The Environmental Footprints Explorer - a database for global sustainable accounting

Konstantin Stadler*[†], Radek Lonka*, Daniel Moran*, Georgios Pallas*, Richard Wood*

* Industrial Ecology Programme, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

[†] Email: konstantin.stadler@ntnu.no

Abstract—**Environmentally Extended Multi Regional Input Output tables and analysis (EE MRIOs) have emerged as one of the main tools to analyze resource use and environmental impacts across international supply chains. They provide insights into the life cycle impacts of the production and consumption of commodities world wide, taking into account the global supply chain of purchased commodities. Currently half a dozen EE MRIO databases are available which differ in their environmental and economic focus as well as in the level of detail. As these databases become increasingly large, it has become increasingly difficult for the non-input-output expert to access the most important attributes and results of basic calculations. Here we present an integrated web-platform, the Environmental Footprints Explorer (http://www.environmentalfootprints.com), designed to access indicator results calculated based on these databases. The main functionality of the web-platform include (1) exploring environmental accounts based on a single database (2) comparison between databases using a common classification system and (3) exporting analysis results visualization. The presented web-platform removes the obstacle for policy-makers and the public alike to access EE MRIO results.**

I. INTRODUCTION

Evidence guided policy making aiming for lessening the negative environmental and social impacts of our society require a comprehensive accounting principle. Such a principle must not only take into account direct domestic emissions and resource usage but also make the connection across global production networks - ultimately we are often interested in what forms of consumption have driven the impacts caused in production processes.

Global Environmentally Extended Multi Regional Input-Output (EE MRIO) tables provide such an system by taking into account the interrelations between production and consumption. EE MRIO tables link supply chains from the source of an impact, across countries, across processing stages, and to the final consumer. As such, estimates can be made about the amount of greenhouse gas emissions occurring in China to produce steel used in European televisions, or the amount of land used in Brazil required to feed British consumers. An important aspect of EE MRIO tables is that they are macro level economy-wide systems that provide a holistic picture of global production and consumption.

During the last years, several EE MRIO databases have been published [1]. These databases differ in their environmental and regional focus and also due to the applied accounting principles and implementation details [2]–[4].

Analysing EE MRIO databases require a certain degree of training and the increasing size of the underlying matrices

also set high requirements on used hardware. Thus, although most of the databases are free to use the detailed results of the analysis of these databases are often hidden in the supplements of scientific articles and reports.

Here we present the Environmental Footprints Explorer (Figure 1), http://www.environmentalfootprints.org , a web platform which provide access to the calculated results of various EE MRIO databases. The included EE MRIO databases have been aggregated into a common classification framework in order to make them comparable. Therewith, the presented platform allows to compare the environmental impacts of production and consumption of goods and services.

Fig. 1. The Environmental Footprints Explorer

The rest of the article unfolds as follows. In the next section we give some background information on environmental accounting followed by an overview about recently published EE MRIO databases which are included in the Environmental Footprint Explorer. The development section describes the architecture of the web platform, the routines used for calculating the results and the Common Classification System [5] applied to the MRIOs in order to make them comparable. We then present the platform and highlight some use cases. We conclude with a description of the future development.

A. Environmental Accounting

Principally, pressures arising from economic activity can either be tallied at the actual place of production or at the point of the consumption. Traditionally, the accounting at the actual place of production has been used for policy decisions. For example, the Kyoto Protocol was based on the production

principle, which is now discussed to be one of the reasons for its limited success [6].

Consumption based accounting (CBA), on the other hand, has been gaining momentum for policy making [7] as increasing globalisation of production networks occur. In CBA, all resource use and environmental pressures (for example emissions) occurring along the the supply chain of products are added up and allocated to the final consumer of the product. This allows to assess the environmental pressure caused by a domestic demand abroad [8], [9].

Indicators based on consumption based accounting are also known as various types of 'footprints'. Nowadays, these are increasingly used for informing policy makers as well as the public about ongoing environmental [10]–[13] and social problems [14].

CBA requires a comprehensive description of the global socio-economic metabolism including among other the structure of domestic economies, their resource use and efficiency and the amount of trade between countries and regions. Environmentally Extended Multi Regional Input-Output databases (EEMRIO) provide all these data in a consistent framework.

B. EE MRIO databases

1) EXIOBASE: EXIOBASE is a global EE MRIO aiming to support analysis of technologies, policies, and standards in relation to EU sustainability policies. The environmental focus of the database is reflected in a high level of detail in the agriculture, energy, mining, transport, and waste management sectors. EXIOBASE provides satellite accounts for over 300 environmental interventions.

The database was developed and analysed in three consecutive EU projects: EXIOPOL [1], CREEA [15] and the ongoing project DESIRE. The currently available version, EXIOBASE 2, implements the economic and environmental accounting principles proposed in the UN System of Economic and Environmental Accounts [16]. The ongoing development of EXIOBASE 3 concentrates on providing a time series of EE MRIOs and now-casting this time series to the current year.

Currently, EXIOBASE consists of EE MRIOs for 27 (28 in the upcoming version 3) EU countries, 16 major economies and 5 rest of world regions in industry by industry (163 sectors) as well as product by product (200 sectors) classification.

2) OPEN:EU: OPEN:EU [11], [17] is an MRIO model based on the Global Trade Analysis Project (GTAP - v7) [18] follwing a method describe by Peters et al. [19]. This MRIO model consists of 94 explicitly modelled countries together with 19 composite rest of the world regions. OPEN:EU was constructed for the base-year 2004.

3) WIOD: The World Input Output Database (WIOD) was also constructed as an alternate tool for analysing the effects of globalisation on trade patterns, environmental pressures and socio-economic development on a global level [20]. WIOD consists of a time series (1995–2011) of IOT for 27 EU countries, 13 non-EU countries, and 1 RoW region. WIOD distinguishes 35 industries and 59 products. The WIOD has prioritized aggregate accounts as consistent as possible with official statistics. The database has been used extensively to analyse fragmentation of supply chains and trade in value added.

4) Eora: Eora is a time-series (1990-2011) of input-output tables with high country detail (187 countries and 1 RoW region), utilizing asymmetric levels of detail and concepts of supply-use. There is further a smaller version of Eora at 26 sectors common for all countries. The total database has 15,909 sectors with the size of the system having just over 250 million variables. The database has 35 types of environmental indicators covering air pollution, energy use, greenhouse gas emissions, water use, Ecological Footprint, and Human Appropriation of Net Primary Productivity. A key point of the Eora database is its in-homogenous classification in the full detail version.

II. DEVELOPMENT

Calculation of EE MRIO accounts (Multipliers, Footprints, impacts embodied in trade, etc) followed standard IO methodology. We used the open source tool pymrio (https://github.com/konstantinstadler/pymrio) for the calculations.

All results are calculated through input-output analysis (IOA) following classic Leontief demand style modeling. IOA is essentially an allocation of production based impacts (here denoted $\mathbf{F}$) to the goods and services that flow to final demand (here denoted $\mathbf{y}$). The allocation starts from the basic production balance, where gross output $\mathbf{x}$ is the sum of total intermediate demand $\mathbf{T}$ (with $\mathbf{1}$ being the summation vector of appropriate size) and final demand.

$$\mathbf{x} = \mathbf{T} * \mathbf{1} + \mathbf{y} \qquad (1)$$

Normalising intermediate production (to produce one unit of output, we can calculate the required inputs, giving the technical coefficient matrix $\mathbf{A}$)

$$\mathbf{A} = \mathbf{T} * \mathbf{x}^{-1} \qquad (2)$$

Then we can combine the above two equations, using what has been known as the Leontief inverse ($\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$), to estimate the total output ($\mathbf{x}$) for any given demand $\mathbf{y}$:

$$\mathbf{x} = \mathbf{L} * \mathbf{y} \qquad (3)$$

In MRIO modelling, for a certain demand, in a certain country, the production required to satisfy the demand is calculated. The point of departure from national accounting in gross domestic product terms is that imports are endogenised in the flows of goods to demands, and exports are excluded from a country's demand – in line with gross national expenditure calculations. Environmental inputs or emissions of economic production can be linked to the input-output table through a stressor (environmental intervention) matrix $\mathbf{F}$. Similar to the basic input-output relationship, environmental intensities (environmental factors per unit production, $\mathbf{S}$) can than be calculated:

$$\mathbf{S} = \mathbf{F} * \mathbf{x}^{-1} \qquad (4)$$

TABLE I
COUNTRIES AND REGIONS OF THE MRIOS INCLUDED IN THE
ENVIRONMENTAL FOOTPRINT EXPLORER. THE ORIGINAL COUNTRIES OF
THE MRIOS WERE MODIFIED TO HAVE A COMPARABLE COUNTRY SET
FOR EACH MRIO. THE NEW SET INCLUDES THE EU COUNTRIES EXCEPT
CROATIA (EU27) AND OTHER MAJOR ECONOMIES ACCOUNTING FOR
ABOUT 90 OF THE GLOBAL GDP [2]. UN CODES FOR TAIWAN AND THE
AGGREGATED ROW ARE NOT AVAILABLE (N.A.).

Number	ISO3 Code	UN Code	Name
1	AUS	36	Australia
2	AUT	40	Austria
3	BEL	56	Belgium
4	BRA	76	Brazil
5	BGR	100	Bulgaria
6	CAN	124	Canada
7	CHN	156	China
8	CYP	196	Cyprus
9	CZE	203	Czech Republic
10	DNK	208	Denmark
11	EST	233	Estonia
12	FIN	246	Finland
13	FRA	250	France
14	DEU	276	Germany
15	GRC	300	Greece
16	HUN	348	Hungary
17	IND	356	India
18	IDN	360	Indonesia
19	IRL	372	Ireland
20	ITA	380	Italy
21	JPN	392	Japan
22	LVA	428	Latvia
23	LTU	440	Lithuania
24	LUX	442	Luxembourg
25	MLT	470	Malta
26	MEX	484	Mexico
27	NLD	528	Netherlands
28	POL	616	Poland
29	PRT	620	Portugal
30	ROM	642	Romania
31	RUS	643	Russia
32	SVK	703	Slovakia
33	SVN	705	Slovenia
34	KOR	410	SouthKorea
35	ESP	724	Spain
36	SWE	752	Sweden
37	TWN	n.a.	Taiwan
38	TUR	792	Turkey
39	GBR	826	United Kingdom
40	USA	840	United States
41	RoW	n.a.	Rest of the World

TABLE II
SECTORS OF THE MRIOS INCLUDED IN THE ENVIRONMENTAL
FOOTPRINT EXPLORER. THE ORIGINAL CLASSIFICATION OF THE MRIOS
WERE AGGREGATED INTO THE COMMON CLASSIFICATION SYSTEM [5] IN
ORDER TO MAKE THEM COMPARABLE.

Number	Code	Name
1	AGRF	Agriculture, forestry, hunting, and fisheries
2	MINQ	Mining and quarrying
3	FOOD	Food products, beverages, and tobacco
4	CLTH	Textiles, leather, and wearing apparel
5	WOOD	Wood, paper, and publishing
6	PETC	Petroleum, chemical, and non-metal mineral products
7	METP	Metal and metal products
8	ELMA	Electrical equipment and machinery
9	TREQ	Transport equipment
10	MANF	Manufacturing and recycling
11	ELGW	Electricity, gas and water
12	CNST	Construction
13	TRAD	Trade
14	TRNS	Transport
15	POST	Post and telecommunications
16	BSNS	Financial intermediation and business activities
17	PAEH	Public administration, education, health, recreational, and other services

For the data storage the MySQL RDBMS was used. The results of the calculation which were in csv format files was used to update mysql database table on web server. Wordpress CMS was used for web development. The tool for data exploration was done using wordpress plugin which query data, using php, directly from mysql database table. The data are shown in html table with possibility to select and filter different options and witf functionality to export selected data into different formats (csv, pdf, excel). Visualization of data was interpreted using plotly web tool based on d3js.

III. TOOL DESCRIPTION

The interactive database provides three main functionalities:

1) Exploring environmental accounts based on a single database
2) Comparison of accounts between databases using a common classification system
3) Visualization and exporting

We describe these three functions below together with a short example of an use case.

A. Exploring environmental accounts based on a single database

The first choice in the Data Explorer of the Environmental Footprint Explorer allows to specify a certain EE MRIO model. Within one MRIO model, several parameters can be selected (Figure 2), including:

- Base-year
- Stressor (environmental/social) intervention or factor of production, impacts
- Countries/regions
- Sector of the database (industry, product or final demand category)
- Perspective (Footprint, production/territorial accounts, embodied stressors in imports and exports, Multipliers and Intensities)

In order to calculate overall upstream impacts (aka footprints $\mathbf{D}$) due to a certain demand $\mathbf{y}$, we utilize the Leontief Inverse $\mathbf{L}$ as per standard input-output analysis:

$$\mathbf{D} = \mathbf{S} * \mathbf{L} * \mathbf{y} \qquad (5)$$

Direct emissions of final demand (e.g. gas cooking or fuel consumptions) are handled separatley and added to the calculated $\mathbf{D}$.

In order to compare the different EE MRIOs included, we aggregated each into the Common Classification System [5]. This system comprises the common denominator for all EE MRIOs available and leads to an aggregation to 41 regions (40 countries and 1 Rest of the World, see Table I) and 17 sectors (see Table II). Due to the European focus of most EE MRIO projects, the Common Classification includes all European Union countries (except the new member state Croatia).

Based on the selection of the table of accounts gets updated and can be sorted as required (by each column). The length of the table can be adjusted and a search box allows to find entries within the table.
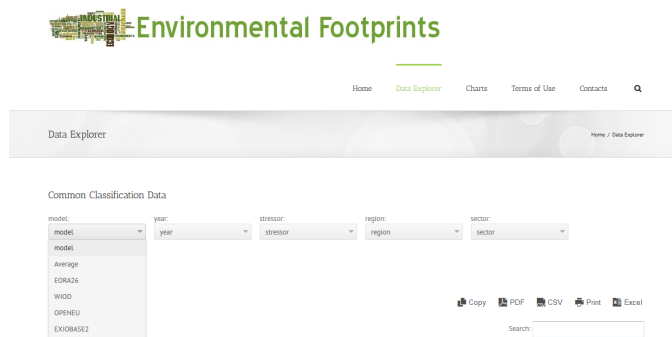

Fig. 2. The Environmental Footprint Explorer aim to ease the data extraction from global EE MRIO databases. Users can select between different databases and specify the perspectives, region and sectors they are interested in.

B. Comparing accounts across databases in a common classification system

The main problem in any EE MRIO comparison is the sector and accounting mismatch between the databases. To solve that issue, we aggregated every database into a Common Classification System [5].

Leaving the model field in the selection unspecified allows to compare results across databases. In addition, we compiled one additional database based on the average results of all included MRIOs. As such, the Environmental Footprints Explorer provides a consistent way to access environmental accounts of different EE MRIO databases and to compare these results across databases.

The implementation of the Environmental Footprints Explorer allows to easily extend the number of EE MRIO databases accessible. In the short term, EXIOBASE 2, WIOD, EORA and OPEN:EU have been integrated. We plan to extend the list of available MRIO as further databases become publicly available.

Some recent studies analyzed the differences between EE MRIO databases [2]–[4]. These studies provided important background information on the reasons of the observed differences and some exemplified comparisons on the effect of the differences of indicators. In order to get the amount of difference for other indicators, any practitioner would need to redo the whole study, starting from parsing several EE MRIO databases, aggregating to a common system and re-analyze the indicator results. The proposed web-platform provides an alternative approach. The comparison of the EE MRIO databases is readily available through the user interface as is the access to the detailed results (Figure 3)..

C. Visualization and exporting

The table view in the Data Explorer provides several possibilities to export the data: The data can be either copies to

Fig. 3. Results of a data query are presented as a table, here showing the differences of carbon footprints across MRIO databases for Germany 2007.

clipboard, or exported as excel, csv or pdf file (Figure 3). All export functions work on the currently specified dataset-view.

The Environmental Footprint Explorer provides several interactive visualization functions.

In order to compare total impacts per country, a bar chart can be generated (Figure 4). This chart includes the total amount of impact/stressor for each country and for each specified model. For trends over time, line plots are available. For example, the Green House Gas Emission of China vs USA can be plotted over time for the consumption based (footprint) perspective. Again, this plot can also be used to assess differences between databases (Figure 5).

IV. CONCLUSION AND OUTLOOK

Here we described an integrated web-interface, the Environmental Footprints Explorer, developed to ease the access to EE MRIO results. The platform provides functionality for the in depth exploration of a single database as well as for the comparison across several EE MRIO databases.

Although several EE MRIO have been developed and published in the past couple of years, the use of their results in informing the policy development process has been potentially limited. The reasons for that, are on the one hand, some expertise are needed to calculate indicators based on EE MRIO accounting, and on the other hand due to the often overwhelming amount of data provided by current EE MRIO databases.

Some EE MRIO projects have tried to overcome that problem in the past by providing various kind of open access result reporting. For example, the OPEN:EU projects provides the policy tool EUREAPA to allow easy access to environmental and economic data for an EE MRIO model based on GTAP [21]. The EE MRIO Eora [22] includes a web-interface to access the main results (http://worldmrio.com) and the EXIOBASE project provide a booklet summarizing the main results for a policy audience [10]. Similar initiatives exist also on the national level, for example the Open IO-Canada allows to retrieve environmental information based on the Canadian economic input-output tables (http://ciraigdev.polymtl.ca). However, all these initiatives fall short in enabling a comparison across databases.

The overall goal of the Environmental Footprints Explorer is to deliver the newest environmental accounting results to
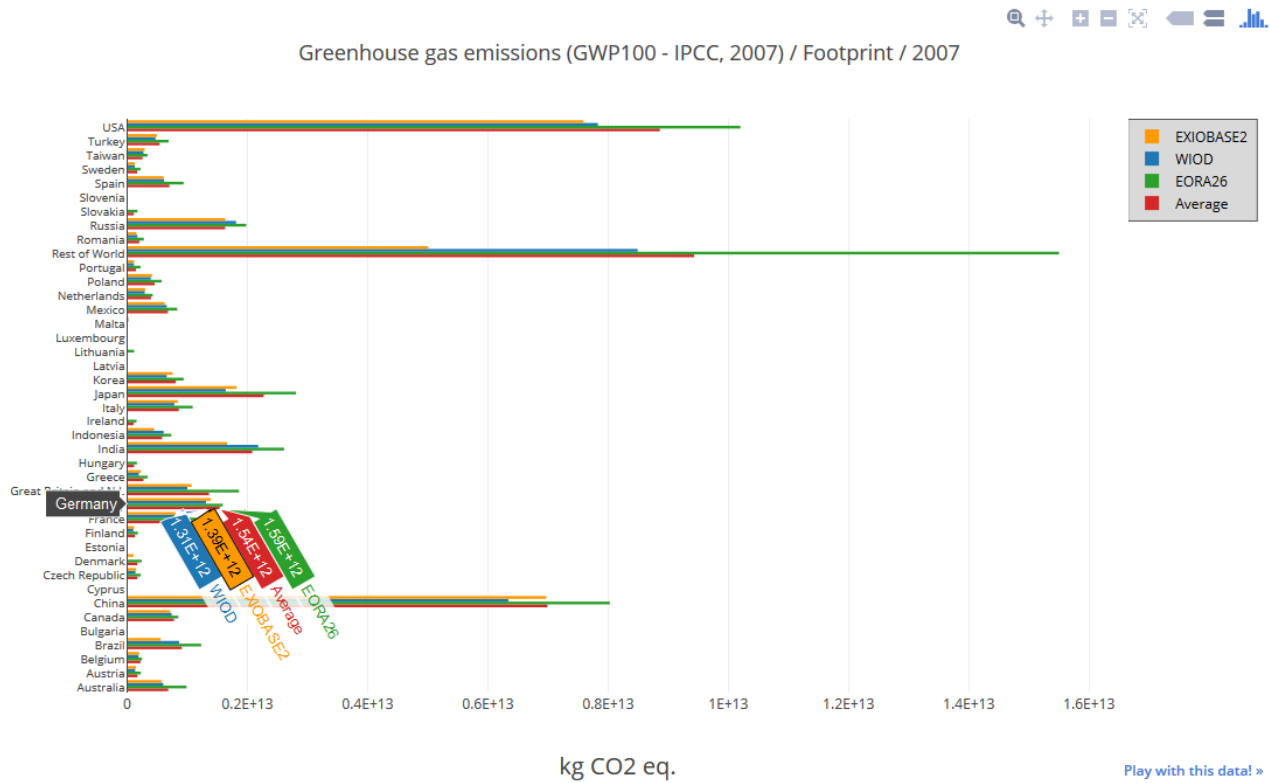
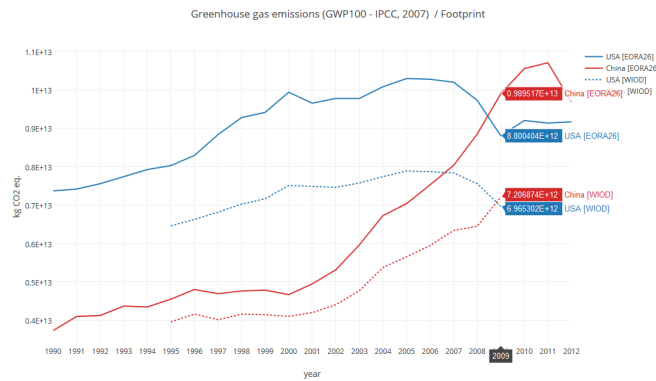Fig. 4. An automatic visualization procedure provides a quick overview about the extracted data.

Fig. 5. Comparison of the the time course of green house gas emissions between USA (blue) and China (red) for EORA (full) and WIOD (dotted). EORA estimates the overtaking of USA by China in regard to GHG footprints one year before WIOD.

policy makers and the public. Previously, these data was filtered by the analyst of the databases and often restricted to the top level results considered novel enough for a scientific publication. Detailed data or the newest updates of previously published data may still be hidden in the databases, although they could be critical for informing targeting policy development.

Recently, the European Science Policy (http://ec.europa.eu/programmes/horizon2020/en/h2020-section/open-science-open-access) as well as various scientific journals [23]–[25] committed to a open science and data scheme. We feel, that, in an ideal situation, open science should not only provide open access to the raw data used for any analysis, but also provide a way to utilize the data for non-experts. The Environmental Footprints Explorer represents a first step in that direction.

The use of the data included in the Environmental Footprint Explorer means the acceptance of the terms of use of the databases providing this data (OPEN:EU, EXIOBASE, WIOD, EORA). Users are referred to the respective database home-pages for further information. The results presented here are a (near as possible) harmonization of environmental impact categories across the databases. Notwithstanding, results displayed in the Environmental Footprints Explorer platform are based upon these aforementioned databases, but any calculation errors are the responsibility of the developers of this web platform.

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