the use of Cobalt in society. The introduction provides some general information about the metal, its extraction, production and use in different applications, as well as its importance as a critical material for emerging technologies. Chapter two explains MFA methodology in short, explains the goal and system boundaries of the study and discusses the issues surrounding data availability for MFA and SFA studies. Identified inefficiencies are presented in chapter 3, together with drivers and examples of best practices to avoid them. Conclusions are summarized in chapter 4.

4.1.1 Why Cobalt

The extraction of cobalt has increased in recent years, partly driven by increasing demand from emerging technologies such as batteries for electric vehicles and other electric devices. At the same time, the discussion about resource supply and efficiency has increased in society, using terminology such as footprints and planetary boundaries (Rockström et al. 2009). There are a number of political incentives that identify Cobalt as a critical raw material for the future, both in Europe and worldwide, which motivates a closer look at the efficiency of current cobalt use in society.

4.1.2 Background and strategic focus

Cobalt (Co) is a bluish-white, lustrous, hard and brittle metal. It has fairly low thermal and electrical conductivity, is ferromagnetic and very chemically active. Cobalt and its compounds are considered to be slightly toxic (British Environmental Agency 2011).

The European Union names cobalt as one of 41 “critical raw materials” in a report from 2010, identifying materials of economic and strategic importance for the union. It has relatively large economic importance, but the supply risk is not very high because of large resources and production capacity. The share of demand from emerging technologies in relation to production was 21% in 2006 and estimated to 43% for 2030 given the current level of production (European Commission 2010). Other economies have also identified cobalt as an important metal for the future. In December of 2010, The U.S. Department of Energy (DOE) outlined its “Critical Materials Strategy.” Cobalt is one of 14 elements defined as a critical metal to enable clean energy production over the next 5-15 years. The DOE sees cobalt as such a critical metal because of its use in lithium ion batteries, and predicts that each electric-powered vehicle (PHEVs and EVs) will demand 9.4 kg of cobalt. The rest of the list is dominated by rare-earth elements (Dove 2011).

4.1.3 Production

Cobalt's abundance in the earth's crust is 25 ppm, and it can be found in several common ores (cobaltite, erythrite, glaucodot and skutterudite). It can also be found in economic concentrations in olivine, spineland chlorite, in lateric and hydrothermal deposits. Generally, production of cobalt is as a byproduct of copper metallurgy and as a byproduct of nickel production.

Because cobalt is extracted from a wide variety of ores, there is an equally extensive variety of mining, extraction and refining methods. For example, the process of purifying cobalt bearing copper sulphide ore involves crushing and separating the ore, to subsequently roast and leach the concentrate with sulphuric acid. The cobalt can then be separated from the pulp as cobalt hydroxide. After the other metals have been removed the hydroxide is re-dissolved in acid. The world's cobalt reserves are concentrated in Central Africa. Interestingly, about 36% of refined cobalt production is based on imported material processed by countries that have no cobalt mining production (British Environmental Agency 2011). This implies the strategic importance of the metal, and may be the major reason why the United States are stockpiling a reserve of the metal.

4.1.4 Use

Cobalt is most commonly used as an alloy constituent or chemical compound that can provide chemical resistance and high temperature strength. The two main commercial applications of cobalt are in rechargeable batteries, who stand for 25-29% of the end use (depending on data source), and super-alloys for jet turbine parts and other types of turbines, using 22% (British Environmental Agency 2011). In this study, these two applications are chosen for further studies of material flows and inefficiencies. The other applications are shown in Figure 76.

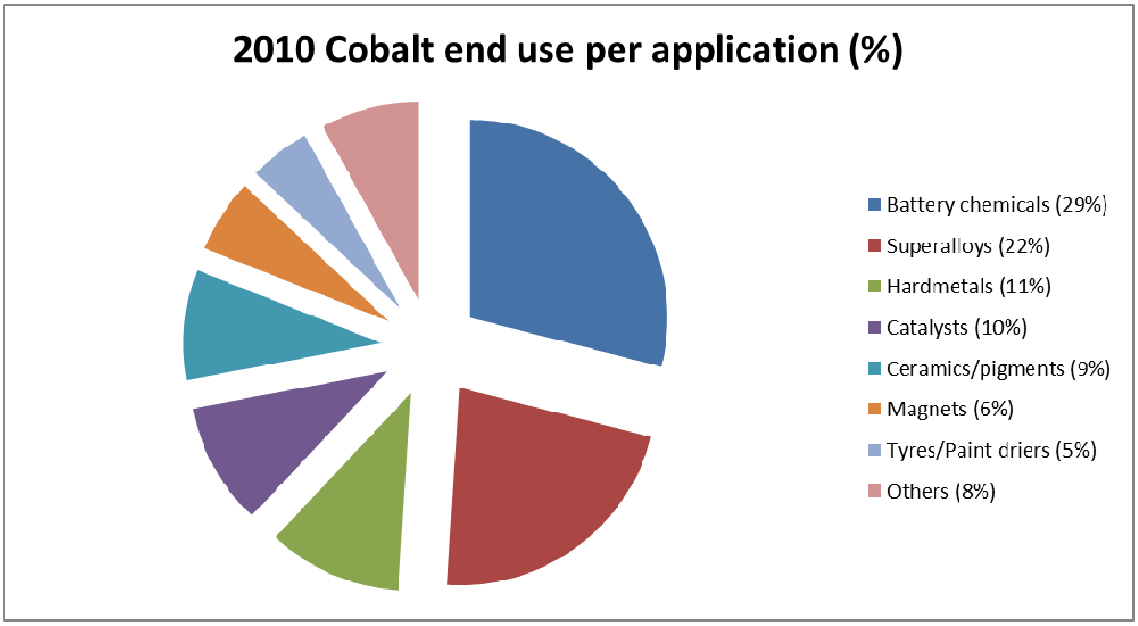


Figure 76 Cobalt demand by end use, 2010 (Darton Commodities Ltd 2010)

Cobalt in batteries

The use of lithium ion batteries has increased greatly over the last decade due to development in transportation and electric and electronic devices. The table below lists a number of lithium ion battery technologies, some of them containing Cobalt.

Table 15 Li-ion battery technologies and their Cobalt content (Darton Commodities 2010)

Battery technology	Full name	Cobalt content (%)
LCO	Lithium Cobalt Oxide	60
LNCMO	Lithium Nickel Cobalt Manganese Oxide	~ 15
LNCAO	Lithium Nickel Cobalt Aluminum Oxide	~ 9
LMO	Lithium Manganese Oxide	0
LFPO	Lithium Iron Phosphate	0

Substitution of the traditional $LiCoO_2$ (LCO = 60% Co) cathode material with mixed metal oxide materials is a continuing trend. The share of LCO cathode chemistry in lithium ion batteries dropped from 70% in 2008 to 49% in 2010. Over the same period the use of $LiNiCoMnO_2$ (NCM = 15% Co) grew from 14% to 36%. This substitution trend will decelerate the long-term growth rate for cobalt demand in the battery sector. However, a strong growth in electronic devices is expected to more than offset the market share decline of $LiCoO_2$ with cobalt continuing to play a critical role in the performance of mixed metal cathode chemistry. Estimations made by one of the large producing companies in 2010 predicted that cobalt consumption in batteries would continue to grow at a compounded average growth rate of 9% per annum, despite the usage of lower cobalt containing chemistry in battery cathode materials. As a result, cobalt consumption Li-ion batteries was expected to exceed 21,000 MT in 2012 (Darton Commodities Ltd 2010).

Although the use of rechargeable batteries for automotive applications (HEV, EV and PHEV) is growing, the actual usage of cobalt will strongly depend on the battery and cathode technology that will dominate in the future. The current focus of batteries for HEV use is Li-ion technology, which is believed to become the dominant technology, reaching 70% of market share by 2020. Due to the variations in cathode use and the uncertainty surrounding market penetration rates for HEV and EV in the global markets, it is very difficult to estimate the future use of cobalt in automotive battery applications. Nevertheless, Deutsche Bank estimated in its 2008 study 'Electric Cars; Plugged-in' that automotive related lithium ion battery demand for automotive applications may require 2,380 MT of cobalt in 2012, growing to 18,900 MT by 2020 (Darton Commodities Ltd 2010).

Super alloys

Super alloys account for about 20-25% of the total cobalt demand. The manufacturing requires very high quality of the metal, with cobalt content in end products around 30-50% (The Cobalt Development Institute 2006). The main industry using cobalt based super alloys is airplane manufacturing, in particular jet engine producers. Other fields of application for super alloys are industrial land based turbines for power generation, high speed trains and the automotive sector.

Nickel-based alloys, also commonly used in airplane engines, contain around 10% cobalt (Jovanovich et al. 2007). These alloys usually constitute 40-50% of an aircraft engine (Pollock and Tin 2006). Since they are not as hard as nickel based super alloys, cobalt super alloys are not as sensitive to cracking under thermal shocks as other super alloys. Co-based super alloys are therefore more suitable for parts that need to be worked or welded, such as those in the intricate structures of the engine combustion chamber (Jovanovich et al. 2007). The super alloy industry is very market sensitive, which became evident in 2009, when Cobalt demand from the super alloy sector was severely impacted as the commercial aerospace, energy, chemical processing and automotive markets were all suffering from a significant reduction in downstream orders due to the global economic regression (Darton Commodities Ltd 2010).

4.1.5 Cobalt scarcity

As mentioned earlier, there is no severe physical scarcity of cobalt in the world today. This is reflected by the diagram presented by the European commission (Figure 77), where cobalt is located lowest in the cluster of critical material, indicating low supply risk (European Commission 2010).

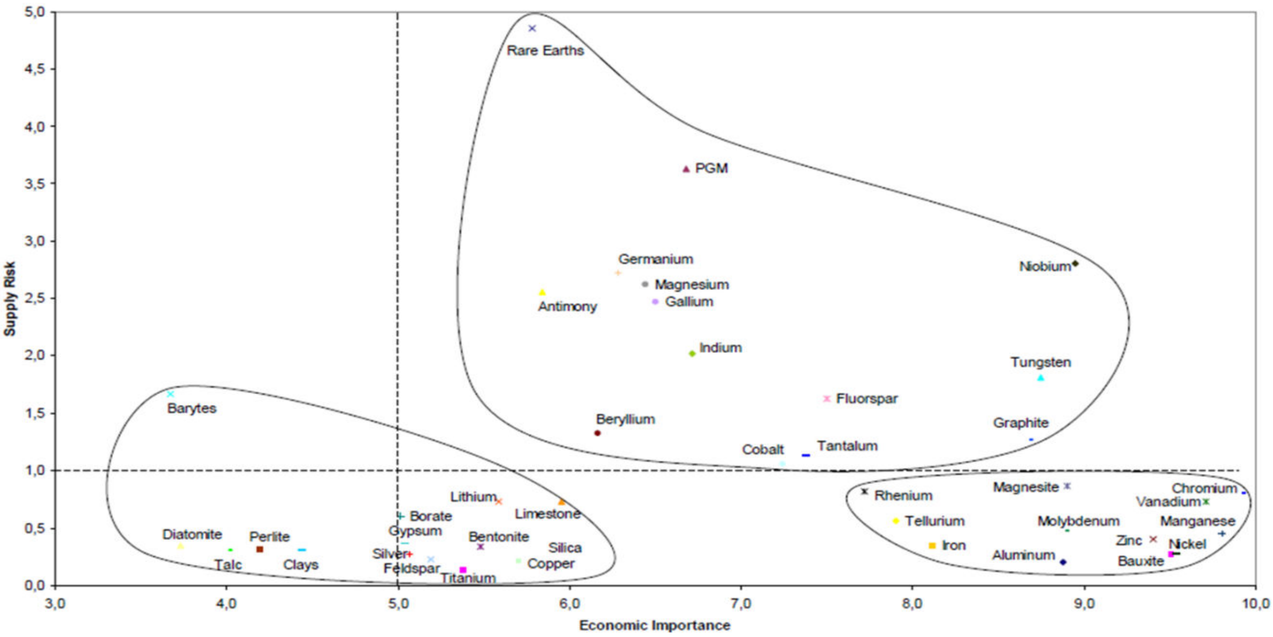


Figure 77 Supply risk and economic importance of materials in the EU (European Commission 2010).

Instead, the matter of Cobalt supply is more a strategic issue, since the mining is not carried out in the same countries as the refining operations. The large imbalance between mining and refining implies a high dependency of refining countries on main mining countries such as the Democratic republic of Congo. Finland is currently the only European country mining Cobalt. The country is expanding its mining and beneficiation, with two new mines that were scheduled to start production in 2012, as well as extension of existing operation at one existing site (U.S. Geological Survey 2012).

Also the US had one new mine and refinery site scheduled to start production in 2012 and two more mines scheduled to start production in 2013. This will be the first US production since the 1970s, and is a strategic move to ensure future supply safety.

4.2 Goal and systems definition

This study is not a complete SFA, but uses the basic methodology of Type IIc since the substance cobalt is studied in regard to estimated total throughput worldwide and within the EU rather than impacts per unit flow of cobalt.

This study aims at:

- Finding inefficiencies in the cobalt life cycle of the two main uses
- Finding key drivers for the identified inefficiencies
- Describing best practice that reduce the inefficiencies
- Investigate connections between policy and efficiency for cobalt

The scope is cobalt use in rechargeable batteries and super alloys. Reference year for the data used is 2010. The study describes use within one year but the total use over many years is included in the interpretation. The geographical boundary includes both the EU and the world to ensure inclusion of critical issues both in the primary area: the EU and the supporting area: the world.

4.3 Cobalt on a global scale

The table below shows global mining production and refinery production of cobalt per country in 2010, also indicating the main forms of the produced cobalt.

Table 16 World mine production and refinery production of Cobalt in 2010, divided by type (U.S. Geological Survey 2012).

Country	2010 mine prod. (t Co content)	2010 refinery prod. (t Co content)	Form
Belgium		2600	metal powder & oxide hydroxide
Finland	140	9413	metal powder, salts
France		302	chloride
Norway		3208	metal
Australia	3850	4120	
Botswana	325		metal powder, oxide, hydroxide
Brazil	1600	1369	
Canada	4568	4650	metal
China	6500	32900	metal, metal powder, oxide
Congo (Kinshasa)	47400	4182	metal, metal powder, oxide, salts
Cuba	3600		metal

Country	2010 mine prod. (t Co content)	2010 refinery prod. (t Co content)	Form
Indonesia	1600		
India		1187	
Japan		1935	metal, salts
Madagascar	700		metal
Morocco	2200	1545	
New Caledonia (FR)	1000		metal, oxide
Philippines	2200		
Russia	6200	2460	Unspecified
South Africa	1800	833	Unspecified
Uganda		624	metal powder, sulfate
Zambia	5700	5026	metal
Zimbabwe	79		metal
World total (rounded)	**89322**	**79864**	

Cobalt in the European Union

European production of cobalt metal amounted to 20.4% of the world total in 2010 (British Geological Survey 2012). The total mining production in Europe will increase from 140 to 3280 tons as a result of the new and extended mining operations in Finland (U.S. Geological Survey 2012). This is still a small part of the global mining production. The refining capacity will also increase, adding to the capacity of 15523 tons refined in Belgium, Finland, France and Norway in 2010 (Table 16).

Table 17 European mining and production of cobalt. **Some metal production in China is recorded in Belgium* (British Geological Survey 2012).

Country	Metal production 2010 (t metal content)	Mine production 2010 (t metal content)
Belgium*	2 600	-
Finland	9 413	30
France	302	-
Norway	3 208	-
EU 34 Total	15 500	30

4.4 (In)efficiency

This chapter estimates the main inefficiencies found for cobalt in this study, and describes some of the drivers for these inefficiencies. Examples of best practices are briefly described, and based on these a number of policy impacts, both existing today and suggested for the future, are presented.

4.4.1 Identification

The main inefficiencies identified for cobalt; beneficiation losses and alloys in scrap aircraft, are described below. Since both are occurring on the global scale, no attempt is made to specify losses for the European Union. A very rough estimation of losses in automotive battery applications is also made, based on recycling targets. Assumptions and estimates used in the calculations are described and implicates that there are large uncertainties in the presented numbers.

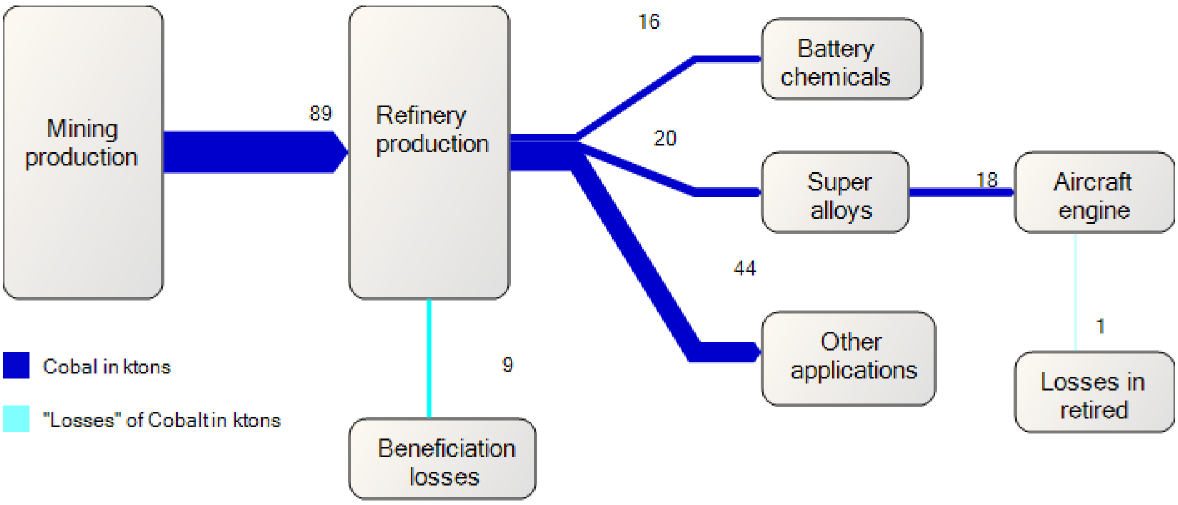


Figure 78 Flow chart of cobalt application and identified losses.

Beneficiation losses

The largest identified loss is found in refinery production, where cobalt losses to tailings and slags can be roughly estimated to 9458 tons globally in 2010. This number is simply calculated as the difference between mining production and refinery production, since both figures are given in the unit metal content, and therefore are comparable. The possible stockpiling of acquired cobalt ore from one year to the next is not taken into account.

Super alloys in non –recycled (scrap) aircraft

There were 27 047 aircraft in the global fleet in 2010, according to the Flightglobal ACAS database. Geographically, North/South America was the dominant region with 10,661 aircraft and a 39.4% share, followed by Europe with 8,220 aircraft and a 30.4% share (Kingsley-Jones 2010). The number of retired aircrafts in 2010 was 520 units. There is no global common practice for recycling of aircraft, which indicates large losses of materials in retired aircraft, among them cobalt. An attempt is made to estimate the cobalt losses below, using a number of assumptions.

A large aircraft engine weighs around 6 metric tons. In this estimate we use an engine commonly used in civil aircrafts weighing 6,4 tons (Rolls Royce 2012). Assuming each aircraft in retired has two engines[23] and each engine consists of 50% co-alloys and 50% in-alloys. These estimates result in a total content of around 3 metric tons of cobalt in each aircraft. As only 150 of the 520 retired aircrafts were recycled (see section 3.3.1.) the amount of cobalt lost in end-of-life aircrafts amounted to over 1100 metric tons for the year 2010.

Automotive batteries

The growing market for lithium ion batteries in electric vehicles indicates that this sector will be increasingly important for an efficient use of cobalt in the future. The current mandatory recycling rate of 50% for automotive batteries in electric vehicles entered into force in late 2011, and it is uncertain how soon this rate will increase. As a best estimate, we assume that all cobalt in each recycled EV battery is recovered, and apply the 2011 recycling target in 2010.

Table 18 Estimated losses of cobalt in 2010 (*EV EOL: End of Life electric vehicles).

Loss mechanism	Estimated losses (t)
Beneficiation	9 458
Retired aircrafts	1 100
Automotive batteries	Maximum 50% of amounts in EV EOL*

4.4.2 Drivers

An attempt was made to map the underlying mechanisms resulting in inefficient resource use. Both economic and political drivers were identified, and are described below:

Mining & refining technologies

In industrial beneficiation processes for cobalt it is very difficult to control specific parameters critical for the cobalt yield, such as sulphur pressure (Toscano and Utigard 2003). Since cobalt is often refined together with other metals (i.e. copper, nickel), optimising the yield for one metal may reduce the yield of another. The lack of cobalt optimising beneficiation technologies is an economic driver for inefficiency. As long as cobalt is relatively abundant and prices do not rise substantially, there are no strong drivers to increase efficiency of beneficiation techniques, since such improvements could result in very costly investments.

Insufficient recycling targets

Airplanes are not subject to product responsibility legislation, like cars and electronics. Introducing product responsibility and recycling targets would also introduce reporting systems, and allow countries and regions, such as the EU, to follow up progress, processes

[23] In reality, aircraft with an engine size of 6 tons have four engines, while aircraft with smaller engines only have two.

and efficiency of airplane recycling. This is in line with the recommendations by the Ad hoc working group on critical raw materials (see section 3.4 below). For EV batteries, the recycling rate is still relatively low, and political will in combination with successful broad implementation of recycling technologies will determine how fast this rate can increase.

4.4.3 Best practice

The two best practices identified in this study are both recycling initiatives. A difference between the two is that aircraft recycling is not (yet) subject to legislative targets, but carried out by industry initiative.

Aircraft recycling

The global industry association Aircraft Fleet Recycling Association (AFRA) was founded in 2006, and organizes main manufacturers, disassemblers and recycling companies (Aircraft Fleet Recycling Association 2013). In 2010, they treated around 150 aircraft, recycling 70% of their materials (mainly frames and engines). The recyclability goal for 2016 is set to 90% (by weight). This recycling rate is still lower than the regulated targets for vehicles, which are set to 85% reuse and recycling and 95% reuse and recovery (by weight) for the year 2015. However, the industry acceptance and participation in AFRA is promising, and will hopefully lead to a strong increase of aircraft recycling for the future.

Electrical vehicle batteries recycling

In Belgium, one of the large battery producers have established recycling plants to recover rechargeable batteries such as Li-Ion and Li-Metal hydride from electric vehicles and other applications, using a pyrometallurgical process (Umicore 2013). After dismantling, the EV batteries are put through a smelter and granulated before going through a number of refining steps. The metals, including cobalt, are then shipped to Asia, where they are transformed into battery chemicals such as Ni(OH)2 and LiMeO2. Rare earths are treated separately, and slags are used as construction material. Total recycling efficiency of the process is not reported.

4.4.4 Policy impacts

This section highlight which policies are already affecting the efficiency of cobalt use today, and which measures that could be implemented to increase efficiency in the future.

Existing policies

Batteries for electrical vehicles are covered by the producer responsibility as laid out in the European battery directive (2006/66/EC). From September 2011, the recycling rate of industrial and automotive batteries should be at least 50%. The batteries are also indirectly regulated with regard to heavy metal content by the End- of- Life Vehicle directive 2000/53/EC. The growing product categories of electronic devices using lithium ion batteries are covered by the WEEE directive, prescribing a re-use and recycling rate of 70% (2012/19/EU).

Recommendations for the future

The European ad hoc working group on defining critical raw materials recommend in their report (European Commission 2010) that policy actions are undertaken to make recycling of raw materials or raw material-containing products more efficient, in particular by:

- mobilising End of Life products with critical raw materials for proper collection instead of stockpiling them in households (hibernating) or discarding them into landfill or incineration;
- improving overall organisation, logistics and efficiency of recycling chains focus on interfaces and system approach;
- preventing illegal exports of EoL products containing critical raw materials and increasing transparency in flow;
- promoting research on system optimisation and recycling of technically challenging products and substances.

All these recommendations are good means of increasing resource efficiency in the EU, should they be followed to a large extent. How they may be implemented into policy, in Europe and possibly globally, is yet to be seen.

4.5 Conclusions

There are large inefficiencies in cobalt beneficiation technologies and cobalt containing products that are not recycled.

Successful reduction of these inefficiencies depends on political will to improve policies, creating incentives for industry initiatives and technology development. One example could be implementing producer responsibility with binding recycling targets for aircraft.

Given the global markets and operations of industry, policy should aim to be globally harmonized to avoid shifting of inefficiencies to other parts of the world.

5 Water mapping in the European Union

5.1 Introduction

Water is constantly abstracted to meet the demands of society. Freshwater is the main source for this. In Europe, 75 % of the abstracted volumes are surface water and 25 % is groundwater. Small amounts come from desalination of sea water and from reuse of treated effluents (Kinner et al. 1999). Of the earth's entire water resources, only 3 % is freshwater, by which only 0.3 % is available for the humans (McGlade and Werner 2012). Figure 79 illustrates the main flows of inland water resource system and the economy.

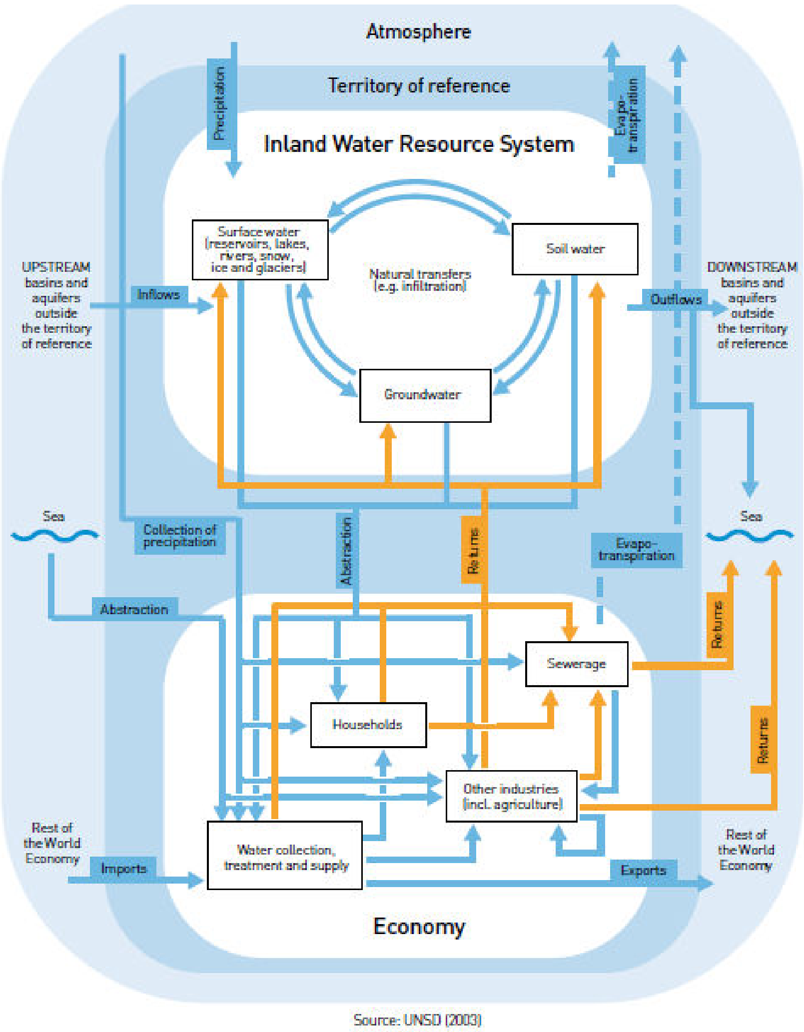


Figure 79 Main water flows within the inland water resource system and the economy (McGlade and Werner 2012)

The freshwater resources are constantly refilled due to precipitation. About 65 % of this is returned to the atmosphere through evapotranspiration, while the remaining recharges aquifers, lakes and streams, called run-off. Europe has in total a relatively large run-off, but the fact that it is unevenly distributed, both in space and in time, ranging from 300 mm per year in parts of Norway to less than 25 mm in parts of Spain, divides Europe in water abundant and water scarce areas. Also, in some regions, the local demand exceeds the local availability. For a sustainable usage, the rate of water use must not exceed the rate of water renewal (Kinner et al. 1999).

The pressure on freshwater resources in a country can be measured by the water exploitation index (WEI), which is the annual ratio of total freshwater withdrawal to the total renewable resources. A number over 20 % indicates that the resources are under water stress, and above 40 %, severe water stress (McGlade and Werner 2012). Table 19 presents the WEI of the EU-27 member states (Aquastat 2013). The data have been recalculated as an average of four different years between periods of 1998-2012. For some countries, data was inadequate; therefore, the results should be used with some caution. Table 19 also presents the dependency ratio, an indicator which expresses the percentage of total renewable water resources originating outside the country. A country with a dependency ration of 100 % means that the country receives all its renewable water from upstream countries, and is not producing any own.

Table 19 Pressure on water resources in EU-27 (Aquastat 2013)

Country	Freshwater withdrawal as % of total actual renewable water resources (WEI)	Dependency ratio %
Austria	4.8	29.21
Belgium	38.9	34.43
Bulgaria	29.9	1.41
Cyprus	23.1	*
Czech Republic	15.1	*
Denmark	12.4	*
Estonia	8.9	0.75
Finland	2.0	0.73
France	15.6	5.21
Germany	25.2	30.52
Greece	11.5	21.89
Hungary	5.5	94.23
Ireland	-	5.77
Italy	23.7	4.6
Latvia	1.0	52.78
Lithuania	7.3	37.51
Luxembourg	2.8	67.74
Malta	210.6*	*
Netherlands	10.7	87.91

Country	Freshwater withdrawal as % of total actual renewable water resources (WEI)	Dependency ratio %
Poland	21.4	12.99
Portugal	12.3	44.69
Romania	5.4	80.04
Slovakia	2.1	59.88
Slovenia	2.3	41.42
Spain	30.8	0.269
Sweden	1.6	7.724
United Kingdom	9.0	1.361

* *data uncertainty*

Globally, freshwater abstraction has tripled over the last 50 years and the global demand for water is estimated to be 40 % higher in 2030 than it is today. Hence, Europe will face great challenges in the future (McGlade and Werner 2012).

5.2 Scope

In this study, focus has been limited to water abstraction from its source (fresh and brackish water) to usage. Quantification of the largest water flows has been performed on an aggregated EU-27 level, which has been the main focus. Sources for different inefficiencies in these flows have been found in literature. Also, water savings potential have been calculated for those areas where it has been possible. In some areas it has been difficult to find figures for possible water savings, in those cases, only a qualitative assessment has been made.

In the study, only the physical water has been viewed upon, meaning that virtual water (water embodied in a product not in a real sense but in a virtual) has been excluded. Neither have contaminated water been measured or quantity assessed.

5.3 Water flows in EU-27

The total water abstraction in EU-27 is on average 247 020 million m^3 per year (Dworak et al. 2007). Usage of this water can be divided into four main sectors; energy, agriculture, public sector and industry. Figure 27 shows the European water flows on an aggregated level. Disaggregated water withdrawal would differ from country to country. For instance, in Sweden the largest volume is used in industry whereas in Greece, it is agriculture (Dworak et al. 2007).

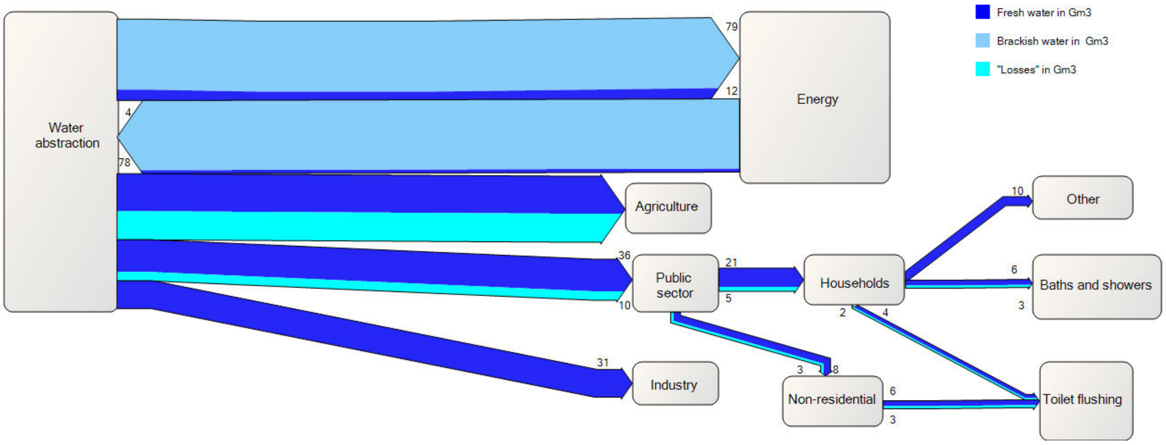


Figure 80 Sectorial use of water in Europe (EU-27), the flowchart does not illustrate all losses (Dworak et. al, 2007).

The energy sector appears to be the largest water user. Here water is mainly used for cooling purposes in thermoelectric power plant. However, most of the water is brackish, (light blue arrows in Figure 27), and almost all of this water is normally returned to the local environment (Dworak et al. 2007)

After energy, agriculture and the public sector are the largest consumers of freshwater in Europe. For the public sector, abstracted water first passes a treatment plant system before it is distributed to the consumers. It is then discharged to the wastewater treatment plant again from which it is returned to the recipient. In agriculture on the other hand, most of the water abstracted is consumed by evapotranspiration or bound in the plant, therefore 70 % of the abstracted water is not returned to a recipient (European Environment Agency 2012a).

5.3.1 Water use in the public sector

About 20% of the water abstracted in Europe is for the public sector, which includes households, hospitals, smaller businesses, industries, schools, hotels and offices, of which households is the largest water consumer (Mudgal et al. 2012). In Spain for instance, 70% of the urban water consumption is for households, whereas 24% is for small businesses and services and 6% for public services (Dworak et al. 2007).

Figure 28 presents the residential water usage per person per day in EU-27 member states (Ecotapware 2011). The amount varies of course based on living standard, age, environmental education etc. (Dworak et al. 2007) and some differences can probably be explained by statistical inconsistences The high consumption in Italy, according to Mudgal et al. 2012, can partly be explained by a low price elasticity of the water demand.

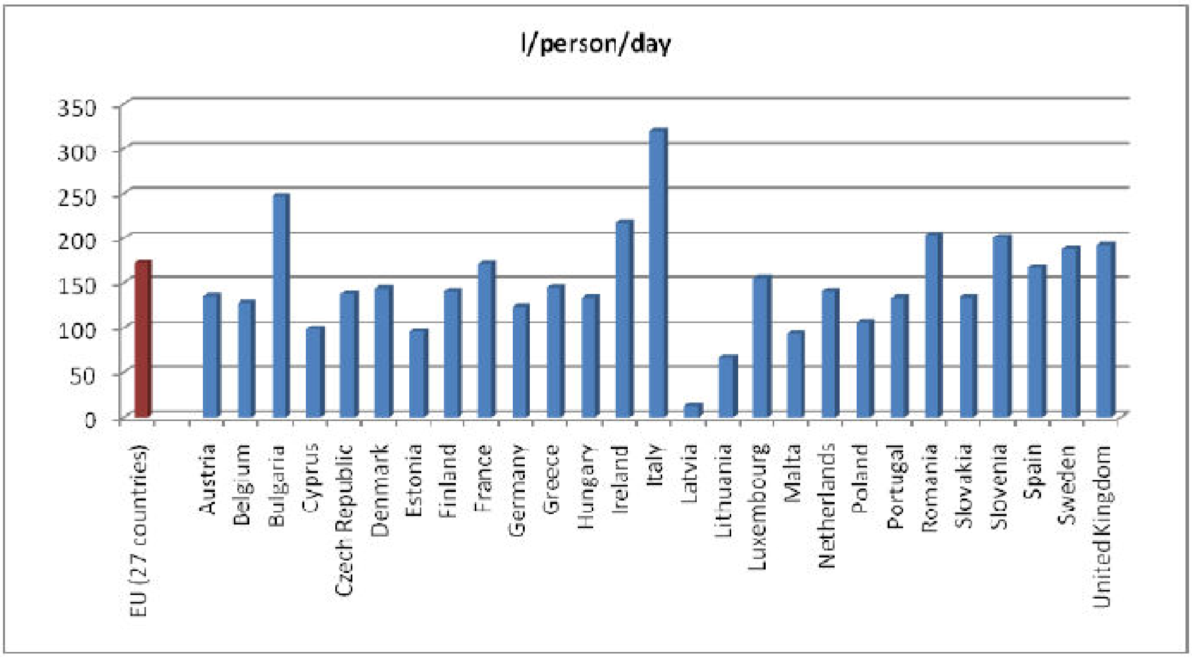


Figure 81 Residential water use in EU-27 (Ecotapware 2011)

5.3.2 Agriculture

One of the largest pressures on water resources in the EU is agriculture, were it accounts for approximately 33% of the total water use in EU (European Environment Agency 2012a). Within this sector, irrigation is the largest water consumer whereas livestock farming and aquaculture (e.g. fish-farming) are considered marginal (Dworak et al. 2007). The southern parts of Europe are the main consumers of water for agriculture purpose and basically all this water is for irrigation (European Environment Agency 2012a). 85 % of the total irrigated area in EU is situated mainly in Greece, France, Italy, Spain and Portugal, It is also among these countries the water stress is most significant, (Kinner et al. 1999).

Table 20 shows the water withdrawal for agriculture of the total water withdrawal for four southern countries and average for the northern and eastern countries.

Table 20 Water withdrawal for agriculture of the total water withdrawal for four southern countries and average for northern and eastern countries (Kinner et al. 1999)

Country	Water withdrawal for agriculture of the total water withdrawal
Greece	83 %
Spain	68 %
Italy	57 %
Portugal	52 %
Northern and eastern countries	<10 %

The need for irrigation is the difference between the total water requirement of the plants and the effective rainfall (Dworak et al. 2007). The amount of water used for irrigation depends on different factors, such as; crop type, climate, soil characteristics, cultivation practices and method of application (Kinner et al. 1999) (Agriculture and rural development 2012).

5.3.3 Water use in the energy and industry sector

The energy sector constitutes an average of 44% of the EU-27 total water abstraction; meanwhile the industry sector abstracts 15% (Dworak et al. 2007). In the energy sector the consumption of brackish water is large (84%), of which most is used for cooling purposes; however this water is often returned to its source with somewhat higher temperature than before (Pöyry 2012). The water use in the industry sector differs tremendously, e.g. the paper industry usage 138 m^3 / (1000 € gross value added) water meanwhile the textile industry has a water abstraction of 1 m^3/ (1000 € gross value added)(Flörke and Alcamo 2004).

Finland, France, Germany, Sweden, Spain and Italy are the largest consumer of water for industrial purposes. Finland and Sweden use 71 % respective 42 % of their total industrial consumption in the pulp and paper industry. The water consumption in the chemical sector is largest in Germany and Italy, where it constitutes 38 % respectively 36 % of the domestic industrial water consumption.

During the last 30 years the water abstraction has decreased in long- industrialized countries due to closure in high water use industries and introduction of cleaning technology. In central and eastern Europe the water abstraction has decreased with 70%. However in some industries the water abstraction has increased because of a higher demand of better quality of product which might have caused a higher water abstraction. This has been shown in the textile, paper and chemical industries, in Denmark, Ireland and the UK.

5.4 Inefficiency

5.4.1 Identification

Public sector

In the public sector there are two main areas where inefficiencies have been found and those are leakage in the public supply system and unnecessarily water use in buildings. Pöyry 2012 calculated the leakages in EU-27 countries in the public water supply system based on data from Eurostat. Data gaps were estimated with neighboring or similar countries. Dworak et. al 2007 also estimated leakages based on data from year 2003. Table 21 compares the results from those two sources. As can be seen, the leakage in the public supply system varies between 2 % in France to 61 % in Bulgaria (Pöyry 2012). Based on Table 21 and distribution of population the average for EU-27 was calculated to 21 %. The large variation between the member states is due to the difference in technical performance of the supply system network and the difference between the sources can perhaps be explained by data errors or in some cases measures for leakage reduction might have been taken. However, it is clear that leakages in the network system are of great importance for an efficient water supply.

Table 21 Leakages in the supply system for EU-27 according to (Pöyry 2012, 14–15) compared to data from (Dworak et al. 2007, 60)

Country	Leakages in the public sector system (Pöyry)	Comment/year	Leakages (Dworak)	Comment/year
Austria	11 %	Estimation with Germany	32 %	Estimation with Czech Republic
Belgium	4 %	2009	3 %	Germany
Bulgaria	61 %	2009	50 %	2003
Cyprus	26 %	Estimation with Greece	30 %	Estimation with Italy
Czech Republic	23 %	2008	32 %	2003
Denmark	9 %	2009	10 %	2003
Estonia	25 %	2009	27 %	Estimation with Slovakia
Finland	17 %	Estimation with Sweden	15 %	2003
France	2 %	2001	30 %	2003
Germany	11 %	2007	3 %	2003
Greece	26 %	2007	30 %	Estimation with Italy
Hungary	24 %	2009	35 %	2003
Ireland	34 %	2007	34 %	2003
Italy	39 %	2008	30 %	2003
Latvia	22 %	Estimation with Lithuania	27 %	Estimation with Slovakia
Lituania	22 %	2009	27 %	Estimation with Slovakia
Luxemburg	4 %	-	3 %	Estimation with Germany
Malta	3 %	2009	30 %	Estimation with Italy
Netherlands	9 %	-	3 %	Estimation with Germany

Poland	25 %	-	32 %	Estimation with Czech Republic
Portugal	26 %	2008	22 %	Estimation with Spain
Romania	37 %	2009	31 %	2003
Slovakia	23 %	2007	27 %	2003
Slovenia	28 %	2009	40 %	2003
Spain	36 %	2008	22 %	2003
Sweden	17 %	2007	17 %	2003
United Kingdom	18 %	2007	22 %	2003

Figure 82 shows the average residential water distribution in EU-27 In non-residential buildings, i.e. sectors such as food and drink, retail, education, health work, public administration etc. 70-95 % of the water use is for toilets (Mudgal et al. 2012). It is clear that showerheads and taps together with toilet flushing and household machines accounts for the largest water consumption in the buildings. It is important to mention that the efficiency of households technology differs between the member states, for example, a shower in Finland may use 3.75 times more water per shower than one in France (Ecotapware 2011). By installation of water-saving technologies, the water consumption for toilets, showers and bath can be reduced, for instance, by installation of taps which are regulated by sensors, water savings up to 70 % can be achieved (European Environment Agency 2012a).

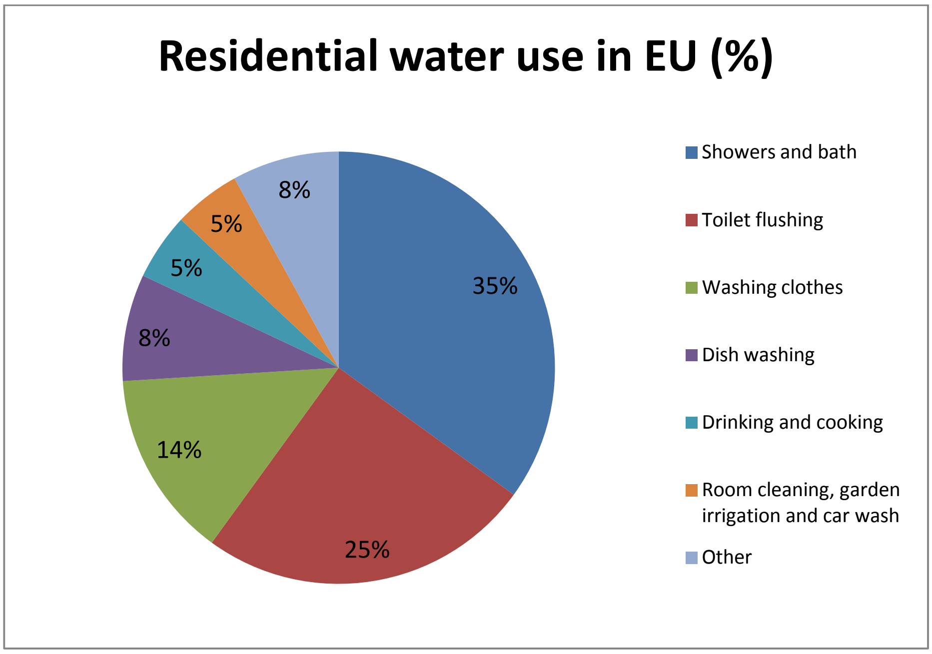


Figure 82 The water use in residential in EU-27 (Mudgal et al. 2012)

The major inefficiencies in the public sector are leakage in the supply system as well as excessive water consumption for toilets, showers and baths.

Agriculture

Since irrigation is the largest water consumer within agriculture, this has been the focus of the study. There are mainly three types of irrigation technologies utilized for irrigation:

- Drip irrigation – water is applied directly to the base of the plant by being slowly dripped onto the soil surface or directly on the root zone.
- Sprinkler – water is sprayed onto the vegetation.
- Open channel/furrow/gravity – water is distributed over the soil surface by gravity.

The water efficiency of an irrigation system mainly depends on two things, the conveyance efficiency and the field application efficiency. The conveyance efficiency is the percentage of water taken from the source, which actually reaches the irrigated field. The field application efficiency is the ratio between the water used by the crop and the total amount of water delivered to the fields (Dworak et al. 2007). Table 22 reports the conveyance and field application efficiencies for the different irrigation technologies.

Table 22 Irrigation technologies and source of water for the largest irrigation countries in EU (Baldock et al. 2000)

Country	Irrigation technology	Source of water
Spain	60 % gravity, 24 % sprinklers, 17 % drip	68 % % is surface water, 28 % from aquifers
Portugal	Gravity	On-farm surface water
Greece	Sprinklers	85 % surface water, groundwater
Italy	51 % gravity, 33 % sprinklers, 10 % drip, 4 % flooding	66 % from rivers, 28 % from wells and springs 6 % from reservoirs
France	85 % sprinklers, 10 % gravity, 5 % drip	-

Based on Table 22 and on data of the total irrigated area for each country in southern EU, the total distribution of the irrigation systems for France, Spain, Greece, Italy and Portugal have been calculated.

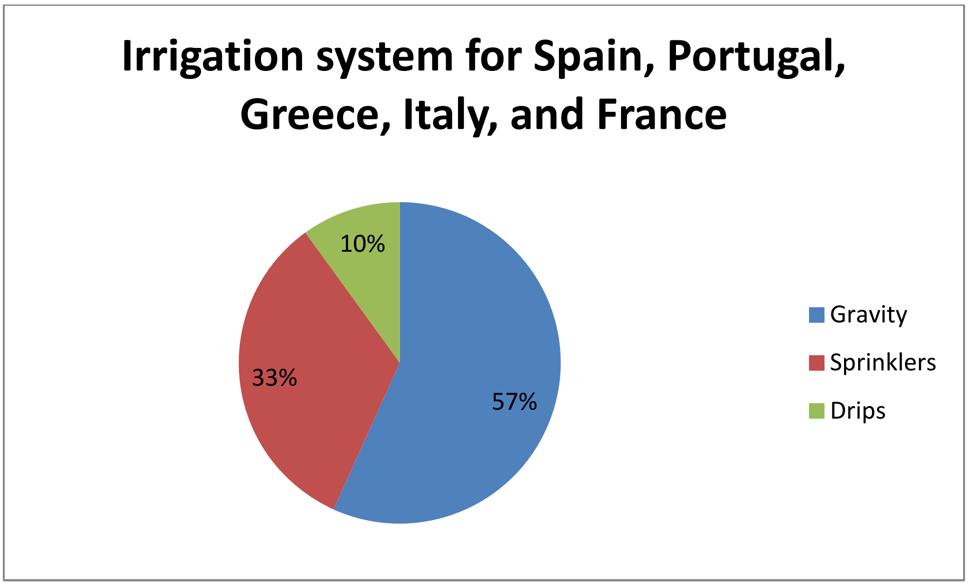


Figure 83 The distribution of the irrigation system for Spain, Portugal, Greece, Italy and France. Calculations have been weighted on irrigation areas for each country.

According to Table 2 drip irrigation appears to be the most efficient technology. Baldock et. al. 2000 states that drip irrigation is also the best method for avoiding soil erosion. Unfortunately, drip irrigation is least utilized in France, Spain, Italy, Greece and Portugal. Both the occurrence and risk of soil erosion due to irrigation are most significant in these countries (Baldock et al. 2000). Based on Figure 83 and Table 23, an average efficiency was calculated to 51 % for the countries mentioned above.

Table 23 Water efficiency of the different irrigation methods (Dworak et al. 2007, 45)

Distribution and irrigation system	Water conveyance efficiency	Field application efficiency	Global gross efficiency
Open channel main network + furrow etc.	70%	55%	39%
Pressurized + Sprinkler	90%	75%	68%
Pressurized + Drip	90%	90%	81%

According to European Environment Agency 2012a, the three main measures for water reduction in agriculture can be made by improving the irrigation technology, change to more drought resistant crops and reuse wastewater.

Energy

Depending on the type of cooling system, the water usage differs somewhat. For instance, a once through system uses more water, although, most of the water is returned to its source. Meanwhile, in a wet cooling tower, a large amount of the water withdrawal is lost in evaporation (Pöyry 2012).

Table 24 shows water withdrawal and water consumption for different cooling systems, clearly, pond cooling and cooling towers have high percentage water consumption. The distribution is the same for other fuels like nuclear and natural gas (Dworak et al. 2007).

Table 24 Water withdrawal and water consumption for different cooling systems (Dworak et al. 2007)

Plant and cooling system type	Water withdrawal [l/MWh]	Typical water consumption [l/MWh]	Water consumption as % of withdrawal
Fossil/biomass/waste -fueled steam, once-through	75800- 189500	1137	1 %
Fossil/biomass/waste -fueled steam, pond cooling	1137-2274	1137-1819	87 %
Fossil/biomass/waste -fuels steam, cooling towers	1895-2274	1819	87 %

There are large differences between water withdrawals between different cooling systems. The type of system used is largely dependent on the location of the power plant. It is difficult to find obvious measures for the energy sector; however, some examples given in literature are; utilizing water with low quality, reuse and recycling of cooling water and change to other coolants

Industry

Due to lack of data it is difficult to find the largest inefficiencies, however, some general measures have been found; for instance, close-loop recycling, reuse of wastewater, and counter current rinsing.

5.4.2 Drivers

Public sector

Reasons for the large leakages in the public supply system are that the piping systems are often old and that the system is poorly supervised. Improvements of the systems are perhaps not performed due to high costs.

Regarding buildings, older buildings often consumes more water. Since these are often equipped with older, more water consuming devices, such as taps, toilets and showers. Exchanging older toilets for newer ones are associated with high costs due to replacement of the existing piping system.

Agriculture

In agriculture, the awareness of effective water usage is perhaps poor in some regions in EU. For instance, Spain is the most arid country in the European Union and it also allocates much of its water resources to irrigation. Aldaya et. al. 2008 states that the water shortage in Spain is e.g due to bad management within the agricultural sector. (Martinez Aldaya et al. 2008) Another important aspect is that small farmers often don't have the economic resources for shifting to a more efficient irrigation system (Baldock et al. 2000).

5.4.3 Best practice

Public sector

To reduce leakages in the public supply system, Dworak et. al. 2007 suggests four main management strategies;

- <u>Pipeline and Assets Management</u>: due to high costs, old pipes are not being replaced at a sufficient rate. Preventative network maintenance and renewal of pipes have high impact of the leakages, and should therefore be considered.
- <u>Pressure management</u>: controlling the pressures in the network, have had an effective outcome of the management of leakages.
- <u>Speed and quality of repairs</u>: the awareness time, the location and the repair time for a leak, is essential in water loss management.
- <u>Active leakage control to locate unreported leaks</u>: Flow data can for instance provide in which areas night flows are high, these areas can then be taken into annually routine surveys. In Zurich, leakage control of about half of the total distribution network is performed every year. This decreased losses by 10 to 5 % between the years 1997 and 2007.

Different measures for water reduction in buildings can be made. By shifting the household devices to more water-saving technologies, the water abstraction can be reduced; these are summarized in Table 25. It should be mentioned that a reduction in water use will also lower the energy consumption e.g. less energy is required for heating, pumping of water and filtration. Also, fewer chemicals are needed to clean the wastewater.

Table 25 Reduction potential in the public sector.

Measures	Reduction potential [%]	Source
Use the shower instead of a bath	33	(Ecotapware 2011)
Use sensor taps	70	(European Environment Agency 2012a)
Use low flush and dual flush	30.5	(Mudgal et al. 2012)
Water-saving washing machine	79	(Krozer et al. 2011)

**This number has been calculated based on data from* Mudgal et al. 2012.

Some other technical measures for reducing freshwater abstraction in the public sector are reuse of wastewater and rainwater harvesting. Wastewater from baths, showers, washing machines, kitchen use etc. can for instance be used directly for toilet flushing or for non-edible plant irrigation. For instance, wastewater is reused for irrigation on golf courses, parks etc. in Cyprus, France, Greece, Malta, Italy, Portugal and Spain (European Environment Agency 2012a) (Dworak et al. 2007).

Rainwater harvesting is when rainwater is collected in storage tanks, from which it can be used for irrigation of gardens, in washing machines and toilet flushing Although, this would require alternation of existing plumbing systems, depending on the scale and complexity of such, exchanging the installation can for instance increase greenhouse gases emissions. Also, in some countries the legislation is strict about usage of harvested rainwater, e.g. in Germany, meanwhile it is more extensively utilized along the Mediterranean coast due to water scarcity (European Environment Agency 2012a).

Agriculture

Since irrigation is the major water abstractor in agriculture, this has been the main focus. According to European Environment Agency 2012a, some particularly interesting examples on how to make water use more efficient within irrigation are shown in Table 26.

Table 26 Reduction potential in the agriculture sector in EU-27 (Dworak et al. 2007)

Measure	Reduction potential
Shift to water efficient irrigation technology, such as drip irrigation	60 %
Change to more drought resistant crops	50 %
Wastewater reuse	10 %
Total	43 %

Clearly, water savings can be done by improving the efficiency of the irrigation system. For instance, a prospective study reported in Dworak et. al. 2007 showed that by improving the irrigation system in countries near the Mediterranean, a 65 % saving potential can be achieved. Also, drip irrigation may save up to 60 % water compared to traditional surface irrigation in southern Europe (Dworak et al. 2007) . According to European Environment Agency 2012a, by improving the conveyance efficiency alone in Europe, by for instance converting open channels to pressurized pipe networks, estimated water savings are 25 % of water abstracted.

In Crete in Greece, water for irrigation was decreased by 9-20 % by simply matching the timing of irrigation with the water requirement of the crop. Although, this requires that the farmers are well informed on the soil moisture and the changes in crop water demand. In Crete, the farmers where informed by phone by the irrigation advisory service, on when and how they should apply water. The advice were based on estimates of daily crop evaporation, soil type, growth stage and rainfall (European Environment Agency 2012a).

There are also other ways to reduce the water required for irrigation, by for instance carefully selecting less water demanding crops. The crop water demand depends partly on season and on the depth of the root system. Crops with deep root systems can better resist periods of water stress then those with shorter roots, since they are able to draw moister from further down in the soil. Early sowing is a way to utilize the winter rains and helps to avoid the most intense evapotranspiration which becomes significant during summertime in the Mediterranean areas (European Environment Agency 2012a).

Reuse of wastewater can have significant impact of abstracted freshwater, especially in areas where water is scarce. One example is in Gran Canarias, where 20 % of the water used in all sectors, comes from treated waste water. Cyprus have set a target that 28 % of 2008 water demand for agriculture should be represented by reused water by 2014. By doing this, it also makes the natural freshwater source available for drinking water demand instead. However, it is important to consider the chemical and bacterial load of reused wastewater. According to European Environment Agency 2012a, although regulations in some EU member states is taking this into account, a more uniform direction on regulations and implementations of water recycling in agriculture would perhaps lead to a more extensive implementation. In a study of the Aegean islands compared desalination of seawater, importing water and recovering of wastewater. It showed that reuse of wastewater has the lowest cost and requires the least energy of the three mentioned (European Environment Agency 2012a).

Energy

Some measures to reduce the water usage in the energy sector have been found. For instance, Dworak et. al 2007, suggests technical measures for water reduction in thermoelectric power plants:

- Use water with lower quality, meaning, water too contaminated for drinking.
- Reuse and recycling of the cooling water
- Dry cooling systems in which no water is required

Industry

The saving potential in the industry sector can be between 15 to 90 % and Table 27 shows the average water-saving potential for different measures. Different industries can obtain different saving-potential, depending on the process and earlier implemented measures (Dworak et al. 2007).

Table 27 Saving potential for different measures in the industry sector (Dworak et al. 2007)

Efficiency measures	Percentage of water saved [%]
Closed loop recycling	90
Closed loop recycling with treatment	60
Automatic shut-off	15
Counter current rinsing	40
Spray/jet upgrades	20
Reuse of waste water	50
Scrapers	30

Efficiency measures	Percentage of water saved [%]
Cleaning in place (CiP)	60
Pressure Reducing	Variable
Cooling tower heat load reduction	Variable

In a study from Catalonia, in Spain, the chemical sector has the highest water-saving potential at 50 % while the pulp industry has the lowest potential at 25 %. Probably, some of the measures are already implemented because the study is from 1999 which probably implies that the potential is lower today (Dworak et al. 2007).

5.4.4 Policy impact

Policies can become an important tool for a reduction of EUs water abstraction; however it is difficult to predict their effect.

Public sector

During summertime, the water demand in the public sector increases, meanwhile the availability of surface and groundwater becomes less. This put extra pressures on the southern countries of Europe, due to the combination of low rainfall and high tourism. The Mediterranean countries as well as South East of England are mostly affected. Possible policies for water reduction can therefore be set to target certain regions and at a specific time of the year (Mudgal et al. 2012).

According to Mudgal et al. 2012, although consumer behavior is an important factor for water savings in buildings, it is difficult to predict how potential policies might affect behavior. However, product-level policies are perhaps easier for the consumers to understand, such policies could therefore be appropriate in the short term. Meanwhile, policies made on building-level might have a larger effect on water reduction, but are perhaps more suitable in the long-term, since they are more costly, especially for existing buildings. However, such costs can be much easily incorporated in the initial project phase for new buildings. Mudgal et al. 2012 still estimates that policies on macro, building and product level have the potential of 30 % water savings by 2050 (Mudgal et al. 2012).

Agriculture

For an efficient water supply, measures can be taken in several dimensions, for example, improving the efficiency of the irrigation technology. Also, development of the existing infrastructure such as improved drainage, leveling of fields, and concrete lining of canals. However, actions can also be taken at a non-technological level by for instance improving organization and management, improve knowledge about water losses, establish information systems, adjustment of water allocation and promote users initiatives for improvements and tariff systems. Also, it is important to develop the coordination between public water management authorities, irrigation farmers association and the final users (Kinner et al. 1999). Another measure is to allow for controls for where irrigation can be practiced, performed by for instance regional and national governments or more local organisations (Baldock et al. 2000).

Baldock et.al 2000 states some measures which can be taken for more efficient water use: changing to drip irrigation would both decrease water abstraction and soil erosion; however, the net water quantity will be the same if this only leads to an increase of the irrigated area. For instance, in some parts of Spain, an improvement in efficiency led to that the area of irrigation was tripled (European Environment Agency 2012b) Also, it might encourage new plantation of more water demanding crops than before (Dworak et al. 2007). Therefore, other potential policies for water quantity reduction are suggested; such as economic and regulatory policies for instance water metering and charging and time-limited abstraction permits (Baldock et al. 2000). European Environment Agency 2012a, reports that in some cases farmers which have drip irrigation, still does not make usage of its potential efficiency. It might therefore also become important to support farmers with advice when an upgrade of the irrigation technology is being made.

In areas where water is scarce, illegal water abstraction becomes an important factor, especially during periods of drought. Although there is little information on the quantities, it is known that most of the illegal water is used for irrigation purposes. The water can for instance be taken from an unlicensed well, or extraction larger volumes than what is allowed for from a licensed well (European Environment Agency 2012a).

According to the European Environment Agency (2012a), one possible way to decrease the pressure on freshwater is desalination plants, where the salt in seawater is removed. Spain is the largest utilizer of this in Europe. However, there are negative impacts of the desalination method as well, such as the large amount of energy required, high carbon emissions and the waste and chemicals generated in the process, which might damage organisms in the sea. The European Environment Agency therefore stresses that other water savings measures should be implemented in first place.

The problem with irrigation is not easily solved since it becomes important to consider the socio-economic perspective of regulations and policies. Most of the irrigation in southern Europe is performed by small farms, and for them the availability of irrigation is crucial for their survival and there is also a risk that policies such as water metering and charging might strike them hard (Baldock et al. 2000).

Industry and energy sector

Since most of the water abstracted in the energy sector is brackish and the water abstracted for industry is relatively small, the focus for policies should perhaps be focused on the other sectors.

5.5 Conclusion

Europe's freshwater water abstraction can be divided into four main groups, energy, agriculture, public sector and industry. An average of 247 020 million m^3 per year (surface and groundwater) is abstracted in EU-27. Which sector is the most water demanding one varies between member states. However, on the aggregated level, it is clear that the largest freshwater quantities are abstracted for agricultural and public sector purposes and also in those sectors there is a large water saving potential. In the public sector the water saving potential can be up to 50 % respective 43 % in the agriculture sector. The most important conclusions are summarized below:

- A European average shows that in the public sector, households are the largest water consumers. Here, water is mainly used for baths, showers, taps and toilet flushing. In non-residential buildings toilet flushing is the largest consumer.
- A large part of the abstracted water seems to be lost in the network through leakages. The amount differs largely between the member states (from 3 % in Malta to 61 % in Bulgaria). On a European level, 21.5 % of the water is lost through leakages.
- By replacing highly water consuming toilets for low/dual flush in EU, the potential water reduction was calculated to be 30.5 %.
- Up to 50 % water savings have been estimated for the public sector by reducing leakages, installing water saving devices and water saving household machines.
- Greece, France, Italy, Spain and Portugal, which together account for 85% of the total irrigated area in the EU, are still using inefficient irrigation technologies, such as gravity.
- There is clearly an over-abstraction of freshwater for irrigation, due to inefficient usage. Improvement in conveyance efficiency for the irrigation method alone is estimated to save water up to 25 % in Europe.
- Estimates show that savings up to 43 % in total can be made in agricultural sector by taking measures such as making the irrigation technology more efficient, shift to drought resistant crops, reuse wastewater and change agricultural practices.
- Due to lack of data for water usage in the industry sector, it is difficult to quantify water flows and find inefficiencies. However, some general technical measures can be found such as shift to close-loop recycling and reuse of wastewater.

Water efficiency within the public, energy and industry sector is likely to be achieved through improved urban planning, ecological design, innovations and process design. A reduction in the water use also decreases the energy consumption for wastewater treatment and achieves more efficient chemical use, hence, lowering other environmental burdens. In the industry and energy sectors it is probably more difficult, costly and time consuming to exchange existing technology than for instance in the public sector such as installation of water reducing taps and toilets. Also, depending on the purpose of water usage, it is important to consider the water quality, using fresh drinking water for toilet flushing can been seen as an inefficient approach to make use of finite resources.

Due to data uncertainties it is also important to develop better measurement for quantification of water usage in the future, hence, inefficiencies may become easier to determine and therefore regulate.

It would probably be more sufficient to focus policies to water scare areas. Also, perhaps they should be set differently depending on the region. Possible measures regarding the southern parts of Europe should be implemented firstly. Since agriculture and public sector are the main freshwater consumers and also have high water saving potential, policies regarding these areas, should therefore be the main focus.

References

Agriculture and rural development. 2012. *Agriculture and Water. Agriculture and rural development*. http://ec.europa.eu/agriculture/envir/water/index_en.htm.

Aircraft Fleet Recycling Association. 2013. http://www.afraassociation.org/.

Allwood, J.M and Cullen, J.M. 2012. *Sustainable Materials: with both eyes open*. UIT Cambridge Ltd, Cambridge.

APEAL (the Association of European Producers of Steel for Packaging). 2013. http://www.apeal.org/en/apeal/who-we-are

Aquastat. 2013. *Aquastat*. FAO. www.fao.org/nr/aquastat/.

Ayres RU, Ayres LW, editors. 2002. *A handbook of industrial ecology* [Internet]. Edward Elgar Publishing ltd; Available from: http://ilona.uni-mb.si/samec/Handbook_Industrial_Ecology_2002.pdf#page=100

Baldock, David, Helen Caraveli, Janet Dwyer, Silke Einschutz, Jan Erik Petersen, Jose Sumpsi-Vinas, and Consuelo Varrla-Ortega. 2000. *The Environmetal Impacts of Irrigation in the European Union*. Instiute for European Environmental Policy.

Berg M van den. 2011. *EU Resource Efficiency Perspectives in a Global Context*. The Hague: PBL Netherlands Environmental Assessment Agency.

Bigum M, Borgaard L, Christensen T H. 2012. *Metal recovery from high-grade WEEE: A life cycle assessment*. Journal of Hazardous Materials 207–208 (2012) 8–14.

Bio Intelligence Service. 2011. *Service contract on management of construction and demolition waste-SR1*. Final report, Task 2.

Bogaert et al., 2008. *Study on RoHS and WEEE Directives*. N° 30-CE-0095296/00-09 Final report European Commission DG Enterprise and industry

Bringezu S, Moriguchi Y. 2002. *Material flow analysis* [Internet]. In: *A handbook of industrial ecology*. Edward Elgar Publishing ltd; Available from: http://ilona.uni-mb.si/samec/Handbook_Industrial_Ecology_2002.pdf#page=100

British Environmental Agency. 2011. *Study into the Feasibility of Protecting and Recovering Critical Raw Materials Through Infrastructure Development in the South East of England*. European Pathway to Zero Waste Protecting and Recovering Critical Raw Materials. http://www.environment-agency.gov.uk/static/documents/Business/EPOW-recovering-critical-raw-materials-Annex-T5v2.pdf.

British Geological Survey. 2012. *European Mineral Statistics 2006-10.* ISBN 978-0-85272-699-0. http://www.bgs.ac.uk/mineralsuk/statistics/europeanStatistics.html.

Brown LR. Full Planet, Empty Plates. 2012. *The new geopolitics of Food Scarcity*. New York: W.W. Norton & Company.

Brunner PH, Rechberger H. 2003. *Practical handbook of Material Flow Analysis*. Lewis Publishers.

CEWEP (Confederation of European Waste-to-Energy Plants). 2009. *Environmentally sound use of bottom ash.*

Chen W-Q, Graedel T E. 2012. *Anthropogenic Cycles of the Elements: A Critical Review.* Environmental Science and Technology. 2012, 46, 8574–8586.

Cordell D, Drangert J., White S. 2009. *The story of phosphorus: Global food security and food for thought*. Global Environmental Change 2009;19:292–305.

Cordell D. 2010. *The story of phosphorus*.

Darton Commodities Ltd. 2010. *Cobalt Market Review 2010-2011*. http://www.dartoncommodities.co.uk/pdf/Cobalt_Market_Review_2010-2011.pdf.

Dahlström K, Ekins P, He J, Davis J, Clif R. 2004. *Iron, steel and aluminum in the UK: Material flows and their economic dimensions*. Final Project Report. CES Working Paper 03/04.

Davis J., Geyer R., Ley J., He J., Clift R., Kwan A., Sansom M., Jackson T. 2007a. *Time-dependent material flow analysis of iron and steel in the UK Part 1. Production and consumption trends 1970-2000.* Resources, Conservation and Recycling 51 (2010) 118-140.

Davis J., Geyer R., Ley J., He J., Clift R., Kwan A., Sansom M., Jackson T. 2007b. *Time-dependent material flow analysis of iron and steel in the UK Part 2. Scrap generation and recycling.* Resources, Conservation and Recycling 51 (2010) 118-140.

Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy. [date unknown].

Dove, Justin. 2011. *Cobalt: A Critical Metal to Clean Energy*. http://www.investmentu.com/2011/September/cobalt-critical-metal-clean-energy.html.

Dworak, Thomas, Maria Berglund, Cornelius Laaser, Pierre Strosser, Josselin Roussard, Benoit Grandmougin, Maggie Kossida, et al. 2007. *EU Water Saving Potential (Part 1-Report)*. Ecologic-Institute for Inernational and European Environmental Policy.

Ecotapware. 2011. *Task 2: Economic and Market Analysis Task 3: User Behaviour*.

Eurofer. 2011. *European Steel in Figures 2007-2011.*

European Commission. 2010. *Critical Raw Materials for the EU Report of the Ad-hoc Working Group on Defining Critical Raw Materials*. http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/report-b_en.pdf.

(JRC and IPTS) European Commission Joint Research Centre and Institute for Prospective Technological Studies. 2010. *End-of-waste Criteria for Iron and Steel Scrap: Technical Proposals.*

European Environment Agency. 2012a. *Towards Efficient Use of Water Resources in Europe.*

European Environment Agency 2012b. *Europe's Water: Efficient Use Is a Must.* http://www.eea.europa.eu/articles/europe2019s-water-efficient-use-is.

(EIPPCB and IPTS) European Integrated Pollution Prevention and Control Bureau (EIPPCB) at the European Joint Research Centre – Institute for Prospective Technological Studies (IPTS). 2010. *Best Available Techniques (BAT) Reference Document for Iron and Steel Production Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control*.

(ETC/SCP) European Topic Centre on Sustainable Consumption and Production. 2009. *EU as a Recycling Society Present recycling levels of Municipal Waste and Construction & Demolition Waste in the EU*. ETC/SCP working paper 2/2009.

Euroslag. 2010. *Statistics 2010.*http://www.euroslag.com/researchlibrarydownloads/downloads/

Eurostat. 2012. *Economy-wide Material Flow Accounts (EW-MFA) Compilation Guide 2012.* http://epp.eurostat.ec.europa.eu/portal/page/portal/environmental_accounts/documents/Economy-wide%20material%20flow%20accounts%20compilation%20guide%20%20-.pdf.

Fertilizers Europe. 2012. *Partnership for growth - Sustainable agriculture in Europe*.

Flörke, Martina, and Joseph Alcamo. 2004. *European Outlook on Water Use.* Centrer for Environmental Systems Research University of Kassel.

Gyllenram R, Ekerot S, Jönsson P. 2008. *Lubricating the recycling machine 2*. LUBRICATING Royal Institute of Technology, KTH, Stockholm, Sweden.

Huisman J et al. 2008. *Review of Directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE)*. Final report.

Jasinski SM. 2006. *Phosphate Rock, Mineral Commodity Summaries* [Internet]. US Geological Survey; Available from: http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/phospmcs06.pdf

Jasinski SM. 2008. *Phosphate Rock, Mineral Commodity Summaries* [Internet]. US Geological Survey; Available from: http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mcs-2008-phosp.pdf

Jasinski SM. 2010. *Phosphate Rock, Mineral Commodity Summaries* [Internet]. US Geological Survey; Available from: http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mcs-2010-phosp.pdf

Jasinski SM. 2012. *Phosphate Rock, Mineral Commodity Summaries* [Internet]. US Geological Survey; Available from: http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mcs-2012-phosp.pdf

Jovanovich, Milan T, Borislav Lukic, Zoran Miskovic, Ilija Bobic, Ivana Cvijovic, and Biljana Dimcic. 2007. *Processing and Some Applications of Nickel, Cobalt and Titanium-based Alloys.* Metallurgical & Materials Engineering 13 No 2. http://www.metalurgija.org.rs/mjom/vol13/No%202/1MJOVANOVIC.pdf.

Kingsley- Jones, Max. 2010. *Airliner Census 2010 – Fleet Growth Marginal and Idle Jets at Record High.* Flightglobal. http://www.flightglobal.com/news/articles/airliner-census-2010-fleet-growth-marginal-and-idle-jets-at-record-high-346301/.

Kinner, W, C. Lallana, T. Estrela, S. Nixon, T. Zabel, L. Laffo, G. Rees, and G Cole. 1999. *Sustainable Water Use in Europe Part 1: Sectoral Use of Water*. European Environment Agency.

Krozer, Anatol, Anders Björk, Anne-Charlotte Hanning, Anne Wendel, Ebba Magusson, Fredrik Persson, Krister Holmberg, and Kristian Jelse. 2011. *S´wash Clean Development and Demonstration-Sustainable Domestic washing-S´wash.* IVL.

LKAB 2013. *Personal communication*. 2013-02-26.

Madariaga BM, Ramos MJ, Tarazona JV. 2007. *Model implementation and quantification of the eutrophication risk associated to the use of phosphates in detergents* [Internet]. 2007. Available from: http://ec.europa.eu/enterprise/sectors/chemicals/files/studies/ceep_final_study_april_2007_en.pdf

Martinez Aldaya, Maite, A Garrido, M.R Llamas, C Varela-Ortega, P Novo, and R Rodríguez. 2008. *The Water Footprint of Spain.*

McGlade, Jacqualine, and Beate Werner. 2012. *Measuring Water Use in Green Economy*. UNEP.

Metson GS, Bennett EM, Elser JJ. 2012. *The role of diet in phosphorus demand.* Environmental research letters 2012;7

Moakley J, Weller M, Zelic M. 2010. *An Evaluation of Shredder Waste Treatments in Denmark*. Interactive Qualifying Project completed in partial fulfillment of the Bachelor of Science Degree at Worcester Polytechnic Institute, Worcester, MA

Mudgal, Shailendra, Sandra Berman, Eric Hoa, Sarah Lockwood, Eric Labouze, Christine Pout, Roger Hitchin, and Ralph Philip. 2012. *Water Performance of Buildings*. European Commission.

Nakamura et al., 2013. *Quality- and Dilution Losses in the Recycling of Ferrous Materials from End-of-Life Passenger Cars: Input-Output Analysis under Explicit Consideration of Scrap Quality.* Environ. Sci. Technol. 2012, 46, 9266–9273.

Passarini F, Ciacci L, Santini A, Vassura I, Morselli L. 2012. *Auto shredder residue LCA: implications of ASR composition evolution*. Journal of Cleaner Production 23 (2012) 28-36.

Pollock, Tresa M, and Sammy Tin. 2006. *Nickel-Based Superalloys for Advanced Turbine Engines: Chemistry, Microstructure and Properties.* Journal of Propulsion and Power Vol. 22 (No. 2): 361–374. doi:10.2514/1.18239.

Pöyry. 2012. *Preparatory Action-Development of Prevention Activites to Halt Desertification in Europe-Service Contract to Contribute to the Building of Water and Ecosystem Accounts at EU Level*. European Commission-Directorate General Environment.

Reck B.K, Graedel T.E. 2012. *Challenges in metal recycling.* Science Vol 337.

Richards IR, Dawson CJ. 2008. *Phosphorus imports, exports, fluxes and sinks in Europe.* York: International Fertiliser Society.

Rockström J, Steffen W, Noone K, Persson Å, Chapin S, Lambin E, et al. 2009. *Planetary Boundaries: Exploring the Safe Operating Space for Humanity*. Ecology and Society 2009;14(2)

Rolls Royce. 2012. *Trent 900.* http://www.rolls-royce.com/Images/Trent%20900_tcm92-11346.pdf.

Schröder J., Cordell D, Smit A., Rosemarin A. 2010.*Sustainable use of phosphorus*. Plant research international, part of Wageningen UR 2010.

Shu L, Schneider P, Jegatheesan V, Johnson J. 2006. *An economic evaluation of phosphorus recovery as struvite from digester supernatant*. Bioresource Technology 2006 Nov;97(17):2211–2216. [cited 2013 Apr 3]

Simic V and Dimitrijevic B. 2012. *Production planning for vehicle recycling factories in the EU legislative and global business environments. Resources, Conservation and Recycling 60 (2012) 78–88.*

Söderholm P and Ejdemo T. 2008. *Steel scrap markets in Europe and the USA.* Minerals and Energy 2008, 2:57-73.

Testfakta. 2008. *Maskindiskmede*l.

The Cobalt Development Institute. 2006. *Cobalt Facts*. http://www.thecdi.com/cdi/images/documents/facts/COBALT_FACTS-Metallurgical_%20uses.pdf.

Toscano, P, and T.A. Utigard. 2003. *Nickel, Copper and Cobalt Slag Losses During Converting.* Metallurgical and Materials Transactions B 34B (February): 121–125.

U.S. Geological Survey. 2012. *2010 Mineral Yearbook, Cobalt (advance Release)*. http://minerals.usgs.gov/minerals/pubs/commodity/cobalt/myb1-2010-cobal.pdf.

Umicore. 2013. *Battery Recycling Process.* http://www.batteryrecycling.umicore.com/UBR/process/.

Van der Voet, Ester. 2002. *Substance Flow Analysis Methodology.* In *A Handbook of Industrial Ecology*. Edward Elgar Publishing ltd. http://ilona.uni-mb.si/samec/Handbook_Industrial_Ecology_2002.pdf#page=100.

Wang T, Daniel B, Müller, Graedel T.E. 2007. *Forging the anthropogenic iron cycle.* Environmental Science and Technology. 2007. 41, 5120-5129.

Yellishetty M., Ranjith P.G., Tharumarajah A. 2010. *Iron and ore steel production trends and material flows in the world: Is this really sustainable?* Resources, Conservation and Recycling 54 (2010) 1084-1094.

Yellishetty M, Mudd G M, Ranjith P.G., Tharumarajah A. 2011. *Environmental life-cycle comparisons of steel production and recycling: sustainability issues, problems and prospects*. Environmental science & policy 14 (2011) 650-663.

Miljömål.se. 2013- *Den svenska miljömålsportalen* [Internet].; Available from: http://www.miljomal.nu/

För en hållbar livsmedelskonsumtion behöver vi äta mindre kött och välja kött med omsorg [Internet]. 2013; [cited 2013 Apr 3] Available from: http://www.jordbruksverket.se/formedier/nyheter/nyheter2013/forenhallbarlivsmedelskonsumtionbehoverviatamindrekottochvaljakottmedomsorg.5.5df17f1c13c13e5bc4f800039393.ht