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Use of future world scenarios within an attributional input-output framework

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Abstract

Life Cycle Assessment (LCA) and Environmentally-Extended Input Output (EEIO) analysis are increasingly being used to quantify the environmental impacts of specific activities within future scenarios, in order to guide decision-making. Many prospective assessments rely on a consequential approach, which are useful for modeling small-scale changes in the near future. For larger scale changes over the long-term, prospective attributional techniques have been proposed as a more suitable approach.

This report details a method that can be used to efficiently and accurately integrate the energy mixes from three future world energy scenarios into modified Input-Output (IO) tables, which can then be used in prospective attributional hybrid LCA-IO studies to analyze specific activities within future scenarios, e.g. modeling the environmental impacts associated with producing electric vehicles in 2035.

The modified IO matrices were used to analyze the life cycle impact intensities of all 129 industries in the EXIOPOL EEIO database, comparing changes between year 2000 and the three International Energy Agency (IEA) scenarios in 2035. The electricity generation and distribution sector had the highest GWP100 impact intensity of all sectors, but also experienced the greatest reduction in emissions across all scenarios due to decreases in coal and increases in renewables. As a result, industries that relied heavily on electricity in their energy mix experienced large reductions in their lifecycle impact intensities. In contrast, industries that relied primarily on oil in their energy mix, such as transport and agriculture, saw less reduction in impact intensities. This is partly due to less available alternatives to displace oil and reduce emissions compared to electricity, but also because of the higher than expected upstream impacts from extraction of crude oil.

In conclusion, this project was an ambitious effort to find a solution to efficiently and accurately modify an EEIO to model a future energy scenario. These modified IO tables would be useful for prospective attributional hybrid LCA-IO studies used to evaluate prospective technologies, and also for gaining insights through analyzing and comparing the environmental performance across different industries.

Table of Contents

Table of Figures

Introduction

Motivation

Life Cycle Assessment (LCA) and Environmentally-Extended Input Output (EEIO) are increasingly being used to quantify the environmental impacts of specific activities within future scenarios to guide decision-making. For instance, such analyses could be used to model the environmental impacts of prospective technologies such as electric vehicles.

Most LCAs and EEIOs are attributional and retrospective; they use past data with a central tendency approach to determine the impact of activities that are already embedded *within* a production-consumption system. On the other hand, so-called prospective-consequential LCAs analyze perturbations to a system, e.g. the introduction of new technologies or a change in consumption levels, and are therefore targeted at guiding decisions in the present and near future.

For large scale perturbations or more long-term decisions into the future, however, the consequential approach has been criticized as either losing transparency through complex modeling or relying overly much on *ceteris paribus* assumptions. It has recently been proposed that a *prospective attributional* approach to lifecycle studies could fill this void. Such an approach involves estimating the environmental impacts that can be attributed to the lifecycle of a future good or service embedded within exogenously defined scenarios of the future economy. Little has been done in this direction so far.

The separate use of process-based LCA and EEIO has already been criticized in retrospective studies as leading to either truncated or heavily aggregated assessments. Hybridization of LCA and EEIO seems to be even better suited for prospective attributional studies, especially considering how the EEIO framework is ideal for integrating future economic scenarios. Thus, there is a need for further development in the direction of prospective attributional hybrid EEIO-LCAs.

State of the Field

Consequential vs. Attributional

Prospective studies assign responsibility for future environmental impacts in two different ways: consequential and attributional. Attributional studies assume a steady-state system and allocate responsibility using average data, as is done when using LCA databases for retrospective studies. In contrast, consequential studies evaluate a change or disturbance to a steady state system, and thus use marginal data. (Sanden & Karlstrom 2007)

Most prospective LCA assessments have used consequential approaches, which are good for modeling small-scale disturbances in the system over the short term, but are generally not well suited for long-term or large-scale changes (Sanden & Karlstrom 2007). To address some of these shortcomings, the Macro-LCA approach has been proposed by Dandes to model larger scale and longer-term changes in a consequential framework using Computational General Equilibrium Modeling (CGEM) (Dandres et al. 2012). However, approach like these are complex and challenging, requiring endogenous modeling of critical aspects of future scenarios such as economic growth rates and technological innovation.

Prospective attributional approaches have also been used in recent years, but are less common. One study modified the LCI unit processes using a Formative Scenario Analysis (FSA) method in order to assess regional transportation (Spielmann et al. 2005). Another effort undertaken by the NEEDS project modified 17 Ecoinvent background LCI processes relating to energy, transport, construction, and electricity mix under multiple scenarios for 2025 and 2050 using a bottom up approach (ESU & IFEU 2008). Manually updating even a small selection of LCI processes requires great effort and yields limited value. LCI processes are not well suited to represent a snapshot of an economy operating in a single year, whether in the present or in the future, because background processes are made up of a patchwork of different studies performed in different years.

Prospective Attributional approaches are better suited for changing EEIO databases rather than LCA inventories. There are a range of methods to update or change Input-Output tables, including RAS (Jackson & Murray 2004), GRAS (Lenzen et al. 2007), and Sign Preserving Absolute Differences (SPAD) (Strømman 2009). These methods are used to optimize values throughout the input-output table with the introduction of new information, such as updated total output X vector, which can then be used to calculate the new interindustry flow Z matrix. Such methods are useful for modifying the monetary IO tables such as the Z and A matrices, but are not as useful for non-square environmental extensions in physical units.

Various IO databases have been used for environmental analysis, each with their own strengths and weaknesses. The GTAP global IO database covers 129 regions with year 2007 data, but only has a resolution of 57 commodities (Center for Global Trade Analysis, 2012). It also has poor environmental and energy extensions, making it less suitable for hybrid LCA analysis. The most comprehensive EEIO database is CEDA, which covers the US, UK, and China, with a resolution of over 400 commodities for the US, based on year 2002 data (CEDA, 2012). This database is very suitable for use in hybrid LCAs, but the main limitation is in its geographical scope. EXIOPOL is a global EEIO that covers 44 regions with a resolution of 129 commodities based on year 2000 data (EXIOBASE, 2012). The advantage of this database is that it has both global scope and comprehensive environmental extensions. The weakness lies in its outdated data, however this can be mitigated if an appropriate technique is used to update it.

What might prospective attributional approaches be used for? To answer this question, a useful distinction should be made between *product* and *technology* LCAs. For product LCAs, it is important to use data that is specific to the situation or state pertaining to that product. However, to evaluate the environmental performance of *technologies*, it is more useful to use data based on many different or more general circumstances. Therefore, Sanden believes that one good use of prospective attributional studies is to evaluate the environmental performance of future technologies:

"Prospective attributional technology LCAs could be used to analyze the general performance of a technology under different circumstances. The key methodological problem is to analyze the technology in a relevant state or scenario of consecutive states." (Sanden & Karlstrom 2007)

As Sanden points out, when conducting prospective attributional studies, it is important to ensure that the technology is analyzed in a relevant state or scenario. For example, to evaluate the environmental impacts of future global adoption of electric vehicles by the year 2035, it would be useful to evaluate the electric vehicle technology based on the average global energy mix in 2035. Since the environmental footprint of an electric vehicle depends heavily on the energy mix used, it is important that we evaluate future adoption of this technology in a relevant scenario. Using a global energy mix is useful for assessing technologies, as it may be produced through many different variations in international supply chains and can also be deployed to many different countries using different energy mixes. Using a global energy mix would form a useful basis for comparison between alternative technologies that may be deployed across many different countries.

Hybrid LCA - IO

Process-based LCA studies are often criticized for having truncated results that systematically underestimate environmental impacts, while EEIO alone lead to results that are heavily aggregated. Hybridization of LCA and IO can address the weaknesses of both approaches and lead to more robust analysis. Various studies have shown that process-based LCAs produce results that are 20-60% lower than similar hybrid LCA-IO assessments (Majeau-Bettez et al. 2011).

Hybrid techniques that utilize modified IO background databases would be particularly useful for prospective analyses, given how well suited IO tables are at modeling economies of particular points in time. Moreover, since hybrid LCA-IO techniques depend on normalized unit matrices rather than flow matrices, the methods used to alter the IO tables can be simplified. Therefore, a modified IO database that is representative of current and future scenarios would be useful for prospective attributional hybrid LCA-IO analysis.

IO Database

The utility of an IO database that is representative of future scenarios goes beyond its applicability for case studies using hybrid LCA-IO. The database itself can be analyzed to see how different industries compare across impact categories, and how they change over time under various future scenario conditions. Huppes performed an insightful retrospective analysis of the environmental impacts of consumption in the EU using a high-resolution input output table (Huppes et al. 2006). However, that study was based on integrating various sources of poor quality data, rather than on a database built from more unified data gathering techniques. The recent release of the EXIOPOL database in 2012 (EXIOBASE, 2012), complete with high quality environmental extensions, makes this a good opportunity to explore this database to compare the environmental performance between industries, not only from the past, but also under future scenarios.

Given that a modified EXIOPOL global EEIO table would be useful both for hybrid LCA-IO and for deeper analysis on the environmental performance between different industries, the question then becomes: What is the best way to modify an IO table to reflect future scenarios? The techniques that have previously been mentioned are generally too complex, incomplete, or inaccurate. How can we strike a balance between accuracy and efficient use of effort?

Energy mix is one of the most important factors that influence the results of LCA and EEIO studies. Over 80% of all anthropogenic greenhouse gases are energy-related, mostly due to the combustion of fossil fuels (IEA 2011). For the purposes of modeling future scenarios in IO tables, the most important aspect to focus on and ensure accurate representation of, is the energy mix used in every industry. Luckily, there are many detailed studies that model future energy scenarios with rigor. Therefore, energy scenarios could be defined exogenously, taking away the need to endogenously model aspects like economic growth rates and projecting future energy demand and supply scenarios. The energy mix of every industry could be modified according to future energy scenarios, making use of the detailed environmental and energy extensions available for EXIOPOL.

Synthesis

To synthesize the previous points, prospective LCA and EEIO analysis can help guide our decisions regarding products, policies, and technologies. The consequential approach is useful for understanding small-scale and short-term changes to a system, while an attributional approach would be more useful to understand larger changes to the economy over the long term. Prospective attributional approaches are particularly useful for evaluating adoption of future technologies. There have been a wide range of approaches to modify both LCA and IO databases to reflect current and future scenarios, however such approaches often require too much effort, are incomplete, or are inaccurate.

Input-Output databases are better suited to modeling future scenarios of the economy than process-based LCA databases. A modified IO table could be useful for hybrid LCA-IO analysis. A brief comparison between the CEDA, GTAP, and EXIOPOL databases showed EXIOPOL to be desirable for this project due to its high quality environmental extensions, broad coverage of the global economy, and relatively high resolution of 129 industries. By integrating future energy scenarios into EXIOPOL, an interindustry technical coefficients A matrix using an energy mix defined by future scenarios could be used as a background for hybrid LCA-IO analyses. This would also allow for a detailed comparison of the environmental performance between different industries and show how changes in energy mix influence industries differently.

Research Goals

The overarching objective of this research is to improve our understanding of the manner in which future world scenarios can be efficiently integrated in EEIO models. The specific elements to be included in this thesis are:

- Develop a method that efficiently and accurately incorporates future world energy scenarios into a global single region EEIO table, which can serve as background data for prospective attributional hybrid LCAs.
- Analyze and compare the environmental performance of different industries, along with their sensitivity to changes across different future energy scenarios.

Case Description and Data

Overview:

In order to integrate future world energy scenarios with a global EEIO database, a brief description of both the energy scenarios and the EXIOPOL EEIO database is provided below.

Future Energy Scenarios

Survey of Energy Scenarios

Initially, a survey of various different energy scenarios was conducted in order to select a suitable set of scenarios. The aim of this study is to integrate multiple credible future energy scenarios into an EEIO table. Note the distinction between scenario and prediction. The aim is not to produce an EEIO table that reflects our best guess or prediction of what the world energy landscape will look like in the future, but rather to integrate multiple scenarios that cover a wide spectrum of plausible futures. Upon evaluating which scenarios to choose for this research, some of the key criteria included the comprehensiveness of model, the age of the data from which the scenarios are based on, and the credibility of organization producing the scenarios. Energy scenarios that were considered include the 4th Assessment Report in 2007 by the IPCC (IPCC 2007), the Global Energy Outlook 2012 by Exxon (ExxonMobil 2012), the International Energy Outlook 2011 by the US Energy Information Administration (EIA 2011), and the World Energy Outlook 2011 by the International Energy Agency (IEA 2011).

The IPCC scenarios are comprehensive, however are based on outdated data, as their latest major report was published in 2007 (IPCC 2007). Exxon produced a Global Energy Outlook (Exxon 2012) that is also quite comprehensive and up to date, however given that the source is the largest oil company with a vested interest in shaping how the future energy landscape will look, these scenarios were not chosen either. The US EIA's International Energy Outlook 2011 produces global scenarios that are also very comprehensive, outlining a reference case that is closely aligned with the IEA WEO 2011 Current Policy Scenario (EIA 2011). Although the US EIA's scenarios would have been suitable, the IEA scenarios were chosen because of the wider range of scenarios represented in the IEA. Also, the physical energy extension data of the EXIOPOL EEIO table is based on IEA data, so this would ensure consistency in the data.

IEA World Energy Outlook

The IEA has been publishing World Energy Outlook every year since 1998, and is one of the most reputable organizations doing such work. Developed over many years, the World Energy Model is the basis for IEA's medium and long-term projections. It consists of six main modules (IEA 2011):

1. Final energy demand (with sub-models covering residential, services, agriculture, industry, transport and non-energy use)
2. Power generation and heat
3. Refining/petrochemicals and other transformation
4. Oil, natural gas, coal, and biofuels supply
5. CO2 emissions
6. Investment

The WEM is designed to analyze:

- Global energy prospects: These include trends in demand, supply availability and constraints, international trade and energy balances by sector and by fuel (currently through to 2035).
- Environmental effects of energy use: CO2 emissions from fuel combustion are derived from the detailed projections of energy consumption.
- Effects of policy actions and technological changes: Scenarios and cases are used to analyze the impact of policy actions and technological developments on energy demand, supply, trade, investment and emissions.
- Investment in the energy sector: The model evaluates the investment requirements in the fuel-supply chain needed to satisfy projected energy demand. It also evaluates demand-side investment requirements.

The IEA World Energy Outlook 2012 analyzes three future energy scenarios for 2035, which are described by the IEA as follows (IEA 2011):

NPS (New Policy Scenario)

The central scenario of this Outlook incorporates the broad policy commitments and plans that have been announced by countries around the world to tackle energy insecurity, climate change and local pollution, and other pressing energy-related challenges, even where the specific measures to implement these commitments have yet to be announced. This scenario provides a benchmark to assess the *achievements and limitations of recent developments in climate and energy policy. As many of the formal commitments that have been modeled in the New Policies Scenario relate to the period to 2020, we have assumed that additional unspecified measures are introduced that maintain through to 2035 a similar trajectory of global decline in carbon intensity measured as emissions per dollar of gross domestic product.*

CPS (Current Policy Scenario)

WEO-2011 also presents updated projections for the Current Policies Scenario (called the Reference Scenario prior to WEO-2010) to show how the future might look on the basis of the perpetuation, without change, of the government policies and measures that had been enacted or adopted by mid-2011. A number of the policy commitments and plans that were included in the New Policies Scenario in WEO-2010 (IEA, 2010a) have since been enacted so are now included in the Current Policies Scenario in this Outlook.

450 (450ppm Scenario)

The Outlook presents updated projections for the 450 Scenario, which sets out an energy pathway that is consistent with a 50% chance of meeting the goal of limiting the increase in average global temperature to two degrees Celsius (2°C), compared with pre-industrial levels. For the period to 2020, the 450 Scenario assumes more vigorous policy action to implement fully the Cancun Agreements than is assumed in the New Policies Scenario (which assumes cautious implementation). After 2020, OECD countries and other major economies are assumed to set economy-wide emissions targets for 2035 and beyond that collectively ensure an emissions trajectory consistent with stabilization of the greenhouse-gas concentration at 450 ppm.

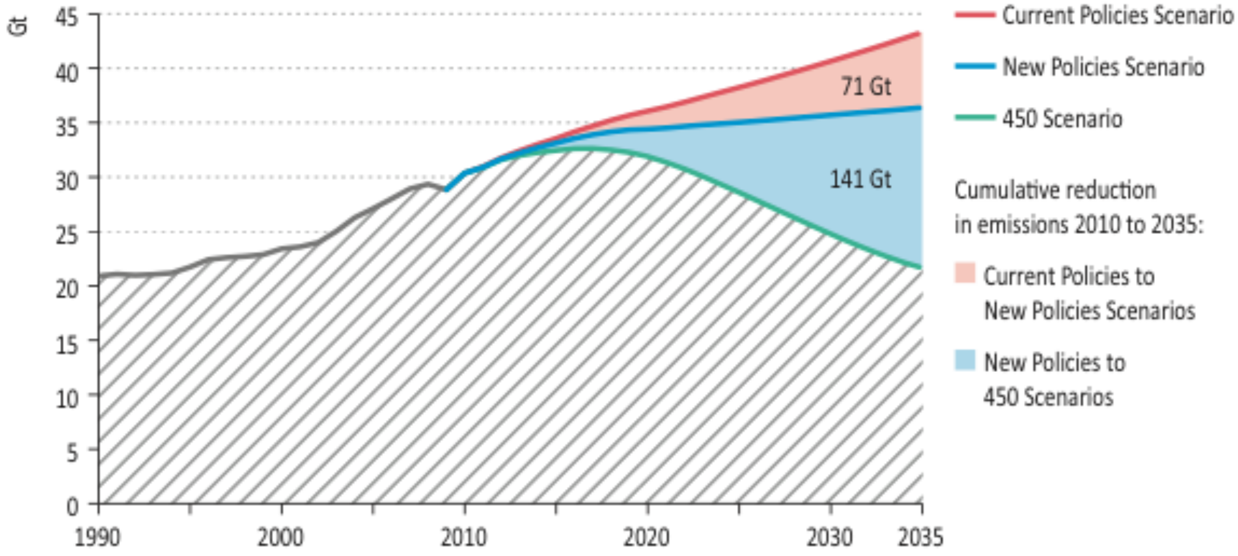


Figure 1 - World energy-related CO2 emission by scenario (IEA 2011)

Figure 1 shows the range in CO2 emissions represented by the three IEA scenarios. The CPS can be thought of as a business as usual case where no new actions are taken, while the 450 scenario is a very ambitious scenario that outlines drastic changes to the way energy is produced and used. To give a sense of how ambitious the 450 scenario is, the IEA calculates that 80% of the emissions calculated in the 450 scenario are already locked in from our existing energy infrastructure. If meaningful actions are not taken by 2017, all newly built energy facilities would have to be zero carbon, which they say is theoretically possible at very high cost, but probably not practicable in political terms (IEA 2011). Thus, these three IEA energy scenarios give a good representation of the range of plausible future energy scenarios.

In addition to the three future scenarios to the year 2035, the IEA also publishes the most recently available data. Since EXIOPOL is based on year 2000 data, the IEA World Energy Outlook 2002 was also used as reference, since this report contains actual data for the year 2000 (IEA 2002). This is useful because the data would be defined and presented in the same format as the other World Energy Outlook scenarios for 2035.

The World Energy Outlook 2011 published the most recent data for the year 2009. However, since the focus of this research is on future energy scenarios, this year 2009 data was not included in this analysis. This could however, be easily integrated into the analysis as a way to update the energy mix of EXIOPOL to the most recent data. Alternatively, other future energy scenarios could also be analyzed as part of future work that builds on this research.

IEA Energy Mix

Figure 2 shows the normalized energy mix as defined by the IEA for the year 2000 and the three 2035 scenarios. The IEA WEO presents energy data for 17 types of energy carriers in the form of Total Primary Energy Demand (TPED), as shown in top section of Figure 2. The TPED measures the total amount of energy used throughout the entire economy, and is a summation of the other 6 categories shown below TPED in Figure 2. Note that the word “category” will be used to refer to the 6 IEA categories (Power Generation, Other Energy, Industry, Buildings, Transport, Other) for the remainder of this report.

TPED is divided across 6 categories, 2 of which are energy production categories (Power Generation and Other Energy), and 4 of which are energy use categories (Industry, Buildings, Transport, and Other). Of the 17 energy carriers, 6 are different types of electricity. The IEA WEO only specifies how much electricity is used in each of the 6 categories, so this total electricity number was disaggregated into 6 different types of electricity based on the overall global electricity mixes specific to their respective scenarios. Note that the energy carriers are labeled in Figure 2 either as fuels (F_XXX) or electricity / power generation (PG_XXX). Since the IEA WEO records TPED, it also accounts for the primary energy demand of renewables. In this sense, primary energy is described as a fuel, so F_Hydro would be the energy in the water flowing through the hydroelectric facilities, which then generates electricity as PG_Hydro.

In Input-Output terms, this IEA energy data includes both intermediate and final energy demand. However, this scenario data from the IEA is used to change only the intermediate interindustry aspects of the IO table, and not the final demand parts. This highlights an assumption that has been made, stating that changes in energy mix in the intermediate demand are the same as the changes in the energy mix across the whole economy, which includes final consumption.

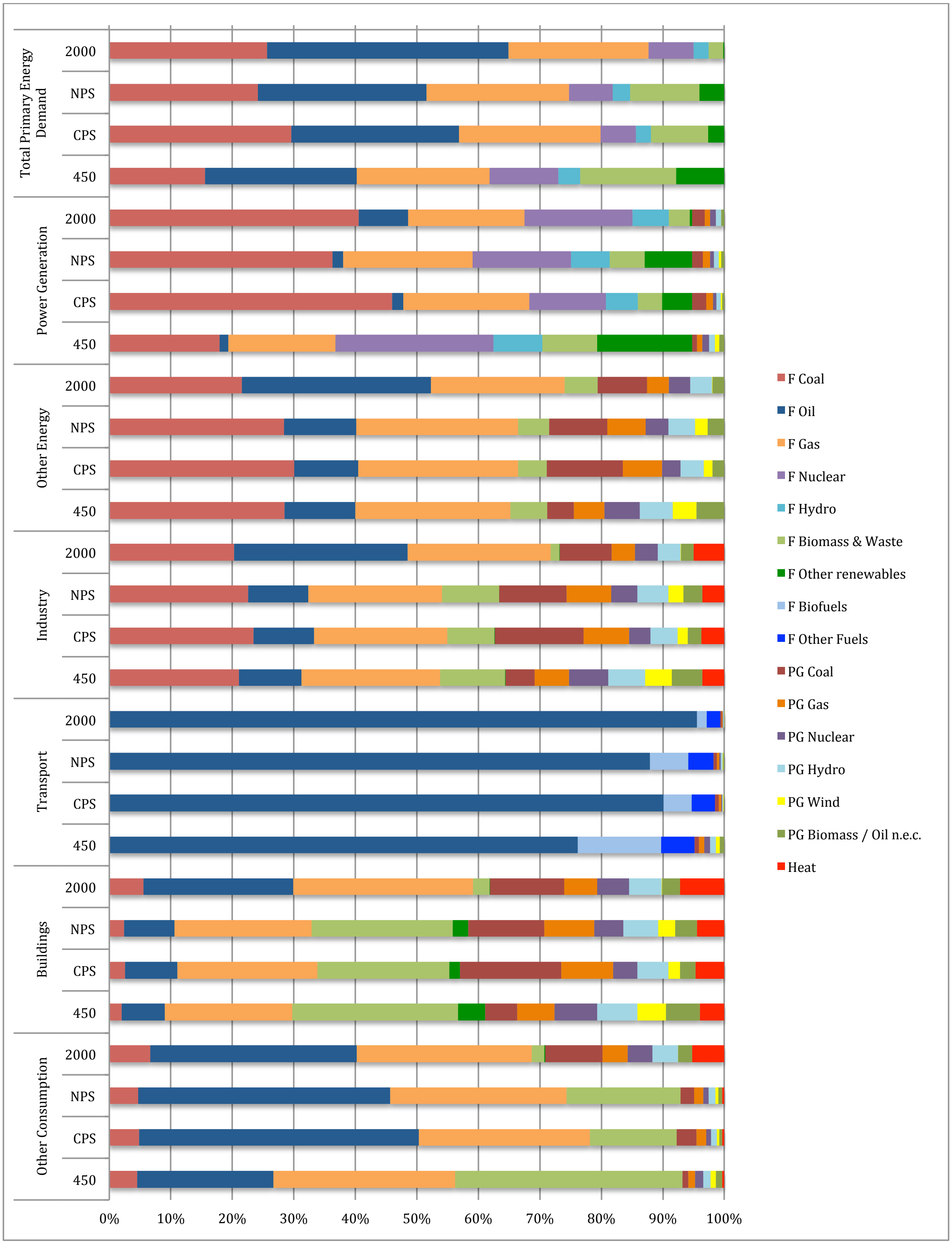


Figure 2 – IEA energy mixes across future scenarios

EXIOPOL

The IO database that will be used for this analysis is the EXIOPOL global, multi-regional Environmentally-Extended Input Output (EEIO) table. This database covers 43 countries and 1 rest of world region. The 43 countries are roughly the EU27 + Norway and Switzerland, the OECD countries outside Europe, and the Non-OECD countries. In order to simplify this analysis, the EU and non-EU regions have been aggregated into a one region global IO table. This reduces the complexities associated with dealing with trade between regions. Also, a global IO table would be ideal for analyzing technologies within an attributional framework, since it gives a common basis for comparison of technologies that can be produced and deployed across many different countries.

The EXIOPOL database is a Supply and Use Table (SUT) that has been converted to a 129 product x 129 product Symmetric Input Output Table (SIOT). Note that the product SIOT was chosen over the industry SIOT because hybrid LCAs call for units of products, not units of industries. However, both the product and industry classification names are the same, and it is often easier to think of each of these "products from an industry" as "industries" themselves. Therefore, for the remainder of this report, the word "industry" will be used instead of "products". Also, this report will also be grouping these 129 "industries" (which are really products), into 13 groups of industries that will be referred to as "sectors". For example, the Power generation and distribution "sector" may contain "industries" such as Power generation from Coal, Gas, and Nuclear etc.

The EXIOPOL input-output table comes with environmental (emissions and natural resources use), material and economic extensions. One of the key strengths of this methodology is that it uses the physical energy and emission extensions as the basis for making changes to the Input-Output tables, which is more reliable than making such changes in monetary units. This means that changes in the energy mixes and emissions are done in physical units first, before being translated into corresponding changes in the matrices using monetary units. This approach utilizes the strengths of EXIOPOL by making use of its comprehensive energy and environmental extensions in physical units.

Method

Overview

Figure 3 shows the key matrices used in this method for updating the energy industries of the EXIOPOL IO table. All of the matrices shown in this figure are global one-region matrices. Some of the key calculations are also shown on this figure, and will be described in greater detail below. Note that variables that end with “_XXX” indicate future scenarios, where XXX could stand for 2009, NPS, CPS, or 450. Table 1 shows the corresponding names and descriptions of the variables shown in Figure 1. One of the strengths of this methodology is that the changes to the IO table are based on changes in elements that are in physical units first (UG and E), before the changes are translated to the monetary elements (Z, A, X, and Y). This method section will first go through calculations on energy, then emissions, then the interindustry flows, before finally calculating the impacts. All Matlab codes are in Appendix 2.

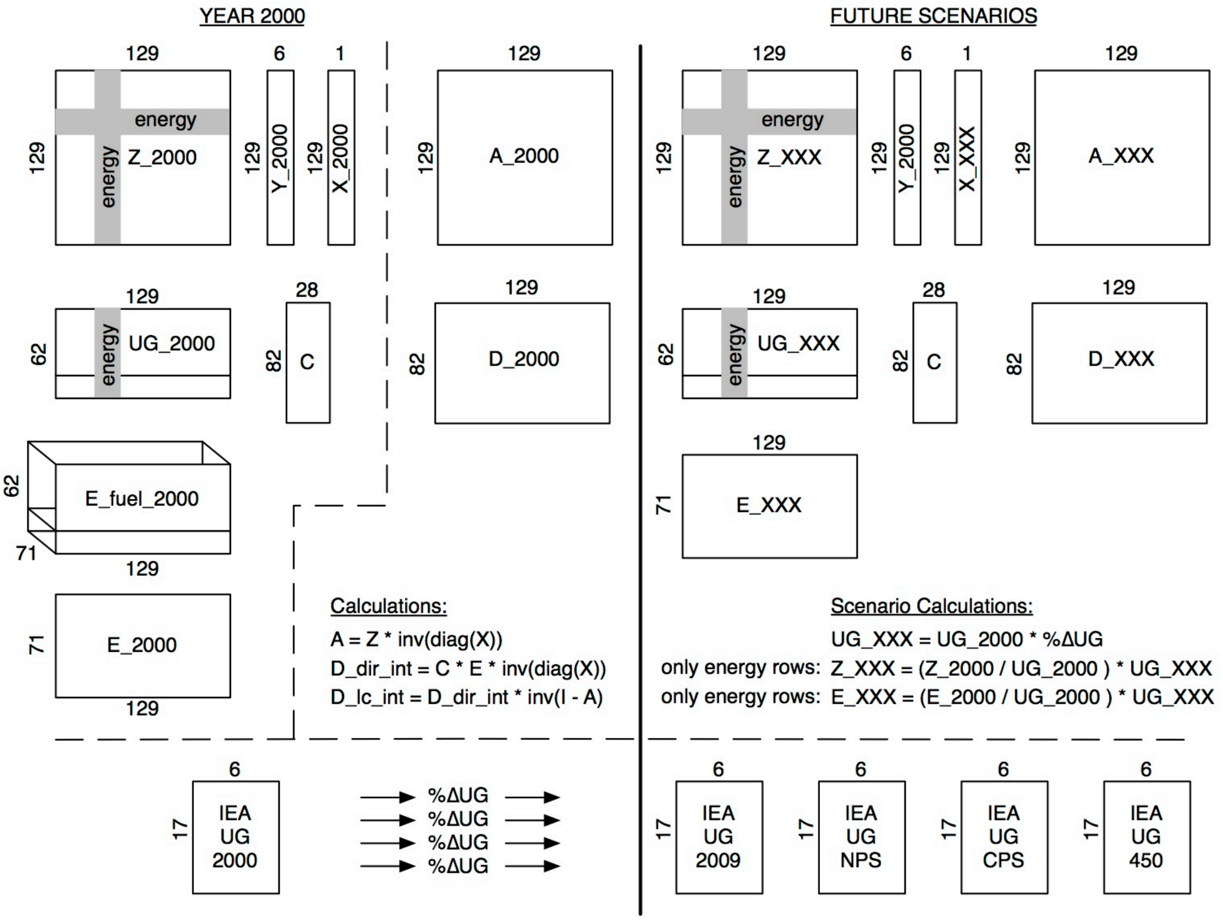


Figure 3 – Overview of matrices involved in calculations

Table 1 - Description of matrices

Symbol	Rows x Columns	Unit	Description
Z	129 x 129	Million €	interindustry requirements flow matrix
UG	62 x 129	TJ	gross energy use
E_fuel	62 x 129 x 71	kg	emissions per fuel(62) per industry(129) per pollutant(71)
E	71 x 129	kg	emissions per industry per pollutant
Y	7 x 129	million €	final demand
X	1 x 129	million €	final output
A	129 x 129	€ / €	interindustry unit requirements matrix
C	82 x 28	impact / kg	characterization matrix
D	82 x 129	impact	impact matrix

Energy

Changes in physical energy use UG between the different scenarios forms the basis of changes in other non-energy matrices such as Z and E. With regards to energy, there are two main sources of information related to physical energy use in this study. First, there is the data from the IEA World Energy Outlook (WEO), which contains information about future energy scenarios. The other source of energy information is from UG, which shows how much energy input each industry uses, disaggregated into 56 different types of energy carriers. Original IEA WEO energy data is included in Appendix 1.

IEA Future Energy Scenarios

The IEA_UG_XXX matrices shown in the bottom of Figure 3 represent the energy consumed across the 6 IEA categories from 17 different types of energy. This information is based on the IEA WEO 2011 (IEA 2011), and show growth in total energy consumption for all future scenarios relative to year 2000. However, for the calculation purposes of this project, the total amount of energy consumed in all of the future scenarios are scaled back to the year 2000 total energy level, allowing for comparability of energy mixes in flow terms. Since the main aim of this report is to produce an A matrix with updated energy mix information, accuracy in the interindustry flow Z matrix is not deemed as important, so scaling energy use of future scenarios back to year 2000 levels is appropriate. Next, changes in energy mix are calculated by finding the percentage difference between IEA_UG_XXX and IEA_UG_2000 for every single value within the 17x6 matrix. This %ΔUG is shown along the bottom of Figure 3, and is the basis for updating UG_2000 (62x129) to the energy mixes represented in the future scenarios.

UG - Gross Energy Use

There are three different energy extensions in EXIOPOL, which are Gross Energy Use (UG), Emissions-Relevant Energy Use (UE), and Gross Energy Supply (S). The calculations for this report only make use of the UG matrix. UG_2000 represents the gross energy used in all 129 industries, broken down into 56 different energy carriers. One of the energy carriers represented in UG is electricity. Since UG does not disaggregate the type of electricity used by each industry, the ratios between types of electricity used from the Z matrix for each of the 129 industries was used to disaggregate the UG electricity value. As a result, 6 additional rows were added to the bottom of UG, leading to a total of 62 types of energy carriers. Note that UG only looks at *gross* energy use, which is not the same as *net* energy use. Since some industries not only consume energy, but also produce energy, the net energy use would be UG - S, where S is energy supply. TPED, as used in the IEA scenarios, is comparable to net energy use UG - S, not to UG itself. However, an assumption for these calculations that changes in gross energy use follow the same relative changes as net energy use, as defined by the IEA.

The 17x6 %ΔUG matrix based on the IEA_UG_XXX data is used to transform the 62x129 UG_2000 matrix into future scenario UG_XXX matrices. Therefore, it is necessary to correlate how the 62 types of energy carriers in UG_2000 aggregate into the 17 types of energy carriers from IEA_UG_XXX. Similarly, it is important to know how the 129 industries fit into the 6 IEA categories (Power Generation, Other Energy, Industry, Buildings, Transport, and Other).

For example, IEA_UG_XXX may specify that coal use in the buildings category grows by 6% relative to year 2000. This ΔUG growth rate of 6% will be applied to the 4 different types of coal represented in UG_2000, across all 22 industries defined as buildings. This method limits information loss, since changes in energy mix from the 17x6 %ΔUG_XXX matrices are applied, while still preserving the initial energy mix structure from the original 62x129 UG_2000 matrix. This is how the initial version of UG_XXX is calculated. Further adjustments need to be made to make results more accurate, as described below.

UG - Scaling energy end-use industries

As previously mentioned in the IEA Future Energy Scenarios part, the overall TPED for all future scenario is scaled back to equal to the TPED in year 2000. Therefore, this method of applying %ΔUG ensures that rates of increase and decrease across the different energy carriers cancel out, with no net change in

TPED across the economy for any scenario. However, this method does pose some problems when analyzing individual industries. For a simple hypothetical example, suppose an industry uses 100 TJ of energy overall, with 90 TJ for coal and 10 TJ for gas in year 2000. Now suppose %ΔUG_NPS in the buildings category for coal is +10% and is -10% for gas. This would lead this particular industry to use 108 TJ of energy overall, with 99 TJ for coal, and 9TJ for gas. Total energy use grew by 9%, even though the total energy use across the economy in this scenario is supposed to stay at year 2000 levels. Since the main aim of this project is not to produce and accurate Z matrix, but an accurate A matrix, it is more important to correct the amount of energy used within each industry back to the year 2000 levels. Therefore, for this example, the amount of coal used is 99 * (100/108) = 91.7 and gas use is 9*(100/108) = 8.3.

UG - Energy Efficiency

This approach of rescaling the columns of UG for future scenarios back to year 2000 levels works well for the IEA categories that are energy end users (Industry, Buildings, Transport, Other), but not for the energy producers (Power Generation, Other Energy). The reason is due to the energy efficiency assumptions embedded in the way energy mixes are defined within future IEA scenarios. To illustrate this point, note that in UG, the columns of every industry represent the upstream energy inputs, while the rows represent the downstream use of that energy product. The ratio between the upstream energy inputs and downstream energy use can be used as a measure of energy efficiency.

For example, if the PG_Coal industry requires 10 TJ of coal input to satisfy 3 TJ of downstream coal electricity use, it has a 30% energy conversion efficiency. However, if future IEA scenarios indicate that the coal inputs for PG_Coal drop by 50%, while the downstream demand of PG_Coal only drops by 33%, we see a change in energy efficiency. In the new scenario, PG_Coal requires 5TJ of coal input to satisfy 2TJ, yielding an energy conversion efficiency of 40%. Differences in the rates of change between energy production and energy use categories lead to changes in energy efficiencies. If the PG and OE columns in UG_XXX were to be scaled back to the same energy levels as in UG_2000, then in this example, PG_Coal would require 10 TJ of coal input, since coal is the main energy input for the PG_Coal industry. This would mean that PG_Coal requires the same amount of coal as in year 2000 to satisfy 30% less downstream coal electricity use, which would obviously be incorrect.

It makes sense to scale all downstream energy use categories (I, B, T, O) to year 2000 levels, because their output levels do not change, and so we assume they require the same amount of energy inputs. However, since we are changing the energy mixes of all downstream energy use categories, this should lead to changes in the amount of energy input required for the PG and OE categories.

Most energy industries require the same type of energy input as it produces. For example, electricity generation from coal mainly requires coal as an input. Motor gasoline coming from oil refineries mainly requires crude oil as an input. This is true for all secondary energy products (electricity from coal or motor gasoline) that are transformed from the primary energy product (coal and crude oil). Transforming primary energy products into secondary products involves industries related to refining, processing, and electricity generation. Therefore, by not re-scaling the PG and OE categories back to year 2000 levels, this generally allows the energy inputs to correlate with the changes in downstream energy demands, while still capturing the energy efficiency assumptions embedded in the IEA scenarios.

UG - Limitations of extraction on energy products

However, there is one area where this method fails to accurately represent the changes in the energy mixes, which is for extraction of energy products. This is because extraction of a particular energy product does not always depend on that form of energy input. Crude oil extraction does not primarily depend on oil, but on natural gas. Uranium extraction generally does not depend on electricity generated from nuclear. This is one of the main flaws of this approach, which is reflected in the abnormal results obtained for the energy extraction industries shown later. This flaw could potentially be fixed by scaling the energy inputs of all extraction industries to match the changes in downstream energy demand, while also incorporating the energy efficiency assumptions embedded in the IEA scenarios. However, given the limited timeframe for this project, this additional change was not carried out. The implications of this flaw in our method will be discussed in the results section.

UG - Summary

What initially seemed to be a straightforward exercise in changing the energy mix of every industry, turned out to have some unexpected complexities which required some specific adjustments, such as re-scaling downstream energy use categories and not the energy production categories. However, aside from the flaws in representing the energy extraction industries, this methodology could be considered as a good balance between accuracy and efficiency. After making these adjustments, we have the final UG_XXX matrices that will be used. The difference between UG_XXX and UG_2000 results in the dUG_XXX (62x129) change in energy use matrix, which will be used to calculate the change in the E and Z matrices.

Emissions

There are two sources of emissions information in EXIOPOL. The first source is the matrix that contains the aggregated total emissions of all pollutants for each of the 129 industries, which will be called E_original. The second source disaggregates this information by fuel type as well, which will be called E_fuel. In theory, if the emissions across all fuel types were added up from E_fuel, the resulting matrix, which we call E_2000, would equal E_original. However, a comparison between the two shows some discrepancies in the data.

Table 2 shows 23 industries where E_2000 differs from E_original by more than 20%. Given these inconsistencies, it was decided to only use one source of data for all of our emissions calculations. This means that E_2000 was used instead of E_original.

Data for E_fuel is based on a comprehensive dataset of over 700,000 data points adapted from the IEA, which contains data on the 44 countries/regions represented in EXIOPOL. Aggregating these 44 countries/regions into a global one-region model was a very computationally intensive process that required some efficient MATLAB coding to minimize computation. The resulting aggregated E_fuel 3-dimensional matrix contains information for 129 industries, 62 fuels, and 71 pollutants. Note that one of the categories of fuels is called “NO FUEL”, which accounts for all of the non-energy related emissions of every industry.

Table 2 - Comparison of E_2000 and E_fuel

Industry	E_2000 based on E_fuel	E_original	Relative Δ%
Mining of nickel	1,753,381,137	537,225,294	226.4%
Prod. of electricity nec, incl. oil, biomass & waste	971,146,099,118	597,846,796,445	62.4%
Transmission of electricity	637,045,570	480,773,610	32.5%
Prod. of electricity by gas	1,788,101,520,022	1,364,816,110,375	31.0%
Manuf. of furniture; manufacturing n.e.c.	275,810,197,573	221,354,592,138	24.6%
Research and development	22,662,684,859	29,935,514,707	-24.3%
Processing of Food products nec	37,734,959,323	54,517,837,601	-30.8%
Real estate activities	36,850,599,693	53,995,246,985	-31.8%
Manuf. of fabricated metal products	40,970,611,348	60,898,276,501	-32.7%
Manuf. of petr. & other hydrocarbon gases	18,355,674,402	27,727,548,015	-33.8%
Renting of machinery, equip., & personal goods	38,780,882,770	58,791,412,538	-34.0%
Prod. of electricity by hydro	884,546,753	1,380,204,468	-35.9%
Manuf. of wood products	27,988,996,481	47,181,914,963	-40.7%
Manuf. of medical & precision instruments	18,778,449,275	33,320,788,881	-43.6%
Mining of precious metals	7,027,637,557	13,845,457,290	-49.2%
Computer and related activities	10,428,658,238	21,438,636,046	-51.4%
Mining of other non-ferrous metals	2,078,370,066	4,678,340,549	-55.6%
Construction	224,317,357,384	556,104,813,910	-59.7%
Retail sale of automotive fuel	8,580,498,465	46,999,784,545	-81.7%
Prod. of electricity by wind	6,085,342	66,040,303	-90.8%
Manuf. and distr. of gas	12,067,847,642	172,560,062,641	-93.0%
Processing of nuclear fuel	7,928	351,551,448	-100.0%
Recycling of non-metal waste and scrap	-	12	-100.0%

To calculate the change in emissions, we must first calculate the emissions intensity, or Unit_Emissions. As previously mentioned, in addition to the UG matrix, there is also the UE matrix, which represents only the fraction of UG that is emissions-relevant energy use. This means for instance, that energy from renewables or CCS coal would not be included in UE. In theory, the most accurate way of calculating Unit_Emissions is to divide E_fuel by UE, since Unit_Emissions should only apply to emissions relevant energy use. However, our calculations are based changes in UG for future scenarios, not changes in UE. Therefore, if we assume that the changes in energy use for future scenarios retains the same UE : UG ratio specific to each industry, then dividing E_fuel by UG_2000 yields the accurate Unit_Emissions matrix needed for our calculations.

This Unit_Emissions matrix can then be multiplied with the change in energy use dUG_XXX to get the change in emissions dE_fuel_2000. This matrix can be summed across all fuel types to produce an overall change in emissions dE_2000, which can be added to E_2000 to calculate E_XXX. In our calculations, it was assumed that the Unit_Emissions would not change from year 2000 levels.

$$Unit\_Emissions = E_{2000}/UG_{2000}$$

$$dE_{fuel_{XXX}} = dUG_{XXX} * Unit\_Emissions$$

$$dE_{XXX} = \sum_{i=1}^{fuel} dE_{fuel_{XXX}}$$

$$E_{XXX} = E_{2000} + dE_{XXX}$$

Hybrid LCA-IO also requires the emissions intensity matrix (E_int_XXX) for future scenarios, which can be calculated by dividing the E_XXX matrix by the diagonalized X_XXX matrix.

$$E_{2000_{int}} = E_{2000} * \hat{X}_{2000}^{-1}$$

$$E_{XXX_{int}} = E_{XXX} * \hat{X}_{XXX}^{-1}$$

Monetary Flows

The Z matrix of EXIOPOL has monetary information from the year 2000 on 129 industries, of which 24 are related to the extraction, manufacture, and distribution of energy. The rows and columns of the Z matrix that are related to energy have been shaded in grey in Figure 3. Electricity generation is disaggregated between 6 different sources (coal, gas, nuclear, hydro, wind, and n.e.c.). Note that the n.e.c. category combines electricity generated from oil, biomass, waste, and other renewables. Obviously, it is not ideal to combine electricity generated by oil with other renewables like solar, but this is a limitation of EXIOPOL's industry classifications.

To transform the Z_2000 table for future scenarios, the Unit_Prices (price per unit energy) for all of the energy industries must be calculated. This requires that the 62 rows of energy for UG_2000 and dUG_2000 must be aggregated into the corresponding 24 rows of energy industries defined in the Z_2000 matrix. Then, the 24 energy-related rows of Z_2000 are divided by the aggregated 24 row UG_2000, yielding a Unit_Prices (24x129) matrix. The change in monetary flow can then be calculated by multiplying the aggregated version of dUG_XXX by Unit_Prices, which gives dZ_XXX. Finally, dZ_XXX can be added to Z_2000 to calculate Z_XXX.

$$Unit\_Prices = Z_{2000}/UG_{2000}$$

$$dZ_{XXX} = dUG_{XXX} * Unit\_Prices$$

$$Z_{XXX} = Z_{2000} + dZ_{XXX}$$

To calculate the total output of each industry X, the rows of Z and Y need to summed up and added together. Note that it is assumed that final demand Y_2000 does not change over time. Thus, for the future scenarios, X_XXX = Z_XXX + Y_2000. Finally, to calculate the A_XXX matrix, we must divide Z_XXX by the diagonalized X_XXX. This A_XXX is one of the main results of this study, as it can be used for hybrid LCA-IO analysis.

$$X_{2000} = Z_{2000}i + Y_{2000}$$

$$X_{XXX} = Z_{XXX}i + Y_{2000}$$

$$A_{2000} = Z_{2000} * \hat{X}_{2000}^{-1}$$

$$A_{XXX} = Z_{XXX} * \hat{X}_{XXX}^{-1}$$

Impacts

One of other main aims of this project is to calculate the direct and life cycle emission intensities across all 129 industries, and see how these change across different future scenarios. Additionally, these industries have been grouped into 13 aggregated sectors, which will be described in the next section on "Aggregated Sectors".

The direct and life cycle impact intensities are calculated in the equations below. The indirect impacts can be calculated by subtracting the direct impacts from the life cycle impacts. This set of calculations can be used on both the 129 industry matrices and the 13 aggregated sector matrices.

$$D_{2000_{int_{dir}}} = C * E_{2000} * \hat{X}_{2000}^{-1}$$

$$D_{XXX_{int_{dir}}} = C * E_{XXX} * \hat{X}_{XXX}^{-1}$$

$$D_{2000_{int_{lc}}} = D_{2000_{int_{dir}}} * (I - A_{2000})^{-1}$$

$$D_{XXX_{int_{lc}}} = D_{XXX_{int_{dir}}} * (I - A_{XXX})^{-1}$$

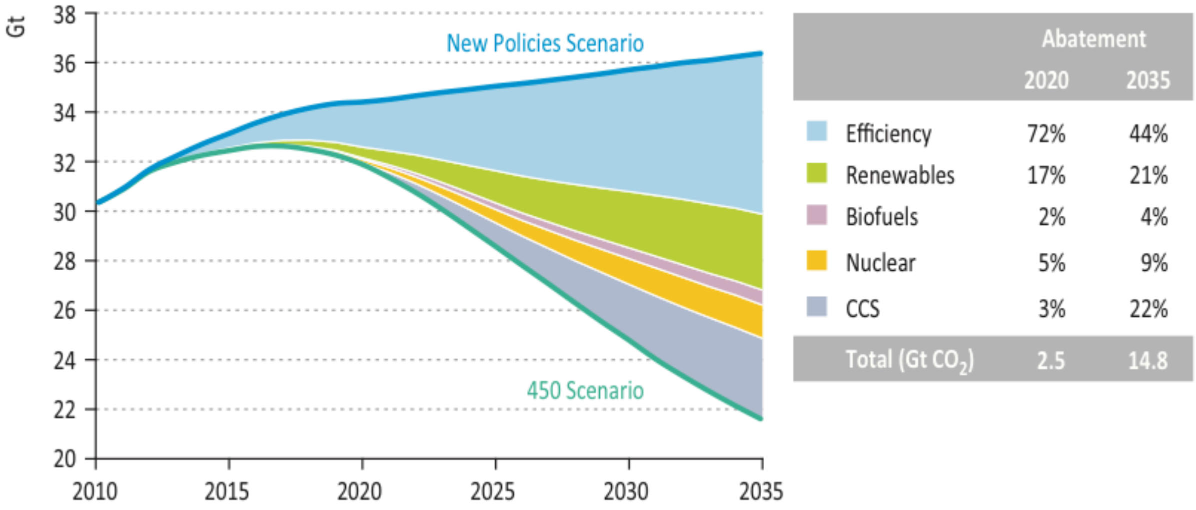
Aggregated Sectors

To develop broader insights about the results, 125 out of the 129 industries have been aggregated into 13 sectors. This allows similar industries to be grouped together into sectors. The results for these aggregated sectors are calculated using the same methodology for 129 industries as described above, but applied to 13 aggregated sectors instead. Note that 4 industries have not been included because these individual industries did not aggregate easily into the 13 defined categories. The industries are listed below, and the results for these industries will be shown in the “129 Industry Comparison” part of the results section.

- p02 - Forestry and logging activities
- p05 - Fishing and fish farms/hatcheries
- p41 - Collection, purification, and distribution of water
- p45 – Construction

450 No Efficiency Scenario

In the IEA scenarios, there are assumptions embedded in the way energy mixes are defined, such that there are changes in energy efficiencies between the energy producing categories (Power Generation and Other Energy) and the energy end-use categories (Industry, Buildings, Transport, Other). This can be seen in Figure 4, which shows the large role that energy efficiency plays in the 450 scenario. However, to study how much of the change in impact can be attributed to energy efficiency rather than to changes in energy mix alone, a “450 No Efficiency” scenario has been created.



	Abatement	
	2020	2035
▨ Efficiency	72%	44%
🟩 Renewables	17%	21%
▨ Biofuels	2%	4%
🟨 Nuclear	5%	9%
▨ CCS	3%	22%
Total (Gt CO_2)	2.5	14.8

Figure 4 - World energy-related CO2 emissions abatement in the 450 Scenario relative to the New Policy Scenario (IEA 2011)

In this scenario, the 4 IEA energy end-use categories (Industry, Buildings, Transport, Other) retain the same energy mixes as with the original 450 scenario. The only difference with the 450 No Efficiency scenario is in the Power Generation and Other Energy categories, where the columns for the 24 industries associated with the PG and OE categories are changed to the original year 2000 A matrix columns. By keeping the PG and OE columns of the A matrix the same as in year 2000, we assume that these categories have the same energy input requirements per unit energy output, thus negating any gain in energy efficiency between the energy producing categories and the end use categories.

Similarly, the PG and OE columns in E_int_XXX have been replaced by E_int_2000, showing that emissions intensities also do not change in those categories. Therefore, in this scenario, all changes in impacts for future scenarios are only a result of changes in the 4 energy mixes of the energy end use categories (I, B, T, O). This scenario is not a major feature of the results section, but has only been conducted to show the significance of energy efficiency.

Results

The results based on integrating the three IEA scenarios into the EXIOPOL EEIO will be split into two sections. In the first section, the results for the 13 aggregated sectors will be presented, comparing the impact intensities of these sectors across the three IEA scenarios as well as the year 2000 EXIOPOL data. These 13 aggregated sectors will also be compared in other graphs showing the relative change between scenarios, the differences in energy mix, as well as the environmental performance in other impact categories. In the second part of this results section, the results for all 129 industries will be shown, with detailed figures showing the relative change of every industry according to each scenario.

It is important to clearly define some of the terminology used before proceeding to the results. For the remainder of this report, the word impact will refer to the GWP100 impact category, unless explicitly stated otherwise. As such, the word “impact” may be used interchangeable with the word “emissions”, since we are referring to CO2e emissions. Also, the word “intensity” may be used interchangeably with the word “unit”, such that “unit emissions” is equivalent to “impact intensity”. There will be one graph showing other impact categories, but the main focus of this entire report is on climate change impacts. Also, the word “sector” is used to describe an aggregated group of “industries”. Finally, as previously mentioned, the word “industries” actually refers to “products from particular industries”. This distinction is made because in Input Output terminology, a product-by-product SIOT table was used, rather than an industry-by-industry table.

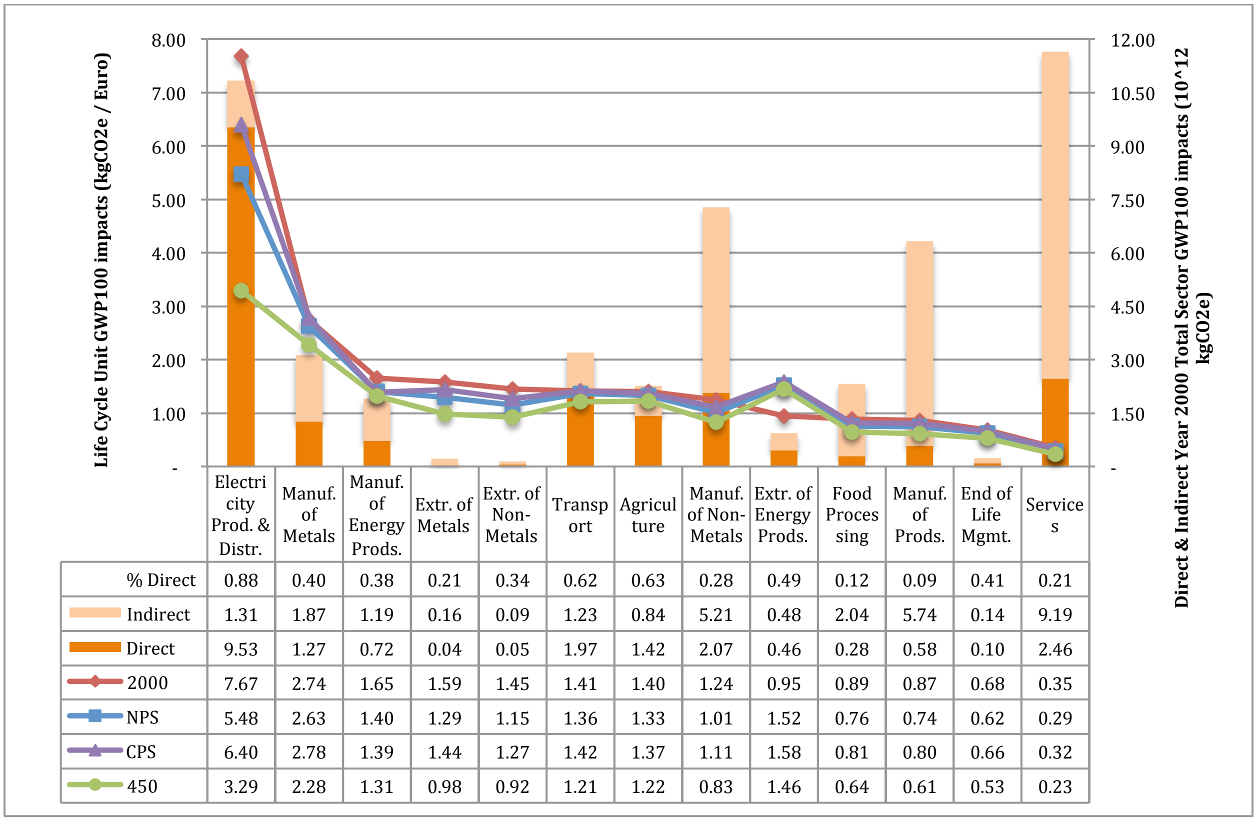
All changes in impacts are a result of a combination of changing energy mixes as well as energy efficiency gains. Energy efficiency gains relate to how much energy input is required per unit energy output. However, changes in emission intensities (emissions per unit energy) are not modeled and are assumed to be the same as year 2000 levels. This may underestimate the emissions reduction outlined in certain scenarios, such as the 450 scenario, which relies on CCS for 22% of the emissions reduction, as shown in Figure 4.

Aggregated Sector Comparison

The results for the 13 aggregated sectors are shown in Figure 5, with the life cycle impact intensities (kgCO2e / Euro) plotted as line graphs. The different colors of line graphs represent the different scenarios, with the red line showing the year 2000 data from EXIOPOL. The sectors are organized from highest emission intensity on the left, to lowest emission intensity on the right, based on the year 2000 red line graph. The data from which these graphs are based on is shown below in the data table. The orange bar graphs show the size of each sector's impact from a flow perspective, meaning the total impact of all industries grouped into each sector is added up throughout the economy. This gives an indication of the size of the sector in the economy, with the dark orange bars representing the direct emissions, and the light orange bars representing the indirect emissions. These bar graphs are based on the EXIOPOL year 2000 data, and not on the data from other scenarios, since the methodology was not designed to accurately model flow results, but rather for unit results only. The bar graphs representing flow results are plotted on the secondary Y-axis to the right, with units of Gt CO2e. To calculate the total emissions across the economy, only the direct emissions of each sector should be added together, since including indirect emissions would involve double counting. For clarity, in the data table below, the first row of data shows the percentage of impact that is direct, relative to the lifecycle impact. Note that the units for this row are such that 0.88 actually means 88% direct impact. Note that all impact intensities in the results section are given in the unit kgCO2e / Euro.

Judging from the life cycle impact intensities, electricity production and distribution is clearly the highest at 7.67 in year 2000. Burning coal, oil, and gas releases a large amount of direct emissions. Since unit emissions are calculated on a per Euro basis, emissions from electricity generation is particularly high due to the amount of energy input per Euro, since it is an energy sector. However, this sector is also where the greatest change in impact intensity occurs between the scenarios, with the 450 case leading to a drop to 3.29. Since electricity is used in many sectors and also makes up a large part of the upstream emissions of a sector, this significant decrease in unit emissions from power generation is one of the major causes of decreases in the life cycle impacts of downstream sectors throughout the economy.

The second highest emitting sector is manufacturing of metals at 2.74, due to its energy intensive processes. In general, sectors relating to the extraction and manufacturing of energy and materials, along with transportation and agriculture, are relatively high emitting sectors ranging from 1.65 - 0.95 in year 2000. One of the main determinants of the impact intensity of a sector is the life cycle energy from fossil fuels per euro of output. The services sector has the lowest impact intensity because it generally has a low life cycle energy per euro of output, since much of the money goes towards value unrelated to energy. The service sector is a particularly large grouping of industries, comprising of 23 industries. One interesting note is the orange bar for services representing the size of this sector, which has the largest life cycle impact of any sector. Conventional process-based LCA databases do not factor in most of the service industries, leading to truncated results that do not capture the life cycle impacts related to services. This is one of the primary arguments for the use of hybrid LCA-IO.



	Electricity Prod. & Distr.	Manuf. of Metals	Manuf. of Energy Prods.	Extr. of Metals	Extr. of Non-Metals	Transport	Agriculture	Manuf. of Non-Metals	Extr. of Energy Prods.	Food Processing	Manuf. of Prods.	End of Life Mgmt.	Services
% Direct	0.88	0.40	0.38	0.21	0.34	0.62	0.63	0.28	0.49	0.12	0.09	0.41	0.21
Indirect	1.31	1.87	1.19	0.16	0.09	1.23	0.84	5.21	0.48	2.04	5.74	0.14	9.19
Direct	9.53	1.27	0.72	0.04	0.05	1.97	1.42	2.07	0.46	0.28	0.58	0.10	2.46
2000	7.67	2.74	1.65	1.59	1.45	1.41	1.40	1.24	0.95	0.89	0.87	0.68	0.35
NPS	5.48	2.63	1.40	1.29	1.15	1.36	1.33	1.01	1.52	0.76	0.74	0.62	0.29
CPS	6.40	2.78	1.39	1.44	1.27	1.42	1.37	1.11	1.58	0.81	0.80	0.66	0.32
450	3.29	2.28	1.31	0.98	0.92	1.21	1.22	0.83	1.46	0.64	0.61	0.53	0.23

Figure 5 – Aggregated sector GWP100 impact intensities across scenarios

Relative Change in Impacts and Energy Mix:

Overview

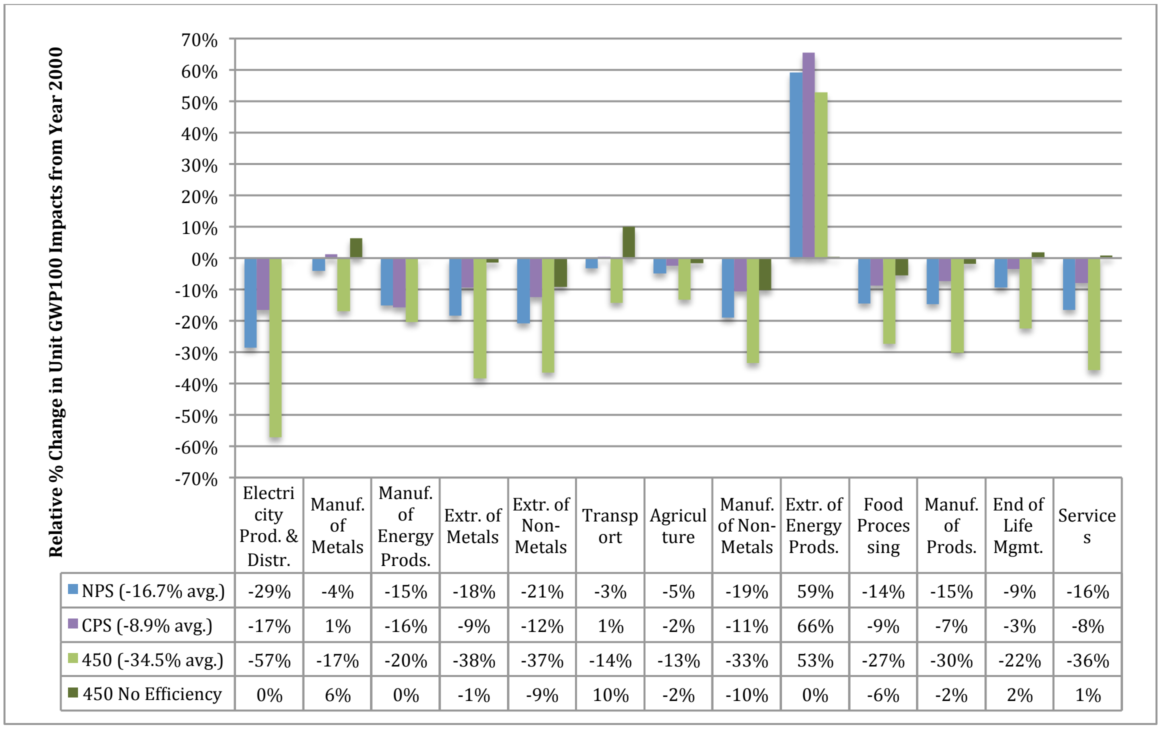
Figure 6 and Figure 7 will be analyzed together in order to understand the relationship between how changes in energy mix can influence relative changes in emissions.

Figure 6 graphs the relative change in impacts of the 3 IEA scenarios relative to year 2000, showing which sectors are particularly influenced by changes in energy supply. The data for the bar graphs are shown in the data table below. The names in the legend next to the data table show the average economy-wide percentage change in emissions for each scenario, such as “NPS (-16.2% avg.)”. This allows for easy comparison to see which sectors reduce emissions beyond the scenario average and vise versa.

Figure 7 shows normalized data for the 17 types of energy inputs across 13 aggregated sectors for year 2000 and the 450 scenario. This figure is the integration of the 17x6 IEA energy mixes shown in Figure 2, disaggregated according to the 13 aggregated sectors instead of the 6 categories defined by the IEA. As described in the methodology section, effort was placed to preserve information between the different sources of energy data, which can be observed in this figure with the integration of the IEA scenario energy mixes and the existing year 2000 energy mixes defined within EXIOPOL. By comparing this figure with Figure 6, correlations between changes environmental impact and changes in energy mix can be observed. Note that all values shown below represent the direct gross energy input UG, not the net energy input, which would be gross energy input UG subtracted by gross energy supply S. Also, note that the names in the legend uses “F_” to represent Fuel, and “PG_” to represent Power Generation.

There are some general trends that can be described regarding changes in energy mix between the 3 IEA scenarios and the year 2000. First, natural gas consumption across all sectors remains relatively stable, whereas large reductions in coal and oil consumption are observed in many sectors. For electricity generation, coal is dramatically reduced and offset by the rise of renewables like wind and other renewables. Oil consumption across all sectors decrease, displaced by an increase in F_Biomass and Waste and as well as in electrification of sectors.

First, sectors that showed high reduction in impact relative to the scenario average will be analyzed, followed by sectors that showed low reduction in impact. When analyzing a sector, the relative changes in life cycle impact intensities from Figure 6 will be described, followed by an analysis of the changes in the energy mix used in that sector from the 450 scenario, shown in Figure 7.



	Electricity Prod. & Distr.	Manuf. of Metals	Manuf. of Energy Prods.	Extr. of Metals	Extr. of Non-Metals	Transport	Agriculture	Manuf. of Non-Metals	Extr. of Energy Prods.	Food Processing	Manuf. of Prods.	End of Life Mgmt.	Services
NPS (-16.7% avg.)	-29%	-4%	-15%	-18%	-21%	-3%	-5%	-19%	59%	-14%	-15%	-9%	-16%
CPS (-8.9% avg.)	-17%	1%	-16%	-9%	-12%	1%	-2%	-11%	66%	-9%	-7%	-3%	-8%
450 (-34.5% avg.)	-57%	-17%	-20%	-38%	-37%	-14%	-13%	-33%	53%	-27%	-30%	-22%	-36%
450 No Efficiency	0%	6%	0%	-1%	-9%	10%	-2%	-10%	0%	-6%	-2%	2%	1%

Figure 6 – Percent change in GWP100 impact intensities of future scenarios relative to year 2000

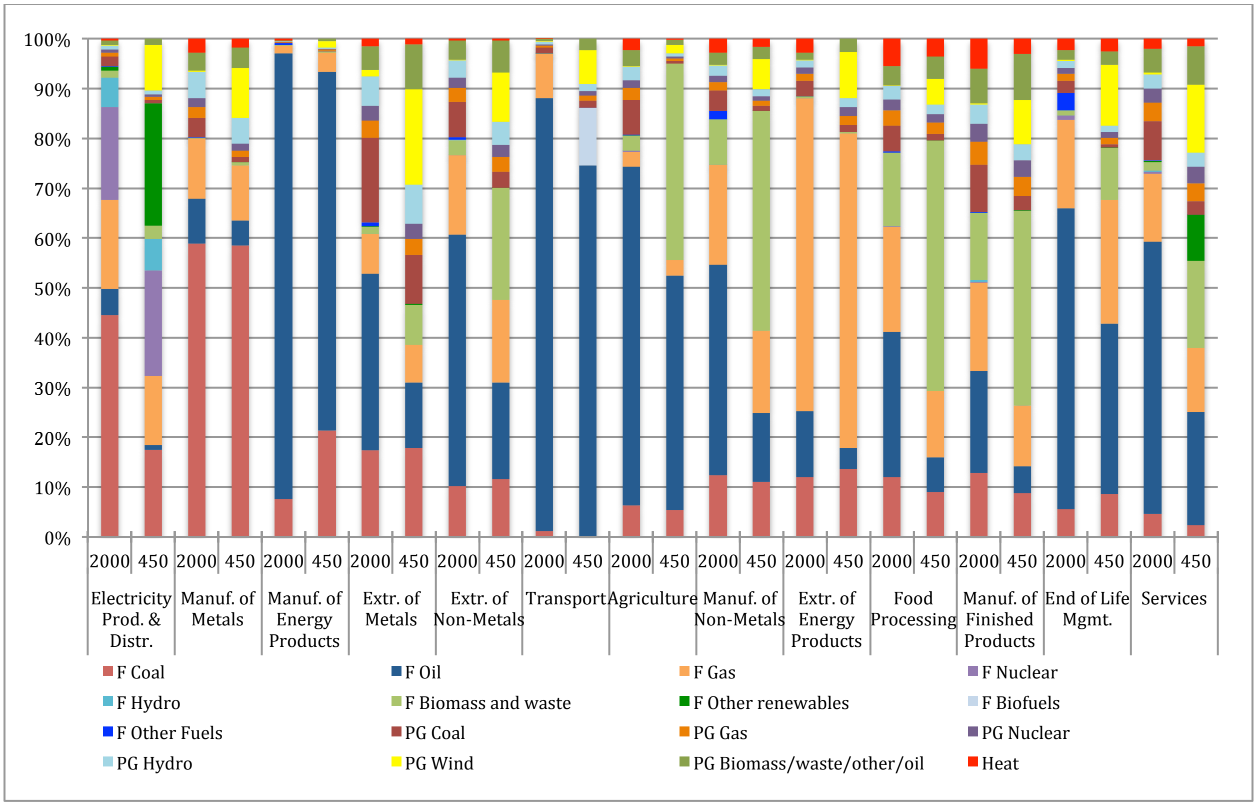


Figure 7 – Aggregated sector energy mixes for year 2000 and 450 scenario

High Reduction in Impact

Electricity Production and Distribution

In analyzing the sectors that show above average reductions in impact, it is clear that the power generation sector sees the greatest reductions out of all of the sectors. Since Electricity production is where the changes to energy mix most affects, this is where the greatest changes happen. This is also the biggest sector, with the highest direct impacts, both in aggregate and as a percentage 88%. Across all 3 scenarios, the rate of reduction is roughly double the average economy-wide emissions reduction.

As can be seen from Figure 7, this large reduction in the power generation sector's impact intensities can largely be attributed to increase of F_Other Renewables from 1% to 24% of total mix in the 450 scenario. Note that while the notation "F_" means fuel, in the context of F_Other Renewables, this refers only to primary energy input such as wind and sun, and as such may not fit into the conventional definition of fuel. In addition to changes in renewables, there has also been a large reduction of oil in the power generation sector as an input. Nuclear sees a slight increase from 19 to 21% while natural gas declines from 18 to 14%.

Other Sectors

In the 450 scenario, the average economy wide change in impact intensity relative to year 2000 is -34.5%. Aside from the Power generation and distribution sector, few other sectors show substantial increases relative to the average. Generally, the sectors where electricity make up a large part of the energy mix are the ones that are influenced the most. This is because with electricity, there is greater scope for emissions reduction, since there are so many alternative sources such as nuclear, hydro, and renewables. Sectors that depend on fuels such as oil generally have less scope for emissions reductions.

The sectors that showed the greatest reductions in emission intensities all had dramatic increases in electrification in their energy mixes, which came mainly from renewable sources in the 450 scenario. This includes the extraction of metals (-38%), extraction of non-metals (-37%), and services (-36%) sectors.

Low Reduction in Impact:

The sector that stands out the most in Figure 6 is the Extraction of energy products sector, which has a major increase in emission intensities for all 3 IEA scenarios, while most other sectors showed a decrease. Looking at the changes in energy mix for this sector does not point to an obvious reason why there is such a large increase in impact intensity. The reason for this was partly explained in the methodology section, as there is a flaw in the methodology that was used in this research which incorrectly modeled the Extraction of crude oil industry, showing a much higher than expected impact intensity for this industry. This error will be further discussed later in the “129 industry comparison” part of this results section.

In general, sectors that have a high dependence on fuels in the year 2000 show lower than average reduction in impact intensities. This is because there is less scope for reductions in emissions from fuels like oil, as compared to the electricity sector. From Figure 7, it can be seen that oil consumption was reduced throughout the economy. However, due to the flaw in calculating the upstream impacts associated with extraction of crude oil, downstream sectors that consume oil saw less than expected reductions in impact intensity.

The three sectors that depended most heavily on oil are the three sectors that showed the least reduction in impact intensities. These sectors are manufacturing of metals (-17%), transport (-14%) and agriculture (-13%) in the 450 scenario, which relied on oil for 89%, 87%, and 68% of their energy mix respectively. To displace oil emissions, the main options are to use biofuels or to increase electrification of the sector, thus creating more options to use less emission intensive sources. For example, this is what was done in the transport sector, where biofuels increased to 12% of the energy mix and electrification by wind and biomass displaced 9% of fuel input in the 450 scenario.

450 No Efficiency

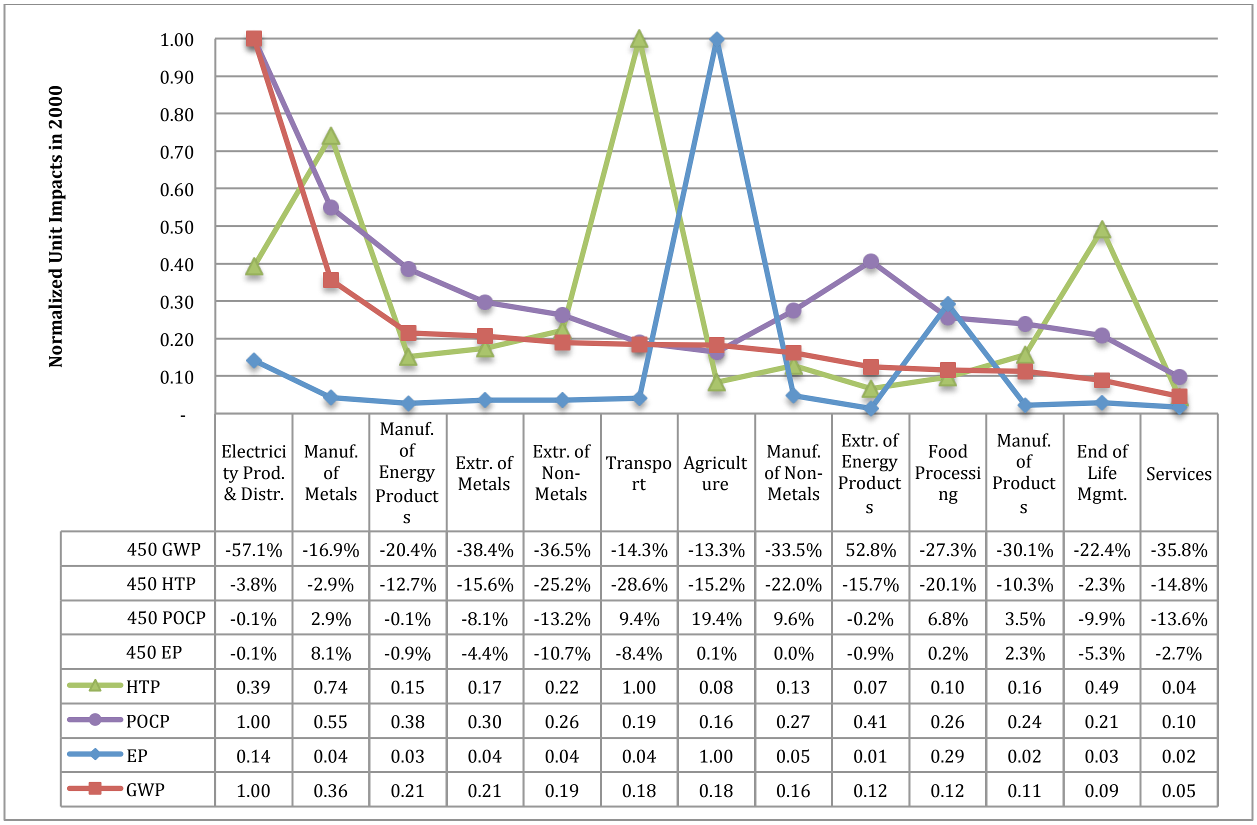
In Figure 6, a fourth scenario called “450 No Efficiency” is shown in dark green bars, along with the other three IEA scenarios. The methodology used to calculate this scenario has been described in the methodology section. This scenario reflects only changes in energy mixes for energy end use sectors, but does not show any changes in the energy producing sectors such as Extraction of energy products, Manufacturing of energy products, and Electricity production and distribution. Comparing this scenario to the regular 450 scenario will show how energy efficiency influences the overall result. As can be seen, compared with the other three IEA scenario, the 450 No Efficiency scenario shows the least change in emission intensity across all sectors. This shows the overwhelming influence of the role of energy efficiency, which are assumptions embedded within the energy mixes defined by the IEA. Note that changes in energy efficiencies over time are not only a result of improved efficiencies in energy technologies, but also from the replacement of old inefficient energy infrastructure over time.

Other Impact Categories

Although the focus of the analysis is primarily on GWP100 impacts, Figure 8 shows a graph of how different environmental impact categories compare across these aggregated sectors. All of the lines shown in this figure are based on year 2000 data from EXIOPOL. The percentage change from year 2000 in the 450 scenario has been outlined in the data table, but not graphed. The GWP impacts are graphed along with the Photochemical Oxidation Potential (POCP), Human Toxicity Potential (HTP), and Eutrophication Potential (EP), with each impact category normalized to the highest emitting sector.

The various impact categories follow mostly similar trends to the GWP curve, with a few particular exceptions. For EP, Agriculture is the highest impact category, followed by Food Processing, with the remaining other sectors having much lower EP impacts. For HTP, Transport has the highest impacts, and Manufacturing of metals and End of life management both have higher HTP impacts than Electricity production. POCP generally follows a similar trend as GWP, aside from Extraction of energy products having slightly higher impacts. The Services sector enjoys low impact across all impact categories.

As for the 450 scenario, the changes in energy mix for this scenario have the greatest overall impact on GWP impact category, decreasing GWP by 35% on average throughout the economy. For HTP, the Transport sector had the highest impact in year 2000, but sees a significant decrease of 28.6% in the 450 scenario due in part to the transition towards biofuels and the electrification of vehicles. The 450 scenario had little effect on highest impacting sectors for POCP (Electricity production) and EP (Agriculture), as these sectors saw less than 0.1% change from year 2000 levels.



	Electricity Prod. & Distr.	Manuf. of Metals	Manuf. of Energy Products	Extr. of Metals	Extr. of Non-Metals	Transport	Agriculture	Manuf. of Non-Metals	Extr. of Energy Products	Food Processing	Manuf. of Products	End of Life Mgmt.	Services
450 GWP	-57.1%	-16.9%	-20.4%	-38.4%	-36.5%	-14.3%	-13.3%	-33.5%	52.8%	-27.3%	-30.1%	-22.4%	-35.8%
450 HTP	-3.8%	-2.9%	-12.7%	-15.6%	-25.2%	-28.6%	-15.2%	-22.0%	-15.7%	-20.1%	-10.3%	-2.3%	-14.8%
450 POCP	-0.1%	2.9%	-0.1%	-8.1%	-13.2%	9.4%	19.4%	9.6%	-0.2%	6.8%	3.5%	-9.9%	-13.6%
450 EP	-0.1%	8.1%	-0.9%	-4.4%	-10.7%	-8.4%	0.1%	0.0%	-0.9%	0.2%	2.3%	-5.3%	-2.7%
▲ HTP	0.39	0.74	0.15	0.17	0.22	1.00	0.08	0.13	0.07	0.10	0.16	0.49	0.04
● POCP	1.00	0.55	0.38	0.30	0.26	0.19	0.16	0.27	0.41	0.26	0.24	0.21	0.10
◆ EP	0.14	0.04	0.03	0.04	0.04	0.04	1.00	0.05	0.01	0.29	0.02	0.03	0.02
■ GWP	1.00	0.36	0.21	0.21	0.19	0.18	0.18	0.16	0.12	0.12	0.11	0.09	0.05

Figure 8 – Aggregated sector impact intensities across 4 different impact categories

129 Industry Comparison

Overview:

The life cycle GWP100 impacts results for all 129 industries are plotted in Figure 9 to Figure 14. Unless stated otherwise, the word impact refers to GWP100 impacts, expressed in kgCO2e / Euro. These results give us an in-depth look at how each individual industry performs. Given the complexity and large amount of data within the EXIOPOL EEIO table, it is useful to have a graphical representation of this data. This can be useful for hybrid LCA-IO practitioners to know within this large database, what the unit impacts of each industry are and how changes in energy mixes could influence industries differently. Such knowledge could guide practitioners to focus particular attention on the industries that could have a significant impact on their results, and ensure good quality data is obtained for those industries.

Figure 9, Figure 11, and Figure 12 show year 2000 data from EXIOPOL. The proportion of direct and indirect life cycle unit GWP impacts are shown in the blue and orange bar graph. The magnitude of the unit life cycle impacts shown in the red bar graph, plotted on a logarithmic scale, with the data labels showing the actual values in kgCO2e / Euro. Note that these figures only represent data that is already part of EXIOPOL for year 2000. Average industry emissions in year 2000 are 1.53, with a maximum of 30.45 (PG from coal) and a minimum of 0.15 (p70 - Real estate activities).

Figure 10, Figure 12, and Figure 14 show the relative percent change in unit impacts from year 2000 levels corresponding to each of the 3 future IEA scenarios. The orange line shows the overall change in emissions across the entire economy for that particular scenario. This orange line serves as a benchmark for how industries within a particular scenario perform, relative to the economy wide average. Given the large amount of information displayed in these figures, only the industries that show significant deviations from the benchmarked orange line results will be discussed.

First, the industries that increase emissions by 30% or more beyond the average for the NPS scenario (-16.7%) , will be discussed. Note that industries that outperform the economy wide average in the NPS scenario, tend to also outperform the average in the other scenarios as well, although this is not strictly always the case. The NPS scenario was selected as the basis for selecting which industry results to present below, since this is the main scenario that the IEA focuses on for the WEO 2012. Afterwards, the industries that reduce emissions by 20% or more beyond the average for the NPS scenario (-16.7%) will be discussed.

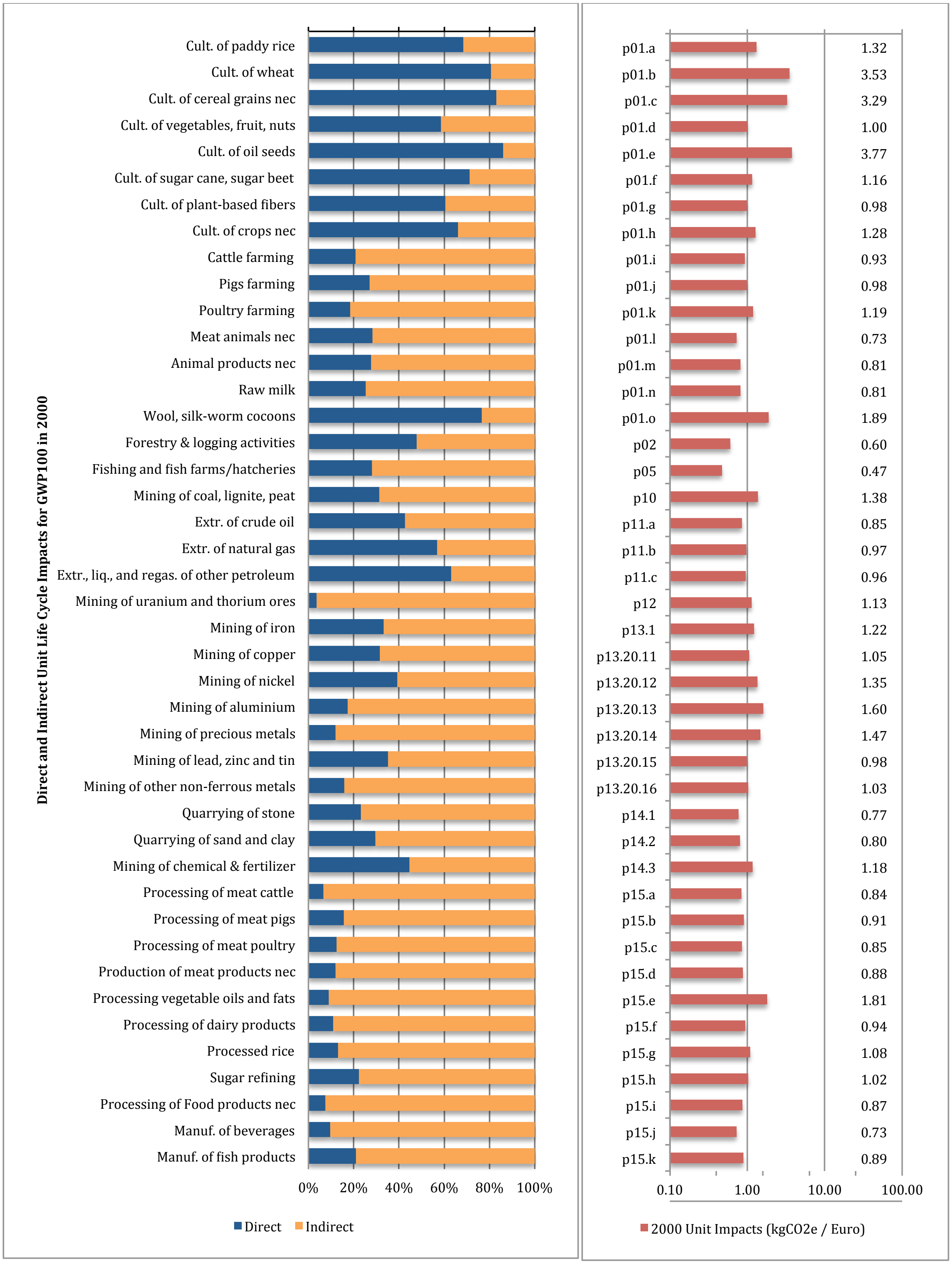


Figure 9 –Lifecycle impact intensities of industries 1-43 in year 2000

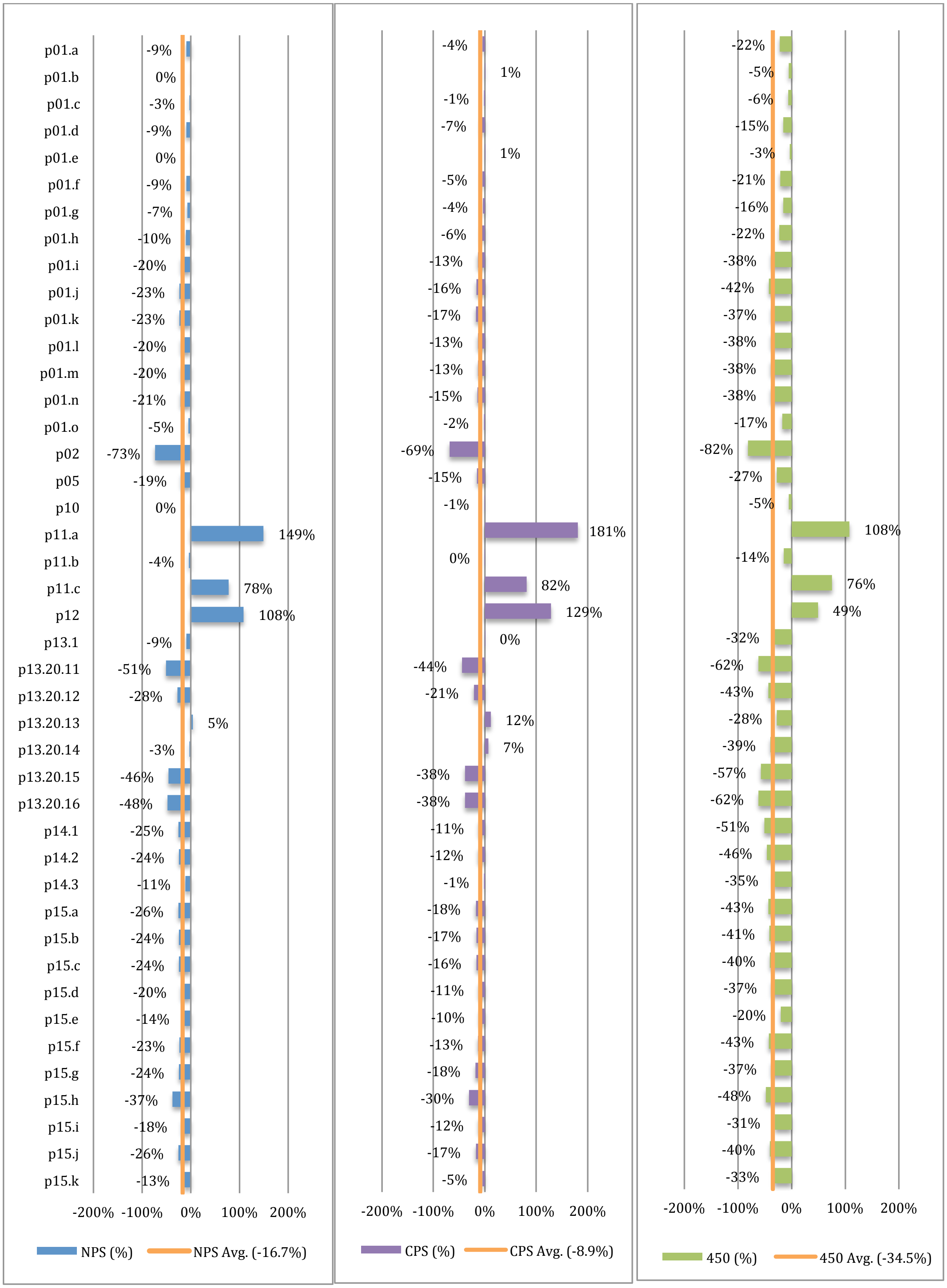


Figure 10 – Relative change in lifecycle impact intensities between future scenarios and year 2000 for industries 1-43

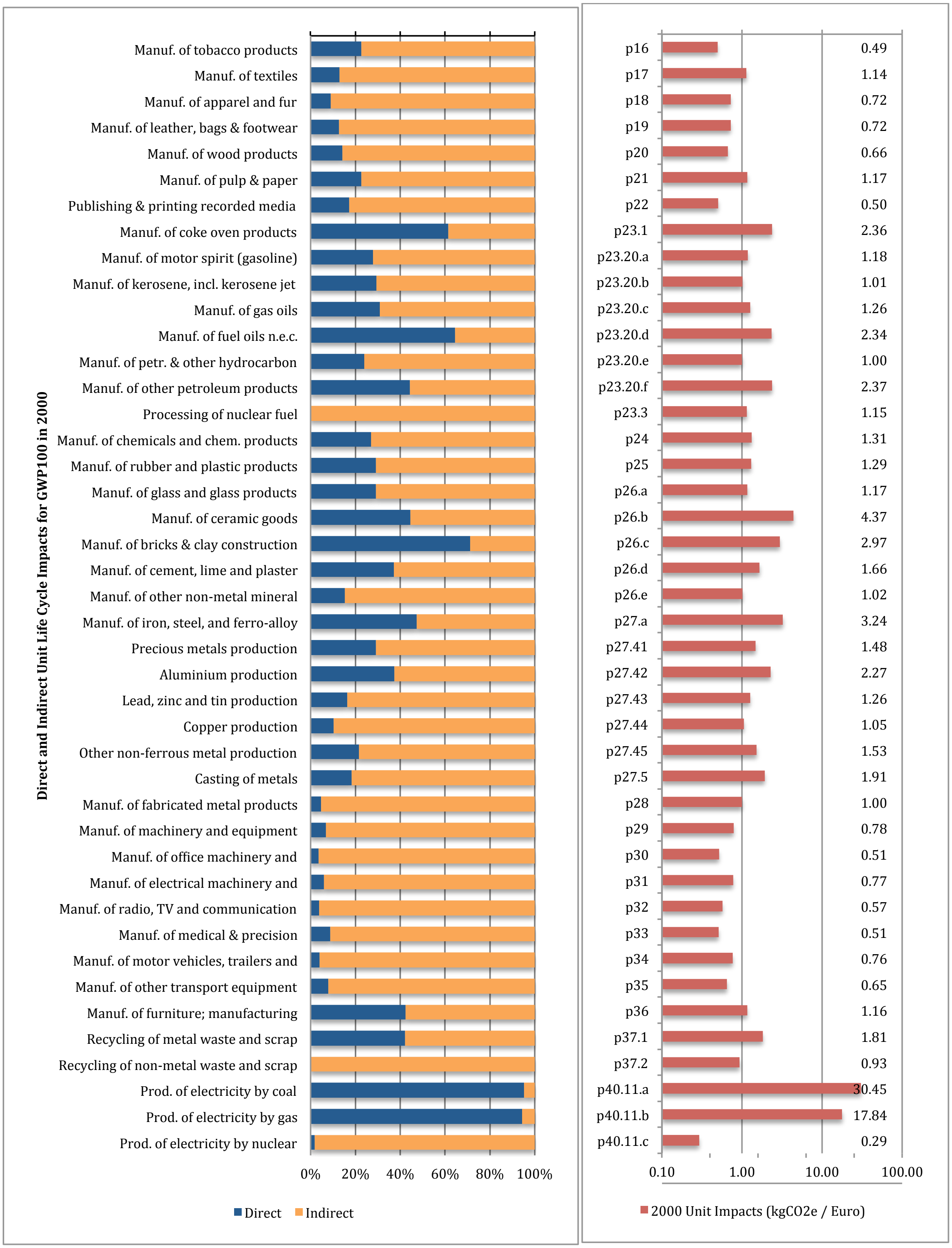


Figure 11 – Lifecycle impact intensities for industries 44-86 in year 2000

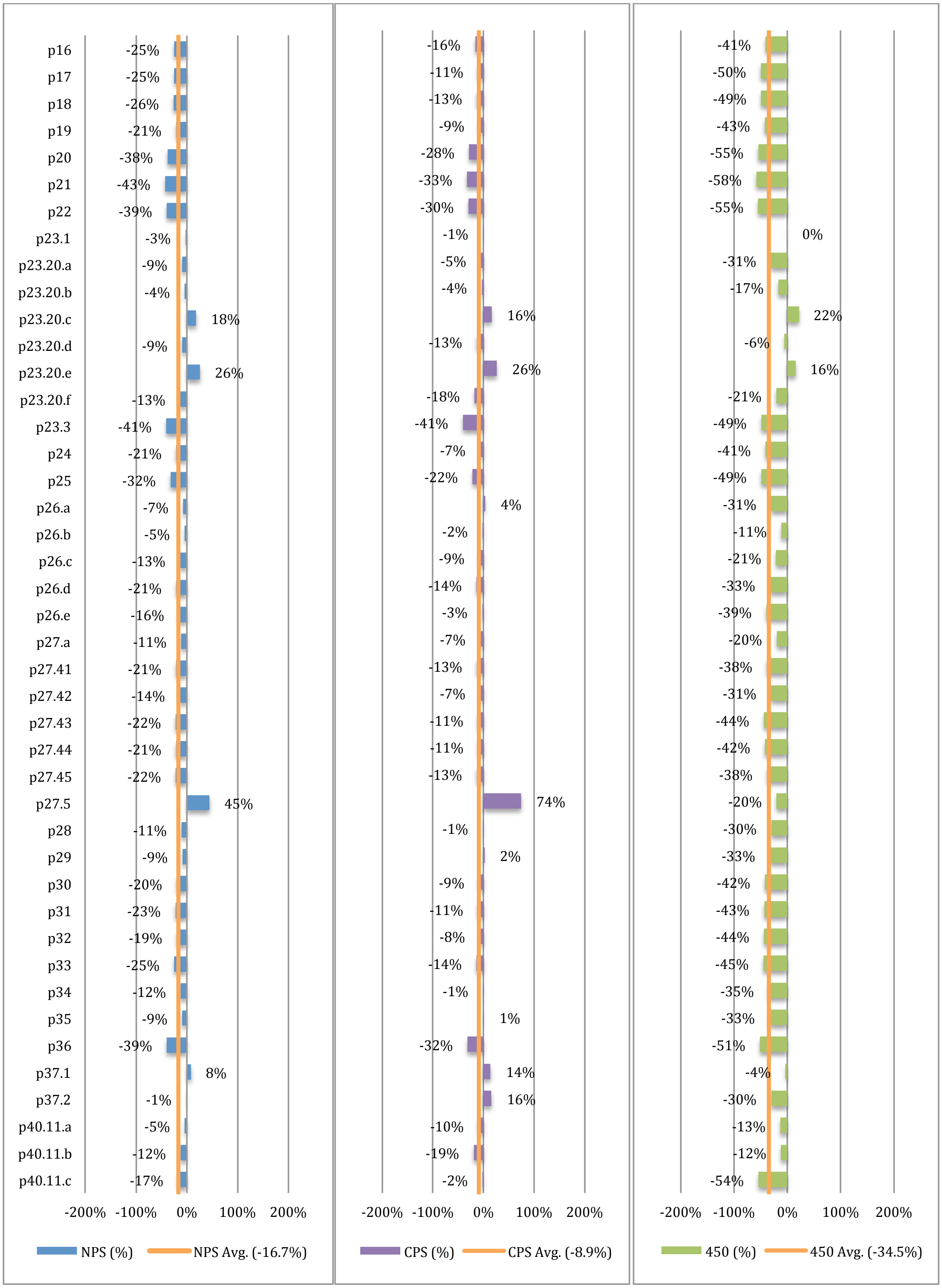


Figure 12 - Relative change in lifecycle impact intensities between future scenarios and year 2000 for industries 44-86

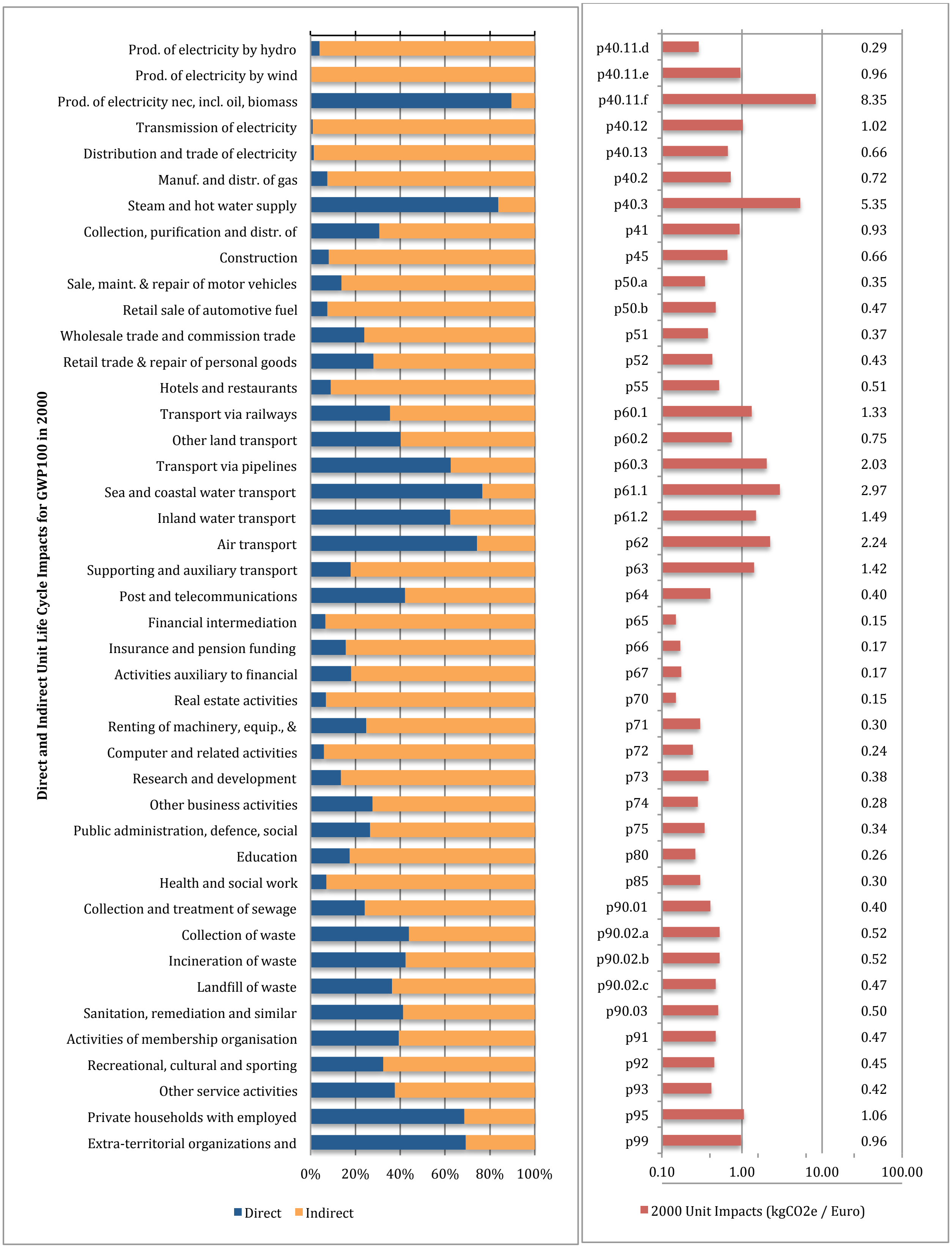


Figure 13 – Lifecycle impact intensities of industries 87-129 in year 2000

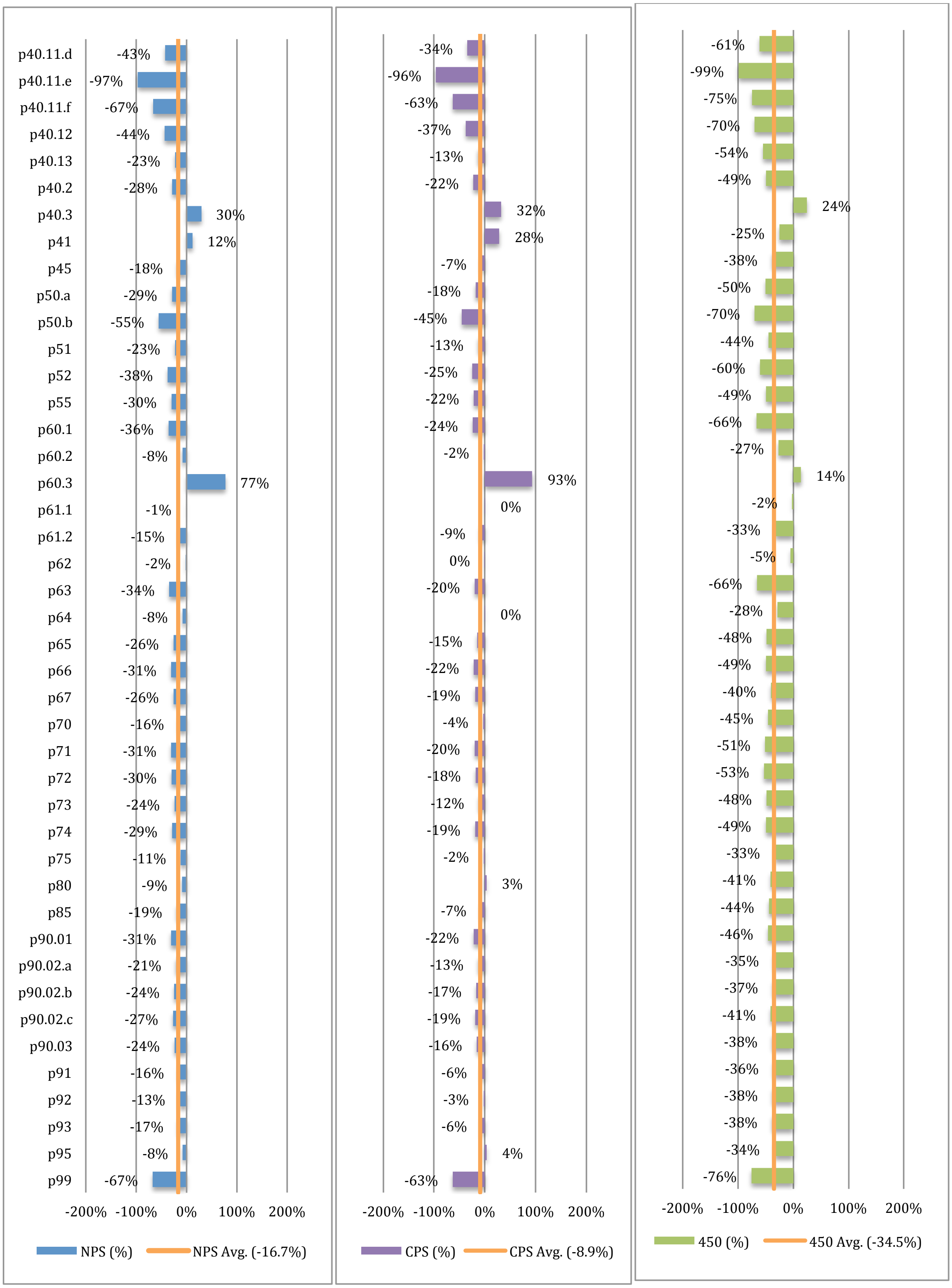


Figure 14 - Relative change in lifecycle impact intensities between future scenarios and year 2000 for industries 87-129

High Increase in Impact

Extraction of Energy Products

From the aggregated sector impacts, it was shown that the industries related to the extraction of energy products show an unusual increase in impact intensities, whereas most other industries show a decrease relative to year 2000. Reasons for this have been explained previously in the methodology section, but now it is possible to analyze which specific industries show the most unusual changes within this aggregated sector ranging from p11.a to p12.

It is clear that p11.a - Extraction of crude petroleum and related services has the highest increase in impact intensity of all 129 industries. For the NPS, extraction of crude oil shows a 149% increase in impact intensity compared to year 2000. This is due to a flaw of this methodology that only affects the extraction of crude oil industry. This is because extraction of crude oil does not primarily depend on oil products as an energy input to the industry. Instead, 72% of its energy input is from natural gas, and only 20% from oil. In such situations where the energy producing industry does not primarily use the same type of energy as an input to the industry, this methodology runs into trouble. For most energy transformation industries, this is not the case, and so is accurately calculated with this methodology. For example, oil refining requires oil as an input. Power generation from coal mainly relies on coal as an input.

The reason that extraction of crude oil has such a dramatic increase in impact intensity is because downstream oil consumption decreases significantly, while the energy input to the industry increases slightly. Decreasing downstream demand for oil lowers the total output X for extraction of crude oil, thus when calculating the impact intensity figures, which is now divided by a much smaller X, the impact intensity for extraction of crude oil is much higher.

Hypothetically, if extraction of crude oil did primarily depend on oil as an input, then there would be a significant decrease in energy input, since the IEA shows a significant decrease of oil consumption in the energy mix for the Other Energy category. Thus, the energy input would have decreased significantly to match the downstream decline in oil consumption. However, since this industry primarily depends on natural gas, which slightly increases in prominence for future scenarios, there is a net increase in energy input for the crude oil extraction industry.

In addition to extraction of crude oil, there are two other industries that also demonstrate abnormally high increases in emission intensities. For p11.c - Extraction, liquefaction, and regasification of other petroleum and gaseous materials, a 78% increase in impact intensity relative to NPS was observed. The underlying reason is similar to extraction of crude oil, as 89% of the energy input for this industry is from natural gas. For p12 - Mining of uranium and thorium ores, a 108% increase in impact intensity from NPS was observed. This industry relied on oil to supply 72% of its energy input. Over 95% of the life cycle impacts for this industry is indirect, most of which is associated with higher than expected impact intensity for extraction of crude oil.

Other Industries

Beyond the industries associated with the Extraction of energy products sector, there were a few other industries that showed unusually high impacts. The industries highlighted below all show an increase in GWP impact intensity by 30% or more beyond the average for the NPS scenario (-16.7%) . In general, industries that have an extremely high dependence on oil as an energy input (>90%), but are not in the energy extraction sector, show a large increase in impact intensity. This occurs even if future scenarios show significant decreases of oil in the energy mix. The reason lies in the methodology, because all energy end use categories (Industry, Building, Transport, Other) have their energy input rescaled back to year 2000 levels.

For example, the industry p23.2c - Manufacturing of gas oils has 97% of its energy inputs from oil in year 2000, leaving only 3% from other energy sources. In the NPS scenario for the Industry category, oil declines by 65%. However, no matter how much the 3% of other energy sources grew in the NPS scenario, oil would still by far be the largest energy input after rescaling back to year 2000 levels. It is important to note that this is not a flaw in the methodology, because an industry such as manufacturing of gas oils that relies on 97% oil energy input, cannot be expected to experience major changes types of energy input. Thus, the high reliance on oil in the NPS scenario leads to a large increase in upstream emission intensity for the manufacturing of gas oils industry. Similarly, p23.2e - Manufacturing of petroleum and other hydrocarbons (94% oil), p27.5 - Casting of metals (96% oil), and p60.3 - Transport via pipelines (97% oil). For the NPS scenario, these industries increased impact intensity relative to year 2000 by 26%, 45%, and 77% respectively.

There are also factors beyond oil energy input that may lead industries to have increases in impact intensities. P40.3 - Steam and hot water supply, which is part of the “Other Energy” category as defined by the IEA, shows a 30% increase in the NPS scenario, even though the energy input from oil for this industry was only 9%. The reason is because this industry relies on coal for 36% and natural gas for 45% of energy input, both of which go up in significantly in the “Other Energy” category for future scenarios. These changes in energy mix can be observed in Figure 2.

High Reduction in Impact

Electricity Generation

From Figure 5 showing the aggregated sector impacts, it is clear that the electricity production and distribution sector (p40.11.a - p40.11.f) has by far the highest GWP impacts, with an average of 7.79. However, there is a large range in unit impacts within this sector, with coal at 30.45, natural gas at 17.84, and the renewables and nuclear at less than 1.00. For the power generation industries using fossil fuels, over 90% of their life cycle impacts are direct, whereas over 95% of the life cycle impacts of hydro, nuclear, and wind are indirect.

In the 450 scenario, power generation from coal and gas decrease by 13% and 12% respectively, illustrating moderate gains in energy efficiency. The renewables see dramatic improvements, with wind reducing unit emissions by 99%. This large reduction in life cycle emissions from wind was almost entirely due to indirect emissions, which decreased greatly in this scenario.

One particular drawback of EXIOPOL data is that in p40.11.f, power generation from oil is grouped together with power generation from biomass and other renewables such as solar. In the physical energy UG tables, these energy types are kept separate and calculated accurately, but the results are aggregated to fit into the industry classifications used by EXIOPOL. Thus, this industry has emissions of 8.35, although power generation from oil should be higher than gas (>17), and the other renewables should be much lower in value (<2). In the NPS scenario, the unit impacts of this industry reduces dramatically by 67%, which is likely due to a decrease in power generation from oil and an increase in the biomass and other renewables relative to year 2000.

Other Industries

Beyond the industries associated with the Power generation and distribution sector, there were a few other industries that showed higher than average reductions in impact intensities. Before analyzing these industries individually, it is important to refer back to the points made about industries with >90% energy input from oil, described in the prior section on "High Increase in Impact". If industries have >90% energy input from oil, then regardless of how the energy mix changes over time, it is likely to have little effect on the energy input of that industry under future scenarios because other energy inputs have such a small base from which to grow from. But for example, if an industry has such as Forestry and logging activities has 72% energy input from oil and 28% from other sources, then the other energy sources have a much bigger base from which to grow from, which could then have a significant impact on the energy input mix under the new scenario after rescaling.

The industries highlighted in Table 3 all show a reduction in the GWP impact intensity by 20% or more beyond the average for the NPS scenario (-16.7%), and are also part of the IEA "Industry" category. In the right column, this table shows the breakdown in energy input for the three fossil fuels from year 2000. Under the IEA "industry" category in Figure 2, the relative change in energy mix from 2000 to the NPS scenario shows that oil decreases by 65%, gas decreases by 6%, and coal increases by 11%. The significant reduction in oil matched with only a modest increase in coal explains why there are quite a few industries within the IEA "Industry" category that experience significant reduction in impact intensities.

Table 3 – Industries with high reduction in impact intensities in NPS and corresponding energy mix in 2000

Industry Name	Δ% NPS	Energy Mix in 2000
p02 - Forestry and logging activities	-73%	72% oil, 14% coal, 4 gas
p13.20.11 - Mining of copper	-51%	31% oil, 20% coal, 19% gas
p13.20.15 - Mining of lead, zinc and tin	-46%	50% oil, 19% coal, 14% gas
p13.20.16 - Mining of other non-ferrous metals	-48%	44% oil, 26% coal, 11% gas
p20 - Manufacture of wood products	-38%	19% oil, 14% coal, 16% gas
p21 - Manufacture of pulp and paper	-43%	15% oil, 19% coal, 22% gas
p22 - Publishing and printing recorded media	-39%	31% oil, 6% coal, 21% gas
p36 - Manufacture of furniture	-39%	21% oil, 22% coal, 19% gas

The industries that fall within the IEA buildings category also saw some major reductions in impact intensities due to big reductions to all three fossil fuels. From Figure 2, it can be seen that there is a reduction of 57% for coal, 66% for oil, and 24% for gas in the NPS scenario. The IEA buildings category saw the greatest changes in energy mix out of all six categories defined by the IEA. For example, p50.b - Retail sale of automotive fuel reduced impact intensity by 55% in NPS. This industry had an energy input of 56% from oil, 5% from coal, and 24% from gas in year 2000, all of which decreased significantly in the NPS scenario. Also, p99 - Extra-territorial organizations experienced a 67% reduction in impact intensity in NPS, with large decreases across all three fossil fuels used as energy inputs.

Discussion and Conclusion

Goal Completion

The main focus of this research was to develop a method to efficiently and accurately integrate energy mixes from multiple IEA future world scenarios into the EXIOPOL EEIO. This has been done successfully, producing technical coefficient A matrices and emission intensity E_int matrices that can be readily used in hybrid LCA-IO analyses. This methodology uses energy in physical units as the basis for all modifications to the input-output monetary tables, which may be more accurate than purely monetary methods, especially for environmental analysis purposes. Moreover, one of the motivations of this research was to develop a method that would be efficient with respect to research effort. While the task of replacing energy mixes within an IO table proved to be more difficult than initially expected, it was ultimately achievable. This methodology was successfully developed and completed over the course of a 4 month masters project, and can be readily used to integrate other energy scenarios beyond the ones considered in this research.

The second aim of this research was to analyze the EXIOPOL data and compare the environmental performance across different industries. The emission intensities of all 129 industries have been analyzed under the base year 2000, along with the 2035 IEA scenarios for NPS, CPS, and 450. The relative changes from the year 2000 for every industry is graphically shown, outlining which sectors see both above and below average levels of change, and are also benchmarked against the average change in impact intensities under the respective scenarios. 125 of these industries were aggregated into 13 sectors and compared once again, identifying general patterns in emission intensities and breakdowns between direct and indirect emissions between sectors.

Quality Assessment

Internal Quality Assessment

Strengths of model

The methodology used to incorporate future energy scenario information into EXIOPOL strikes a good balance between accuracy and efficiency of research effort. It utilizes credible future energy scenarios by the IEA, and integrates it into the energy extensions of EXIOPOL. Every calculation step that required aggregating and disaggregating data was done carefully to limit the amount of information loss between the three different sources of energy data: IEA_UG_2000 (17x6), UG_2000 (62x129), and energy-related industries in Z_2000 (24x129). For example, the original structure of the energy mix in each of the 129 industries was preserved, and relative changes in energy mixes as defined from the IEA scenarios were applied. Also, this methodology modeled energy efficiency gains between the energy producing categories and the energy end-use categories, which are implicitly defined based on the energy mixes defined by the IEA scenarios.

Limitations of model

Despite the strengths of this research, there are also some limitations that should be discussed. As noted in the results section, the model used for this research produced inaccurate results for the extraction of energy products sector. In particular, the extraction of crude oil and of uranium both saw dramatic increases in emission intensities, even as most other industries saw great reductions. This is due to the methodology used, which for these particular cases, did not properly adjust energy input relative to changing energy output, for the reasons stated in the methodology and results sections. If these processes were modeled more accurately, it could lead to a further reduction in life cycle emission intensities for industries that rely heavily on oil. Aside from these two industries however, the other industries are thought to be modeled accurately.

Changes in emission intensities have not been included, as they are assumed to remain at the same level as year 2000. Such changes would have been difficult to include, unless data from the IEA modeling was readily available for this. For example, the 450 scenario relies on CCS for 22% of the emissions reduction relative to the NPS scenario in 2035 (IEA 2011). This information is currently not modeled in this research, however, such modeling would likely reduce life-cycle emission estimates as well.

The structure of the economy is assumed not to change from the year 2000. Changes to this could be done by utilizing techniques such as RAS, GRAS, and SPAD to modify the monetary tables. However, such changes are thought to be less significant relative to changes in energy mix and energy efficiencies, particularly if the end goal is to produce a normalized A matrix, rather than a Z flow matrix. It is worth noting however, that the IEA scenario projections do account for changes in the structure of the economy, which lead to the energy mixes they have for their future scenarios. Only the energy mixes for the year 2035 have been directly incorporated into EXIOPOL.

Also, given that the aim is to produce a modified A matrix to represent future energy scenarios, the changes made only influence the interindustry production elements. The IEA scenarios represent energy use throughout the entire economy, including both production and final consumption. The assumption was made that the changes in energy mix modeled by the IEA, which includes final consumption, are the same as the energy mix that affect only the interindustry production elements of EXIOPOL. This research does not make any modifications to the final consumption and value added parts of the IO table, nor does it account for changes in capital infrastructure. Therefore, this research cannot be used to address research questions focused on changes in consumption patterns.

One of the limitations of the IEA energy scenario data from the World Energy Outlook is that it presents energy mix data at a resolution of 6 categories (PG, OE, I, B, T, O), while EXIOPOL has a 129-industry resolution. Obviously, if there was higher resolution data available that further disaggregates the 6 categories represented in the IEA scenarios, the modeling of energy mixes within each of the 129 industries would be more accurate.

External Quality Assessment

To evaluate the accuracy of the EXIOPOL model of the IEA scenarios, a comparison can be made with the emission figures reported by the IEA, shown in Table 4. There is an obvious change in Total Primary Energy Demand (TPED) over time, as the IEA models an increase from 9,179 MtCO2 in 2000 to 16,961 MtCO2 in 2035 under the NPS. Since the primary aim of this research was to obtain an accurate A matrix, not a Z matrix, the TPED of future scenarios were scaled back to the same level of TPED in 2000. This was done to calculate relative changes in the energy mix on a comparable basis in our methodology. Therefore, the total CO2 emissions calculated using EXIOPOL for future scenarios cannot be directly compared with the emission figures given by the IEA. Instead, the emission figures from the IEA scenarios are scaled back based on the percent difference in TPED between the scenario and year 2000. This allows for the comparison between the scaled back IEA emissions with the calculated figures from EXIOPOL.

The last two lines of **Error! Reference source not found.**Table 4 show the relative percent change in emissions relative to year 2000 for both the scaled IEA figures and the calculated ones. For both NPS and

CPS, the calculated EXIOPOL change in emissions show greater reductions relative to 2000 than the scaled IEA figures by 3.6% and 4.9% respectively. However in the 450 scenario, the opposite trend is observed, as the scaled IEA figures show a 6.7% greater reduction in CO2 compared to the calculated emissions. This may be due to the fact that changes in emission intensities are not modeled, so emission reductions from CCS deployment in the 450 scenario is not reflected in the EXIOPOL results.

Note that the calculated emissions reflect only emissions from interindustry sources, and not final consumption, which may partly explain why the calculated CO2 emissions are generally lower than the scaled IEA numbers. While there are discrepancies between the emissions modeled in EXIOPOL with the scaled IEA figures, it seems that this method of incorporating energy mixes into EXIOPOL was reasonably accurate, especially given that it was not intended to produce accurate results for the flow matrices, but rather for unit matrices.

Table 4 – Comparison between model calculated and scaled IEA economy-wide CO2e emission

	2000	**NPS**	**CPS**	**450**
IEA TPED (MtCO2e)	9,179	16,961	18,302	14,870
IEA CO2 (MtCO2e)	22,639	36,367	43,320	21,574
IEA Scaled CO2 (MtCO2e)	22,639	19,681	21,726	13,317
Calculated CO2 (MtCO2e)	21,315	17,752	19,417	13,953
IEA Scaled Δ% from 2000		**-13.1%**	**-4.0%**	**-41.2%**
Calculated Δ% from 2000		**-16.7%**	**-8.9%**	**-34.5%**

Implications

Efficient and Accurate Modifications to IO

The method developed in this research can be used to integrate future world energy scenarios into a global one-region EXIOPOL model. This report focused on changing the energy mixes defined by the IEA energy scenarios for 2035, but could easily be adapted and used to update the energy mix to the current year, or to integrate other energy scenarios for further analysis. This opens up many opportunities for further research, both for the modified EEIO tables created in this project, but also for creating new modifications to the energy mixes to model other energy scenarios not yet considered. One of the key advantages of this approach is that it is not time-intensive, which enables quick integration of new energy scenarios. Major changes to projections within the global energy system can take place in a few short years, so it is important that our models can quickly adapt to provide more accurate information. Also, using the physical energy extensions of EXIOPOL as the basis for changing energy mixes and emissions may be more accurate than purely monetary methods of transformation. As Table 4 shows, this method proved to be reasonable accurate at modeling the changes, compared with the changes modeled from the IEA. There are of course limitations to this model, as mentioned in the Internal Quality Assessment section, however, this approach can still be considered to be a good balance between accuracy and level of effort involved.

Hybrid LCA

One of the main outcomes of this research is to produce modified IO tables that model different future energy scenarios for use in hybrid LCA-IO analysis. Hybrid LCA-IO analysis combines the strengths of both approaches and addresses aggregation issues and system completeness.

There are three primary types of hybrid LCA methodologies, of which two are particularly applicable with this research (Strømman 2010). The method that is not well suited for the modified IO tables is called the “Tiered hybrid LCA” method, which integrates both a process-based LCA background database as well as an IO based background database. This poses challenges, since the IO background database integrates an energy mix based on future scenarios, while the process-based LCA background database uses old energy mix data. As can be seen from the NEEDS study, it can be a major challenge to change the energy mix of background LCI processes (EMAC 2006). Therefore, hybrid LCA methods that do not utilize LCA background databases would be more suitable.

$$A = \begin{bmatrix} A_{ff} & A_{fn} \\ A_{nf} & A_{nn} \end{bmatrix}$$

The two hybrid LCA methods that would work well with the modified IO tables are the “IO based hybrid LCA” and the “Integrated hybrid LCA” method. Both methods have an Aff process-based foreground matrix, an Anf matrix describing inputs from the background economy to the foreground processes, and an Ann background IO table. The difference is in the upper right matrix Afn, which is defined for the “Integrated hybrid LCA” method, but is defined as zero for the “IO based hybrid LCA” method. This Afn matrix defines flows from the foreground processes to the background economy. The reason that the “IO based hybrid LCA” method defines this matrix as zero is because it is assumed that the product flows associated with the foreground system are assumed to be so small that they are negligible relative to the background economy, or that they are produced solely for final demand and are not intermediate goods. However, the “Integrated hybrid LCA” method is used for instances where the foreground flows are of a size that is not considered negligible relative to the background economy, and so require correcting for double counting between processes represented in both the foreground and the background.

Evaluating Prospective Technologies

With the creation of modified IO tables representing future energy scenarios, it is possible to evaluate the environmental impacts of prospective technologies such as widespread adoption of electric vehicles. By using credible energy scenarios that outline a wide range of realistic possible futures, it shows the spectrum of what future environmental impacts might be for a particular technology. This study focused on three realistic IEA scenarios, where the CPS indicates the worst-case environmental impact, NPS indicates the likely environmental impact, and the 450 indicate the best-case environmental impact. As Sanden described, prospective attributional studies may be well suited for evaluating technologies (Sanden & Karlstrom 2007).

Using a global EEIO table that models future energy scenarios is ideal for evaluating prospective technologies, because technologies can have complex international supply chains that change over time, and technologies can also be deployed in many different countries using different energy mixes. Comparing technologies using very specific local contexts with local energy mixes does not provide a good common basis for comparison of technologies. It is hard to compare two technologies that use two different energy mixes, because the results can be influenced more by differences in energy mixes than by differences in the actual technologies. Until recently, there has not been a good global EEIO database until EXIOPOL. Many hybrid LCA studies may use the US CEDA database because of its comprehensive environmental extensions, even if the study is not related to the US. GTAP is another global IO database, but the environmental extensions and the low 60-industry resolution may not be useful enough for hybrid LCA studies.

Increasing Practitioner Understanding of IO

Given the size and complexity of an IO table, it is hard for an LCA/IO practitioner to know what information is embedded in the database before simulating the final results of their study. This report shows a detailed breakdown of the direct and lifecycle emission intensities of all 129 industries represented in EXIOPOL, allowing for easy understanding of how these different industries compare without running any Matlab calculations. This can be a useful guide to practitioners before they gather data, because they can get a quick idea of which industries are most important from an environmental point of view, and ensure that particular attention is paid to gather high quality data for those industries. In fact, since the life cycle unit emissions of all 129 processes have already been calculated for this report in kgCO2e / Euro units, one could get a quick idea of the level of environmental impact from the background industries of their study just by multiplying the cost per functional unit for each background industry that is directly connected to the foreground processes. This can be done not only for the existing year 2000 EXIOPOL data, but also for the future scenarios modeled in this research. Thus, without performing any complex Matlab calculations, a practitioner can get a quick overview of how much emissions result from their background IO system through simple multiplication with the unit lifecycle impacts, and can also see how this changes between different future energy scenarios.

Comparing Industries and Sectors

The results section showed detailed impact intensity information for all 129 industries as well as for 13 aggregated sectors for both year 2000 as well as the three IEA future energy scenarios. Many insights were gained by comparing the environmental performance of each industry, as well as how this impact changes with respect to changes in the energy mix. The changes in each industry's life cycle impacts were benchmarked not only relative to year 2000 levels, but also with the overall average change in impact across the economy for that particular scenario. Thus, it is possible to see which industries show above average change in emissions intensities, and which industries are below average.

The electricity generation and distribution sector has the highest GWP100 impact intensity of all sectors at 7.67 kgCO2e/Euro in year 2000, compared to the average across all 129 industries at 1.53 kgCO2e/Euro. Within this sector there is wide variation in impact intensities, with coal at 30.45 kgCO2e/Euro, natural gas at 17.84 kgCO2e/Euro, and the renewables at less than 1.00 kgCO2e/Euro in year 2000. Across all future scenarios, the impact intensity of this industry reduced dramatically due to less coal and more renewables, with the 450 scenario dropping down to 3.29 kgCO2e/Euro. As a result, industries where electricity makes up a large part of their energy mix experience large reductions in their lifecycle impact intensities.

Due to a shortcoming in the methodology used to integrate energy mixes into EXIOPOL, the extraction of crude oil industry showed unusually high impact intensities in future scenarios. Some industries that relied primarily on oil in their energy mix, such as transport and agriculture, saw less than expected reduction in impact intensities as a result of the higher upstream emissions associated with oil extraction.

Influence of Energy Efficiency

By comparing the original 450 scenario with the 450 No Efficiency scenario, it was discovered that most of the reduction in emissions in the original 450 scenario are primarily a result of energy efficiency gains, rather than due to changes in energy mixes. Energy efficiency assumptions are an implicit result of the way energy mixes are defined in the IEA energy scenarios, and can be a due to both advances in energy technology as well as replacement of old inefficient energy infrastructure. This result is consistent with the information shown in Figure 4, as the IEA states that energy efficiency is responsible for 44% of reduction in emissions compared with NPS. Moreover, since CCS was not modeled in this project, which makes up 22% of the reduction in the 450 scenario, energy efficiency should play an even larger role in the emissions reduction modeled in this project.

Future Research

The calculations used to change the energy mix of the EXIOPOL EEIO table can also be used to integrate other energy scenarios. Currently, the Matlab code used to perform these calculations are specific to the specific IEA scenarios that were used in this study. However, with some small modifications to the Matlab codes, a generic spreadsheet detailing the energy mix in the same (17 energy types X 6 categories) format as is used by the IEA, could be integrated to the Matlab codes. Thus, changing the energy mixes of the IO table would just require inputting new values into the generic 17x6 energy mix spreadsheet, and running the Matlab scripts to produce the corresponding A and D_int matrix. This could be used to assess how the unit impacts of different industries compare under the new energy scenario. It could also be used as the background IO table representing this new energy scenario, as part of a hybrid LCA analysis. These hybrid LCAs could be performed as case studies that show how the environmental impact of technologies such as electric vehicles changes under the various future energy scenarios.

As shown in Figure 9, Figure 11, and Figure 13, the lifecycle unit impacts of all 129 industries within EXIOPOL have already been calculated. By making this information easily available to other researchers, this could help researchers and practitioners in two ways. First, by understanding at a glance, what the unit lifecycle impacts of each industry is, a practitioner would be able to discern which industries are of particular importance for their hybrid LCA analysis, and thus know the which industries to pay particular attention to and ensure high quality data is obtained. Second, this unit lifecycle impact information for all 129 industries, for 2000 as well as the 3 IEA scenarios, can be made easily available online for other researchers and practitioners to use. Such information could be used by practitioners to make quick calculations on the impacts from the background IO system of their hybrid LCA studies. This can be done simply by multiplying the monetary values that would essentially be in the Anf matrix, with the unit lifecycle impacts of the relevant industries. This may not replace the full hybrid LCA methodology, especially in instances where double counting is a concern, but could perhaps serve as a “back of the envelope” calculation for practitioner. Although use of hybrid analysis has many strengths over the separate use of process-based LCA and EEIO, it has not yet reached widespread adoption, partly due to the complexity involved. It is difficult to visualize or understand the data embedded within a large database such as EXIOPOL, so making this information available in a way that is transparent and understandable can lead to higher quality analysis.

Further refinements to the calculations related to the extraction of energy products are needed. One of the main flaws of this method was its overestimation of the lifecycle impacts of the extraction of energy products sector, and in particular, for extraction of crude oil and for uranium. As previously described, this was due to the reason that changes in energy input did not properly correspond with changes in downstream demand for the energy product. Given the time constraints of this project, this issue was not corrected. However, future work can focus on developing a calculation that ensures that changes in energy input do properly correlate with changes in downstream energy demand, particularly for the energy extraction sector. This calculation should also factor in the energy efficiency assumptions which are embedded in the IEA energy scenario calculations, rather than assuming the same energy efficiency levels as in year 2000.

Changes in emission intensities can be modeled as future work. In this research, the emission intensities per unit energy were assumed to be the same as year 2000 levels. If data was available from the IEA on the emission intensity levels assumed within their models for all their future energy scenarios, then this could be integrated in. Without this data in a readily useable format however, this task may prove to be very challenging. Changes in emission intensities from year 2000 to 2035 can be significant, not only because of advances in energy efficiencies of the latest technologies, but also due to the replacement of old inefficient energy infrastructure. In the 450 scenario, 22% of the emissions reduction relative to the NPS scenario in 2035 is a result of CCS, which is not currently captured in this research. Therefore, if data is available, integrating changes in emission intensities can enhance the accuracy of this models representation of the IEA scenarios.

This research used an aggregated global one-region EEIO table, however this work can be expanded to a multi-regional IO table. This would increase the complexity of the model, as trade between regions would also need to be accounted for. However, a higher resolution model, whether it is a regional model such as EU and non-EU, or a country specific model, could be more useful. The IEA WEO does publish data for different regions and countries in the same format as the ones used in this research for the entire world, so all of the data needed for a multi-regional model is readily available.

Conclusion

A method was developed through this research to efficiently and accurately integrate energy mixes from multiple IEA world scenarios for 2035 into the EXIOPOL EEIO based in year 2000. Comparisons between the calculated impacts from this research and the reported impacts by the IEA show that this method was reasonably accurate at integrating these scenarios. However, some of the calculated impacts for industries related to extraction of energy products were deemed to be inaccurate, due to a minor flaw in the methodology that could be addressed in future work that builds upon this project.

The energy mixes defined in these future scenarios were used to modify the energy extensions of EXIOPOL, which in turn were used to calculate new unit matrices that could be readily used as a background IO database for hybrid LCA-IO analyses. These modified IO matrices are deemed suitable for the “IO based hybrid LCA” and the “Integrated hybrid LCA” methods, but not for the “Tiered hybrid LCA” method. The use of prospective attributional hybrid LCA studies that utilize a global energy mix could be useful for evaluating prospective technologies such as electric vehicles.

The modified IO matrices were used to analyze and compare the environmental performance for all 129 industries and 13 aggregated sectors for both year 2000 and the three IEA future energy scenarios. This detailed analysis of the lifecycle impact intensities of all 129 industries can serve as a useful guide to LCA and IO practitioners, giving them an initial overview of which industries in their analysis are most environmentally significant, thus identifying key industries to focus on to ensure high quality data is obtained.

The electricity generation and distribution sector had the highest GWP100 impact intensity of all sectors, but it also experienced the greatest reduction in emissions across all scenarios due to decreases in coal use and increases in renewables. As a result, industries that relied heavily on electricity in their energy mix experienced large reductions in their lifecycle impact intensities. In contrast, industries that relied primarily on oil in their energy mix, such as transport and agriculture, saw less reduction in impact intensities. This is partly due to less available alternatives to displace oil and reduce emissions compared to electricity, but also because of the higher than expected upstream impacts from extraction of crude oil, which was a result of the flaw in the methodology.

By comparing the original 450 scenario with the 450 No Efficiency scenario, it was discovered that most of the reduction in emissions in the original 450 scenario are primarily a result of energy efficiency gains, rather than due to changes in energy mixes. Energy efficiency assumptions are an implicit result of the way energy mixes are defined in the IEA energy scenarios, and can be a result of both advances in energy technology as well as replacement of old inefficient energy infrastructure.

In conclusion, this project was an ambitious effort to find a solution to efficiently and accurately modify an EEIO to model a future energy scenario. These modified IO tables would be useful for prospective attributional hybrid LCA-IO studies used to evaluate prospective technologies, and also for gaining insights through analyzing and comparing the environmental performance across different industries.

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Appendix

Appendix 1 – IEA World Energy Outlook 2011 Original Data

This appendix shows the original IEA WEO data for all scenarios.

Appendix 1 - IEA World Energy Outlook 2011 Original Data

IEA WEO 2011	Past	Current		New Policy Scenario				Current Policy Scenario				450 Scenario			
	Energy Dema	Energy Dema	Share (%)	Energy Demand (Mtoe)		Share (%)	CAAGR(%)	Energy Demand (Mtoe)		Share (%)	CAAGR(%)	Energy Demand (Mtoe)		Share (%)	CAAGR(%)
	2000	2009	2009	2020	2035	2035	2009-2035	2020	2035	2035	2009-2035	2020	2035	2035	2009-2035
Total Direct Primary Energy Demand	**9179**	**12132**	**100.0%**	**14769**	**16961**	**100%**	**1.3**	**15124**	**18302**	**100%**	**1.6**	**14185**	**14870**	**100%**	**0.8**
Coal	2355	3294	27.2%	4083	4101	24%	0.8	4416	5419	30%	1.9	3716	2316	16%	-1.3
Oil	3604	3987	32.9%	4384	4645	27%	0.6	4482	4992	27%	0.9	4182	3671	25%	-0.3
Gas	2085	2539	20.9%	3214	3928	23%	1.7	3247	4206	23%	2.0	3030	3208	22%	0.9
Nuclear	674	703	5.8%	929	1212	7%	2.1	908	1054	6%	1.6	973	1664	11%	3.4
Hydro	228	280	2.3%	377	475	3%	2.1	366	442	2%	1.8	391	520	3%	2.4
Biomass and waste	216	1230	10.1%	1495	1911	11%	1.7	1449	1707	9%	1.3	1554	2329	16%	2.5
Other renewables	17	99	0.8%	287	690	4%	7.8	256	481	3%	6.3	339	1161	8%	9.9
Power generation	**3636**	**4572**	**100.0%**	**5850**	**7171**	**100%**	**1.7**	**6070**	**8002**	**100%**	**2.2**	**5553**	**6149**	**100%**	**1.1**
Coal	1555	2144	46.9%	2667	2744	38%	1.0	2957	3883	49%	2.3	2376	1163	19%	-2.3
Oil	310	267	5.8%	189	135	2%	-2.6	201	152	2%	-2.1	171	95	2%	-3.9
Gas	725	1003	21.9%	1253	1591	22%	1.8	1247	1729	22%	2.1	1144	1130	18%	0.5
Nuclear	674	703	15.4%	929	1212	17%	2.1	908	1054	13%	1.6	973	1664	27%	3.4
Hydro	228	280	6.1%	377	475	7%	2.1	366	442	6%	1.8	391	520	8%	2.4
Biomass and waste	129	94	2.1%	187	429	6%	6.0	172	332	4%	5.0	206	576	9%	7.2
Other renewables	15	82	1.8%	248	586	8%	7.9	219	410	5%	6.4	293	1002	16%	10.1
Other energy sector	**949**	**1263**	**100.0%**	**1490**	**1629**	**100%**	**1.0**	**1522**	**1766**	**100%**	**1.3**	**1428**	**1386**	**100%**	**0.4**
Coal	246	332		414	447			428	513			396	382		
Oil	351	259		237	185			238	177			230	155		
Gas	248	269		344	414			349	444			326	338		
Biomass and waste	1	64		74	80			73	79			73	81		
Electricity	*235*	*284*	*22.5%*	*365*	*448*	*28%*	*1.8*	*375*	*493*	*28%*	*2.1*	*348*	*386*	*28%*	*1.2*
Total Final Consumption	**6032**	**8329**	**100.0%**	**10177**	**11629**	**100%**	**1.3**	**10348**	**12303**	**100%**	**1.5**	**9841**	**10400**	**100%**	**0.9**
Coal	554	818	9.8%	1002	910	8%	0.4	1031	1023	8%	0.9	944	*771*	7%	-0.2
Oil	2943	3461	41.6%	3958	4325	37%	0.9	4043	4663	38%	1.2	3781	3421	33%	0.0
Gas	1112	1267	15.2%	1617	1923	17%	1.6	1651	2033	17%	1.8	1560	1740	17%	1.2
Electricity	1088	1440	17.3%	2033	2670	23%	2.4	2082	2893	24%	2.7	1960	2386	23%	2.0
Heat	247	253	3.0%	292	295	3%	0.6	301	325	3%	1.0	275	250	2%	0.0
Biomass and waste	86	1072	12.9%	1234	1402	12%	1.0	1204	1296	11%	0.7	1275	1672	16%	1.7
Other renewables	2	17	0.2%	40	104	1%	7.1	36	71	1%	5.6	46	160	2%	8.9
Industry	**2102**	**2279**	**100.0%**	**3089**	**3388**	**100%**	**1.5**	**3153**	**3695**	**100%**	**1.9**	**2981**	**3090**	**100%**	**1.2**
Coal	427	640	28.1%	820	765	23%	0.7	843	865	23%	1.2	773	650	21%	0.1
Oil	593	320	14.0%	352	332	10%	0.1	361	365	10%	0.5	344	316	10%	0.0
Gas	488	442	19.4%	636	736	22%	2.0	655	802	22%	2.3	624	695	22%	1.8
Electricity	458	580	25.4%	898	1118	33%	2.6	920	1243	34%	3.0	861	989	32%	2.1
Heat	105	110	4.8%	131	121	4%	0.4	135	137	4%	0.9	125	110	4%	0.0
Biomass and waste	31	186	8.2%	252	315	9%	2.0	239	282	8%	1.6	252	326	11%	2.2
Other renewables	0	0	0%	1	1	0%	2.9	1	1	0%	2.9	1	3	0%	7.7
Transport	**1775**	**2283**	**100.0%**	**2734**	**3257**	**100%**	**1.4**	**2776**	**3466**	**100%**	**1.6**	**2628**	**2744**	**100%**	**0.7**
Oil	1696	2135	93.5%	2499	2863	88%	1.1	2553	3124	90%	1.5	2367	2090	76%	-0.1
Of which: Bunkers	-	*329*	*14.4%*	*376*	*454*	*14%*	*1.2*	*375*	*468*	*14%*	*1.4*	*364*	*388*	*14%*	*0.6*
Electricity	12	23	1.0%	36	58	2%	3.6	35	53	2%	3.2	39	133	5%	6.9
Biofuels	28	52	2.3%	107	202	6%	5.4	97	159	5%	4.4	127	370	13%	7.9
Other fuels	39	73	3.2%	92	134	4%	2.3	92	130	4%	2.2	94	150	5%	2.8
Buildings	**1475**	**2844**	**100.0%**	**3282**	**3804**	**100%**	**1.1**	**3331**	**3935**	**100%**	**1.3**	**3166**	**3409**	**100%**	**0.7**
Coal	82	125	4.4%	124	90	2%	-1.2	130	100	3%	-0.8	115	69	2%	-2.3
Oil	359	327	11.5%	338	313	8%	-0.2	347	337	9%	0.1	314	239	7%	-1.2
Gas	431	612	21.5%	716	850	22%	1.3	729	896	23%	1.5	672	705	21%	0.5
Electricity	455	796	28.0%	1042	1414	37%	2.2	1068	1508	38%	2.5	1003	1189	35%	1.6
Heat	106	140	4.9%	158	170	4%	0.8	163	184	5%	1.1	146	136	4%	-0.1
Biomass and waste	40	828	29.1%	867	870	23%	0.2	859	844	21%	0.1	873	920	27%	0.4
Other renewables	2	17	0.6%	37	97	3%	7.0	34	67	2%	5.5	43	150	4%	8.8
Other	**680**	**923**	**100.0%**	**1072**	**1180**	**100%**	**0.9**	**1088**	**1208**	**100%**	**1.0**	**1066**	**1157**	**100%**	**0.9**
Coal	45	53		58	55			58	58			56	52		
Oil	228	554		570	481			593	548			535	256		

Gas	193	213		265	337			267	335			264	340		
Electricity	162	41		57	80			59	89			57	75		
Heat	36	3		3	4			3	4			4	4		
Biomass and waste	15	58		115	217			106	170			150	426		
Electricity Generation (TWh)															
Total Power Generation	**15391**	**20043**	**100.0%**	**27881**	**36250**	**100.0%**		**28569**	**39368**	**100.0%**		**26835**	**32224**	**100.0%**	
Coal	5989	8118	40.5%	10860	12035	33.2%		12040	16932	43.0%		9648	4797	14.9%	
Oil	1241	1027	5.1%	713	533	1.5%		750	591	1.5%		644	360	1.1%	
Gas	2676	4299	21.4%	6020	7923	21.9%		5967	8653	22.0%		5543	5608	17.4%	
Nuclear	2586	2697	13.5%	3576	4658	12.8%		3495	4053	10.3%		3741	6396	19.8%	
Hydro	2650	3252	16.2%	4380	5518	15.2%		4254	5144	13.1%		4547	6052	18.8%	
Biomass and waste	167	288	1.4%	635	1497	4.1%		579	1150	2.9%		701	2025	6.3%	
Other renewables	82	362	1.8%	1697	4085	11.3%		1484	2845	7.2%		2012	6986	21.7%	
Wind	*31*	*273*	1.4%	*1282*	*2703*	*7.5%*		*1130*	*2005*	*5.1%*		*1486*	*4320*	*13.4%*	
Geothermal	*49*	*67*	0.3%	*131*	*271*	*0.7%*		*120*	*200*	*0.5%*		*148*	*407*	*1.3%*	
Solar PV	*1*	*20*	0.1%	*230*	*741*	*2.0%*		*195*	*435*	*1.1%*		*279*	*1332*	*4.1%*	
CSP	*0*	*1*	0.0%	*52*	*307*	*0.8%*		*37*	*166*	*0.4%*		*96*	*845*	*2.6%*	
Marine	*1*	*1*	0.0%	*2*	*63*	*0.2%*		*2*	*39*	*0.1%*		*3*	*82*	*0.3%*	
CO2 Emissions (Mt CO2)															
Total CO2	**22639**	**28844**	**100.0%**	**34407**	**36367**	**100.0%**		**36067**	**43320**	**100.0%**		**31885**	**21574**	**100.0%**	
Coal	8875	12455	43.2%	15423	14949	41.1%		16725	20182	46.6%		13917	5356	24.8%	
Oil	9108	10629	36.8%	11699	12554	34.5%		11983	13638	31.5%		11118	9616	44.6%	
Gas	4656	5760	20.0%	7284	8865	24.4%		7360	9500	21.9%		6850	6603	30.6%	
Power Generation	**8958**	**11760**	**100.0%**	**14146**	**14757**	**100.0%**		**15331**	**19836**	**100.0%**		**12582**	**4758**	**100.0%**	
Coal	6276	8562	72.8%	10613	10617	71.9%		11772	15309	77.2%		9371	2254	47.4%	
Oil	992	845	7.2%	598	426	2.9%		636	481	2.4%		542	302	6.3%	
Gas	1689	2353	20.0%	2936	3714	25.2%		2924	4046	20.4%		2668	2203	46.3%	
Total Final Consumption	**12442**	**15618**	**100.0%**	**18559**	**19791**	**100.0%**		**18993**	**21516**	**100.0%**		**17686**	**15346**	**100.0%**	
Coal	2442	3619	23.2%	4445	3990	20.2%		4569	4474	20.8%		4203	2843	18.5%	
Oil	7474	9142	58.5%	10461	11454	57.9%		10693	12441	57.8%		9961	8769	57.1%	
Transport	*4666*	*6358*	*40.7%*	*7447*	*8539*	*43.1%*		*7605*	*9315*	*43.3%*		*7057*	*6252*	*40.7%*	
Of which: Bunkers	-	*1016*	*6.5%*	*1160*	*1395*	*7.0%*		*1158*	*1440*	*6.7%*		*1126*	*1201*	*7.8%*	
Gas	2526	2857	18.3%	3653	4346	22.0%		3730	4602	21.4%		3522	3733	24.3%	
Other Energy	**1239**	**1466**	**100.0%**	**1702**	**1819**	**100.0%**		**1743**	**1968**	**100.0%**		**1617**	**1470**	**100.0%**	
Coal	232	274	18.7%	365	342	18.8%		384	399	20.3%		343	259	17.6%	
Oil	543	642	43.8%	640	674	37.1%		654	716	36.4%		615	545	37.1%	
Gas	465	550	37.5%	695	805	44.3%		706	852	43.3%		660	667	45.4%	
CO2 Emissions Intensity (Mt CO2/[energy])															
Total Primary Energy Demand (r	**2.47**	**2.38**		**2.33**	**2.14**			**2.38**	**2.37**			**2.25**	**1.45**		
Coal	3.77	3.78		3.78	3.65			3.79	3.72			3.75	2.31		
Oil	2.53	2.67		2.67	2.70			2.67	2.73			2.66	2.62		
Gas	2.23	2.27		2.27	2.26			2.27	2.26			2.26	2.06		
Power generation (mtoe)	**2.46**	**2.57**		**2.42**	**2.06**			**2.53**	**2.48**			**2.27**	**0.77**		
Coal	4.04	3.99		3.98	3.87			3.98	3.94			3.94	1.94		
Oil	3.20	3.16		3.16	3.16			3.16	3.16			3.17	3.18		
Gas	2.33	2.35		2.34	2.33			2.34	2.34			2.33	1.95		
Power Generation (TWh)	**0.58**	**0.59**		**0.51**	**0.41**			**0.54**	**0.50**			**0.47**	**0.15**		
Coal	1.05	1.05		0.98	0.88			0.98	0.90			0.97	0.47		
Oil	0.80	0.82		0.84	0.80			0.85	0.81			0.84	0.84		
Gas	0.63	0.55		0.49	0.47			0.49	0.47			0.48	0.39		
Total Final Consumption (mtoe)	**2.06**	**1.88**		**1.82**	**1.70**			**1.84**	**1.75**			**1.80**	**1.48**		
Coal	4.41	4.42		4.44	4.38			4.43	4.37			4.45	3.69		
Oil	2.54	2.64		2.64	2.65			2.64	2.67			2.63	2.56		
Transport	*2.75*	*2.98*		*2.98*	*2.98*			*2.98*	*2.98*			*2.98*	*2.99*		
Of which: Bunkers	*#VALUE!*	*3.09*		*3.09*	*3.07*			*3.09*	*3.08*			*3.09*	*3.10*		
Gas	2.27	2.25		2.26	2.26			2.26	2.26			2.26	2.15		
Other Energy	**1.31**	**1.16**		**1.14**	**1.12**			**1.15**	**1.11**			**1.13**	**1.06**		

Appendix 2A – Matlab Script 1

This Matlab script, which is called “EXIOPOL_OneRegion_Aggregation_v20.m”, is the first part of the calculations that aggregate the matrices into a one-region model, as well as performing some of the initial calculations.

```
%-----Script1 Calculations-----
% clear all;

%-----------------------------------
%Aggregate Z, E, UG, UE, S, and Y into a one world region.

%Load EXIOPOL SIOT data
load('SIOT_2region_pxp_v11.mat');

%Define arrays for Z, E, UG, S, and UE from imported SIOT data
Z_IOIO = siot(1:129, 1:129);
Z_IOROW = siot(1:129, 130:258);
Z_ROWIO = siot(130:258, 1:129);
Z_ROWROW = siot(130:258, 130:258);
E_IO = siot(292:627, 1:129);
E_ROW = siot(292:627, 130:258);
UG_IO = siot(628:683, 1:129);
UG_ROW = siot(628:683, 130:258);
Y_IOIO = siot(1:129, 259:265);
Y_IOROW = siot(1:129, 266:272);
Y_ROWIO = siot(130:258, 259:265);
Y_ROWROW = siot(130:258, 266:272);


%Calculate sizes of the imported matricies for use as indexes in for loops.
[Zi_max, Zj_max] = size(Z_IOIO);
[Ei_max, Ej_max] = size(E_IO);
[UGi_max, UGj_max] = size(UG_IO);
[UEi_max, UEj_max] = size(UE_IO);
[Si_max, Sj_max] = size(S_IO);
[Yi_max, Yj_max] = size(Y_IOIO);

%Aggregate Z into a two quadrants, and then into one region.
for i = 1:Zi_max
    for j = 1:Zj_max
        Z_IO(i,j) = Z_IOIO(i,j) + Z_IOROW(i,j);
        Z_ROW(i,j) = Z_ROWIO(i,j) + Z_ROWROW(i,j);
    end
end
for i = 1:Zi_max
    for j = 1:Zj_max
        Z_One(i,j) = Z_IO(i,j) + Z_ROW(i,j);
    end
end

%Aggregate E into one region.
for i = 1:Ei_max
    for j = 1:Ej_max
        E_One(i,j) = E_IO(i,j) + E_ROW(i,j);
    end
end

%Aggregate UG into one region.
for i = 1:UGi_max
    for j = 1:UGj_max
```

```
        UG_One(i,j) = UG_IO(i,j) + UG_ROW(i,j);
    end
end

%Aggregate Y into a two quadrants, and then into one region.
for i = 1:Yi_max
    for j = 1:Yj_max
        Y_IO(i,j) = Y_IOIO(i,j) + Y_IOROW(i,j);
        Y_ROW(i,j) = Y_ROWIO(i,j) + Y_ROWROW(i,j);
    end
end
for i = 1:Yi_max
    for j = 1:Yj_max
        Y_One(i,j) = Y_IO(i,j) + Y_ROW(i,j);
    end
end

%-----------------------------------
%UG currently lacks any consumption of biofuels. To fix this according to
%IEA WEO 2000 biofuels figures, we will manually change specific "Biogasol"
%values for the 6 transport related sectors.
UG_One(56,101) = 3240;
UG_One(56,102) = 307267;
UG_One(56,103) = 28928;
UG_One(56,104) = 278;
UG_One(56,105) = 70620;
UG_One(56,106) = 3643;



%-----------------------------------
%Aggregate the 129 products of Z into the 6 IEA categories (PG, OE, I, T, B, O).
%!! consider moving this
IEA_Z_ctg_code = importdata('IEA_Z_ctg.xls'); %129 Z rows labeled with corresponding 6↙
IEA categories
IEA_ctg_code = importdata('IEA_ctg.xls');
Z_ctg = zeros(Zi_max,6);
for j = 1:Zj_max
    for n = 1:6
        if strcmp(IEA_ctg_code(n) ,IEA_Z_ctg_code(j));
            Z_ctg(:,n) = Z_ctg(:,n) + Z_One(:,j);
        end
    end
end



%-----------------------------------
%Based on Z monetary breakdown of types of electricity for each of the 129
%products, we disaggregate the UG ELEC row into 6 additional UG physical
%electricity rows.

%Import Pcode vectors that correlate the UG energy products with the
%energy-related products in the Z matrix.
UG_Pcode = importdata('UG_Pcode.xls');
```

```
Z_Pcode = importdata('Z_Pcode.xls');
Z_Elec_Pcode = importdata('Z_Elec_Pcode.xls'); %24 Z energy-related Pcodes

Z_Elec_Mix = zeros(6,129);
Z_Elec_Sum = zeros(1,129);

for i = 1:Zi_max
    for n = 1:6
        if strcmp(Z_Elec_Pcode(n,1), Z_Pcode(i,1))
            Z_Elec_Sum(1,:) = Z_Elec_Sum(1,:) + Z_One(i,:);
        end
    end
end

for i = 1:Zi_max
    for n = 1:6
        if strcmp(Z_Elec_Pcode(n,1), Z_Pcode(i,1))
            Z_Elec_Mix(n,:) = Z_One(i,:) ./ Z_Elec_Sum(1,:);
        end
    end
end

%Apply the Z_Elec_Mix to disaggregate UG ELEC (row 40) into new electricity
%type rows that will be added to UG_One (rows 57:62)
UGi_max_elec = UGi_max + 6;
UG_One_Elec = UG_One;
UG_One_Elec(57:62,:) = zeros(6,129);
for i = 1:6
    UG_One_Elec(56+i,:) = Z_Elec_Mix(i,:) .* UG_One_Elec(40,:);
end


%------------------------------------------
%Compare UG year 2000 data with the IEA 2000 data, by aggregating
%UG_One_Elec results (62x129) into a comparable format as IEA (17x6).
%This is only used as a check.

%Aggreate the 56 UG fuels into the 17 energy categories defined by IEA, and
%then aggregate the 129 columns of products into the 6 IEA categories.
IEA_UG_conv_code = importdata('IEA_UG_conv.xls'); %56 UG rows labeled with 17 IEA↙
energy types
IEA_conv_code = importdata('IEA_conv.xls'); %17 IEA energy types
IEA_conv_max = size(IEA_conv_code);

IEA_UG_conv = zeros(17, UGj_max);
for i = 1:UGi_max_elec
    for n = 1:17
        if strcmp(IEA_conv_code(n), IEA_UG_conv_code(i));
            IEA_UG_conv(n,:) = IEA_UG_conv(n,:) + UG_One_Elec(i,:);
        end
    end
end

IEA_PG_share = importdata('IEA_PG_share.xls');
```

```
%Aggregate IEA_UG_conv into the 6 IEA categories (IEA_UG_ctg)
IEA_UG_ctg = zeros(17, 6);
for j = 1:UGj_max
    for n = 1:6
        if strcmp(IEA_ctg_code(n), IEA_Z_ctg_code(j));
            IEA_UG_ctg(:,n) = IEA_UG_ctg(:,n) + IEA_UG_conv(:,j);
        end
    end
end

%NOTE: IEA_UG_conv and IEA_UG_ctg are double counting ELEC, since it has
%the total ELEC and the disaggregated.


%-----------------------------------------
%Import IEA magnitude and share matrices for 2000, 2009, NPS, CPS, 450.
IEA_mag = importdata('IEA_mag.xls'); %Note last 3 rows is Total, Heat, Elec.
IEA_share = importdata('IEA_share.xls');
IEA_mag(isnan(IEA_mag)) = 0;
IEA_share(isnan(IEA_share)) = 0;

%converting mtoe to TJ
IEA_mag_2000 = IEA_mag(:,1:6) .* (4.1868*10^4);
IEA_mag_2009 = IEA_mag(:,7:12) .* (4.1868*10^4);
IEA_mag_NPS = IEA_mag(:,13:18) .* (4.1868*10^4);
IEA_mag_CPS = IEA_mag(:,19:24) .* (4.1868*10^4);
IEA_mag_450 = IEA_mag(:,25:30) .* (4.1868*10^4);

IEA_share_2000 = IEA_share(:,1:6);
IEA_share_2009 = IEA_share(:,7:12);
IEA_share_NPS = IEA_share(:,13:18);
IEA_share_CPS = IEA_share(:,19:24);
IEA_share_450 = IEA_share(:,25:30);

%Summing up the columns of IEA_mag_2000 so that we can calculate what the
%magnitude of the IEA scenarios would be like in their respective energy
%mixes, but with no growth in energy use (total energy still sums up to year 2000
%energy, but with future energy mixes)
sum_share_2000 = sum(IEA_mag_2000(1:16,:));

%Calculate the change in share percentage to reach the mixes in future
%scenarios. These "d_share_XXX" factors will be multiplied with the
%monetary flows to get the new energy mixes.
Z_mag_2009 = IEA_share_2009 * diag(sum_share_2000);
d_share_2009 = Z_mag_2009 ./ IEA_mag_2000;
d_share_2009(isnan(d_share_2009)) = 0;

Z_mag_NPS = IEA_share_NPS * diag(sum_share_2000);
d_share_NPS = Z_mag_NPS ./ IEA_mag_2000;
d_share_NPS(isnan(d_share_NPS)) = 0;

Z_mag_CPS = IEA_share_CPS * diag(sum_share_2000);
d_share_CPS = Z_mag_CPS ./ IEA_mag_2000;
d_share_CPS(isnan(d_share_CPS)) = 0;
```

```
Z_mag_450 = IEA_share_450 * diag(sum_share_2000);
d_share_450 = Z_mag_450 ./ IEA_mag_2000;
d_share_450(isnan(d_share_450)) = 0;

%Calculate change in energy supply for future scenarios. This is used as a
%check, so if the sum total for the scenarios add up to 0, then it is correct.
d_mag_2009 = Z_mag_2009 - IEA_mag_2000;
d_mag_NPS = Z_mag_NPS - IEA_mag_2000;
d_mag_CPS = Z_mag_CPS - IEA_mag_2000;
d_mag_450 = Z_mag_450 - IEA_mag_2000;


%-----------------------------------------
%Using the d_share_XXX values (XXX represents scenarios), multiply with IEA_UG_conv to↙
change the energy mix
%for the UG energy values for all 129 sectors.
IEA_UG_2009 = zeros(17,UGj_max);
for j = 1:UGj_max
    for n = 1:6
        if strcmp(IEA_ctg_code(n) ,IEA_Z_ctg_code(j));
            IEA_UG_2009(:,j) = (d_share_2009(:,n))' * diag(IEA_UG_conv(:,j));
        end
    end
end

IEA_UG_NPS = zeros(17,UGj_max);
for j = 1:UGj_max
    for n = 1:6
        if strcmp(IEA_ctg_code(n) ,IEA_Z_ctg_code(j));
            IEA_UG_NPS(:,j) = (d_share_NPS(:,n))' * diag(IEA_UG_conv(:,j));
        end
    end
end

IEA_UG_CPS = zeros(17,UGj_max);
for j = 1:UGj_max
    for n = 1:6
        if strcmp(IEA_ctg_code(n) ,IEA_Z_ctg_code(j));
            IEA_UG_CPS(:,j) = (d_share_CPS(:,n))' * diag(IEA_UG_conv(:,j));
        end
    end
end

IEA_UG_450 = zeros(17,UGj_max);
for j = 1:UGj_max
    for n = 1:6
        if strcmp(IEA_ctg_code(n) ,IEA_Z_ctg_code(j));
            IEA_UG_450(:,j) = (d_share_450(:,n))' * diag(IEA_UG_conv(:,j));
        end
    end
end


%Setting row 17 (ELEC) of all these projections to 0, because it is already
%accounted for in the disaggregated electricity mix. But before this is
```

```
%done, we will save a copy of these projections including ELEC for future
%use.

%Keeping the electricity mixes for later
IEA_mag_2000_ELEC = IEA_mag_2000;
IEA_UG_2009_ELEC = IEA_UG_2009;
IEA_UG_NPS_ELEC = IEA_UG_NPS;
IEA_UG_CPS_ELEC = IEA_UG_CPS;
IEA_UG_450_ELEC = IEA_UG_450;

%Setting ELEC (row 17) to zero
IEA_mag_2000(17,:) = 0;
IEA_UG_2009(17,:) = 0;
IEA_UG_NPS(17,:) = 0;
IEA_UG_CPS(17,:) = 0;
IEA_UG_450(17,:) = 0;


%-----------------------------------------
%Calculate the prices per unit energy in EXIOPOL by dividing monetary flow
%by energy.

Z_Energy_Pcode = importdata('Z_Energy_Pcode.xls');

UG_Pcode_conv = zeros(24, UGj_max);
for i = 1:UGi_max_elec
    for n = 1:24
        if strcmp(Z_Energy_Pcode(n), UG_Pcode(i));
            UG_Pcode_conv(n,:) = UG_Pcode_conv(n,:) + UG_One_Elec(i,:);
            if strcmp('p12',UG_Pcode(i));
                UG_Pcode_conv(14,:) = UG_Pcode_conv(14,:) + UG_One_Elec(i,:); %both↙
mining and processing use UG_nuclear
            end
            if strcmp('p40.12',UG_Pcode(i));
                UG_Pcode_conv(22,:) = UG_Pcode_conv(22,:) + UG_One_Elec(i,:); %both↙
transmission and distribution use UG_ELEC
            end
        end
    end
end

Z_Pcode_conv = zeros(24, Zj_max);
for i = 1:Zi_max
    for n = 1:24
        if strcmp(Z_Energy_Pcode(n), Z_Pcode(i));
            Z_Pcode_conv(n,:) = Z_Pcode_conv(n,:) + Z_One(i,:);
        end
    end
end

EnergyPrice_Z_UG = Z_Pcode_conv ./ UG_Pcode_conv;

% Final results are saved under 'script1_Data_v2.mat'
```

Appendix 2B – Matlab Script 2

This Matlab script, which is called “Emissions_Calc_v5.m”, is used to aggregate a very large database of over 700,000 data points, detailing emissions per country per industry per fuel per pollutant. An efficient method had to be developed so that loop computations were minimized, as it was very computationally intensive to aggregate 44 regions of data into one global region.

```
%Code for aggregating Emissions by fuel by sector by countries into a one
%world region.

clear all;

%Need to run 'EXIOPOL_OneRegion_Aggregation_v12.m' script first
load('script1_Data_v2.mat');

%Import emissions by fuel by sector database (db.mat)
db = load('db.mat');
db_Values_max = size(db.dbvals);

%Import row indexes for pollutants, fuel type, and Z industry codes, along
%with max sizes of these indices.
PollutantCode = importdata('PollutantCode.xls');
FuelCode = importdata('FuelCode.xls');
Z_Icode = importdata('Z_Icode.xls');

Z_Icode_max = size(Z_Icode);
FuelCode_max = size(FuelCode);
PollutantCode_max = size(PollutantCode);


%Create a bridge matrix that indicates which pollutant each row in db.vals
%is represented. Similar matricies are created for FuelCode and Z_Icode.
%PollutantCode_matrix(696096x71)
PollutantCode_matrix = zeros(db_Values_max(1,1), PollutantCode_max(1,1));
for r = 1:db_Values_max(1,1)
    for i = 1:PollutantCode_max(1,1)
        if strcmp(db.dbtext(r,3),PollutantCode(i))
            PollutantCode_matrix(r,i) = 1;
        end
    end
end

FuelCode_matrix = zeros(db_Values_max(1,1), FuelCode_max(1,1));
for r = 1:db_Values_max(1,1)
    for i = 1:FuelCode_max(1,1)
        if strcmp(db.dbtext(r,5),FuelCode(i))
            FuelCode_matrix(r,i) = 1;
        end
    end
end

Z_Icode_matrix = zeros(db_Values_max(1,1), Z_Icode_max(1,1));
for r = 1:db_Values_max(1,1)
    for i = 1:Z_Icode_max(1,1)
        if strcmp(db.dbtext(r,2),Z_Icode(i))
            Z_Icode_matrix(r,i) = 1;
        end
    end
end


%Using the code matrices above, we can find the index row and column for
```

```
%each row, and temporarily store it as temp_A. We then use sort rows to
%order these indexes properly for all three dimensions: FuelCode, PollutantCode, and↙
Z_Icode.
[FuelCode_indexRow, FuelCode_indexCol] = find(FuelCode_matrix);
temp_A = [FuelCode_indexRow, FuelCode_indexCol];
FuelCode_index = sortrows(temp_A,1);

[PollutantCode_indexRow, PollutantCode_indexCol] = find(PollutantCode_matrix);
temp_B = [PollutantCode_indexRow, PollutantCode_indexCol];
PollutantCode_index = sortrows(temp_B,1);

[Z_Icode_indexRow, Z_Icode_indexCol] = find(Z_Icode_matrix);
temp_C = [Z_Icode_indexRow, Z_Icode_indexCol];
Z_Icode_index = sortrows(temp_C,1);

%Create Emissions_index, which combines all three dimensions into 3
%columns.
Emissions_index = [FuelCode_index(:,2), Z_Icode_index(:,2), PollutantCode_index(:,2)];


%--------------------------------
% --To skip all steps above, run CalculationsData_v4.mat
% load('CalculationsData_v4.mat')
% --Run db_One

%Sum up db.vals across all of the countries, such that when countries share
%the same FuelCode, Z_Icode, and PollutantCode, they get added together.
%db_One (67x129x71)
db_One = zeros(FuelCode_max(1,1), Z_Icode_max(1,1), PollutantCode_max(1,1));

for r = 1:db_Values_max(1,1)
    db_One(Emissions_index(r,1), Emissions_index(r,2), Emissions_index(r,3)) = db_One↙
(Emissions_index(r,1), Emissions_index(r,2), Emissions_index(r,3)) + db.dbvals(r,1);
end

%Final results are saved under 'script2_Data_v1.mat'
```

Appendix 2B – Matlab Script 3

This Matlab script, which is called “Final_Calculation.m”, which contains the remainder of the calculations. Note that in order to simulate the results for this project, only this script needs to be run, since the data from the previous two Matlab scripts are already pre-loaded into this script.

```
%Script 3 Calculations
clear all
load('script2_Data_v6.mat');

%Initialize matricies
db_One_max = size(db_One);
Unit_Emission = zeros(UGi_max_elec, UGj_max, db_One_max(1,3));
UG_FuelCode = importdata('UG_FuelCode.xls');
db_One = db_One(:,1:129,:);


%-----------------------------------------
%Calculate Unit_Emissions by dividing emissions by UG.
%To divide by UG, invert UG only if non-zero to avoid errors.
for i = 1:UGi_max
    for j = 1:UGj_max
        if UG_One(i,j) ~= 0
            inv_UG_One(i,j) = 1 ./ UG_One(i,j);
        end
    end
end

%For sum total of emissions per sector, aggregate emissions in db_One across
%all fuels.
temp_D = sum(db_One,1);
for k = 1:71
    for j = 1:129
        E_db_One(k,j) = temp_D(1,j,k);
    end
end

%For all pollutants, divide db_One emission value by respetive UG value to
%get Unit_Emissions.
for r = 1:PollutantCode_max(1,1) %pollutant axis
    for i = 1:UGi_max_elec %fuel axis for UG
        for n = 1:FuelCode_max(1,1) %fuel axis for db
            if strcmp(UG_FuelCode(i,1), FuelCode(n,1))
                Unit_Emission(i,:,r) = db_One(n,:,r) .* inv_UG_One(i,:);
            end
        end
    end
end


%-----------------------------------------
%convert IEA_UG_XXX(17x129) scenarios into UG_XXX(56x129) using
%IEA_UG_conv_code reversed. Every product under a particular label (e.g.
%F_C) will grow by the corresponding IEA scenario percentage.

%invert only if non-zero for IEA_UG_conv
for i = 1:17
    for j = 1:129
        if IEA_UG_conv(i,j) ~= 0
            inv_IEA_UG_conv(i,j) = 1 ./ IEA_UG_conv(i,j);
        end
```

```
    end
end

%Determine the percentage breakdown of UG_One_Elec 62 fuels into the 17 IEA fuel
%categories (e.g. 1 IEA category for Coal as fuel is comprised of 4
%different types of coal as defined by UG).
%Multiply these percent breakdowns by the scenario energy mixes IEA_UG_XXX_ELEC
%projections to disaggregate the IEA projections into the 62 UG categories.

%UG_XXX_temp is a temporary matrix that will later be corrected so that the
%the total UG for each sector remains the same.
for i = 1:UGi_max_elec
    for n = 1:IEA_conv_max
        if strcmp(IEA_UG_conv_code(i), IEA_conv(n))
            UG_2009_percent(i,:) = (UG_One_Elec(i,:) .* inv_IEA_UG_conv(n,:));
            UG_NPS_percent(i,:) = (UG_One_Elec(i,:) .* inv_IEA_UG_conv(n,:));
            UG_CPS_percent(i,:) = (UG_One_Elec(i,:) .* inv_IEA_UG_conv(n,:));
            UG_450_percent(i,:) = (UG_One_Elec(i,:) .* inv_IEA_UG_conv(n,:));

            UG_2009_temp(i,:) = IEA_UG_2009_ELEC(n,:) .* UG_2009_percent(i,:);
            UG_NPS_temp(i,:) = IEA_UG_NPS_ELEC(n,:) .* UG_NPS_percent(i,:);
            UG_CPS_temp(i,:) = IEA_UG_CPS_ELEC(n,:) .* UG_CPS_percent(i,:);
            UG_450_temp(i,:) = IEA_UG_450_ELEC(n,:) .* UG_450_percent(i,:);
        end
    end
end


%-----------------------------------------
%Calculate UG_XXX, which takes UG_XXX_temp and scales it to match the total
%UG under each of the 129 sectors
UG_One_sum = zeros(1,129);
UG_2009_temp_sum = zeros(1,129);
UG_NPS_temp_sum = zeros(1,129);
UG_CPS_temp_sum = zeros(1,129);
UG_450_temp_sum = zeros(1,129);
UG_2009_temp_elec_sum = zeros(1,129);
UG_NPS_temp_elec_sum = zeros(1,129);
UG_CPS_temp_elec_sum = zeros(1,129);
UG_450_temp_elec_sum = zeros(1,129);

for j = 1:129
    for i = 1:56
        UG_One_sum(1,j) = UG_One_sum(1,j) + UG_One(i,j);
        UG_2009_temp_sum(1,j) = UG_2009_temp_sum(1,j) + UG_2009_temp(i,j);
        UG_NPS_temp_sum(1,j) = UG_NPS_temp_sum(1,j) + UG_NPS_temp(i,j);
        UG_CPS_temp_sum(1,j) = UG_CPS_temp_sum(1,j) + UG_CPS_temp(i,j);
        UG_450_temp_sum(1,j) = UG_450_temp_sum(1,j) + UG_450_temp(i,j);
    end
end

%Calculate the percentage mix for
for i = 1:56
    UG_2009_temp_percent(i,:) = UG_2009_temp(i,:) ./ UG_2009_temp_sum(1,:);
    UG_NPS_temp_percent(i,:) = UG_NPS_temp(i,:) ./ UG_NPS_temp_sum(1,:);
```

```
    UG_CPS_temp_percent(i,:) = UG_CPS_temp(i,:) ./ UG_CPS_temp_sum(1,:);
    UG_450_temp_percent(i,:) = UG_450_temp(i,:) ./ UG_450_temp_sum(1,:);

    UG_2009(i,:) = UG_2009_temp_percent(i,:) .* UG_One_sum(1,:);
    UG_NPS(i,:) = UG_NPS_temp_percent(i,:) .* UG_One_sum(1,:);
    UG_CPS(i,:) = UG_CPS_temp_percent(i,:) .* UG_One_sum(1,:);
    UG_450(i,:) = UG_450_temp_percent(i,:) .* UG_One_sum(1,:);
end

%Calculate the electricity breakdown, given the new electricity number for
%each of the 129 categories.
for i = 57:62
    UG_2009_temp_elec_sum(1,:) = UG_2009_temp_elec_sum(1,:) + UG_2009_temp(i,:);
    UG_NPS_temp_elec_sum(1,:) = UG_NPS_temp_elec_sum(1,:) + UG_NPS_temp(i,:);
    UG_CPS_temp_elec_sum(1,:) = UG_CPS_temp_elec_sum(1,:) + UG_CPS_temp(i,:);
    UG_450_temp_elec_sum(1,:) = UG_450_temp_elec_sum(1,:) + UG_450_temp(i,:);
end

for i = 57:62
    for j = 1:129
        if UG_2009_temp_elec_sum(1,j) ~= 0
            UG_2009(i,j) = UG_2009(40,j) * (UG_2009_temp(i,j) / UG_2009_temp_elec_sum↙
(1,j));
        end
        if UG_NPS_temp_elec_sum(1,j) ~= 0
            UG_NPS(i,j) = UG_NPS(40,j) * (UG_NPS_temp(i,j) / UG_NPS_temp_elec_sum(1,↙
j));
        end
        if UG_CPS_temp_elec_sum(1,j) ~= 0
            UG_CPS(i,j) = UG_CPS(40,j) * (UG_CPS_temp(i,j) / UG_CPS_temp_elec_sum(1,↙
j));
        end
        if UG_450_temp_elec_sum(1,j) ~= 0
            UG_450(i,j) = UG_450(40,j) * (UG_450_temp(i,j) / UG_450_temp_elec_sum(1,↙
j));
        end
    end
end

%To allow for energy efficiency, the sectors related to PG and OE in UG_XXX will be
%restored to the UG_XXX_temp numbers.
for j = 1:129
    if strcmp('PG',IEA_Z_ctg_code(j))
        UG_2009(:,j) = UG_2009_temp(:,j);
        UG_NPS(:,j) = UG_NPS_temp(:,j);
        UG_CPS(:,j) = UG_CPS_temp(:,j);
        UG_450(:,j) = UG_450_temp(:,j);
    elseif strcmp('OE',IEA_Z_ctg_code(j))
        UG_2009(:,j) = UG_2009_temp(:,j);
        UG_NPS(:,j) = UG_NPS_temp(:,j);
        UG_CPS(:,j) = UG_CPS_temp(:,j);
        UG_450(:,j) = UG_450_temp(:,j);
    end
end
```

```matlab
%-----------------------------------------
%d_UG_XXX = UG_XXX - UG_One (which is year 2000) in order to see the
%changes in each energy product for each industry.
d_UG_2009 = UG_2009 - UG_One_Elec;
d_UG_NPS = UG_NPS - UG_One_Elec;
d_UG_CPS = UG_CPS - UG_One_Elec;
d_UG_450 = UG_450 - UG_One_Elec;

%E_dUG_fuel_XXX = d_UG_XXX * Unit_Emission to get the corresponding change in
%emissions across all industries/fuels.
for r = 1:PollutantCode_max(1,1)
    for i = 1:UGi_max
        E_dUG_fuel_2009(i,:,r) = d_UG_2009(i,:) .* Unit_Emission(i,:,r);
        E_dUG_fuel_NPS(i,:,r) = d_UG_NPS(i,:) .* Unit_Emission(i,:,r);
        E_dUG_fuel_CPS(i,:,r) = d_UG_CPS(i,:) .* Unit_Emission(i,:,r);
        E_dUG_fuel_450(i,:,r) = d_UG_450(i,:) .* Unit_Emission(i,:,r);
    end
end

%Sum up the totals across all fuels for each pollutant under each industry
%to get E_dUG_total_XXX for each scenario.
E_dUG_total_2009 = sum(E_dUG_fuel_2009, 1);
E_dUG_total_NPS = sum(E_dUG_fuel_NPS, 1);
E_dUG_total_CPS = sum(E_dUG_fuel_CPS, 1);
E_dUG_total_450 = sum(E_dUG_fuel_450, 1);

%Convert 3 dimensional matrix E_dUG_total_XXX into 2 dimensional form,
%since the 3rd dimension was the fuel category that was previously summed
%up.
E_dUG_2009 = zeros(PollutantCode_max(1,1), UGj_max);
E_dUG_NPS = zeros(PollutantCode_max(1,1), UGj_max);
E_dUG_CPS = zeros(PollutantCode_max(1,1), UGj_max);
E_dUG_450 = zeros(PollutantCode_max(1,1), UGj_max);

for r = 1:PollutantCode_max(1,1)
    for j = 1:UGj_max
        E_dUG_2009(r,j) = E_dUG_total_2009(1,j,r);
        E_dUG_NPS(r,j) = E_dUG_total_NPS(1,j,r);
        E_dUG_CPS(r,j) = E_dUG_total_CPS(1,j,r);
        E_dUG_450(r,j) = E_dUG_total_450(1,j,r);
    end
end


%-----------------------------------------
%Aggregate E_One stressors (multiple CO2s into one) according to how
%stressors are defined in the characterisation matrix E_char. Aggregate
%E_dUG_XXX stressors also in the same manner.

%Correlate the pollutants from E_dUG_total_XXX to E_One (year 2000) by
%using the vector "E_UG_code".
E_char_index = importdata('E_char_index.xls');
E_One_index = importdata('E_One_index.xls');
E_db_index = importdata('E_db_index.xls');
```

```
%E_One based on EXIOPOL E table
E_One_sum = zeros(size(E_char_index,1),Ej_max);
for i = 1:size(E_char_index,1);
    for n = 1:size(E_One_index,1);
        if strcmp(E_One_index(n,1), E_char_index(i,1))
            E_One_sum(i,:) = E_One_sum(i,:) + E_One(n,:);
        end
    end
end

%E_db_One based on EmissionsByFuel sum. This will be used instead of E_One.
E_db_One_sum = zeros(size(E_char_index,1), Ej_max);
for i = 1:size(E_char_index,1);
    for n = 1:size(E_db_index,1);
        if strcmp(E_db_index(n,1), E_char_index(i,1))
            E_db_One_sum(i,:) = E_db_One(n,:);
        end
    end
end

E_dUG_2009_sum = zeros(size(E_char_index,1),Ej_max);
E_dUG_NPS_sum = zeros(size(E_char_index,1),Ej_max);
E_dUG_CPS_sum = zeros(size(E_char_index,1),Ej_max);
E_dUG_450_sum = zeros(size(E_char_index,1),Ej_max);
for i = 1:size(E_char_index,1);
    for n = 1:size(E_db_index,1);
        if strcmp(E_db_index(n,1), E_char_index(i,1))
            E_dUG_2009_sum(i,:) = E_dUG_2009_sum(i,:) + E_dUG_2009(n,:);
            E_dUG_NPS_sum(i,:) = E_dUG_NPS_sum(i,:) + E_dUG_NPS(n,:);
            E_dUG_CPS_sum(i,:) = E_dUG_CPS_sum(i,:) + E_dUG_CPS(n,:);
            E_dUG_450_sum(i,:) = E_dUG_450_sum(i,:) + E_dUG_450(n,:);
        end
    end
end


%-----------------------------------------
%E_XXX = E_db_One + E_dUG_total_XXX to get the new emissions for each pollutant and
%sector. Note that E_db_One is used instead of the one from EXIOPOL, E_One
E_2009 = E_db_One_sum + E_dUG_2009_sum;
E_NPS = E_db_One_sum + E_dUG_NPS_sum;
E_CPS = E_db_One_sum + E_dUG_CPS_sum;
E_450 = E_db_One_sum + E_dUG_450_sum;


%-----------------------------------------
%convert physical energy values UG_XXX(62x129) into monetary Z_XXX(24x129)
%using "EnergyPrice_Z_UG".
Z_Energy_Pcode = importdata('Z_Energy_Pcode.xls');

d_Z_2009 = zeros(24,129);
d_Z_NPS = zeros(24,129);
d_Z_CPS = zeros(24,129);
d_Z_450 = zeros(24,129);
```

```
for i = 1:UGi_max_elec
    for n = 1:24
        if strcmp(Z_Energy_Pcode(n,1), UG_Pcode(i,1))
            d_Z_2009(n,:) = d_Z_2009(n,:) + (d_UG_2009(i,:) .* EnergyPrice_Z_UG(n,:));
            d_Z_NPS(n,:) = d_Z_NPS(n,:) + (d_UG_NPS(i,:) .* EnergyPrice_Z_UG(n,:));
            d_Z_CPS(n,:) = d_Z_CPS(n,:) + (d_UG_CPS(i,:) .* EnergyPrice_Z_UG(n,:));
            d_Z_450(n,:) = d_Z_450(n,:) + (d_UG_450(i,:) .* EnergyPrice_Z_UG(n,:));
        end
    end
end

Z_2009 = Z_One;
Z_NPS = Z_One;
Z_CPS = Z_One;
Z_450 = Z_One;

for i = 1:129
    for n = 1:24
        if strcmp(Z_Energy_Pcode(n,1), Z_Pcode(i,1))
            Z_2009(i,:) = Z_One(i,:) + d_Z_2009(n,:);
            Z_NPS(i,:) = Z_One(i,:) + d_Z_NPS(n,:);
            Z_CPS(i,:) = Z_One(i,:) + d_Z_CPS(n,:);
            Z_450(i,:) = Z_One(i,:) + d_Z_450(n,:);
        end
    end
end


%-----------------------------------------------
%Aggregate 129 products into 13 broad categories
Z_Icode_agg_few = importdata('Z_Icode_agg_few.xls');
Z_Icode_agg = importdata('Z_Icode_agg.xls');

%initialize matricies
temp_2000_agg = zeros(13,129);
temp_2009_agg = zeros(13,129);
temp_NPS_agg = zeros(13,129);
temp_CPS_agg = zeros(13,129);
temp_450_agg = zeros(13,129);

Z_2000_agg = zeros(13,13);
Z_2009_agg = zeros(13,13);
Z_NPS_agg = zeros(13,13);
Z_CPS_agg = zeros(13,13);
Z_450_agg = zeros(13,13);

Y_One_agg = zeros(13,7);

E_2000_agg = zeros(28,13);
E_2009_agg = zeros(28,13);
E_NPS_agg = zeros(28,13);
E_CPS_agg = zeros(28,13);
E_450_agg = zeros(28,13);
```

```
%aggregate 129 into 13
for i = 1:129
    for n = 1:13
        if strcmp(Z_Icode_agg(i,1), Z_Icode_agg_few(n,1));
            %aggregate the rows in a temporary matrix
            temp_2000_agg(n,:) = temp_2000_agg(n,:) + Z_One(i,:);
            temp_2009_agg(n,:) = temp_2009_agg(n,:) + Z_2009(i,:);
            temp_NPS_agg(n,:) = temp_NPS_agg(n,:) + Z_NPS(i,:);
            temp_CPS_agg(n,:) = temp_CPS_agg(n,:) + Z_CPS(i,:);
            temp_450_agg(n,:) = temp_450_agg(n,:) + Z_450(i,:);

            %aggregate rows of Y_One
            Y_One_agg(n,:) = Y_One_agg(n,:) + Y_One(i,:);

            %aggregate columns of E
            E_2000_agg(:,n) = E_2000_agg(:,n) + E_db_One_sum(:,i);
            E_2009_agg(:,n) = E_2009_agg(:,n) + E_2009(:,i);
            E_NPS_agg(:,n) = E_NPS_agg(:,n) + E_NPS(:,i);
            E_CPS_agg(:,n) = E_CPS_agg(:,n) + E_CPS(:,i);
            E_450_agg(:,n) = E_450_agg(:,n) + E_450(:,i);
        end
    end
end

%aggregate columns of temporary Z matrix
for i = 1:129
    for n = 1:13
        if strcmp(Z_Icode_agg(i,1), Z_Icode_agg_few(n,1));
            Z_2000_agg(:,n) = Z_2000_agg(:,n) + temp_2000_agg(:,i);
            Z_2009_agg(:,n) = Z_2009_agg(:,n) + temp_2009_agg(:,i);
            Z_NPS_agg(:,n) = Z_NPS_agg(:,n) + temp_NPS_agg(:,i);
            Z_CPS_agg(:,n) = Z_CPS_agg(:,n) + temp_CPS_agg(:,i);
            Z_450_agg(:,n) = Z_450_agg(:,n) + temp_450_agg(:,i);
        end
    end
end


%-----------------------------------------------
%Calculate X by summing up the intermediate demand Z, and the final demand
%Y. Note that final demand Y never changes between scenarios.
X_One = sum(Z_One,2) + sum(Y_One,2);
X_2009 = sum(Z_2009,2) + sum(Y_One,2);
X_NPS = sum(Z_NPS,2) + sum(Y_One,2);
X_CPS = sum(Z_CPS,2) + sum(Y_One,2);
X_450 = sum(Z_450,2) + sum(Y_One,2);

X_2000_agg = sum(Z_2000_agg,2) + sum(Y_One_agg,2);
X_2009_agg = sum(Z_2009_agg,2) + sum(Y_One_agg,2);
X_NPS_agg = sum(Z_NPS_agg,2) + sum(Y_One_agg,2);
X_CPS_agg = sum(Z_CPS_agg,2) + sum(Y_One_agg,2);
X_450_agg = sum(Z_450_agg,2) + sum(Y_One_agg,2);


%calculate the A_One and A_XXX
```

```
A_One = Z_One * inv(diag(X_One));
A_2009 = Z_2009 * inv(diag(X_2009));
A_NPS = Z_NPS * inv(diag(X_NPS));
A_CPS = Z_CPS * inv(diag(X_CPS));
A_450 = Z_450 * inv(diag(X_450));

A_2000_agg = Z_2000_agg * inv(diag(X_2000_agg));
A_2009_agg = Z_2009_agg * inv(diag(X_2009_agg));
A_NPS_agg = Z_NPS_agg * inv(diag(X_NPS_agg));
A_CPS_agg = Z_CPS_agg * inv(diag(X_CPS_agg));
A_450_agg = Z_450_agg * inv(diag(X_450_agg));


%calculate the total emissions by summing across all sectors.
E_total_2000 = sum(E_db_One_sum,2);
E_total_2009 = sum(E_2009, 2);
E_total_NPS = sum(E_NPS, 2);
E_total_CPS = sum(E_CPS, 2);
E_total_450 = sum(E_450, 2);

E_total_2000_agg = sum(E_2000_agg,2);
E_total_2009_agg = sum(E_2009_agg, 2);
E_total_NPS_agg = sum(E_NPS_agg, 2);
E_total_CPS_agg = sum(E_CPS_agg, 2);
E_total_450_agg = sum(E_450_agg, 2);


%calculate emissions intensity matrix for E_int_XXX
E_int_One = E_db_One_sum * inv(diag(X_One));
E_int_2009 = E_2009 * inv(diag(X_2009));
E_int_NPS = E_NPS * inv(diag(X_NPS));
E_int_CPS = E_CPS * inv(diag(X_CPS));
E_int_450 = E_450 * inv(diag(X_450));

E_int_2000_agg = E_2000_agg * inv(diag(X_2000_agg));
E_int_2009_agg = E_2009_agg * inv(diag(X_2009_agg));
E_int_NPS_agg = E_NPS_agg * inv(diag(X_NPS_agg));
E_int_CPS_agg = E_CPS_agg * inv(diag(X_CPS_agg));
E_int_450_agg = E_450_agg * inv(diag(X_450_agg));


%calculate direct impacts with characterisation matrix.
C = importdata('Characterisation.xls');


%-------------------------------------------------
%calculate total economy wide direct impact
D_total_2000 = C' * E_total_2000;
D_total_2009 = C' * E_total_2009;
D_total_NPS = C' * E_total_NPS;
D_total_CPS = C' * E_total_CPS;
D_total_450 = C' * E_total_450;

D_dir_flow_2000_agg = C' * E_2000_agg;
D_dir_flow_2009_agg = C' * E_2009_agg;
```

```
D_dir_flow_NPS_agg = C' * E_NPS_agg;
D_dir_flow_CPS_agg = C' * E_CPS_agg;
D_dir_flow_450_agg = C' * E_450_agg;


%calculate direct intensity impacts
D_dir_int_2000 = C' * E_db_One_sum * inv(diag(X_One));
D_dir_int_2009 = C' * E_2009 * inv(diag(X_2009));
D_dir_int_NPS = C' * E_NPS * inv(diag(X_NPS));
D_dir_int_CPS = C' * E_CPS * inv(diag(X_CPS));
D_dir_int_450 = C' * E_450 * inv(diag(X_450));

D_dir_int_2000_agg = C' * E_2000_agg * inv(diag(X_2000_agg));
D_dir_int_2009_agg = C' * E_2009_agg * inv(diag(X_2009_agg));
D_dir_int_NPS_agg = C' * E_NPS_agg * inv(diag(X_NPS_agg));
D_dir_int_CPS_agg = C' * E_CPS_agg * inv(diag(X_CPS_agg));
D_dir_int_450_agg = C' * E_450_agg * inv(diag(X_450_agg));

%Calculate the direct UG energy usage.
UG_dir_int_2000 = UG_One * inv(diag(X_One));
UG_dir_int_2009 = UG_2009 * inv(diag(X_2009));
UG_dir_int_NPS = UG_NPS * inv(diag(X_NPS));
UG_dir_int_CPS = UG_CPS * inv(diag(X_CPS));
UG_dir_int_450 = UG_450 * inv(diag(X_450));

UG_dir_int_2000_sum = zeros(1,129);
UG_dir_int_2009_sum = zeros(1,129);
UG_dir_int_NPS_sum = zeros(1,129);
UG_dir_int_CPS_sum = zeros(1,129);
UG_dir_int_450_sum = zeros(1,129);

%Sum up all direct energy use of each column, except for the disaggregated
%electricity in rows 57-62, as it is already reprsented in row 40 in
%aggregated total.
for i = 1:56
    UG_dir_int_2000_sum(1,:) = UG_dir_int_2000_sum(1,:) + UG_dir_int_2000(i,:);
    UG_dir_int_2009_sum(1,:) = UG_dir_int_2009_sum(1,:) + UG_dir_int_2009(i,:);
    UG_dir_int_NPS_sum(1,:) = UG_dir_int_NPS_sum(1,:) + UG_dir_int_NPS(i,:);
    UG_dir_int_CPS_sum(1,:) = UG_dir_int_CPS_sum(1,:) + UG_dir_int_CPS(i,:);
    UG_dir_int_450_sum(1,:) = UG_dir_int_450_sum(1,:) + UG_dir_int_450(i,:);
end

%--------------------------------------------------

%calculate the total life cycle intensity impacts (direct and indirect)
I = eye(129);
I_agg = eye(13);

D_lc_int_2000 = C' * E_int_One * inv(I - A_One);
D_lc_int_2009 = C' * E_int_2009 * inv(I - A_2009);
D_lc_int_NPS = C' * E_int_NPS * inv(I - A_NPS);
D_lc_int_CPS = C' * E_int_CPS * inv(I - A_CPS);
D_lc_int_450 = C' * E_int_450 * inv(I - A_450);

D_lc_int_2000_agg = C' * E_int_2000_agg * inv(I_agg - A_2000_agg);
```

```
D_lc_int_2009_agg = C' * E_int_2009_agg * inv(I_agg - A_2009_agg);
D_lc_int_NPS_agg = C' * E_int_NPS_agg * inv(I_agg - A_NPS_agg);
D_lc_int_CPS_agg = C' * E_int_CPS_agg * inv(I_agg - A_CPS_agg);
D_lc_int_450_agg = C' * E_int_450_agg * inv(I_agg - A_450_agg);

%calculate the life cycle energy usage of each sector.
UG_lc_int_2000 = UG_dir_int_2000 * inv(I - A_One);
UG_lc_int_2009 = UG_dir_int_2009 * inv(I - A_2009);
UG_lc_int_NPS = UG_dir_int_CPS * inv(I - A_NPS);
UG_lc_int_CPS = UG_dir_int_NPS * inv(I - A_CPS);
UG_lc_int_450 = UG_dir_int_450 * inv(I - A_450);

UG_lc_int_2000_sum = zeros(1,129);
UG_lc_int_2009_sum = zeros(1,129);
UG_lc_int_NPS_sum = zeros(1,129);
UG_lc_int_CPS_sum = zeros(1,129);
UG_lc_int_450_sum = zeros(1,129);


%Sum up all lc energy use of each column, except for the disaggregated
%electricity in rows 57-62, as it is already reprsented in row 40 in
%aggregated total.
for i = 1:56
    UG_lc_int_2000_sum(1,:) = UG_lc_int_2000_sum(1,:) + UG_lc_int_2000(i,:);
    UG_lc_int_2009_sum(1,:) = UG_lc_int_2009_sum(1,:) + UG_lc_int_2009(i,:);
    UG_lc_int_NPS_sum(1,:) = UG_lc_int_NPS_sum(1,:) + UG_lc_int_NPS(i,:);
    UG_lc_int_CPS_sum(1,:) = UG_lc_int_CPS_sum(1,:) + UG_lc_int_CPS(i,:);
    UG_lc_int_450_sum(1,:) = UG_lc_int_450_sum(1,:) + UG_lc_int_450(i,:);
end

D_lc_flow_2000_agg = D_lc_int_2000_agg * diag(X_2000_agg);
%D_lc_flow_2000_agg = D_dir_flow_2000_agg * inv(I_agg - A_2000_agg);


%----------------------------------
%Aggregate UG_One_elec and UG_450 into 17 IEA fuel types
IEA_UG_2000_temp = zeros(17,129);
IEA_UG_450_temp = zeros(17,129);
for i = 1:UGi_max_elec
    for n = 1:17
        if strcmp(IEA_conv_code(n), IEA_UG_conv_code(i));
            IEA_UG_2000_temp(n,:) = IEA_UG_2000_temp(n,:) + UG_One_Elec(i,:);
            IEA_UG_450_temp(n,:) = IEA_UG_450_temp(n,:) + UG_450(i,:);
        end
    end
end

%Aggregate IEA_UG_conv into 13 sectors. Do the same for IEA_UG_450.
IEA_UG_2000_agg = zeros(17,13);
IEA_UG_450_agg = zeros(17,13);
for i = 1:129
    for n = 1:13
        if strcmp(Z_Icode_agg(i,1), Z_Icode_agg_few(n,1));
            IEA_UG_2000_agg(:,n) = IEA_UG_2000_agg(:,n) + IEA_UG_2000_temp(:,i);
            IEA_UG_450_agg(:,n) = IEA_UG_450_agg(:,n) + IEA_UG_450_temp(:,i);
```

```
        end
    end
end

%Calculate the fraction of energy sectors as a proportion of X. Aggregate
%into sectors. Keep in flows.
Z_Energy_2000 = zeros(129,1);
Z_Energy_2000_agg = zeros(13,1);
for i = 1:129
    for n = 1:24
        for j = 1:129
            if strcmp(Z_Pcode(j,1), Z_Energy_Pcode(n,1))
                Z_Energy_2000(i,1) = Z_Energy_2000(i,1) + Z_One(i,j);
            end
        end
    end
end

for i = 1:129
    for n = 1:13
        if strcmp(Z_Icode_agg(i,1), Z_Icode_agg_few(n,1));
            Z_Energy_2000_agg(n,1) = Z_Energy_2000_agg(n,1) + Z_Energy_2000(i,1);
        end
    end
end

Energy_Percent_agg = Z_Energy_2000_agg ./ X_2000_agg;


%----------------------------------
%CHECK #1 on calculations
E_dUG_test_450 = E_dUG_fuel_450(:,:,6);
Unit_Emission_test = Unit_Emission(:,:,6);
db_One_test = db_One(:,:,6);

%Check between E_One_sum CO2 and E_db_One_sum.
B_check = E_db_One(6,:);
C02_check = E_One_sum(4,:);
```