Carbon emission mitigation by Consumption-based Accounting and Policy

SEVENTH FRAMEWORK PROGRAMME

Carbon-CAP

Consumption-based Accounting and Policy

D8.2 Final Project Report

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About Carbon-CAP

Climate change mitigation now focuses on production, where upward drivers of GHG emissions come from consumption. Demand side oriented policies hence can complement domestic GHG reduction efforts. The core aim of this project is to

1. Stimulate innovative demand side oriented climate policies by improved shared insight into consumption emissions
2. Realize a more effective policy mix for achieving the objectives of the EU policy packages (e.g. Low carbon economy roadmap)

There are significant questions about Consumption Based Carbon Accounting (CBCA) systems (Gap 1: 'CBCA reliability') and demand side policies (Gap 2: 'effectiveness and feasibility of demand side tools' and Gap3: 'Impacts on innovation, competitiveness, economy'). Stakeholders hence can easily question their added value (Gap 4: 'no critical mass for support, no shared view on implementation pathway'). Our project will overcome the identified gaps via the following responses:

1. (WP4). Comparing the major CBCA databases (EXIOBASE, WIOD, GTAP, EORA), identifying key factors causing uncertainty, assessing upward drivers, resulting in CBCA that can be implemented by formal players in the climate community (UNFCCC, IEA, others)
2. (WP5 and WP6). Providing an in-depth analysis of the feasibilities of consumption based and trade related policies, assessing their effectiveness, and compatibility with e.g. WTO rules (WP5). Specific case studies will zoom in on practical improvement options and implications for specific sectors (WP6)
3. (WP7). Improving some of the most ambitious global economic models, E3ME/E3MG, EXIOMOD and IPTS's FIDELIO relation to point 1 so that they capture side-effects and rebound effects, impacts on trade, investment etc. of consumption based policies
4. (WP8 and WP2). Creating an implementation roadmap for consumption based accounts and policies (WP8) endorsed by a critical mass of stakeholders via policy-science brokerage activities (WP2)

The project is complemented by Management (WP1) and an inception phase (WP 3) and executed by a group of the most renowned institutes in CBCA, economic modelling and climate policy.

Partners are:

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2. Wirtschaftsuniversität Wien (WU), Vienna, Austria
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Table of contents

List of Figures

List of Tables

Executive Summary

Carbon-CAP project has identified promising demand-side strategies and their associated policy instruments, providing an additional suite of instruments to complement production based policies. Each of these is assessed against criteria of Effectiveness (how much carbon reduction is achieved in a given product or service if applied successfully), Scope (how much of the global flow of carbon is then affected), Economic Equity (how are the costs distributed within society), and Political, Legal and Institutional Acceptance.

Global drivers of change in carbon emissions

Current climate policies are mainly shaped via territorial emission reduction approaches. There is a number of arguments why complementing these territorial approaches with approaches from a consumption oriented perspective have added value: (1) consumption- and trade oriented policies can explicitly address issues like carbon leakage and for instance identify situations where an apparent reduction of carbon emissions in a country is mainly the result of structural change in which carbon-intensive industries were relocated abroad; and (2) such policies are more directly addressing consumption as a driver for rising greenhouse gas (GHG) emissions.

Aspects in the current EU climate policy landscape that require attention in evaluating consumption-based carbon policy instruments:

- Consumption-based emission accounting requires reliable emission data and robust methods to track embodied emissions in trade and consumption.
- A transformation towards low carbon consumption produces winners and losers. The changes in consumption patterns in big consuming countries impact producing countries.
- In order to reduce emissions embodied in trade and consumption, policies can intervene at the level of the producers, intermediaries or final consumers.
- Carbon pricing policies were often guided by the principle of implementing a carbon price as much upstream as possible in the expectation that the carbon price will feed through the value chain and thus incentivise all involved actors to shift their decisions toward lower carbon options.
- The analysis of food labelling approaches showed that numerous voluntary carbon labelling initiatives have emerged, mainly driven by the private sector, although some public bodies and international organization have also been involved.
- The effectiveness of a policy instrument to achieve a reduction in embodied emissions in trade and consumption depends also on its synergy and potential for conflict with existing (non-carbon) policy instruments.

The analyses in efficiency (emissions, energy, and labour per unit output), the changes due to trade related effects (both for intermediate producers and final consumers), the changes due to technology effects (both for intermediate producers and final consumers), and the change due to affluence and population indicate that trade is an important driver for global greenhouse gas emissions growth. However, it is not as important as growth in affluence and overall industry efficiency. This is only true, however, when looking at global emissions growth. When taking into account regional shifts in greenhouse gas emissions footprints over time, the displacement of industries from developed economies in the European Union and the OECD and the increase in imports to final demand contributes to emissions growth, mainly from combustion. For non-combustion

emissions, changes in trade partners seems to decrease GHG footprints. Different dynamics act on the footprint growth over time and in different regions. Greenhouse gas emissions and energy consumption are mainly driven by the increase of consumption per capita in developing economies, such as China, and in the European Union. This growth in affluence reduces (or even reverses) gains in carbon and energy efficiency. It can be seen that trade is an important driver for labour footprints change in developed economies, in a higher proportion than for energy and greenhouse gas footprints. That indicates that the displacement of industries to labour-abundant countries might not have a significant effect in the growth of emissions embodied in trade.

Consumption based carbon accounting

The underlying question of the Carbon-CAP project is, to assess whether a consumption based carbon accounting and consumption based climate policy can have an added value to the already existing production based accounting and associated policy as a means to reduce GHG emissions. A consumption based approach differs from a production based approach in the definition of the system boundaries. A production based approach, requires a geographically identified system. A consumption oriented approach requires a functional, cradle-to-grave or "footprint" approach, usually including processes in different geographical areas. So far, policy has mainly focused on production and nations, and therefore, has used a territorial approach. This is also apparent when looking at GHG emission databases: they are organized by country and by activity. A consumption based approach needs something different. Requirements to a consumption based information base:

- GHG emissions should be linked to consumption activities and consumption categories
- GHG emissions should be specified on a cradle-to-grave basis
- The information base should provide information at a relevant spatial and time scale
- The quality of the information should be sufficiently reliable
- The information base should allow for analysing the past as well as forecasting the future, or rather, imagining the future under different assumptions.

Since the advent of environmental footprint approaches in general, and consumption based carbon accounting (CBCA) approaches specifically, many policy makers have been looking at ways to derive consumption-based policies. Whilst these efforts can be lauded, it has not been clearly established in the literature that consumption-based policies are more effective or more cost-effective than traditional policies based on control of territorial emissions. Further complicating the policy arena is that many policies could be considered both traditional and consumption-based (insulation of houses, for example). Alternatively, CBCA can be seen to be policy relevant, whilst not policy prescriptive. CBCA can give a key macro-level indication about the carbon intensity of an economy relative to baselines and targets. Such reporting of emission accounts can further underline the need for multi-lateral action, and for the increased responsibility needed to be shouldered by economies with growing net-import of emissions. CBCA can further strengthen resolve around uptake of instruments around, for example, the clean development mechanism (through encouraging investment from the developed world in trade partner countries in the developing world), or for the need for additional investment in emission offsets.

Promising consumption based policy measures

More than 30 policy instruments have been assessed in Carbon-CAP, covering products and services in Transport, Manufacturing, Food, Buildings, Paper/Plastics and Textiles. To assist with choices between policy instruments, a shortlist of promising instruments (see table below) were ranked in three tiers. The first tier contains instruments that are judged to be strong across the four criteria of acceptability (economic, legal, international/political, institutional). The third tier contains instruments for which there is a significant barrier to acceptance on at least one of the criteria.

1st rank	2nd rank	3rd rank
▪ Approved technology lists ▪ Supply chain procurement requirements ▪ Carbon-intensive materials charge ▪ Infrastructure improvements ▪ Product location at sale ▪ Retailer product choice	▪ Regulatory standards ▪ EGS trade agreement ▪ Recycling requirements, waste targets & prices ▪ Voluntary agreements by trade associations ▪ Business emission agreements & allowances	▪ Government procurement ▪ Information campaigns ▪ Rang & award campaigns ▪ Voluntary trade body standards ▪ Minimum price limits

To effectively reduce emissions at the global level, consumption-based climate policy instruments will have to be part of the policy mix. Introducing instruments in a portfolio has three main advantages. First, consumer-oriented policy should not have the effect of wholly 'individualising' responsibility solely on end-users. It should spread responsibilities across many sectors, across consumers and across producers. Second, emissions are caused by many different decisions at many different levels from primary production to consumption to disposal. Consumer-oriented policies only act on part of these, and individual consumer-based instruments further focus the scope of application. Finally, experience has shown policies are often most effective when developed in mutually reinforcing ways since weaknesses in any one instrument can be counterbalanced by strengths of another instrument. This often helps in negotiations between groups implementing and affected by an instrument.

The assessments carried out by the project provide a useful first overview of promising instruments and a starting point for identifying opportunities and challenges to focus on in future deliberations and analyses. A key lesson is that consumer choice is difficult to influence when consumers have equal access to high and low carbon goods that meet the same needs. Therefore, the rankings of effectiveness and acceptability of instruments developed in this briefing reflect a tiered approach in which instruments that alter the range of products available, their ease of access and/or the cost (due to carbon charges) are applied first. The second and third ranks of instruments might then be considered means to support the instruments in the first rank. This is consistent with the lesson that instruments are most effective when introduced as complementary portfolios.

Modelling consumption based emission reduction

The modelling of the Carbon-CAP project assesses the effects of consumption-based emission reductions options on emissions and the economy. It focuses on the three main

areas for improvement options: food, the built environment and transport. It uses a suite of three different models, each one based on different assumptions, to test the robustness of outcomes in relation to different modelling approaches.
The models used are E3ME, EXIOMOD and FIDELIO. E3ME is a macro-econometric model of the world's economic and energy systems and the environment, based on post-Keynesian principles. EXIOMOD is a Computable General Equilibrium (CGE) Model. FIDELIO is a dynamic econometric input-output model that combines aspects of CGE models and linear 'Input-Output philosophy'.

The IEA WEO 2014 current policies scenario is used as the main reference scenario for this report. In addition to the reference scenario and improvement options scenarios (food, transport and buildings), two additional sets of scenarios were included in the modelling exercise. The first additional scenario is the Nationally Determined Contributions Scenario (NDC), which is based on the pledges that were put forward at the Paris Conference of the Parties in 2015 and NDC plus improvement options. The second scenario is a Material Charge Scenario that considers a specific taxation instrument in Europe. Both the additional scenarios were modelled using E3ME only.

The improvement options in all three sectors that where selected for this study (food, buildings and transport) combined have a maximum potential to deliver household emission reductions at EU level of 47-67%, and total production-based emission reductions of 16-26% relative to the reference scenario in 2050. The impacts on production-based CO_2 emissions outside the EU are small and mostly negative. However, when behavioural responses to individual policies, that could realise the improvement options, are considered, then there is a maximum 14% reduction (7.5-14%) in total CO_2 production-based emissions reductions in the EU by 2050, relative to the reference scenario. These more modest reductions could be considered more realistic as many of the actions and policy measures considered were voluntary.

The most potential for reducing EU territorial CO_2 emissions comes from the transport and buildings scenarios. The food options have less potential when CO_2 only are considered. Therefore, because of the rebound effect a small increase in the EU households' emissions is possible. All models show a slight decrease in consumption-based EU CO_2 emissions under the combined food scenario (-0.2 to -3.6%). The range of impacts on consumption-based emissions is slightly wider range than the reductions in the territorial emissions (-0.3 to -1.2%).

The economic impacts of the combined scenario on the EU's GDP are small, ranging from about 0.78% loss to a very small positive impact (0.06%) in 2050, depending on the model. The overall impact on employment in the EU in 2050 is very small and positive. Sectoral employment impacts vary depending on the improvement option and span from a 20% decrease in the vehicle manufacturing sector to a 61% increase in the provision of transport services.

The modelling undertaken in Carbon-CAP shows that various consumption-based policies relating to food, buildings and transport have considerable potential to reduce territorial CO_2 emissions in Europe, especially with regards to household CO_2 emissions. However, the reduction in consumption-based emissions is rather small and the relative gap between consumption- and production-based emissions is expected to increase. More detailed modelling will be required to estimate more comprehensively the total GHG emissions reduction potential of each of the individual policy packages and their implementation over the modelling time horizon 2020-2050. The consumption-based emission reduction measures used in this study have small impact on trade related emissions and therefore more attention should be paid to designing and assessing policies that address these emissions, including innovative measures such related to the options provided by the ITC sector. It should be also highlighted that there is high uncertainty related to modelling the policy impacts, especially on consumption-based emissions. Also using macromodels in addition to MRIO models for impacts assessments is feasible and desirable as it will help to asses feedback effects between in the economic system. Further development of model in this area is necessary to achieve more robust results, but differences in the results will remain as the models build on different theoretical backgrounds and these have to be considered while conducting impact assessments.

Further Research

Based on the feedback received through discussion with business stakeholders at the end of the Carbon-CAP project, it is also important to note the following, which could be explored in future related research projects. There is agreement amongst businesses consulted that this is an important conversation and there is interest on the part of business in discussing how to select the most effective policies for reducing consumption based emissions. Collaboration initiatives between government, business and consumers will be necessary to identify, develop and implement the most effective policies. Guidelines and criteria that governments should consider when engaging with business on new policy approaches for reducing emissions based on consumption might also be useful. More research may still be needed to iron out remaining uncertainties in the use of consumption-based accounting systems and developing whole-economy models capable of analysing and forecasting consumption-side emissions. More research could be undertaken on the full scope of the implementation of different consumption-side policy packages. In addition, Carbon-CAP established that it is possible to use consumption-based emissions from macroeconomic models as an indicator to assess future policies as well as allocating historical responsibility. This additional step could add substantial value to comprehensive policy assessments. However, there is a lot of work to be done on improving consumption-based emissions accounting in macromodels, as policy impacts on these emissions resulted in greater uncertainty than the impacts on production-based emissions. This need for further research does not preclude the possibility of the EU starting to recognise and quantify consumption-based emissions, and trade-embodied carbon, and to step up efforts to identify and implement new consumption policies with high levels of anticipated take-up and effectiveness.

1 Introduction

Carbon-CAP aims to stimulate an effective climate policy mix – in the EU and internationally – that can address increasing consumption-related emissions in addition to the current focus on production emissions. It combines work on accounting models with cutting-edge policy research. Tackling climate change requires complementing production-focused policies with consumption-based approaches. Doing so can also help to more directly address consumption as a driver of increasing emissions by realising a wider range of mitigation options along the value chain and at the point of final consumption.

Background and objectives

Under the UN Climate Convention (UNFCCC) the EU reports, and has targets to reduce, the greenhouse gas emissions (GHG) produced within its territory. However, production emissions do not tell the whole story of the EU's role in global carbon emissions. Through globalisation, the EU's emission impact goes beyond country borders of its Member States. Through trade, materials act as a carrier of industrial energy resulting in the transfer of embodied emissions between countries. With a growing share of emissions embodied in imports and exports from one country to another, the emissions linked to consumption by a country can differ substantially from the emissions linked to production within its borders. Whilst emissions produced within the EU's territory declined 13% from 1990 to 2010, its actual footprint, including emissions embodied in imports, increased 8%. This is because the growing demand for consumer goods and services in the EU is being met increasingly by imports from countries without binding GHG emissions reduction targets, driven by globalisation of production processes as markets chase the lowest labour, energy and materials costs. The current production emissions accounting approach provides a mechanism by which countries can import carbon intensive products, yet they do not assume responsibility for the carbon emitted in producing those products. It makes it possible for the EU to outsource manufacturing – largely driven by globalising market forces not in response to climate policies or with the intention to off-shore greenhouse gas emissions- and account for territorial emissions reductions even though domestic consumption drives additional emissions elsewhere. The amount of net imported emissions to the EU so far has exceeded the size of its Kyoto-specified emissions reduction target and there are no binding agreements to regulate the growth of this imported carbon (Kanemoto, 2014).

The aim of the Carbon-CAP project is to quantify the mitigation potential of underexploited strategies that target the consumption of products, and hence influence emissions embodied in trade. These strategies are in the form of policy instruments applied to specific sectors of goods and services in the global economy. Demand-side strategies can intervene at the level of final producers (e.g. industry), intermediate producers (e.g. firms in the supply chain of final producers), intermediaries (e.g. transport sector) or final consumers (e.g. shoppers). Consumption policies are complementary to existing domestic mitigation efforts that have focused largely on production-based instruments. The project considers a range of strategies across the different stakeholders and prioritize those that have both the highest mitigation potential with respect to reducing emissions associated with consumption, but are also politically, legally and institutionally feasible and have the ability to significantly influence consumer behaviours.

Concept and work plan

The potential to complement current domestic GHG reduction efforts with policies that address consumption patterns is clear. However, developing a new, more balanced mix of policies will require overcoming various important gaps and hurdles. To overcome the gaps, the project has the following specific scientific and technical objectives.

Gap 1: Quantification of global emissions related to consumption of goods and services and understanding drivers for upward trends.

- ✓ Carbon-CAP: Review and assessment of consumption-based carbon accounts and upward drivers

Gap 2: Understanding of the levers, potential mechanisms, and feasibility of demand side tools and policies.

- ✓ Carbon-CAP: Identification and evaluation of demand side tools and policies in relation to desired technical and behavioural improvement options.

Gap 3: Understanding of the effectiveness and impacts of demand side tools and policies.

- ✓ Carbon-CAP: Modelling and assessment of impacts of consumption based emission reduction pathways at macro level

Gap 4: No shared view on the added value, implementation challenges and acceptability of demand side tools/policies and related accounts, and no "roadmap" of evolution from production towards consumption-based policies.

- ✓ Carbon-CAP: Creating an implementation roadmap for consumption based accounts and policies endorsed by a critical mass of stakeholders via policy-science brokerage activities

The project is specifically designed to overcome these gaps and convince a critical mass of the climate policy community of the added value of demand side policies and accounts. The project draws on a well-designed process of interactive learning between the project team and key players in this policy area, led by one of the most prominent networking organisations in the field (Climate Strategies).

The gaps, related specific objectives, and unique features of our approach are summarized in Figure 1.1.

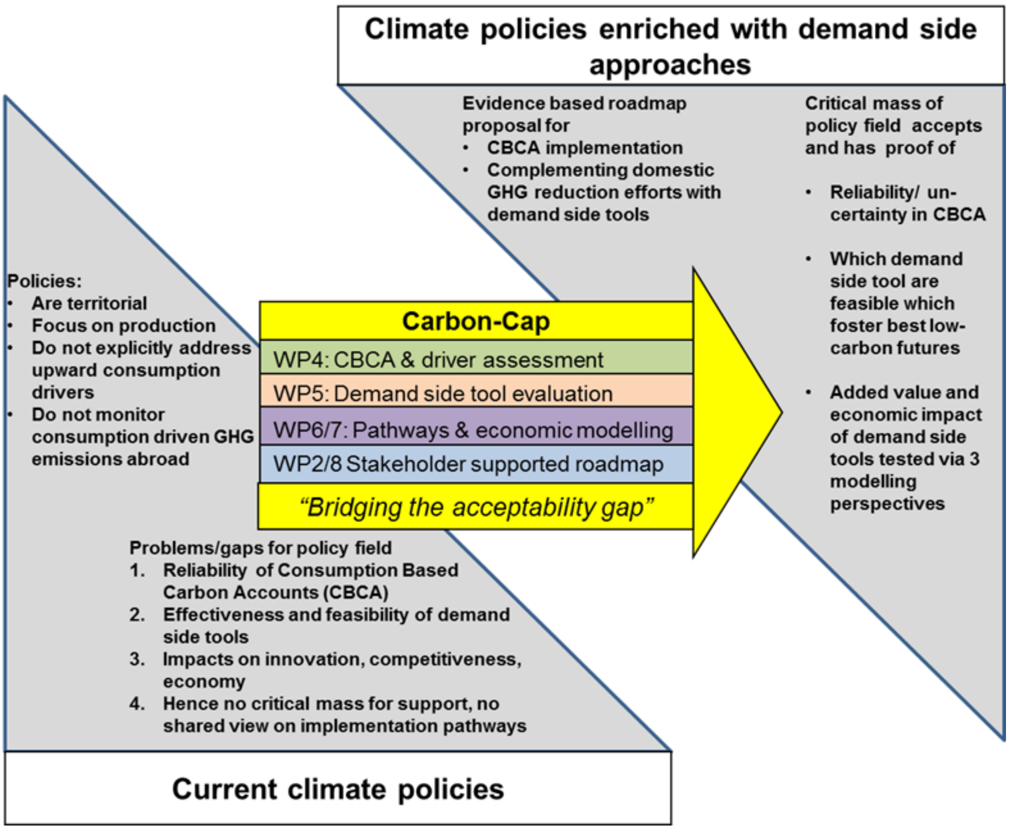

Figure 1.1 Progress from knowledge to action on demand side policies envisaged by the Project.

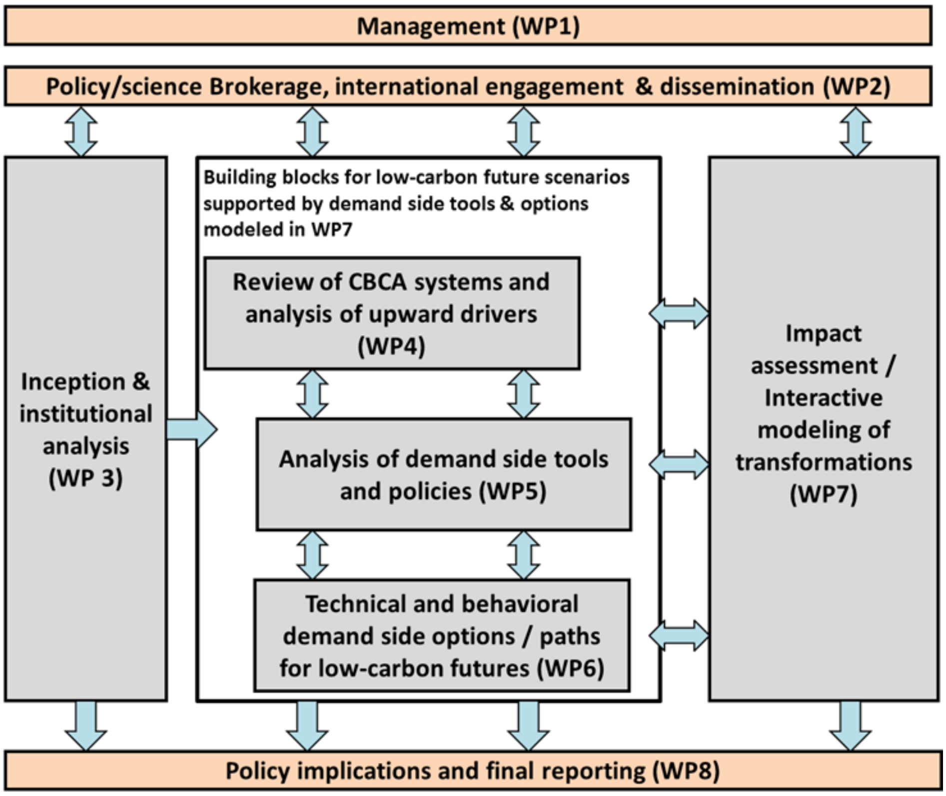

Figure 1.2 Work package structure based on the gap analysis and specific objectives, including a management WP.

The aim of this report is integrating the earlier deliverables of all work packages in a way that gives insight into how, and via which steps, existing domestic greenhouse gases (GHG) emission reduction efforts can be complemented with adequate policy instruments that address the influence of consumption patterns. The policy recommendations will be primarily focused on the EU but will also highlight the international level of climate policy agreements.

Note: this final report does not concern the formal final reporting to the EC but, as mentioned, provides a condensed summary of all former deliverables and recommendations.

2 Key challenges

Climate policies are formulated on a national or regional level and differ in stringency and approach reflecting differences in economic development, political culture and will. They further mainly focus on production sectors. Yet, growing consumption is a main driver behind rising greenhouse gas (GHG) emissions. Further, our economy is increasingly a single, global economy: international trade has risen threefold since 1990/91. Current climate policies are mainly shaped via territorial emission reduction approaches. There is a number of arguments why complementing these territorial approaches with approaches from a consumption oriented perspective have added value: (1) consumption- and trade oriented policies can explicitly address issues like *carbon leakage* and for instance identify situations where an apparent reduction of carbon emissions in a country is mainly the result of structural change in which carbon-intensive industries were relocated abroad; and (2) such policies are more directly addressing consumption as a driver for rising GHG emissions. Therefore, the next section addresses the current EU climate policy landscape, followed by section 2.2 looking at the global drivers of change in carbon emissions. However, a sound climate policy requires an information base, to monitor past developments, spot trends, and also to estimate the effectiveness and side-effects of policy measures. The EU climate policy, as well as global policy as agreed on in the Kyoto protocol and succeeding agreements, already has a large information base. But for a consumption oriented climate policy, such as investigated in the Carbon-CAP project, these do not provide sufficient information to allocate emissions responsibility through the production layers and supply chains through to consumers. Additional databases and modelling approaches have to be developed to support such a consumption oriented policy. In section 2, we will first investigate what is needed to provide such an information base.

2.1 Current EU climate policy landscape

2.1.1 Introduction

Carbon emissions embodied in the import and export of goods and services from one country to another are growing: almost one fourth of global emissions can be attributed to international trade. The 2014 IPCC report recognises consumption as an important driver for emissions and highlights the gap between countries' territorial based and consumption based emissions as a result of increasing emissions embodied in trade. Many European countries including Germany, France, Italy, Spain, Sweden, and the UK are net importers of carbon embedded in commodities and final products, while some countries such as the Czech Republic and Poland are net exporters. The carbon flows along supply chains that are linked to European consumption are increasingly well understood, although it is not yet clear how these flows can be reduced through policy instruments that influence consumption options and choices.

The increased information on carbon emissions embodied in consumption and trade raises a series of questions:

- What policy instruments are in place to address the increase in carbon emissions embodied in consumption and trade?

- How can effectiveness of consumption-based policy instruments be measured?
- What were successes, shortcomings and challenges (including trade-related challenges) of consumption-based policy instruments?

The aim of this section is to identify the main aspects relevant to the definition of and effectiveness of consumption-based policy instruments that warrant attention in the subsequent analysis of potential policy interventions and modelling of policy impacts in the Carbon-CAP project.

2.1.2 Approach

To answer the questions above, a number of steps have been taken. The first one addresses the main sectors that are relevant for embodied emissions in consumption and trade keeping in mind that Europe drives non-European emissions through the consumption of both intermediate and final goods and services that are produced beyond its borders. For example, Davis and Caldeira (2010) find that for several Western European countries, including the UK, more than 30% of the emissions embodied in final products were accounted for by foreign sources of emissions in 2004. At the EU productive sector-level 17 sectors represent the full range of production activity in the EU. Each sector’s total consumption attribution represents the extent of global emissions that could be influenced by that sector and is decomposed into four 'Scope' components. The concept of emissions 'Scopes' has been promoted by the Greenhouse Gas Protocol (WRI and WBCSD (2011). However, in this analysis only upstream (i.e., supply chain) indirect emissions are considered in Scope 3, whereas in the Greenhouse Gas Protocol, downstream indirect emission (i.e., emissions enabled by the sale of products) are also considered. This suggests a focal menu of up to six main sectors of interest to study in more depth: manufacturing, 2) construction, 3) metals production and processing, 4) motor vehicles manufacturing, 5) transport, and 6) agriculture and land use.
The second step that has been taken was the classification of consumption-based policy instruments: instruments that aim to change consumption patterns. This includes both changes in the overall demand (e.g. changes in the amount of carbon intensive materials consumed) and changes in the substitutable options for meeting that demand (e.g. shift to less carbon intensive materials). Consumers may be classified into either final consumer, such as households and governments purchasing finished products, or intermediate consumers purchasing intermediate products to which subsequent producers provide additional value. Furthermore, the term ‘policy’ is used to describe (i) the aims or goals to be achieved (e.g. to reduce carbon emissions by 80% in the EU), (ii) the actors responsible for creating and administering the implementation (iii) and the means of evaluating success. By contrast, the term ‘policy instrument’ is used to describe a specific instrument (e.g. a tax placed on the carbon content of consumer goods) (Sterner, 2003; Cram, 2005). The focus of this analysis is on policy instruments as these are the means by which the policy affects the decisions of or product options available to consumers. Based on The Three Pillars of Policy (Grubb , 2014, see figure below) a policy instrument taxonomy has been developed and 27 policy instruments were divided into three categories: standards and engagement, markets and prices, and strategic investments.

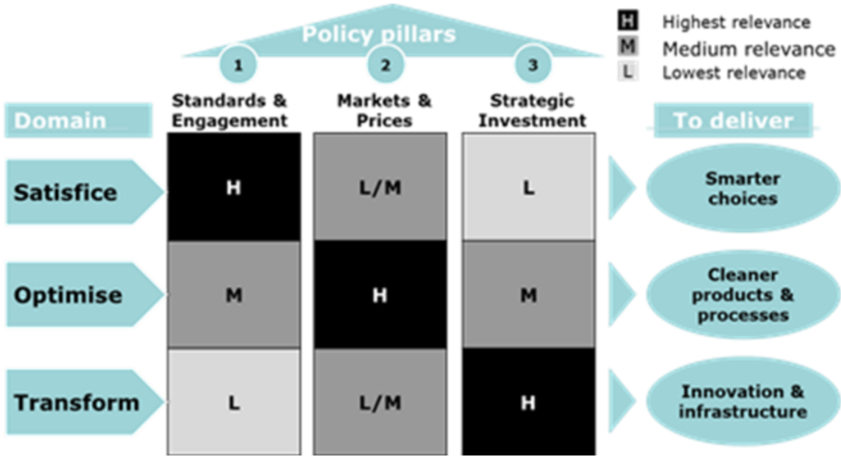

Figure 2.1 The three Pillars of Policy (Grubb et al.,2014)

The next step was to answer the question of how well these policy instruments perform in practice. Concerning this, a policy evaluation framework has been developed such as that in the UN ESCAP Virtual Conference Section C (UN ESCAP, 2014) and shown in the figure below. While the performance evaluation of a climate policy instrument is crucial, it is also important to consider the process that leads to the design and adoption of the instrument, and the manner and effectiveness of its implementation. Thus, a policy and associated instrument can also be judged by criteria related to the way in which that policy instrument was generated and/or selected. However, these process criteria can only be applied in specific historic instances of policy/instrument development, whereas insights into performance criteria can be gained from past historical applications or from theoretical assessments Therefore, process evaluation criteria are provided here only for purposes of completeness, and for future applications of policy evaluation outside the current project. Regarding effectiveness, a distinction should be made between theoretical and empirical effectiveness. Theoretical effectiveness of a policy generally derives from the estimates of carbon reduction derived from models rooted in economic theory, decision theory and behavioural science. Empirical effectiveness refers to measured impacts of policies. The potential disconnect between conclusions drawn on the basis of models and those drawn on empirical tests of policy effectiveness is evident in the 'efficiency gap' in which the rate of uptake of energy efficiency measures by consumers is significantly below that indicated by cost effectiveness alone (Brown, 2001). Efficiency programmes noted have helped to narrow, but not close this gap; and the costs are generally higher, and delivery lower, than technology assessments alone would predict.

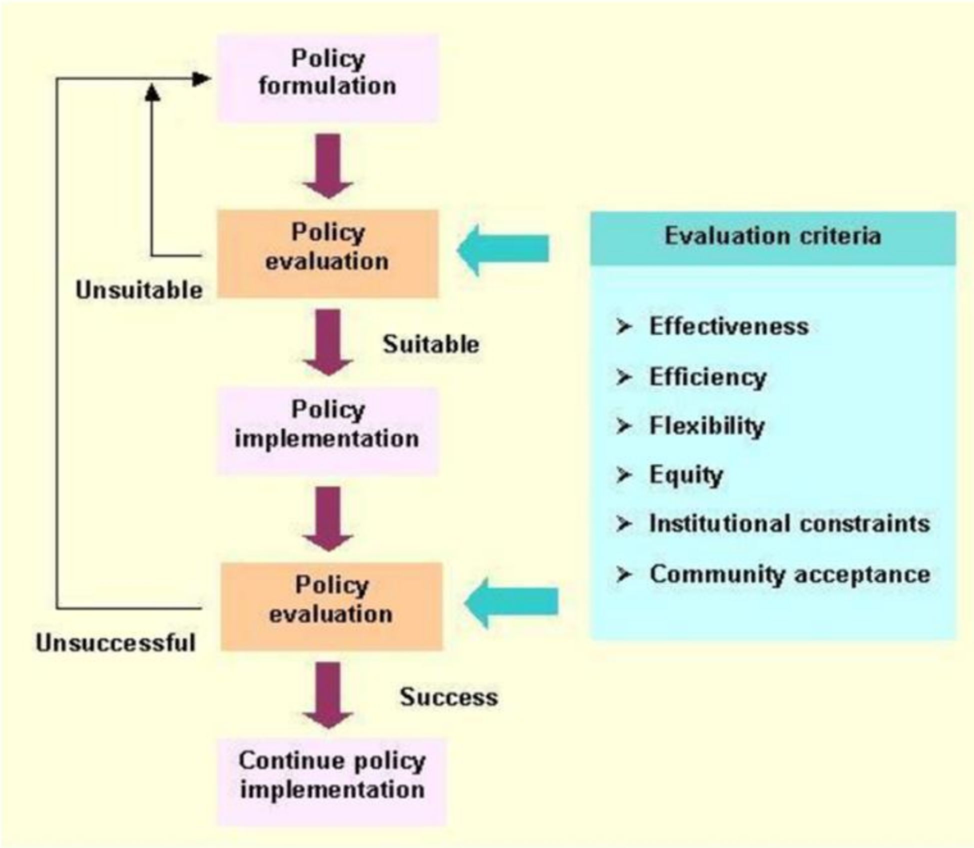

Figure 2.2 Evaluation framework, Source: UN ESCAP Virtual Conference Section C

The evaluation criteria are applied to three case studies:

- Manufacturing
- Cement
- Food

The supply chain emissions associated with the EU manufacturing sector arise all over the world, with 44% (242 Mt CO_2) of overall supply chain emissions found beyond the borders of the EU (Skelton, 2013). Cement is used as an example of a very carbon intensive commodity whose carbon emissions are priced under the European Emission Trading System (EU ETS). The production of cement accounts for more than 5% of global CO_2 emissions (IEA and WBCSD, 2009). According the IPCC's Fifth Assessment Report, the CO_2 emitted from agriculture is considered neutral, "being associated to annual cycles of carbon fixation and oxidation through photosynthesis." Nitrous oxide (N_2O) emissions from agricultural soils and methane (CH_4) emissions from livestock, rice cultivation and manure management are the largest emission sources (IPCC, 2014).

The purpose of the case studies is to test the evaluation framework and to identify key aspects relevant to policy effectiveness that need to be reflected in the analysis of potential policy interventions.

2.1.3 Conclusions main challenges

2.1.3.1 Conclusions from the case studies

This aforementioned inception analysis as well as discussions among experts during the first Carbon-CAP project workshop highlighted some aspects that require further attention in evaluating consumption-based carbon policy instruments.

Consumption-based accounting methodology

Consumption-based emission accounting requires reliable emission data and robust methods to track embodied emissions in trade and consumption.

Winners and losers from low carbon transformation

A transformation towards low carbon consumption produces winners and losers. The changes in consumption patterns in big consuming countries impact producing countries. In this context, consumption based accounting can also help to identify the emission hotspots of the intermediate commodities and final goods that are traded between producers and consumers. For example, the analysis of the EU manufacturing supply chain revealed that the carbon emission hotspots occur in a limited number of transactions and border crossings. Thus, early engagement with the relevant parties can help to address potential impacts of transformational policies. Furthermore, a quantified understanding of the scale of impact provides a basis for an informed policy debate.

Supply chain sensitive perspective on policy implementation

In order to reduce emissions embodied in trade and consumption, policies can intervene at the level of the producers, intermediaries or final consumers. The question of how far down the value chain a policy should focus its efforts can be informed by a good understanding of the actors and the transactions in the manufacturing supply chain. For each step in the supply chain, three domains of decision making by the relevant actors can be differentiated: optimising, satisficing, and transforming. All three domains of decision making, and in particular the domain of satisficing behaviour such as the inertia of habits or other suboptimal consumer responses, need to be reflected in the analysis of policy interventions and the modelling of policy impacts on consumer choices.

Price instruments in a supply chain

Carbon pricing policies were often guided by the principle of implementing a carbon price as much upstream as possible in the expectation that the carbon price will feed through the value chain and thus incentivise all involved actors to shift their decisions toward lower carbon options. In practice, emission tracking has sometimes been implemented further downstream in order to create more visible impacts for actors, and thus also address non optimising aspects of decision processes. The EU ETS is, for example, installation based rather than linked to the providers of the fossil fuels. With declining confidence of converging carbon prices by for example 2020, leakage protection measures are likely to remain in place and formulated in a way that is robust for longer periods. If the most common approach of leakage protection, free allowance allocation, is used, then for the ‘benefiting’ carbon intensive traded commodities the carbon price signal can already be largely muted at the intermediate goods stage as well as for all stages further downstream. Two categories of policy options can under such circumstances be used to reinstate the carbon price signal for intermediate and final consumers within the region covered by the scheme, (i) border levelling policy instruments combined with the full auctioning of EU ETS allowances for producers , and (ii) an additional consumption charge based on a benchmarked carbon content of basic materials (e.g. per ton of steel, clinker (cement) or aluminium. Both policy instruments incentivise intermediate and final consumers to change consumption patterns. They also retain incentives for upstream producers to invest in and use low carbon alternatives while providing opportunity to recover (part of the) incremental costs from consumers.

Public policy instruments catalysing private sector initiatives
The analysis of food labelling approaches showed that numerous voluntary carbon labelling initiatives have emerged, mainly driven by the private sector, although some public bodies and international organization have also been involved. Labelling methodologies differ: some labels display the product carbon footprint based on emissions embodied in production and distribution (cradle-to-gate), others account for the full life cycle including use and recycling/ disposal (cradle-to-grave). Methodologies also differ in the accounting of direct and indirect emissions. This raises the question of the respective roles of public and private sector labelling initiatives in preventing potential abuses and catalysing the use of such information tools across supply chains. Carbon labelling can also have trade and equity implications that need to be considered. The discussion within the project on labelling initiatives stressed that the credibility (and community acceptance) of consumption-based policy instruments will hinge on clear communication of the improvements that they can achieve. Hence, their evaluation and transparent representation will be critical for subsequent policy success and up-scaling potential.

Compatibility between policy instruments
The effectiveness of a policy instrument to achieve a reduction in embodied emissions in trade and consumption depends also on its synergy and potential for conflict with existing (non-carbon) policy instruments. The analysis of consumption charges on cement in Section 6 showed how consumption can be included in the EU ETS. It also pointed to the value of combining such a charge with labelling instruments to unlock demand-side responses. In addition, undesired interactions between policy instruments need to be considered in order to track and evaluate policy performance.

2.1.3.2 Conclusions on the international policy framework

Under the UNFCCC framework countries report the (territorial) greenhouse gas emissions they produce. With growing shares of emissions embodied in imports and exports from one country to another, the emissions embedded in the consumption of a country can differ substantially from the emissions linked to its production. Is it therefore necessary to move from production to consumption-based accounting? When discussing the advantages of either approach at least two dimensions need to be considered (and possibly quantified, following the principles of the Carbon-CAP project).

First, what incentives do both approaches provide for policy implementation? Efficiency improvements at the production site are linked to policy instruments in the producing country. In contrast, changes in consumption behaviour will be largely influenced by policy instruments in the consuming countries. Despite increasing international trade, many products are still produced and consumed in the same country. Therefore, adopting policy instruments that target the consumption of carbon-intensive commodities will also help to reduce the production of these commodities in the same country, and their implementation would thus be incentivised by production-based emission targets. Likewise, the adoption of policy instruments that enhance the carbon efficiency of production will also reduce the carbon emissions embedded in local consumption, and would thus be incentivised by consumption-based instruments.

Second, how do both approaches support policy makers in the implementation and management of policies? Typically an indicator that measures more closely the outcome of a policy instrument will be more helpful in understanding its success and improvement opportunities. Hence, in principle, consumption-based policy instruments are likely to benefit from indicators of consumption-based emissions and vice versa. As policy instruments are implemented at different levels of the value chain, this might require the parallel tracking of different indicators.

2.2 Global drivers of change in carbon emissions

2.2.1 Introduction

Today we live in a world in which economic production process and supply chains are international and global trade of goods and services from production sites in one country to final consumers in another is very common. In this globalized network of production- and consumption linkages an active debate remains over the question 'which side should be held accountable for reducing the associated GHG emissions, the producer or the 'consumer'? The Kyoto Protocol (1997) and its follow-up agreements envisage a production based accounting system. Production based accounts differ substantially from consumption-based accounts where goods associated with emissions are ultimately consumed. Over time the discussion of production vs. consumption based accounting took on many facets, among those sprung up questions of how to appropriately account for consumption based emissions along global supply chains, which data and models to use to trace emissions, topics that have been addressed in Carbon-CAP reports are summarized in Wiedmann (2009).

One constant in the debate outlined above is the role of international trade in respect to carbon leakage (Peters and Hertwich, 2008). The shifting of CO_2 emissions from developed- to developing countries has been well documented in the literature and is a problem because emerging economies, under original Kyoto agreements, do not have a legal obligation to reduce these emissions. Lately, scholars have been estimating the contribution of GHG emissions from international trade compared to domestic emissions. Estimates indicate that nowadays international export-based emissions make up to 30% of global emissions (Andrew et al., 2013; Caldeira and Davis, 2011; Peters et al., 2011; Peters and Hertwich, 2008). For example, Peters et al. (2011) find that 23% of global CO_2 emissions, or 6.2 Gigatonnes CO_2, were traded internationally - primarily as exports from China and other emerging markets to consumers in developed countries. In European countries more than 30% of consumption-based emissions were imported, with net imports to many Europeans countries actually exceeding 4 tons of CO_2 per person in 2004. Contrast these numbers with Chinese export emissions which reach 30% of total emissions produced in China (Liu et al., 2016). Finally, a consumption-based inventory of the UK found that growing consumption in the country increased embodied emissions in imports faster than those in domestic production. Consequently, the UK's total carbon footprint increased 12% between 1992 and 2004, whereas its production based emissions inventory decreased by only 5% (Wiedmann et al., 2010). Beyond the mere quantification of GHG emissions embodied in international trade, there is the question of which factors drive the growth of emissions. Answering such broad questions requires an understanding of changes in international global trade structures, final demand structures (consumption), production technologies and emissions factors. Few studies have carried out a composite decomposition of global embodied carbon pathways, although such an exercise is critical for a full understanding of production and consumption based emissions. To support policy based on a consumption based accounting perspective, it is of the foremost importance to understand the drivers of global emissions and the role of international trade. We focus on two critical areas in this work: 1) the internationalisation of greenhouse gas supply chains; and 2) the role of energy and labour in the internationalisation of greenhouse gas supply chains.

2.2.2 Internationalisation of GHG emissions

In the light of the effects of rapid globalization and escalating international trade on environmental impacts at the national level, research has recently narrowed its focus of evaluating the role of consumption in driving greenhouse gas (GHG) emissions and the potential for consumer-based changes in behaviour in order to reduce such emissions. Several scholars have pointed towards the growing influence of international trade on national emission trends, in particular the growing regional disparity between western developed countries and global producer havens such as China and India (Peters et al., 2011; Wiedmann et al., 2010). Most developed countries have increased their consumption based emissions more than territorial emissions. A number of studies have quantified the emissions embodied in global trade. Davis and Caldeira (2010) found that between 1990 and 2008 emissions from production of traded goods and services have increased from 4.3 Gt CO_2 to 7.8 Gt CO_2. Consumption includes final domestic consumption, end-use organisational consumption, and the consumption involved in intermediate goods and supply chains. For example, we know that behaviour, lifestyle, and culture have a considerable influence on energy use and associated emissions, with a high mitigation potential in some sectors, in particular when complementing technological and structural change (Edenhofer et al., 2014). European policy makers have sent a signal that evaluating consumer behaviour is important: for example, the Roadmap for moving to a competitive low carbon economy in 2050 and the Transport White Paper both acknowledge that behavioural changes may be needed to reach the emissions targets and that the targets may be reached at lower costs if the adoption of more sustainable consumption patterns and lifestyles are achieved. Next to quantifying the impacts of consumer behaviour on emissions through, for example trade, it is essential to identify the forces that have caused such changes over time. For China, it was found that increase of emissions by household consumption in Chinese mega cities was partially offset by an improvement in technology (efficiency improvements) in some key manufacturing sectors (Guan et al., 2008). Therefore, when evaluating drivers of emissions in Europe, such undertaken must be guided by questions such as: "how does change over time in production structure towards green growth and a service sector oriented and knowledge based economy within a single European market affect emissions?". Secondly, "how does Europe's change in international trade over time affect emissions embodied in trade?" In order to quantify drivers of emissions change and evaluate the impact of consumer behaviour structural decomposition analysis (SDA) within a global multi-regional input-output framework (MRIO) is used. A MRIO allows for tracing all emissions that are associated with final products back to the country that generated emissions, and therefore provides much more accurate estimates than bilateral trade models or single region models. A MRIO model called EXIOBASE, which has a highly disaggregated sector classification (augmenting environmentally sensitive sectors such as energy and agriculture), and a fully trade-linked system under test (SUT), is used.

Analyses show that absolute changes in total GHG footprint between 1995 and 2009 are dominant in China, India, Middle East, US, and Mexico and that that changes in emission intensity, changes in the production structure, and affluence, measured in total consumption per capita, dominate as drivers for the changes. The large footprint difference for some countries – and large changes in different factors – makes it difficult to perceive the trend across different countries. For that reason, the contribution of each factor is further calculated in relative terms. The observed pattern is common for most countries – with affluence and efficiency improvements growing in large, and often in opposite directions. The changes in the global supply chains are also relevant. It can be noted that, for some countries like China, the United States and Taiwan, the production structure plays a major role in GHG emissions growth. In other countries, such as Mexico, Korea, and Denmark (DK), the change in the origin of inputs becomes a more important driver for changes in GHG footprints. The factors that influenced the most, however, vary between regions. In China, the production structure and affluence greatly influenced the emissions growth until 2007, reflecting a period of high economic growth and industrialization. For the EU, affluence was the main driver for emissions growth, and together with the production structure, it contributed to the growth of emissions before 2007, and to the decrease in the footprints after 2007. The structure of the economy, both the production and trade partners, was the main driver for the emissions growth in the OECD in the late 1990s. Emissions grew at a constant pace from 1995 top 2007, decreasing after the financial crisis mainly due to the decrease in consumption per capita. Furthermore, there are important changes in the decomposition of GHG footprints from combustion and non-combustion processes. Overall, most changes in GHG footprints come from combustion processes. For non-combustion processes, affluence no longer becomes the main driver. We can also note that the non-combustion emissions present a much smaller growth than combustion emissions during the entire period for all regions, in absolute (total emissions) and relative terms (compared to 1995 emissions).

2.2.3 Labour and energy footprints in international trade

While there has been much attention in the past decade dedicated to the assessments of environmental footprints and the effects that the internationalisation of supply chains has had on greenhouse gas emissions, socioeconomic aspects are often left aside. However, socioeconomic factors are often linked to countries' comparative advantage and thus, to the globalisation of supply chains. In the past decade's advances in transportation and communication technology have allowed for a strong rupture in the regional links between production and consumption. Although global supply chains have existed for centuries, it was in the past decades that the offshoring of manufacturing to resource-abundant countries have increased substantially. Today finished and unfinished products can be transported globally in unprecedented cost and speed (Grossman and Rossi-Hansberg, 2008). In this context, labour costs have been assumed to be an important

driver for the migration of manufacturing stages, especially those characterized by high labour intensity, from capital-abundant economies to labour-abundant regions (Feenstra and Hanson, 1996). Nevertheless, labour-abundant regions tend to present lower energy productivity (Simas et al., 2014). Thus, the relocation of manufacturing stages can lead to an overall increase in energy consumption and, ultimately, trim down the impacts of GHG reductions in developed countries. The study of social and socioeconomic footprints from a global perspective is still a new subject. While input-output studies involving socioeconomic factors such as total labour, skilled labour, or value added are a tradition in economic assessments (for example, early studies by Leontief have already examined total and skilled labour associated with exports in the U.S. (Leontief, 1956, 1953)), they have often focused on impacts in national economies. In recent years, studies on labour footprints from a cross-national point of view have been emerging (Alsamawi et al., 2014; McBain and Alsamawi, 2014; Simas et al., 2014), but they have not yet been analysed from a time-series perspective.
In the same way, structural and index decomposition studies have been performed from a regional or national perspective, accounting for impacts that structural changes in the economy and in trade might bring to domestic labour force (Dietzenbacher et al., 2000; Hong et al., 2015; Yang and Lahr, 2010). The present project shifts the focus of the analysis, and tries to understand what are the drivers for changes in total labour footprints. The decomposition of energy indicators has a large tradition. Early index decomposition analysis originated after the 1970s oil shocks, in order to study the impacts that changes in production mix would have on industrial energy demand (Ang and Zhang, 2000). Since then, several studies have provided a view on energy consumption (Wachsmann et al., 2009; Zhang and Lahr, 2014), energy-related greenhouse gas emissions (Arto and Dietzenbacher, 2013; Feng et al., 2015), and other environmental impacts (Yang et al., 2016). The study of how energy consumption has been influenced by the outsourcing of industries and the globalisation of supply chains is a topic that needs further exploration. This report presents a vis-a-vis analysis of the changes in labour and energy footprints from 1995, as well as the drivers behind these changes. Structural index decomposition analysis is used to look at the influence of international trade to the change of energy and labour footprints from different regions.

As expected, analysis show that changes in the energy and labour factors of production underlie much of the behaviour seen in the greenhouse gas account. Between 1995 and 2009, most countries presented a growth in both energy and labour footprints. When decomposing energy and labour in absolute changes, the same countries display the highest growth in both indicators. The highest growth in energy footprint was in China with significant changes also in India, the Middle East, the Asia and Pacific region and the United States. Changes in labour footprint, in absolute terms, occur mainly in the Asia and Pacific region, Africa, the Middle East, the United States, India, and China. Switching to relative changes, there are more outliers when looking at energy decomposition compared to labour, but relative changes and the contribution of the drivers are, in most cases, within the same range. If ignoring the outliers, there is a similar pattern for both energy and labour and same behaviour as greenhouse gas emissions, with energy/labour intensity and final consumption growing in different directions. For both energy and labour, there is a higher contribution of final demand and a lower contribution of trade for footprint change than for GHG emissions. Changes in energy footprints are similar to changes in GHG footprints, as expected – especially since most changes in GHG footprints derive from combustion processes. Changes in labour footprints, on the other hand, present different dynamics. For China, the period between 1999-2003 presented a small reduction in labour footprints, while it experienced a significant increase in its energy footprints. This reflects the period of high industrialization: production became much more energy-intensive due to growth of manufactured products, which at the same time presents lower labour intensity. Most changes in labour footprints in the region derive from final consumption. Affluence, or consumption per capita of the Chinese citizens, increased the demand for production (thus, labour), while the change on final demand structure resulted in an opposite force. Change in final demand structure reflects the purchases of households, governments, building of stocks, and other final consumers. The change in the final demand structure here might arise from two factors: first, with affluence and urbanisation of the Chinese society, the consumption habits of households might have changed considerably. Second, purchases by the government and the build-up of infrastructure (with rising urbanisation) might be important factors for this change in final demand structure. These changes, however, do not impact energy footprints in the same magnitude, and this is a subject that deserves further investigation. In Europe and in the OECD, impact of changes in labour intensity increases after the financial crisis, in contrast to the impact of energy intensity. Labour intensity is defined as the amount of people in labour divided by the output of the industries. Labour and capital are, in most cases, fixed costs to production, as opposed to energy. This results in a smaller decrease of employment levels compared to the decrease of output. For energy, however, the decrease of output also means a decrease in energy consumption by industries. For both regions, the change of origin of imports to national industry and direct imports to final demand have higher effects on labour footprints than for energy footprints, suggesting that labour intensity of production is higher outside of these regions.

2.2.4 Conclusions Global drivers of change

The analyses in efficiency (emissions, energy, and labour per unit output), the changes due to trade related effects (both for intermediate producers and final consumers), the changes due to technology effects (both for intermediate producers and final consumers), and the change due to affluence and population indicate that trade is an important driver for global greenhouse gas emissions growth. However, it is not as important as growth in affluence and overall industry efficiency. This is only true, however, when looking at global emissions growth. When taking into account regional shifts in greenhouse gas emissions footprints over time, the displacement of industries from developed economies in the European Union and the OECD and the increase in imports to final demand contributes to emissions growth, mainly from combustion. For non-combustion emissions, changes in trade partners seems to decrease GHG footprints. Different dynamics act on the footprint growth over time and in different regions. Greenhouse gas emissions and energy consumption are mainly driven by the increase of consumption per capita in developing economies, such as China, and in the European Union. This growth in affluence reduces (or even reverses) gains in carbon and energy efficiency. It can be seen that trade is an important driver for labour footprints change in developed economies, in a higher proportion than for energy and greenhouse gas footprints. That indicates that the displacement of industries to labour-abundant countries might not have a significant effect in the growth of emissions embodied in trade.

2.3 Key challenges and opportunities

2.3.1 Introduction

A climate policy requires an information base, to monitor past developments, spot trends, and also to estimate the effectiveness and side-effects of policy measures. The EU climate policy, as well as global policy as agreed on in the Kyoto protocol and succeeding agreements, already has a large information base. This consists of measurements, especially of GHG concentrations in the atmosphere, of databases, such as the UNFCCC database of greenhouse gas (GHG) emissions and the various databases on energy use, and of models, especially the Integrated Assessment models such as IMAGE, GCAM, MESSAGE, PRIMES and POLES, GEM-E3 and E3EM, or the economic RICE-DICE model (Nordhaus & Boyer, 2000). Those together supply a strong foundation for climate policy. However, these data and models are mainly targeted at production sectors and their (point source) emissions. For a consumption oriented climate policy, such as investigated in the Carbon-CAP project, these do not provide sufficient information to allocate emissions responsibility through the production layers and supply chains through to consumers. Additional databases and modelling approaches should be developed to support such a consumption oriented policy.

A number of databases, models and tools exist that do have a consumption based approach. This section aims at reviewing the literature on such approaches. The main question for this review is: do any of these approaches, or a combination of them, provide a sufficient basis for attributing emissions in a consumption based climate policy? And if not, which gaps need to be addressed before we do have a satisfactory information base?

To answer these questions, it is first investigated what is needed to provide such an information base and review several databases in the light of these requirements. This leads to a picture of the present possibilities as well as the gaps in data and models that still must be closed and some general conclusions.

2.3.2 Consumption-based Accounting and Policies

The underlying question of the Carbon-CAP project is, to assess whether a consumption based carbon accounting (CBCA) and consumption based climate policy can have an added value to the already existing production based accounting and associated policy as a means to reduce GHG emissions.

A consumption based approach differs from a production based approach in the definition of the system boundaries. A production based approach, requires a geographically identified system. A consumption oriented approach requires a functional, cradle-to-grave or “footprint” approach, usually including processes in different geographical areas. So far, policy has mainly focused on production and nations, and therefore, has used a territorial approach. This is also apparent when looking at GHG emission databases: they are organized by country and by activity. A consumption based approach needs something different. In order to relate GHG emissions to consumption activities or consumption categories, chains of processes have to be assessed, while for production activities it is sufficient to assess the processes (plants) themselves. This places much higher demands, not so much on the accounting of GHG emissions, but rather on the ability to connect processes (with their GHG emissions) in the assessment to form cradle-to-grave chains. Moreover, it has to be considered that these emissions and productions may take place in different countries all over the world, and that the analysis of consumption within a region therefore requires coverage of imports.

- Based on the above, the following desirable properties can be formulated: To enable a consumption based approach, it is essential that the GHG emissions can first be linked to sectors of production, and then further linked to consumption categories such as food, housing, transport, recreation and suchlike. Usually, as many supply chains of consumption are international, many national authorities are involved.
- Consumption categories are characterized by their cradle-to-grave chain, thus, the information base should allow for an analysis of consumption systems that essentially cannot be confined to geographical boundaries.
- For consumption based systems, the relevant scale lies beyond nations and activities and is much wider, ranging all the way from the micro-level of consumers and products, via the national level where some policies are implemented, up to the global level where products are traded and the (emissions) impacts take place.
- The data quality should be sufficient as a base for policy, i.e. (1) it should not put policy on the wrong foot and (2) the margins of uncertainty should not be so large that results are meaningless. As consumption based accounting and modelling is relatively new, this is probably a major issue in reviewing the approaches that are presently available. For databases, this refers mainly to data uncertainty.
- Monitoring developments is of course essential to spot trends and see whether past policy has resulted in emission reductions. Data for the past can also be used to assess hotspots and identify most important consumption categories, setting priorities for policy. Scenario development and analysis is useful to explore what the future could look like, and how various policy options could change consumption systems and their GHG emissions.

A recent investment in global multi-regional input/output (MRIO) modelling has led to the development of a number of databases suitable for calculating consumption based carbon accounts for recent history.

2.3.2.1 Practical issues in implementing Consumption-based Carbon Accounts

Currently there are five global databases used in CBCA, with a few extra variations on this, and a few extra regionally focused databases, e.g. for Asia. None of these databases are accepted as 'official"' by national governments, with the OECD Inter-Country Input-Output database the only MRIO database currently available within a non-academic sphere. Efforts are ongoing to establish a reputable international database through the OECD work, and with links to the UN and Eurostat. However, in the opinion of the authors, we see that there is unlikely to be a universally accepted database for all countries in the near future. This is partly due to the necessary compromises made in establishing CBCA databases, where, because of the nature of CBCA, statistics must be wholly consistent across country borders. This implies that a certain nation's imports must be consistent with other countries' reporting of their exports. Currently, this is far from the case, with current trade data showing a significant gap between reported imports and exports even at the global level.

This has led to a number of efforts by statistical offices to establish their own CBCA based on linking national level data to available MRIO models. Such efforts show that statistically approved national level CBCAs are possible. However, the resources required to establish such accounts are not available to many countries. Even for the EU, current Eurostat data uses outdated assumptions (not using an MRIO, and hence ignoring differences in emission intensity of trade partners) to estimate CBCA. This has led to official Eurostat CBCA results showing Europe to be a net exporter of carbon emissions, despite all other MRIO models showing EU to be a net importer.

From a basic accounting point of view, our findings give a number of straightforward suggestions for future harmonization of CBCA databases:

a) Ensure that basic principles with regard to allocation, using a residential instead of a territorial approach, and accounting for all activities/emissions and resource uses (rather than neglecting e.g. bunkers) are applied.
b) Harmonize extensions like CO_2 emissions, between databases, which is likely the single biggest cause for differences in calculated country footprints.
c) Ensure further that total final demand and total product output by country form the same share of global GDP.
d) Ensure that the domestic / national IO matrix is sound, i.e. having an as good as possible fit with official statistics.
e) Look in particular at rates of change in CBCA estimates rather than absolute values across CBCA databases – the variability in a rate of change (e.g. a 5% growth in CBCA from 2007) across models is much less than the variability in absolute values across current CBCA databases.

2.3.2.2 Political issues in implementing Consumption-based Carbon Accounts

CBCA has been seen as a way to increase the international participation in establishing common climate policy. With most Annex-II countries under the Kyoto protocol being net exporters of embodied carbon, and most Annex-I countries being net importers of embodied carbon, it was postulated as providing a way to engage nations across differentiated responsibilities. However, with the complexity on obtaining global agreement on basic forms of emissions accounting, such concepts have to date been far from the central negotiating spotlight. Furthermore, because of the largely unexplored secondary effects that could result from attempting to set binding CBCA targets (such as impacts on trade relationships, and hence value creation in developing countries), there has not been serious international discussion within the context of the UN Conference of the Parties of adopting binding targets on a consumption level.

2.3.2.3 The uses of Consumption-based carbon accounts

Since the advent of environmental footprint approaches in general, and CBCA approaches specifically, many policy makers have been looking at ways to derive consumption-based policies. Whilst these efforts can be lauded, it has not been clearly established in the literature that consumption-based policies are more effective or more cost-effective than traditional policies based on control of territorial emissions. Further complicating the policy arena is that many policies could be considered both traditional and consumption-based (insulation of houses, for example).

Alternatively, CBCA can be seen to be policy relevant, whilst not policy prescriptive. CBCA can give a key macro-level indication about the carbon intensity of an economy relative to baselines and targets. Such reporting of emission accounts can further underline the need for multi-lateral action, and for the increased responsibility needed to be shouldered by economies with growing net-import of emissions. CBCA can further strengthen resolve around uptake of instruments around, for example, the clean development mechanism (through encouraging investment from the developed world in trade partner countries in the developing world), or for the need for additional investment in emission offsets.

2.3.3 Review of consumption based approaches, tools and models

The review of tools for consumption based accounting and models for consumption based policies is based on a literature study. These approaches and tools all have in common that they specify aspects of society's metabolism, and have a quantified link between society and the environment. For our aim, the specification of GHG emissions is especially relevant. The approaches include accounting schemes, such as energy accounts and material flow accounts, but also attributional models such as Life Cycle Assessment (LCA) and Environmentally extended Input Output Analysis (EE-IOA). They also include different scale levels, from the micro-level (LCA) all the way up to the global macro-level. The approaches found in the literature will be held up to the light of the criteria mentioned in the previous section. The following approaches are reviewed:

- Energy accounts
- Life cycle assessment (LCA)
- Environmentally extended Input Output Analysis (EE-IOA)
- Hybrid IOA/LCA
- Footprint accounts
- Material flow accounting / analysis (MFA)
- Energy-economy-environment (3E) models
- Integrated assessment models (including energy models)

Other approaches such as energy system models and partial equilibrium models are not discussed per se, but are considered alongside 3E and IAM models where the connection to the overall society function (required for consumption based approaches) is performed.

	Linking consumption to GHG's?		Scope of chains considered		Relevant scales					Sufficient quality?	Time horizon	
					micro		macro					
	CO_2	All GHG	cradle-to-gate	cradle-to-grave	P	C	S	N	G		Past	Future
LCA	Green	Green	Green	Green	Yellow	Green	Red	Red	Red	Green	Red	Red
EE-IOA	Green	Green	Yellow	Red	Red	Red	Green	Green	Red	Yellow	Green	Red
MR-EE-IOA	Green	Green	Green	Red	Red	Red	Green	Green	Green	Yellow	Yellow	Red
Hybrid LCA	Green	Green	Green	Green	Yellow	Green	Red	Red	Red	Green	Red	Red
hybrid IOA	Green	Green	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow	Yellow	Red
Ecological Footprint	Yellow	Red	Green	Red	Red	Red	Red	Yellow	Green	Yellow	Green	Red
Material flow accounting	Red	Red	Red	Red	Red	Red	Red	Yellow	Green	Yellow	Green	Green
Dynamic material flow analysis	Yellow	Red	Green	Green	Yellow	Yellow	Green	Green	Green	Yellow	Green	Green
Energy databases	Red	Red	Red	Red	Yellow	Red	Yellow	Green	Green	Yellow	Green	Red
GHG emission databases	Green	Green	Red	Red	Yellow	Red	Yellow	Green	Green	Yellow	Green	Yellow
Energy-environment-economy	Green	Green	Green	Red	Red	Red	Green	Green	Green	Yellow	Green	Green
Integrated assessment	Green	Green	Red	Red	Red	Red	Yellow	Yellow	Green	Yellow	Green	Green

Table 2.1 Strong points and limitations of the different approaches according to the aforementioned requirements

Note: The following abbreviations are used: P – individual plant, C – micro-level consumption system (product or service), S – sector, N – nations or states, G – globe or world. Red: not possible/not included. Green: possible/included. Yellow: in between.

Besides this review it is also important to review the approaches in the light of underlying concrete policy options like:

1. What is the contribution of the different consumption categories to GHG emissions?
2. What are trends in consumption in categories with high GHG emissions?
3. What can be expected from the development of consumption categories over the next decades?
4. How is the burden of domestic consumption chains distributed over the world?
5. What is the effectiveness of consumption oriented policy measures?
6. What are trade-offs, indirect effects, side-effects and rebound effects related to consumption oriented policy measures?

The six issues in the top row of the table below refer to the six questions in the bulleted list above. An x in a cell means the approach is suitable to use for answering the question.

	GHG perfor-mance of consumption categories	Past trends	Future develop-ments	Burden shifting to other regions	Effective-ness of policy measures	Side-effects
Energy accounting		X				
LCA	X				X	X
EE-IOA	X	X			X	X
MR EE-IOA	X	X		X	X	X
Hybrid LCA	X				X	X
Hybrid IOA	X	X		X	X	X
Ecological footprint	X	X				
EW-MFA		X				
Dynamic MFA		X	X	X	X	
Energy – environment-economy models		X	X	X	X	X
Integrated assessment			X		X	

Table 2.2. Questions and the approaches

Note: The following abbreviations are used: P – individual plant, C – micro-level consumption system (product or service), S – sector, N – nations or states, G – globe or world. Red: not possible/not included. Green: possible/included. Yellow: in between, x= the approach is suitable to use for answering the question

2.3.4 Conclusions Challenges and opportunities

There are a variety of databases, tools, methods and models that can be used to assess aspects of consumption based carbon emissions. For assessing the past and the present, the integration of Life Cycle Assessment and environmentally extended Input Output analysis "hybrid LCA" seems to be the most ideal approach. This enables assessments at the micro- as well as the macro-level. Chains can be traced back to the point of extraction and hotspots can be identified. Burden shifting to other locations can be detected, and in theory also to other impact categories. Other approaches miss essential elements. The disadvantage of the approach is that significant work must be done on the integration of the process based life-cycle inventories with the macro IO tables. As such, integration is suitable only for product groups containing highly divergent products in terms of embodied carbon content.

3 Policy options identified through Carbon-CAP

3.1 Introduction

This section is aimed at understanding the effectiveness of policies and policy instruments in reducing national and global carbon emissions through a focus on influencing consumption choices and practices as a supplement to production practices. While the previous section focused on providing a broad framework of categorising policies and strategies, this section provides a summary of policy instruments that might underpin consumption-based reductions in national and global carbon, including initial assessments of each policy instrument against a sub-set of well-defined criteria of policy. It also extends the analysis to include consideration of political, legal, social and administrative barriers to implementation of each policy instrument at-scale, meaning at sufficient scale - geographically and with regard to economic sectors reached – to bring about meaningful reductions in national and/or global carbon, and suggests how these barriers might be reduced to improve the effectiveness and reach of an instrument. It also extends the analysis further by assessing the potential behaviour of the policy instruments within economic systems, and hence the effectiveness of the policies at reducing consumer demand for high carbon products and practices. These results will provide a quantitative measure of the reduction in demand for specific categories of goods or services that appear in the macroeconomic modelling, the comparison of the options and the preferred options. The present report examines specifically policy instruments rather than policies objectives. Policy objectives usually state broad aims (e.g. carbon reduction in the transport sector), while instruments are the means to achieving policy objectives. The overall policy objective throughout the report is to reduce emissions through consumer decisions and behaviours, while attempting to realize co-benefits or at last avoiding excessive impacts on for example employment.

3.2 Towards potential demand-side tools, policies and scope

3.2.1 Evaluation approach

In evaluating instruments, there is a distinction between 'theoretical effectiveness', meaning the effectiveness suggested by models (for example global macroeconomic models in the case of price mechanisms used to drive consumption changes), and 'empirical effectiveness', meaning the measured impact of the instrument on consumer behaviour and resulting carbon emissions. We recognise that as knowledge increases, these two forms of effectiveness converge, but at least at the present there is a significant performance gap (Chenet et al 2000) between expected and actual performance of policies; therefore, the focus on this section is largely on empirical experience.

Empirical research indicates that consumers will adjust their demand for goods and services under price rises or loss of income, but not in quite the way posited in applications of price elasticity. Instead of a simple percentage reduction in demand as price of a good or service rises by a percentage point, there is a hierarchy of adjustments consumers make in their 'portfolio' of consumption decisions. Research conducted by Bauman (1998, 1999) and Bernstein et al (2001) addresses questions such as: What will a household give up first if it doesn't have enough money for all necessities? and What will a household do to try to keep food on the table? A key consequence of this hierarchy is that the impacts of price-based instruments can be quite different in different economic groups, leading to different behaviours in these groups as the price is increased, and in a regressive outcome of the policy. This is in part an explanation of the differences in attitudes noted in the POLFREE (2014) study, where these differences can in part be traced to the economic settings in different countries and sub-populations surveyed. This suggests that policies aimed at reducing consumption of carbon intensive energy, goods or services must reflect a hierarchy when all of these factors may be changing simultaneously in the lives of the consumers (e.g. during periods of economic downturn).

Much effort has been made recently by retailers to influence consumer behaviour and to decrease the embodied energy and carbon of products sold to consumers. These efforts have generally been led by the industry or trade associations, and hence are supplier-supplier relationships, but there also are crucial areas in which governments and multinationals coordinate action (OECD 2010) and where the companies act directly with consumers (Bocken 2014). Parag and Darby (2009) point to three additional relationships, each of which must be maintained and coordinated by instruments (or more importantly, clusters or mixes of instruments) for effective shifting of demand to lower-carbon choices: government-suppliers, suppliers-consumers and consumers-government. They note that each of these relationships can be the target of instruments aimed at demand reduction, with specific incentives required to strengthen each.

This knowledge is used to consider what kind of instrument may be most relevant and desirable, at each potential point of intervention and to which kinds of decision makers. So, the assessment criteria are:

- Effectiveness
- Efficiency
- Flexibility
- Equity
- Institutional coherence
- Community acceptance
- Sustainability

Additionally, three auxiliary criteria are included: Coordination, Consistency and Spillover effects. The instruments may be aimed at any or all of the following three general categories of influence:

- Final consumer: Government policies aimed directly at final consumer choices
- Intermediate consumer: Government policies aimed at intermediate stages in the production chain, affecting the consuming behaviours of these organisations as these influence the carbon characteristics of goods and services available to the consumer
- Supply chain management**:** Policies – often by corporates or in support of corporate initiatives – that affect overall supply chain management, again influencing the consumer choices of intermediate producers.

Focusing largely on the final consumer, the point of intervention may be any combination of the possibilities. The interventions will have interactions, so that an intervention at one level or step will have associated impacts at other levels or steps. This is discussed later in considering policy mixes.

- Processing steps at the outlet for the good or service: This application of the instrument influences the outlet's choices of which products to offer, and how the lower carbon options are featured within the outlet (e.g. how close to the front door or to the checkout). In the tables that follow, this is indicated as Available Choice at the Outlet (ACO).
- Information campaigns: This application of the instrument influences the outlet's choice of information displayed on the goods or services offered (e.g. displays of carbon implications of fuel efficiency of cars). In the tables that follow, this is indicated as Consumer Choice Decisions (CCD) because the information acts to influence that choice.
- Consumer choice as to level of demand: This application of the instrument influences the level of demand by a consumer for categories of goods or services (e.g. the choice as to how much meat one will consume). In the tables that follow, this is indicated as Demand Reductions (DR).
- Purchasing choice by the consumer: This application of the instrument influences the choice by the consumer of the goods or services to meet the demand (e.g. the specific boiler selected for an office building). In the tables that follow, this is indicated as Consumer Choice Decisions (CCD).
- Usage by the consumer post-purchase: This application of the instrument influences how the consumer uses the goods or services after purchase (e.g. how they dispose of a purchased white good). In the tables that follow, this is indicated as Consumer Use Practices (CUP) or Consumer Disposal Practices (CDP).

To structure this mapping further the instruments into three broad categories or 'arenas' of policy application:

- Government or private sector policies aimed directly at final consumer choices - which may encompass private, corporate and government consumers as components of final demand
- Government or private sector policies aimed at intermediate consumption stages in the production chain – i.e. affecting corporate choices and the characteristics of products sold on through the supply chain, which in turn influence the choices available to consumers and the prices they see in making these choices
- Policies and procedures – often by corporates or in support of corporate initiatives – that affect overall supply chain management, largely down to procurement policies of the large corporations which affects the range of offerings to final consumers in the consumer-facing organisations.

3.2.2 Evaluation results

A listing of 33 potential policies – applied across six product/sector categories each, is developed and assessed by the Carbon-CAP team, identifying the nature of the policy (Grubb et al, 2015); the point of intervention; the economic sectors/products to which it might most effectively be applied; and the aspect of consumer behaviour influenced. Table 3.1 below expands on the information in the listing by providing a (subjective) judgment in Column 3 of the Category of Influence as defined previously: Final Consumer (A), Intermediate Consumer (B) or Supply Chain Management (C). The focus of Carbon-CAP is largely on category A, including Scopes 1 through 3, although categories B and C are relevant where an intermediate production organisation is a consumer of goods and services from organisations further up the production chain. Therefore, judgments are included for categories B and C where they are associated with the Scope 3 consumption (backward-linked) behaviour of organisations in those categories. This is especially important where these consumption behaviours are outside the jurisdiction of national authorities. The same category of instrument can apply across the three categories of influence depending on where the instrument is applied. In each case, the table selects the categories of influence from which the instrument is judged to be most likely to arise. Column 4 contains the judgment of the primary points of intervention; Available Choice at the Outlet (ACO); Consumer Choice Decisions (CCD); Demand Reduction (DR); Consumer Use Practices (CUP); or Consumer Disposal Practices (CDP). These points of intervention may also be conceived as the behavioural characteristic most likely to be influenced by the instrument. Again, the same category of instrument can apply across the five points of intervention, influencing two or more of these simultaneously. In each case, the table selects the behavioural determinant(s) judged to be most likely to be significantly influenced.

Instrument	Summary definition	Category	Primary point(s) of intervention
Regulatory standards	Direct regulation of performance of products available at point of sale	A or B	ACO
Sector trade body standards	Voluntary product performance standards set by trade organisations	B	ACO
Product labels	Requirement of embodied and/or usage carbon information on labels	A	ACO and CCD
Carbon embodied tax	Explicit price attached to product related to embodied and /or usage carbon	A or B	ACO and CCD
Information campaign	Information provision to potential consumers regarding carbon implications of consumption patterns	A	CCD and CUP and CDP
Consumer carbon budget / personal carbon allowances	Consumers are provided an annual carbon budget and cannot exceed this, most proposals allow for trading	A	DR and CCD
Business emission agreements / allowances, at least Scope1+2	Businesses (eg retail) required to acquire allowances for Scope 1 & 2 (at least) emissions, generally with trading	B	ACO
Subsidy	Government or trade subsidy of low carbon products	A or B	ACO and CCD
Product user fees	A fee is attached at point of sale based on carbon associated with subsequent use	A	CCD and CUP and CDP
Licenses	License is required either to sell [or purchase ?] high carbon products	A or B	ACO
Refund mechanism	Part of the price of purchase is refunded based on lower than average embodied and/or usage carbon	A	CCD and CDP
Product location at sale	Low carbon products are given preferential placement at retail stores, internet sites, etc	A or C	CCD
Supply chain procurement requirements	Retailers establish embodied carbon requirements on intermediate producers	B or C	ACO
Government procurement	Government gives preferential procurement to low carbon options	A or B	ACO
Voluntary agreements by trade organisations	Trade organisations adopt voluntary commitments to reducing embodied and/or usage carbon of products	B or C	ACO
Recycling requirements	Retailer and/or consumer have responsibility for recycling product, with a ban on landfilling	A or B	ACO and CDP

Product ban	Products are banned based on criterion of embodied and/or usage carbon	A or B	ACO
Shop product choice	Point of sale operators voluntarily restrict products to lower embodied and/or usaeg products	A	ACO
Waste targets, requirements and/or prices	Product recycling is motivated through waste policies	A or B	CCD and CDP
Rankings and Award campaigns	Product manufacturers and/or sellers are given publically celebrated awards for low carbon performance	C	ACO
Deposits on purchased goods	Deposits are initiated to enhance recycling of goods to reduce raw materials requirements	A	DR and CCD and CDP
Minimum price limits	Very low prices are banned to remove from markets products that have less incorporation of externalities	A	DR and ACO and CCD
Approved technology lists	List of eg. "efficient technologies" approved by a public authority for sale or procurement	B or C	ACO and CCD
Product tax incentives	eg. Enhanced tax depreciation based on product performance / embodied carbon	A or B	ACO and CCD
Trade Env Goods and Services agreements - eg tariffs	Proposal for tariff reductions on EGS products	A or B	ACO
Limits on percentage ownership or use	Restrictions on the number of a given product (such as cars) that can be purchased and/or owned.	A	DR and CCD
Enabling recycling	Creation of the infrastructure for re-cycling of goods between consumers	A or B or C	DR and CCD
Extension of product lifetime	Restrictions on the practice of planned obsolescence, or requirements of product lifespan	A or B or C	DR and CCD
Enabling product sharing	Creating infrastructure for shared ownership and/or use of products (e.g. Zipcar)	A	DR and CCD
Mandatory metering	Requirement of metering for power and gas use in buildings to signal energy consumption	A or B	DR and CCD
Graduated tax on advertising	Tax on advertising that increases with carbon content of a product or service	B	DR and CCD
Preferential finance terms	Lower interest rates for low carbon investments (e.g. energy efficiency improvements in buildings)	A or B	DR and CCD
Infrastructure improvements	Improvements to infrastructure that enable low carbon options (e.g. public transport)	A	DR and CCD

Table 3.1 Summary table of instrument categories
considered (Column 1); definition (Column 2); category of influence (Column 3); and most likely point of intervention/behavioural impact (Column 4)

An initial judgment is formed of the potential level of success of the instrument in reducing consumer demand for high carbon goods and services, and the embodied carbon and usage emissions.
The judgments are categorical rather than fully quantitative, given the significantly qualitative nature of this specific part. The judgments here are therefore LOW (the instrument is likely to yield a less than 10% reduction in carbon associated with demand for the product/service category due to its effectiveness and scope); MEDIUM (between 10 and 30% reduction) and HIGH (>30% reduction).

The scoring system is as follows. Depending on the percentage of the carbon associated with a product in a particular sector, a Scope score is assigned between 1 and 3:

- A Scope score of 1 if scope is 20% or less of the carbon of that product in that sector
- A Scope score of 2 if scope is 20-40% of the carbon of that product in that sector
- A Scope score of 3 if the scope is >40% of the carbon of that product in that sector

The instrument/sector is then assessed as to conditional effectiveness (i.e. effectiveness at reducing carbon associated solely with that product in that sector). An Effectiveness score of 1 to 3 is again assigned:

- An Effectiveness score of 1 if the instrument is likely to produce 10% or less conditional reduction in carbon. This assignment is given to instruments that rely primarily on consumer information to drive behavioural change
- An Effectiveness score of 2 if the instrument is likely to produce 20-40% conditional reduction in carbon. This assignment is given to instruments that rely primarily on price signals and voluntary trade sector programs to drive behavioural change
- An Effectiveness score of 3 if the instrument is likely to produce >40% conditional reduction in carbon. This assignment is given to instruments that rely primarily on regulation and infrastructure change to drive behavioural change. These judgments are provided in the table below.

				Buildings					
Instrument	Transport	White goods and electronics	Food	Building materials	Heat demand	Power demand	Lighting	Paper and plastics	Textiles
Regulatory standards	(2)(3)	(2)(3)	(2)(2)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(2)	(2)(2)
Sector trade body standards	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)
Product labels	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)
Carbon embodied tax	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)
Information campaign	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)
Consumer carbon budget / personal carbon allowances	(2)(2)	(1)(2)	(1)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(1)(2)	(1)(2)
Business emission agreements / allowances, at least Scope1+2	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)
Subsidy	(2)(2)	(2)(2)	(2)(1)	(2)(2)	(2)(2)	(2)(2)	(2)(2)		
Product user fees	(2)(2)	(2)(2)	(1)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(1)(2)	(1)(2)
Licenses	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)
Refund mechanism	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(2)	(2)(1)	(2)(1)
Product location at sale	(1)(1)	(2)(2)	(2)(2)	(2)(2)	(1)(1)	(1)(1)	(2)(2)	(2)(2)	(2)(2)
Supply chain procurement requirements	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)
Government procurement	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)
Voluntary agreements by trade organisations	(3)(1)	(3)(1)	(3)(1)	(3)(1)	(3)(1)	(3)(1)	(3)(1)	(3)(1)	(3)(1)
Recycling requirements	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(1)(1)	(1)(1)	(1)(1)	(2)(2)	(2)(2)
Product ban	(3)(2)	(3)(2)	(3)(2)	(3)(2)	(3)(2)	(3)(2)	(3)(2)	(3)(2)	(3)(2)
Shop product choice	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)
Waste targets, requirements and/or prices	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)
Rankings and Award campaigns	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)
Deposits on purchased goods	(1)(2)	(1)(2)	(1)(2)	(1)(2)	(1)(2)	(1)(2)	(1)(2)	(1)(2)	(1)(2)
Minimum price limits	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)
Approved technology lists	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)	(2)(3)
Product tax incentives	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(1)(2)	(1)(2)
Trade Env Goods and Services agreements - eg tariffs	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)
Limits on percentage ownership or use	(1)(3)	(1)(3)	(1)(2)	(1)(3)	(1)(3)	(1)(3)	(1)(3)	(1)(2)	(1)(2)
Enabling recycling	(1)(2)	(1)(2)	(1)(2)	(1)(2)	(1)(1)	(1)(1)	(1)(2)	(1)(2)	(1)(2)
Extension of product lifetime	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(1)	(2)(1)	(2)(2)	(2)(2)	(2)(1)
Enabling product sharing	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(1)	(2)(1)	(2)(2)	(2)(1)	(2)(1)
Mandatory metering	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(2)	(2)(2)	(2)(2)	(2)(1)	(2)(1)
Graduated tax on advertising	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)	(2)(1)
Preferential finance terms	(2)(3)	(2)(2)	(2)(2)	(2)(2)	(3)(2)	(3)(2)	(2)(2)	(2)(1)	(2)(1)
Infrastructure improvements	(2)(3)	(2)(1)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(2)	(2)(1)	(2)(1)

Table 3.2 Summary Product score judgments of the potential success of the policy instruments (Rows) for each of the product/sector categories (Columns).

The previous assessment considered primarily the issues of scope and effectiveness of individual instrument categories. Both of these can be enhanced if instruments are combined, improving the evaluation criterion of Institutional Coherence as well as the secondary criterion of coordination, and can potentially improve upon Equity (if the mixture of policies provides opportunities to redress problems of regressive policies) and Community Acceptance (if wins and losses by a particular subpopulation are balanced in the mix) and Sustainability (especially if the policy mix includes some component of social norming). The policy mix has also been selected to include instruments targeting each of the points of intervention that can contribute significantly to the intervention points identified previously as Available Choice at the Outlet (ACO); Consumer Choice Decisions (CCD); Demand Reduction (DR); Consumer Choice Decisions (CCD); Consumer Use Practices (CUP) or Consumer Disposal Practices (CDP). The policy mixes to be considered are divided between the six sector/product categories previously used are:

- Transport: Regulatory standards on vehicle fuel efficiency; government procurement of vehicles and infrastructure; product labels; information campaigns on low carbon vehicle options accompanied with messages on social norming; carbon tax on embodied and operational carbon at point of sale; enabling product sharing; preferential finance terms for lower carbon vehicles; product tax incentives; enabling product sharing.
- White goods and electronics: Regulatory standards on product energy performance; product placement in store; information campaigns on low carbon product options accompanied with messages on social norming; carbon tax on embodied and operational carbon at point of sale; recycling infrastructure and refunds; product labels; preferential finance terms for lower carbon products.
- Food: Product placement in store; information campaigns on low carbon product options accompanied with messages on social norming; shop product choice; graduated tax on advertising.
- Buildings: Regulatory standards on building energy performance; government procurement of low carbon building supplies; product labels; information campaigns on low carbon building materials and operation options accompanied with messages on social norming; carbon tax on embodied and operational carbon at point of sale; enabling product sharing (e.g. office space and/or vacation lets); preferential finance terms for lower carbon buildings; infrastructure improvements to enable low carbon energy options in the grid; product tax incentives.

3.2.3 Conclusions Demand-side tools, policies and scope

- 33 distinct categories of policy instruments are available to drive consumer behaviours towards lower carbon goods and services
- These instruments are appropriate for direct consumer influences, influences on consumer-facing organisations (such as retail outlets) and influences on the consuming behaviours of intermediate production.
- The instruments are divided usefully into three categories: (i) government policies aimed at final consumer choices; (ii) government policies aimed at intermediate stages of production; and (iii) policies of supply chain management for the business and industrial sectors.
- Most instruments can be applied across all six categories of sectors/products considered

- Effectiveness – as measured in this preliminary assessment (suggest a rank ordering of effectiveness from high to low for (i) regulatory and infrastructure provision, (ii) price signals and trade sector programs, and (iii) information provision.
- Portfolios or mixtures of policies are important in affecting behavioural change, targeting decisions of multiple kinds and at different points of intervention.

3.3 Political, legal and administrative feasibility of measures

3.3.1 Approach

In the previous section and sections more than 30 consumption-related policy instruments to deliver lower carbon lifestyles and business activities were assessed. Two major questions arise. The first relates to the potential to bring about changes when the instrument is implemented. The second concerns the acceptability of the instrument for its implementation. Four meanings of 'acceptable' and related questions can be considered:

- Economic: Does the instrument place the economic burden on members of society best able to bear that burden, or onto the poorest members?
- Legal: Is the instrument likely to face legal challenges it will be unable to withstand?
- International/ political: Will the instrument raise trade concerns that may affect international political acceptability?
- Institutional: Will the instrument encounter administrative challenges due to constraints on institutional capacity?

The acceptability of a policy instrument can differ significantly across sectors of goods and services. Therefore, the analysis of policy instruments was divided into applications in transport, food, buildings, paper and plastics, textiles and consumer goods/ machinery. The evidence base for judgments of acceptability is based on literature reviews, analysis of existing legal frameworks including the World Trade Organization (WTO), economic analysis of the impacts of policy instruments on different socio-economic groups, and experience within the European Union when applying similar instruments. For each of the sectors and aspects of 'acceptability', scores are assigned between 1 (a significant barrier to adoption) and 3 (not a significant barrier). These are then combined for a multiplicative compound score.

3.3.2 Towards promising consumption based policy measures

This section is focused on identifying policy instruments likely to achieve the highest level of acceptability, based on each of the 'acceptability' criteria, and on developing a short list of promising consumption based policy measures

Economics (distributional impact on consumers)

Based on an analysis of national expenditure statistics for different groups of goods in six European countries, instruments that exclude entire groups of households from consumption were found to be most at risk of causing unacceptable distributional effects. Unsurprisingly, the food sector as well as energy provision for households are most prone to such effects. Instruments penalizing the cost-advantage of many conventional, carbon-intensive products run the risk of negative distributional effects. However, this regressive effect can be reduced through fees, taxes or subsidies. 'Soft' policy instruments which enhance consumer knowledge of carbon implications of product choice - such as information campaigns, labelling initiatives, rankings and award campaigns or product placement - will have fewer distributional effects. Government procurement policies and approved technology lists can also be used without much risk of distributional effects.

Legal and international/political issues

Many of the policy instruments could have impacts beyond European Union borders (spill-over effects) due to their objective of tackling emissions embodied in internationally traded goods and services. This would in turn have impacts on trade which is significant because of its role as an engine for growth and development. Consumption-based instruments would alter trade flows due to changes in demand patterns induced through product substitution and/or consumption reductions. Some policy instruments would only lead to indirect trade impacts. These include waste targets and/or requirements, refund mechanisms and deposit systems, recycling requirements, improved recycling infrastructure, mandatory metering of power and heat consumption, product sharing, transport and building infrastructure improvements, information campaigns or benchmarked carbon-intensive material charges. However, some instruments can have direct impacts on trade when they affect market access or when they involve a risk of discrimination. These include consumer subsidies, product tax incentives, preferential finance terms, government procurement or approved technology lists. Two instruments in particular would lead to significant trade barriers: product bans and limits on the number of products that can be sold annually within a country. Trade impacts can be both positive and negative, and, at least to some extent, managed. For example, developing robust and harmonised carbon foot printing methodologies helps reduce compliance costs for producers where technical regulations, labels or other instruments require carbon footprint information. This lowers market access barriers for producers and reduces the risk of bias against some producers or countries introduced by inconsistent methodologies. Given global trade interactions, it is also important to consider how the instruments fits within the WTO’s legal framework. While a full assessment is only possible once the details of the instrument’s design and implementation are known, many of the proposed measures are theoretically WTO-compatible. When implementing measures on the basis of embodied carbon, the issue of whether products embodying different levels of carbon are to be considered ’like’ products under Article III of the General Agreement on Tariffs and Trade (GATT) will arise. Generally, WTO rules apply to product-related process and production methods (PPMs) which affect the physical characteristics of the final product. The rules have long been interpreted as not applying to non-product related PPMs (npr-PPMs) which are not physically incorporated in the product. So far the interpretation of ‘likeness’ under WTO case law has largely been limited to the physical characteristics of the products, while embodied carbon relates to the methods of production. This would mean that two otherwise identical products with different levels of embodied carbon are considered to be ‘like’ and hence subject to WTO disciplines. The understanding is however evolving with recent case law and the increasing uptake of instruments targeting embodied carbon, such as carbon labels.

Institutional (administrative and procedural complexity)

At a national level, the introduction of innovative policy instruments into legislation is often constrained by a complex set of factors. The Network of European Environment Protection Agencies has noted multiple barriers to EU-wide environmental policy planning

- barriers that could reduce institutional acceptability, especially when they conflict with EU-wide goals such as the development of the single economic market in Europe.EU decision-making processes can be unwieldy and result in a loss of coherence of the original proposal. For industries that will be affected, the lack of certainty can reduce the ability to modernise or adapt quickly. Conversely, decisions on proposals can also be made at very short notice with insufficient time for effective involvement by all interested parties. For example, there are a number of areas where there are inconsistencies and overlaps between the EU Integrated Pollution Prevention and Control (IPPC) Directive and other (sectoral) directives. These kind of inconsistencies could delay implementation of consumer-based policies and instruments. The key finding here is that consumer policy instruments that are similar in resources and institutional knowledge to existing programs in the EU, will find the greatest acceptability. The clearest cases are infrastructure improvement, supply chain procurement requirements and approved technology lists. All of these have analogues in other areas of EU and national policy.

Shortlist of promising instruments
To assist with choices between policy instruments, the options were ranked in three tiers. The first tier contains instruments that are judged to be strong across the four criteria of acceptability. The third tier contains instruments for which there is a significant barrier to acceptance on at least one of the criteria. Instruments in the middle (second) tier have only medium acceptability on most categories.

1st rank	2nd rank	3rd rank
▪ Approved technology lists ▪ Supply chain procurement requirements ▪ Carbon-intensive materials charge ▪ Infrastructure improvements ▪ Product location at sale ▪ Retailer product choice	▪ Regulatory standards ▪ EGS trade agreement ▪ Recycling requirements, waste targets & prices ▪ Voluntary agreements by trade associations ▪ Business emission agreements & allowances	▪ Government procurement ▪ Information campaigns ▪ Rang & award campaigns ▪ Voluntary trade body standards ▪ Minimum price limits

3.3.3 Future for consumption policies

To effectively reduce emissions at the global level, consumption-based climate policy instruments will have to be part of the policy mix. Introducing instruments in a portfolio has three main advantages. First, consumer-oriented policy should not have the effect of wholly ‘individualising’ responsibility solely on end-users. It should spread responsibilities across many sectors, across consumers and across producers. Second, emissions are caused by many different decisions at many different levels from primary production to consumption to disposal. Consumer-oriented policies only act on part of these, and individual consumer-based instruments further focus the scope of application. Finally, experience has shown policies are often most effective when developed in mutually reinforcing ways since weaknesses in any one instrument can be counterbalanced by strengths of another instrument. This often helps in negotiations between groups implementing and affected by an instrument.

A range of instruments are available for application in various combinations with each other and with production-side policies. Each instrument will encounter different types of barriers in terms of 'impact' and 'acceptability' that will be largely influenced by their exact design and implementation, as well as the context and combination in which they will be applied.

The assessments carried out by the project provide a useful first overview of promising instruments and a starting point for identifying opportunities and challenges to focus on in future deliberations and analyses. A key lesson is that consumer choice is difficult to influence when consumers have equal access to high and low carbon goods that meet the same needs. Therefore, the rankings of effectiveness and acceptability of instruments developed in this briefing reflect a tiered approach in which instruments that alter the range of products available, their ease of access and/or the cost (due to carbon charges) are applied first. The second and third ranks of instruments might then be considered means to support the instruments in the first rank. This is consistent with the lesson that instruments are most effective when introduced as complementary portfolios.

3.3.4 Consumer and business response

This aims at estimating the responses of consumers and businesses to the demand side tools identified previously, focusing on the construction and buildings, transportation, and food sectors. For this purpose the respective pick-up rate of promising improvement options – that is actors' willingness to adopt lower-carbon like-for-like products or substitutes and/or reduce consumption through behavioural changes- was evaluated. The focus was on the degree of support for consumer-based policy instruments by organisations that are at the interface of producers and consumers of goods and services. These organisations were selected because they receive signals of acceptability both forward and backward in the supply chain, meaning signals from within their organisation, signals from the organisations from which they purchase transport options, and signals from the consuming public. The structure of the analysis was one of agent-based assessment of attitudes and behaviours, seeking to understand how specific groups of actors – ultimately responsible for the success or failure of an instrument – view the challenges and enabling factors for implementation of an instrument. These attitudes and behaviours were assessed through surveys examining primarily the point of interaction between the production and consumption chains, supplemented by a review of the literature.

3.3.4.1 Buildings

The general challenge is that most of the analysis focused on so far unexplored territory of the climate policy landscape. Only some of the improvement options taken from Rodrigues, Prado et al. (2015) are widely used already in some form or the other and the same is true for the policy measures summarized in Grubb, Hawkins et al. (2015). Accordingly, the existing literature is relatively mute on concrete improvements in uptake of improvement options as a reaction to policy measures. Furthermore, the focus both in the academic and the policy-oriented literature lies with energy efficiency as opposed to embodied carbon, which is one of the key foci of the Carbon-CAP project. This reflects that also most existing regulations concern building insulation, efficient heating regulations, carbon taxes/subsidies for energy efficiency, as well as procurement regulations concerning energy-efficient construction styles. The notable exceptions to this rule are existing programs on labelling as well as information campaigns. Also, regarding waste recycling, trade agreements and procurement regulations, the existing literature is generally mostly about energy efficiency or operational carbon emissions, or about the carbon footprint in the economy overall, but not specifically in the building sector. A research gap is diagnosed on policy measures relevant to consumers, as even many information campaigns are still only directed towards suppliers. Consequently, there is almost no literature that estimates or measures concrete pick-up rates among consumers since there are only very few policies in place that address embodied carbon consumption in the building sector. To complement the literature analysis, an expert elicitation was exercised based on an online questionnaire, in order to gather specific information on improvements in pick-up of selected improvement options as a reaction to selected consumption-oriented policy measures. Guided by the technical potential estimates from Rodrigues, Prado et al. (2015) and ex-ante assumptions on some improvement options, the focus was on the uptake of (1) zero-emission or passive houses, (2) refurbishment and renovation of buildings, (3) thermal insulation of houses, (4) increased use of low-carbon and renewable building materials as well as (5) efficient use of (conventional) cement and concrete. For each of these improvement options tailored policy packages including a wide array of consumption-oriented policies, differentiating between the effect of voluntary versus mandatory measures as well as the combined effect of voluntary and mandatory measures, have been constructed. Unsurprisingly, the pick-up increases with a longer duration of the policies (2050 compared to 2030) and mandatory policies lead to higher pick-up compared to voluntary policies. Usually pick-up is even higher for the combination of voluntary with mandatory policies, which points to large complementarities of policies that are generally viewed as soft, such as capacity building and information, with more stringent policies such as charges and fees or direct regulation by regulatory standards. Generally, future pick-up depends to a large extent on current pick-up, but fast growth is likelier for underutilized options such as passive houses. Given the long-time horizon of the analysis, uncertainty in the results is huge (see Figure 3.1).

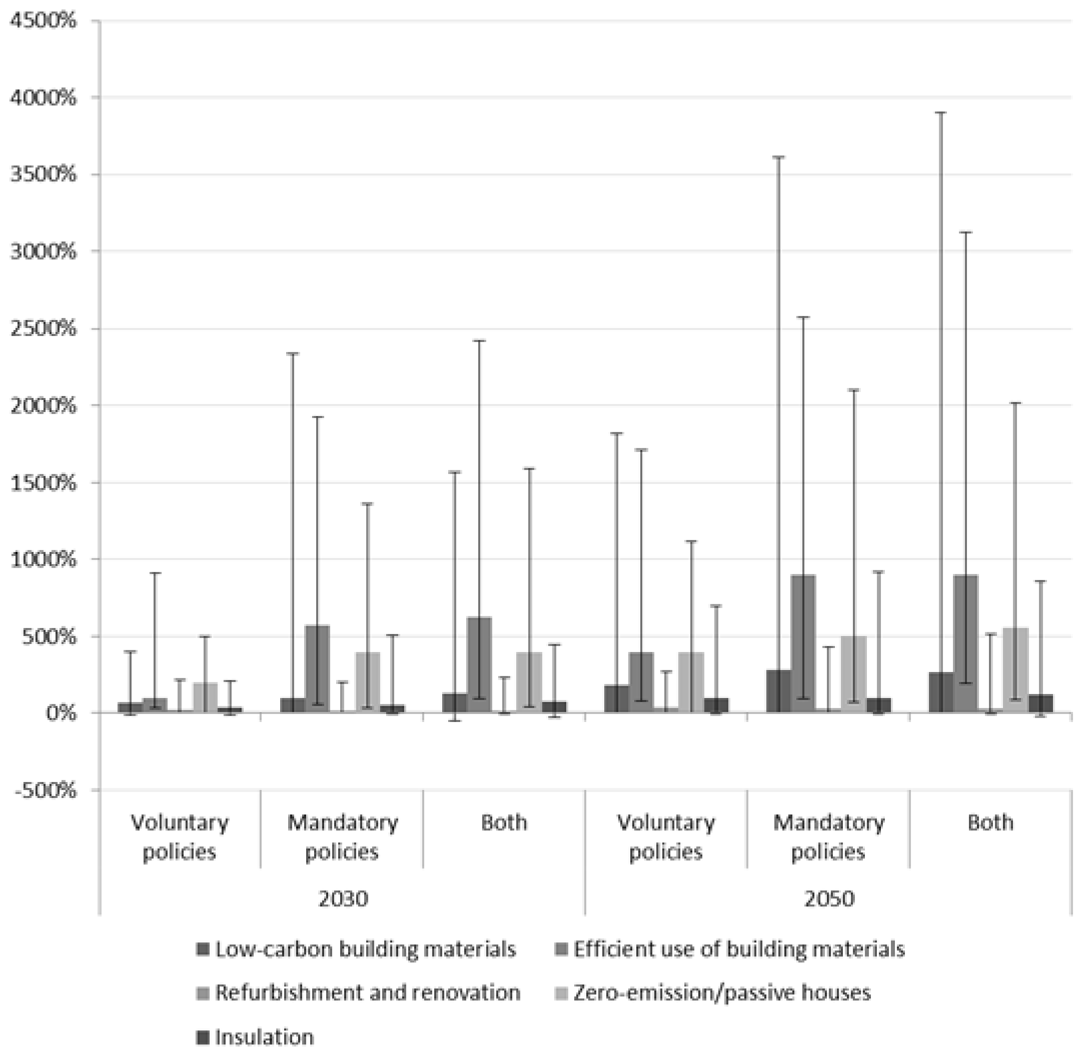

Figure 3.1 Median pick-up of mitigation options in the building sector relative to baseline by policy scenario.

Note: Bars give the median change of respondents' pick-up estimates relative to their baseline estimate, spikes give the 5th and 95th percentile.

3.3.4.2 Transport

- As with the Buildings and Food sectors, the assessment of the Transport sector focused on the acceptability and degree of support for consumer-based policy instruments by organisations that are at the interface of producers and consumers of transport-related goods and services. Survey respondents were selected to cover the range of actors involved in both public sector and private sector procurement of low carbon (or more generally, green) transport. While the focus is on the consumer of the transport option (who might be an individual traveller or a public-sector body purchasing a public transport system), it was necessary to also explore the attitudes and behaviours of the providers of those options to determine how they might respond to instruments that either force or nudge them towards provision of lower carbon options in the market. Rather than confronting the respondents with 30+ separate instruments to analyse, all instruments were divided between five broad categories: Technology Requirement; Information Provision; Financial Incentive; Infrastructure Provision; and Regulatory & Administrative. In addition, groupings of the instruments were identified as either Voluntary or Mandatory. Respondents provided their answers with respect to these groupings. To further clarify the kinds of decisions consumers might make, seven points of intervention were identified as the focus of the research. Each point of intervention relates to a specific selection by the consumer (again, an individual traveller or the purchasing arm of public transport procurement) from amongst transport options available in the market and/or the local community. These were: (1) Purchase choices by consumers to shift from gasoline/diesel to electric and hydrogen cars, (2) Mode shift by consumers to public transport, especially low carbon public transport, (3) Purchase choices by consumers towards reduced car weight, (4) Supply chain decisions by intermediate consumers to produce cars from secondary materials (with the recognition that producers of vehicles are also consumers of the materials that go into those vehicles), (5) Purchase choices by consumers to reduce the number of cars per household, (6) Design and process decisions by intermediate consumers, and purchase/operation decisions by consumers, to extend car life span, and (7) Decisions by consumers to reduce air transport and other long-distance travel. The following key points emerged from the survey and the literature analyses: Respondents held a strong view that any instrument could be either voluntary or mandatory, depending on how it was applied.

- With respect to purchase of low carbon transport through public or business procurement, there is a lack of clarity and agreement on methods to quantify low carbon credentials of transport options offered. This is the case for both operational and embodied carbon, making it difficult to calculate and compare life-cycle carbon for the options.
- In addition, consideration of initial capital cost dominates current purchase decisions, with 'sustainability credentials' not yet migrating into the daily decision criteria of purchasers of either public or business procurement practices.
- Providers of low carbon options are not yet receiving a clear signal of the demand for such options from either 'board level' of purchasing groups or the market.
- There has been very limited past experience with the specific policy instruments in the transport sector. Therefore, it is difficult to assess how well they will perform when applied.
- There is a lack of consistent political leadership on the issue, although it was also noted that when this leadership is available, it helps move towards low carbon offerings by providers.
- It is especially difficult for procurers to assess the low carbon credentials of innovations with little history of application. Given an aversion to investment risk and fear of technology lock-in, this significantly weakens the ability of purchasers to select innovative transport solutions even where there is potential for high levels of carbon reduction.
- Consumers are lacking information (and especially information known to be reliable) on the carbon credentials of options. Information that is available is often conflicting, context-dependent (an example repeated many times was the carbon credentials of an electric vehicle being a function of the degree of grid decarbonisation) and at least perceived to be influenced more by marketing than scientific analysis.
- With respect to public sector procurement, there is a perceived lack of clarity of allowed technology solutions under EU green procurement rules. Procurers are therefore unwilling to innovate in their purchases for fear of falling afoul of these rules.
- There is a need for significant improvements in the processes by which consumers/procurers and the providers interact so providers can have confidence that low carbon features they introduce into their products or services will find acceptance

in the market, and so consumers/procurers can understand and certify the low carbon credentials of available products or services.

In summary, the responses indicate a willingness of providers to offer low carbon options, and for consumers (especially public sector procurers) to select these options, but the acceptability of policy instruments to create demand for these options at present is significantly weakened by the lack of (i) a clear and consistent political signal, (ii) an agreed and certified assessment process against which competing options can be judged, and (iii) a signal that life cycle carbon rather than initial capital expenditure is a key performance criterion in purchases. Respondents also stated clearly that were these weaknesses to be overcome, there would be improvement in the acceptance of the policy instruments examined.

3.3.4.3 Food

The literature review focused on five interventions: (i) carbon labelling of food products, (ii) taxes, (iii) information and education campaigns, (iv) public procurement and (v) portion/plate size. The literature review supported the following conclusions:

- EU Member States have developed policies to improve the diets of their populations. These have been implemented in many of the nations.
- However, they have rarely undertaken evaluations of the effectiveness of these policies. Such evaluations are necessary to increase the acceptance of the policy instruments by organisations that sit between primary producers and consumers (such as food retailers).
- Taxes and subsidies have proven to be the most effective policy instruments in adjusting consumer behaviours with respect to food. Taxes on high sugar and calorie products, and subsidies for fresh fruits and vegetables, have produced changes in produce choice of between 20% and 40% in modelling.
- Empirical experience with the same taxes and subsidies are less prevalent in the literature, and show lower impacts on product choice than the model results suggest.
- Policy makers have expressed reluctance to impose taxes and subsidies on food, other than those associated with improving trade competitiveness of a nation’s products. This reduces the level of acceptance for such instruments, at least if they are made mandatory.
- Experience with information campaigns is at least suggestive of reductions in waste generation. The results for a switch away from a meat-based diet or a movement towards higher nutrient value foods, is less clear. Unfortunately, the programmes examined to date have compared consumption and waste between 2007 and today. There is therefore the interfering effect of the global recession to be accounted for in interpreting the results. Still, these studies suggest information campaigns can reduce waste by 10% to 20%, with a slightly smaller percentage change in food consumption choices.
- Public procurement of food for government facilities and services (for example food banks) has the potential to significantly affect patterns of consumption by providing a stable market for lower carbon foods and reduced consumption of food more generally. In these government sector programmes, carbon content of consumed food has declined by between 20% and 40%. Similar experiences are not available in the private sector food industry.
- Portion and plate size have been shown to significantly reduce food consumption at a sitting (by up to 20%). However, these studies did not examine instances where

consumers were offered two different sizes of portions or plates, so it is not clear whether the same results would be obtained if there were complete freedom of choice.

A survey was conducted of the response of two broad groups to the voluntary and mandatory clusters of policy instruments considered in this report: (i) representatives of the policy, academic and NGO community, who frame and analyse policy instruments and (ii) representatives of the food services industry, especially markets, who sit at the interface between the food industry and consumers. Four specific intervention options were considered: (i) reduction of food waste; (ii) reduction of meat consumption; (iii) reduction of dairy consumption; (iv) reduction of consumption of foods with low nutrient value. Qualitative findings of the survey are:

- Answers on acceptability showed significant variance across respondents. This large variance was due primarily to large variance between the non-industry respondents, and a difference between industry and non-industry respondents.
- The greater uniformity of response across industry representatives is a result of both shared experiences in affecting consumer choice and behaviour, and the use of a single-round Delphi method for that group. These respondents have daily experience dealing with consumers (unlike most of the respondents in the first group), and report similar experiences across members of the industry. They also have a strong network for sharing those experiences through their sustainability and CSR offices, which would tend to cause convergence of judgments.
- Voluntary measures tended to have higher levels of acceptance than mandatory measures. This was true for both industry and non-industry respondents. However, as the pick-up rates were judged to be higher for mandatory than voluntary measures. See also figure…
- Levels of acceptance by the food companies and consumer groups increased from 2030 to 2050, as might be expected given that both industry and consumers would have greater time to adjust behaviours by 2050.
- However, it was also clear that many of the respondents continued to provide Low to Medium judgments of acceptance even out to 2050. This had two causes: (1) a belief by some respondents that food is a matter of consumer choice and that policy interventions are not justified (their judgments therefore reflected a general attitude towards the appropriateness of government intervention in food decisions by either the consumer or food service industry) and (2) past experience with attempts to influence the behaviours of consumers, which they perceived to have produced marginal success and created some conflict with tier consumer base. The second answer was more prevalent than the first and indicates a belief that consumer behaviour is very difficult to shift, meaning the food services industry might be required to spend resources on implementing the policy instruments to little effect.
- Measures of Acceptability by the industry representatives generally ranged from Low to Medium, with few respondents stating High levels of acceptance even out to 2050. Informal discussions with that group of respondents indicates that this reflects their experience that retailers are significantly affected by consumer opinion, and that therefore the retailers are unlikely to show high levels of acceptance until consumers have sent a clear and reliable signal that they also accept the policy instruments and their implications for food choice.

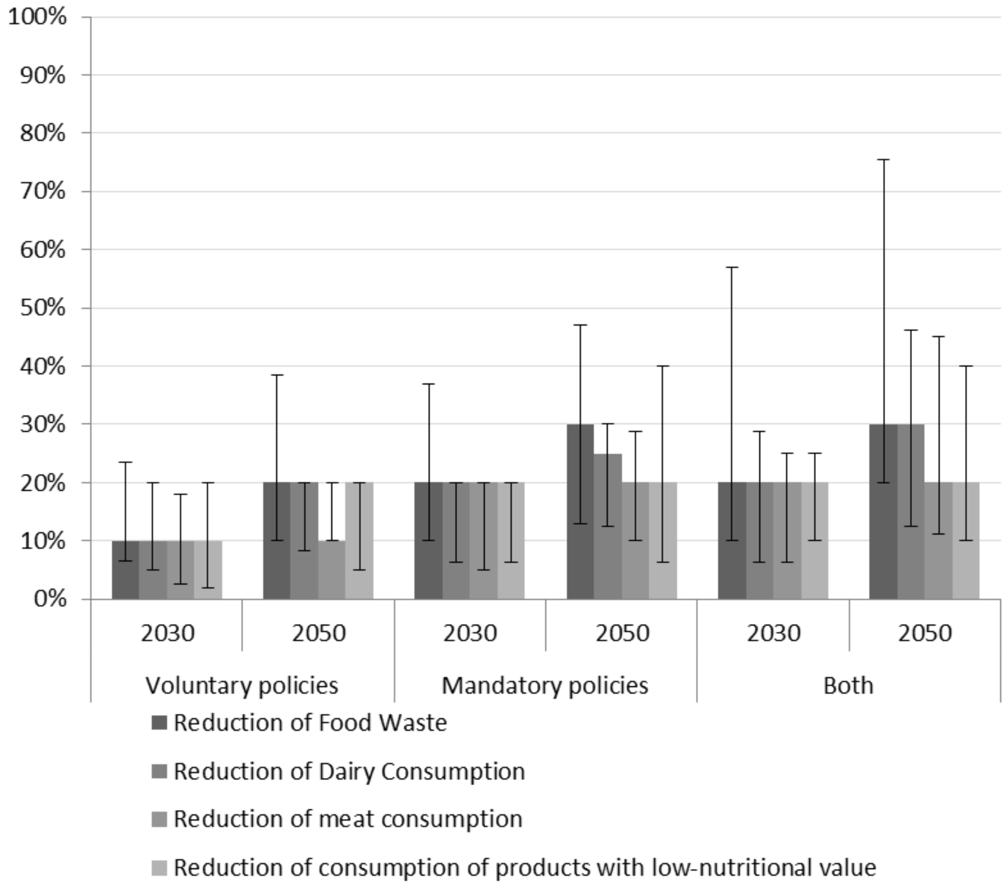

Figure 3.2 Median pick-up rate of mitigation options in the food sector by policy scenario.

Note: Bars give the respondents' median pick-up rate estimates, spikes give the 5th and 95th percentile.

3.4 Identification of improvement options in key areas

An innovative conceptual framework was developed which illustrates prevalent strategies and sub-strategies for final consumers (as well as intermediate actors) to mitigate emissions embodied in products. The mitigation strategies are framed into four overarching categories based on their primary mode of effect on GHG emissions: (i) direct reduction; (ii) indirect reduction; (iii) direct improvement; and (iv) indirect improvement. Within that framework the categories are subdivided into a set of six mitigation strategies (coloured boxes) and nine sub-strategies (blank boxes).

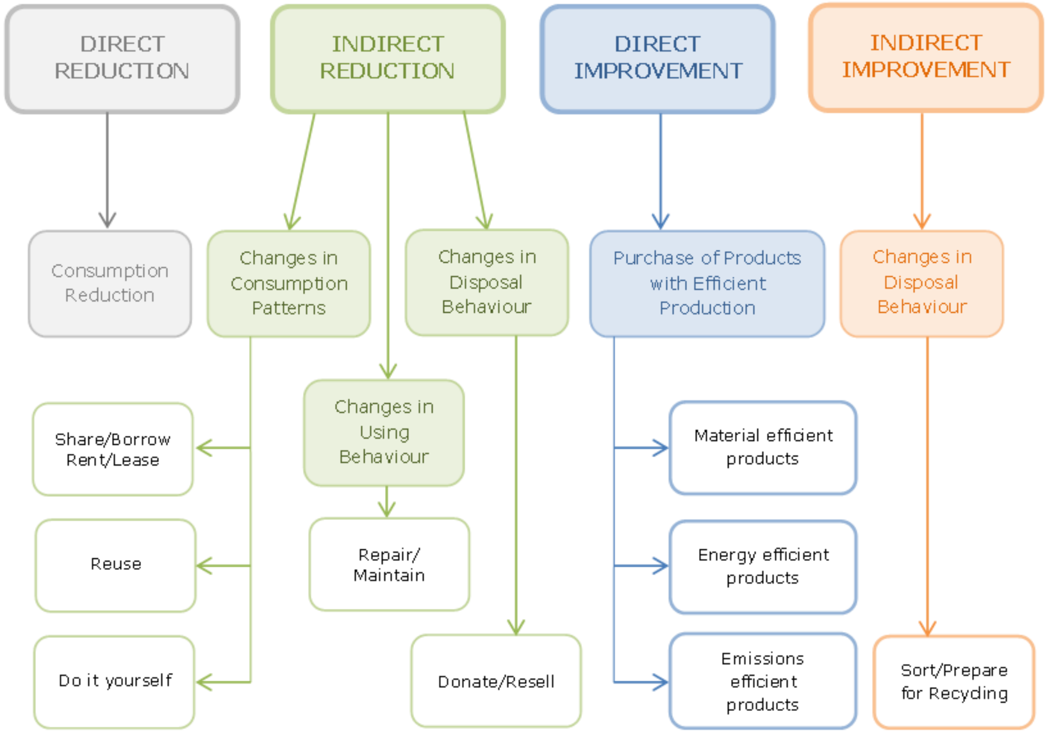

Figure 3.3 The Carbon-CAP framework for mitigation strategies and sub-strategies

In the following, the key outcomes regarding options in each of the priority areas are summarized.

3.4.1 Improvement options Food

In the field of food, there is a large variety of potential options to reduce GHG emissions. Consumers may shift their preferences to lower carbon intensive alternatives within the same product group e.g. changing from GHG-intensive meats (ruminants) to less intensive meats (pork and poultry) or select lower-carbon food product categories (vegetarian, vegan or low meat diet). Another option which has gained increasing attention within climate-smart food consumption in the past years is the recommendation to consume local and seasonal foods. Some studies also highlight the benefits of organic food with regard to low carbon options. There is also significant potential to reduce emissions from food consumption by options related to the reduction of the overall level of food consumption as well as of foods with low nutritional value e.g. alcohol, tea, coffee, or chocolate. Life-cycle assessment (LCA) studies on this type of options are still rare and contested among scientists. What is unchallenged is the fact that all final consumers need to reduce post-consumer food waste dramatically. Many studies point to the fact that food waste is an important issue and that there is an enormous mitigation potential in addressing this issue. Managing unavoidable food waste properly (e.g. using food waste for animal feed, as fertilizer, compost, or to recover energy from anaerobic digestion) is also a potentially GHG-saving solution. Additionally, there is a remarkable upswing in community gardening and a trend towards self-growing food. However, the quantification of mitigation benefits of self-grown food or community-based agriculture is still lacking.

3.4.2 Improvement options Transport

The preferred options within the transport sector focus on reducing the number of cars and the associated production emissions. This might be achieved through attempts to increase the intensity of use through shared ownership (car sharing/ pooling/ renting) or a shift to public transport or other low carbon transport modes (bike, walk). Car sharing can enable people to forego buying their own cars and thereby reducing the emissions occurring in the production phase. Selecting a car with low embodied emissions may also be a promising mitigation option for consumers. Lighter and smaller cars with less material input due to improvements in the product design can also prove a good solution in reducing impacts from vehicle production. Currently, vehicles are only labelled with regard to their operational efficiency and do exclude information on embodied emissions arising during all processes of production. Therefore, it is crucial to improve existing information schemes to get a better oversight about the hidden emissions within products.

3.4.3 Improvement options Buildings / construction

Having examined the likely impacts of the different options within the building sector, the most promising potential lies in the use of reclaimed construction materials and/or recycled materials (e.g. higher recycled content blocks, locally recycled aggregates). Except for cement, where there is currently no route to create new cement from old, recycling (in which used material is reduced to liquid form) is significantly less energy intensive than primary production, thus already containing a strong economic motivation. Obviously, also smaller homes and a reduced living space per person can be an effective way of reducing greenhouse gas emissions. Switching to GHG extensive construction materials (e.g. sustainable sourced timber or other renewable building materials instead of steel) constitutes effective means in mitigating GHG emissions. The success of proposed actions like co-housing and shared (office) spaces which also intend to reduce the living space per person are not entirely confirmed yet.

3.4.4 Improvement options for intermediate actors

In addition to final consumer-oriented options, the most important intermediate hot-spots in the various supply-chains were identified and corresponding options for intermediate actors (e.g. producers) compiled. Inputs for electricity production by coal and gas turned out to be the number one intermediate hot-spot in a large number of supply chains. Increasing the energy efficiency of production processes to reduce electricity demand as well as switching the energy mix (e.g. substituting electricity by direct on-site renewable energy production) are the most important category of intermediate options. Production of resource-intensive materials and products, such as iron and steel or chemicals was another intermediate hot-spot that was observed across a large number of supply-chains. Reducing the corresponding material inputs through increased material productivity and re-design or material substitution is therefore a key intermediate option to decrease the embodied emissions of final products.

3.4.5 Conclusions improvement options

These results revealed that a large number of options for reducing emissions embodied in products and services exist across selected priority consumption areas. There thus exist significant potentials for change and related reductions of human pressures on the climate.

However, we have also often found mitigation options which have been proposed by one study, but rejected by another study which claimed the opposite effect on embodied GHG emissions. Reducing one type of greenhouse gas emission may lead to increases in another; similarly reductions in GHG can prompt trade-offs with other non-climate related environmental issues (e.g. water, land-use or resources). It seems that even where absolute reductions can be achieved it may clash with other social or economic priorities.

Therefore, it is hardly possible to propose a "one-fits-all" high-priority list of mitigation options that will reduce embodied GHG emissions of final products. Instead, what it takes is a careful consideration and assessment of different side-effects and weighing of interests of the various options.

3.5 Effectiveness of improvement options in a consumption based approach

3.5.1 Methodology

The main database and model for the calculations of the potential effectiveness is the Multi-regional Environmentally Extended Input-Output table EXIOBASE. EXIOBASE covers the world; it distinguishes 43 countries and a RoW, and 200 sectors. Trade links are internalised, therefore, region-specific footprint analyses can be performed, which make it a very suitable tool to calculate the effectiveness of consumption-based policies.

We have conducted two analyses, that provide separate results but nevertheless are linked since basically the same methodology was used.

- The first analysis was a quick scan: a rapid assessment of all 113 improvement options that were identified (Schanes et al., 2015). In a quick-and-dirty manner, all improvement options have been translated into adaptations of the coefficients in EXIOBASE at the aggregate EU level, assuming a maximum uptake rate, to obtain insight into the potential effectiveness of the options.
- The second analysis is a more detailed one, where we take the twenty or so most effective options out of the quick scan and do a more in-depth analysis. This may serve as a correction of the assumptions in the quick scan, but at the same time is useful to obtain more insight into the regional differentiation and the variability even within countries. Both the complete overview and the more detailed analysis could provide useful information for a consumption based GHG reduction policy.

The modelling framework used for both the quick scan and the more detailed analysis is environmentally extended multiregional input-output (EE-MRIO) analysis (Minx et al., 2009). Input-output models that follow the Leontief demand-driven approach (Leontief and Ford, 1970) calculate the supply-chain environmental impact due to a certain quantity of consumer (or more precisely, "final") demand. Hence the socio-economic consequences of each intervention can be translated in order to derive input parameters for the model in terms of changed demand, or changed production pathways. In the following, the general EE-MRIO modelling framework is presented, and then an outline of the coupling of the interventions with this framework.

For the detailed analysis, the MR-EE-IO framework was used as well, but added additional information in various ways:

- Country specific information: the improvement options have different potential in different countries. This can be due to the structure of the economy, but also due to other things, for example climatological circumstances: reducing fuel use for heating is not very effective in countries where houses are generally not heated.
- LCA / technological information: improvement options have to be specified in their technological detail to assess their potential properly. This then can be used to detail the input-output tables, which usually are highly aggregate and do not allow for much technological details.
- Hybrid LCA: an even more sophisticated way to deal with improvement options is to translate the technological specifications of the improvement options in a set of foreground data, to be linked to the input output model as a background system.

A combination of these modelling options was used in the more detailed analysis.

Buildings

It seems that the built environment is a good place to start a consumption based GHG policy. Improvement options in that category are among the most effective. The zero emissions / passive house is the most effective option; however, it is also an option that in fact combines a number of other options, especially thermal insulation and the introduction of solar cells on the roof. Reducing energy use in the use phase contributes most to GHG emission reduction, but the contribution to a renewable energy system and the use of different building materials are also effective.

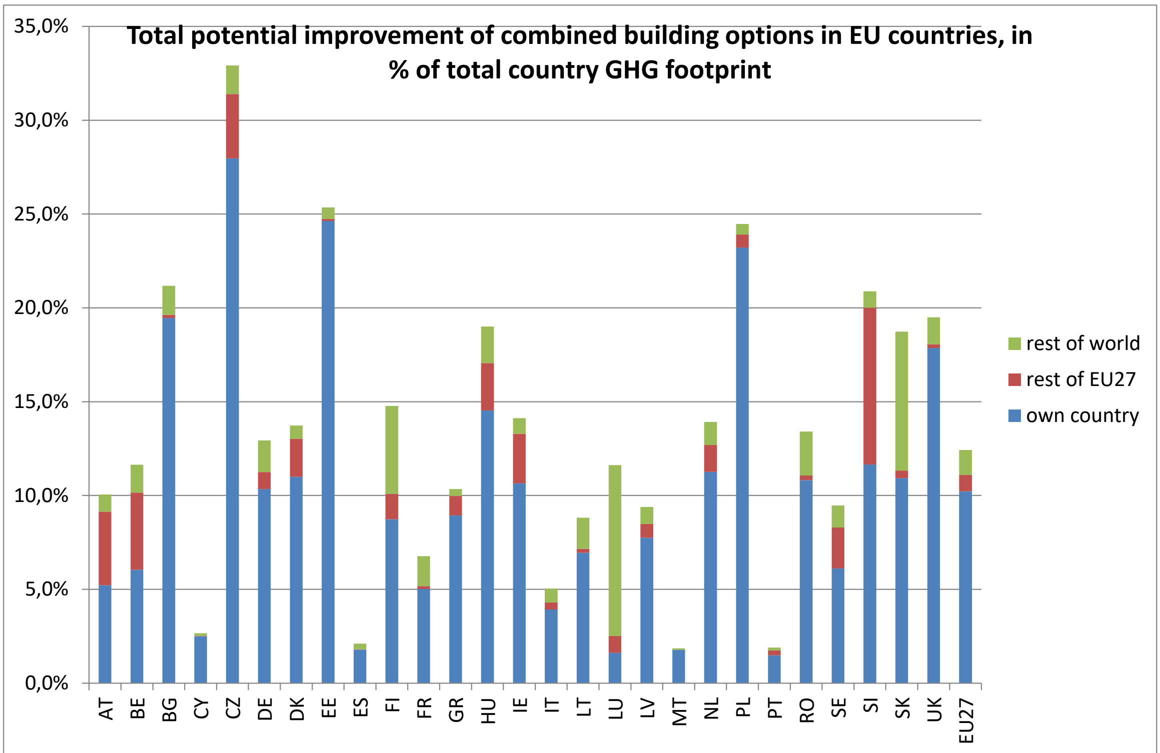

Figure 3.4 Improvement potential of the combined building options, corrected for overlaps, per country and for the EU total

The numbers are relative to the country's own total GHG emission footprint.

The first conclusion is that the improvement potential of the building options for EU27, 12% according to the detailed analysis, differ from the quick scan, where it amounted to 20%. Differences with the quick scan are to be expected, but this seems to be considerable. It seems that the quick scan assumptions have been too optimistic in this respect.

A second conclusion is that, once again, it seems that improvement options in the built environment reduce domestic emissions especially. This is in line with quick scan results, and with expectations: the options primarily reduce domestic energy use. In the EU, 94% of reductions are due to reduced fuel and electricity consumption. This also is a warning signal: these improvement options may be less effective when combined with transition to a renewable, or at least low GHG, energy system. That is illustrated for example by the case of France, where the improvement potential is only 6%. This is most likely due to the large share of nuclear energy in their energy system.

The most effective option is the zero emissions house. This differs from the passive house option by including renewable energy generation in houses, mainly solar on roofs. Passive house options are not considered for implementation in Southern European countries, as due to the climate little energy is needed, and the standard is actually reached without improvement options. The same is true for thermal insulation. Zero emission houses do have a positive impact throughout the EU. Replacing steel and concrete constructions with timber is not very effective.

Transport

The comparison between the results of the quick scan and the detailed analysis concerning transport is not straightforward since the modelling details and sometimes even the verbal formulation of the improvement option was different. The analysis showed seven categories that were easy to compare: hydrogen/electric cars; carpooling; public transport; reduction in weight; car sharing; increased recycled content; and less air travel. Car sharing yielded much higher savings in the quick scan than it did in the detailed analysis (3.52e11 kgCO_2eq vs 5.36e10 kgCO_2eq), while in all other options the reverse was true. In the case of air travel this difference was very high (6.06e10 kgCO_2eq in the detailed analysis vs. 1.27e9 kgCO_2eq in the quick scan). In all other cases the two methods yielded results in the same order of magnitude, with the quick scan figures ranging between 15% (for carpooling) and 85% (for increased recycled content) of the detailed analysis ones. The question as to where those savings occur was also answered differently by the two methods. In the quick scan all interventions yielded between 25% and 47% of CO_2 emission savings occurring inside the EU. In the detailed analysis, there was a much wider variation. Increasing recycled content resulted in only 6% of savings within the EU, reflecting the EU dependence in imports of raw materials. By contrast, all other options involved at least 45% of savings within the EU, with the reduction in weight reaching 83%.The summing of improvement options is problematic since the different interventions are overlap (e.g., it is impossible to have a conversion of the whole private transportation fleet both to hydrogen fuel and to electric cars), but it is a way to have an idea of the differences between countries. If the policies are implemented country by country, the one with the largest savings is Germany (20% of the total), and a set of four countries (Germany, France, United Kingdom and Italy) accounts for two thirds (65%) of all savings. A total of 85% of total savings is achieved by adding six more countries to this list (Spain, Hungary, Poland, Netherlands, Belgium and Greece). The individual contribution of each of the remaining countries is less than 2%.From this analysis it can be concluded that the most effective improvement options are the ones that lead to a decrease in the use of internal combustion private transportation: a shift to hydrogen and electric cars, carpooling and a shift to public transportation.

Food
According to these calculations, the options reducing food consumption altogether come out most effective.

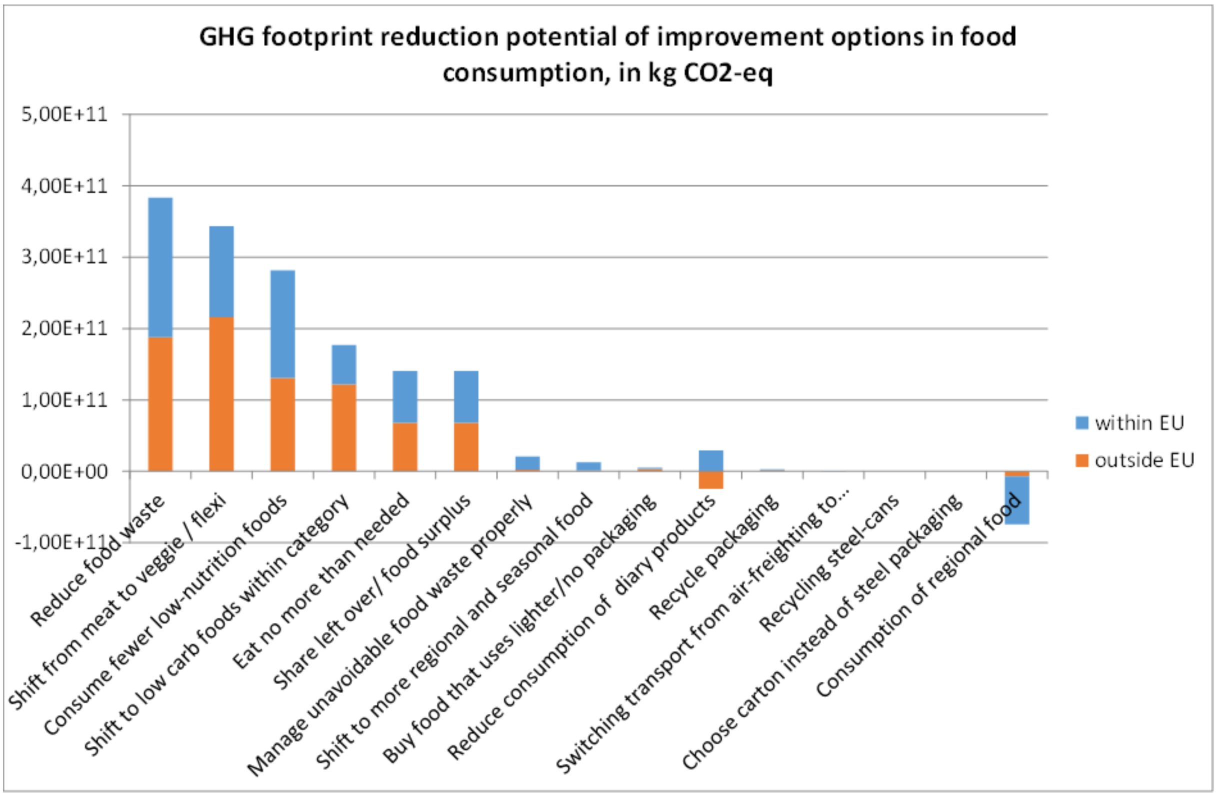

Figure 3.5 Reduction potential of a number of food related improvement options

Their combined reduction potential is estimated at 20% of the total EU footprint. No country-specific analyses were performed for the food improvement options.

The GHG emission reduction of shifts in diet can be considerable as well, especially those options that reduce overall consumption. However, these options are suspected to have high rebound effects, higher than those in transport or the built environment. Animal products are expensive and when the money saved on those products is spent elsewhere, the net effectiveness is lower. A brief exploration leads to the conclusion that the rebound effect might reduce the overall effectiveness by an order of magnitude.

Other options, such as regional and seasonal food consumption or addressing food packaging, are less effective according to our assumptions.

For food, there is a significant share of emission reductions outside EU: nearly 50% of the EU footprint reduction actually occurs outside the EU.

Potential of consumption based GHG reduction options
The total technical GHG reduction potential of all options combined is considerable: it is estimated at 48%, overlaps and synergies being accounted for. This leads to the conclusion that a consumption based approach, additional to a production oriented approach, certainly has potential.

An important part of the improvements is due to a reduced consumption of energy, by consumers but also up-chain by producers. One of the main remaining questions is, how these improvements will hold up when a shift towards a renewable energy system will happen. Certainly, the reduction in energy use will still be visible, only the GHG emission reduction will in most cases be a lot less.

Most effective options can be found in the food, building and transport consumption categories. These are analysed in more detail. The main improvements for buildings are expected to occur within EU territory, and even within the same country. The energy systems as well as the construction systems appear to be locally oriented. For transport and food, this is different. The non-EU part of the footprint is considerably larger, therefore, improvement options also have consequences for the non-EU part of the EU footprint.

Other important issues, included in this analysis only to a limited extent, are side-effects and rebound effects. The project has not investigated whether these improvement options have co-benefits for other environmental impact categories, or whether they may lead to increased environmental impacts, for example for land use, eutrophication, or toxicity. Rebound effects have been looked at in a very superficial way, but there are indications that especially the food related improvement options will lead to significant rebound effects, taking away much of the reduction potential.

3.5.2 Options and barriers for diffusion

This sub-paragraph presents barriers and obstacles for diffusion and for realising the full upscaling potential of consumption-based carbon mitigation options. There is also a first attempt to estimate potential pick-up rates of these mitigation options, given adequate policy measures.

The assessment is based on expert surveys, supplemented by a review of the literature. Underpinning the analysis is a formalised framework for behavioural, social, institutional and economic barriers that helped frame the analysis and especially aligning carbon mitigation options and the adequate policies. The work relies heavily on previous work within the Carbon-CAP project that provided the selection and description of policy measures analysed (Crawford-Brown, Skelton et al., 2014), a rating of the expected implementability and effectiveness of these policies (Grubb, Hawkins et al., 2015) as well as the selection and description of mitigation options (Schanes, Giljum et al., 2015) and the assessment of the technical mitigation potential of these options (Rodrigues, Prado et al., 2015).

There follows a summary of findings for the three key sectors analysed.

Buildings

The literature regarding consumers' options to reduce especially embodied carbon, one key focus of the Carbon-CAP project, in the building sector is not extensive and even less so when it comes to estimations of pick-up rates of such options. The project was more successful in identifying the improvement option-specific barriers to widespread uptake.
It is fair to conclude that most of the existing literature about mitigation options is about options directed towards engineers or architects and much less towards consumers, such as home-owners. In most cases, the collected data on the uptake of mitigation options does not allow for any inference to which degree consumers, as opposed to intermediaries or producers are responsible for the reduction. This stands to reason, since the different policy audiences are highly interrelated. In the building sector, the opportunity for actual emissions mitigation usually occurs at the level of production and construction, while it is on the consumer to trigger the pick-up of such options, e.g. by demanding carbon-friendly building materials and construction methods. Most barriers to higher pick-up rates mentioned in literature affect the supply side as well as the demand side. A wide variety of barriers impedes the uptake of improvement options, especially including internal factors, such as preferences, habits or awareness as well as the institutional, economic and technological context.

To complement the literature analysis, an expert elicitation exercise was conducted based on an online questionnaire (Grubb, Hawkins et al, 2015), in order to gather specific information on improvements in pick-up of selected improvement options as a reaction to selected consumption-oriented policy measures. Guided by the technical potential estimates from Rodrigues, Prado et al. (2015) and ex-ante assumptions on some improvement options, we focus on the uptake of (1) zero-emission or passive houses, (2) refurbishment and renovation of buildings, (3) thermal insulation of houses, (4) increased use of low-carbon and renewable building materials as well as (5) efficient use of (conventional) cement and concrete. For each of these improvement options tailored policy packages were constructed including a wide array of consumption-oriented policies, differentiating between the effect of voluntary versus mandatory measures as well as the combined effect of voluntary and mandatory measures. The project concludes that the potential increase of uptake relative to existing levels triggered by adequate policies is especially high for the so far underutilised options, namely including the efficient use of (conventional) building materials as well as passive and zero-emission houses. Still, future pick-up depends to a large extent on current pick-up, leading to especially high absolute future uptake rates for options such as refurbishment and renovation. In general, and unsurprisingly given the long-time horizon of this analysis, uncertainty about future uptake improvements through additional policies is huge.

Transport

Pick-up rates and levels of acceptability by stakeholders for each of seven intervention options were assessed using both a literature review and stakeholder surveys. The literature review focused on past instances of temporal changes in consumer behaviour within the seven intervention options considered, and under five different categories of policy instruments: Technology requirement; Information provision; Financial; Infrastructure provision; Regulatory and administrative. The surveys solicited expert judgements of pick-up rates under these same categories of policy instruments in 2030 and 2050, drawing on a wide range of stakeholders involved in provision or purchase of transport options at the point of interaction between the market and the consumer.

Combining the results of the literature review and surveys, results for the intervention options are summarised as:

1. Purchase choices by consumers to shift from gasoline/diesel to electric and hydrogen cars. This is the percentage of consumers who make this purchase choice. The baseline rate is effectively zero given the low penetration currently for electric and hydrogen vehicles in the EU market. It is less than 1% for most EU nations, with exceptions of Sweden (approximately 3%). The median pick-up rates increase from 10% to 30% between 2020 and 2050 for economic (financial) instruments; 5% to 20% between 2020 and 2050 for the portfolio of voluntary, non-economic instruments; and 10% to 40% between 2020 and 2050 for the portfolio of mandatory, non-economic instruments.

2. Mode shift by consumers to public transport, especially low carbon public transport. This is the percentage of consumers who choose public transport (taken here to be rail, bus or tram) rather than personal vehicles. The baseline rate for the EU is 20%, with values of between 15% and 30% depending on the city considered. %). The median pick-up rates increase from 5% to 20% between 2020 and 2050 for economic (financial) instruments; 5% to 15% between 2020 and 2050 for the portfolio of voluntary, non-economic instruments; and 5% to 25% between 2020 and 2050 for the portfolio of mandatory, non-economic instruments.

3. Purchase choices by consumers towards reduced car weight. This is the percentage of consumers who specifically choose lower weight vehicles at the time of purchase. The data currently available examine low carbon vehicles generally, rather than low weight vehicles specifically. The baseline rate is effectively zero as the policy instrument effect is measured against the current fleet composition in the EU. %). The median pick-up rates increase from 10% to 30% between 2020 and 2050 for economic (financial) instruments; 10% to 40% between 2020 and 2050 for the portfolio of voluntary, non-economic instruments; and 20% to 80% between 2020 and 2050 for the portfolio of mandatory, non-economic instruments.

4. Supply chain decisions by intermediate consumers to produce cars from secondary materials. This is the percentage of manufactured vehicles who make significant use of secondary materials in creating vehicles for sale. It is NOT the percentage of consumers who purchase vehicles with significant secondary material use – this value is unknown because consumers do not generally have this information available at time of purchase. Low weight vehicles are defined here as vehicles whose gross road weight is at least 25% lower than that of competing models in the market, with this reduced weight resulting in an assumed equivalent 25% increase in fuel efficiency. The baseline rate is effectively zero as the policy instrument effect is measured against the current fleet composition in the EU. The median pick-up rates increase from 10% to 30% between 2020 and 2050 for economic (financial) instruments; 10% to 40% between 2020 and 2050 for the portfolio of voluntary, non-economic instruments; and 20% to 80% between 2020 and 2050 for the portfolio of mandatory, non-economic instruments.

5. Purchase choices by consumers to reduce the number of cars per household. This is the percentage of households who choose to reduce the number of vehicles in the home, from the current average cars per inhabitant. The current distribution per household is approximately 25% with 0 cars; 7% with 3 or more cars; 23% with 2 cars; and 45% with 1 car. Note that only 30% (7% + 23%) can reduce without giving up a personal vehicle

completely, but this figure could increase to 75% if households with a single vehicle were to give up that vehicle and rely on other modes of transport. The baseline rate is assumed to be zero since data are unavailable on the percentage of households who have already voluntarily elected to reduce number of vehicles, and that current vehicle-related emissions already reflect the distribution of vehicles per household. The median pick-up rates increase from 5% to 20% between 2020 and 2050 for economic (financial) instruments; 5% to 10% between 2020 and 2050 for the portfolio of voluntary, non-economic instruments; and 5% to 15% between 2020 and 2050 for the portfolio of mandatory, non-economic instruments.

6. Design and process decisions by intermediate consumers, and purchase/operation decisions by consumers, to extend car life span. This is the percentage of manufactured vehicles which make significant improvements in lifespan relative to the current fleet average for the EU. It is NOT the percentage of consumers who purchase vehicles with significantly longer lifetime – this value is unknown because consumers do not generally have this information available at time of purchase. Long lifetime vehicles are defined here as vehicles whose lifetime is at least 25% longer than that of competing models in the market, and hence reduce the replacement rate of these new vehicles by 25%. The baseline rate is effectively zero as the policy instrument effect is measured against the current fleet composition in the EU. The median pick-up rates increase from 10% to 20% between 2020 and 2050 for economic (financial) instruments; 5% to 50% between 2020 and 2050 for the portfolio of voluntary, non-economic instruments; and 10% to 70% between 2020 and 2050 for the portfolio of mandatory, non-economic instruments.

7. Decisions by consumers to reduce air transport and other long-distance travel. This is the percentage of consumers who elect to avoid one or more instance of air or other long distance travel per year. The assumption is that each such consumer (electing this reduction) reduces such travel by 1 long distance trip per year. The baseline value for the EU is approximately 3 trips per person per year1, so the consumer decision would reduce instances of travel by 33%. The median pick-up rates increase from 5% to 20% between 2020 and 2050 for economic (financial) instruments; 0% to 15% between 2020 and 2050 for the portfolio of voluntary, non-economic instruments; and 0% to 20% between 2020 and 2050 for the portfolio of mandatory, non-economic instruments.

Food

Several improvement options that could be applied by consumers in order to mitigate climate change have been suggested in Task 6.1 of the Carbon-CAP project (Schanes et al. 2015). The reduction potential of some of the identified mitigation options within the food sector is potentially very high (Rodrigues, Prado et al. 2015). In the food sector the most promising options are reducing food waste, reducing meat, lowering dairy consumption and reducing the intake of foods with low nutritional value. As a first step a literature review was conducted on the barriers to the two most promising options. Reducing meat consumption and food waste are the options that have been vividly discussed in literature. Other improvement options like reducing the demand intake of foods with low nutritional value involve on the one hand too many different product groups and the barriers for different products are therefore difficult to assess, and on the other hand they are usually not debated sufficiently in the literature. Therefore only the latter two options were included in the survey. In the review the focus was therefore exclusively on meat consumption and food waste and an assessment of the factors that shape food consumption and disposal behaviour. The conclusions outline the factors that might hinder reducing meat consumption and food waste on the consumer level. Scientific research of the last decades has clearly demonstrated that food consumption patterns are not determined by a single factor, but rather various internal and external factors are important determinants of special importance. Eating patterns are to a large degree habitual and difficult to change. Literature also shows that diets are not only part of an individual lifestyle but are also shaped by unconscious external cultural and social factors.

In addition, a survey (Grubb, Hawkins et al, 2015) was conducted on the response of two broad groups to the voluntary and mandatory clusters of policy instruments considered in this report: (i) representatives of the policy, academic and NGO community, who frame and analyse policy instruments and (ii) representatives of the food services industry, especially markets, who sit at the interface between the food industry and consumers.

Four specific intervention options were considered:

- Reduction of food waste
- Reduction of meat consumption
- Reduction of dairy consumption
- Reduction of consumption of foods with low nutrient value

Qualitative findings of the survey are as below:

- Answers on acceptability showed significant variance across respondents. This large variance was due primarily to large variance between the non-industry respondents, and a difference between industry and non-industry respondents.
- The greater uniformity of response across industry representatives is a result of both shared experiences in affecting consumer choice and behaviour, and the use of a single-round Delphi method for that group. These respondents have daily experience dealing with consumers (unlike most of the respondents in the first group), and report similar experiences across members of the industry. They also have a strong network for sharing those experiences through their sustainability and CSR offices, which would tend to cause convergence of judgments.
- Voluntary measures tended to have higher levels of acceptance than mandatory measures. This was true for both industry and non-industry respondents. However, the pick-up rates were judged to be higher for mandatory than voluntary measures.
- Levels of acceptance by the food companies and consumer groups increased from 2030 to 2050, as might be expected given that both industry and consumers would have greater time to adjust behaviours by 2050.
- However, it was also clear that many of the respondents continued to provide Low to Medium judgments of acceptance even out to 2050. This had two causes: (1) a belief by some respondents that food is a matter of consumer choice and that policy interventions are not justified (their judgments therefore reflected a general attitude towards the appropriateness of government intervention in food decisions by either the consumer or food service industry) and (2) past experience with attempts to influence the behaviours of consumers, which they perceived to have produced marginal success and created some conflict with tier consumer base. The second answer was more prevalent than the first and indicates a belief that consumer behaviour is very difficult to shift, meaning the food services industry might be required to spend resources on implementing the policy instruments to little effect.

- Measures of Acceptability by the industry representatives generally ranged from Low to Medium, with few respondents stating High levels of acceptance even out to 2050. Informal discussions with that group of respondents indicates that this reflects their experience that retailers are significantly affected by consumer opinion, and that therefore the retailers are unlikely to show high levels of acceptance until consumers have sent a clear and reliable signal that they also accept the policy instruments and their implications for food choice.

3.6 Modelling results

3.6.1 Introduction

The modelling of the Carbon-CAP project assesses the effects of consumption-based emission reductions options on emissions and the economy. It focuses on the three main areas for improvement options: food, the built environment and transport. It uses a suite of three different models, each one based on different assumptions, to test the robustness of outcomes in relation to different modelling approaches.

The models used are:

- E3ME is the global macro-econometric (Energy-Environment-Economy) E3 model of Cambridge Econometrics (CE). The model covers 59 regions (including all European countries), up to 69 economic sectors and 14 air pollutants including all GHGs. One of the strengths of this model is the underlying econometric specification, which provides a strong empirical basis for the analysis .

- EXIOMOD is a Computational General Equilibrium (CGE) model that was recently developed by TNO. It is based on detailed EXIOBASE multi-regional environmentally extended input output tables (MREEIO), covering 43 countries, 5 rest of the world regions, 129 economic sectors and 40 GHG and non-GHG emissions.

- FIDELIO is a model from the European Commission's Joint Research Centre's Institute for Prospective Technological Studies (IPTS). FIDELIO is a dynamic econometric input-output model based on Eurostat's supply and use tables and the WIOD database covering 27 EU countries, 7 large countries outside Europe, 59 products/ economic sectors, 3 types of GHG emissions and 5 types of non-GHG emissions.

The reference scenario used by all three models presents the results from the 'current policy scenario' as described in the International Energy Agency's 2014 World Energy Outlook (IEA WEO, 2014). Assumed trends in the reference scenario include population and productivity growth, trajectories for oil prices, energy efficiency, and global energy prices up to 2050. Technology shares for electricity production (fossil fuel/nuclear/renewables) are also taken from the current policy scenario for EXIOMOD and FIDELIO where there is no endogenous power sector model (but not for the E3ME, which includes an endogenous power sector component). The effects of policies on the economic and environmental indicators are reported relative to the reference scenario results.

In addition to the reference scenario and improvement options scenarios, two additional sets of scenarios were included in the modelling exercise. The first additional scenario is the Nationally Determined Contributions Scenario (NDC), which is based on the pledges that were put forward at the Paris Conference of the Parties in 2015 and NDC plus improvement options. The second scenario is a Material Charge Scenario that considers a specific taxation instrument in Europe. Both the additional scenarios were modelled using E3ME only.

The main reference case for the analysis presented in this section is the Current Policies Scenario in the 2014 edition of World Energy Outlook (IEA, 2014). The baseline projections in each of the three models - E3ME, EXIOMOD and FIDELIO - are set to be consistent with the IEA figures to the maximum extent possible. The reference case shows a decrease in emissions intensity of trade from 2020-2050 in Europe while the gap between production- and consumption-based emissions increases (i.e. trade-related emissions increase).

If not otherwise mentioned, the modelling results in this section are presented as percentage difference from the reference scenario by 2050. Where a range is given, these figures reflect the differing results from the three models (EXIOMOD, FIDELIO and E3ME).

In the modelling, the results were estimated for a case where the maximum emissions reduction potential is realized, and for a case with more moderate pickup-rates (i.e. where the full potential is not realised due to consumers' modest response to the policies).

3.6.2 Improvement option scenarios

The improvement scenarios focus on three different areas: food, transport and buildings. In each area, a mixture of policies is introduced and modelled on top of the reference scenario.

3.6.2.1 Food

Two food-related improvement options – a reduction in food waste, and a switch to less emission-intensive diets – were selected for modelling. The two options are also modelled together as a combined food scenario. A selection of various voluntary and mandatory policy instruments can be used for shifting consumer behaviour towards these low carbon options, for example including supply chain procurement requirements and product labelling and educational campaigns.

The environmental impacts of the food-related improvement scenarios are small in scale. The maximum potential for production-based CO_2 emissions reduction from the food-related improvement options is very small, ranging from 0.3% (E3ME) to 1.2% (FIDELIO) in the EU for the combined scenario. The results for scenario with less food waste are the lowest, with one model suggesting that CO_2 emissions may increase (relative to the reference scenario) due to rebound effects – i.e. when spending on food declines, spending could increase in other, more carbon-intensive consumption categories.

The impacts of the food-related measures on sectoral employment and output are more considerable, with the results for the food waste scenario showing a loss in output of 11-12% and a 9% decline in employment in the agriculture and food processing sector by 2050, relative to the reference scenario. However, these negative impacts are compensated at the EU level by increases in other sectors' outputs, and the overall impact on the EU GDP is potentially positive (range from -0.1% to +1.3%), with and a slight increase in employment also expected.
It is worth noting that the modelling here focused on CO_2 emissions only. If the analysis was extended to include methane emissions, the results may look very different. EXIOMOD estimates a 14% reduction in methane emissions. Furthermore, the positive impacts of reduced food consumption (and consumption of dairy and meat) on land use and ecosystem services could be more significant. As a result, more land could be freed up for bioenergy production, which could substitute for fossil fuels and bring about further emission reductions.

3.6.2.2 Buildings

Two buildings-related improvement options – a shift to near-zero emissions buildings (NZEBs) and an increased installation of natural fibre insulation for the existing housing stock (NFI) – were selected for modelling. Both options were also modelled together as a combined buildings scenario. In these scenarios, a selection of voluntary and mandatory policy instruments could be used for shifting consumer behaviour towards these low carbon options. The policies include standards, approved technology lists, financial incentives, product labelling and educational campaigns.

The environmental impact of the combined building scenario is considerable, with an estimated potential reduction in household CO_2 emissions of between 8.5% and 20.1% by 2050, relative to the reference scenario. This impact stays high even when pick-up rate estimates are included in the modelling, largely due to the obligatory nature of some of the policy measures, such as the mandatory shift to NZEBs by 2020. In the maximum impact scenario, EU-level production-based CO_2 emissions are estimated to be reduced by 5-7%, relative to the reference scenario, while consumption-based emissions fall by 4-7%.

The economic impacts are expected to be positive but small. The output of affected industries, such as construction and wood and wood products are estimated to increase slightly due to increased demand for insulation and more expensive building works (e.g. NZEBs with timber frames). The estimated overall impact on GDP in the EU ranges from -0.2% to 0.9%, depending on the model.

3.6.2.3 Transport

Transport has the largest number of sub-scenarios modelled, covering eight different transport-related improvement options. All the individual policy measures are also modelled together as a combined transport scenario. In these scenarios, a selection of voluntary and mandatory policy instruments could be used to incentivise a shift in consumer behaviour towards low carbon options; the policy measures include strengthening existing standards, introduction of new standards, infrastructure improvements, subsidies and educational campaigns.

The estimated impacts of the eight different transport scenarios on CO_2 emissions by 2050 (full potential, relative to the reference scenario) vary considerably, depending on the improvement option and the model used. The maximum CO_2 reduction potential for the combined scenario (including measures to reduce air transport), is estimated to result a reduction in production-based CO_2 emissions in the EU of between 7.2% (FIDELIO) and 20.3% (E3ME), with emissions from the household sector estimated to decline by as much as 46.2% (FIDELIO). Consumption-based emissions were estimated to be reduced less, by 4-14%, in the combined scenario.

Of the sub-scenarios, a shift to electric and hybrid cars has the greatest maximum emissions reduction potential, leading to a CO_2 reduction in the EU of between 5% (FIDELIO) and 14% (EXIOMOD) by 2050, relative to the reference scenario. A switch to public transport was also estimated to have reasonably high maximum emissions reduction potential of up to 7% (for the EU, by 2050).

In economic terms, full implementation of the combined transport scenario by 2050 is likely to have only small impacts on economic output, with EU GDP estimated to decline by less than 1% (all models), relative to the reference scenario.

3.6.3 Combined scenarios

3.6.3.1 Environmental impacts

Consumption-based policies can impact both production- and consumption-based emissions. The maximum emissions reduction potential of production-based emissions in the EU is estimated to be between 16% and 26% by 2050, for a combined scenario including policy measures that impact food, buildings and transportation. If we assume that there are more moderate behavioural responses to the individual policies, the maximum impact on production-based CO_2 emissions in the EU is between 7.5% and 14% by 2050, relative to the reference scenario. The impacts on production-based CO_2 emissions outside the EU are very small, indicating no substantial carbon leakage.

The maximum potential reduction in consumption-based CO_2 emissions (i.e. the EU's carbon footprint) is estimated to be lower than the reduction in production-based emissions, ranging from 12% to 17% for a combined scenario including policy measures affecting food, buildings and transportation (by 2050). Assuming the more realistic behavioural response, the estimated CO_2 emissions reduction is 4-10% by 2050. As was the case for production-based emissions, the greatest contributions to reducing consumption-based CO_2 emissions come from buildings (4% to 7%) and transport (4% to 12%). However, it is worth noting that the results for the three scenarios (food, buildings and transport) produced by the three models vary noticeably, indicating uncertainty related to model use.

3.6.3.2 Economics impacts

The economic impacts of the combined scenario (food, buildings and transport) on the GDP in the EU are small, ranging from -0.78% to 0.06% in 2050, depending on the model. The GDP impact for the regions outside the EU ranges from -0.27% (EXIOMOD) to +1.08% (FIDELIO). In FIDELIO and E3ME, the positive economic impact on the regions outside the EU come from increased economic activities brought about by the improvement options in consideration.

The impacts on sectoral output in the EU are influenced by the nature of the consumption-based improvement options. The results show a significant increase in the output of transport services (up to 60% for the full implementation of the improvement options and up to 19% while considering the more modes policy uptake), because of increased use of public transport. More modest, but positive impacts are predicted in the wood and wood products sector, because of increased use of timber frames in the construction of private homes. Some other sectors see declines in output (compared to the reference scenario), including manufacturing of motor vehicles and, to a lesser extent, agriculture, food and food products, and manufactured fuels and chemicals. Again, however, the results vary considerably between the three models.

The overall employment impacts in the EU by 2050 are very small but positive, largely due to growth in the transport services sector. Positive effects in this sector outweigh the negative employment impacts in other sectors.

3.6.3.3 The NDC+ Scenario

The NDC scenario adopts countries' climate change mitigation pledges as they have been submitted to the UNFCCC (2016) and puts these on top of the IEA WEO current policies scenario (IEA, 2014). The scenario assumes that countries will meet their emissions reduction targets by 2030.

In our modelling, the NDC + improvement options scenario assumes that the consumption-based policy measures are added to the combined IEA WEO Current Policies and the NDCs scenario, and are fully implemented (i.e. the pick-up rates are expected to be in line with the scenario specifications and assumptions for maximum potential impact). The results, from E3ME only, show an additional reduction of around 13% in total CO_2 emissions in the EU by 2030, and a slight additional reduction (of around 1%) in global CO_2 emissions. The economic impacts to be felt in the EU in 2050 are likely to be small but positive.

3.6.3.4 The material charge scenario

The Material Charge Scenario provides a market-based approach to reducing emissions in the industrial sector by focusing on consumption of energy-intensive materials.

The results from the materials charge scenario, modelled using E3ME only, show a considerable reduction in the demand for basic metals (up to 14%) and non-metallic mineral products (3-4%), due to lower material consumption. The potential impacts on emissions (assuming a fixed ETS price) is around 6%, increasing up to 10% when the reductions in process emissions are included. The reductions in process emissions could be particularly important as there are limited technological options for cutting these in any other way. Very small negative impacts on GDP can be avoided by recycling the revenues from the materials charges.

3.6.4 Conclusions Modelling results

The concept of consumption-based emissions is now well established as an important part of understanding the responsibility for emissions in a world with high volumes of international trade. Numerous studies have used input-output techniques to show primarily that the developed world accounts for a larger share of global emissions if embodied carbon is taken into account.

While previous analysis has focused on allocating emissions on an historical basis, here the focus turns to how future emissions levels could be changed by policy (or other economic factors). There is thus a distinction made between *average* levels of consumption-based emissions and *marginal* changes in consumption-based emissions.

The approach required to look at the two types of measure is different. To look at marginal changes in consumption-based emissions, the basic input-output framework must be replaced with a macroeconomic modelling approach. Although the models typically include input-output relationships in their basic structure, they also relax a string of assumptions that are standard in input-output analysis. Notably, final demands, prices, input-output coefficients and bilateral trade relationships are all allowed to vary, whereas in a standard input-output model they are fixed as exogenous.

The results from two macroeconomic models, E3ME and Fidelio, show how important these assumptions can be and large differences were found. The sectoral results from the E3ME model highlighted two key issues: the importance of accounting for variable energy prices and the potential role for energy-efficient equipment, that would be of interest to policy makers.

It is possible to use consumption-based emissions from macroeconomic models as an indicator to assess future policies as well as allocating historical responsibility. As demonstrated by the results in this report, this additional step could add substantial value added to a comprehensive policy assessment.

The IEA WEO 2014 current policies scenario is used as the main reference scenario for this report. Looking at the historical development of the EU trade related emissions from 1960-2015 and thereafter E3ME projections up to 2050 it is possible to see that if no new polices will be implemented, then the current declining net emission transfers will be reversed and the gap between production- and consumption-based emissions will start increasing again.

The improvement options in all three sectors that where selected for this study (food, buildings and transport) combined have a maximum potential to deliver household emission reductions at EU level of 47-67%, and total production-based emission reductions of 16-26% relative to the reference scenario in 2050. The impacts on production-based CO_2 emissions outside the EU are small and mostly negative. However, when behavioural responses to individual policies, that could realise the improvement options, are considered, then there is a maximum 14% reduction (7.5-14%) in total CO_2

production-based emissions reductions in the EU by 2050. These more modest reductions could be considered more realistic as many of the actions and policy measures considered in D5.2 were voluntary. In addition, majority of these measures were conventional and were mostly addressing domestic user emissions. Overall these emissions reductions are considerable and it is worth giving some thought on innovative policy measures that could help to change behaviour and achieve the maximum potential of the improvement options and address trade related emissions. With the current fast technology developments new measures emerge, such as for example the on platform FoodCloud that helps to reduce food waste and tackle malnutrition at the same time.

The most potential for reducing EU territorial CO_2 emissions comes from the transport and buildings scenarios. Some EU countries, such as France, already considering addressing consumption based emissions in their low carbon policy planning [add reference].

The food options have less potential when CO_2 only are considered. For example, for the food waste scenario there is less money spent on food in this scenario and therefore spending on other consumption categories is increased proportionally. These other sectors are generally more carbon intensive than food (and include for example travel and leisure). Therefore, because of the rebound effect a small increase in the EU households' emissions is possible. All models show a slight decrease in consumption-based EU CO_2 emissions under the combined food scenario (-0.2 to -3.6%). The range of impacts on consumption-based emissions is slightly wider range than the reductions in the territorial emissions (-0.3 to -1.2%). This result emphasises larger modelling uncertainty related to consumption-based emissions.

The food-related consumption-based CO_2 emissions reductions (max 1.2%) in the EU are much smaller than the maximum of percentage reduction estimated in D6.2 using a static MRIO analysis (4.2% reduction in GHG emissions for the food waste option only) and this is emphasising again a need to look at the entire economic system while analysing potential policy impacts (using, for example, macromodels). Doing this would help to consider alternative policy measures that can help to reduce the potential rebound effects.

When we consider the 14% reduction in methane emissions then the reduction potential from food options then the overall reduction in GHG emissions is about 4%. Given the effort that should go into implementing and enforcing the policy measures to reduce food-related GHG emissions, these emission reduction options are not most promising. However, this analysis does not take into account impacts on land use and ecosystem services that might outweigh the GHG impacts that are shown here (for example, if food production falls then there is more land available for growing biofuels).

In the reference scenario, the models show a widening gap between the EU's consumption-based and production-based emissions. A similar trend is likely if the consumption-based policies considered in this report are implemented to their full potential. All models show reductions in consumption-based emissions (12-17%) attributable to the improvement options considered. When the policy-related pick-up rats are taken into account, the emissions reductions are 4-10%. These reductions are mainly achieved domestically in the EU and are not much related to emissions embedded in trade. The gap between consumption based emissions decreases by 3-4% (FIDELIO and EXIOMOD) in 2050 when the maximum potential of the improvement option is realised. E3ME shows 21% widening of the gap that mainly comes from higher reductions in production based emissions compared to the other two models.

The economic impacts of the combined scenario on the EU's GDP are small, ranging from about 0.78% loss to a very small positive impact (0.06%) in 2050, depending on the model. The GDP impact outside the EU ranges from a small loss of 0.27% (EXIOMOD) to a positive (1.08%) impact in FIDELIO. When the moderate policy pick-up rates are considered the direction of change stays the same for all three models. And similar to the case above, the impacts on GDP outside EU are likely to be small (-0.2 to +0.3%) and the Chinese economy could experience a small increase in both cases (with FIDELIO showing 1% increase if the full emissions reduction is achieved). This could be explained by comparative advantage of the Chinese products compared to increasing prices in the EU as well as by increased demand for Chinese components used in low carbon technologies in the EU.

The impacts on individual sectors vary considerably depending of the nature of the intervention option. For example, moving to near zero carbon housing with timber frames and increased insulation in the existing housing stock is likely increase the output of the construction and wood sectors.

The overall impact on employment in the EU in 2050 is very small and positive. One of the models, EXIOMOD, does not allow for changes in the EU total employment as it does not incorporate involuntary unemployment. Sectoral employment impacts vary depending on the improvement option and span from a 20% decrease in the vehicle manufacturing sector to a 61% increase in the provision of transport services. When pick-up rates from policy measures are taken into account the employment impacts are smaller, but the EU level employment benefits are becoming higher.

In the NDC scenario we assume that the consumption-based emission reduction options are added to the IEA WEO 2014 Current Policies plus NDCs scenario and are fully implemented. In 2030 this could result in 13% CO_2 of additional emissions reductions in the EU. Looking at NDCs + consumption-based improvement options impacts on consumption based emissions in the EU, a 10% additional decrease by 2030 might be possible. Implementing NDCs has the potential of not only curbing domestic emissions, but it also ensuring continuous decrease of net emission transfers between the EU28 and the rest of the world. While looking at the impact of NDCs in terms of unit of GDP in the EU28 then implementing NDCs can have a significant impact in terms of reducing CO_2 per unit of GDP, especially outside the EU. The gap between consumption and territorial emissions however will widen.

The above measures are not implemented via price mechanism. The only economic policy measure that looked promising in WP5 was a material charge on carbon intensive materials. The tax rate considered in the modelling exercise with E3ME was set to be equivalent to carbon charges of €20/tCO_2 in 2020, gradually rising to €80/tCO_2 in 2050. Summing the effects on energy and process emissions, the total reduction in CO2 emissions in the EU (excluding land use) from this measure could be as much as 10% by 2050. In other words, if this policy measure is used then it could incentivise the achievement of up to half of the maximum potential of the consumption based emission reduction considered measures in this study.

4 Main findings and recommendations

The results indicate that policy instruments which change the characteristics of products available to consumers (such as minimum standards or requirements) should have priority, while policies that affect consumer choices between products on the market could be applied at a second stage, and as a way to support the priority measures. The total greenhouse gas (GHG) reduction potential of all options combined is considerable: reducing around half of EU footprint emissions. The options with the highest potential appear to be in the food, building and transport consumption categories, so new policies may need to be put in place to tackle these emissions.

4.1 Main findings and policy recommendations

Carbon emissions are currently managed by the country where they occur, but international trade means that consumption in one country can lead to production emissions in another. For example, 2Gt of China's 7Gt emissions in 2007 relate to its net exports. This is not to say the importing countries would have incurred the 2Gt if they had made the product at home, as the carbon intensity of the Chinese economy is different from that of importing countries. The EU Commission-funded Carbon-CAP project's analysis has made these exchanges more visible.

Global drivers of change in carbon emissions

The analyses in efficiency (emissions, energy, and labour per unit output), the changes due to trade related effects (both for intermediate producers and final consumers), the changes due to technology effects (both for intermediate producers and final consumers), and the change due to affluence and population indicate that trade is an important driver for global greenhouse gas emissions growth. However, it is not as important as growth in affluence and overall industry efficiency. This is only true, however, when looking at global emissions growth. When taking into account regional shifts in greenhouse gas emissions footprints over time, the displacement of industries from developed economies in the European Union and the OECD and the increase in imports to final demand contributes to emissions growth, mainly from combustion. For non-combustion emissions, changes in trade partners seems to decrease GHG footprints. Different dynamics act on the footprint growth over time and in different regions. Greenhouse gas emissions and energy consumption are mainly driven by the increase of consumption per capita in developing economies, such as China, and in the European Union. This growth in affluence reduces (or even reverses) gains in carbon and energy efficiency. It can be seen that trade is an important driver for labour footprints change in developed economies, in a higher proportion than for energy and greenhouse gas footprints. That indicates that the displacement of industries to labour-abundant countries might not have a significant effect in the growth of emissions embodied in trade.

How can we quantify global emissions related to consumption of goods and services and understanding drivers for upward trends?

A key issue, raised amongst others by world trade experts, is the need for a reliable dataset that is fit for purpose to assess the potential effectiveness of specific policy instruments in driving consumer behaviour towards lower carbon goods and services.

Carbon-CAP supported that aim by establishing a methodological base to allow such an assessment. A consumption-based carbon accounting (CBCA) system, while not currently accepted politically, is crucial for providing baseline levels and targets for emissions associated with consumption. Governments will need to be flexible, adopting a CBCA system that is consistent over a temporal timescale, and complementary to the current territorial carbon emissions accounting system already in place.

Consumption based carbon accounting (CBCA)
A consumption oriented approach requires a functional, cradle-to-grave or “footprint” approach, usually including processes in different geographical areas. Requirements to a consumption based information base:

- GHG emissions should be linked to consumption activities and consumption categories
- GHG emissions should be specified on a cradle-to-grave basis
- The information base should provide information at a relevant spatial and time scale
- The quality of the information should be sufficiently reliable
- The information base should allow for analysing the past as well as forecasting the future, or rather, imagining the future under different assumptions.

A recent investment in global multi-regional input/output (MRIO) modelling has led to the development of a number of databases suitable for calculating consumption based carbon accounts (CBCA) for recent history.

Since the advent of environmental footprint approaches in general, and CBCA approaches specifically, many policy makers have been looking at ways to derive consumption-based policies. Whilst these efforts can be lauded, it has not been clearly established in the literature that consumption-based policies are more effective or more cost-effective than traditional policies based on control of territorial emissions. Further complicating the policy arena is that many policies could be considered both traditional and consumption-based (insulation of houses, for example).
Alternatively, CBCA can be seen to be policy relevant, whilst not policy prescriptive. CBCA can give a key macro-level indication about the carbon intensity of an economy relative to baselines and targets. Such reporting of emission accounts can further underline the need for multi-lateral action, and for the increased responsibility needed to be shouldered by economies with growing net-import of emissions. CBCA can further strengthen resolve around uptake of instruments around, for example, the clean development mechanism (through encouraging investment from the developed world in trade partner countries in the developing world), or for the need for additional investment in emission offsets.

By all indications, results from CBCA are going to be an academically, and politically relevant metric in the foreseeable future. Even under the unlikely scenario of globally consistent climate policy, CBCA is a useful approach to highlight the connection between development or wealth and environmental impact. It is recommended that governments establish a statistically acceptable method of arriving at CBCA that is consistent over a relevant temporal scale. By all indications, the choice of model or approach will matter less than the need for consistent reporting. By establishing a statistically and politically acceptable CBCA at the national level, it is hoped that governments begin to set non-binding, or even binding, targets on emissions reduction for the consumption side at the same level as those for current nationally determined contributions.

Demand side tools and policies

To effectively reduce emissions at the global level, consumption-based climate policy instruments will have to be part of the policy mix. Introducing instruments in a portfolio has three main advantages. First, consumer-oriented policy should not have the effect of wholly 'individualising' responsibility solely on end-users. It should spread responsibilities across many sectors, across consumers and across producers. Second, emissions are caused by many different decisions at many different levels from primary production to consumption to disposal. Consumer-oriented policies only act on part of these, and individual consumer-based instruments further focus the scope of application. Finally, experience has shown policies are often most effective when developed in mutually reinforcing ways since weaknesses in any one instrument can be counterbalanced by strengths of another instrument. This often helps in negotiations between groups implementing and affected by an instrument.

An interactive web-based tool (carboncap.eu/onlinetool) was also developed at the end of the Carbon-CAP project to enable stakeholders to navigate through the results and pursue interests in a particular sector or a policy instrument. Users can change the inputs to the tool and see the impact of these changes. This tool will remain online for a few years after the official end of the project. The total greenhouse gas (GHG) reduction potential of all available consumption side options combined is considerable: reducing around half of EU footprint emissions. The options with the highest potential appear to be in the transport, building and food consumption categories:

- reducing over-purchasing and food waste
- shifting from meat to lower-carbon food categories
- all houses built after 2020 to be near-zero emission buildings (NZEBs)
- improved thermal insulation
- increased uptake of electric and hydrogen cars
- an increasing share of population using the option of car-pooling and car sharing
- more light-weight (more fuel-efficient) passenger car
- the use of more recycled steel in the production of cars
- the shift from cars to public transport
- the shift from air transport to public transport

The Carbon-CAP results show that not one single instrument is likely to be dominant and mutually reinforcing packages of instruments will be required for significant impact. The instruments and policy packages would need to be tailored to each scenario where they are to be applied, owing to varying factors across regions, sectors and policies.

While the CBCA analysis focused on allocating emissions on a historical basis, Carbon-CAP also looked at how future emissions levels could be changed by policy (or other economic factors). To look at policy impacts on consumption-based emissions, the basic input-output framework must be replaced with a macroeconomic modelling approach.

Modelling consumption based emission reduction

The modelling of the Carbon-CAP project assesses the effects of consumption-based emission reductions options on emissions and the economy. It focuses on the three main areas for improvement options: food, the built environment and transport. It uses a suite

of three different models (E3ME, EXIOMOD and FIDELIO), each one based on different assumptions, to test the robustness of outcomes in relation to different modelling approaches.
The IEA WEO 2014 current policies scenario is used as the main reference scenario for this report. In addition to the reference scenario and improvement options scenarios (food, transport and buildings), two additional sets of scenarios were included in the modelling exercise. The first additional scenario is the Nationally Determined Contributions Scenario (NDC) and the second scenario is a Material Charge Scenario that considers a specific taxation instrument in Europe.

Improvement options in all three sectors that were selected for this study (food, buildings and transport) combined have a maximum theoretical potential to deliver household emission reductions at EU level of 4767%, and total territorial emission reductions of 16-26% relative to the reference scenario in 2050. The production-based CO_2 emissions outside the EU are also slightly reduced (up to 5%).
However, after considering behavioural responses to individual policies that could realise the improvement options, then there is a maximum 14% reduction in territorial emissions and 10% in the carbon footprint in the EU by 2050. These more modest, but still significant, reductions could be viewed as more realistic as many of the actions and policy measures considered were voluntary. If a policy of imposing charges on carbon intensive materials was adopted, then it alone could achieve of up to half of the emissions reductions.
When the consumption-based emission reduction options are added to the EU NDCs scenario and fully implemented, then in 2030 this could result in 13% CO_2 emissions on top of existing EU plans.
The majority of the consumption-based policy measures considered in Carbon-CAP were conventional and were mostly addressing domestic user emissions resulting in a very small reductions in trade-related emissions. The latter is much more difficult to tackle and could be done, for example, through trade restrictions that is not desirable for any trading partners. However the emission intensity of the trade-related (per euro traded) emissions has been decreasing since 2010 and will continue decreasing in the policy scenarios (especially if the consumption-based policies are implemented in addition to NDCs). This is true even if trade emissions will not decrease a lot.
Overall the emissions reductions above are considerable and it is clearly worth giving more thought to innovative policy measures that could help to change behaviour and achieve the maximum potential of the improvement options, and address trade-related emissions. With the current fast developments in technology, new measures emerge, such as for example the online-platform FoodCloud5 which helps to reduce food waste and tackle malnutrition at the same time.
The combined economic impact of the improvement options in all three sectors on the EU's GDP are small. Impacts range from about 0.78% loss to a very small positive impact (0.06%) in 2050, depending on the model. The GDP impact outside of the EU ranges from -0.27% to +1.08%. The impacts on individual sectors vary considerably depending of the nature of the intervention option. For example, moving to near-zero carbon housing with timber frames and increased insulation in the existing housing stock is likely to increase the output of the construction and wood sectors, but shifting to public transport will decrease the output of the vehicle manufacturing sector. Identifying the sectors that will lose has also value as it would allow the consideration of policies and measures that can mitigate these negative impacts. The overall impact on employment in the EU in 2050 is very small but positive, varying again across the sectors.

The greatest potential for reducing EU territorial CO_2 emissions comes from the transport and buildings scenarios. Some EU countries, such as France, are already considering addressing consumption-based emissions of these sectors in their low carbon policy planning. The food options have less potential (max 1.2%) when CO_2 only is considered. For example, for the food waste scenario there is less money spent on food in this scenario and therefore spending on other, often more carbon intensive, consumption categories is increased proportionally. Therefore, because of this rebound effect a small increase in EU households emissions is possible.

When we consider the 14% reduction in methane emissions then the reduction potential from food options is increased to about 4%. However, this analysis does not take into account impacts on land use and ecosystem services that might outweigh the GHG impacts that are shown here (for example, if food production falls then there is more land available for growing biofuels).

The food-related consumption-based emissions reduction in the EU are much smaller than the maximum percentage reduction estimated in a static MRIO analysis, and this emphasises a need to look at the entire economic system while analysing potential policy impacts (using, for example, macromodels). Doing this would help to consider alternative policy measures that can help to reduce the potential rebound effects.

4.2 Reflection on the gaps

The potential to complement current domestic GHG reduction efforts with policies that address consumption patterns is clear. However, developing a new, more balanced mix of policies will require overcoming various important gaps and hurdles. To overcome the gaps (see Introduction, section 1), the project answers the following specific scientific and technical objectives.

Gap 1: Quantification of global emissions related to consumption of goods and services and understanding drivers for upward trends.

As for the drivers, Carbon-CAP showed the following. The analyses in efficiency (emissions, energy, and labour per unit output), the changes due to trade related effects (both for intermediate producers and final consumers), the changes due to technology effects (both for intermediate producers and final consumers), and the change due to affluence and population indicate that trade is an important driver for global greenhouse gas emissions growth. However, it is not as important as growth in affluence and overall industry efficiency. This is only true, however, when looking at global emissions growth. When taking into account regional shifts in greenhouse gas emissions footprints over time, the displacement of industries from developed economies in the European Union and the OECD and the increase in imports to final demand contributes to emissions growth, mainly from combustion. This is caused by the fact that this displacement takes place to countries with in the period until now had a carbon intensive energy infrastructure, such as China. For non-combustion emissions, changes in trade partners seems to decrease GHG footprints.

Gap 2: Understanding of the levers, potential mechanisms, and feasibility of demand side tools and policies.

From previous research confirmed by Carbon-CAP, it is known that the areas of food, mobility and built environment dominate the life cycle impacts including carbon emissions from final consumption. Carbon-CAP identified a number of improvement options in these areas.

Two food-related improvement options – a reduction in food waste, and a switch to less emission-intensive diets – were selected for modelling. The two options are also modelled together as a combined food scenario. A selection of various voluntary and mandatory policy instruments can be used for shifting consumer behaviour towards these low carbon options, for example including supply chain procurement requirements and product labelling and educational campaigns.

Two buildings-related improvement options – a shift to near-zero emissions buildings (NZEBs) and an increased installation of natural fiber insulation for the existing housing stock (NFI) – were selected for modelling. Both options were also modelled together as a combined buildings scenario. In these scenarios, a selection of voluntary and mandatory policy instruments could be used for shifting consumer behaviour towards these low carbon options. The policies include standards, approved technology lists, financial incentives, product labelling and educational campaigns.

Transport has the largest number of sub-scenarios modelled, covering eight different transport-related improvement options. These include reducing the number of cars, enhancement of carpooling and sharing, lighter and smaller cars, and reduction of air transport. All the individual policy measures are also modelled together as a combined transport scenario. In these scenarios, a selection of voluntary and mandatory policy instruments could be used to incentivise a shift in consumer behaviour towards low carbon options; the policy measures include strengthening existing standards, introduction of new standards, infrastructure improvements, subsidies and educational campaigns.

Gap 3: Understanding of the effectiveness and impacts of demand side tools and policies.

The combination of improvement options and supportive policies were modelled with three different types of models:

1. E3ME, the global macro-econometric (Energy-Environment-Economy) E3 model of Cambridge Econometrics (CE). One of the strengths of this model is the underlying econometric specification, which provides a strong empirical basis for the analysis .
2. EXIOMOD is a Computational General Equilibrium (CGE) model that was recently developed by TNO. It is based on detailed EXIOBASE multi-regional environmentally extended input output tables (MREEIO), covering 43 countries, 5 rest of the world regions, 129 economic sectors and 40 GHG and non-GHG emissions.
3. FIDELIO is a model from the European Commission's Joint Research Centre's Institute for Prospective Technological Studies (IPTS). FIDELIO is a dynamic econometric input-output model based on Eurostat's supply and use tables and the WIOD database covering 27 EU countries, 7 large countries outside Europe, 59 products/ economic sectors, 3 types of GHG emissions and 5 types of non-GHG emissions.

The modelling results show that various consumption-based policies have considerable potential to reduce territorial CO_2 emissions in Europe, especially with regards to buildings (4-7%) and transport (4-14%). For food, direct emission reduction of e.g. limiting food waste is significant, but unfortunately the cheaper food basked then causes a rebound effect that annihilates this reduction. A limitation of the modelling is that CH_4 is not included in E3ME and FIDELIO; EXIOMOD suggests the combined food scenario results in 14% reduction in methane emissions. Overall these three areas of consumption based options and policies contribute however just in a limited to the already planned production-oriented emission reductions. The net emission transfers between the rest of the world and Europe will stay stable or may slightly reduce, but as a percentage of total (reduced) emissions will grow.

A significant proportion of embodied carbon from imports is unavoidable. This is because it arises from foreign mining operations which are not conducted in the EU, and domestic alternative materials do not exist. In relation, the consumption-based emission reduction measures used in this study have small impact on trade related emissions and therefore more attention should be paid to designing and assessing policies that address these emissions. Policies addressing rebounds are highly relevant too.

Gap 4: No shared view on the added value, implementation challenges and acceptability of demand side tools/policies and related accounts, and no "roadmap" of evolution from production towards consumption-based policies.
There are a variety of databases, tools, methods and models that can be used to assess aspects of consumption based carbon emissions. For assessing the past and the present, environmentally extended Input Output analysis (possibly hybridized with LCA) seems to be the most ideal approach. Our research showed that by far the largest uncertainty in such carbon footprint analysis comes from data already used widely in climate negotiations: sector and country level CO_2 emission data. Jus harmonizing such data across IO databases reduces uncertainty in footprint analyses with 50%. In a similar way, forward looking models such as E3ME, EXIOMOD and FIDELIO could be harmonized. This will allow for a robustness of calculating past and future consumption based carbon emissions with a level of uncertainty that is not significantly worse as current information on country- or sector level carbon emissions in the past, or carbon emissions modelled for the future.

Consumption oriented carbon reduction policies have added value and can support an additional reduction of carbon emissions compared to current scenarios. In this, implementing policies addressing rebound effects (like carbon taxes) are essential. Policies that would also address trade-related emissions directly or even indirectly however do not sit well in the UNFCCC process. If introduced formally, administrative challenges and other objections for instance if compatible with WTO rules will be the result. It seems much more fruitful that given a specific situation with regard to trade related emissions, trade partners may agree on a voluntary basis to share responsibilities for such emissions differently as analysed via a purely production based approach. Overall, it is therefore clear that consumption oriented policies should be seen as a complement to the traditional production oriented approach.

4.3 Further research

Based on the feedback received through discussion with business stakeholders at the end of the Carbon-CAP project, it is also important to note the following, which could be explored in future related research projects. There is agreement amongst businesses consulted that this is an important conversation and there is interest on the part of business in discussing how to select the most effective policies for reducing consumption based emissions. Collaboration initiatives between government, business and consumers will be necessary to identify, develop and implement the most effective policies. Guidelines and criteria that governments should consider when engaging with business on new policy approaches for reducing emissions based on consumption might also be useful. More research may still be needed to iron out remaining uncertainties in the use of consumption-based accounting systems and developing whole-economy models capable of analysing and forecasting consumption-side emissions. More research could be undertaken on the full scope of the implementation of different consumption-side policy packages. In addition, Carbon-CAP established that it is possible to use consumption-based emissions from macroeconomic models as an indicator to assess future policies as well as allocating historical responsibility. This additional step could add substantial value to comprehensive policy assessments. However, there is a lot of work to be done on improving consumption-based emissions accounting in macromodels, as policy impacts on these emissions resulted in greater uncertainty than the impacts on production-based emissions. This need for further research does not preclude the possibility of the EU starting to recognise and quantify consumption-based emissions, and trade-embodied carbon, and to step up efforts to identify and implement new consumption policies with high levels of anticipated take-up and effectiveness.

5 References

Alsamawi, A., Murray, J., Lenzen, M. (2014). The Employment Footprints of Nations: Uncovering Master-Servant Relationships. J. Ind. Ecol. 18, 59–70.

Andrew, R.M., Davis, S.J., Peters, G.P. (2013). Climate policy and dependence on traded carbon. Environ. Res. Lett. 8, 034011.

Ang, B.W., Zhang, F.Q. (2000). A survey of index decomposition analysis in energy and environmental studies. Energy 25, 1149–1176.

Arto, I., Dietzenbacher, E. (2013). Drivers of the growth in global greenhouse gas emissions. Presented at the 5th Spanish Input-Output Analysis Conference, Seville, Spain.

Bauman, K. (1998) Direct Measures of Poverty as Indicators of Economic Need: Evidence from the Survey of Income and Program Participation, U.S. Census Bureau Population Division Technical Paper No. 30.

Bauman, K. (1999) Extended Measures of Well-Being: Meeting Basic Needs, U.S. Census Bureau Current Population Reports No. P70-67.

Bernstein, J., Boushey. H. and Brocht, C. (2001) Hardships in America: The Real Story of Working Families, Economic Policy Institute.

Bocken, N. (2014) Business-led Sustainable Consumption Initiatives – Impacts and Lessons Learned, University of Cambridge, Report prepared for the First Stakeholder Workshop of Carbon-CAP, October 2014.

Brown, M. (2001). Market Failures and Barriers as a Basis for Clean Energy Policies. Energy Policy, 29, 1197-1207.

Caldeira, K., Davis, S.J. (2011). Accounting for carbon dioxide emissions: A matter of time. Proc. Natl. Acad. Sci. 108, 8533–8534.

Chenet, P., Tynan, C, and Money, A. (2000) The Service Performance Gap: Testing the Redeveloped Causal Model, European Journal of Marketing, 34, 472 – 497.

Cram, L. (2005). Policy-Making in the European Union: Conceptual Lenses and the Integration Process. New York, Routledge Press.

Davis, S.J., Caldeira, K. (2010). Consumption-based accounting of CO_2 emissions. Proceedings of the National Academy of Sciences 107, 5687-5692.

Dietzenbacher, E., Hoen, A.R., Los, B. (2000). Labor Productivity in Western Europe 1975–1985: An Intercountry, Interindustry Analysis. J. Reg. Sci. 40, 425–452.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Kadner, S., Minx, J.C., Brunner, S., Agrawala, S., Baiocchi, G., Bashmakov, I.A., Blanco, G., Broome, J., Bruckner, T., Bustamante, M., Clarke, L., Conte Grand, M., Creutzig, F., Cruz-Núñez, X., Dhakal, S., Dubash, N.K., Eickemeier, P., Farahani, E., Fischedick, M., Fleurbaey, M., Fulton, L., Gerlagh, R., Gómez-Echeverri, L., Gupta, S., Harnisch, J., Jiang, K., Jotzo, F., Kartha, S., Klasen, S., Kolstad, C., Krey, V., Kunreuther, H., Lucon, O., Masera, O., Mulugetta, Y., Norgaard, R.B., Patt, A., Ravindranath, N.H., Riahi, K., Roy, J., Sagar, A.D., Schaeffer, R., Schlömer, S., Seto, K.C.-Y., Seyboth, K., Sims, R., Smith, P., Somanathan, E., Stavins, R., von Stechow, C., Sterner, T., Sugiyama, T., Suh, S., Ürge-Vorsatz, D., Urama, K., Venables, A., Victor, D.G., Weber, E., Zhou, D., Zou, J., Zwickel, T. (2014). Technical Summary, in: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Feenstra, R.C., Hanson, G.H. (1996). Globalization, Outsourcing, and Wage Inequality. Am. Econ. Rev. 86, 240–245.

Feng, K., Davis, S.J., Sun, L., Hubacek, K. (2015). Drivers of the US CO_2 emissions 1997-2013. Nat. Commun. 6, 7714.

Grossman, G.M., Rossi-Hansberg, E. (2008). Trading Tasks: A Simple Theory of Offshoring. Am. Econ. Rev. 98, 1978–1997.

Grubb, M., Hawkins, S., Jegou, I., Guei, F., Petrick. S., Vilaneuva, A., Lindner, S., Crawford-Brown D. and Emmert S. (2015). Policy Instruments: Evaluation and shortlisting. Carbon-CAP project Deliverable 5.2.

Grubb, M., Hourcade, J-C. and Neuhoff, K. (2014). Planetary Economics: energy, climate change and the three domains of sustainable development. Routledge Press.

Guan, D., Hubacek, K., Weber, C.L., Peters, G.P., Reiner, D.M. (2008). The drivers of Chinese CO2 emissions from 1980 to 2030. Glob. Environ. Change 18, 626–634.

Hong, J.P., Byun, J.E., Kim, P.R. (2015). Structural changes and growth factors of the ICT industry in Korea: 1995-2009.

IEA (2014). World Energy Outlook 2014. Paris, France, OECD/IEA.

International Energy Agency and World Business Council for Sustainable Development (2009). Cement Technology Roadmap 2009: Carbon emissions reductions up to 2050. Paris, OECD/IEA.

IPCC (2014), Working Group III contribution to the IPCC 5th Assessment Report "Climate Change 2014: Mitigation of Climate Change", Chapter 11, Agriculture, Forestry and Other Land Use (AFOLU).

Kanemoto, K., Moran, D., Lenzen, M. and Geschke A. (2014). International trade undermines national emission reduction targets: New evidence from air pollution. Global Environmental Change, 2014. 24: p. 52-59.

Leontief, W. (1953). Domestic production and foreign trade: The American capital position re-examined. Proc. Am. Philos. Soc. 97, 332–349.

Leontief, W. (1956). Factor proportions and the structure of American trade: Further theoretical and empirical analysis. Rev. Econ. Stat. 38, 386–407.

Liu, Z., Davis, S.J., Feng, K., Hubacek, K., Liang, S., Anadon, L.D., Chen, B., Liu, J., Yan, J., Guan, D. (2016). Targeted opportunities to address the climate-trade dilemma in China. Nat. Clim. Change 6, 201–206.

McBain, D., Alsamawi, A. (2014). Quantitative accounting for social economic indicators. Nat. Resour. Forum 38, 193–202. doi:10.1111/1477-8947.12044

Nordhaus, W. & J. Boyer (2000). Warming the World: Economics Models of Global Warming. MIT press.

Parag, Y. And Darby, S. (2009) Consumer-Supplier-Government Triangular Relations: Rethinking the UK Policy Path for Carbon Emissions Reduction from the UK Residential Sector, Energy Policy, 37, 3984-3992.

Peters, G.P., Hertwich, E.G. (2008). CO_2 Embodied in International Trade with Implications for Global Climate Policy. Environ. Sci. Technol. 42, 1401–1407.

Peters, G.P., Minx, J.C., Weber, C.L., Edenhofer, O. (2011). Growth in emission transfers via international trade from 1990 to 2008. Proc. Natl. Acad. Sci. 108, 8903–8908.

POLFREE (2014) D1.2- Lessons from the EU Policy Experiences, POLFREE D1.2 Report, 13-5-2014.

Policy Brief 1, Consumption-based Accounting and Policies: Challenges and Opportunities ahead, Carbon-CAP, 2016

Policy Brief 2, Acceptance of Consumption-based Climate Policy Instruments and Implementation Challenges, Carbon-CAP, 2016

Policy Brief 3, Consumption-based Accounting and Policies: The Future of Consumption-based Carbon Accounting Systems, Carbon-CAP, 2017

Policy Brief 4, Consumption-based Accounting and Policies: Project Findings and Conclusions, Carbon-CAP, 2017

Rodrigues, J., V. Prado, E. van der Voet, D. Moran and R. Wood (2015). Effectiveness of improvement options to reduce GHG emissions in a consumption based approach. Carbon-CAP project Deliverable D6.2.

Schanes, K., Giljum, S., Hinterberger, F., Wieland, H., E. van der Voet (2015). List of life-cycle micro-level options for consumption based climate mitigation. Carbon-CAP project Deliverable 6.1

Simas, M., Wood, R., Hertwich, E. (2014). Labor Embodied in Trade: The Role of Labor and Energy Productivity and Implications for Greenhouse Gas Emissions. J. Ind. Ecol.

Skelton, A. (2013). EU corporate action as a driver for global emissions abatement: A structural analysis of EU international supply chain carbon dioxide emissions. Global Environmental Change, 23(6), 1795–1806.

Sterner, T. (2003). Policy Instruments for Environmental and Natural Resource Management. Washington, D.C., Resources for the Future Press Series

UN ESCAP Virtual Conference Section C (2014). Available at http://www.unescap.org/drpad/vc/orientation/M5_6.htm, Accessed 12 March 2014.

Wachsmann, U., Wood, R., Lenzen, M., Schaeffer, R. (2009). Structural decomposition of energy use in Brazil from 1970 to 1996. Appl. Energy 86, 578–587.

Wiedmann, T. (2009). A review of recent multi-region input–output models used for consumption-based emission and resource accounting. Ecol. Econ. 69, 211–222.

Wiedmann, T., Wood, R., Minx, J.C., Lenzen, M., Guan, D., Harris, R. (2010). A carbon footprint time series of the UK – results from a multi-region input–output model. Econ. Syst. Res. 22, 19–42.

WRI and WBCSD (2011). "The Greenhouse Gas Protocol, A Corporate Accounting and Reporting Standard" Revised edition. World Business Council for Sustainable Development & the World Resources Council. http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf

Yang, L., Lahr, M.L. (2010). Sources of Chinese labor productivity growth: A structural decomposition analysis, 1987–2005. China Econ. Rev. 21, 557–570.

Zhang, H., Lahr, M.L. (2014). China's energy consumption change from 1987 to 2007: A multi-regional structural decomposition analysis. Energy Policy 67, 682–693.