DYNAMIX Decoupling growth from resource use and environmental impacts

Physical and environmental assessment

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DYNAMIX PROJECT PARNTERS

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LIST OF ABBREVIATIONS

BEV	Battery Electric Vehicles
EU	European Union
EV	Electric Vehicles
GHG	Greenhouse Gases
HEV	Hybrid Electric Vehicles
ICES	Intertemporal Computable Equilibrium System
ICEV	Internal Combustion Engined Vehicles
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MPA	Material Pinch Analysis
PHEV	Plugin Hybrid Electric Vehicles
RFP	Representative Food Products
RMC	Raw Material Consumption
VAT	Value-added tax

Executive Summary

The project DYNAMIX aims to identify and assess dynamic and robust policy mixes to shift the European Union (EU) onto a pathway to absolute decoupling of long-term economic growth from resource use and environmental impacts and to a sustainable future. To support this objective we established the following five targets for the year 2050:

- Reduce the consumption of virgin metals by 80%
- Limit greenhouse gas (GHG) emissions to 2 tonnes of CO_2 equivalent per capita per year
- Eliminate net demand of non-EU arable land
- Reduce nitrogen and phosphorus surpluses in the EU to levels that can be achieved by the best available techniques
- Eliminate water stress in the EU

We outlined three dynamic policy mixes to respond to these targets: one that focuses on the efficient use of metals and other material, one that focuses on land use and the production and consumption of food, and an overarching policy mix to reduce GHG emissions and obtain overall resource efficiency. The policy mixes are assessed with a combination of quantitative and qualitative methods in different parts of the project. This report presents quantitative estimates of the environmental significance of changes in material flows that can result from specific instruments in the policy mixes. We applied life cycle assessment (LCA), carbon footprinting, and material pinch analysis to estimate the potential resource and environmental benefits of the following elements of the policy mixes:

- Policy mix on metals:
    - Research and development (R&D) to improve copper removal in car dismantling
    - Product standards that specify material choice in water piping
- Policy mix on land-use:
    - Information campaigns to change diets and food-waste management
    - Redistribution and donation of food to reduce food waste
- Overarching policy mix:
    - A feebate system on cars, where the environmentally best products are subsidised while a fee is levied on the purchase of the worst products.

Our results indicate that R&D, changes in diets and feebate systems have a large potential for resource efficiency and/or environmental improvements.

We carried through a material pinch analysis to estimate how improved car dismantling can increase actual copper recycling and the maximum recycling of steel in the very long term. We assumed that an improved dismantling process can reduce the copper content in the steel scrap from cars by 75%. If such improved car dismantling is applied globally, the increase in copper recycling corresponds to 5-10% of the current use of virgin metals in the EU. Our results indicate that the long-term increase in maximum steel recycling is in the same order of magnitude. Spending on R&D on improved car dismantling alone could potentially give noticeable contributions to reducing the dependency on extraction of metal ores.

A product standard that prescribes polymers rather than copper in water piping would have little impact on total resource efficiency and GHG emissions, partly because only a small share of the copper is used for water piping and partly because a shift to plastic piping is on its way even without a product standard.

Changes in diets were assessed through a limited LCA that included climate impacts, land use, and water use as these impact categories had available robust data. The greatest potential benefits came from eliminating the overconsumption of protein through lower meat consumption. If the total daily protein intake is reduced from the current 105 g/capita to 59 g/capita, our results indicate that the impacts of food consumption would be greatly reduced: GHG emissions associated with food consumption are reduced by 40%, land use by 30%, and water consumption by 20%. This could be sufficient to reach the DYNAMIX target of no net demand of non-EU arable land. It would also give an important contribution towards the GHG target of 2 tonnes CO_2-equ./capita-year. However, even with this change in diets, the food consumption in the EU alone would still drive emissions of 1.5 tonnes CO_2-equ./capita-year.

Food redistribution and changes in food-waste management were assessed with a similar LCA. The social benefits of food redistribution were not part of our assessment. Environmental benefits are less than in the case with reduced protein intake and occur, according to our model, only if the reduction in food waste is associated with a corresponding reduction in food production. Future food-waste management in itself is likely to be a source of energy and nutrients, rather than an environmental burden.

The feebate system on cars was assessed through calculations of the carbon footprint of the current and future car fleets in the EU. To estimate the potential benefit of the feebate, we assumed that it would be highly effective in reducing car size and/or stimulating the development and use of electric and more efficient cars. We found that technological changes (more electric and more efficient cars) bring a greater potential for reducing GHG emissions, compared to reductions in car size. When the feebate just affects the car size, the feebate reduces GHG emissions from the car fleet by 15% in our model year 2050. When the feebate shifts the car fleet towards electric and more efficient cars, the model indicates a 40% reduction in the emissions. If the feebate is successful in reducing the car size as well as improving the technology, the feebate can reduce emissions by more than 70% - particularly if the electricity production in 2050 is dominated by renewable electricity. This would, of course, be an important step towards reaching the GHG target of 2 tonnes CO_2-equ./capita-year.

The results above all relate to the *potential* benefits of the policy mixes. We assumed the policy instruments would be effective in changing the material flows and calculated the resource and environmental benefits of such changes.

In addition, we made rough estimates of the *actual* impacts of a few other policy instruments:

- Policy mix on metals:
    - Tax on all materials used in the EU
- Policy mix on land-use:
    - Changes in the Pesticides Directive
    - Increase value-added tax (VAT) on meat

The effectiveness of these instruments was estimated with a macro-economic model. We then used LCA to estimate the environmental significance of these effects. These estimates are very rough because they are affected by simplifications and assumptions in the macro-economic model as well as the LCA model and because the structures of the two models do not fit well together. Interpreting the results very carefully, we can still state that changes in the pesticides directive and the VAT on meat are likely to have very little impact on the total GHG emissions and resource depletion of the EU. The models indicate that even a high materials tax will only give a limited contribution to reaching the DYNAMIX targets. A materials tax that doubled the cost of using materials will, in the models, not be sufficient, on its own, even to keep resource use from continuing to grow.

This indicates that the ambitious DYNAMIX targets require significantly stronger and more effective policy measures than the preliminary policy mixes we so far outlined in the project. Such strong policies will, of course, be difficult to implement. It might also be difficult to model their consequences, because they are likely to change things that he models take for granted: the economic structure, the level of technology, behavioural patterns, etc.

Even though we modelled individual elements of the policy mixes separately, we can draw a couple of conclusions regarding how policies can be combined. The feebate systems in the overarching policy mix could, for example, be combined with sustained and increased spending on R&D, from the metals policy mix, to increase the likelihood that the large potential benefits of a feebate system are realised.

Further benefits can be obtained if the DYNAMIX policy mixes are combined with policies outside the scope of DYNAMIX. Instruments such as R&D spending and feebate systems can result in electrification of cars and other products. This is more likely to increase resource-efficiency and reduce GHG emissions if combined with an energy policy that makes the electricity production more efficient and carbon-lean.

1 Introduction

1.1 The DYNAMIX project

DYNAMIX stands for 'DYNAmic policy MIXes for absolute decoupling[1] of environmental impacts of EU resource use from economic growth.' The DYNAMIX project is a collaborative project within the 7th European Union (EU) Framework Program (FP7). The aim of the project is to identify and assess dynamic and robust policy mixes to shift the EU onto a pathway leading to absolute decoupling of long-term economic growth from resource use and environmental impacts and to a sustainable future. To support this objective we established the following five key targets for the year 2050 (Umpfenbach 2013):

- **consumption of virgin metals**: to be reduced by 80 % compared to 2010 levels, measured as raw material consumption (RMC) in the EU. This target represents the scarcity of metals and environmental impacts caused by extraction, refinement, processing and disposal of metals;
- **greenhouse gas (GHG) emissions**: to be limited to 2 tonnes of CO_2 equivalent per capita per year. This is to be measured as a footprint to reflect embedded emissions and also in terms of emissions generated within the EU. This target represents climate change impacts of greenhouse gas emissions through energy use as well as agricultural and industrial processes;
- **consumption of arable land**: to reach zero net demand of non-EU arable land. This target represents, as a rough approximation, the impacts of biomass production on soil quality, water quality and biodiversity;
- **nutrients input**: reducing nitrogen and phosphorus surpluses in the EU to levels that can be achieved by the best available techniques. This target represents the impacts of agricultural production on marine and freshwater quality as well as soil quality; and
- **freshwater use**: no region should experience water stress.

During the course of the project the following two project objectives were agreed upon:

1) supporting policy makers with advice on analytical frameworks and/or best practices to identify and design appropriate policy mixes to achieve absolute decoupling; and
2) designing a few policy-mixes and testing them against our own framework.

The second objective will support the first. However, we do neither aim nor feel capable to design policy mixes that policy makers can simply copy and adopt to achieve absolute decoupling in the EU by 2050. Rather, a tailored approach to identifying and developing policy mixes is required, depending on e.g. national circumstances, interests and political expediencies. The findings of the study seek to support policy makers in the process of identifying and developing appropriate policy mixes to meet their decoupling objectives.

[1] In the DYNAMIX project, absolute decoupling is referred to as a delinking of economic output from resource use and environmental impacts, requiring that resource use and/or some measure of environmental impact decline in absolute terms (compared to a reference year), while the economy grows or stagnates and societal well-being improves or continues at present levels (Umpfenbach, 2013).

The DYNAMIX project began with an ex-post analysis of existing inefficiencies in resource use (Tan et al. 2013) and an assessment of past and current resource policies in several case studies across the EU (Mazza et al 2013; Fedrigo-Fazio et al. 2014). These provide a basis for identifying what paradigm shifts are required in the way production and consumption is organized and regulated, and what policy mixes might be able to contribute towards absolute decoupling in the EU by 2050.

The above five DYNAMIX targets guided our selection of relevant policy areas:

- **metals:** to reduce the use of virgin metals,
- **land-use:** to reduce the use of arable land, input of nutrients, and water stress, and
- **overarching**: to reduce the use of virgin metals and GHG emissions.

Relevant findings from the previous steps helped shape a dynamic policy mix for each of these policy areas (Ekvall et al. 2015). These promising policy mixes are tested, for example in this report, through ex-ante assessments for effectiveness (benchmarked against absolute resource and impact decoupling), efficiency, and socio-economic sustainability. The ex-ante assessments utilize innovative environmental and economic quantitative modelling. These are powerful tools for assessing economic and environmental impacts in the EU and globally; however, models have limitations in representing various social, political and legal aspects, including factors influencing human behaviour. DYNAMIX will thus also systematically integrate qualitative assessments to fully assess the real-world performance of the proposed policy mixes.

The results from the ex-ante assessments will be used to revise the proposed policy-mixes. and to enable policy recommendations adapted to the lessons learnt from the assessments.

The primary target group for the project is policy-makers directly involved in designing and implementing policies addressing levels of resource use and related environmental impacts at the EU and national levels. The project aims at strengthening the capacity of these policy makers in selecting, identifying, designing and implementing effective policies and strategies to reduce EU resource use and its related environmental impacts. Accordingly, a group of policy-makers and key stakeholders is continuously being involved in a systemic participatory process throughout the whole project. This process is designed to facilitate mutual learning and allow policy-makers the opportunity to influence the project’s design based on their needs. This approach will help increase the likelihood that the results of DYNAMIX can provide tangible support to EU policy-making for resource efficiency.

1.2 The report

This report presents part of the ex-ante assessment of the policy mixes: the quantitative environmental modelling. We have not modelled the full policy mixes, but only a selection of the instruments in the policy mixes because the policy mixes include soft instruments (e.g. retraining of the workforce), which are difficult to quantify and model in physical terms. We have modelled the instruments where our modelling methods can provide useful findings contributing to the overall ex-ante assessment.

The methods used in our part of the assessment are briefly described in Chapter 2. The results and conclusions are summarised and discussed in Chapters 3 and 4. Chapter 5 and the annexes include a more elaborate description of the methodological choices used in the modelling of each instrument. The detailed model results are also presented and discussed in Chapter 5.

2 Methods

The methods used for assessing the environmental impacts of proposed policy mixes include life cycle assessments (LCA) and carbon footprinting, both of which quantify emissions from the life cycle of a product. In addition, we apply the newly developed method of material pinch analysis (MPA).

2.1 Life cycle assessment and carbon footprint

Life cycle assessment (LCA) is used as a method to capture the quantifiable environmental impacts of proposed policy mixes. Life cycle assessment is described in international standards (ISO 2006a, 2006b) and is a commonly used tool to assess the environmental impact of products and processes. Simply put, LCA is a collation and evaluation of environmental flows to and from the processes in the full life cycle of a product (see Figure 1), and of the environmental impacts these inputs and outputs can cause.

Carbon footprinting is similar to LCA, except that it is limited to greenhouse gas (GHG) emissions and their impact on the climate.

Figure 1: A typical product life cycle

Source: IVL

2.1.1 Goal and scope

The goal and scope of an LCA provides a basis for the many methodological decisions made in the study. The common goal for all DYNAMIX LCAs is to assess the environmental impacts of introducing instruments in the policy mixes. This means that each study is a comparative LCA, where a system with the policy is compared to the same system without the policy.

We model the impacts of proposed policies by using a consequential LCA approach, rather than an attributional approach, as the focus was on the environmental consequences of the policies. An attributional LCA includes all parts of the product life cycle but nothing else. A consequential LCA, in contrast, ideally includes the parts of the technological system that are affected by the policy, disregarding of whether these are part of the product life cycle or not.

If a policy reduces food waste, for example, it can reduce the energy and nutrients extracted from incineration, digestion and composting of food waste. This means that energy and nutrients have to be provided from other sources. In a consequential LCA, the system investigated is typically expanded to include such production of competing goods, when it is affected by the policy.

At current state-of-the-art, consequential LCA is typically limited to that which is affected by changes in the physical flows. It does not account for consequences of changes in the cost or price associated with goods or services. If a policy results in a significant change in electricity demand, this can affect the price of electricity and, hence, the use of electricity in other parts of the system. Such indirect effects are not accounted for. Other rebound effects are also not included in a typical LCA.

When a policy affects the demand changes for electricity and other goods that are produced in large volumes, the production of these goods are affected on the margin. Data on marginal production of the goods should ideally be used in a consequential LCA. However, we use data on average production in most parts of the models even when production systems are affected only on the margin. This is because of lack of data on the marginal production of most goods.

The environmental impacts and resources included in the models vary between the studied instruments. The DYNAMIX targets relate to GHG emissions, land use, water use, and the use of virgin metals and nutrients. In the assessment of most food-related policy instruments, we included just GHG, emissions, land use and freshwater (bluewater) use. This makes the study a limited LCA. In a life cycle model of the EU car fleet, we only included GHG emissions. This makes the study a carbon footprint, rather than an LCA.

2.1.2 Functional Unit

The functional unit is the base for comparison with and without implementation of policy mixes and all flows and emissions in the models refer to the chosen functional unit. For each of the instruments assessed below, a functional unit is chosen, e.g. in the food modelling instruments, the functional unit is the annual food production.

2.1.3 System Boundaries and Life Cycle Inventory

The system boundaries for the modelling has been chosen to capture all significant processes related to the comparison of introduced policy mixes and the background scenario. For these studies the geographical boundary is not limited to EU-28 but includes also inputs and emissions outside of EU-28, thus providing a complete life cycle perspective. The LCA will include not only emissions in the EU-28 but also emissions that occur outside of EU-28 due to imports and exports of goods, services and materials.

2.1.4 Environmental Impact Assessment

The environmental impacts considered in the LCAs are limited to GHG emissions (CO_2-eq), resource use, land use and water stress. Characterisation and classification of emissions are based on characterization factors provided by CML (2015).

In order to portray the extent to which policy instruments contribute toward reaching targets outlined in the DYNAMIX project, results were compared with figures for different base years in the results; 2007, 2010 or 2013 depending upon the model and input data. Thus results are ‘normalized’ by setting values for the base year at 100% and comparing to see how impacts may increase or decrease in future years.

2.1.5 Interpretation

Life cycle assessment model results can be subject to a number of analyses to ensure that results are stringent enough and correct given the question for the model to answer: sensitivity analysis, completeness check, consistency check, and dominance analysis. These are all described in the international standard for life cycle assessment (ISO 2006b). The analyses related to interpretation of the results have been carried through in part and informally during the course of the study, but they are neither systematic nor complete and not presented in this report. This is partly because the report includes several different studies. The number of models and results is large and would threaten to be unmanageable with the additional analyses. In this sense the LCAs and carbon footprints can be regarded as simplified.

However, the models try to predict the future and the uncertainties involved are great. This means that the results from the models should not be interpreted as precise estimates, but as indications of the potential scale of changes in environmental flows.

2.1.6 Combining LCA and Economic Modelling

We also developed an overarching LCA model to assess the environmental intensity of different economic sectors in the EU. The environmental intensity is the environmental impacts (e.g. GHG emissions etc.) associated with the production of a monetary unit of products from the sector. The approach is different from environmentally extended input-output models, as it will link environmental impacts to representative products from different sectors. The procedure begins by assigning environmental impacts and monetary values per given physical unit (e.g., kg) to representative products in each sector of the European economy. The monetary values are assumed to be held constant for the different years. Using outputs for the total economic output value for each sector for reference and future scenarios, the environmental impacts of a sector or the entire economy can be computed by linking changes in economic output to the environmental impacts of representative products in each sector. In the future scenarios, changes in the total economic output will cause increases or decreases in the output of representative products; which will result in increases or decreases of the environmental impacts.

We used this approach to estimate the environmental significance of the output from a specific macro-economic model: the Intertemporal Computable Equilibrium System (ICES). The ICES model was used in another part of the project (Bosello et al. 2016) to estimate how a handful of the policy instruments affect different parts of the economy of the EU member states, and their economy as a whole. The impacts on the economic outputs from each sector in the national economies were aggregated into the impact on a corresponding EU-wide economic sector. These aggregated results were fed into our overarching LCA model to obtain a rough estimate of how the policy instruments affect the total emissions and resource use of the EU.

2.2 Material Pinch Analysis

Material Pinch Analysis (MPA) is a new method used in DYNAMIX to assess the long term recycling potential of steel globally. It is further described in Ekvall et al. (2014) and only a brief description is given here.

Pinch analysis is a set of methods originally developed for optimising energy use in process industries to minimize energy losses. Different processes require different pressure and temperature and pinch analysis gives the most efficient use of hot flows for heating and cool flows for cooling by using the lowest possible grade of energy for each flow.

In DYNAMIX the principles of pinch analysis have instead been used for global steel flows where the energy quality equivalent is set to steel quality in terms of copper impurities. Even small impurities of copper in steel decrease its quality significantly and the full range of impurity is between zero and one percent copper content. An MPA matches the sources (and the quality of each source) and sinks (and the quality requirements of each application) to find the pinch point where quality is just sufficient for each use. Thus this methodology yields the amount of steel scrap that cannot be directly recycled because of high copper contamination. It also allows for the calculation of the amount of poor scrap which can be mixed with superior scrap or ore-based metal to enable the sources and sinks to match even better. The results of this calculation provide an estimate of the maximum recycling rate, the minimum quantity of ore-based metal needed as input to the system, and the minimum quantity of low-grade scrap that has to be discarded.

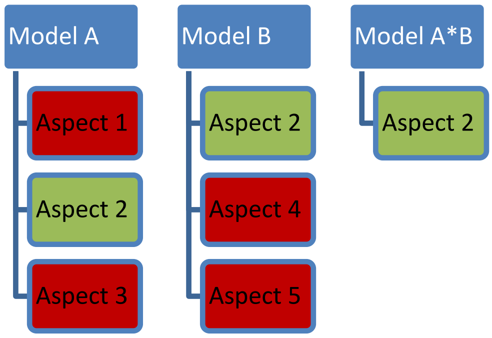
2.3 Limitations of the Methodological Framework

Modelling of sociotechnical or economic systems typically give new insights and knowledge on how the systems work, on what parts of the system are really important and on what causal relationships are the most crucial. These insights are often more useful than the numbers generated as output from the models. The quantitative results should always be interpreted as no more than rough estimates. This is because the systems investigated are very complex and the models, for this reason, include several simplifications, assumptions, and uncertainties.

In this project, results from the quantitative environmental modelling have sometimes been developed using the output of the economic models and assumptions for the policy mixes. This provides a broad assessment but also entails several difficulties and limitations for results. Using several models in successive order means that the results are cumulatively affected by the simplifications and other limitations of each model, which can make the usefulness of the final results limited.

Figure 2 shows an example where Model A and Model B both cover three aspects of reality, but when combined they have only one aspect in common and can thus only produce results based on this single aspect.

Figure 2: Example of model multiplication of simplifications and other limitations



This situation is very much the case when combining macro-economic models with LCA models. LCA covers the full life cycle of the products regardless of where they are produced. The method is most commonly applied on single products or product systems to compare the environmental impact of existing products and services or impacts of introducing new products and services. This makes it appropriate for managing detailed mass flows connected to products but less accurate at studying sector wide mass flows with a variety of products. A macro-economic model, in contrast, describes the economic flows of a full economy in a geographic area. Since the system modelled is extremely complex, the model is highly aggregated. The structure of the model is based on economic sectors, while the structure of an LCA is based on individual production processes or clusters of such processes. Because of the different scope and structure between the models, particular care should be taken when using or referring to the results from our successive combination of macro-economic and LCA models.

Another issue is the lack of available data for mass flows of products within the EU and outside EU. One key example is the fundamentally different statistical systems for production within EU and imports to the EU. Statistics may not be available for products, but only for raw materials. This is the case, for example, in the databases with food consumption statistics. In addition, not all statistics are provided in mass, but rather to a large extent they are available only in monetary values, which further complicates the translation into total mass flows (and thus total product flows). When interpreting the statistics, it may also be hard to account for losses and true ‘consumption’ figures for different products in the EU.

A third problem is related to the time frame of the project as a whole, which ranges until 2050. This creates several uncertainties of which one may be technological development. This is partly managed in the model for Feebate on cars where the cornerstone scenarios allow for different development paths but it is not included in the environmental models based on the economic models. In the land use scenarios (i.e. food production and waste management) no improvements in production are included, which suggests that the environmental benefits accruing to policies may be overstated, as may the total residual level of environmental impact in 2050. The interface between the economic models and the environmental model of total consumption within a sector does not necessarily differ with possible paradigm shifts with a sector. As an example, if the electricity sector would become carbon neutral, this would not necessarily change the total consumption in the sector in terms of € and with the environmental model using a static division of technological development, this could be completely missed in the combined output. In the assessments, average data for a reference year is often used, and assumed to be the same in 2030 and 2050, which again may not be entirely accurate.

3 Overarching Conclusions

We used the methods described in Chapter 0 to model parts of the three policy mixes presented by Ekvall et al. (2015). We could conclude, even before modelling, that the policy areas are relevant for addressing all five DYNAMIX targets:

- The metals policy mix addresses the target to reduce the use of virgin metals.
- The land-use policy mix addresses the targets to reduce the use of arable land, water and nutrients.
- The overarching policy mix addresses, at least, the target to reduce GHG emissions.

After modelling we can add that a land-use policy also has the potential to make important contributions to reducing GHG emissions. A radical reduction in the production of excess protein (Scenarios 1 and 3 in Section 5.1) could, for example, reduce the GHG emissions from food production by 40%.

We cannot conclude, however, even after modelling, if the policy mixes presented by Ekvall et al. (2015) are sufficient to reach the DYNAMIX targets to the year 2050. This is because the modelling does not give accurate information on the effectiveness of the policy mixes. Part of the mixes is assessed through models of the physical flows only. Assumptions on the effectiveness of the policy instruments are needed as an input to these models. They do not estimate the effectiveness, but they estimate the environmental significance of a policy given an assumed effectiveness. In other words, they estimate the *potential* environmental benefits of the policy rather than the *actual* environmental benefits.

Modelling of potential environmental benefits can be useful because they indicate where the policy mixes should focus to reach the very ambitious DYNAMIX targets. Our models indicate a great potential for environmental benefits from reduced production and consumption of food in general and protein in particular (Sections 5.1 and 5.2). We currently consume almost double the amount of protein we need. Radically reducing the excess intake of protein will not only contribute to reducing GHG emissions. It can eliminate the net use of non-EU agricultural land for food production. It can also reduce the use of freshwater and nutrients.

The reduction in protein production and intake is in the model assumed to result from successful information campaigns. This is not a realistic assumption. Information is typically not a very effective policy instrument in itself. However, it is important as a supplement to other policy instruments. To achieve a radical reduction in the production of excess protein, the information probably needs to be combined with other strong instruments (see, e.g., Åström et al. 2013, Vinnari & Tapio 2012, Fraser et al. 2016).

Our models also indicate a great potential for environmental benefits from research and development (R&D). This is illustrated by the results from the MPA on improved car dismantling (Section 5.5), which illustrated that a substantial improvement in this single process can give significant contributions to reducing the use of virgin metals in the world.

Sustained and increased spending on R&D could be combined with, for example, feebate systems. Our model of a feebate system on cars (Section 5.4) indicates that it can give important contributions to reducing GHG emissions in the EU, particularly if successful technological development allows for a widespread use of electric vehicles and the share of fossil fuel in the electricity production is greatly reduced. Increased R&D spending could contribute to both of these developments.

Further benefits can be obtained if the DYNAMIX policy mixes are combined with policies outside the scope of DYNAMIX. Instruments such as R&D spending and feebate systems can result in electrification of cars and other products. This can be resource efficient and reduce GHG emissions if the electricity production is efficient and carbon-lean. The benefits of these instruments can be enhanced if they are combined with energy-policy instruments such as green certificates for renewable electricity production, tradeable emission permits for carbon, feed-in tariffs for electricity from wind and photovoltaics, etc. Such instruments were not included in the DYNAMIX policy mixes, because of the wealth of previous research in the area of energy policy.

The actual effectiveness of a few policy instruments was estimated with macro-economic models. We then used LCA to estimate the environmental significance of these effects. This is an estimate of the *actual* impact of the policy instruments. However, as discussed in Section 2.3, this estimate is very rough. Interpreting these results very carefully, we can still state that several of the instruments in the policy mixes are likely to have very little impact on the total GHG emissions and resource depletion of the EU. The models indicate that even a high materials tax will only give a limited contribution to reaching the DYNAMIX targets. It will not be sufficient, on its own, to even decouple resource use from the economic growth.

This indicates that the ambitious DYNAMIX targets require significantly stronger policy mixes than the ones presented by Ekvall et al. (2015). Such strong policies will, of course, be difficult to implement. It might also be difficult to model their consequences, because they are likely to change things that he models take for granted: the economic structure, the level of technology, behavioural patterns, etc.

4 Environmental Impacts of Each Policy Mix

This chapter briefly outlines the three DYNAMIX policy mixes that Ekvall et al. (2015) describe in detail. The chapter also summarizes the findings from the ex-ante assessments made through our models and presents the overall conclusions that can be drawn for each policy mix.

4.1 Metals Policy Mix

This policy mix primarily aims at reducing the use of virgin metals in the EU, in terms of RMC, through increased recycling and material efficiency. The EU use of metals, when measured in terms of RMC, is dominated by iron, copper and gold (Eurostat 2013). Iron is used in great quantities. The raw material consumption of copper and, in particular gold, is high because of the low metal content in the ore from which the gold and copper are extracted. A large quantity of ore has to be extracted to produce a single kg of gold.

The metals policy mix also aims to avoid merely shifting burdens to the use of other resources or regions in the world, or to increase environmental impacts. For this reason, the metals policy mix includes several instruments of an overarching character. Ekvall et al. (2015) consider the following instruments in the mix particularly important to focus on in the ex-ante assessment:

- Full internalisation of external environmental costs.
- Tax on materials used in the EU.
- Promotion of sharing systems.
- Increased spending on research and development (R&D).
- Standards for specific metals products.

These five instruments are embedded in a set of supporting and complementary instruments. These include, for example, an EU strategy for dematerialization, information campaigns, and advanced recycling centres.

This report presents modelling of environmental impacts of all five key instruments, except for the promotion of sharing systems. The environmental impacts of the supporting instruments cannot be quantified, at least not with the methods in our toolbox.

4.1.1 Tax on Materials used in the EU

This is a value-based tax on all materials that are used in the EU: steel, concrete, paper, polymers, glass, textiles, etc. The materials tax is to be levied on all types of materials in order to avoid burden shifting from metals to other materials. It is levied even on recycled and renewable materials because also these materials need to be used efficiently. The tax is levied on domestically produced as well as imported materials, but not on materials that are exported outside the EU. This is to allow for domestic material producers to compete on level terms with producers outside the EU (Ekvall et al. 2015).

The tax is introduced at a very low level in the year 2020. It increases gradually to 30% of the net price of the material in the year 2030. After that it increases more steeply and reaches 200% of the net price in 2050.

The materials tax is likely to have the greatest impact on the manufacturing and construction industry. This is where the cost of material can be a significant part of the total production cost and, hence, where the total cost can be most affected by an increase in the material cost. However, since the tax described by Ekvall et al. (2015) eventually becomes quite high, it can have a significant impact also on other sectors.

The effects of the tax on various sectors in the Reference DYNAMIX background scenario (Gustavsson et al. 2013) have been estimated using the Intertemporal Computable Equilibrium System (ICES) model and other macroeconomic models (Bosello et al. 2016). The ICES model was not able to find a solution with the very high materials tax in the year 2050, but we obtained results for the year 2040, where the tax should be slightly above 100% of the material net price. These results indicate that the materials tax will reduce the activity in several industrial sectors in the EU: oil products, chemicals, metals, minerals, construction, and manufacturing (see Table 63).

We estimated the environmental significance of these effects using LCA. According to the LCA results, the overall EU resource depletion, the freshwater consumption and the toxicity impacts on humans are all in the order of 10% lower in the model year 2040 when the material tax is implemented (Section 5.6.7). The impact on the EU total GHG emissions is small, however (Figure 21). Even with the rather high materials tax implemented in 2040, the resource depletion and environmental impacts are also greater than in 2007. In other words, the models indicate that even a high materials tax is not sufficient, on its own, to obtain absolute decoupling. It is far from sufficient to reach the DYNAMIX targets of 80% reduced virgin metals use, etc. But it could give a contribution to reaching these targets.

We do not know to what extent the ICES results reflect effects that can be expected in reality. Macroeconomic models are adequate for modelling small changes within a given economic and technological structure. Reducing virgin metals use by 80% would require great changes in the processes and systems, and macroeconomic models can give no more than a rough idea of the economic impacts of such drastic changes. When modelling the materials tax in the year 2040, the ICES model came close to the limit where it can find any solution. It is reasonable to assume that this solution can be very different from how the actual economic and technological system would react to a high materials tax.

4.1.2 Increased R&D Spending

This instrument implies continued and strengthened public funding in the EU of R&D for recycling and material efficiency. The R&D for recycling will include:

- Design for recycling;
- Efficient and consumer-adapted systems for collection, and identification of the role for the public sector in ensuring their provision;
- Technology for dismantling and separation of components and material; and
- Technology for recycling.

The R&D for material efficiency will include, for example:

- improved processes and products;
- new business models; and
- non-material alternatives for safe investments.

The objective of the last item in the list is to find ways to substitute metals, particularly gold, with other ways of delivering the service safe investments (Ekvall et al. 2015).

The model presented in this report (Section 5.5) focusses on a single area of research for recycling: technology for dismantling. To be specific, we use material pinch analysis to estimate how successful R&D on the dismantling of passenger cars and light trucks can affect the maximum recycling rate of copper and steel. This case study illustrates that successful technological R&D can significantly increase the maximum recycling rates. It gives a good indication that R&D on technology, systems, behaviour etc. has the potential to be important for increased materials recycling, increased material efficiency and, hence, for reaching the DYNAMIX targets.

4.1.3 Standards for Specific Metal Products

This instrument entails the development of standards for specific metals products and metals components that regulate the design to, for example (Ekvall et al. 2015):

- Improve the modularity to increase reparability and reuse of components, taking into account impacts on energy efficiency.
- Reduce the unnecessary use of material.
- Substitute metals for other materials when appropriate, for example shifting from copper water-piping to polymer piping.

The calculations presented in this report (Section 5.3) concern the last of these three areas only. To be specific, we use results from previous LCAs to estimate how a shift from copper water pipes to polymer water pipes would affect the copper use and the emissions of greenhouse gases.

The results and our discussion show that a product standard specifying that copper should not be used for water piping would contribute very little to achieving the DYNAMIX targets of decoupling and sustainability. Product standards for more important product groups, or a large number of product standards, might give more significant contributions. However, since product standards are consensus document, they are not likely to stipulate much more than solutions that are being adopted. The product standard might make the shift to the new solution quicker and perhaps also more complete, but it is not likely to cause the shift to happen. This means product standards probably do not contribute much to reaching the DYNAMIX targets.

4.1.4 Overall Conclusions on the Metals Policy Mix

We modelled most of the key instruments in the metals policy mix under the assumption that the instruments are effective. The supporting instruments where not modelled but their function is mainly to increase the likelihood that the key instruments are effective. We also did not model sharing systems. These are likely to have a positive but limited environmental impact because the products that are suitable for sharing systems (cars, bicycles, tools, etc.) contain a limited share of the total materials used in the society.

Product standards are likely to have a small effect only. A materials tax and increased spending on R&D has the potential to give important contributions to the objectives of the policy mix and the DYNAMIX project. However, the outcome of R&D processes is highly uncertain. Part of the effects of successful R&D can also be off-set by rebound effects.

The main target of the metals policy mix is to reduce the use of virgin metals by 80%. The assessments in this report indicate that the policy mix can contribute to reducing not only the use of virgin metals but also the use of other resources and the emissions of greenhouse gases and pollutants. However, based on the quantitative results of the models, it is reasonable to assume that the policy mix would be sufficient to reach only part of the way to the 80% target for reduced metal use.

4.2 Land use policy mix

The policy mix on land use could alternatively be described as two policy mixes: one focusing on food production, and one on food consumption and food waste (Ekvall et al. 2015). Together they aim to reduce land-use, freshwater use and nutrient surplus. The policy mix on food production includes five key parts:

- Stronger and more effective environmental and climate dimension for EU land management in the Common Agricultural Policy (CAP).
- Revised emissions levels in the National Emissions Ceilings Directive (NECD) and additional measures for better management of the nitrogen cycle on farmland.
- Promotion of Payment for Ecosystem Services programmes.
- Revised regulation for land use, land-use change and forestry.
- Revised Pesticides Directive, and guidance to farmers on pesticide management.

These five key instruments are in the policy mix supported by a range of accompanying measures. These include, for example, increased prices on irrigation water, the establishment of an EU soil legislation and the promotion of research and monitoring.

The policy mix on land-use also includes the following three instruments to influence the food consumption and food waste:

- Targeted information campaigns on changing diets and on food waste.
- Development of food redistribution programmes/food donation to reduce food waste.
- Increased value-added tax (VAT) on meat.

This report presents modelling of environmental impacts of a revised Pesticides Directive and of the instruments related to food consumption and food waste. However, revision of the CAP and NECD, the payment for ecosystem services, and the revised regulation for land use, land-use change and forestry are all difficult to quantify based on the information given by Ekvall et al. (2015) - at least with the methods available in our toolbox.

4.2.1 Revised Pesticides Directive, etc.

This is a package of instruments aiming to reduce the use of pesticides in the agriculture. The Directive on Sustainable Use of Pesticides would be revised and require the EU Member States to strengthen their National Action Plans with more demanding requirements in terms of reduced use of pesticides, and improved pest management. Farmers would be offered advice on integrated pest management. Incentives for implementation of integrated pest management would be created through, for example, a revised CAP with a stronger environmental dimension. Member States could also remove VAT exemptions on pesticides and introduce fiscal instruments to reduce pesticide use.

This package will primarily affect the agricultural sector. It can be expected to reduce the ecotoxicity impacts of the agricultural system. It might also reduce toxicity impacts on humans. These effects cannot be modelled with the methods in our toolbox.

Further restrictions in the use of pesticides might reduce the productivity of the agriculture and, hence, increase the land area needed to produce a given quantity of food. This would make it more difficult to reach the DYNAMIX target to eliminate the net dependency on arable land outside the EU. This effect can also not be quantified with the methods in our toolbox.

However, the agriculture and other sectors can be indirectly affected through, for example, changes in food prices, pesticides demand, and land-use patterns. The effects on all economic sectors of a tax on pesticides, aiming to reduce the use of pesticides, have been estimated using macroeconomic models (Bosello et al. 2016). The results from the economic model ICES indicate that a change in the pesticides directive will have very little impact on the economic output from all sectors in the economy, including agriculture. We estimated the environmental significance of the very small effects using LCA, and the LCA results accordingly indicate that the environmental benefits of the indirect effects of the policy measure are negligible (see Section 5.6.7).

4.2.2 Information campaigns

This instrument is an awareness campaign that aims to encourage and achieve a change in diets and a reduction in food waste. The measure would provide information on the environmental impacts of food production and the serious issue of food wastage in order to increase respect for food and promote diets that are healthy, more environmentally friendly and less resource intensive. Information and tips on shopping, shelf life, storage, preparation, and waste-management options could also be provided to consumers to allow them to contribute to improving the situation (Ekvall et al. 2015).

We apply life cycle calculations to estimate how the information campaigns would affect the GHG emissions, land use and water use if they are very effective for changing the diets (see Section 5.1) for reducing the food-waste flow from households and retailers, and/or for improving the source separation and management of food waste (Section 5.2). The changes in diets we model are a radical reduction in the excess intake of protein and also a change in the mix of meat consumed.

The results indicate that radically reducing the excess intake of protein until the year 2050 can reduce GHG emissions from food production by 40% compared to the current emissions, even though the European population is expected to grow. At the same time, land use is reduced by more than 30%, and water use is reduced by 20% (Section 5.1). All of these impacts occur at a global, rather than specifically EU, level.

Changes in the type of meat consumed will have only small effects in comparison. This is because the share of bovine, which is the meat with the greatest impact on climate, is already rather small (24%). Reducing it further will have little impact on the total emissions of meat and vegetables production.

A 40% reduction in the emissions from food production would be an important contribution towards the DYNAMIX target of reducing the GHG emissions to 2 tonnes of CO_2 equivalents per year. However, the DYNAMIX target requires that the GHG emissions are reduced by nearly 80% compared to current emissions. To reach this target, additional measures will be required in the agricultural sector and food industry to further reduce the GHG emissions.

A 30% reduction in land use is sufficient to keep the net demand of non-EU agricultural land below zero (see Table 12). Eliminating the excess use of protein is sufficient for the food production to reach its part of the DYNAMIX land-use target, which is zero net demand on arable land in general outside the EU.

A 20% reduction in water use in food production is likely to contribute to achieving also the DYNAMIX target on freshwater use: that no region should experience water stress. However, since our model does not distinguish between different regions, it is not possible to conclude on whether the 20% reduction in the overall food production is sufficient to eliminate regional water stress, or even if it is an important step towards that target.

We model several scenarios with reduced flows of food waste from households and retailers (see Section 5.2.3). The scenarios vary in terms of waste flows and also on the impact on food production. The results clearly indicate that a reduction in waste flows reduces GHG emissions, land use and water use, if it results in a reduction in food production (Scenario 1c in Section 5.2.6). The environmental benefits are less than the effect of reducing excess protein intake, but greater than changing the types of meat we consume.

If reducing food waste does not affect food production, there is no reduction in GHG emissions, land use and water use (Scenarios 1b and 1d in Section 5.2.6). Reducing the quantity of food waste in itself does not reduce environmental impacts. In a modern waste-management system, with anaerobic digestion, composting, incineration and efficient landfill-gas extraction, food waste can be a resource – a source of both renewable energy and nutrients. This means that the message of the information campaigns should not be Eat more – Waste less (e.g., “Finish your plate!”). The message should instead be Waste less – Buy less – Produce less.

The significance of food waste as a resource increases if the waste management is improved. We model scenarios where waste disposal (landfill and incineration without energy recovery) is greatly reduced and anaerobic digestion and incineration with energy recovery is increased. The use of biogas from digestion is also shifted from producing electricity in power plants to a more valuable use as fuel for vehicles (Section 5.2.5). The results indicate that improving the system for management of food waste has very little effect on the land use and little effect on the water use. However, it reduces the GHG emissions to an extent that is comparable to reducing the food waste and associated food production (Scenario 3a in Section 5.2.6).

The combined results from our modelling of potential impacts of effective information campaigns show that the greatest potential lies in the reduction of excess protein intake. Reduction of the quantity of food waste can give significant contributions if it results in a reduction in food production. Increased source separation and improved management of food-waste can give significant contributions to the reduction of GHG emissions. Note that this describes the potential effects only. The model is not designed or able to estimate the actual effects of information campaigns.

As a contrast, the impacts of a policy to shift dietary patterns for all economic sectors in the EU have been estimated using macroeconomic models (Bosello et al. 2016). The results from the economic model ICES indicate that such a policy will have very little impact of the economic output from all sectors in the economy, including agriculture. We estimated the environmental significance of the very small effects using LCA, and the LCA results accordingly indicate that the environmental benefits of the indirect effects of the policy measure are negligible (see Section 5.6.7).

4.2.3 Food redistribution programmes

Food donation can provide a crucial support for the most deprived and could also be an important tool for the reduction of food waste in Europe. This policy instrument aims to reduce the generation of food waste through the development of food redistribution programmes. These would encourage retailers and other relevant food stakeholders to donate eligible food products to charities etc. for distribution among the homeless, poor, etc.

The environmental and health impacts of food donation strongly depend on the alternative. If food donation means that the recipients of the food have better access to an appropriate diet, and are less at risk of hunger, this will contribute to improving their health. It will at the same time reduce the flows of food waste; however, it will not necessarily affect the food production because it will merely avoid food from becoming waste and instead divert it to the increased health and well-being of the targeted beneficiaries.

The consequences will be very different if the food donation system means that the poor spend less money on buying food. This will not necessarily improve their health, but it will improve their economic wellbeing. At the same time, it will reduce waste flows and the sales of the food retailers. This, in turn, can be expected to reduce the business of food wholesalers and the food production.

We apply life cycle calculations to estimate how food redistribution programmes can affect GHG emissions, land use and water use if the flows of food waste are reduced but food production is not affected (see Section 5.2.4). The results indicate that such a system would, although beneficial for the health of the recipients, not bring benefits for the climate, land use or water use (Scenario 2a in Section 5.2.6). This is because food production is not affected. As discussed in Section 4.2.2, simply reducing the management of food waste does not reduce the environmental impacts of the society.

In reality it seems reasonable to expect that a food donation system has several different effects: that the recipients of the food eat more, that they eat a better diet, and that they spend less money on food. This should be beneficial to the health as well as the economy of the food recipients. It would also reduce the food production somewhat. The environmental impacts are difficult to estimate, particularly since it depends in part on the consumption choices of poorer households which benefit from increased disposable income as a result of the policy.

4.2.4 VAT on meat products

Most EU Member States currently apply a reduced VAT rate for meat products. The proposed policy would mean that the standard VAT rate in each country is applied on meat products; with possible exemptions for certain types of meat products that promote environmental protection and health: organic meat products or meat that has been produced following very strict environmental criteria, meat being donated to charities and food donation programmes, etc. (Ekvall et al. 2015).

Applying the standard rate of VAT to meat products aims to reduce meat consumption. It affects mainly the meat producers and the households who pay the VAT. However, the impact might affect also other sectors through, for example, changes in consumption patterns. The effects on all economic sectors of a meat VAT have been estimated using macroeconomic models (Bosello et al. 2016). The results from the economic model ICES indicate that the meat VAT will have little impact of the economic output from all sectors in the economy. Even the output from the livestock sector is reduced by no more than 1.5% in the model (see Table 59 and Table 60). We estimated the environmental significance of these effects using LCA. The LCA results accordingly indicate that the environmental benefits of the indirect effects of the policy measure are negligible (see Section 5.6.7).

4.2.5 Overall conclusions on the land-use policy mix

We modelled several of the key instruments in the land-use policy mix, but with two different approaches. Revision of the Pesticides Directive, as well as the implementation of standard VAT rates on meat, were modelled with a combination of macroeconomic models and LCA. The results of the economic models were used as input to the LCA.

Changes in Directives are complex and partly soft instruments. These are difficult to model. The economic models are based on assumptions regarding part of the effects of the revisions. This means that the results of the modelling of revisions of the Pesticides Directive to a large extent reflect the assumptions used as input to the economic models. They can be regarded as estimates of *possible* effects of revising the Directive. The results also do not account for what is probably the most important environmental effect of such a revision: the reduction in toxicity impacts on the ecosystem.

In contrast the macro-economic models are suitable for modelling effects of changes in the VAT. The results from the modelling of the meat VAT, which indicates that the VAT will have little impact on the GHG emissions, water use, etc., can be interpreted as estimates of the *actual* effects of implementing standard VAT rates on meat. However, the successive use of different models means that the estimates are affected by the limitations of both models and by the inconsistencies between the models (see Section 2.3). This means the estimates are quite crude.

To model the effects of information campaigns and programmes for food redistribution we used a life-cycle model of the physical flows only. The results were calculated under the assumption that all instruments and targets for the Land-use policy mixes outlined in Ekvall et al. (2015) were effective. The results from this model can be interpreted as estimates of the *potential* effects of information campaigns and food donation.

The results show that there is a great potential for environmental benefits from changing the habits and behaviour of retailers and consumers, but only if this reduces the food production. The greatest potential benefits seem to lie in reducing the production and excess intake of protein; however, a general reduction in food production can also give important contributions to reducing GHG emissions, land use and water use. A land-use policy mix that effectively addresses these aspects can also be expected to reduce the input of nutrients to agriculture. This means it is highly relevant to four of the five DYNAMIX targets.

A policy mix of land use will not in itself be sufficient to reach the DYNAMIX target on climate, because most of the GHG emissions occur in other parts of the economy. However, our results indicate that there is a potential, at least, to reach the DYNAMIX target on land use through reducing the protein intake.

Realizing the potential resource and environmental benefits is, of course, a challenge. The policies outlined here aim, for example, at reducing and shifting meat consumption, but the issue of meat consumption is complex. Meat is a rich source of high quality protein and nutrients. There are also social and cultural aspects of meat consumption, which, as the qualitative assessments make clear, may make it hard to reduce in certain cultures and countries. Retailers, in addition, may be reluctant to reduce their offerings of meat products, which account for a large share of their income and provide competitive advantages.

4.3 Overarching policy mix

The third policy mix has an explicit overarching focus. It aims at reducing overall resource consumption in the EU and also at reducing the emissions of greenhouse gases and other pollutants. This policy mix includes a broad variety of instruments (Ekvall et al. 2015):

- Taxes on the extraction of selected virgin materials and on landfilled and incinerated waste.
- Feebate schemes for selected products.
- Reduced VAT for the most environmentally advantageous products and services.
- Boost of the extended producer responsibility.
- Skill enhancement programme.
- Local currencies for labour-based services.
- Enabling a shift from consumption to leisure.
- Step-by-step restrictions of advertising and marketing.
- Minimum requirements on the life-cycle performance of products.
- Compulsory sustainability reporting for companies.

This report only includes modelling of the potential climate impacts of a feebate scheme for cars (Section 5.4). Most of the other instruments in the overarching policy mix are difficult to model with the methods available in our toolbox.

We modelled the feebate on cars under the assumption that this instrument would be highly effective in reducing car size and/or stimulating the development and use of electric and more efficient cars. This means that we estimated the potential rather than the expected climate gain of the feebate.

The results indicate that the potential climate gain is rather small if the feebate focusses on the size of the cars, but larger if the focus is on stimulating the development and application of more efficient technologies. When the feebate has a substantial effect on car size but no effect on the technology (cf. Back to Nature scenario in

Figure 15), the feebate reduces GHG emissions from the car fleet by 15% in our model year 2050. When the feebate shifts the car fleet towards electric and more efficient cars, but without affecting the car size (cf. Economic Bonanza scenario in

Figure 15), the model indicates a 40% reduction in GHG emissions from the car fleet in 2050. If the feebate is successful in reducing the car size as well as improving the technology, the feebate can reduce the GHG emissions from the car fleet by more than 70% - at least if the electricity production in 2050 is dominated by renewable electricity (cf. Safe Globe scenario in Figure 15).

Although technology has a greater potential than car size for reducing GHG emissions, the opposite holds for material efficiency. A feebate system that reduces the car size is likely to reduce the use of metals and other materials.

Since we could model only a small part of the overarching policy mix, we have little basis for conclusions on whether this policy mix is sufficient to reach absolute decoupling and the DYNAMIX targets. We can, however, conclude that a major shift in the type and size of cars used can have a great impact on the GHG emissions from the car fleet, particularly if the future electricity system is dominated by carbon-lean and renewable power production. This indicates that a feebate system for cars is an interesting policy instrument, and that it should ideally be combined with policies to foster R&D in clean automotive technology, and a policy for decarbonisation of electricity production. This is a good example of how a broad systems perspective on policy-making is useful for finding effective combinations of policies.

5 Detailed model descriptions

5.1 Information campaigns on food (LAND)

Consumers are becoming more aware of the impact that their behavioural choices may have on the environment. In the developed world, behavioural choices, such as dietary choices, have a large influence on their environmental impact (Heller and Keoleian 2014). Jones and Kammen (2011) identified dietary changes as one of the most economically effective abatement options for climate change. Furthermore, many developed country consumers are well above dietary recommendations for different protein sources and calorie intake. It is therefore possible to target specific foods to reduce the production and thus environmental impacts from their production and consumption. There is also an abundance of food production in European nations. In many studies, the impact of certain food sources, such as meat, has become a focus for reductions (Westhoek et al., 2014) in addition to policies outlined in this study.

5.1.1 Scope

This study reviews instruments provided in the policy mixes addressed by Ekvall et al. (2015) aiming to generate a shift towards reduced environmental impacts created from future food production. This is done by addressing reduced consumption of meat and dairy products in order to lower environmental impacts, water consumption and land requirements. Scenarios are created for current (2010) food consumption and targets for 2030 and 2050.

5.1.2 Model

Identifying the impact that food consumption changes have in the European Union requires a review of the current consumption and projections on the possible changes in the future. In order to develop different scenarios for behavioural choices, food consumption, waste and food donations statistics from the Food and Agricultural Organisation Food Balance Sheets were used. The statistics identify the import, export, use and waste of food (and various categories of foods) for the European Union with a base year of 2010. Food consumed in this study included only food for consumption and manufacturing, excluding that used for fodder and seed. The food categories included all categories listed in Table 1.

Within each food category there are a large number of separate food products. Representative food products (RFP) were therefore chosen within each category to represent at least 80% of the mass of the product category, as some food products made up a large portion of the respective category and in order to simplify the quantification of environmental impacts. A scaling factor was thereafter employed in order to compensate for the food products excluded by choosing the RFPs.

Table 1: Food Categories in the FAO Food Balance Sheets (FAO Stat 2014)

Food Categories	
Cereals	Spices
Starchy Roots	Alcoholic

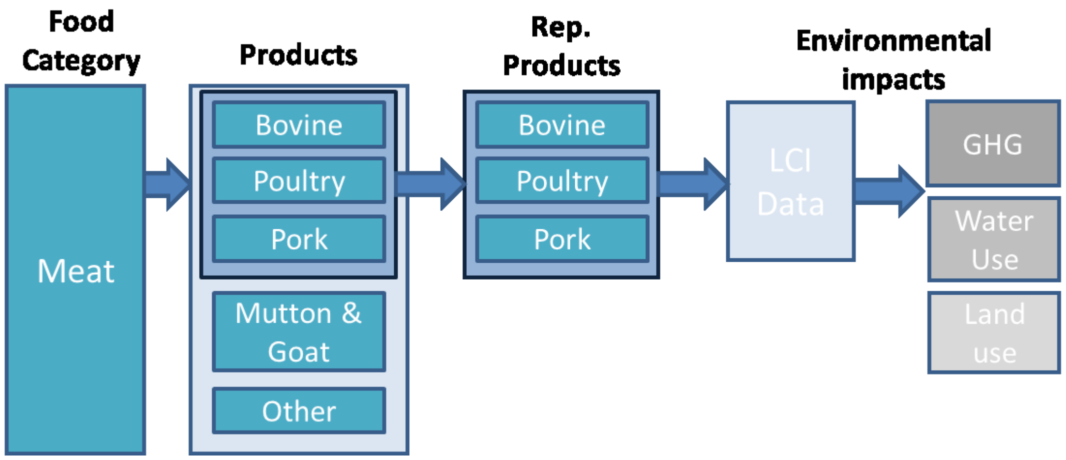
Food Categories	
Sugar Crops	**Beverages**
Sweeteners	**Meat**
Pulses	**Offals**
Treenuts	**Animal Fats**
Oil crops	**Eggs**
Vegetable Oils	**Milk (Excluding Butter)**
Vegetables	**Fish, Seafood**
Fruits	**Crustaceans**
Stimulants	**Aquatic Products**
	Infant Food
	Miscellaneous

Environmental impact data for the life cycle inventory was collected through a meta-study of previous LCAs and data was input for the different RFPs for each food category. Water use figures were provided from the Water Footprint Network (2015) for blue water[2] use. From the meta-study however, a limited number of studies provided LCI data for the different foods, with CO_2-eq emissions being most common. Other impact categories, such as emissions leading to eutrophication, toxicity and acidification were not available for a large number of the food products. When data were not available, comparable data was obtained from databases such as PE International (which recently changed name to Thinkstep) and EcoInvent 2.2. As such, impact categories in the life cycle assessments are limited to carbon footprint, blue water use and land use. See Annex B for more information on assumptions and sources for the data and the food categories used in the assessment.

For each modelled scenario and year, the environmental impacts are computed by compiling the environmental impacts of the aggregated result of all RFPs. The figures for each food product may differ depending upon the scenarios reviewed; see Scenarios section below. Figure 3 illustrates this procedure for the case of meat, which is represented by bovine, poultry and pork products.

[2] Blue water refers to water sources from surface or groundwater resources and includes losses through use in the product, evaporation or returned to another source (Water Footprint Network, 2015).

Figure 3: Method used to identify Representative Food Products and link to Environmental Impacts



The life cycle assessments of the different scenarios were conducted using GABI version 6.4 software and employing characterization factors from CML (2015), which excludes biogenic carbon dioxide, to provide results in kg CO_2-equivalent emissions. Results are also provided for resource consumption, e.g. blue water consumption (kg) and Land occupation indicator (m^2) from the same method.

Our approach assumes that productivity and yields in the agriculture sector will remain static; and that the environmental impacts associated with each kilogram or litre of production will be unchanged. In practice, however, further productivity gains are likely. To the extent that such productivity gains result in a decreased level of environmental impact per unit of production, our results can be assumed to somewhat over-estimate the impact of dietary change, and to over-estimate the total environmental impacts of production in the absence of dietary change.

5.1.3 Dietary Choice and Limit Scenarios

Using data for food consumption from the FAO and environmental impact data, different scenarios were created to model the environmental impacts related to the implementation of policies for changes in dietary choices in the European Union. For all scenarios, population increases were also taken into account for the years 2030 and 2050 (Eurostat 2015). The scenarios and associated assumptions are described below.

Table 2: Population in the EU in 2010 and projections for 2030 and 2050

2010*	2030	2050
506 014 000	518 499 055	525 527 890

*-Eurostat, 2015

Scenario 0-Food Consumption 2010

This scenario reviews the impacts associated with food consumption in the European Union based on the reference year for this study, i.e. 2010. For each subsequent time series (i.e.

2030 and 2050) the consumption of protein and total food are kept constant although the population increases according to figures in Table 3.

Scenario 1-Reduced Protein Scenario

In this scenario, the proportion of animal based protein was reduced to 35% and 25% for 2030 and 2050 respectively as outlined in the policy targets (Ekvall et al. 2015). This corresponds to a reduction of 27% and 48% for 2030 and 2050 respectively based on 2010 levels, see Table 3 below.

Table 3: Protein intake from different sources used in Scenario 1

		2010	2030	2050
Total Protein Animal and Fish	g protein/capita/day	61.3	29.6	14.7
Total Protein Vegetable	g protein/capita/day	43.5	54.9	44.2
Total	g protein/capita/day	104.8	84.5	58.9
Total Protein Animal, Milk, Eggs (no fish)	g protein/capita/day	53.0	25.6	12.7
% from Animal, Milk & Eggs	%	51%	35%	25%

In order to achieve this target, the animal based protein (from Milk, Eggs, Meat, Fish and Fats) was decreased by roughly 52% and 76% for 2030 and 2050 respectively compared to 2010 levels. The amount of vegetable based protein (from Cereals, Starchy Roots, Pulses, Vegetables and Fruits) was increased by roughly 26% in 2030. In 2050 a roughly 2% increase in vegetable protein compared to 2010 levels can be seen. This is due to the fact that the total amount of protein per capita was decreased significantly compared to 2010 and roughly 75% of that amount was to come from vegetable sources (i.e. 44.2 g) which is only slightly higher than 2010 levels, while in 2030 it will be necessary to increase the share of vegetable base protein to reach the targets. The respective intake of protein for 2010, 2030 and 2050 for different protein sources are shown in Table 4.

Table 4: Change in Protein from Animal and Vegetable Sources

		2030	2050
Animal Protein	% change	-52%	-76%

Vegetable Protein	% change	26%	2%

Scenario 2-Limits to Certain Meats

In this scenario, the proportion of animal based protein (from bovine, pork and poultry meat) is limited to regulated amounts as these sources have large land requirements and resource consumption. A shift to more poultry and a decrease in bovine and pork is included in this scenario. Table 5 below outlines the total percentages of each protein source and their respective increase and decrease. However, the model does not include an overall decrease in the total protein intake from these sources, only a shift from one meat source to another.

Table 5: Intake and percentage of various animal protein sources used in Scenario 2 to model limits for bovine, pork and poultry meat consumption

	2010		2030		2050	
	g protein/ capita/day	%	g protein/ capita/day	%	g protein/ capita/day	%
Bovine	6.2	**24%**	2.6	**10%**	1.3	**5%**
Pork	11.2	**43%**	10.4	**40%**	5.2	**20%**
Poultry	8.6	**33%**	13.0	**50%**	19.5	**75%**
Total from Bovine, Pork, Poultry (Excluding others)	26.0	**100%**	26.0	**100%**	26.0	**100%**

Scenario 3-Reduced Protein and Limits

Scenario 3 builds on the limits from Scenario 2, but also models an overall decrease in animal based protein as in Scenario 1. Thus, Scenario 3 is a hybrid of Scenario 1 and 2, modelling a decreased consumption of protein and then assigning limits to the amount of protein from bovine and pork, but increasing the amount of poultry.

Table 6: Intake and percentage of various animal protein sources used in Scenario 3 to model limits for bovine, pork and poultry meat with a decrease in animal protein consumption

	2010		2030		2050	
	g protein/ capita/day	%	g protein/ capita/day	%	g protein/ capita/day	%
Bovine	6.20	24%	1.25	10%	0.31	5%
Pork	11.20	43%	5.02	40%	1.25	20%
Poultry	8.60	33%	6.27	50%	4.69	75%
Total from Bovine, Pork, Poultry (Excluding others)	26.00		12.54		6.25	

5.1.4 Results

GHG Emissions

Results from the modelling are provided in Figure 4 and Figure 5 below in normalized emissions based on the emissions from the food balance of 2010. Table 7 below also outlines the emissions from each scenario in MTonne CO_2 equivalent per year.

Figure 4: Emissions of GHGs in Scenarios 0-3 for 2010, 2030 and 2050 (MTonnes CO_2-eq/year)

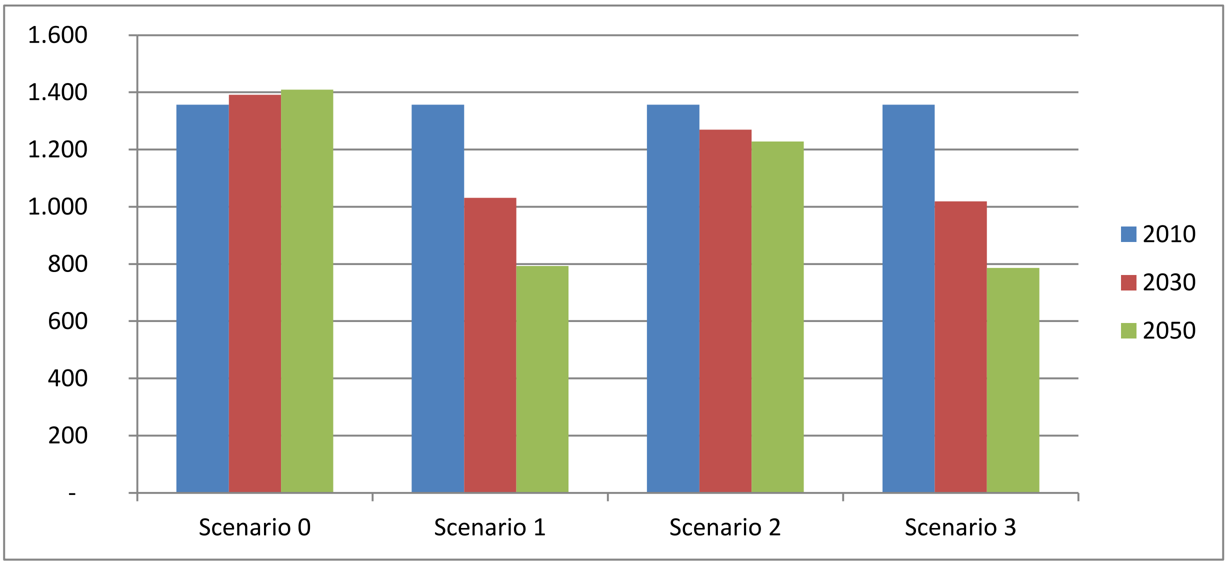
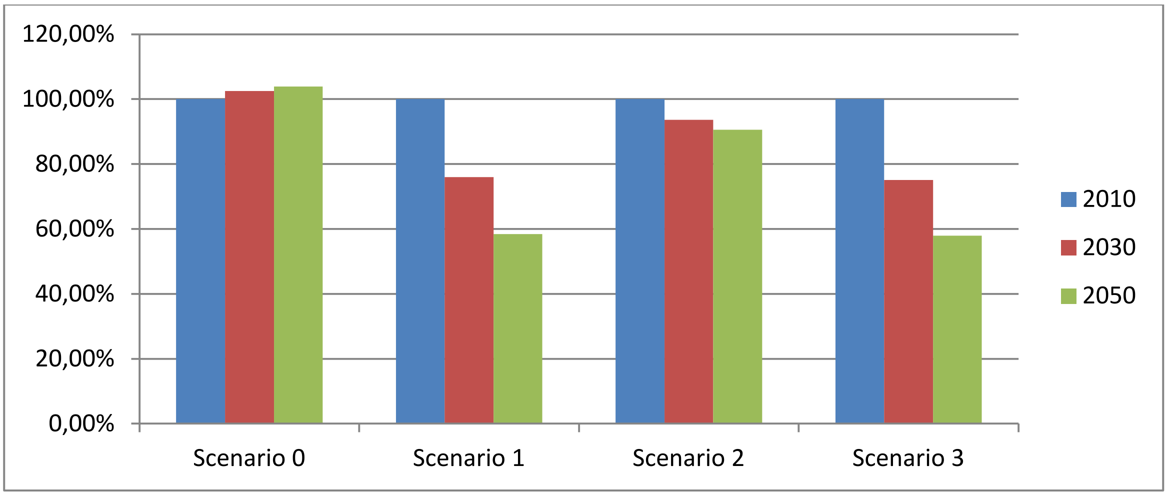


Figure 5: Normalized GHG Emissions Values based on 2010 values for Scenario 0

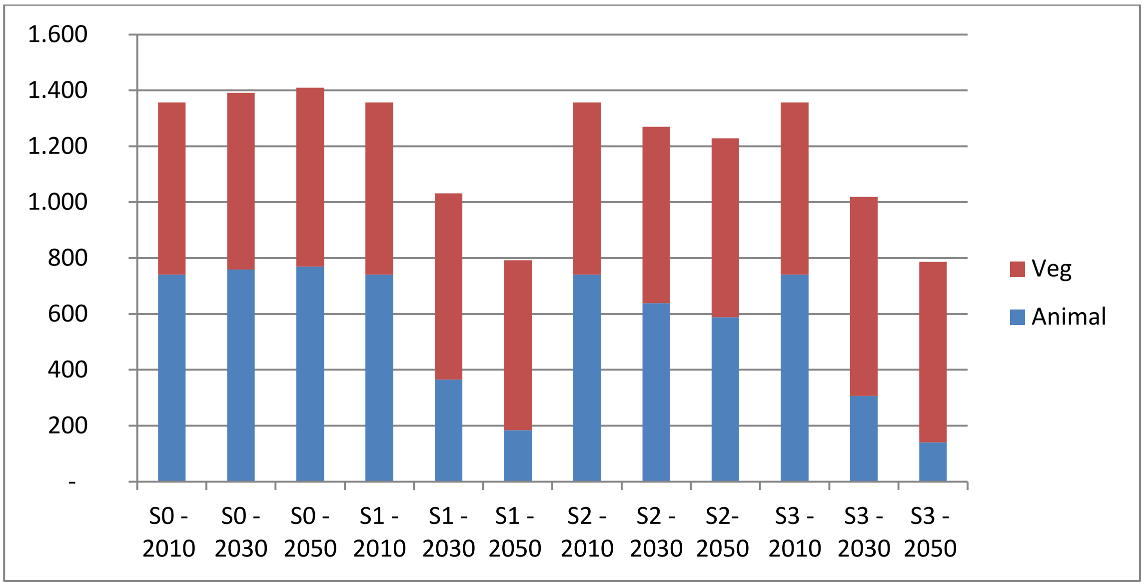


It can be seen in the figures above for Scenario 0 if no change is produced, an increase in emissions will occur. This is due to the fact that the consumption is assumed to be the same, while population increases accounting for this increase in emissions.

Table 7: GHG Emissions for Scenarios 0-3 (MTonnes CO_2-eq/year)

	2010	2030	2050
Scenario 0	1 360	1 390	1 410
Scenario 1	1 360	1 030	790
Scenario 2	1 360	1 270	1 230
Scenario 3	1 360	1 020	790

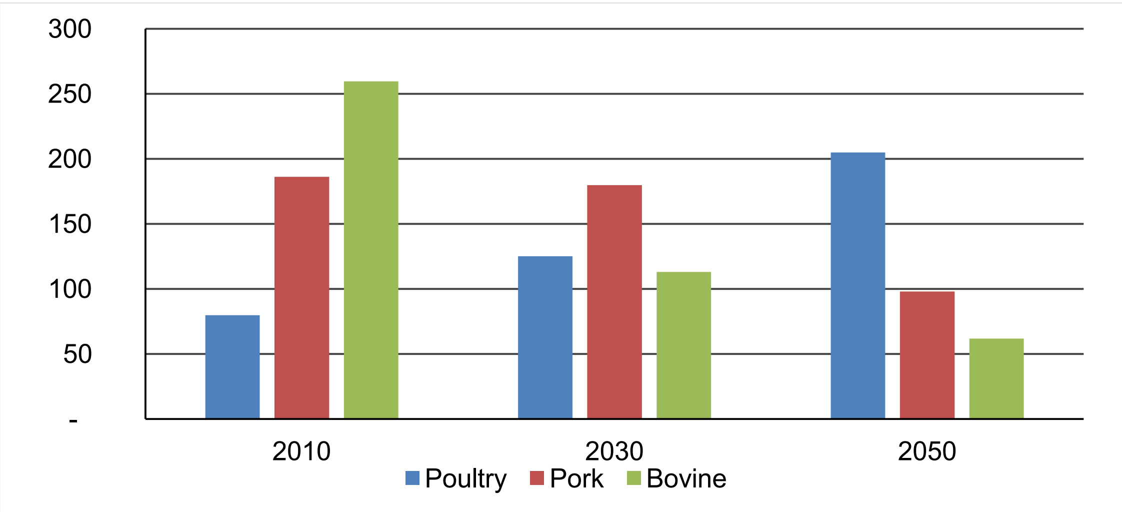
Figure 6: Emissions of GHGs for Vegetable and Animal Protein in Scenarios 0-3 for 2010, 2030 and 2050 (MTonnes CO_2-eq per year)



Scenario 1 illustrates a relatively large reduction in emissions, due primarily to the decrease in animal protein. This illustrates the potential for climate mitigation from this policy. However, the modelled system assumes that while animal protein decreases, vegetable base protein increases in 2030 (though per capita consumption is similar in 2050 to levels for 2010). As such, if vegetable protein was assumed to stay the same as 2010 levels, a larger decrease in emissions may be observed.

In Scenario 2 the animal protein origins are simply shifted to include more poultry and less bovine based protein. This shift results in large GHG emissions reductions (CO_2-eq) in both Pork and Bovine meats although a significant increase in poultry emissions occur, see Figure 6 and Table 7.

Figure 7: GHG Emissions from animal protein sources shifted in Scenario 2 (MTonnes CO_2-eq/year)



In Scenario 3, a decrease in animal-based protein consumption, including a shift toward more poultry was modelled. This resulted in slightly lower impacts in comparison to Scenario 2, again due to the scenario being a synthesis of Scenario 1 and 2.

It can be concluded from the results of the scenarios that, under the assumptions of this model, policies geared toward reducing protein intake have the largest impact to reduce the environmental impacts associated with CO_2-eq emissions.

Land Occupation

Figure 8 provides results for land occupation for the years 2010, 2030 and 2050 for the different scenarios. The resulting increase and decrease in land occupation follow similar trends as the emissions provided in Figure 4. This is due to the fact that the emissions from the food production are largely coupled to the agricultural production, and thus land occupation.

Figure 8: Land occupation normalized to the base year of 2010 (Million hectares per year)

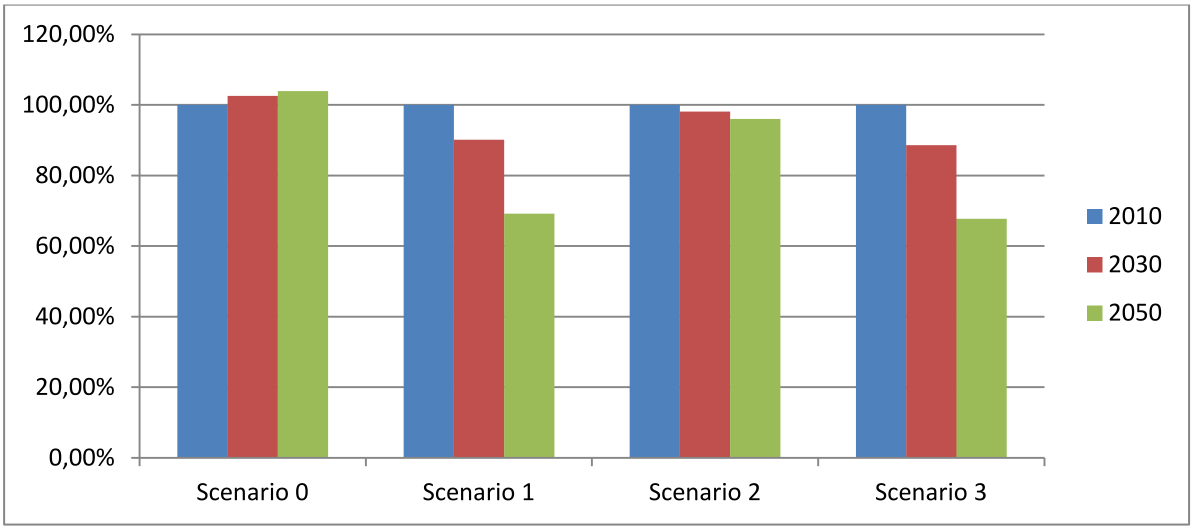


Table 8: Land occupation for Scenarios 0-3 (Million hectares per year)

Scenario	2010	2030	2050
0	310	320	325
1	310	280	220
2	310	305	300
3	310	280	210

Water Consumption

Figure 9 below provides results for the water consumption for the years 2010, 2030 and 2050 for the different scenarios.

Figure 9: Blue Water Consumption for Scenarios Normalized to 2010 Values

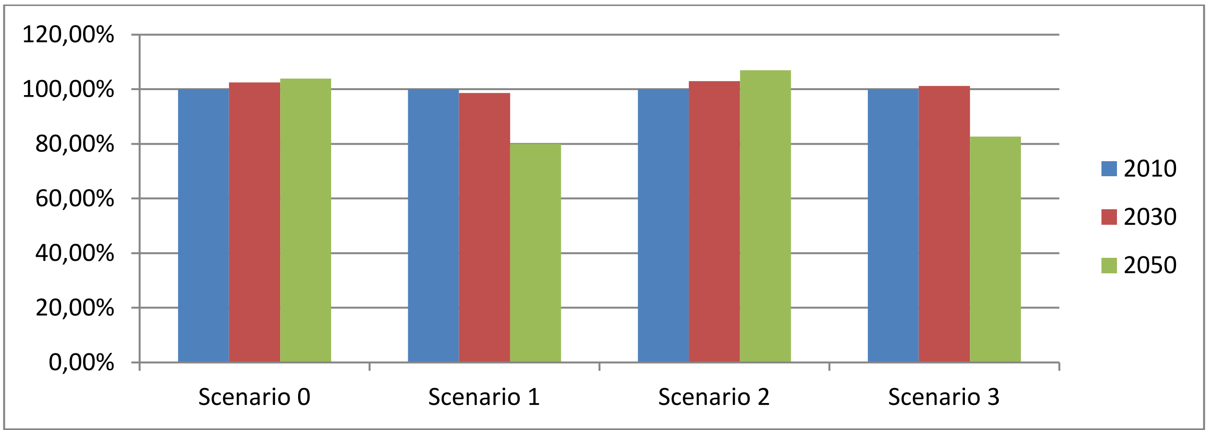


Table 9: Water consumption for Scenarios 0-3 (Mm^3 per year)

Scenario	2010	2030	2050
0	98 700	101 200	102 600
1	98 700	97 300	78 900
2	98 700	101 600	105 500
3	98 700	99 900	81 600

Results for the scenarios again follow a similar trend to the land occupation and GHG emissions, assuming similar food consumption but increased population. Scenario 3 shows the largest climate mitigation potential, although Scenario 1 has the largest single reduction using the policies to reduce protein consumption.

5.1.5 Addressing Decoupling through Dietary Policies

GHG Emissions

In 2010, GHG emissions per capita outlined in EEA (2012) were roughly 9.4 tonnes CO_2-eq. The goal is to improve this and have a maximum of 2 tonnes CO_2-eq per capita in 2050 Umpfenbach (2013). Assuming a 40% reduction in emissions per capita to 2030, this would provide a level of 5.64 tonnes CO_2-eq per capita in 2030; see

Table 10.

Table 10: GHG Emissions for 2010, 2030 and 2030 based on emissions reduction target (Tonnes CO_2-eq per capita and total emissions per year)

	2010	2030	2050
Per Capita Emissions (Tonnes CO_2-eq per capita)	9.4	5.6	2.0
Population	506 014 000	518 499 060	525 527 890
Total Emissions (Tonnes CO_2-eq per year)	4 756 531 600	2 924 334 670	1 051 055 780

Table 11 shows the normalized emissions for the food sector and compares it with total European emissions. In 2010, the food sector (i.e. impacts related to food consumption in the EU) accounted for roughly 29% of all emissions based on the emissions per year calculated in the preceding assessments. As Table 7 shows, for Scenarios 1-3, emissions reductions occur in 2030 and 2050. However, compared to targets to reduce per capita emissions in 2050 to 2.0 tonnes per capita, the modelled scenarios, although showing improvements and environmental impact reductions, do not show a large potential for decoupling economic growth and environmental impacts in the food sector. Furthermore, in 2050 from the given scenarios, the food sector is seen to have a large share of the European emissions, with some scenarios over shooting the entire targets.

Table 11: Normalized GHG emissions for modelled EU-27 food consumption scenarios in total CO_2-eq emissions in comparison to total European emissions

Scenario	2010	2030	2050
0	29%	48%	134%
1	29%	35%	75%
2	29%	43%	117%
3	29%	35%	75%

Despite emissions reduction potential, more may need to be done in the food sector to decouple the environmental impacts and meet European targets. This study reviewed only reducing dietary considerations. However, as many of the impacts from the agricultural sector come from agricultural processes, improvements in these systems by using less conventional fertilizers, greater efficiency, ecological production and many other scenarios could be combined to see the effects that these may have for the years 2030 and 2050.

Land Use

It was estimated that the European Union had roughly 164 million hectares of cultivated land and 76 million hectares of permanent pasture land (Fischer et al. 2010) as a reference for 2010.

Table 12 provides a review of the land use for production of food (including livestock) for the different scenarios in the years 2010, 2030 and 2050. Normalized figures based on the land use in 2010 were used to understand how the land use may change in the years 2030 and 2050 for the food production scenarios in the policy mix. It is important to address that in Table 12, figures for more than 100% of the land currently used for food production in Europe are presented, which is due to imports of food.

Table 12: Land Use Figures for food production scenarios in total hectares in comparison to total European agricultural land availability

Scenario	2010	2030	2050
0	130%	133%	135%
1	130%	117%	90%
2	130%	127%	125%
3	130%	115%	88%

Scenarios 1-3 show a reduction in overall agricultural land use. These reductions thus extend to land outside of the EU, and a reduction in non-EU and EU land may be identified. The largest reductions in land use are apparent in Scenarios 1 and 3 which account for reduced food production due primarily to a reduction in meat. Imports and exports of food were not considered in the model. However, it may be interesting to understand where the land use occurs in further detail, as this will affect the nature and extent of environmental impacts including, for example, through deforestation.

Water Consumption

As a whole, the freshwater resource of Europe is renewed by a total of around 2 270 km^3 each year. Only a relatively small proportion is abstracted: it is estimated that roughly 13% of this resource is abstracted for various uses (EEA 2009). In order to identify if water stress occurs from the policy mixes reviewed in Scenarios 0-3, the freshwater resources and the amount used for the production of different foods were assessed. Estimates for 2009 from the European Environmental Agency of a withdrawal of 288 km^3/year were assumed for 2010 (EEA 2009). These were thereafter compared with figures for the years 2010, 2030 and 2050 outlined in the quantifications above.

Table 13 provides a review of the total water consumption of available resources in Europe for the production of food in Scenarios 0-3 in the years 2010, 2030 and 2050. No significant increase in water consumption can be identified in the scenarios. Scenarios 1 and 3 show a slight reduction in water consumption. Again, it should be noted that these environmental impacts are not EU-specific, and will occur both within and outside the EU.

However, as the comparison is based on figures for 2010, and does not assume an increase in population, a slight increase in water consumption for 2030 and 2050 per capita may be neglected. Furthermore, while the results show little to no reduction in water consumption for the different scenarios and years, the distribution and abstraction varies across regions, leading to imbalances across Europe. However, these have not been modelled in this project, as further details on where different foods are produced were not included.

Table 13: Use of Available Water Resources for Food Production in Europe in Scenarios 0-3

Scenario	2010	2030	2050
0	4.3%	4.5%	4.5%
1	4.3%	4.3%	3.5%
2	4.3%	4.5%	4.6%
3	4.3%	4.4%	3.6%

5.2 Food redistribution programmes and food waste (LAND)

In the EU, it is estimated that roughly 90 million tonnes of food are wasted every year (Monier et al., 2010). In order to tackle these losses, the European Commission (2011) has developed goals to halve the amount of edible food wastes in the EU by 2020 by targeting resource efficiency in the food sector. The EU Waste Framework Directive sets a target for recycling of household waste at 50% by 2020, which also includes biodegradable waste. Furthermore, the EU Landfill Directive also requires Member States to reduce landfill of municipal biodegradable waste.

Waste is created in all processes along the life cycle from agricultural production to final consumption. Agricultural processes associated with the production of food account for nearly 15% of European emissions (Scholz et al. 2014). Nonetheless, with regards to food waste, the retail and household sectors are considered to be of utmost importance in industrialized countries as a large quantity of waste is generated in these sectors which can be avoided (Gustavsson et al. 2011; WRAP 2014). Households have been identified as the single largest producer of food waste, representing roughly 42% of the total in 2009 (BIO Intelligence 2010; 2012).

Food wastes can be reduced, in particular for the retail and household sectors, through information campaigns and food donation programs (Schneider 2013; BIO Intelligence,2012). As food waste also relates to dietary choices, consumers are of utmost importance to influence the environmental impact associated with food wastes. This can include addressing careless buying, portion sizes and accepting less visual appealing and ripe foods. It is also possible to address the possibility of food donation programs to divert foods to new uses before they are wasted.

The organic fraction of waste varies considerably between Member States. Norway and Latvia reported having less than 20% of the municipal waste containing biodegradable waste (which includes food and other fractions such as paper, etc.) while Greece, Portugal and Slovakia may have over 50% of their municipal solid waste from biodegradable sources. There is a general lack of statistics on the treatment of organic and food wastes from municipal waste in Europe. As food wastes are often included in municipal waste, we assume in our calculations that food waste is managed with the same way as municipal waste.

5.2.1 Scope

This study addresses policy mixes addressed by Ekvall et al. (2015) aiming to assess the environmental impacts created from food waste generated from households and retailers. This is done by addressing measures for reductions in avoidable food wastes and limits for higher generation of food waste per capita in the future. Furthermore, the study will also review the potential improvements that may be seen from food donation programs. Environmental impacts and consequences of food system changes will be reviewed. This will include altered food waste handling alternatives, e.g. increased anaerobic digestion and reduced landfilling. Scenarios are created for current (2010) food consumption and targets for 2030 and 2050. The study does not take into account changing food patterns and dietary choices outlined above. Changes to food wastes (and composition of the foods) are furthermore not taken into account and the food waste composition is assumed to be constant.

5.2.2 Model

The food waste modelling is based on the model created for the dietary choices and limits for protein intake as described above, which uses the same FAO statistics from the Food Balance Sheets for 2010. The model for food redistribution programs and food wastes will also review scenarios related to policy mixes in 2030 and 2050 as outlined by Ekvall et al (2015).

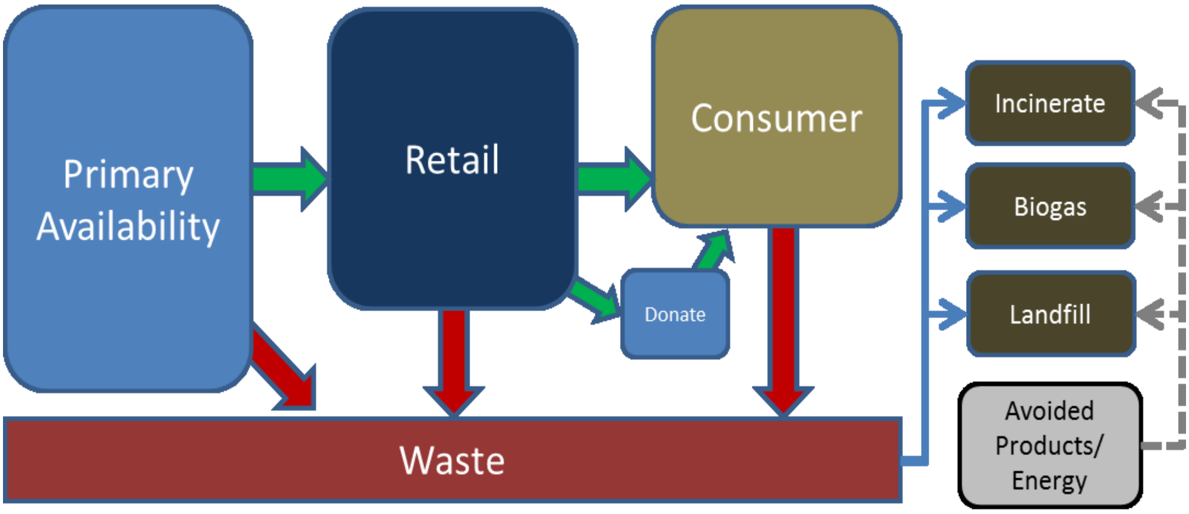
In order to model the waste created along the food life cycle, assumptions are made for the waste amounts produced from the primary availability, retail and consumers. Waste from the primary availability stage, i.e. agricultural and food manufacturing, was not modelled in this study as the focus was on changes in the retail and consumer markets and no change was assumed in the agricultural and production industries. Thus waste figures and amounts to treatment options, e.g. incineration, biogas production, landfilling, etc. are based on waste figures from the retail and consumer stages (Eurostat 2015).

Scenarios are used to review of the implications of policies to reduce environmental impacts for wastes and waste handling:

- Scenario 1 simulates the implications of reductions in waste at the retail and consumer sectors. Scenario 1 will also test the assumptions related to the amount of avoidable waste in the retail and household sectors. The proportion of production wastes is assumed to be comparable for 2030 and 2050.
- Scenario 2 simulates the implications that food donations (otherwise wasted) from consumers and retail have on the environmental impacts.
- Scenario 3 simulates the implications that changes in waste handling will have on the environmental impacts and include the potential benefits from avoided products and energy.

Furthermore, for each scenario several sub-scenarios will be tested. These include e.g. a change in the production input of foods (due to a reduction in food wastes).

Figure 10: Life cycle stages for modelling food wastes. Avoided products and energy have also been included from the different waste handling methods to account for fertilizers, products and energy replaced (denoted with a grey box and dashed arrows)



5.2.3 Scenario 1-Changes in Food Wastes from Retail and Households

Assumptions have been made for losses throughout the life cycle based on information provided by the FAO Stat (2014), which are losses based on the input of each food category into the e.g. the Retail and Household stage. Beverage losses are assumed to be similar to Milk. Avoidable waste estimates for foods and beverages for retail and household wastes are provided from WRAP (2012) and have been assumed to be relevant for 2010 in Europe (60% for foods and 58% for beverages). Ekvall et al. (2015) outline reductions in avoidable food waste of 60% for 2030 and 85% reduction for 2050. The final waste share has been calculated by taking into account the avoidable fraction and reducing this by the targets set for 2030 and 2050 in Scenario 1d which can be compared with Scenarios 1a and 1b.

Scenario 1a

Scenario 1a modelled waste handling for the years 2030 and 2050 based on figures from 2010 with no change in handling methods. Scenario 1a reviews increased population and thus waste in order to compare with changes made in other scenarios. Waste created from each sector and for the different food categories have been assumed to be the same as those identified for the reference system in 2010. In Scenario 1a, it was assumed that all food waste is avoidable in the retail and household sectors (a comparison is made in Scenario 1d for avoidable wastes of roughly 60% from the household and retail sectors). See Annex B for a review of the total amounts of waste for each sector for all scenarios.

Table 14: Waste Percentages from Different Sectors for each Food Category used in Scenario 1a

Food Category	Avoidable Losses	% Waste from Each Sector		
		Production	Retail	Households
Cereals	100%	15.8%	2.0%	25.0%
Roots and Tubers	100%	38.1%	7.0%	17.0%
Oilseeds and Pulses	100%	15.4%	1.0%	4.0%
Fruit & Veg	100%	25.5%	10.0%	19.0%
Meat	100%	8.6%	4.0%	11.0%
Fish/Seafood	100%	15.3%	9.0%	11.0%
Milk	100%	5.1%	0.50%	7.0%
Beverages, Other	100%	5.1%	0.50%	7.0%

Table 15: Average Waste from Different Sectors in Scenario 1a

	2010	2030	2050
Production	21%	21%	21%
Retail	4%	4%	4%
Household	14%	14%	14%

In Scenario 1a waste treatment processes were assumed to be similar to the levels from 2010, see

Incineration of food waste was modelled as *Waste incineration of biodegradable waste action in municipal solid waste* (PE-professional database). For the incineration of waste with energy recovery, the transformation to electricity and heat replaces 0.5 MJ of European electricity and 1.3 MJ of European heat per kg of biodegradable waste. Incineration with no energy recovery was assumed to have no replaced conventional energy sources.

Table 16. Further scenarios reviewed the effects of changing the waste handling systems toward less landfilling and more energy production from food wastes.

Incineration of food waste was modelled as *Waste incineration of biodegradable waste action in municipal solid waste* (PE-professional database). For the incineration of waste with energy recovery, the transformation to electricity and heat replaces 0.5 MJ of European electricity and 1.3 MJ of European heat per kg of biodegradable waste. Incineration with no energy recovery was assumed to have no replaced conventional energy sources.

Table 16: Waste Handling Percentages used in Scenario 1a

Waste Management	2010-2050
Incineration	7%
Incineration w/ Energy Recovery	24%
Anaerobic Digestion	10%
Composting	9%
Landfill	50%

Anaerobic digestion of the food waste was modelled based on the LCI data from PE International, labelled *Biowaste to anaerobic digestion*. It was assumed that 85% of the food waste is digested while 15% is classified as reject and incinerated. Biogas produced from the anaerobic digestion process was assumed to be upgraded to roughly 96% methane with a lower heating value of 23 MJ/Nm3. Digestate produced from the anaerobic digestion process was assumed to replace conventional fertilizer. Every tonne of digestate produced in the biogas plant (wet weight) was assumed to replace 8.00 kg N, 5.00 kg NH4, 1.00 kg P and 1.50 kg K (Martin et al., 2014). In the model, NH_4 was assumed as N-fertilizer. Composting was assumed to replace an avoided amount of produced inorganic fertilizer, and the amount was assumed to be equal to the digestate produced in the biogas plant.

Landfilling of food waste was assumed to occur with methane capture and subsequent electricity production. This was modelled as *Landfill of biodegradable waste* (PE-professional database) with 0.26 MJ of electricity produced for every 1kg of food waste landfilled.

Scenario 1b

Scenario 1b is used to model policy targets outlined by Ekvall et al. (2015) on improvements in household and retail wastes. These include 60% less wastes (total output from Europe) from the retail and household sectors in 2030 and thereafter increasing this to 85% in 2050. Once again, it was assumed that 100% of the food waste in the retail and household sectors is avoidable and reductions are used to model the amount of waste going into food waste handling systems, see Table 17 below. Similar Waste Management handling systems are used in Scenario 1b as in 1a.

From the figures above, averages for the total food waste the production, retail and household sectors have been calculated as shown in Table 18.

Table 17: Wastes for Food Categories at the Retail and Household Stages for 2010, 2030 and 2050 used in Scenario 1b

	Avoidable Waste	2010		2030		2050	
		Retail	Households	Retail	Households	Retail	Households
Cereals	100%	2.0%	25.0%	0.80%	10.0%	0.30%	3.75%
Roots and Tubers	100%	7.0%	17.0%	2.80%	6.80%	1.05%	2.55%
Oilseeds and Pulses	100%	1.0%	4.0%	0.40%	1.60%	0.15%	0.60%
Fruit & Veg	100%	10.0%	19.0%	4.00%	7.60%	1.50%	2.85%
Meat	100%	4.0%	11.0%	1.60%	4.40%	0.60%	1.65%
Fish/Seafood	100%	9.0%	11.0%	3.60%	4.40%	1.35%	1.65%
Milk	100%	0.5%	7.0%	0.20%	2.80%	0.08%	1.05%
Beverages, Other	100%	0.50%	7.0%	0.20%	2.80%	0.08%	1.05%

Table 18: Average Waste from Different Sectors in Scenario 1b

	2010	2030	2050
Production	21%	21%	22%
Retail	4%	2%	1%
Household	14%	5%	2%

Scenario 1c

Scenario 1c is based on Scenario 1b, with waste reductions as outlined above. However, as waste is reduced, and if it is assumed that we consume similar amounts of food per capita and year, production of food may be reduced. In Scenario 1c, reductions in production of food are modelled. This is done by setting the consumption of food the same as in Scenario 1a and b and thereafter calculating the amount of waste from and food entering the retail, household and production sectors using the waste percentages above. Thus, the production figures of different RFPs can be calculated for the years 2030 and 2050. This resulted in e.g. a reduction of 12% total food production in 2030 and 16% in 2050.

Scenario 1d

Scenario 1d will review the reduction of avoidable waste compared to 2010 levels in order to test the assumptions in Scenario 1b of 100% avoidable food waste for all food categories. Avoidable wastes are outlined by WRAP (2012), as mentioned previously, to include 60% from foods and 58% from beverages. Table 19 and

Table 20 below show the new wastes created for each food category and sectors for 2010, 2030 and 2050. Waste management scenarios used in Scenario 1a were also used in Scenario 1d (thus, an assumption that no change in waste management occurred) in order to understand the differences in decreasing the amount of waste produced.

Table 19: Wastes for Food Categories at the Retail and Household Stages for 2010, 2030 and 2050 used in Scenario 1d (including 60% avoidable waste)

	Avoidable Waste	2010		2030		2050	
		Retail	Households	Retail	Households	Retail	Households
Cereals	60%	2.0%	25.0%	0.32%	4.00%	0.12%	1.50%
Roots and Tubers	60%	7.0%	17.0%	1.12%	2.72%	0.42%	1.02%
Oilseeds and Pulses	60%	1.0%	4.0%	0.16%	0.64%	0.06%	0.24%
Fruit & Veg	60%	10.0%	19.00%	1.60%	3.04%	0.60%	1.14%
Meat	60%	4.0%	11.0%	0.64%	1.76%	0.24%	0.66%
Fish/Seafood	60%	9.0%	11.0%	1.44%	1.76%	0.54%	0.66%
Milk	58%	0.5%	7.0%	0.08%	1.18%	0.03%	0.44%
Beverages, Other	58%	0.50%	7.00%	0.08%	1.18%	0.03%	0.44%

Table 20: Average Waste from Different Sectors in Scenario 1d

	2010	2030	2050
Production	21%	21%	22%
Retail	4%	2%	1%
Household	14%	7%	2%

5.2.4 Scenario 2- Food Donation Systems

The amount of food from the retail sector is assumed to include 20% of all food wastes. Furthermore, an 80% efficiency is assumed (i.e. 80% of food donated is consumed with 20% ending as a waste). Donations are assumed to only occur from the retail sector only and include 0.8% from the retail sector in 2030 and 1.3% in 2050. It is assumed that waste management systems are similar to Scenario 1a.

Table 21: Waste Shares from Each Sector with Donations in Scenario 2a

Waste Management	2010	2030	2050
Production	21%	21%	21%
Retail	4%	3.2%	2.7%
Household	14%	14%	14%

Scenario 2b thereafter reviews how donations may be affected by the reduction of food wastes in the retail sector when using the same reductions as in Scenario 1b, again with a fraction of the waste from the retail sector destined for donations.

Table 22: Waste Shares from Each Sector with Donations in Scenario 2b

Waste Management	2010	2030	2050
Production	21%	21%	21%
Retail	4%	1.5%	0.5%
Household	14%	14%	14%

5.2.5 Scenario 3- Changed Waste Handling Systems

Scenario 3 is based upon Scenario 1, but will take into account the policy targets on reduced waste production. These include limits to food wastes in the EU, taking into account population increases. In 2030 this is set at a maximum of 30% increase in waste while the cap is set at 15% increase in waste production in 2050 compared to 2010 levels. In each of the scenarios assumptions have been made on the waste handling processes for food wastes. Once again, waste from the primary availability stage was not modelled and has remained the same. Table 23 provides a review of the assumptions used for the distribution of food wastes to different waste treatment options.

Scenario 3a uses wastes shares from the different sectors (i.e. production, retail and households) from Scenario 1a. Scenario 3b uses wastes shares from Scenario 1b to review how reductions in Wastes will affect the environmental impacts associated waste handling systems with less waste.

Table 23: Waste Treatment Options for Different Scenarios in Scenario 3

	2010	2030	2050
Incineration	7%	5%	0%
Incineration w/ Energy Recovery	24%	35%	45%
Anaerobic Digestion	10%	30%	40%
Composting	9%	5%	5%
Landfill	50%	25%	10%

Many European countries use biogas for electricity production, although e.g. Sweden uses most biogas for vehicle fuel (EuroObserv'ER 2014). It is assumed that biogas will continue to grow as a vehicle fuel in Europe to meet targets for renewable fuels in the transportation sector, i.e. 20% by 2020 (European Commission 2009). It was also assumed that 20% of biogas produced will be used as a vehicle fuel in 2030 and 30% in 2050.

Table 24 below outlines the assumptions used for modelling the use of biogas.

Table 24: Assumptions for biogas utilization

	2010	2030	2050
Electricity	99.5%	80%	70%
Vehicle Fuel	0.5%	20%	30%

5.2.6 Results

GHG emissions

Figure 11: GHG Emissions for Scenarios 1a-3b for Food Production and Waste Management for years 2010, 2030 and 2050 (Million tonnes CO_2-eq/year)

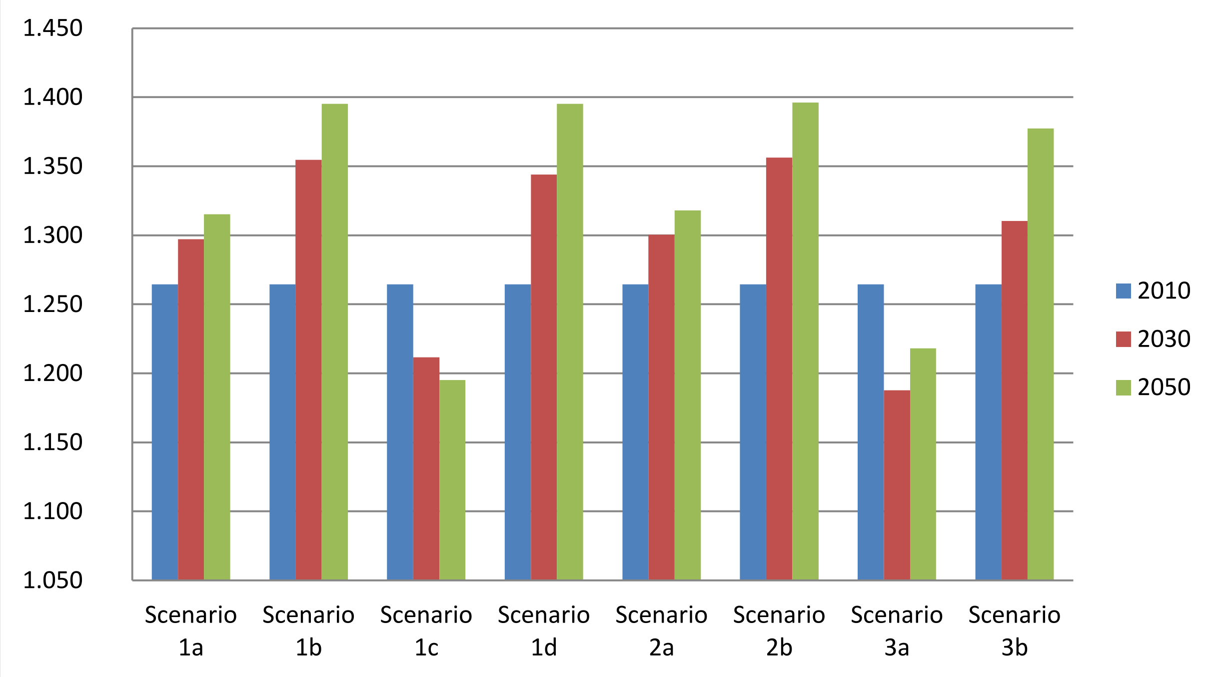


Figure 12: Normalized GHG Emissions for Food Production and Food Waste Management Scenarios to 2010 levels

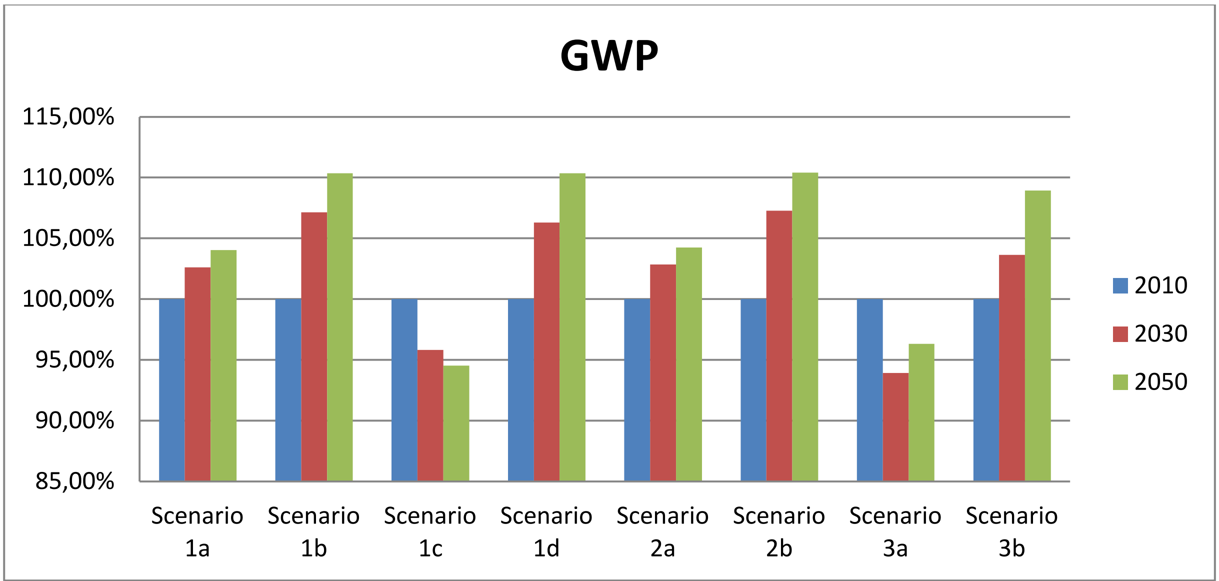


Figure 11 and Figure 12 above shows results for the GHG emissions for the different scenarios. In Scenario 1a no change in waste management is modelled for the different years, although an increasing amount of waste from the food sector is associated with a population increase. Scenario 1b shows that by changing the current waste amounts of waste, we may actually increase our emissions. This is due primarily to a reduction in feedstock for incineration plants, which leads to reduced electricity output and thus a reduction in avoided emissions. Furthermore, the model for incineration includes a small share of methane capture from landfills, and thus emissions resulting from methane slip from landfills are not dominant in the results. However, once again Scenario 1b assumes that although waste is reduced, the production would remain the same. Therefore, Scenario 1c was modelled to understand how a reduction in waste would result in a reduction in food production. As such, a large decrease in emissions can be seen, due primarily to the reduction of emissions from food production. While Scenarios 1a-1c review an assumed avoidable waste share of 100%, Scenario 1d thereafter reviews modelling the waste when only 60% is assumed to be avoidable. This led to slightly lower emissions when compared to Scenario 1b but not significant.

Table 25: GHG emissions for food production and food waste management including and avoided products/processes in Scenarios 1a, 3a and 3b for 2010, 2030 and 2050 (Mtonnes CO_2-eq/year)

	Scenario 1a		Scenario 3a		Scenario 3b	
	Waste Manag	**Avoided**	**Waste Manag**	**Avoided**	**Waste Manag**	**Avoided**
2010	1 264	-502	1 264	-502	1 264	-502
2030	1 297	-515	1 188	-1 231	1 310	-487
2050	1 315	-522	1 218	-1 403	1 377	-237

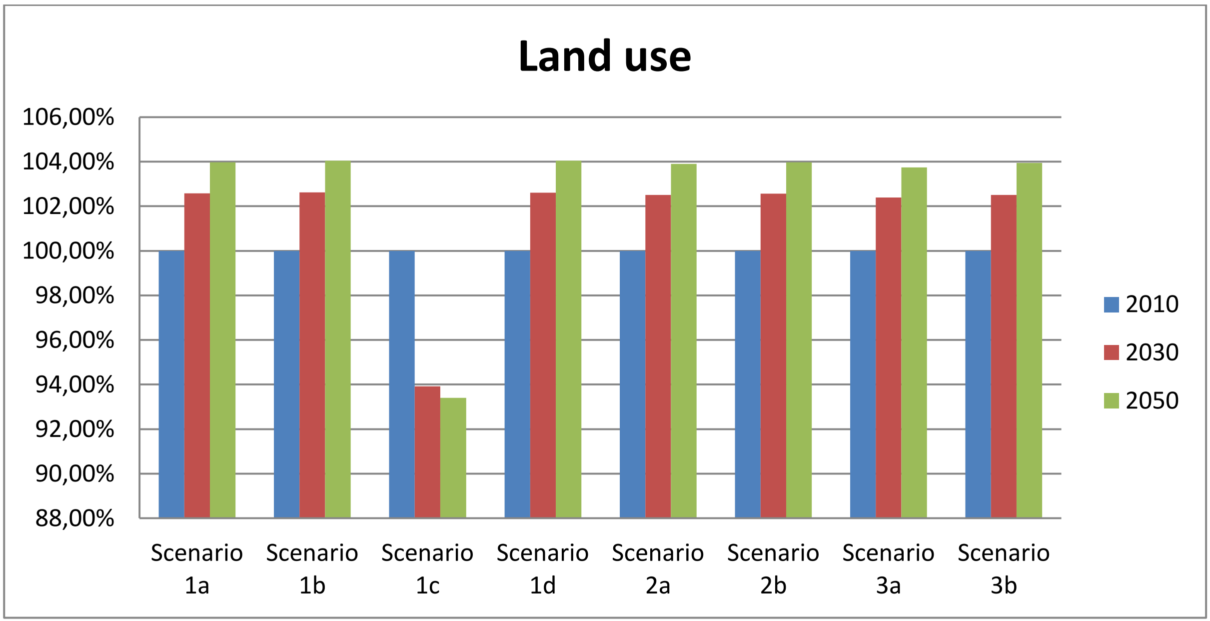
Scenario 2 provides a review of the effects that food donation programs may have. While waste may be avoided, in comparison to the magnitude of the impacts of the production of food and other wastes, the donations did not cause any noticeable emissions reductions. Furthermore, when policies call for a decrease in food wastes, the emissions may seem to increase. Again however, this is due to including negative emissions due to the avoidance of conventional products produced from waste management by-products and energy production.

Scenario 3a and b provide a review of possible changes in the waste handling for food waste to produce more biogas, while reducing the amount of food waste that is landfilled. When comparing Scenario 3a in to Scenario 1a a large decrease in emissions can be seen in 2030 and 2050. This is due to the fact that the by-products and energy produced from avoided products and processes lead to large negative emissions. In Scenario 3b, a relative increase in emissions can be seen, due to less avoided emissions when less waste is produced although the emissions are reduced in comparison to Scenario 1b.

Land Occupation

From Figure 13 it can be seen that the largest reductions in land occupation occur in Scenario 1c. This is due to the fact that in Scenario 1c, the reduced production of foods causes a large reduction in land use. Other scenarios, although they reduced the use of land for landfills, will require land for other purposes (i.e. anaerobic digesters, incineration plants, composting, production of the materials needed, etc.) which do not significantly reduced the land use for the other scenarios in comparison to Scenario 1a.

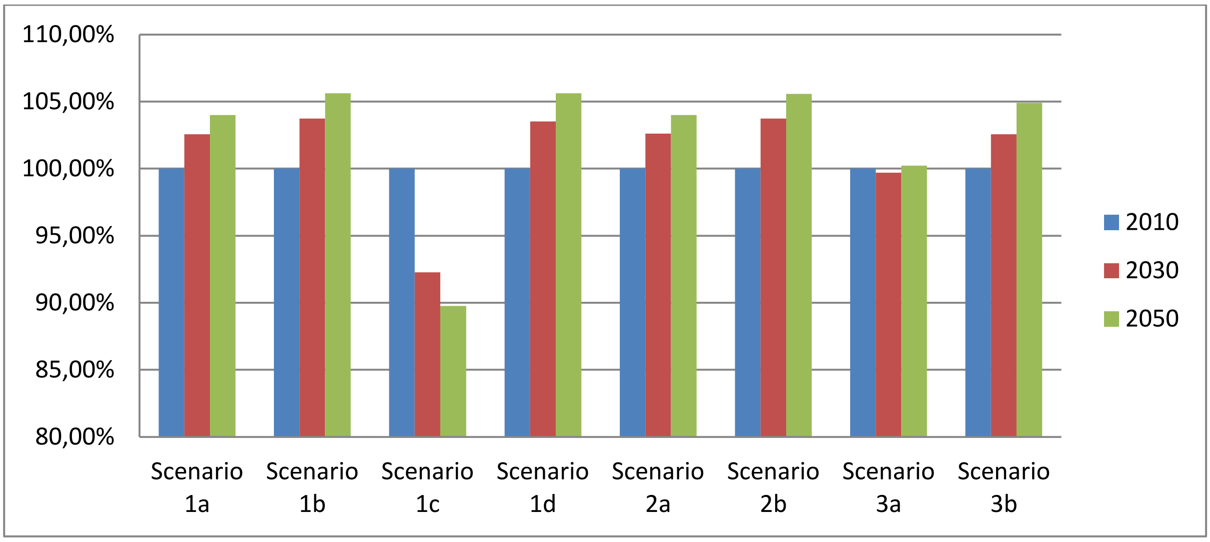
Figure 13: Normalized values for land occupation for Scenarios 1a-3b with reference in 2010 for Scenarios 1a-3b



Water Consumption

From Figure 14, similar to the land use, it can be seen that the largest reductions in water use occur in Scenario 1c. This again is due to the reduction in water use due primarily to the modelling of reduced food consumption in Scenario 1c. Other scenarios may have slight increases and reductions although these are not significant compared to Scenario 1c.

Figure 14: Normalized values for blue water consumption with Reference in 2010 for Scenarios 1a-3b



5.2.7 Addressing Decoupling through Food Waste Policies

While the scenarios may provide environmental impact reductions, it is important to understand how they may relate to targets for EU emissions reductions and the 5 targets of the DYNAMIX Project.

GHG Emissions Reductions

Table 26 provides a review of the share of emissions from food consumption in the EU (and waste handling in this policy mix) and compares them to total EU emissions.

Table 26: Normalized Emissions for Scenarios 1a-3b in total CO_2-eq emissions in comparison to total European emissions

Scenario	2010	2030	2050
Scenario 1a	27%	44%	125%
Scenario 1b	27%	46%	133%
Scenario 1c	27%	41%	114%
Scenario 1d	27%	46%	133%
Scenario 2a	27%	44%	125%
Scenario 2b	27%	46%	133%
Scenario 3a	27%	41%	116%
Scenario 3b	27%	45%	131%

Results are based on reference values for total European emissions from

Table 10. Food consumption and waste management of food waste are relatively large in comparison to total EU emissions (i.e. 27%) in 2010. Using the different scenarios this would increase to between 41 and 46% depending on the scenario in 2030 and overshoot emissions targets in 2050 for all scenarios (again, it should be noted that our estimates of emissions from food production and consumption do not distinguish between emissions taking place inside or outside the EU, so a direct comparison with total EU production emissions should be treated with caution). As such, food production and waste handling policies may need to become even more stringent to meet decoupling goals outlined for a per capita CO_2-eq emission level of 2 tonnes CO_2-eq per capita and year.

Land Use

Table 27: Land Use Figures for Scenarios 1a-3b in total hectares in comparison to total European agricultural land availability

Scenario	2010	2030	2050
Scenario 1a	130%	133%	135%
Scenario 1b	130%	133%	135%
Scenario 1c	130%	122%	121%
Scenario 1d	130%	133%	135%
Scenario 2a	130%	133%	135%
Scenario 2b	130%	133%	135%
Scenario 3a	130%	133%	135%
Scenario 3b	130%	133%	135%

Results from the waste scenarios 1a-1b differ from the protein reduction scenarios. In Scenarios 1a-3b, the land use showed a slight increase. However, in Scenario 1c, which accounts for a reduction of food production. Once again, the other scenarios do not account for this reduction, and have been modelled to identify the reduced environmental impacts associated with different waste management strategies. Although, the increases and decreases are not significant, the results do not provide evidence that targets may be met for reduced land consumption.

Water use

Table 28: Use of Available Water Resources for Food Production and Waste Management in Europe in Scenarios 1a-3b

Scenario	2010	2030	2050
Scenario 1a	4.3%	4.4%	4.4%
Scenario 1b	4.3%	4.4%	4.5%
Scenario 1c	4.3%	3.9%	3.8%
Scenario 1d	4.3%	4.4%	4.5%
Scenario 2a	4.3%	4.4%	4.4%
Scenario 2b	4.3%	4.4%	4.5%

Scenario 3a	4.3%	4.3%	4.3%
Scenario 3b	4.3%	4.4%	4.5%

Similar to the scenarios on protein reductions, an estimated 288 km3/year was assumed for the reference year 2010 (EEA, 2009). Comparisons were then made for the years 2010, 2030 and 2050 to estimate the use of available water resources in Europe for Scenarios 1a-3b. Results showed a similar trend as those in the protein reduction scenarios, i.e. no significant change in water consumption for 2030 and 2050. As such, it can be concluded that the policy mixes may meet targets for no water stress.

5.3 Product standards for water piping (METALS)

The product standards are intended to regulate the design of important products with the aim to, for example:

- increase modularity and reparability of the products,
- reduce unnecessary use of materials, and
- substitute metals for other materials when appropriate.

The quantitative analysis focuses on the principle of substituting metals for other materials; in specific, shifting from copper water-piping to polymer (PEX) piping.

5.3.1 Studied system

Copper pipes have been used for a long time in residential and commercial plumbing systems. During these years, many competing materials have been tested and later plastic pipes have entered the water system in residential buildings (CDA 2014). Today common materials for piping include copper, CPVC and PEX. There are different opinions about the materials, some maintain that copper is to be preferred while others promote plastic water pipes. The information available for the different pipe systems vary depending on the source making it important that the installer of the system considers the circumstances for the specific case.

Most sources found for water pipe system trends relate to the US market. Trends indicate that plumbing with plastic material is increasing. This is primarily due to the fact that it is cheaper, easier to install and that in doesn’t require “junctions” (Rotella 2013). The trend for Europe seems to be similar with an increase use of plastic water pipe systems (DOW 2004). PEX and multilayer pipes have both increased in popularity, and even with reductions in the construction market, the demand for plastic pipes remains strong (CBI 2011). Hybrid solutions, where PEX-piping is layered with aluminium, also seems to be increasing (KWD Globalpipe 2014).

In 2005, the market share between plastic and metal plumbing systems in the building industry were around 50 percent, respectively, but in 2010 the share of metal piping systems in Europe was between 40-45 percent and of plastic 55-60 percent. Plastic pipes have also become a more frequent choice in renovation (Teppfa, Building & Construction 2014a). In 2014 the share of plastic (including multilayer pipes) had reached 63% in terms of length of pipes used (KWD Globalpipe 2014). The market share of copper piping was 28%. The remaining 9% were steel pipes.

Copper pipe systems

Copper is historically the most common material used for piping, and after its introduction in the 1960s, it has become the standard material (LagdonSeah 2013). Copper pipes have a life time of at least 50 years (Buildipedia 2010) and can be recycled (Spirinckx, Peeters och Boonen 2012). Some advantages with copper are that it can resist corrosion and is not affected by ultraviolet rays, which make it suitable also for installations exposed to sunlight. Copper has durable and flexible properties which make it easy to install. There are also some disadvantages with copper, such as the fact that it can corrode when exposed to water with low pH (Networx 2014).

Plastic pipe system

The main types of plastics used for piping for radiators and fresh water installations are Cross-linked polyethylene (PEX), Multilayer PEX, PE and PP (KWD Globalpipe 2014). Most of the plastic materials are not fully recyclable. PEX accounts for nearly 50 percent of all hot and cold water pipes and due to the cross-linked bonds (making it thermoset) it cannot be recycled into new pipes (CORDIS 2014). This chapter will further consider the PEX material.

PEX has been used since 1970´s and has increased in use the last few decades (Teppfa, Fast guide to materials 2014b). The use of PEX water pipes is increasing in green building constructions, and replaces copper because it is less expensive, lighter and easier to install. In the US, PEX is the favourable choice for plumbing, before copper and CPVC (Kelley et al. 2014). PEX is flexible and durable under hot and cold temperatures, but has limitations for different temperatures. In contrast to copper, PEX pipes may be affected by ultraviolet rays and should therefore not be used in exposed installations (Networx 2014).

Prices

PEX pipe is mentioned as less expensive in comparison to copper at many sites (Buildipedia 2010; Teppfa 2014b). Copper piping, in comparison to PEX pipes, can cost around 10 times higher, depending on the size. For example, 3/8” copper pipe costs $4.87 and 3/8” PEX pipe costs $0.38 (Networx 2014). For a household in America the cost for labour and material for copper can range from around $9 000 to $16 000 and $6 500 to $13 000 for PEX, depending on the size of the house (Lee et al. 2013).

5.3.2 Model

Our model assumes that the remaining 28% of copper pipes are replaced by PEX successively until the year 2050. The implications for greenhouse gas emissions are estimated using results from previous LCAs.

In 2012, a study carried out by The European Plastics Pipes and Fittings Association (TEPPFA) and the Flemish Institute for Technological Research (VITO) compared the environmental performance of a hot/cold water pipe system in plastic, comprised of PEX pipes, plastic and brass fittings; and its main competing non-plastic system, made of copper pipes (66% primary copper), solder and copper fittings (Spirinckx, Peeters och Boonen 2012). The comparison was possible through the development of a cradle to grave comparative life cycle assessment of the two mentioned systems covering the following life cycle phases: raw material extraction, material production, production of the pipes and fittings, construction phase, the use phase as well as the processing of the waste at the end of life of the pipes and fittings.

The results showed a better environmental performance of the PEX piping system over the copper based system for all the 6 environmental impact categories analysed, including abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion and photochemical oxidation.

Two sensitivity analyses were carried out in this study in order to assess the influence of the most relevant and most uncertain factors on the results of the study. In the first analysis the amount of recycled copper content in the pipes and fittings were raised from 34%, in the base scenario, to 50% and 80%. In a second analysis an end-of-life approach was used where the impacts as well as the benefits of the recycling of the pipes and fittings were assigned to the life cycle of the copper pipe system, given that in the base scenario the credits of recyclates were assigned to the “next” product life cycle that uses the recyclates. To avoid double counting, the raw materials were assumed to be 100% primary.

The sensitivity analysis scenarios showed a reduction on the environmental impact of the copper based pipe system for all six impact categories. The greatest reduction was identified in the second analysis where impacts and benefits of copper recycling were assigned to the life cycle of the given system. In this case there was a reduction in the environmental impacts, compared to the base scenario, varying from 27% to 75% depending on the impact category assessed. Even with these environmental impact reductions, the PEX piping system showed a better environmental performance for the six impact categories considered (Spirinckx, Peeters och Boonen 2012).

The study cited here was carried out on behalf of the European Plastic Pipes and Fitting Association (TEPPFA) which of course has an interest in the promotion of PEX pipes over copper pipes. The study was, however, conducted by an independent institute and has undergone a third party review. In another cradle-to-gate analysis for copper and PEX pipes the energy requirement for PEX pipe was 25-60 percent less than for copper pipe, and emissions of CO_2 was 50-75 percent less (Kelly et al. 2014).

The study did not include the multilayer piping where aluminium is added to the PEX-pipes to achieve properties for pipe bending similar to copper pipes. Given the wide range of pipe material combinations not additional scenarios have been included. The direct comparison between PEX piping and copper piping shows a potential environmental impact due to a product standard where copper is replaced by PEX. It indicates an order of magnitude of the environmental impact.

For the purpose of the DYNAMIX project, that study has been scaled up to EU-level from the functional unit of one 100 m^2 apartment by average living space per capita, 35m^2 (Entranze 2015; Eurostat 2015) , and EU population in 2010 and 2050 as referenced in the DYNAMIX Common approach (Umpfenbach 2013). The needed copper ore is calculated from British Geological Survey (British Geological Survey 2007) typical copper ore concentration and is as a simplification assumed to be the same in 2010 and 2050. In the underlying LCA, 66% of copper comes from new ore but in the calculations for reduced copper ore, 100% virgin copper has instead been used. This since the 34% recycled copper is then made available for other applications.

5.3.3 Results

The impacts on metal use and global warming are presented below, assuming a replacement of 28% pipes made of copper in 2014 for pipes made of PEX, roughly 400 million meters of pipe annually, and on the basis of the assumptions of the above mentioned study. These results take into account the different expected life spans of the different pipes. It should also be mentioned that the replacement is not 1kg for 1kg but 1 meter pipe for 1 meter pipe as part of an apartment installation, thus covering replacement of the function of the pipe.

Table 29: Annual savings of greenhouse gas emissions and metal ore from replacing copper piping with PEX piping

Year and share of copper piping	Carbon dioxide eq. [ktonne]	Copper needed [ktonne]	Copper ore needed (given ore concentration in (British Geological Survey 2007) [ktonne]
2014 – 28%	130	23	770-4 600
2050 – 0%	48	0	0
Savings	81	23	770-4 600

Comparing the results with the goals for total greenhouse gas emissions from the EU in 2050 (roughly 1 000 000 ktonne (Umpfenbach 2013)) the emission reduction from product standards on pipes is very small (<0.01%). In relation to the target of reducing virgin metal ores by 80% (a reduction of roughly 560 000 ktonnes (Ekvall et al. 2015)) the impact from product standards of pipes is less than 1% and thus also small. A shift from copper piping to PEX piping will give small or very small contributions to the DYNAMIX environmental targets.

Furthermore, the current trend in piping indicates that the shift from copper to PEX and other polymers will happen also without a product standard. The standard might speed up the shift somewhat, but the impact of the product standard will probably be much smaller than the results in Table 29 indicates. In conclusion, the product standard investigated here is likely to give very small contributions, if any, to reaching the DYNAMIX targets of decoupling and sustainability.

Generalizing from this single case to product standards in general is difficult. One of the reasons for this standard being ineffective is that the material used for piping is a quite small share of the total material use in the EU. Product standards for more important product groups might give more significant contributions to a more resource-efficient and sustainable EU. A large number of product standards could potentially also bring a significant combined effect.

However, product standards are consensus documents. A standard that stipulates, for example, the choice of material can probably only be established when the material has clear advantages from most perspectives without being more expensive. The case of copper versus plastic piping is a good example of this. In such cases, a shift to the better material is likely to happen eventually even without the product standard. The product standard might make the shift quicker and perhaps also more complete, but it is not likely to create the shift from one material to another. This indicates that product standards are not likely to be a very effective instrument for making the EU more resource efficient and sustainable.

5.4 Feebate scheme for cars (OVERARCHING)

5.4.1 Scope

The overarching policy mix proposed by Ekvall et al. (2015) includes EU-wide feebate schemes for selected products with an improved version of the French Bonus Malus scheme on cars as a highlighted example. Even though feebate schemes can be applied on a wider range of products, passenger cars is the only product category included in our quantitative environmental modelling. The model is also limited to emissions of greenhouse gases, measured in terms of CO_2-eq. We used the DYNAMIX background scenarios, including the four cornerstone scenarios (Gustavsson, Ekvall och Bosello 2013), to show how an effective feebate scheme can affect the impact of the cars on global warming in different circumstances.

The model includes all passenger cars sold during a given year for use in the EU. The European car fleet is complex and simplifications have been made in the model both for available methods of propulsion and efficiency improvements. The model used has been developed in cooperation with the EUNICE project aimed at Eco-design and validation of In-Wheel Concept for Electric Vehicles (EUNICE 2015). Further details on the model are available in Annex A: LCA-models of internal combustion engine and electric vehicles.

5.4.2 Model

The feebate scheme for sales of new passenger cars has two aims: (i) diverting **consumption** from high-emitting (in terms of CO_2-eq.) to low-emitting cars; (ii) stimulating **technological innovations** that decrease CO_2-eq. emissions per km. High-emitting cars are here simplified as large (heavyweight) cars with high engine capacity and powered by diesel/petrol (high emissions per km); low-emitting cars are defined as small (lightweight) cars, hybrid cars (incl. plug in) and electric cars (low emissions per km or zero pipe emissions in the case of electric cars).

This feebate scheme can potentially influence the sales of the different types of cars (large, medium, small, internal combustion, hybrid and electric) and technological innovations that reduce fuel/electricity use per km (direct emissions). Since the feebate scheme is cost-neutral, we assume it does not affect the total sales of cars. We also assume it has no impact beyond the production and sales of cars. In particular, it does not affect what technologies are used to produce the fuel and electricity needed for propelling the cars. Hence, the emissions associated with the production of, for example, 1 kWh of electricity or 1 litre of diesel are not affected by the introduction of the feebate.

These assumptions are partly based on the ‘EU-wide introduction of feebate schemes for selected products categories’ described in the document ‘Development of DYNAMIX Policy Mixes’ (Ekvall et al. 2015). The results shall be seen as an indication of the potential scale of the effects of an EU-wide feebate on cars.

Baseline assumptions

Table 30 shows parameters related to the use phase of passenger cars that can directly influence climate impacts of the European passenger car fleet sales. Values refer to the year 2013. Data sources used for calculating these parameters are shown in the last column.

Table 30: Input data on the use phase of passenger cars sold in the year 2013

		Unit	Data sources
Fleet sales	Approx. $12x10^6$	No.	a
Share of battery electric vehicle (BEV)	0.2	%	a
Share of hybrid electric vehicle (HEV)	1.5	%	a
Share of internal combustion engine vehicle (ICEV)	98.3	%	a
Share of Large cars	25	%	a
Share of medium size cars	40	%	a
Share of small cars	35	%	a
Direct emissions from ICEV – CO_2-eq. per km (average)	128	g	
Large ICEV	152	g	a-c
Medium ICEV	127	g	a-c
Small ICEV	113	g	a-c
Electricity consumption EV – kWh per 100 km (average)	20	kWh	
Large BEV	25	kWh	a-e
Medium BEV	20	kWh	a-e
Small BEV	15	kWh	a-e
Power grid emissions – CO_2-eq. per kWh	462	g	b
HEV direct CO_2-eq. emissions per km relative ICEV	80	%	d, f
Km lifetime	200 000	Km	c, g, h

a = (ICCT, 2014); b = (Ecoinvent Centre, 2010); c = (Hawkins, Singh, Majeau-Bettez, et al., 2013); d = (Nordelöf, Messagie, Tillman, et al., 2014); e = (Del Duce, Gauch and Althaus, 2014); f = (Helms, Pehnt, Lambrecht, et al., 2010); g = (Daimler AG, 2008); h = (Finkbeiner and Hoffmann, 2006)

Moreover, parameters related to the production and end-of-life of passenger cars were also calculated. This includes the production of the materials in the cars. Table 31 provides the GHG (CO_2-eq.) emissions (kg/car) in different phases of the life cycle, including material production, manufacturing and end-of-life for passenger cars.

Table 31: Greenhouse gas emissions during materials production, manufacturing, and end-of-life phases for passenger cars (in kg CO_2-eq. per car).

	Materials and production	End-of-life	Data sources

Large ICEV	7 965	602	b-e
Large BEV	8 791	841	b-e
Large HEV	8 378	722	b-e
Medium ICEV	6 990	529	b-e
Medium BEV	7 714	738	b-e
Medium HEV	7 352	634	b-e
Small ICEV	5 016	379	b-e
Small BEV	5 536	530	b-e
Small HEV	5 276	455	b-e

b = (Ecoinvent Centre, 2010); c = (Hawkins et al., 2013); d = (Nordelöf et al., 2014); e = (Del Duce et al., 2014);

The input data on the sales and use phase of cars (Table 32) were used as a starting point for developing scenarios about life cycle effects of a feebate scheme on the sales of new passenger cars in Europe for the years 2030 and 2050. The data on material production, manufacturing and end-of-life of cars were used as input data in all scenarios.

Policy scenarios for ‘without the feebate’ and ‘with the feebate’ for the EU fleet sales were developed for each of the DYNAMIX background scenarios. The DYNAMIX background scenarios consist of a reference scenario and four cornerstone scenarios. These are based on different assumptions about the combination of the future rate of innovation (high-low) and the values that dominate the future society (materialism-environmentalism). The reference scenario was titled ‘No surprise scenario’; the four cornerstone scenarios were titled ‘Economic bonanza,’ ‘Safe globe,’ ‘Divided we trudge’ and ‘Back to nature’. The key variables considered in these scenarios are: GDP, population, total factor productivity (TFP), fossil fuel (specifically oil) prices and GHG emissions (Gustavsson, Ekvall and Bosello, 2013).

We assume that the feebate scheme will be effective in all scenarios except for the ‘Divided we trudge’ scenario. Furthermore, the effect will be different depending on the rate of technological innovation and on the degree of materialism. The scenario ‘Divided we trudge’ is dominated by materialistic values and includes little technological innovation. There is also a tendency towards nationalism and separatism. We assume that a feebate scheme will be difficult to implement in this scenario and that, if implemented, it will have no significant effect. The following subsections present the EU car sales and impacts of a feebate scheme for each of the five DYNAMIX background scenarios.

Reference scenario

The Reference scenario was defined as ‘surprise-free’ scenario. In this scenario, the balance between environmental and materialistic values remains essentially the same as today. Major technological break-throughs do not occur to radically transform the society. Nevertheless, efficiency and reliability of current technology continue to improve at a steady pace.

Accordingly, without the feebate scheme, a steady pace for the base-line assumption is also assumed here. Total car sales fleet sales continues to slightly decrease; the sales share of BEV, ICEV and HEV cars follow a historical trend; so does the sales share of large, medium and small cars. Radical technological improvements for curbing direct and indirect emissions do not occur.

The introduction of a feebate scheme would moderately leverage a shift towards purchasing BEV, HEV and small cars (low-emitting cars). Moreover, technological innovations aimed at decreasing fuel/ electricity use per km would also be expected stimulated. As specified earlier, the feebate will not affect total sales or of course power grid emissions.

Table 32 shows the parameters for the cases without and with the feebate within the DYNAMIX Reference scenario. Parameters affected by the feebate are marked as bold.

Table 32: Parameters for the cases without and with the feebate within the DYNAMIX Reference scenario

Reference scenario[3]	*Without feebate*		*With Feebate*	
	2030	**2050**	**2030**	**2050**
Car sales	-5.0%	-10%	-5%	-10%
Share of BEV	1.0%	3.0%	**25%**	**50%**
Share of HEV	3.0%	4.0%	**25%**	**45%**
Share of ICEV	96%	93%	**50%**	**5%**
Share of Large cars	29%	34%	**7%**	**4%**
Share of medium size cars	37%	35%	**30%**	**27%**
Share of small cars	3%	31%	**63%**	**69%**
Direct emissions from ICEV CO_2-eq. per 100 km	-5%	-10%	**-30%**	**-50%**
Power grid emissions CO_2-eq. per kWh	-20%	-31%	-20%	-31%
Electricity consumption BEV kWh per 100 km	-5%	-10%	**-30%**	**-50%**

Economic bonanza

The Economic bonanza scenario is characterised by high rate of innovation, materialistic focus on production and consumption, and higher economic efficiency and economic growth. Therefore, the trend of decreased car fleet sales present in the Reference scenario is expected to be reverted to expansion. The sales share of BEV, HEV and ICEV with and without the feebate remains equal as in the Reference scenario. Moreover, because of the materialistic focus and affluence of this scenario, the feebate does not affect the sales share of large, medium and small cars. A more salient focus is placed on improving the efficiency of electricity use per km than of fuel per km.

Because of the large demand for electricity, massive investments are done to rapidly expand the installed capacity and readily available carbon intense energy sources are used; thus CO_2-eq. emissions per kWh from the power grid will double.

Table 33 shows the parameters for the cases without and with the feebate within the DYNAMIX Economic bonanza scenario. The parameters that differ from the Reference

[3] Relative percentages are compared to the 'base line assumptions' (2013).

scenario are marked with asterisks and parameters affected by the feebate are marked as bold.

Table 33: Parameters for the cases without and with the feebate within the DYNAMIX Economic bonanza scenario

Economic bonanza	***Without feebate***		***With Feebate***	
	2030	**2050**	**2030**	**2050**
Car sales*	5%*	10%*	5%*	10%*
Share of BEV	1.0%	3.0%	**25%**	**50%**
Share of HEV	3.0%	4.0%	**25%**	**45%**
Share of ICEV	96%	93%	**50%**	**5%**
Share of Large cars*	29%	34%	29%*	34%*
Share of medium size cars*	37%	35%	37%*	35%*
Share of small cars*	32%	31%	32%*	31%*
Direct emissions from ICEV CO2-eq. per 100 km	-5%	-10%	**-30%**	**-50%**
Power grid emissions CO2-eq. per kWh*	100%*	100%*	100%*	100%*
Electricity consumption BEV kWh per 100 km*	-20%*	-30%*	**-30%**	**-50%**

Safe globe

The Safe globe scenario combines a high rate of innovation with an environmentalist focus on the well-being of all humanity and future generations. Innovation is in this scenario driven by the need to increase safety in global industrial systems. Consequently, CO_2-eq. emissions from both the power grid and electricity use per km in BEV radically decrease.

Whilst the feebate will continue diverging consumption from ICEV to BEV and HEV, in this scenario new business models such as car sharing and pooling are also included. Thus, car fleet sales are expected to drop more than in the Reference scenario. Table 34 shows the parameters for the cases without and with the feebate within the DYNAMIX Safe globe scenario. The parameters that differ from the Reference scenario are marked with asterisks and parameters affected by the feebate are marked as bold.

Table 34: Parameters for the cases without and with the feebate within the DYNAMIX Safe globe scenario

Safe globe	***Without feebate***		***With Feebate***	
	2030	**2050**	**2030**	**2050**
Car sales*	-15.0%*	-20%*	-15%*	-20%*
Share of BEV	1.0%	3.0%	**25%**	**50%**
Share of HEV	3.0%	4.0%	**25%**	**45%**
Share of ICEV	96%	93%	**50%**	**5%**
Share of Large cars	29%	34%	**7%**	**4%**
Share of medium size cars	37%	35%	**30%**	**27%**
Share of small cars	32%	31%	**63%**	**69%**

Safe globe	***Without feebate***		***With Feebate***	
Direct emissions from ICEV CO2-eq. per 100 km	-5%	-10%	**-30%**	**-50%**
Power grid emissions CO2-eq. per kWh*	-50%*	-75%*	-50%*	-75%*
Electricity consumption BEV kWh per 100 km	-20%*	-30%*	**-30%**	**-50%**

Divided we trudge

The Divided we trudge scenario combines a low rate of innovation with a high level of materialism in production and consumption. Here, no reductions in direct and indirect CO_2-eq. emissions from ICEV and BEV, respectively, are expected to occur. Moreover, the high prevalence of materialistic values dampens the shift away from high-emitting cars. An expansion of the fleet sales is also expected in this scenario.

Table 35 shows the parameters for the cases with and without the feebate within the DYNAMIX Divided we trudge scenario. The parameters that differ from the Reference scenario are marked with asterisks.

Table 35: Parameters for the cases without feebate within the DYNAMIX Divide we trudge scenario. No significant effect of a feebate is expected for this scenario.

Divided we trudge	***Without feebate***		***With Feebate***	
	2030	**2050**	**2030**	**2050**
Car sales*	5%*	10%*		
Share of BEV*	1.0%	3.0%		
Share of HEV*	3.0%	4.0%		
Share of ICEV*	96%	93%		
Share of Large cars	29%	34%		
Share of medium size cars	37%	35%		
Share of small cars	32%	31%		
Direct emissions from ICEV CO_2-eq. per 100 km*	0%*	0%*		
Power grid emissions CO_2-eq. per kWh*	100%*	100%*		
Electricity consumption BEV kWh per 100 km*	0%*	0%*		

Back to nature

The Back to nature scenario combines a low rate of innovation with an environmentalist focus on the well-being of all humanity and future generations. A partly anti-intellectual distrust towards technological research contributes to a low rate of technological innovation.

In this scenario, due to environmentalism and low affluence, the fleet sales contract more than in the Reference scenario; the feebate equally has no effect on purchasing preferences towards BEV and HEV since technological development has declined, thus ICEV continues to dominate. Nevertheless, a shift towards small cars equally seen as in the Reference scenario is likely to take place. The parameters that differ from the Reference scenario are marked with asterisks and parameters affected by the feebate are marked as bold.

Table 36 – Parameters for the cases without and with the feebate within the DYNAMIX Back to nature scenario

Back to nature	*Without feebate*		*With Feebate*	
	2030	**2050**	**2030**	**2050**
Car sales*	-15.0%*	-20%*	-15%*	-20%*
Share of BEV*	1.0%	3.0%	1.0%*	3.0%*
Share of HEV*	3.0%	4.0%	3.0%*	4.0%*
Share of ICEV*	96%	93%	96%*	93%*
Share of Large cars	29%	34%	**7%**	**4%**
Share of medium size cars	37%	35%	**30%**	**27%**
Share of small cars	32%	31%	**63%**	**69%**
Direct emissions from ICEV CO_2-eq. per 100 km*	0%*	0%*	0%*	0%*
Power grid emissions CO_2-eq. per kWh	-20%	-31%	-20%	-31%
Electricity consumption BEV kWh per 100 km*	0%*	0%*	0%*	0%*

5.4.3 Results and conclusions

Table 37 presents the CO_2-eq. emissions during the life cycle phases of passenger cars that are sold in the year 2013. Values are expressed in thousand tonnes CO_2-eq. emissions.

The GHG(CO_2-eq) emissions from each life cycle phase of passenger cars sold in the EU in the year 2030 and 2050 for all the five DYNAMIX background scenarios have been normalized to the total life cycle emissions of the cars sold in the year 2013 (456 Mtonnes of CO_2-eq.). The results are presented in

Figure 15.

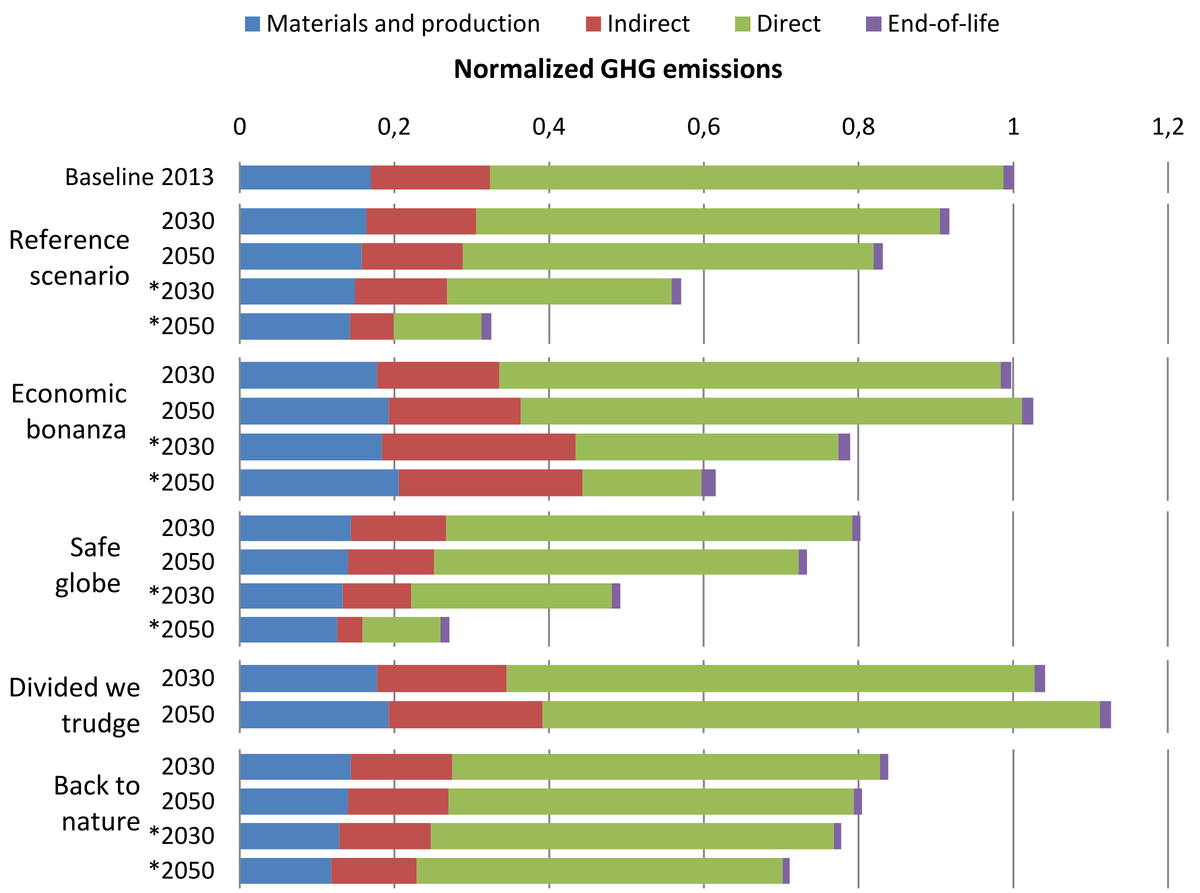
Table 37: The CO_2-eq. emissions in Mtonnes of the cars sold in the EU in the year 2013.

	Materials and production	Use phase		End-of-life	Total life cycle
		Indirect[4]	Direct		
EU total car sales	**77**	**70**	**302**	**6**	**456**
ICEV	76	69	298	6	449
BEV	0.2	0.4	0	0.02	0.6
HEV	1	0.8	4	0.1	6
EU fleet composition					
Large cars	**24**	**21**	**89**	**2**	**136**

[4] For ICEV and HEV, indirect emissions refer to the production of fuel (diesel/petrol); for BEV, indirect emissions refer to the production of electricity.

Large ICEV	23	21	88	2	134
Large BEV	0.05	0.1	0	0.005	0.2
Large HEV	0.4	0.3	1	0.03	2
Medium cars	**33**	**29**	**120**	**3**	**184**
Medium ICEV	32	29	118	2	182
Medium BEV	0.07	0.2	0	0.007	0.3
Medium HEV	0.5	0.3	1	0.04	2
Small cars	**20**	**196**	**93**	**2**	**135**
Small ICEV	20	19	92	16	133
Small BEV	0.04	0.1	0	0.004	0.2
Small HEV	0.3	0.2	1	0.02	2

Figure 15: Normalized CO_2-eq. emissions of EU passenger car fleet for the five background scenarios of DYNAMIX. (* with an effective feebate scheme implemented)



Results marked with asterisks are calculated subject to the feebate. It is important to note that we assumed the sales and use phase parameters (presented in the Tables 32 to 36) to be greatly affected by the feebate system, but that no other parameters are affected; emissions for a given passenger car from materials and production and end-of-life (presented in Table 31) have not been changed from the current values. This was a deliberate choice in order to isolate the effect of decreasing/growing the EU car fleet size.

It can be seen from

Figure 15 that an effective feebate scheme can indeed strongly influence total emissions of greenhouse gases over the life cycle of passenger cars. It can also be noticed that the strength of the influence varies from life cycle stages and scenarios. For example, the feebate scheme has a limited impact in the scenario Back to nature. This is because we assumed the feebate in this scenario to affect only the size of the cars and not the share of hybrid and electric vehicles. In the scenarios where the feebate affects the technology, the impact of the feebate is much greater. The size of the car matters for the climate, partly because less material has to be produced to manufacture small cars and partly because small cars require less fuel to drive. Still, at least in our model, the choice of technology (hybrid and electric vehicles rather than integrated combustion engines) matters much more than the size.

The feebate scheme has less impact in the Economic bonanza scenario compared to, for example, the Reference scenario. This is partly because we assume the feebate only to affect the choice of technology in the Economic bonanza, while the technology as well as the size of the car is affected in the Reference scenario. Another reason for the climate benefit to be smaller in the Economic bonanza scenario is that the electricity sector in this scenario causes double the current emissions of greenhouse gases per kW produced (see Table 33). Emissions from electricity production are an important part of the indirect emissions (red colour in

Figure 15). For this reason, the indirect emissions are greater when the feebate is introduced and more electric vehicles are used. This is despite the fact we assume the feebate to increase the energy-efficiency of the electric cars.

In the Reference scenario and, particularly, the scenario ‘Safe globe’, the feebate reduces not only the direct emissions from the car fleet but also the indirect emissions. This is partly because the greenhouse gas emissions from the production of 1 kWh electricity declines with time in these scenarios (see Table 32 and Table 34). The feebate causes a shift to more electric vehicles, but since it also makes the electric vehicles more efficient and the electricity production is relatively carbon-lean, the net effect of the feebate is to reduce the emissions from electricity production. From this we can conclude that the effectiveness of a feebate scheme from cars depends on how the background system, particularly the electricity production, will develop.

We also normalized the total life cycle emissions of different scenarios to the DYNAMIX target for total annual greenhouse gas emissions from EU. This target is 2 tonnes of CO_2-eq. emissions per capita in the year 2050, aiming to facilitate a global target of keeping the climate change within 2 degrees (Umpfenbach 2013). Considering that the EU population is expected to reach 523 million in 2050 (Gustavsson et al., 2013), the total CO_2-eq. emissions for that year would be 1 050 Mtonnes of CO_2-eq. emissions in that year. Table 38 shows the total life cycle CO_2-eq. emissions from the EU passenger car fleet normalized to the total CO_2-eq. emissions within a 2 degrees target in 2050.

Table 38: Normalized total life cycle CO_2-eq. emissions from the EU passenger car fleet to the total CO_2-eq. emissions within a 2 degrees target in 2050

	2050 without feebate	2050 with feebate
Reference scenario	36%	14%
Economic bonanza	45%	27%
Safe globe	32%	12%
Divided we trudge	49%	not applicable
Back to nature	35%	31%

In conclusion, significant reductions in CO_2-eq. emissions from transport are required if the EU is to achieve its long-term goals. As road transport alone currently contributes about one-fifth of the EU's total CO_2-eq. emissions (European Commission, 2015), an effective feebate scheme can play a vital role in reducing the share of the transport sector towards meeting the 2 degrees target in 2050.

This study is limited to GHG emissions. A feebate on cars can also bring other environmental benefits: reduced acidification, reduced emission of particulate matter, etc. On the other hand, it might also increase environmental and resource burdens. If a large increase in the electricity use in cars is met through an increase in renewable energy production, this can, for example, result in increased land use.

Feebate systems can be introduced also for other product groups (see Section 5.4.1). Most other product groups are much less significant for the environment than cars, however. An exception is buildings: the construction of buildings uses a significant share of the total material flow in society, and the use phase demands a significant share of the total energy supplied in society. A feebate system for buildings would, if effective, give important contributions to reducing the climate impact of society. Such a feebate scheme could perhaps be linked to an internationally accepted environmental assessment methodology for buildings, such as BREEAM (Building Research Establishment Environmental Assessment Method) and/or LEED (Leadership in Energy and Environmental Design).

In the case study on cars we concluded that impacts on technology is more important than impacts on the car size and that the development of background systems such as electricity production is important for how effective the feebate is to curb greenhouse gas emissions. Our conclusion, that technology is more important than size, is difficult to generalize to other product categories. The size decides how much material needs to be produced, and reduced materials production typically means reduced greenhouse gas emissions. However, if this is more or less important than the technological choice will depend completely on the specifics of the available technological options.

The conclusion that the development of background systems can be important for the effectiveness of a feebate can be generalized, however. When a feebate stimulates a shift from fossil fuel to electricity or from electricity to fuel, the environmental gain will greatly depend on how the electricity system develops over time.

5.5 R&D for recycling with car dismantling (METALS)

5.5.1 Scope

Increased spending on research and development (R&D) is part of the policy mix on metals and other materials. This R&D will include various solutions to increase recycling and material efficiency (Ekvall et al. 2015).

Our quantitative analysis focuses on a single area of R&D for increased recycling: the development of technology and procedures for improved dismantling of passenger cars and light trucks. In particular, the improvement in the dismantling processes aims to extract more copper from the dismantled vehicles. Such an improvement will immediately increase the recycling of copper. It will also reduce the copper contamination of steel, which will allow for a higher recycling rate of steel in the very long run (Ekvall et al. 2014).

5.5.2 Model

The impact of improved dismantling processes was estimated by Ekvall et al. (2014) through a material pinch analysis (MPA) of the global steel flows. The quality indicator in the MPA is purity from copper. This is because copper is difficult to separate from steel in the recycling process and because high levels of copper contamination in the steel restricts the usefulness of steel.

This MPA was based on data for the steel use in 2008. In the MPA model the quantity of steel in old, discarded products was the same as the quantity of steel in new products. This means that the model describes a hypothetical future where global steel use no longer increases, and where the level and pattern of steel use is approximately the same as today. Copper was assumed to remain difficult to separate from steel in the recycling process.

The global steel use was divided into three large categories with different tolerance for copper contamination (cf. Nakamura et al. 2012):

- Rolled steel: maximum Cu content 0.1%
- Steel sections: maximum Cu content 0.3%
- Reinforcement bars and castings: maximum Cu content 0.4%

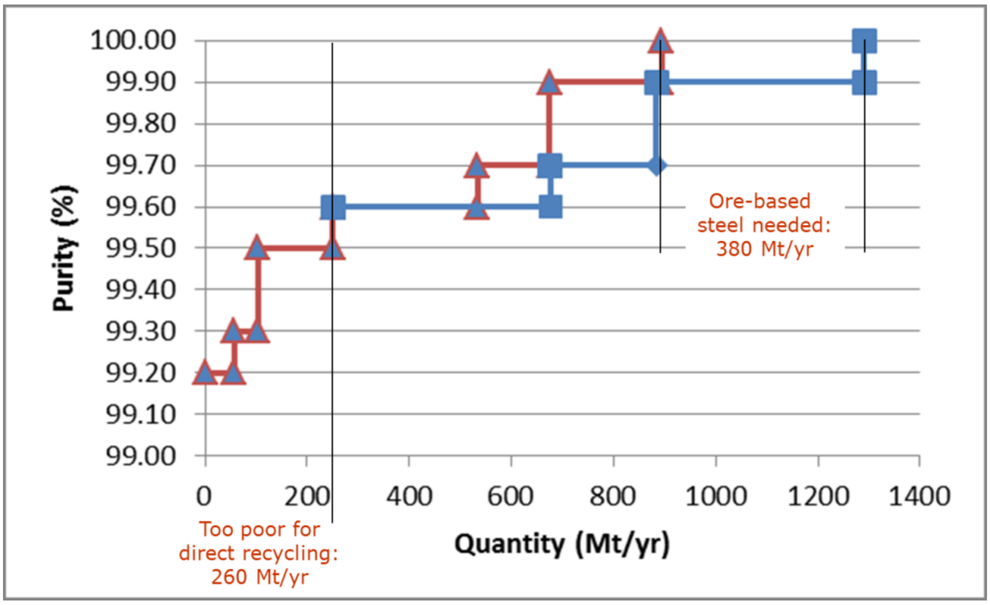
When the total flows of steel no longer increase, copper will accumulate in the steel because new copper is added to the steel flow. Copper cables etc. from machines remain, for example, in the steel scrap as it enters the recycling process. Kakudate et al. (2000) estimated that 4 kg of copper is added to the steel flow for each tonne of steel scrap from machinery. The MPA model of Ekvall et al. (2014) assumes that this holds also for passenger cars and light trucks.

The Cu level in steel scrap from machinery etc. is in the model too high to be directly recycled into new products. Rolled steel from machinery has a Cu content of 0.5% (0.1% from the start and 0.4% from the copper cables etc. in the scrap). This is too high to be accepted even in reinforcement bars and castings. The quantity of steel scrap from machinery is in the model 260 Mtonne/year (see Figure 16). If this scrap is discarded, 380

Mtonne/year of steel has to be produced from iron ore. The 380 Mtonne/year is used to replace the discarded steel scrap from machinery and also the material that the model assumes to be lost in the collection and recycling system.

In practice, recycling of each separate scrap flow is not realistic. Cast iron and rolled steel will be mixed in the scrapping of, for example, a car. Furthermore, scrap with a high copper content can be deliberately mixed with ore-based steel or high-quality scrap to reach an acceptable copper level. This way more scrap can be recycled and the use of ore-based steel can be reduced.

Figure 16: The use of steel (blue curve) and the available steel scrap (red curve) in the material pinch analysis of Ekvall et al. (2014). Purity here refers to the share of non-copper content in the steel.



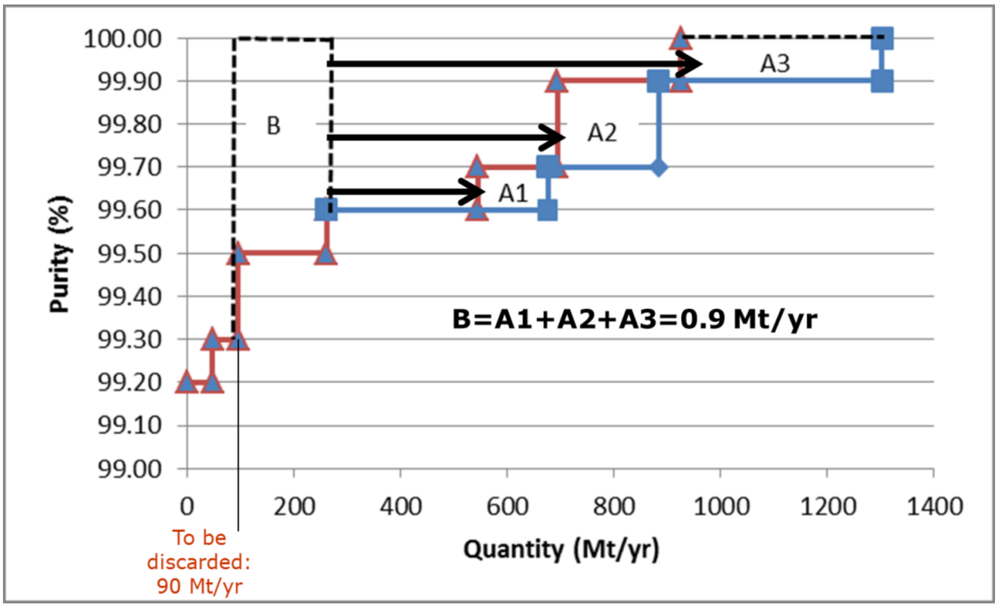
The quantity of extra copper from poor steel scrap that can be tolerated in the recycling system depends on the excess purity in the systems. This is given by Area A1+A2+A3 between the two curves in Figure 17, which is nearly 0.9 Mtonne/year. Area B in Figure 17 has the same size. This means that the copper content in all rolled steel from machinery etc. is small enough to be accepted into the steel recycling system. All rolled steel from machinery etc. can be recycled, if this scrap is mixed with ore-based steel and high-quality scrap that are available in the optimized system. A small share of the sections from machinery etc. can also be allowed into this mix, and only 90 Mtonne/year of steel scrap needs to be discarded.

With an optimum mixing and maximum recycling of steel scrap, approximately 200 Mtonne/year of steel has to be produced from iron ore. This ore-based steel is used to replace the 90 Mtonne/year of discarded steel scrap and also the material that the model assumes to be lost in the collection and recycling system (Ekvall et al. 2014).

The MPA model assumes that the quantity of copper remaining in the scrap from machinery and cars is 4 kg/tonne of steel. Ekvall et al. (2014) assumed that improved dismantling of cars could reduce the quantity of copper cables etc. in the scrap from cars and light trucks by

75%. This means that only 1 kg of Cu per tonne of steel is added to the scrap from light trucks and cars. Ekvall et al. (2014) also assumed that the technology and procedures for car dismantling developed in the EU will diffuse to the rest of the world and be utilized on a global level before 2050.

Figure 17: Optimum mixing of steel scrap in the material pinch analysis of Ekvall et al. (2014). The excess purity is given by the area A1+A2+A3.



5.5.3 Results and conclusions

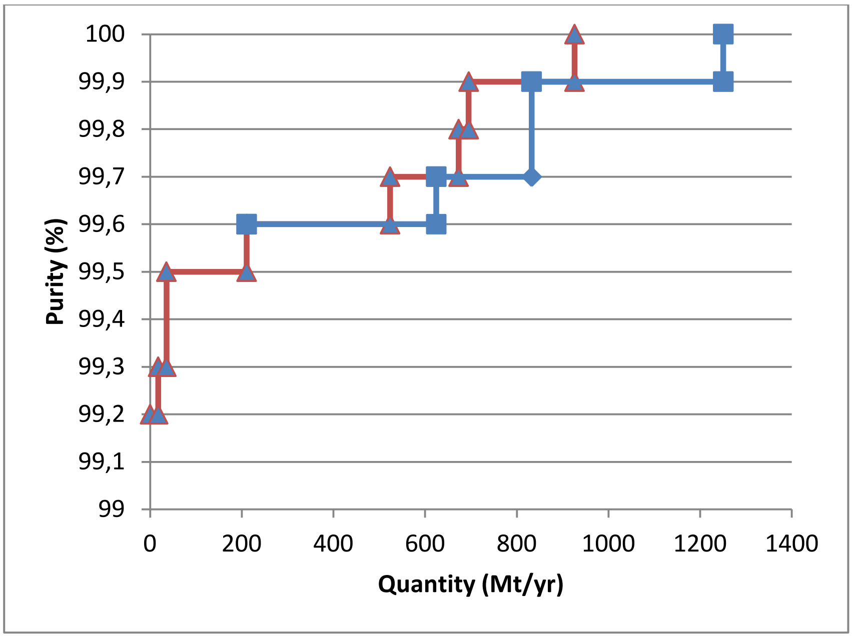
Similar to Ekvall et al. (2014), we assume that successful European R&D on processes for car dismantling will reduce the quantity of copper cables etc. in the steel scrap from cars and light trucks by 75% globally. This means that global copper recovery in the model is increased by nearly 250 ktonne/year (Ekvall et al. 2014). This copper can be recycled to reduce the use of virgin copper. If the copper content in a copper mine is 0.5%, this corresponds to 50 Mtonne/year globally in terms of raw material equivalents (RME) or raw material consumption (RMC).

The European RMC of metals is 700 Mtonne/year, whereof the RMC of copper is approximately 150 Mtonne/year (Ekvall et al. 2015). This means that the single measure of improving car dismantling worldwide can affect global copper flows in a quantity that is a third of the total copper consumption in the EU and 5-10% of total metals consumption in the EU. It is not possible to say, based on the MPA model, how much of the global reduction in copper RMC that actually occurs in the EU.

The improvement in car dismantling also means that the steel scrap from cars and light trucks will be less contaminated by copper – it will have a higher degree of purity in the MPA. This will slightly affect the curve that describes the global steel scrap supply in the MPA (cf. Figure 16 and Figure 18). As a result of the increased purity, the minimum quantity of discarded steel scrap in the model is reduced from nearly 90 Mtonne/year to less than 70

Mtonne/year (Ekvall et al. 2014). The minimum use of virgin (i.e., ore-based) steel is reduced from 200 Mtonne/year to 180 Mtonne/year globally.

Figure 18: The material pinch analysis of Ekvall et al. (2014), when the quantity of copper cables etc. in the global scrap from cars and light trucks is reduced by 75%.



In terms of RMC, the reduction in virgin steel is roughly the same as the reduction in virgin copper: 50 Mtonne/year. However, this reduction occurs in the model because copper contamination restricts recycling in the model. In reality, the increase in global steel use is likely to dilute the copper below the critical levels. Copper contamination of steel will not be a significant problem until global steel use stabilizes, which might be far into the future.

The MPA model of Ekvall et al. (2014) is to a large extent based on assumptions and crude data. The numerical results should not be taken at face value. However, also taking this uncertainty into account, it is clear that the single measure of funding R&D on car dismantling can, if successful, reduce the RMC of metals. It will increase copper recycling and reduce the global use of virgin copper before the year 2050. It can be a significant step on the path to the DYNAMIX policy target of reducing the RMC of metals in the EU by 80% until 2050 (Umpfenbach 2013).

Further into the future, improved car dismantling can also have significant impacts on the steel recycling and the use of virgin steel. In terms of RMC, this effect can be in the same order of magnitude as the increase in copper recycling.

Our case study is on car dismantling, which is a single, rather limited technological area. R&D for recycling and material efficiency is much broader. It includes various areas of technology and also sociotechnical systems, behaviour, etc. We assumed in the case study that the R&D was successful. On a general level, the contribution of R&D to decoupling and sustainability is uncertain. The progress made through R&D cannot be predicted. In addition, if R&D increases the efficiency of a product, process or system, this increase in efficiency can result in increased economic activity rather than reduced environmental impacts. This is the typical rebound effect.

Still, the case study on car dismantling illustrates that successful R&D can give important contributions towards reaching the DYNAMIX targets for decoupling and sustainability. Our model of a feebate scheme for cars (Section 5.4) illustrates that technological improvements in the cars themselves (and in the electricity system) can be important for the climate. Overall, we can conclude that successful R&D on technology, systems, behavior etc. can be important for the recycling rates, the material efficiency and, hence, for the DYNAMIX objectives.

5.6 Instruments assessed with ICES

5.6.1 Introduction

An overarching LCA model has been developed in order to understand the environmental impacts associated with a few policy instruments that were assessed using the macro-economic model ICES. The ICES model and its results are presented by Bosello et al. (2016), which is Deliverable 6.2 of the DYNAMIX project.

The overarching LCA model uses values of the economic output from different economic sectors as input data, which means that the environmental data is extended from individual products and processes to model economic changed for all sectors in the economy. Unlike models provided in previous sections, the overarching LCA model links all sectors to identify the environmental implications of the dynamic policies outlined in Ekvall et al. (2015).

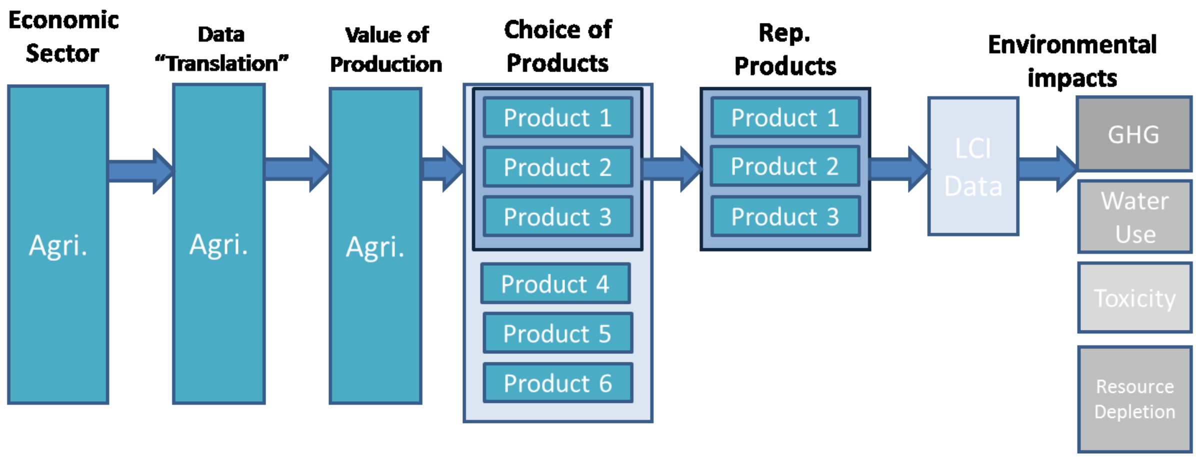
As the environmental impacts associated with the output of economic sectors were difficult to measure, the model included a number of limitations and assumptions to simplify the task. Within each section below, limitations and assumptions are listed. Above all, the translation of data from one model to another (e.g., due to updates in data sets and to match with Eurostat data) to assess the outputs and classification of product outputs from different economic sectors was considered a major limitation with the study.

In order to show the environmental impacts associated with economic changes in the EU, an assessment model was designed to link economic changes within different economic sectors, to the environmental impacts caused by representative outputs from that sector.

The assessment was conducted using a reference year, 2007, by using the outputs from each sector to quantify a representative quantity of products. From the amount of products, measured in kg, environmental data for the different products can be included and the impact from changes in the sector can be computed. The environmental impact categories included in the results section, were computed using the ILCD methodology, and were limited to GWP, resource depletion, freshwater consumption and human toxicity potential. Further environmental impact categories are included in Annex C for each economic sector.

Figure 19 provides a representation of the methodology used to find Environmental impacts for the outputs from different economic sectors.

Figure 19: Representation of Methodology Used to Model Environmental Impacts for Economic Sectors of the EU



The following sections will further outline the methodology used to build the model and assess the environmental impact associated with the results from the ICES model.

5.6.2 Policy Instruments Assessed

Different scenarios were created and tested to show the potential effects of the policies in the years 2030 and 2050. The year 2040 was also included for the assessment of materials tax. Results from the ICES model for the effects on different sectors in the European economy, as modelled by Bosello et al. (2016), are available in Annex C.

Table 39: Policies modelled for different years

Policy	2007	2030	2040	2050
VAT on Meat		x		x
Pesticides		x		x
Dietary Shift		x		x
Materials Tax		x	x	

5.6.3 Economic Sectors Included in the Model

In total, 17 economic sectors were included in the environmental assessment, based on the sector categories provided in the ICES modelling framework. These include sectors such as agriculture, meat industry, food industry, timber, chemical industry, oil products, etc. (see Table 40).

Table 40: ICES Sectors included in the study

	ICES sectors		ICES sectors
1	Agriculture	11	Meat Industry
2	Livestock	12	Food Industry
3	Timber	13	Chemical Industry
4	Fishing	14	Iron and Steel
5	Coal	15	Other Metals
6	Oil	16	Non Metallic Minerals
7	Gas	17	Construction Industry
8	Oil products	18	Other Industry
9	Electricity	19	Market Services
10	Other Mining	20	Public Services

The construction, market and public services sectors were not modelled in this assessment as the output from these sectors (e.g. services) was not compatible with the method used in this assessment.

5.6.4 Economic Value of Representative Products for all sectors Assessed

Based on data provided from Bosello et al. (2016), a review of the economic sectors with significant economic changes were assessed. Sectors with changes higher than 1% in absolute value were included in the review; see Annex C for the changes in each sector for the different dynamic policies. The sectors with significant changes included only:

- Agriculture
- Livestock
- Gas
- Oil products
- Electricity
- Other Mining
- Meat Industry
- Food Industry
- Chemical Industry
- Iron and Steel
- Other Metals

- Non Metallic Materials
- Other industry

5.6.5 Extending Economic values to Review Environmental Impacts across Sectors

In order to create a model in the LCA software package GaBi it was necessary to find a method to translate the monetary values for each sector into a physical unit, such as kilograms for products and MJ for energy outputs. This was required as life cycle inventory datasets are related to a physical unit and not to monetary values.

In order to do so, representative products from each sector were chosen and values were assigned to the products per physical unit, again e.g. in kg or MJ. The following sections describe the methodology used. More information is provided in Annex C.

Representative Products from Economic Sectors

Within each economic sector outlined in the section above, there is a large array of outputs. These outputs from the different sectors can include both products and services. In this assessment only products such as energy and kg of goods/commodities were considered.

For each sector, representative products were chosen, due to the sheer magnitude of modelling all products within each economic sector. In order to identify representative products, an iterative approach was used to outline the products, using the economic output from each sector from Eurostat statistics and classification of products based on the GTAP system classification.

From the sectors outlined in the ICES sectors listed above in Table 40, in order to find a list of products which could be matched with Eurostat data for economic output, product codes were obtained. This involved matching the systems for different classification systems. Eurostat statistics were available for many of the sectors through the PRODCOM database (Eurostat, 2014). Therefore in order to match data to Eurostat statistics, the process involved matching based on GTAP codes for the sectors, which best represented Eurostat sectoral classifications, and finding product codes listed and working with updated versions of ISIC and NACE in order to identify the corresponding PRODCOM database codes[5](Eurostat, 2014; Eurostat, 2016a; Eurostat, 2016b, United Nations, 2016a,b,c). Table 41 provides a review of the codes and steps used to find information for the “other mining” sector. For the agriculture, livestock, electricity and oil and gas product sectors, the general method as described was not applicable as the products are not manufactured and not within the scope of the PRODCOM database. For these sectors, a separate method was used to obtain the economic statistics for product outputs from each sector; see Annex C for more information.

[5] In some cases product codes were also listed for services from the different sectors. Again these were not included as the study was limited to products from each sector.

Table 41: Example of Product Code Classification to generate PRODCOM product codes from GTAP sector classifications (the case of Other Mining Sector) (Purdue University 2013a, b; United Nations 2016 a, b, c)

GTAP	ISIC rev.3	ISIC rev.3.1	ISIC rev.4	NACE rev.2	PRODCOM
18	12	1200	0721	07.21	0721
			0990^{p}	09.90	*
	13	1310	0710	07.10	0710
			0990^{p}	09.90	*
		1320	0729	07.29	0729
			0990^{p}	09.90	*
	14	1410	0990^{p}	08.11	0811
				08.12	0812
			0990^{p}	09.90	*
		1421	0891	08.91	0891
			0990^{p}	09.90	*
		1422	0893	08.93	0893
			0990^{p}	09.90	*
		1429	0990^{p}	08.11	0811
				08.12	0812
			0899	08.99	0899
			0990^{p}	09.90	*

^{p} refers to a partial link meaning that more than one code from the previous classification shares one or more activities/products contained in the code marked with ^{p}

**refers to service supporting activities, not included in the assessment*

Data from Eurostat

Eurostat data were primarily used to assess the economic values of different products from each sector. Data for the economic outputs, measured in value of production (€), from each sector were obtained from Eurostat data. Value of production was chosen over volume of production (kg) in order to extend environmental impacts to economic values from data provided from Bosello et al. (2016; see Annex C). Furthermore, information on value of production was readily available from Eurostat databases.

A cut-off was applied to each sector in order to obtain at least 3 products representing the sector. Defining the cut-off involved identifying the three products with largest value of production (at least 10%) and available environmental data. In some cases a fourth product was included. For example, in the case of the meat industry, bovine meat represented the fourth largest value of production from the sector. It was included as it was assumed that the impacts from bovine meat were representative of the meat industry and due to fact that the meat industry also included dairy products.

In several cases the output products of the sector were so vaguely described that ascribing environmental data was difficult. Therefore, the subsequent product(s) with available environmental data were chosen to represent the sector; see Annex C for more information on the assumption and method for each sector. A scaling-up factor was also included in order to take into account the value of production from other outputs of each economic sector not included.

5.6.6 Assigning Economic Values for Representative Products

For each representative product chosen to represent the economic sectors, a value for the output was required to link to life cycle inventory (LCI) data for the environmental impact assessment. Once again, as the value provided from the economic models was in Euro (€), it was important to find the amount of product outputs (in kg) for the representative products. Therefore, a representative price in kg/€ was necessary. In general, for each sector, this was done primarily using Eurostat data for prices of production for different products. Nonetheless, in some of the sectors, this was not applicable and other methods were used to find the prices of the representative products from that sector; see Annex C for further information.

Once the representative products were found, the market prices (€/kg) for each representative product were found using Eurostat statistics. Thereafter a weighted average was produced of the market prices for the representative products. Thereafter, the weighted average was inversed and multiplied by a scale up factor in order to account for the other products not included as representative products and provided a value in (kg/€). With the value of (kg/€) the value provided in the economic scenarios could simply be multiplied by the representative prices for the representative products to find the amount of products and apply LCI data to these to assess the environmental implications of the policy measures.

See Figure 20 for a short depiction of the method. Annex C presents an overview of all data used to compute the ratio (kg/€) for the different sectors sector. See Annex C for a review of the methodology used to compute the economic value of all sectors reviewed, as outlined in the section above.

Figure 20: Method for finding the representative price to allow for the LCA

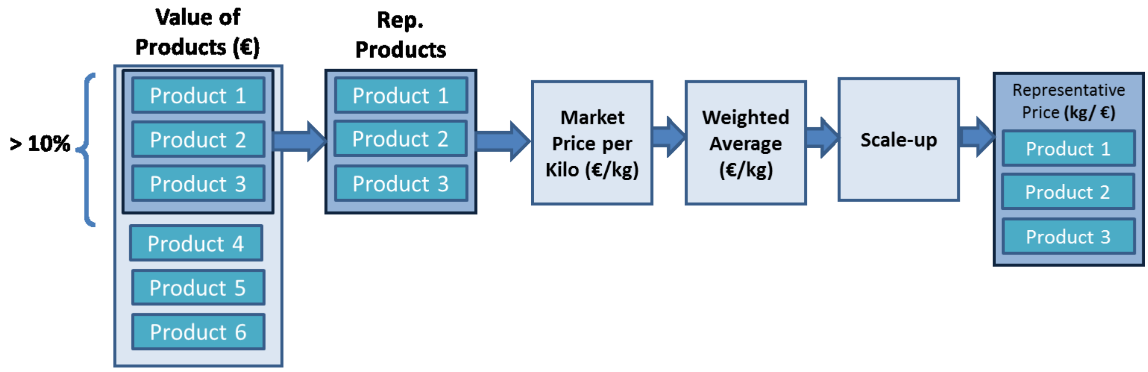


Table 42: RFPs and Economic Values for Livestock Sector

	Raw milk	Cattle	Pig
% of total production value in 2007	34.16%	21.61%	20.90%
Scaling up to 100%	44.55%	28.19%	27.26%
€/kg	0.37	1.04	1.14
€/kg (weighted average)		0.771	
kg/€ (weighted average^{-1})		1.30	
kg/€	0.58	0.37	0.35

5.6.7 Results

The following sections provide an overview of the implications of policies for the years 2030, 2040 and 2050 normalized to 2007 values. More results, and an extended number of impact categories, are provided in Annex C for all sectors separately.

In general the policies had little effect to reduce and decouple emissions from the European economy when reviewing Global Warming Potential, Human Toxicity Potential, Freshwater Consumption and Resource Consumption. As can be seen in Figure 21-Figure 24, all impact categories had levels well above 2007 levels, with increases of at least 20% for 2030 and 40% for 2050.

GWP

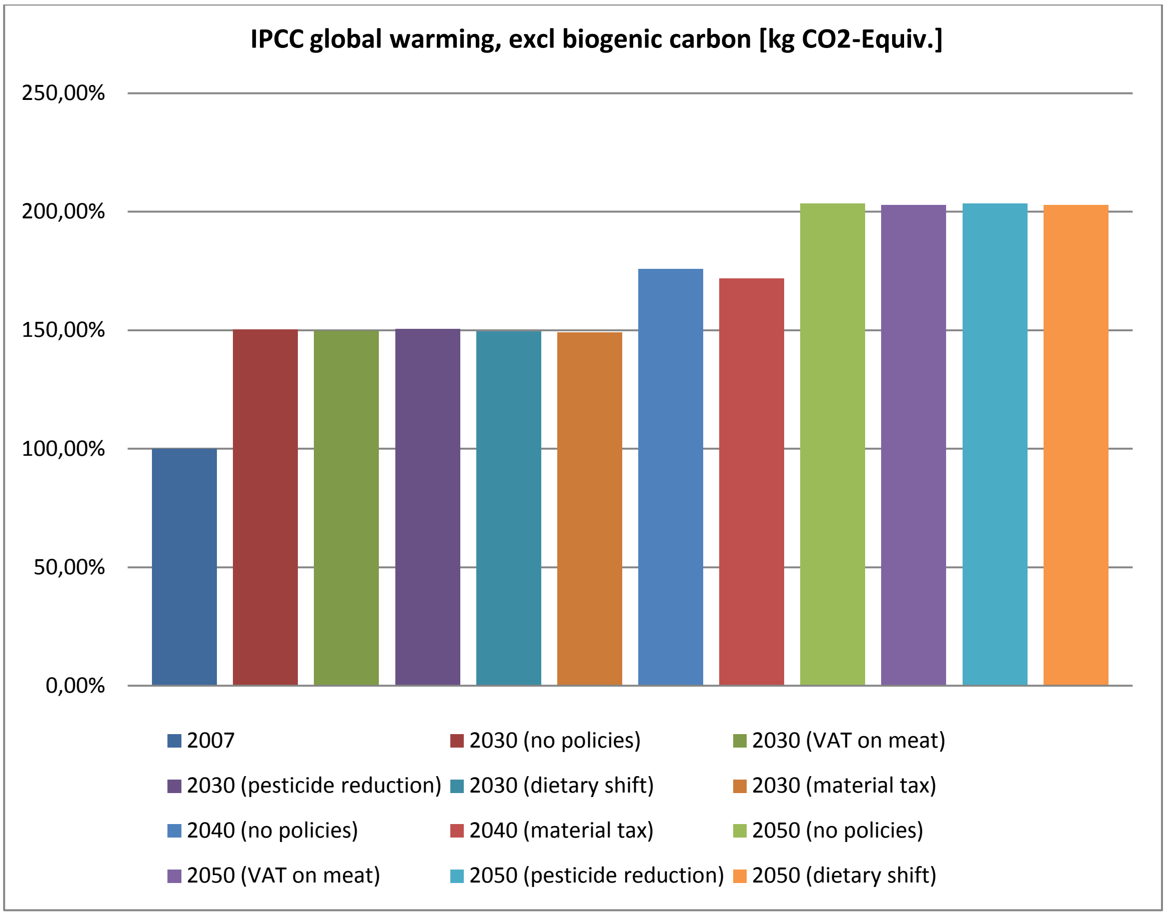


Figure 21: Global Warming Potential (Normalized to 2007 values)

The results of the global warming potential show no decoupling of emissions compared to levels of 2007. In fact, when reviewing the global warming potential in 2030 with and without policies, there is little to no change in emissions. Only the materials tax shows a slight reduction in emissions. The impact of a material tax in 2040 was also estimated. This was a slight reduction in emissions, but once again levels in 2040 were over 60% higher than 2007 levels. Finally, the implications of the policy mixes in 2050 were reviewed. Once again, the policies had little effect to reduce impacts in comparison to the case with no policies, and compared to 2007 levels. A doubling of impacts could be seen in all 2050 scenarios reviewed compared to 2007 levels.

Resource Depletion

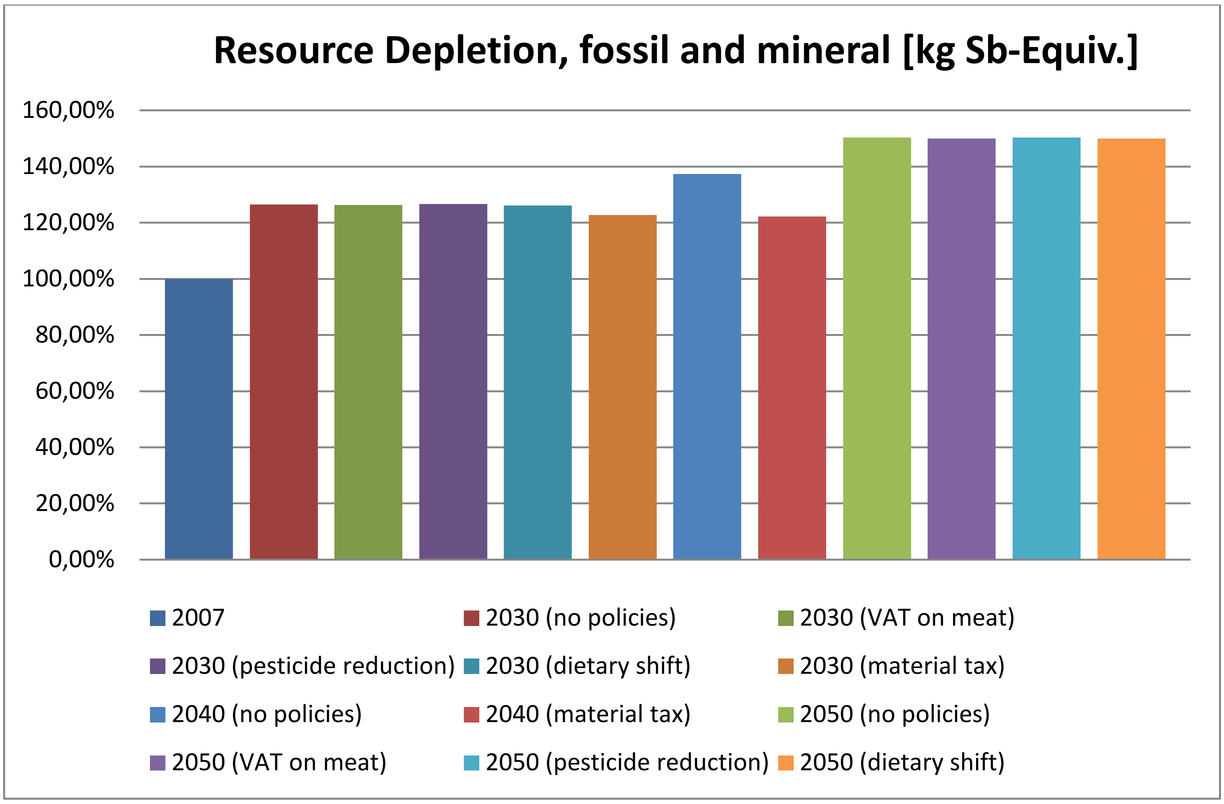


Figure 22: Resource Depletion (Normalized to 2007 values)

Resource depletion increases as seen in the assessment of greenhouse gas emissions. Resource depletion for all policies instruments in 2030 are greater than 20% compared to 2007 values. Furthermore, there was no significant decrease in resource depletion for the policy measures compared to the case in which no policies were introduced. In 2040, material tax was assessed. The material tax policy showed a roughly 10% reduction in resource depletion compared to no policies implemented. In 2050, the policy instruments showed no significant reduction in resource depletion and were roughly 30% higher compared to 2030 values and 50% higher compared to 2007 values. More data can be found in Annex C for all sectors.

Freshwater Consumption

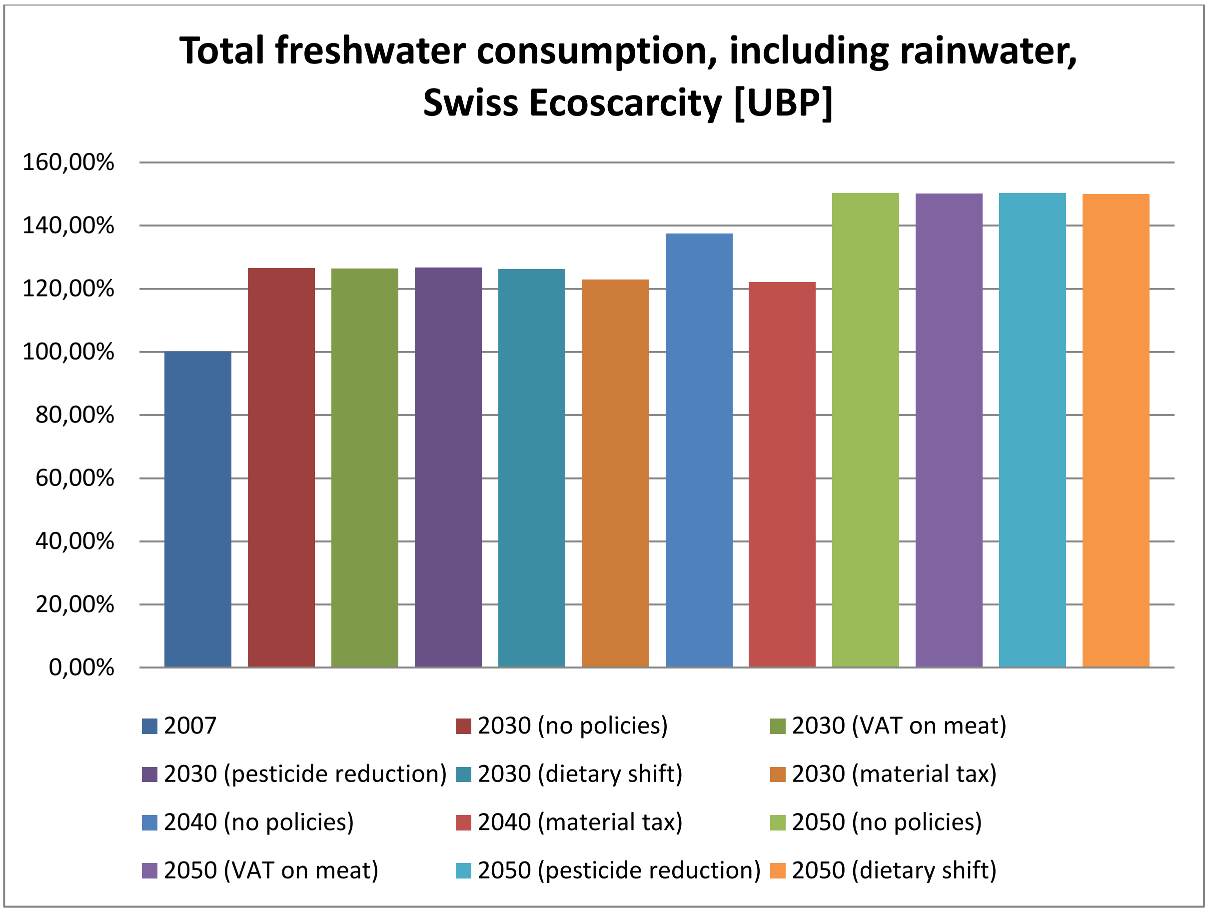


Figure 23: Freshwater Consumption (Normalized to 2007 values)

Freshwater consumption increases similar to the other impact categories. Freshwater consumption for all policies instruments in 2030 are greater than 20% compared to 2007 values. There was no significant decrease in freshwater consumption for the policy measures compared to if no policies were introduced. Once again, in 2050, the policy instruments showed no significant reduction in freshwater consumption and were roughly 30% higher compared to 2030 values and 50% higher compared to 2007 values. More data can be found in Annex C for all sectors.

Human Toxicity

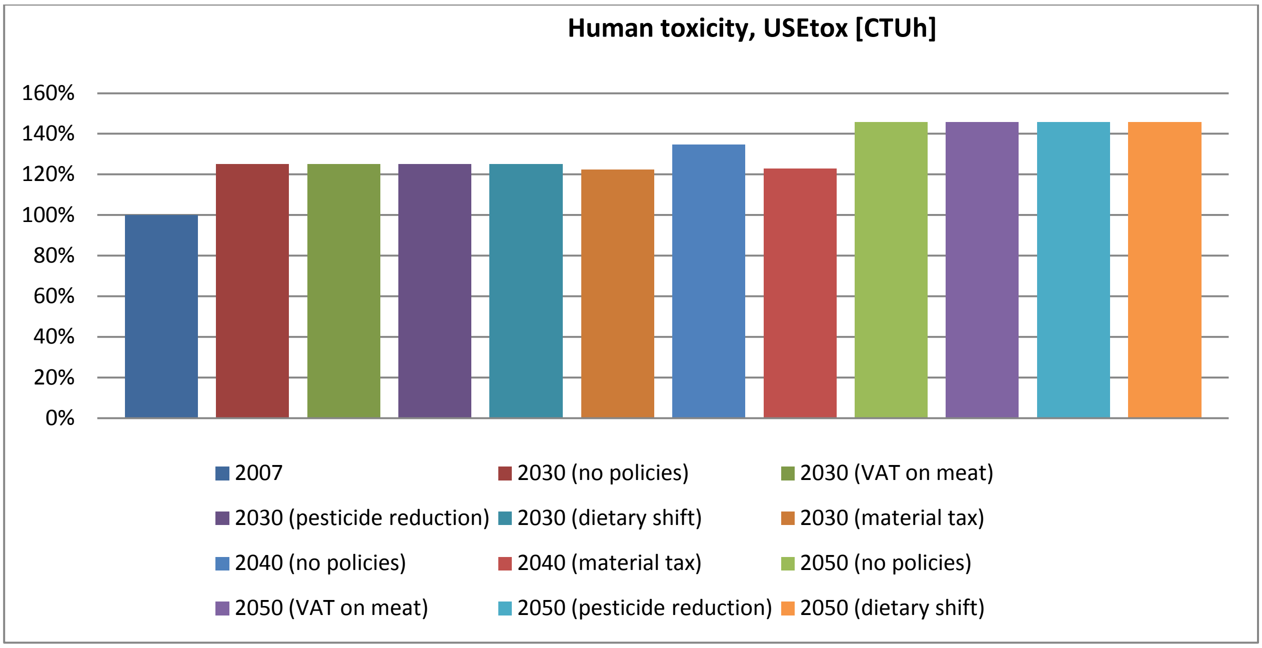


Figure 24: Human Toxicity Potential (Normalized to 2007 values)

The potential toxicity impacts on human health, once again, increases similar to those seen in the other impact categories. No significant reduction can be seen in the years 2030 and 2050 for the policy instruments compared to the scenario when no policies are implemented. In 2040 however, a material tax could decrease human toxicity potential by roughly 10% compared to the scenario when no policies are in place. More data can be found in Annex C for all sectors.

5.6.8 Conclusions

As outlined in the previous sections, when reviewing the environmental implications of policy instruments for the European economic sectors, there is no significant evidence to conclude that the policies lead to reductions in environmental impacts. Of the policy instruments reviewed, only the materials tax showed significant decreases in all environmental impact categories. Nonetheless, environmental impacts in the years 2030, 2040 and 2050 were significantly larger compared with 2007 levels for the different impact categories.

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Annex A: LCA-models of internal combustion engine and electric vehicles

Summary

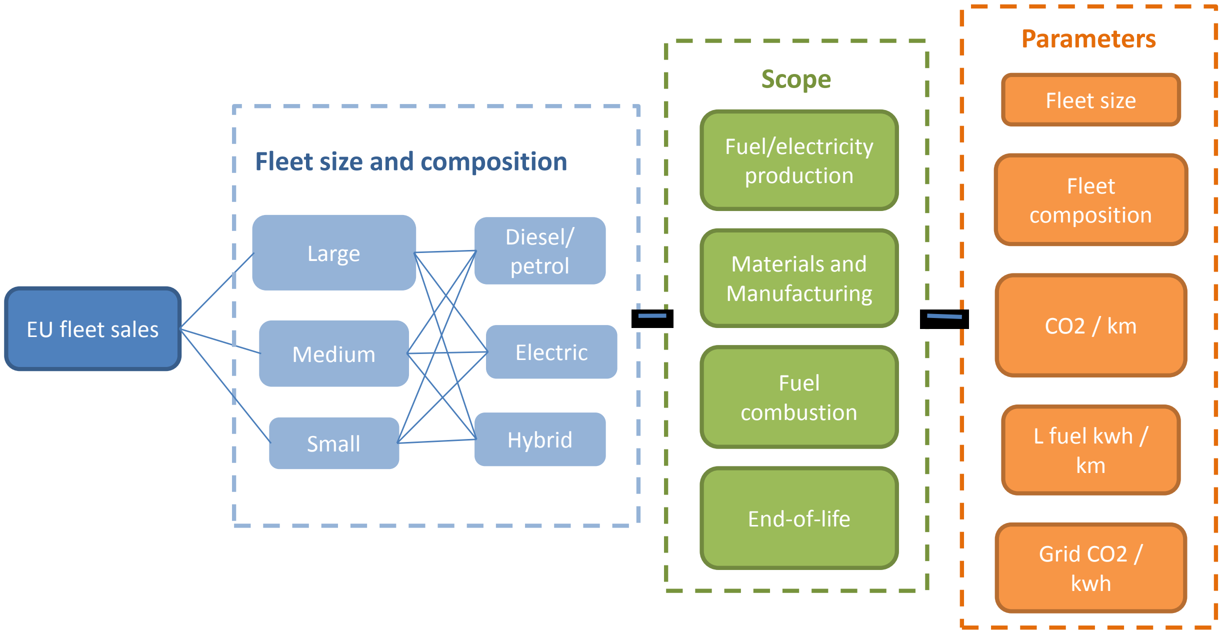
This short report describes the LCA models on generic passenger cars (diesel, petrol and electric) delivered to DYNAMIX and EUNICE projects. The description includes the modelling design implemented in GaBi modelling software, data sources, material composition of the cars, explanation about choices of main datasets, main assumptions, weak points and potential applications. Detailed information about the life cycle inventories used can be found in the project folders.

Introduction

In a joint effort between the projects DYNAMIX and EUNICE, LCA models for internal combustion engine vehicles (ICEV) and for battery electric vehicles (EV) were made in GaBi. Six LCA models were built: large, medium and small ICEV and EV. The large car models were based on Hawkins et al. (2013). Hawkins's model provided an appropriate comparison regarding materials and manufacturing stages and power on wheels to reflect European conditions. Materials and manufacturing stages of the medium and small cars were based on weight extrapolation of the large cars. The other life cycle stages (use, maintenance, end of life) for all models were modelled using Ecoinvent datasets. These models can provide appropriate comparison between vehicle alternatives regarding weight, fuel type (diesel and petrol), electricity for production and electricity for use (in case of EV), vehicle kilometre lifetime and vehicle fleet.

The models were implemented in GaBi to allow for variations in vehicle type (weight and power source), type of fuel/electricity use, country of electricity supply for manufacture and use stages, vehicle kilometre lifecycle, and fleet composition; Figure A1 illustrates this concept. The aim of this report is to describe the modelling approach undertaken, sources of data used, scope of the models, and material composition of the cars. The purpose is that anyone could easily understand the underlying assumptions of the car models in GaBi in order to run analysis and modify them.

Figure A1 - Vehicle types, lifecycle impacts and possible parameters variations



Model design

An appropriate comparison of ICEV and EV requires that the system boundary be set to include all relevant differences between the alternatives. In order for isolating core differences and guaranteeing the comparability of the two alternatives during the production, use, and end-of-life phases two main modelling choices were made. First, a common vehicle glider (vehicle without a powertrain and customised powertrains for petrol, diesel and EVs were established based on Hawking et al. (2013); see glider and powertrains components in Table A1. Second, consistent Ecoinvent datasets for operation, maintenance and end-of-life were selected.

Vehicle glider and powertrains

Materials and manufacturing stages were modelled in GaBi based on hierarchical plans. First, three top-level modules, glider, ICEV assemblies and EV assemblies, were created. Each of these modules is comprised of assemblies, which in turn contain components. Components are made up of materials. Finally, the materials consist of Ecoinvent datasets. All assemblies, components and materials were modelled in individual plans. Unit processes and flows were created to connect the respective plans over the hierarchy. The origins (i.e. country) of electricity supply for the manufacture stage was set in GaBi with global parameters. Medium voltage datasets were chosen for the manufacture stage. With this feature, analyses of impacts from electricity mixes varying with the country of manufacturing can be easily performed. Electricity mixes of all countries available in Ecoinvent datasets were included.

Table A1 provides a list of the different vehicles' assemblies, which are comprised of roughly 140 subcomponents, and the material content of the assemblies. Material composition of the whole vehicles and detailed inventories of the assemblies are provided in in Annex A1-A3.

Table A1 - Vehicle components and material content

Module	Assemblies	ICEV	EV	Material content	Weight (kg)
Glider	Body and doors	X	X	89% steel 5.5% glass 4.5% plastic 1% others	527
	Brakes	X	X	34% steel 59% iron 7% others	31
	Chassis	X	X	92% steel 2% aluminium 2% copper 3% plastic 1% rubber	187
	Interior and exterior	X	X	30% steel 7.5% aluminium 4.5% copper 50% plastic 2% rubber 1% others	235
	Tires and wheels	X	X	59% steel 23% rubber 17% other	80
	Fluids	X	X	-	9
	Final assembly	X	X	-	-
ICEV parts	Engine	X		18% steel 58% iron 19% aluminium 5% others	151
	Other powertrain	X		58% steel 1% aluminium 7% copper 33% plastic	92
	Transmission	X		62% steel 38% aluminium	42
	PbA batteries	X			17
	Fluids (only ICEV)	X		-	44
EV parts	Electric motor		X	55% steel 1% iron 35% aluminium 8% copper	60

	EV Controller		X	39% steel 1% aluminium 5% copper 1% lead 34% plastic 20% others	1
	EV Inverter			59% aluminium 25% copper 13% plastic 2% other	20
	EV Charger		X	60% aluminium 25% copper 13% plastic 1% other	17
	Extra packaging for passively cooled battery		X	100% steel	80
	EV Transmission		X	75% steel 25% iron	10
	LiMn2O4 battery[6]		X	-	214

The compiled foreground LCI, the estimation of the material content of vehicle components and the processes used to produce were made based on Hawkins and colleagues (2013). Hawkins et al. (2013) used detailed industry inventories and reports regarding materials, masses, and processes publicly available. Ecoinvent datasets were used as a background data.

The LCI inventory for each body part was compiled in two matrices, technical requirement and stressor intensity. The requirement matrix was built in a triangularized hierarchical manner, following Nakamura et al. (2008). Material and processing requirements were tracked in matrices for each vehicle component with columns representing subcomponents and rows representing production requirements based on original source data. The second matrix was then developed for each component to associate production requirements based on original source data with the closest matching Ecoinvent dataset. Figure A2 provides a print-screen of part of the matrices for body and doors.

[6] LCI of EV battery was not transparently described in Hawkins and colleagues hence it was modelled using a specific Ecoinvent dataset.

Figure A2 - Print-screen of technical requirement and stressor intensity matrices for body and doors

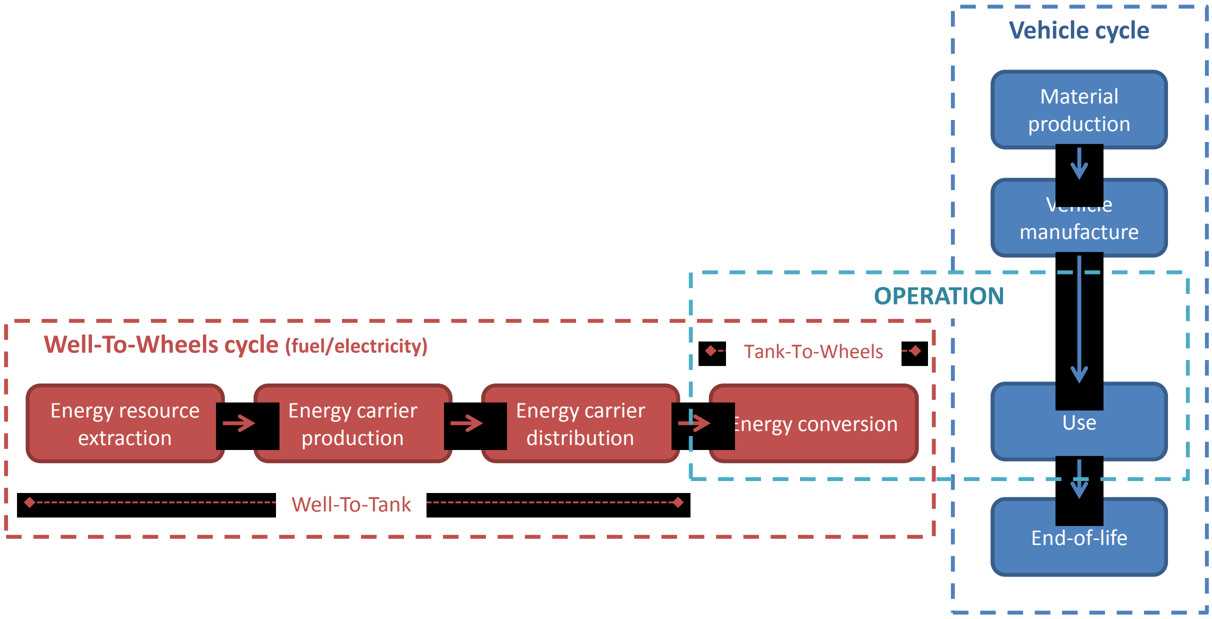
1	Body and Doors			527														
11		Material/Component			Body-in-white	Body panels	Bumpers	Body hardware	Weld blanks and fa…	Weld blanks and fa…	Doors, including tru…	Assembly processe…	Assembly processe…	Assembly processe…	Windscreen glass	Rear screen glass	Side body glass (6)	
12			Units		p	p	p	p	p	p	p	p	p	p	p	p	p	
14	Ferous	Rolled steel	kg	19.12	0	19.12	0	0	0	0	0	0	0	0	0	0	0	
15		EAF steel	kg	19.12	0	10.32	0	0.367	4.217	4.217	0	0	0	0	0	0	0	
16		galv steel	kg	317.2	211.2	4.578	8.433	0	0	0	93	0	0	0	0	0	0	
17		hot rolled steel	kg	33.46	0	33.46	0	0	0	0	0	0	0	0	0	0	0	
18		stainless steel	kg	0.08	0	0	0	0.08	0	0	0	0	0	0	0	0	0	389
19		Cast iron	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	Non-fe	Wrought Aluminium	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21		Cast Aluminium	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22		Copper	kg	0.2	0	0	0	0.2	0	0	0	0	0	0	0	0	0	
23		Magnesium	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
24		Zinc	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
25		Platinum	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26		Lead (Pb)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
27	Glass	Glass	kg	28.83	0	0	0	0.06	0	0	0.075	0	0	0	11.6	4.57	12.53	
28	Polym	Plastic	kg	25	0	0	0	6.151	3.425	3.425	12	0	0	0	0	0	0	
29		Rubber	kg	0.23	0	0	0	0.23	0	0	0	0	0	0	0	0	0	
30	Scrap	Scrap, Rolled steel	kg	4.017	0	4.017	0	0	0	0	0	0	0	0	0	0	0	
31		Scrap, EAF steel	kg	4.017	0	2.168	0	0.077	0.886	0.886	0	0	0	0	0	0	0	
32		Scrap, galv steel	kg	66.65	44.38	0.962	1.772	0	0	0	19.54	0	0	0	0	0	0	
33		Scrap, hot rolled steel	kg	7.029	0	7.029	0	0	0	0	0	0	0	0	0	0	0	
34		Scrap, stainless steel	kg	0.017	0	0	0	0.017	0	0	0	0	0	0	0	0	0	81.731
35		Scrap, glass	kg	1.518	0	0	0	0.003	0	0	0.004	0	0	0	0.611	0.241	0.659	470.73
36	Final A	Oxygen	kg		0	0	0	0	0	0	0	0.038	7E-04	0.022	0	0	0	
37		Acetylene	kg		0	0	0	0	0	0	0	0.003	3E-05	9E-04	0	0	0	
38		Nitrogen	kg		0	0	0	0	0	0	0	0	0.124	0	0	0	0	
39		Carbon dioxide	kg		0	0	0	0	0	0	0	0.258	0.005	0	0	0	0	
40		Natural gas	kg		0	0	0	0	0	0	0	0	1.525	0.272	0	0	0	
41		Drinking water	m^3		0	0	0	0	0	0	0	0.239	0.129	0.102	0	0	0	
42		Operating water	m^3		0	0	0	0	0	0	0	3.052	3.605	8.001	0	0	0	
43		Tech. heat	MJ		0	0	0	0	0	0	0	0	8.491	0	0	0	0	
44		Room heat	MJ		0	0	0	0	0	0	0	553.6	288.7	185.1	0	0	0	
45		Comp. air 6 bar	Nm^3		0	0	0	0	0	0	0	173.2	40.76	205.5	0	0	0	
46		Comp. air 12 bar	Nm^3		0	0	0	0	0	0	0	84.91	0	13.59	0	0	0	
47		Electricity	kWh		0	0	0	0	0	0	0	190.2	139.3	113.8	0	0	0	
48					255.6	81.64	10.21	7.184	8.527	8.527	124.6	1	1	1	12.21	4.811	13.19	529.51

59	ECOINVENT CORRELATIONS				Ferous metals						Non-ferrous metals							Glass	Pol
60					Rolled steel	EAF steel	galv steel	hot rolled steel	stainless steel	Cast iron	Wrought Aluminium	Cast Aluminium	Copper	Magnesium	Zinc	Platinum	Lead (Pb)	Glass	Pla
61					kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg
62					**2.707**	**2.707**	**2.716**	**2.707**	**2.656**	**1.712**	**2.651**	**2.651**	**2.651**	**1.651**	**1.6**	**1.6**	**1.6**	**2.6**	**2**
63	1759	aluminium, production mix, wrought alloy, at	kg	**1**	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
64	1758	aluminium, production mix, cast alloy, at plant	kg	**1**	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
65	**1642**	cold impact extrusion, aluminium, 3 strokes	kg	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66	**1953**	sheet rolling, aluminium	kg	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
67	1924	aluminium product manufacturing, average m	kg	**2**	0	0	0	0	0	0	1	1	0	0	0	0	0	0	
68	1910	steel, converter, low-alloyed, at plant/RER	kg	**3**	0.5	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	
69	1913	steel, electric, un- and low-alloyed, at plant/R	kg	**5**	0.5	1	0.5	0.5	0	0	0	0	0	0	0	0	0	0	
70	1779	chromium steel 18/8, at plant/RER	kg	**2**	0	0	0	0	1	0	0	0	0	0	0	0	0	0	
71	1775	cast iron, at plant/RER	kg	**1**	0	0	0	0	0	1	0	0	0	0	0	0	0	0	
72	**1956**	sheet rolling, steel	kg	**2**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
73	**1948**	hot rolling, steel	kg	**2**	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
74	1703	milling, aluminium, average	kg	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
75	1707	milling, cast iron, average	kg	**0.01**	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	
76	1711	milling, chromium steel, average	kg	**0.01**	0	0	0	0	0.005	0	0	0	0	0	0	0	0	0	
77	1715	milling, steel, average	kg	**0.04**	0.005	0.005	0.005	0.005	0	0	0	0	0	0	0	0	0	0	
78	1939	steel product manufacturing, average metal w	kg	**6**	0	1	1	0	1	0	0	0	0	0	0	0	0	0	
79	**1950**	powder coating, steel	m2	**0.357**	0.051	0.051	0	0.051	0	0.051	0	0	0	0	0	0	0	0	
80	1964	zinc coating, pieces	m2	**0.12**	0	0	0.06	0	0	0	0	0	0	0	0	0	0	0	
81	1799	copper, primary, at refinery	kg	**0.85**	0	0	0	0	0	0	0	0	0.85	0	0	0	0	0	
82	1805	copper, secondary, at refinery	kg	**0.15**	0	0	0	0	0	0	0	0	0.15	0	0	0	0	0	
83	**1961**	wire drawing, copper	kg	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Operation, maintenance and end-of-life

Two different life cycles should be considered when evaluating the energy use and emissions of various vehicle technologies (Figure A3). The first concerns the vehicle cycle – material extraction, production operation and end-of-life (Burnham et al. 2006). The second one comprises the life cycle of the energy carrier used to propel the vehicle, such as liquid fuel (petrol, diesel) or electricity, and it is called well-to-wheels (WTW). The WTW life cycle can be subdivided into the well-to-tank (WTT) stage and the tank-to-wheel (TTW) stage. The environmental burden of the WTT stage differs a lot, depending on the source of production; e.g. hydropower- and coal-fired plants (Nordelöf et al. 2014).

Figure A3 - Vehicle cycle and fuel/electricity cycle



Both vehicle life cycle and fuel/electricity life cycle were included in the GaBi models. Vehicle life cycle comprises of material and vehicle production, use (including maintenance) and end-of-life phases (Figure A3 in blue). Operation energy requirements (fuel/electricity, Figure A3 in red), maintenance and end-of-life were modelled using Ecoinvent datasets of passenger and city cars. Those datasets are based on the performance of vehicles of comparable size, mass, and power.

In the use phase electricity and fuel consumption were tracked, together with their full supply chains. Use phase fuel requirements and emissions for the large, medium and small ICEVs are modelled with the Ecoinvent datasets ‘passenger car, operation’ and ‘city car, operation’, respectively. The emission requirement level EURO5 was chosen for diesel and petrol cars.

Use phase energy requirements for the EV were similarly modelled. Energy mixes for use phase (EVs) were set with process parameters. Electricity mixes of all countries available in Ecoinvent datasets were included. Medium voltage datasets were chosen for the production stage and low voltage for the use stage. This feature was included to allow for easy analyses of energy impacts from both production and use phases by varying the country of power supply.

Equally to the use phase, consistent Ecoinvent datasets for vehicle maintenance and end-of-life were selected. An important highlight concerning maintenance of the large EV is that it includes one replacement and disposal of battery. Ecoinvent datasets for end-of-life assume disposal (incineration) of bulk material (e.g. plastic, rubber, textiles) while metals like steel, aluminium and copper are considered to be fully recycled and thus a cut off allocation is used (for details see Spielmann et al. (2007)).

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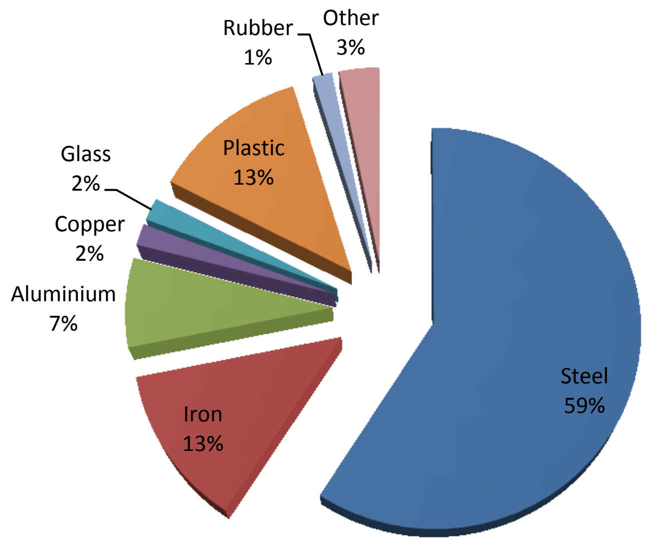
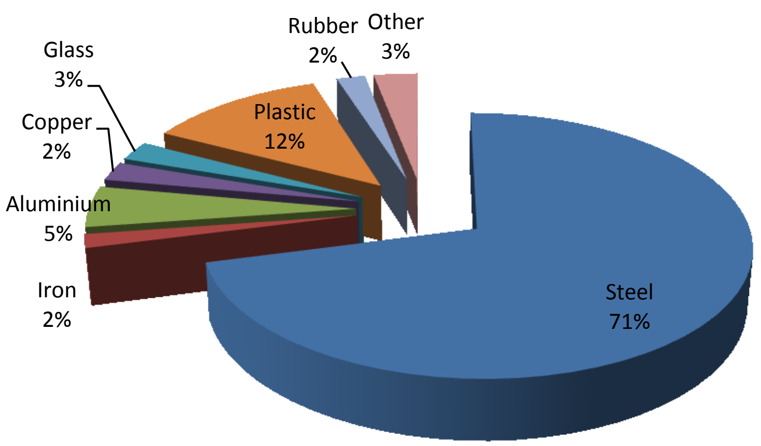
Annex A1 – Material composition of the ICEVs and EVs (kg)

Material composition of the ICEVs



Material composition of the EVs



Annex A2 – Material composition of the glider (kg) – large car

GLIDER	1067.32	Kg
Body & doors	Body hardware [Automotive assemblies]	7.18
	Body panels [Automotive assemblies]	81.64
	Body-in-white [Automotive assemblies]	255.60
	Bumpers [Automotive assemblies]	10.21
	Doors, including trunk lid [Automotive assemblies]	124.62
	Rear screen glass [Automotive assemblies]	4.81
	Side body glass (6) [Automotive assemblies]	13.19
	Weld blanks and fasteners (electronics to body) [Automotive assemblies]	8.53
	Weld blanks and fasteners (other systems to body) [Automotive assemblies]	8.53
	Windscreen glass [Automotive assemblies]	12.21
	TOTAL	**526.51**
Brakes	Brakes, friction material [Automotive assemblies]	2.27
	Brakes, hardware [Automotive assemblies]	28.76
		31.03
Chassis	Chassis electrical [Automotive assemblies]	9.98
	Corner suspension [Automotive assemblies]	40.82
	Cradle [Automotive assemblies]	29.94
	Driveshaft/axle [Automotive assemblies]	73.94
	Steering system [Automotive assemblies]	22.23
	Weld blanks and fasteners (chassis to body) [Automotive assemblies]	9.98
	TOTAL	**186.88**
Fluids used in both EV and ICEV	CH: methanol, at regional storage [organics]	4.50
	RER: dichloromethane, at plant [organics]	0.75
	RER: lubricating oil, at plant [organics]	0.35
	RER: propylene glycol, liquid, at plant [organics]	2.94
	TOTAL	**8.54**
Vehicle Interior and Exterior	Acrylonitrile butadiene styrene (ABS) [Metals]	0.28
	Cast Aluminium [Metals]	5.30
	Copper [Metals]	12.32

	DE: silicon, electronic grade, at plant [refinement]	0.14
	EAF steel [Metals]	0.10
	Ethylene propylene diene monomer (EPDM-TD10) [Metals]	5.07
	Extruded aluminum [Metals]	12.00
	Extruded rubber [Plastics]	0.90
	Galv steel [Metals]	5.30
	High density polyethylene (PE-HD) [Plastics]	0.61
	Magnesium [Metals]	0.24
	Nylon 6 (PA6) [Plastics]	0.27
	Nylon 6, 10% Glass fiber, 20% Minerals (PA6-(GF10+MX20)) [Plastics]	1.29
	Nylon 66 (PA66) [Plastics]	0.20
	Nylon 66, 25% Glass fiber (PA66-GF25) [Plastics]	0.22
	Nylon 66, 30% Mineral powder (PA66-MD30) [Plastics]	0.16
	Polyethylene terephthalate (PET) [Plastics]	0.38
	Polymethyl methacrylate (PMMA) [Plastics]	0.91
	Polypropylene (PP) [Metals]	12.41
	Polypropylene ether (PE) [Metals]	9.67
	Polypropylene, 20% Talc (PP-TD20) [Plastics]	2.37
	Polypropylene, 25% Fiberglass (PP-GF25) [Plastics]	0.87
	Polystyrene (PS) [Plastics]	3.70
	Polyurethane (polyether type) (PUR-E) [Plastics]	9.42
	RER: alkyd paint, white, 60% in solvent, at plant [Manufacturing]	14.15
	RER: zinc, primary, at regional storage [Benefication]	0.10
	Rolled aluminum [Metals]	0.90
	Rolled steel [Metals]	6.20
	Rubber [Plastics]	70.31
	Stainless steel [Metals]	1.20
	Steel [Metals]	57.76
	Wrought Aluminium [Metals]	0.26
	TOTAL	**235.00**
Tires and Wheels	Tires (4x) [Material systems]	37.78
	Wheels (x4) [Automotive assemblies]	41.58
	TOTAL	**79.36**

Annex A3 – Material composition of the ICEV and EV parts (kg) – large cars

ICEV parts	346.08	Kg
	Engine ICEV [Automotive assemblies]	151.07
	Fluids used only in ICEV [Automotive assemblies]	44.05
	Other ICEV Powertrain Components [Automotive assemblies]	92.25
	ICEV Transmission [Automotive assemblies]	42.11
	ICEV Battery [Automotive assemblies]	16.60
EV parts	**401.16**	
	EV Electric Motor [Automotive assemblies]	59.71
	EV Controller [Automotive assemblies]	1.01
	EV Inverter [Automotive assemblies]	20.16
	EV Chargerr [Automotive assemblies]	16.70
	EV Extra packaging for passively cooled battery [Automotive assemblies]	80.00
	EV Differential [Automotive assemblies]	9.59
	GLO: battery, NiMH, rechargeable, prismatic, at plant [Module]	214.00

Annex B: Supplementary Data for Food Consumption and Waste Models

Table 43: Data and References for Food Model

Category	Food Product	GHG Emissions (kg CO2-eq)/kg	Land Use (m2/kg)	Blue water Consumption (kg/kg)	Refs
Meat	Bovine Meat	29.80	0.00	550.14	GWP and Land Use: Tuomisto and Roy, 2012 BW: Mekonnen och Hoekstra 2010a
	Poultry Meat	6.70	0.00	562.54	GWP: Tuomisto and Roy, 2012 Land Use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010a
	Pigmeat	8.50	0.00	304.97	GWP and Land Use: Tuomisto and Roy, 2012 BW: Mekonnen och Hoekstra 2010a
Cereals and Grains	Wheat and products	0.63	0.00	342.46	GWP and Land Use: : Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b
	Barley and products	0.45	0.00	78.87	GWP: EcoInvent 2.2 Land Use: EcoInvent 2.2 BW: Mekonnen och Hoekstra 2010b
	Maize and products	0.49	0.00	81.23	GWP: Noyaa et al., 2015 Land Use: Assumed similar to Wheat BW: Mekonnen och Hoekstra 2010b
Starchy Crops	Potatoes and products	0.51	0.00	32.94	GWP and Land use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b
Sugars	Sugar beet	2.06	0.00	25.54	GWP: EcoInvent 2.2. Land Use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b
	Sugar (Raw Equivalent)	0.60	0.00	166.98	GWP: Röös, 2013 Land Use: Assumed as sugar beet BW: Mekonnen och Hoekstra 2010b
Pulses	Beans	0.61	0.00	124.86	GWP: EcoInvent 2.2. Land Use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b (assumed as pulses)
	Peas	0.83	0.00	33.17	GWP: EcoInvent Land Use: Assumed as beans BW: Mekonnen och Hoekstra 2010b

Nuts and products		1.5	1.50	0.00	
Oil Crops	Soyabeans	1.30	0.00	70.29	GWP and Land Use: Tuomisto and Roy, 2012 BW: Mekonnen och Hoekstra 2010b
	Rape and Mustardseed	0.92	0.00	116.18	GWP: EcoInvent 2.2. Land Use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b
	Olives (including preserved)	0.48	0.00	498.92	GWP: Salomone and Loppolo, 2012 Land Use: Assumed as beans BW: Mekonnen och Hoekstra 2010b
Vegetable Oils	Sunflowerseed Oil	0.77	0.00	292.66	GWP: from Biograce Standard Values Land Use: Audsley et al. 2009 (assumed as sunflower seed) BW: Mekonnen och Hoekstra 2010b
	Rape and Mustard Oil	2.72	0.00	429.40	GWP and Land Use: EcoInvent 2.2. BW: Mekonnen och Hoekstra 2010b
	Soyabean Oil	0.87	0.00	137.34	GWP: Assumed as part of soya beans Land Use: Assumed as soya beans BW: Mekonnen och Hoekstra 2010b
	Olive Oil	0.48	0.00	2388.35	GWP: Assumed as olives Land Use: Assumed as olives BW: Mekonnen och Hoekstra 2010b
Vegetables	Tomatoes and products	1.30	0.00	63.25	GWP and Land Use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b
	Onions	0.48	0.00	44.50	GWP and Land Use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b
Fruits - Excluding Wine	Oranges, Mandarines	0.51	0.00	109.52	GWP and Land Use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b
	Apples and products	0.43	0.00	133.32	GWP and Land Use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b
	Grapes and products (excl wine)	0.42	0.00	96.62	GWP and Land Use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b
Stimulants	Coffee and products	0.81	0.00	116.48	GWP and Land Use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b
	Cocoa Beans and products	1.89	0.00	3.97	GWP and Land Use: Audsley et al. 2009 BW: Mekonnen och Hoekstra 2010b

Spices	Pepper	1.00	0.00	467.21	GWP: Röös, 2013 Land Use: Assumed as onion BW: Mekonnen och Hoekstra 2010b
	Pimento	1.00	0.00	44.50	GWP: Röös, 2013 Land Use and BW: Assumed as onion
Beverages	Wine	0.53	0.00	138.03	GWP: Iannone et al. (2014) Land Use: Mattila et al. (2012) BW: Mekonnen och Hoekstra 2010b
	Beer	2.00	0.00	16.50	GWP: Ecoinvent (Barley) Land Use: Mattila et al. (2012) BW: Mekonnen och Hoekstra 2010b
Eggs		3.04	3.04	0.00	GWP: Ecoinvent Land Use: Mattila et al. 2012 BW: Mekonnen och Hoekstra 2010b
Milk - Excluding Butter		1.1	1.10	0.00	GWP: Ecoinvent Land Use: Mattila et al. (2012) BW: Mekonnen och Hoekstra 2010b
Offals		0.491209	0.49	0.00	GWP: Ecoinvent Land Use: Tuomisto and Roy, 2012 BW: Mekonnen och Hoekstra 2010b
Animal Fats	Butter, Ghee	8.00	0.00	305.25	GWP and Land Use: Assumed as part of milk BW: Mekonnen och Hoekstra 2010a
	Cream	4.00	0.00	65.95	GWP: Röös, 2013 Land Use and BW: Assumed as part of milk
	Fats, Animals, Raw	0.33	0.00	6.05	Assumed as part of bovine meat
Fish, Seafood	Freshwater Fish	4.50	0.00	0.00	GWP: Audsley et al. 2009 Land Use: Assumed as zero BW: Assumed as zero
	Demersal Fish	2.50	0.00	0.00	GWP: Rasenberg, 2013 (an average) Land Use: Assumed as zero BW: Assumed as zero
	Pelagic Fish	3.00	0.00	0.00	GWP: Audsley et al. 2009 Land Use: Assumed as zero BW: Assumed as zero
Aquatic Animals, Others		35	35.00	0.00	GWP: Ziegler et al., 2011 Land Use: Assumed as zero BW: Assumed as zero
Infant Food		0.628	0.63	0.00	Assumed as an average of vegetable and fruits

References:

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Table 44: EU-27 Consumption figures for 2010 in total kg

Category	Food Product	2010 (kg total)
Meat	Bovine Meat	2.59E+11
	Poultry Meat	7.98E+10
	Pigmeat	1.86E+11
Cereals and Grains	Wheat and products	3.94E+10
	Barley and products	4.28E+09
	Maize and products	4.73E+09
Starchy Crops	Potatoes and products	1.90E+10
Sugars	Sugar beet	2.87E+11
	Sugar (Raw Equivalent)	1.17E+10
Pulses	Beans	3.73E+08
	Peas	8.17E+08
Nuts and products		3.38E+09
Oil Crops	Soyabeans	2.00E+10
	Rape and Mustardseed	2.36E+10
	Olives (including preserved)	7.21E+09
Vegetable Oils	Sunflowerseed Oil	2.28E+09
	Rape and Mustard Oil	6.53E+09
	Soybean Oil	2.27E+09
	Olive Oil	1.18E+09
Vegetables	Tomatoes and products	5.73E+10
	Onions	6.47E+09

Fruits - Excluding Wine	Oranges, Mandarines	1.04E+10
	Apples and products	6.74E+09
	Grapes and products (excl wine)	1.54E+10
Stimulants	Coffee and products	2.16E+09
	Cocoa Beans and products	2.17E+09
Spices	Pepper	1.27E+08
	Pimento	2.35E+08
Beverages	Wine	8.13E+09
	Beer	7.40E+10
Eggs		1.87E+10
Milk - Excluding Butter		1.33E+11
Offals		7.56E+08
Animal Fats	Butter, Ghee	1.45E+10
	Cream	8.53E+09
	Fats, Animals, Raw	8.85E+08
Fish, Seafood	Freshwater Fish	1.21E+10
	Demersal Fish	1.28E+10
	Pelagic Fish	1.13E+10
Aquatic Animals, Others		2.73E+09
Infant Food		8.60E+07

Table 45: Food Waste Amounts for Different Scenarios

Scenario	Production	Retail	Households	Total
2010	1.55E+11	2.41E+10	7.39E+10	2.53E+11
2030, 1	1.54E+11	2.50E+10	7.65E+10	2.56E+11
2030, 1b	1.54E+11	9.57E+09	3.02E+10	1.94E+11
2030, 1c	1.33E+11	8.06E+09	2.59E+10	1.67E+11
2030, 1d	1.54E+11	1.32E+10	3.88E+10	2.07E+11
2050, 1	1.61E+11	2.50E+10	7.68E+10	2.63E+11
2050, 1b	1.61E+11	4.16E+09	1.37E+10	1.79E+11
2050, 1c	1.27E+11	3.39E+09	1.13E+10	1.42E+11
2050, 1d	1.61E+11	1.93E+09	6.67E+09	1.70E+11

References:

FAO Stat, 2014. Food Balance Sheets. Available: http://faostat.fao.org/site/368/default.aspx#ancor [Accessed Sept 08 2014]

Annex C: Overarching Model

Economic Output for Sectors with Policy Intervention

Methodology Used for Economic Value of Representative Products

Agriculture

The Eurostat database “Economic accounts for agriculture - values at current prices [aact_eaa01]” includes data on the economic production volume for different agricultural products, calculated in the basic price in 2007. From this database it was possible to find the share of value for different products in the agricultural sector. The three products with the greatest production volume were wheat, barley and potatoes. Wheat represented almost 25% of total value of production for the agricultural sector in 2007, which included a collection of different “wheat products,” including wheat and spelt, soft wheat and spelt and durum wheat. Thereafter, barley and potatoes were chosen to represent the agricultural sector with values of production accounting for roughly 6% and 5% of the total respectively (see Table 46).

We used a scale up factor to scale the production value of these three products to a total of 100%. As such it was possible to define the share of wheat as 69.5%; barley as 16% and potatoes as 14.5%.

Once the production share of each product was defined, the value per output “€/kg” was calculated. The Eurostat database “EU trade since 1988 by HS2-HS4 (DS-016894)” was used for this task, and an approximate price per kilo was defined for the products, considering both import and export trades.

A weighted average price (0.197 €/kg) was then calculated for the mix of the three products, based on the share of value of production of each product. The inverse of this average price (5.07 kg/€) can be used for translating results on the economic output from the agricultural sector to a physical flow of products.

Table 46: RFPs and Economic Values for Agriculture Sector

	Wheat	Barley	Potato
% of total production value in 2007	24.83%	5.69%	5.28%
Scaling up to 100%	69.37%	15.89%	14.74%
€/kg	0.19	0.18	0.25

€/kg (weighted average)		0.197	
kg/€ (weighted average^{-1})		5.07	
kg/€	3.52	0.81	0.75

Livestock

For the livestock sector, data was extracted from the same Eurostat database for agriculture, “Economic accounts for agriculture - values at current prices [aact_eaa01]”. Raw milk, cattle and pigs were selected as the three representative products, given their high value of production in 2007. Here, the same methodology used for agriculture was followed in order to define the share of production and scale up factors.

However the ratio “€/kg” for each product was obtained from different sources compared to the database used for agriculture as the Eurostat database for international trade does not contain data for the said products. The price in Euros per kilo for milk was assumed as being the quotient of the total production value of milk in the EU in 2007, retrieved from the same Eurostat database mentioned above, per the total weight of cow’s milk collected in the EU in the same year, obtained from Eurostat database “Milk collection (all milks) and dairy products obtained - annual data [apro_mk_pobta]”.

Moreover cattle’s price per kilo was defined through Eurostat database “Selling prices of animal products (absolute prices) - annual price (from 2000 onwards) [apri_ap_anouta]”; using “Cows - prices per 100 kg live weight” as the chosen product. The average price for all countries listed was defined as final value. The same database and methodology for cattle was applied to find the price for pigs, however having “Pigs (light) - prices per 100 kg live weight” highlighted as the chosen product. See Table 47 for a review of all data used to compute the ratio (kg/€) for livestock.

Table 47: RFPs and Economic Values for Livestock Sector

	Raw milk	Cattle	Pig
% of total production value in 2007	34.16%	21.61%	20.90%
Scaling up to 100%	44.55%	28.19%	27.26%
€/kg	0.37	1.04	1.14
€/kg (weighted average)		0.771	

kg/€ (weighted average^{-1})		1.30	
kg/€	0.58	0.37	0.35

Gas

For the gas sector, it was assumed that representative products were comprised of products included in the Harmonized System Code (HS4), 2711, "Petroleum gas and other gaseous hydrocarbons." Using the Eurostat database for International Trade (DS-045409-EU Trade Since 1988 by HS2, 4, 6 and CN8) an average price, in €, per kg of product was retrieved. Since just one product is assigned for this sector, i.e. petroleum gas, there was no need for calculating a weighted average and different shares of value of production for different products. See Table 48 for a review of all data used to compute the ratio (kg/€) for the Gas sector.

Table 48: RFPs and Economic Values for Gas Sector

	Petroleum gas
% of total production value in 2007	100%
€/kg	0.68
kg/€	1.46

Oil Products

The representative product for this sector was defined through the Eurostat database “Supply, transformation and consumption of oil - annual data [nrg_102a].” The “Gas/diesel oil (without bio components)” was chosen as the representative product.

The average price, in €/kg of product was retrieved from the Eurostat database for International Trade (DS-045409-EU Trade Since 1988 by HS2, 4, 6 and CN8. The product chosen in the database was the HS4 code 2710, “Petroleum oils and oils obtained from bituminous minerals (excl. crude)”. Since just one product is assigned for this sector there was no need for calculating a weighted average and different shares of value of production for different products. See Table 49 for a review of all data used to compute the ratio (kg/€).

Table 49: RFPs and Economic Values for Oil Sector

	Petroleum oils
% of total production value in 2007	100%
€/kg	0.48
kg/€	2.08

Electricity

Electricity price was defined as an average of both Eurostat databases “Electricity prices for industrial consumers - bi-annual data (from 2007 onwards) [nrg_pc_205]” and “Electricity prices for domestic consumers - bi-annual data (from 2007 onwards) [nrg_pc_204].” The representative product for this sector was assumed as the “average electricity grid mix” for the EU-27 in 2011. The value of electricity was calculated per MJ. See Table 50 for a review of all data used to compute the ratio (kg/€) for electricity.

Table 50: RFPs and Economic Values for Electricity Sector

	Electricity
% of total production value in 2007	100%
€/MJ	0.04
MJ/€	25.1

Other Mining

The Other Mining sector (GTAP sector “omn”) is comprised of the ISIC rev.3 product codes 12, 13 and 14.[7]

Through Eurostat a comprehensive list of Manufactured Goods within EU could be retrieved. The coding system used in the mentioned list (PRODCOM) could be converted in order to match the ISIC rev.3, allowing the possibility to correlate both coding systems. Once the coding was matched, three representative products were selected, including

- crushed stone (PRODCOM 08121230),
- gravel and pebbles (PRODCOM 08121210) and
- construction sands (PRODCOM 08121190).

Defining the €/kg ratio for the representative products was similar to previous sector calculations; see method in Agriculture sector. See Table 51 for a review of all data used to calculate the ratio (kg/€) for the other mining sector.

Table 51: RFPs and Economic Values for Other Mining Sector

	Crushed stone	Gravel and pebbles	Sands
% of total production value in 2007	28.6%	17.4%	15.2%
Scaling up to 100%	46.7%	28.4%	24.9%
€/kg	0.015	0.0097	0.0086
€/kg (weighted average)		0.010	
kg/€ (weighted average^{-1})		97.61	
kg/€	45.62	27.74	24.25

[7] https://www.gtap.agecon.purdue.edu/databases/contribute/concordinfo.asp

Meat Industry

The Meat Industry sector is comprised by the CPC product codes 21111-21119, 2112-2114, 2161-2161 and 22[8].

From data provided by Eurostat (REFERENCE)[9] a comprehensive list of manufactured goods within EU was retrieved. The coding system used in the mentioned list (PRODCOM) could be converted in order to match the CPC, allowing thus the possibility to correlate both coding systems. Once the coding was matched, four representative products were selected in order to include dairy products. These included milk and cream (PRODCOM 10511142); fresh or chilled pig meat (PRODCOM 10111290); cheese (PRODCOM 10514050) and fresh or chilled cuts, of beef and veal (PRODCOM 10111190). Defining the €/kg ratio for the representative products was similar to previous sector calculations. See Table 52 for a review of all data used to calculate the ratio (kg/€) for the meat industry.

Table 52: RFPs and Economic Values for Meat Industry Sector

	Milk and cream	Pig meat	Cheese	Beef meat
% of total production value in 2007	10.7%	6.9%	6.7%	5.4%
Scaling up to 100%	36.0%	23.3%	22.5%	18.2%
€/kg	0.48	2.18	3.5	3.43
€/kg (weighted average)	2.09			
kg/€ (weighted average^{-1})	0.48			
kg/€	0.17	0.11	0.11	0.087

[8] GTAP sectors “cmt”, “omt” and “mil” https://www.gtap.agecon.purdue.edu/databases/contribute/concordinfo.asp

[9] Excel file (http://ec.europa.eu/eurostat/web/prodcom/data/excel-files-nace-rev.2), Prodcom Annual Data 2007 (updated 12/12/2014),

Food Industry

The Food Industry sector (GTAP sectors “vol”, “pcr”, “sgr”, “ofd” and “b_t”) is comprised of the CPC product codes 212-215, 2163-2169, 217-218, 2311-2318, 232-239 and 24-25[10].

Through the Eurostat data[11] a comprehensive list of Manufactured Goods within EU could be retrieved. The coding system used in the mentioned list (PRODCOM) was converted to match the CPC, allowing the possibility to correlate both coding systems. Once the coding was matched, six representative products were selected, including

- beer (PRODCOM 11051000);
- fresh bread (PRODCOM 10711100);
- animal feeding for pigs (PRODCOM 10911033);
- non-alcoholic beverages (PRODCOM 11071950);
- white sugar (PRODCOM 10811230)
- wheat or meslin flour (PRODCOM 10612100).

The subsequent steps for defining a €/kg ratio for every product followed the same methodology as described in the agricultural sector.

Table 53: RFPs and Economic Values for Food Industry Sector

	Beer	Bread	Feeding	Soft drink	Sugar	Flour
% of total production value in 2007	7.2%	5.8%	2.6%	2.5%	2.4%	2.3%
Scaling up to 100%	31.5%	25.5%	11.3%	11.2%	10.6%	9.9%
€/kg	1.17	1.18	0.51	1.28	0.63	0.31
€/kg (weighted average)			0.97			
kg/€ (weighted average^{-1})			1.03			
kg/€	0.33	0.26	0.17	0.17	0.11	0.10

Chemical Industry

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[10] Check: (https://www.gtap.agecon.purdue.edu/databases/contribute/concordinfo.asp)

[11] Excel file (http://ec.europa.eu/eurostat/web/prodcom/data/excel-files-nace-rev.2), Prodcom Annual Data 2007 (updated 12/12/2014),

The Chemical Industry sector (GTAP sector "crp") is comprised of the ISIC rev.3 product codes 241, 242 and 25. Through the Eurostat (2015) Prodcom Annual Data 2007 (updated 12/12/2014), a comprehensive list of Manufactured Goods within EU could be retrieved. The coding system used in the mentioned list (PRODCOM) could be converted in order to match the ISIC rev.3, allowing thus the possibility to correlate both coding systems. Once the coding was matched, three representative products were selected:

- plastic doors, windows and their frames (PRODCOM 22231450);
- ethylene (PRODCOM 20141130)
- polypropylene, in primary forms (PRODCOM 20165130).

The subsequent steps for defining a €/kg ratio for every product was the same as described in the agricultural sector.

Table 54: RFPs and Economic Values for Chemical Industry Sector

	Plastic doors	Ethylene	Polypropylene
% of total production value in 2007	2.83%	2.54%	2.16%
Scaling up to 100%	37.6%	33.7%	28.7%
€/kg	4.95	0.83	1.14
€/kg (weighted average)		2.47	
kg/€ (weighted average^{-1})		0.41	
kg/€	0.15	0.14	0.12

Iron and Steel

The Iron and Steel sector (GTAP sector "i_s") is comprised by the ISIC rev.3 product codes 271 and 2731. Through Eurostat data a comprehensive list of Manufactured Goods within EU could be retrieved. The coding system used in the mentioned list (PRODCOM) could be converted in order to match the ISIC rev.3, allowing the possibility to correlate both coding systems. Once the coding was matched, three representative products were selected:

- hot rolled concrete reinforcing bars (PRODCOM 24106210);
- cold rolled sheet, plate and wide strip of a width of 600 mm or more (of stainless steel) (PRODCOM 24104200)
- other wire rod (of non-alloy steel) (PRODCOM 24106190).

The subsequent steps for defining a €/kg ratio for every product was the same as described in the agricultural sector.

Table 55: RFPs and Economic Values for Iron and Steel Sector

	Re-bars	Cold rolled SS	Wire rod
% of total production value in 2007	10.64%	9.62%	4.88%
Scaling up to 100%	42.3%	38.3%	19.4%
€/kg	0.47	3.45	0.49
€/kg (weighted average)		1.61	
kg/€ (weighted average^{-1})		0.62	
kg/€	0.26	0.24	0.12

Other Metals

The Other Metals sector (GTAP sector “nfm”) is comprised of the ISIC rev.3 product codes 272 and 2732. Through Eurostat data a comprehensive list of Manufactured Goods within EU could be retrieved. The coding system used in the mentioned list (PRODCOM) could be converted in order to match the ISIC rev.3, allowing thus the possibility to correlate both coding systems.

Once the coding was matched, three representative products were selected:

- platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form (PRODCOM 24413030);
- Aluminium alloy bars, rods, profiles and hollow profiles (PRODCOM 24422250)
- Copper wire, refined (transv. section > 6 mm), of copper alloy (PRODCOM 24442330).

The subsequent steps for defining a €/kg ratio for every product followed the same method as described in the agricultural sector.

Table 56: RFPs and Economic Values for Other Metals Sector

	Platinum	Al alloy bars	Copper wire
% of total production value in 2007	55.13%	4.40%	4.24%
Scaling up to 100%	86.5%	6.9%	6.6%
€/kg	33769	3.63	5.38
€/kg (weighted average)		29193	
kg/€ (weighted average^{-1})		3.43E-5	
kg/€	2.96E-5	2.37E-6	2.28E-6

Non Metallic Minerals

Non Metallic Minerals sector (GTAP sector “nmm”) is comprised by the ISIC rev.3 product code 26. From the Eurostat database a comprehensive list of Manufactured Goods within EU could be retrieved. The coding system used in the mentioned list (PRODCOM) could be converted in order to match the ISIC rev.3, allowing for the possibility to correlate both coding systems.

Once the coding was matched, three representative products were selected which included:

- ready-mixed concrete (PRODCOM 23631000);
- prefabricated structural components for building or civil engineering, of cement, concrete or artificial stone (PRODCOM 23611200)
- factory made mortars (PRODCOM 23641000).

The subsequent steps for defining a €/kg ratio for every product followed the same method as described in the agricultural sector.

Table 57: RFPs and Economic Values for Non Metallic Minerals Sector

	Concrete	Structural components	Mortars
% of total production value in 2007	15.52%	8.22%	3.35%
Scaling up to 100%	57.3%	30.3%	12.4%
€/kg	0.04	0.20	0.18
€/kg (weighted average)		0.10	
kg/€ (weighted average^{-1})		9.53	
kg/€	5.46	2.89	1.18

Other Industry

The Other Industry sector (GTAP sectors “tex”, “wap”, “lea”, “lum”, “ppp”, “fmp”, “mvh”, “otn”, “ele”, “ome” and “omf”) is comprised of the ISIC rev.3 product codes 17-22, 243 and 28-37.

Through Eurostat data a comprehensive list of Manufactured Goods within the EU could be retrieved. The coding system used in the mentioned list (PRODCOM) could be converted in order to match the ISIC rev.3, allowing for the possibility to correlate both coding systems.

Once the coding was matched, seven representative products were selected, with five of these related to Motor Vehicles and Parts sector (GTAP “mvh”), one related to Fabricated Metal Products sector (GTAP “fmp”) and one related to Paper & Paper Products sector (GTAP “ppp”). Those representative products were selected after applying an arbitrary 1% cut-off in the value of production of Other Industry sector (instead of the earlier mentioned 10%).

The selected products were:

- vehicle related products (PRODCOM 29102230, 29102330, 29323090, 29322090 and 29104110);
- other structures of iron or steel (PRODCOM 25112360)
- cartons, boxes and cases, of corrugated paper or paperboard (PRODCOM 17211300).

The subsequent step for defining a €/kg ratio for every product was the same as described in the agricultural sector.

Table 58: RFPs and Economic Values for Other Industry Sector

	Vehicle related	Structures of iron/steel	Paperboard
% of total production value in 2007	13.97%	1.37%	1.14%
Scaling up to 100%	84.8%	8.3%	6.9%
€/kg	16.89	1.73	1.10
€/kg (weighted average)		14.54	
kg/€ (weighted average^{-1})		0.069	
kg/€	0.06	0.006	0.005

Economic Output from ICES Sectors for Different Policies

Table 59: Economic Output for 2007, 2030 and 2050 with no policy intervention

		2007	2030		2050	
		Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)
	ICES Sectors	No Policies	No Policies	With Policies	No Policies	With Policies
1	Agriculture	259.53	450.92		539.00	
2	Livestock	86.99	133.24		160.93	
3	Timber	37.65	65.56		78.54	
4	Fishing	19.25	26.71		30.21	
5	Coal	15.67	13.52		12.25	
6	Oil	45.61	29.08		20.52	
7	Gas	38.69	52.38		69.89	
8	Oil products	533.40	478.30		426.72	
9	Electricity	386.35	795.15		1412.10	
10	Other Mining	70.55	119.33		159.11	
11	Meat Industry	166.46	252.67		327.71	
12	Food Industry	987.31	1623.12		2254.05	
13	Chemical Industry	1109.61	1395.49		1689.69	
14	Iron and Steel	275.08	331.10		355.65	
15	Other Metals	161.29	184.68		196.84	
16	Non Metallic Minerals	290.23	463.43		627.31	
17	Construction Industry	2055.17	4011.03		6776.70	
18	Other Industry	4682.10	5740.36		7001.69	
19	Market Services	9465.26	13772.82		18240.67	
20	Public Services	3534.58	4502.79		5551.48	

Note: Original value in $\$_{2007}$. Currency converter used from \$ to €: www.oanda.com, date 30/6/2007.

Table 60: Economic Output of VAT on Meat Policy

		2007	2030		2050	
		Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)
	ICES Sectors	No Policies	No Policies	With ”VAT on MEAT” Policy	No Policies	With ”VAT on MEAT” Policy
1	Agriculture	259.53		451.31		539.55
2	Livestock	86.99		130.52		158.86
3	Timber	37.65		65.57		78.54
4	Fishing	19.25		26.70		30.21
5	Coal	15.67		13.52		12.25
6	Oil	45.61		29.08		20.52
7	Gas	38.69		52.39		69.89
8	Oil products	533.40		478.28		426.68
9	Electricity	386.35		795.19		1411.88
10	Other Mining	70.55		119.35		159.11
11	Meat Industry	166.46		244.42		320.73
12	Food Industry	987.31		1618.76		2248.64
13	Chemical Industry	1109.61		1395.95		1690.04
14	Iron and Steel	275.08		331.25		355.64
15	Other Metals	161.29		184.82		196.89
16	Non Metallic	290.23		463.36		627.10
17	Construction	2055.17		4010.16		6774.18
18	Other Industry	4682.10		5741.70		7001.28
19	Market Services	9465.26		13775.12		18239.98
20	Public Services	3534.58		4506.66		5555.99

Table 61: Economic Output of Pesticide Reduction Policy

		2007	2030		2050	
		Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)
	ICES Sectors	No Policies	No Policies	With ”Pesticide Reduction	No Policies	With ”Pesticide Reduction
1	Agriculture	259.53		450.50		538.77
2	Livestock	86.99		133.33		161.06
3	Timber	37.65		65.56		78.54
4	Fishing	19.25		26.71		30.21
5	Coal	15.67		13.52		12.25
6	Oil	45.61		29.08		20.52
7	Gas	38.69		52.38		69.89
8	Oil products	533.40		478.30		426.72
9	Electricity	386.35		795.17		1412.17
10	Other Mining	70.55		119.33		159.11
11	Meat Industry	166.46		252.89		328.11
12	Food Industry	987.31		1622.66		2253.53
13	Chemical Industry	1109.61		1395.60		1689.83
14	Iron and Steel	275.08		331.15		355.69
15	Other Metals	161.29		184.70		196.86
16	Non Metallic Minerals	290.23		463.45		627.35
17	Construction Industry	2055.17		4011.23		6777.08
18	Other Industry	4682.10		5741.07		7002.37
19	Market Services	9465.26		13773.41		18241.54
20	Public Services	3534.58		4503.02		5551.73

Table 62: Economic Output of Dietary Shift Policy

		2007	2030		2050	
		Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)
	ICES Sectors	No Policies	No Policies	With "dietary shift" Policy	No Policies	With "dietary shift"
1	Agriculture	259.53		452.54		542.85
2	Livestock	86.99		130.15		153.38
3	Timber	37.65		65.56		78.53
4	Fishing	19.25		26.72		30.22
5	Coal	15.67		13.52		12.25
6	Oil	45.61		29.08		20.52
7	Gas	38.69		52.38		69.90
8	Oil products	533.40		478.21		426.52
9	Electricity	386.35		795.16		1412.29
10	Other Mining	70.55		119.33		159.12
11	Meat Industry	166.46		242.35		300.22
12	Food Industry	987.31		1649.20		2328.62
13	Chemical Industry	1109.61		1395.49		1690.63
14	Iron and Steel	275.08		331.02		355.60
15	Other Metals	161.29		184.60		196.77
16	Non Metallic Minerals	290.23		463.49		627.57
17	Construction Industry	2055.17		4011.35		6778.71
18	Other Industry	4682.10		5738.83		7000.08
19	Market Services	9465.26		13767.44		18222.34
20	Public Services	3534.58		4501.18		5547.24

Table 63: Economic Output of Materials Tax Policy

		2007	2030		2040	
		Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)	Total Value of Output (€$_{2007}$ BLN)
	ICES Sectors	No Policies	No Policies	With "materials tax" Policy	No Policies	With "materials tax" Policy
1	Agriculture	259.53		452.21	504.80	510.51
2	Livestock	86.99		133.52	149.65	150.73
3	Timber	37.65		65.04	74.06	73.34
4	Fishing	19.25		26.72	28.65	28.68
5	Coal	15.67		13.53	12.97	13.00
6	Oil	45.61		29.07	24.19	24.20
7	Gas	38.69		52.18	61.05	60.19
8	Oil products	533.40		464.33	459.63	419.86
9	Electricity	386.35		802.69	1065.86	1083.73
10	Other Mining	70.55		118.18	141.99	139.28
11	Meat Industry	166.46		254.45	297.36	307.87
12	Food Industry	987.31		1636.34	1986.82	2068.10
13	Chemical Industry	1109.61		1326.47	1521.38	1352.74
14	Iron and Steel	275.08		322.61	340.85	296.48
15	Other Metals	161.29		166.29	193.04	130.38
16	Non Metallic Minerals	290.23		455.13	549.17	505.64
17	Construction Industry	2055.17		3972.13	5363.40	5104.24
18	Other Industry	4682.10		5712.43	6207.48	5744.10
19	Market Services	9465.26		13772.75	15970.26	15953.29
20	Public Services	3534.58		4507.92	5033.20	5077.90

Results from Environmental Impact Assessment

Table 64: Agricultural Sector Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	1.15E+10	2.00E+10	2.00E+10	2.00E+10	2.01E+10	2.01E+10	2.24E+10	2.26E+10	2.39E+10	2.39E+10	2.39E+10	2.41E+10
Eutrophication (Freshwater) (kg P eq)	1.58E+08	2.75E+08	2.76E+08	2.75E+08	2.76E+08	2.76E+08	3.08E+08	3.12E+08	3.29E+08	3.29E+08	3.29E+08	3.32E+08
Ecotoxicity (CTUe)	3.97E+12	6.90E+12	6.90E+12	6.89E+12	6.92E+12	6.92E+12	7.72E+12	7.81E+12	8.25E+12	8.25E+12	8.24E+12	8.30E+12
GWP (kg CO2-eq)	7.86E+11	1.37E+12	1.37E+12	1.36E+12	1.37E+12	1.37E+12	1.53E+12	1.55E+12	1.63E+12	1.63E+12	1.63E+12	1.64E+12
Freshwater Consumption (UBP)	5.41E+10	9.40E+10	9.41E+10	9.39E+10	9.44E+10	9.43E+10	1.05E+11	1.06E+11	1.12E+11	1.13E+11	1.12E+11	1.13E+11
Resource Depletion (kg Sb-eq)	8.34E+06	1.45E+07	1.45E+07	1.45E+07	1.45E+07	1.45E+07	1.62E+07	1.64E+07	1.73E+07	1.73E+07	1.73E+07	1.74E+07
Human Toxicity (CTUh)	3.45E+05	5.99E+05	6.00E+05	5.99E+05	6.01E+05	6.01E+05	6.71E+05	6.78E+05	7.16E+05	7.17E+05	7.16E+05	7.21E+05

Table 65: Livestock Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	8.94E+09	1.37E+10	1.34E+10	1.37E+10	1.34E+10	1.37E+10	1.54E+10	1.55E+10	1.65E+10	1.63E+10	1.65E+10	1.58E+10
Eutrophication (Freshwater) (kg P eq)	7.11E+07	1.09E+08	1.07E+08	1.09E+08	1.06E+08	1.09E+08	1.22E+08	1.23E+08	1.32E+08	1.30E+08	1.32E+08	1.25E+08
Ecotoxicity (CTUe)	1.52E+12	2.33E+12	2.28E+12	2.33E+12	2.27E+12	2.33E+12	2.61E+12	2.63E+12	2.81E+12	2.77E+12	2.81E+12	2.68E+12
GWP (kg CO2-eq)	4.91E+11	7.52E+11	7.37E+11	7.53E+11	7.35E+11	7.54E+11	8.45E+11	8.51E+11	9.09E+11	8.97E+11	9.10E+11	8.66E+11
Freshwater Consumption (UBP)	8.80E+09	1.35E+10	1.32E+10	1.35E+10	1.32E+10	1.35E+10	1.51E+10	1.52E+10	1.63E+10	1.61E+10	1.63E+10	1.55E+10
Resource Depletion (kg Sb-eq)	3.97E+06	6.08E+06	5.96E+06	6.09E+06	5.94E+06	6.10E+06	6.83E+06	6.88E+06	7.35E+06	7.25E+06	7.36E+06	7.00E+06
Human Toxicity (CTUh)	1.34E+04	2.04E+04	2.00E+04	2.05E+04	2.00E+04	2.05E+04	2.30E+04	2.31E+04	2.47E+04	2.44E+04	2.47E+04	2.35E+04

Table 66: Oil Products Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	4.71E+09	4.22E+09	4.22E+09	4.22E+09	4.22E+09	4.10E+09	4.06E+09	3.71E+09	3.77E+09	3.77E+09	3.77E+09	3.77E+09
Eutrophication (Freshwater) (kg P eq)	2.65E+07	2.38E+07	2.38E+07	2.38E+07	2.38E+07	2.31E+07	2.29E+07	2.09E+07	2.12E+07	2.12E+07	2.12E+07	2.12E+07
Ecotoxicity (CTUe)	7.17E+11	6.43E+11	6.43E+11	6.43E+11	6.43E+11	6.24E+11	6.18E+11	5.64E+11	5.74E+11	5.74E+11	5.74E+11	5.73E+11
GWP (kg CO2-eq)	5.55E+11	4.98E+11	4.97E+11	4.98E+11	4.97E+11	4.83E+11	4.78E+11	4.37E+11	4.44E+11	4.44E+11	4.44E+11	4.44E+11
Freshwater Consumption (UBP)	1.00E+13	9.01E+12	9.01E+12	9.01E+12	9.01E+12	8.75E+12	8.66E+12	7.91E+12	8.04E+12	8.04E+12	8.04E+12	8.03E+12
Resource Depletion (kg Sb-eq)	1.01E+06	9.06E+05	9.06E+05	9.06E+05	9.06E+05	8.80E+05	8.71E+05	7.95E+05	8.08E+05	8.08E+05	8.08E+05	8.08E+05
Human Toxicity (CTUh)	4.24E+05	3.80E+05	3.80E+05	3.80E+05	3.80E+05	3.69E+05	3.65E+05	3.34E+05	3.39E+05	3.39E+05	3.39E+05	3.39E+05

Table 67: Electricity Sector Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	7.21E+09	1.48E+10	1.48E+10	1.48E+10	1.48E+10	1.50E+10	1.99E+10	2.02E+10	2.64E+10	2.64E+10	2.64E+10	2.64E+10
Eutrophication (Freshwater) (kg P eq)	1.60E+06	3.29E+06	3.29E+06	3.29E+06	3.29E+06	3.32E+06	4.40E+06	4.48E+06	5.84E+06	5.83E+06	5.84E+06	5.84E+06
Ecotoxicity (CTUe)	3.79E+10	7.81E+10	7.81E+10	7.81E+10	7.81E+10	7.88E+10	1.05E+11	1.06E+11	1.39E+11	1.39E+11	1.39E+11	1.39E+11
GWP (kg CO2-eq)	1.27E+12	2.62E+12	2.62E+12	2.62E+12	2.62E+12	2.64E+12	3.51E+12	3.57E+12	4.65E+12	4.65E+12	4.65E+12	4.65E+12
Freshwater Consumption (UBP)	1.33E+12	2.74E+12	2.74E+12	2.74E+12	2.74E+12	2.77E+12	3.68E+12	3.74E+12	4.87E+12	4.87E+12	4.87E+12	4.87E+12
Resource Depletion (kg Sb-eq)	8.31E+05	1.71E+06	1.71E+06	1.71E+06	1.71E+06	1.73E+06	2.29E+06	2.33E+06	3.04E+06	3.04E+06	3.04E+06	3.04E+06
Human Toxicity (CTUh)	3.19E+04	6.56E+04	6.56E+04	6.56E+04	6.56E+04	6.63E+04	8.80E+04	8.95E+04	1.17E+05	1.17E+05	1.17E+05	1.17E+05

Table 68: Other Mining Sector Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	1.74E+08	2.95E+08	2.95E+08	2.95E+08	2.95E+08	2.92E+08	3.51E+08	3.44E+08	3.93E+08	3.93E+08	3.93E+08	3.93E+08
Eutrophication (Freshwater) (kg P eq)	2.25E+05	3.81E+05	3.81E+05	3.81E+05	3.81E+05	3.78E+05	4.54E+05	4.45E+05	5.08E+05	5.08E+05	5.08E+05	5.08E+05
Ecotoxicity (CTUe)	4.91E+09	8.30E+09	8.30E+09	8.30E+09	8.30E+09	8.22E+09	9.88E+09	9.69E+09	1.11E+10	1.11E+10	1.11E+10	1.11E+10
GWP (kg CO2-eq)	5.28E+10	8.93E+10	8.93E+10	8.93E+10	8.93E+10	8.84E+10	1.06E+11	1.04E+11	1.19E+11	1.19E+11	1.19E+11	1.19E+11
Freshwater Consumption (UBP)	2.15E+11	3.64E+11	3.64E+11	3.64E+11	3.64E+11	3.61E+11	4.33E+11	4.25E+11	4.85E+11	4.85E+11	4.85E+11	4.85E+11
Resource Depletion (kg Sb-eq)	3.88E+04	6.57E+04	6.57E+04	6.57E+04	6.57E+04	6.51E+04	7.82E+04	7.67E+04	8.76E+04	8.76E+04	8.76E+04	8.76E+04
Human Toxicity (CTUh)	5.88E+03	9.94E+03	9.95E+03	9.94E+03	9.94E+03	9.85E+03	1.18E+04	1.16E+04	1.33E+04	1.33E+04	1.33E+04	1.33E+04

Table 69: Meat Industry Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	8.20E+09	1.25E+10	1.20E+10	1.25E+10	1.19E+10	1.25E+10	1.47E+10	1.52E+10	1.62E+10	1.58E+10	1.62E+10	1.48E+10
Eutrophication (Freshwater) (kg P eq)	1.02E+08	1.54E+08	1.49E+08	1.55E+08	1.48E+08	1.56E+08	1.82E+08	1.88E+08	2.00E+08	1.96E+08	2.01E+08	1.84E+08
Ecotoxicity (CTUe)	1.82E+12	2.76E+12	2.67E+12	2.76E+12	2.65E+12	2.78E+12	3.25E+12	3.36E+12	3.58E+12	3.50E+12	3.58E+12	3.28E+12
GWP (kg CO2-eq)	4.62E+11	7.01E+11	6.78E+11	7.02E+11	6.73E+11	7.06E+11	8.25E+11	8.55E+11	9.10E+11	8.90E+11	9.11E+11	8.33E+11
Freshwater Consumption (UBP)	3.01E+10	4.57E+10	4.42E+10	4.58E+10	4.38E+10	4.60E+10	5.38E+10	5.57E+10	5.93E+10	5.80E+10	5.94E+10	5.43E+10
Resource Depletion (kg Sb-eq)	7.96E+06	1.21E+07	1.17E+07	1.21E+07	1.16E+07	1.22E+07	1.42E+07	1.47E+07	1.57E+07	1.53E+07	1.57E+07	1.44E+07
Human Toxicity (CTUh)	3.15E+04	4.78E+04	4.62E+04	4.78E+04	4.58E+04	4.81E+04	5.62E+04	5.82E+04	6.20E+04	6.06E+04	6.20E+04	5.68E+04

Table 70:Food Industry Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	5.08E+09	8.35E+09	8.33E+09	8.49E+09	8.35E+09	8.42E+09	1.02E+10	1.06E+10	1.16E+10	1.16E+10	1.16E+10	1.20E+10
Eutrophication (Freshwater) (kg P eq)	3.39E+08	5.57E+08	5.55E+08	5.66E+08	5.56E+08	5.61E+08	6.81E+08	7.09E+08	7.73E+08	7.71E+08	7.73E+08	7.99E+08
Ecotoxicity (CTUe)	1.44E+12	2.37E+12	2.37E+12	2.41E+12	2.37E+12	2.39E+12	2.91E+12	3.02E+12	3.30E+12	3.29E+12	3.30E+12	3.40E+12
GWP (kg CO2-eq)	7.21E+11	1.19E+12	1.18E+12	1.20E+12	1.19E+12	1.20E+12	1.45E+12	1.51E+12	1.65E+12	1.64E+12	1.65E+12	1.70E+12
Freshwater Consumption (UBP)	2.03E+11	3.33E+11	3.32E+11	3.38E+11	3.33E+11	3.36E+11	4.08E+11	4.24E+11	4.63E+11	4.62E+11	4.63E+11	4.78E+11
Resource Depletion (kg Sb-eq)	9.91E+06	1.63E+07	1.63E+07	1.66E+07	1.63E+07	1.64E+07	2.00E+07	2.08E+07	2.26E+07	2.26E+07	2.26E+07	2.34E+07
Human Toxicity (CTUh)	-1.62E+04	-2.66E+04	-2.65E+04	-2.70E+04	-2.66E+04	-2.68E+04	-3.26E+04	-3.39E+04	-3.70E+04	-3.69E+04	-3.69E+04	-3.82E+04

Table 71: Chemical Industry Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	5.35E+09	6.72E+09	6.73E+09	6.72E+09	6.72E+09	6.39E+09	7.33E+09	6.52E+09	8.14E+09	8.14E+09	8.14E+09	8.15E+09
Eutrophication (Freshwater) (kg P eq)	1.46E+08	1.83E+08	1.83E+08	1.83E+08	1.83E+08	1.74E+08	2.00E+08	1.78E+08	2.22E+08	2.22E+08	2.22E+08	2.22E+08
Ecotoxicity (CTUe)	4.51E+12	5.67E+12	5.67E+12	5.67E+12	5.67E+12	5.39E+12	6.18E+12	5.49E+12	6.86E+12	6.86E+12	6.86E+12	6.87E+12
GWP (kg CO2-eq)	1.05E+12	1.32E+12	1.32E+12	1.32E+12	1.32E+12	1.25E+12	1.44E+12	1.28E+12	1.59E+12	1.60E+12	1.59E+12	1.60E+12
Freshwater Consumption (UBP)	4.92E+11	6.19E+11	6.20E+11	6.19E+11	6.19E+11	5.89E+11	6.75E+11	6.00E+11	7.50E+11	7.50E+11	7.50E+11	7.50E+11
Resource Depletion (kg Sb-eq)	3.55E+07	4.47E+07	4.47E+07	4.47E+07	4.47E+07	4.25E+07	4.87E+07	4.33E+07	5.41E+07	5.41E+07	5.41E+07	5.41E+07
Human Toxicity (CTUh)	3.07E+05	3.86E+05	3.86E+05	3.86E+05	3.86E+05	3.67E+05	4.21E+05	3.74E+05	4.68E+05	4.68E+05	4.68E+05	4.68E+05

Table 72: Iron and Steel Sector Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	4.25E+09	5.11E+09	5.11E+09	5.11E+09	5.11E+09	4.98E+09	5.26E+09	4.58E+09	5.49E+09	5.49E+09	5.49E+09	5.49E+09
Eutrophication (Freshwater) (kg P eq)	2.34E+06	2.82E+06	2.82E+06	2.82E+06	2.82E+06	2.75E+06	2.90E+06	2.52E+06	3.03E+06	3.03E+06	3.03E+06	3.03E+06
Ecotoxicity (CTUe)	3.81E+11	4.58E+11	4.59E+11	4.58E+11	4.58E+11	4.47E+11	4.72E+11	4.10E+11	4.92E+11	4.92E+11	4.92E+11	4.92E+11
GWP (kg CO2-eq)	4.39E+11	5.28E+11	5.28E+11	5.28E+11	5.28E+11	5.15E+11	5.44E+11	4.73E+11	5.67E+11	5.67E+11	5.67E+11	5.67E+11
Freshwater Consumption (UBP)	1.42E+11	1.70E+11	1.70E+11	1.70E+11	1.70E+11	1.66E+11	1.75E+11	1.53E+11	1.83E+11	1.83E+11	1.83E+11	1.83E+11
Resource Depletion (kg Sb-eq)	2.71E+07	3.26E+07	3.27E+07	3.26E+07	3.26E+07	3.18E+07	3.36E+07	2.92E+07	3.51E+07	3.51E+07	3.51E+07	3.51E+07
Human Toxicity (CTUh)	1.31E+05	1.58E+05	1.58E+05	1.58E+05	1.58E+05	1.54E+05	1.63E+05	1.42E+05	1.70E+05	1.70E+05	1.70E+05	1.70E+05

Table 73: Other Metals Sector Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	4.25E+09	5.11E+09	5.11E+09	5.11E+09	5.11E+09	4.98E+09	5.26E+09	4.58E+09	5.49E+09	5.49E+09	5.49E+09	5.49E+09
Eutrophication (Freshwater) (kg P eq)	2.34E+06	2.82E+06	2.82E+06	2.82E+06	2.82E+06	2.75E+06	2.90E+06	2.52E+06	3.03E+06	3.03E+06	3.03E+06	3.03E+06
Ecotoxicity (CTUe)	3.81E+11	4.58E+11	4.59E+11	4.58E+11	4.58E+11	4.47E+11	4.72E+11	4.10E+11	4.92E+11	4.92E+11	4.92E+11	4.92E+11
GWP (kg CO2-eq)	4.39E+11	5.28E+11	5.28E+11	5.28E+11	5.28E+11	5.15E+11	5.44E+11	4.73E+11	5.67E+11	5.67E+11	5.67E+11	5.67E+11
Freshwater Consumption (UBP)	1.42E+11	1.70E+11	1.70E+11	1.70E+11	1.70E+11	1.66E+11	1.75E+11	1.53E+11	1.83E+11	1.83E+11	1.83E+11	1.83E+11
Resource Depletion (kg Sb-eq)	2.71E+07	3.26E+07	3.27E+07	3.26E+07	3.26E+07	3.18E+07	3.36E+07	2.92E+07	3.51E+07	3.51E+07	3.51E+07	3.51E+07
Human Toxicity (CTUh)	1.31E+05	1.58E+05	1.58E+05	1.58E+05	1.58E+05	1.54E+05	1.63E+05	1.42E+05	1.70E+05	1.70E+05	1.70E+05	1.70E+05

Table 74: Non-Metallic Minerals Sector Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	8.65E+08	1.38E+09	1.38E+09	1.38E+09	1.38E+09	1.36E+09	1.64E+09	1.51E+09	1.87E+09	1.87E+09	1.87E+09	1.87E+09
Eutrophication (Freshwater) (kg P eq)	4.20E+06	6.70E+06	6.70E+06	6.70E+06	6.70E+06	6.58E+06	7.94E+06	7.31E+06	9.07E+06	9.07E+06	9.07E+06	9.07E+06
Ecotoxicity (CTUe)	7.54E+10	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.18E+11	1.43E+11	1.31E+11	1.63E+11	1.63E+11	1.63E+11	1.63E+11
GWP (kg CO2-eq)	3.52E+11	5.63E+11	5.63E+11	5.63E+11	5.63E+11	5.53E+11	6.67E+11	6.14E+11	7.62E+11	7.61E+11	7.62E+11	7.62E+11
Freshwater Consumption (UBP)	5.17E+10	8.25E+10	8.25E+10	8.25E+10	8.25E+10	8.10E+10	9.77E+10	9.00E+10	1.12E+11	1.12E+11	1.12E+11	1.12E+11
Resource Depletion (kg Sb-eq)	2.84E+05	4.54E+05	4.54E+05	4.54E+05	4.54E+05	4.46E+05	5.38E+05	4.95E+05	6.14E+05	6.14E+05	6.14E+05	6.14E+05
Human Toxicity (CTUh)	2.42E+04	3.87E+04	3.87E+04	3.87E+04	3.87E+04	3.80E+04	4.58E+04	4.22E+04	5.23E+04	5.23E+04	5.23E+04	5.24E+04

Table 75: Other Industry Environmental Impacts

	2007	2030 (no policies)	2030 (VAT on meat)	2030 (pesticide reduction)	2030 (dietary shift)	2030 (material tax)	2040 (no policies)	2040 (material tax)	2050 (no policies)	2050 (VAT on meat)	2050 (pesticide reduction)	2050 (dietary shift)
Acidification (Mol H+ eq)	8.44E+09	1.03E+10	1.03E+10	1.03E+10	1.03E+10	1.03E+10	1.12E+10	1.03E+10	1.26E+10	1.26E+10	1.26E+10	1.26E+10
Eutrophication (Freshwater) (kg P eq)	8.21E+08	1.01E+09	1.01E+09	1.01E+09	1.01E+09	1.00E+09	1.09E+09	1.01E+09	1.23E+09	1.23E+09	1.23E+09	1.23E+09
Ecotoxicity (CTUe)	2.07E+13	2.54E+13	2.54E+13	2.54E+13	2.54E+13	2.53E+13	2.75E+13	2.54E+13	3.10E+13	3.10E+13	3.10E+13	3.10E+13
GWP (kg CO2-eq)	1.12E+12	1.38E+12	1.38E+12	1.38E+12	1.38E+12	1.37E+12	1.49E+12	1.38E+12	1.68E+12	1.68E+12	1.68E+12	1.68E+12
Freshwater Consumption (UBP)	6.11E+11	7.49E+11	7.49E+11	7.49E+11	7.49E+11	7.45E+11	8.10E+11	7.49E+11	9.13E+11	9.13E+11	9.13E+11	9.13E+11
Resource Depletion (kg Sb-eq)	9.22E+07	1.13E+08	1.13E+08	1.13E+08	1.13E+08	1.12E+08	1.22E+08	1.13E+08	1.38E+08	1.38E+08	1.38E+08	1.38E+08
Human Toxicity (CTUh)	1.05E+06	1.29E+06	1.29E+06	1.29E+06	1.29E+06	1.28E+06	1.39E+06	1.29E+06	1.57E+06	1.57E+06	1.57E+06	1.57E+06

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