Manuscript Number: ECOLEC-D-15-00303R1

Title: Sector aggregation bias in Environmentally Extended Input Output modelling of raw material flows in Finland.

Article Type: Analysis

Keywords: Material Flow Accounting; Environmentally Extended Input Output; Sector aggregation bias; Footprint

Corresponding Author: Mr. Pablo Piñero,

Corresponding Author's Institution:

First Author: Pablo Piñero

Order of Authors: Pablo Piñero; Mari Heikkinen; Ilmo Mäenpää; Eva Pongrácz

Abstract: This paper presents the impact of sector aggregation bias in Environmentally Extended Input Output (EEIO) models, focusing on raw material flows. Finnish industries are aggregated in different ways and causes of bias are studied. The results show that industries with high raw material use deserve special attention in EEIO models. For Finland, particularly problematic is the aggregation of biomass extractive sectors, since the relative importance of forestry causes noticeable deviations. Sources and strategies to prevent errors, are described separately for biomass and mineral raw materials. A brief comparison between raw material flows and greenhouse gas emissions is also made. It is shown that aggregation of extractive sectors biases more in material flows analyses. This issue might be of significance in the near future, owing to the foreseeable changes in the European Union accounting framework.

1 **Sector aggregation bias in Environmentally**
2 **Extended Input Output modelling of raw material**
3 **flows in Finland.**

4
5 Pablo Piñero^{*,a}, Mari Heikkinen^a, Ilmo Mäenpää^{a,b} and

6 Eva Pongrácz^a

7 ^a *Thule Institute, P.O. Box 7300, University of Oulu, 90014, Finland*

8 ^b *Finnish Environment Institute, P.O. Box 140, 00251 Helsinki,*
9 *Finland*

10

11 ABSTRACT

12 This paper presents the impact of sector aggregation bias in
13 Environmentally Extended Input Output (EEIO) models, focusing on raw
14 material flows. Finnish industries are aggregated in different ways and
15 causes of bias are studied. The results show that industries with high raw
16 material use deserve special attention in EEIO models. For Finland,
17 particularly problematic is the aggregation of biomass extractive sectors,
18 since the relative importance of forestry causes noticeable deviations.
19 Sources and strategies to prevent errors, are described separately for
20 biomass and mineral raw materials. A brief comparison between raw
21 material flows and greenhouse gas emissions is also made. It is shown that
22 aggregation of extractive sectors biases more in material flows analyses.
23 This issue might be of significance in the near future, owing to the
24 foreseeable changes in the European Union accounting framework.

* Corresponding author: Tel +358 294 483552
E-mail addresses: Pablo.Pinero@oulu.fi,
Mari.Heikkinen@oulu.fi, Ilmo.Maenpaa@oulu.fi and
Eva.Pongracz@oulu.fi

25

26 Keywords: Material Flow Accounting, Environmentally Extended Input

27 Output, Sector aggregation bias, Footprint

1 **1. Introduction**

2 On the path towards sustainability, a deeper understanding of the
3 relationship between the economy and the environment is required. To this
4 end, special attention has been paid to two questions: firstly, what are the
5 biophysical flows that fuel the economy and, secondly, how consumers
6 drive environmental deterioration. In respect to the former, the framework
7 of Material Flow Accounting or Economy-wide Material Flow Analysis
8 (Ew-MFA) helps clarifying the biophysical roots of economic prosperity, by
9 measuring the exchanges between the economy and the environment in
10 mass units. Concerning the role of consumers, ‘footprint’ type analyses
11 explore the attribution of environmental pressures to final use categories. In
12 both spheres of research, Environmentally Extended Input Output (EEIO)
13 models have gained growing attention, since their outcomes enable us to
14 trace environmental loads along the supply chain. EEIO models are derived
15 from economic input output (IO) models. Original economic IO models
16 were introduced to depict product flows within the economy using a broad
17 categorization in sectors or industries (Leontief, 1936). This implies
18 unavoidable simplification and aggregation of information, such as
19 averaging data of several firms with different production formulas. As a
20 consequence, significant deviations in results might appear determined by
21 how industries or products are grouped in the model, what is known in the
22 literature as sector aggregation bias. In EEIO, the economic IO framework
23 is broadened to study relevant environmental burden flows, albeit
24 categorization necessity and risks of errors remain. Moreover, heterogeneity
25 of firm-nature interfaces within an industry add an extra level of complexity
26 when studying sector aggregation bias in EEIO (Zhou et al., 2013).
27 Aggregation bias in EEIO has been explored previously, although studies
28 focused mostly on GHG emissions. Nevertheless, there is evidence that
29 aggregation impacts differently depending upon the environmental
30 dimension under consideration (Bouwmeester and Oosterhaven, 2013). The

main purpose of this article is to contribute to the discussion of aggregation bias in the use of EEIO models within the framework of Ew-MFA, by also studying end users as driving forces of material extraction. The focus is on raw material (RM) flows and for reasons of comparison, on greenhouse gas (GHG) emissions using data from Finland. To this end, we use the ENVIMAT₂₀₁₀ model, which has been designed to study environmental pressure of the Finnish economy. We aggregate ENVIMAT₂₀₁₀ classification scheme in different manners and report deviations in outcomes.

40

41 **2. Ew-MFA, attribution of materials to final demand and EEIO**

42 **models**

Ew-MFA measures the flow of materials through the economy on the basis of mass conservation. Since the publication of pioneer studies, such as Ayres, Kneese, & D'Arge (1970), Ew-MFA has matured to an established method (Fischer-Kowalski et al., 2011). Ew-MFA is a useful tool to measure progress toward sustainability, since the overall turnover of material exchange is a generic environmental pressure indicator (Bringezu et al., 2003). For reasons of data availability, the most popular Ew-MFA indicators among statistics agencies are Domestic Material Consumption (DMC) and Direct Material Input (DMI) (Kovanda and Weinzettel, 2013). DMI quantifies all materials entering the economy that is, Domestic Extraction (DE) plus the mass of imports (or 'direct imports' in Ew-MFA's terminology), and DMC measures total material used for domestic production and consumption. In other words, DMC equals DMI minus mass of exports (i.e. 'direct exports'). However, it has been acknowledged that DMC and DMI do not successfully track biophysical flows associated with foreign trade, since products crossing borders are considered at different stages of processing, whereas domestic products are only accounted in raw material terms. This differentiated treatment of products might cause that

61 some environmental burden shifting is not successfully captured, when a
62 given country imports high material-intensive products. To overcome this
63 situation, the use of more consistent Raw Material Equivalents (RME) of
64 trade products was proposed, where RM requirement for imports and
65 exports is also measured (EUROSTAT, 2001). By doing so, it is possible to
66 estimate the Raw Material Consumption (RMC) and the Raw Material Input
67 (RMI) of the economy, in which products are accounted in terms of RM
68 requirements. For estimating RME, upstream RM employed in the
69 manufacturing of traded products need to be calculated. This is called ‘used
70 indirect flows’ in the Ew-MFA’s nomenclature, or RM ‘embodied’, using
71 the terminology of footprint analyses. There are three methodological
72 approaches to this end: EEIO models, coefficients based on process analysis
73 or a combination of both; each hold advantages and drawbacks (see
74 Hirschnitz-Gabers et al., 2014). In this article, only methods using EEIO
75 models are further addressed.

76 EEIO models allow material extraction to be reattributed to final
77 user’s consumption, and it is this property that makes them useful for RME
78 estimation. Simplest EEIO models consider IO data and RM use by
79 industries for a single country. Under these circumstances, RM embodied in
80 final consumption can be affected by which assumption is followed to
81 compile imports: whether imported and domestic intermediates are
82 accounted together or not (Su and Ang, 2013). If no extra information is
83 included, RME estimates presume that the technology used to produce
84 imports is the same as that of the receiver nation, called ‘domestic
85 technology assumption’. This approach is followed by Muñoz et al. (2009),
86 although noticeable errors have been reported under such assumption in
87 Koskela et al. (2011). One way to deal with this simplification is to use
88 world coverage IO models. In this regard, two general methods can be
89 distinguished (Peters, 2008): Single country IO tables could be further
90 linked with bilateral trade data to relocate environmental loads of imports;

91 or the world economy can be considered a whole IO entity by itself, which
 92 is called Multi Regional Input Output (MRIO) model. Both methods differ
 93 in how environmental burdens of imports for intermediate consumption are
 94 allocated, making MRIO models more suitable to pinpoint environmental
 95 burdens along the global production chain (Peters, 2008; Su and Ang, 2011)
 96 and therefore, theoretically more consistent with the RME concept. MRIO
 97 models applied following Ew-MFA's principles can be found in Tukker et
 98 al. (2014) and Wiedmann et al. (2013). Another feasible option is combining
 99 EEIO models with Life Cycle Assessment (LCA) (Kovanda, Weinzettel, &
 100 Hák, 2010; Schaffartzik, Eisenmenger, Krausmann, & Weisz, 2014; Schoer,
 101 Weinzettel, Kovanda, Giegrich, & Lauwigi, 2012; Seppälä et al., 2011).
 102 LCA is a 'bottom-up' approach that pays attention to the exchanges between
 103 natural and social spheres that occur during all the stages of the product life
 104 cycle. Thus, it is possible to carry out LCA of imports and link the
 105 information with EEIO models. This method is called Hybrid LCA or Input
 106 Output LCA (IO-LCA). IO-LCA can also be employed in order to avoid
 107 truncation errors when performing an LCA that is, by where the system's
 108 boundaries are set (Lenzen, 2000). In a sense, this might be seen as the
 109 corresponding methodological shortcoming of sector aggregation bias when
 110 coming down from macro to micro levels (Majeau-Bettez et al., 2011). Both
 111 IO-LCA and MRIO approaches in RME estimation have advantages and
 112 drawbacks, and their merits are under much discussion (Eisenmenger et al.,
 113 2013; Schoer et al., 2013).

114 EEIO models can be also utilized for studying the role of consumers
 115 as drivers of material extraction, similarly to what is done in footprint type
 116 analyses. At this point, some clarification of the terminology is needed.
 117 Footprint analyses can be carried out applying different techniques, usually
 118 LCA, EEIO (single country or MRIO) or combinations of both (European
 119 Commission et al., 2014). Thus, dissimilar approaches may be labelled by the
 120 same name. However, the opposite is also true, for example RMC and

material footprint can be assumed to be equivalent concepts (Wiedmann et al., 2013). In the following, footprint analyses will mean those grounded totally or partially in EEIO.

In Ew-MFA studies, individual attention to the role of consumers as drivers of material extraction seldom occurs, something that has been identified as a task ahead (see Fischer-Kowalski et al., 2011). In general, this is not the case in footprint analyses, in which more detailed attention is paid to different final use categories and groups of industries or products. Moreover, distortions at industry level can offer valuable information to understand aggregation bias (Steen-Olsen et al., 2014), more precisely variations in the ‘multipliers’ (RM or GHG emissions embedded per unit of final product). For these reasons, industry level is the finest resolution considered in this paper. Additionally, given their policy importance, two more coarse levels of analyses are assessed: final use categories and Ew-MFA indicators.

3. Sector Aggregation Bias in Environmentally Extended Input

Output models

In EEIO modelling, the goal is often to re-attribute environmental loads along the production chain. However, sector aggregation can compromise outcomes i.e., loads could be wrongly allocated. For example, in Finland, biomass products (from agriculture, fishing and forestry) have dissimilar RM requirements and uses in the economy. Agricultural products have usually lower RM requirement than forestry products, that is, per unit of output agriculture extracts less biomass from nature than forestry. Therefore, if they are combined to a generic ‘biomass extractive sector’ and, accordingly, an average RM requirement is selected for modelling, RM requirement of agricultural products (e.g. of food industry) would be overestimated, whereas the opposite would happen for forestry products (e.g. of paper industry). These deviations might eventually be transferred to

different end users (e.g. food for households vs. paper products for exports), which would cause distortions in macro indicators. This issue is particularly relevant when such indicators are used in discussing mitigation responsibilities (Lenzen et al., 2004).

To further explain aggregation bias, some notation is required: lower case denotes vector, always in column form, whereas capital letter denotes matrix. Additionally, superscripts $^{-1}$ and $'$; and accent $\hat{}$, denote non-singular matrix inversion, matrix transpose and diagonal matrix, respectively. The general expression of the IO model is,

$$\mathbf{g} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \quad (1)$$

where $\mathbf{g}$ is total output, $\mathbf{f}$ is total final uses, $\mathbf{A}$ is the technical coefficients matrix and $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief Inverse. The latter is a key feature because it represents the indirect and direct requirements of input per unit of output (for further details see Miller & Blair 2009).

Commonly, IO models are used to get an approximation about how much change in total output $\mathbf{g}$ is induced by variations in final demand. From a practitioner's perspective, aggregation bias occurs when different resolution or combination of sectors in IO models give dissimilar total output $\mathbf{g}$ per economic sector. When sectors with different technology (or matrix $\mathbf{A}$) are collapsed together, the outcome might be different than if such aggregation would not have taken place. Aggregation bias has been extensively studied in the literature targeting a consistent or 'perfect' dimensions for IO models (Kymn and Norsworthy, 1976).

In EEIO, the general IO scheme needs to be 'extended' to allocate environmental loads to each industry. These environmental loads might be considered as necessary inputs for production processes, such as RM extracted or water consumption; or as inevitable outputs, such as emissions or solid waste. More precisely, the 'intensity' vector of environmental load $\mathbf{e}'$, which describes for each industry environmental loads per output unit is added, as shown in equation 2. Furthermore, considering that $\mathbf{f} = \mathbf{Fi}$, where

180 $\mathbf{i}$ is a vector of ones, the total final uses vector can be substituted by the final
 181 uses matrix $\mathbf{F}$:

$$\mathbf{l} = \mathbf{e}'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{F} \quad (2)$$

182 With equation 2, it is possible to estimate total indirect and direct
 183 environmental loads for each final use category, denoted by $\mathbf{l}$.

184 Studies focusing on aggregation bias in EEIO are more recent. The
 185 question is, how to prevent sector aggregation bias in the estimation of total
 186 indirect and direct environmental loads $\mathbf{l}$. Earlier studies have described
 187 sector aggregation bias in EEIO, although primarily focused on CO₂ or
 188 GHG emissions and only recently on other environmental loads. Wyckoff &
 189 Roop (1994) performed a sensitivity analysis for aggregation bias by
 190 comparing their benchmark 33-sector model with a 6-sector model, which
 191 caused an around 30% underestimation of GHG emissions embodied in
 192 imports for the countries under study. Lenzen et al. (2004) analyzed changes
 193 in CO₂ multipliers and carbon trade between Denmark, key trade partners
 194 and the rest of the world, using three MRIO models of different complexity.
 195 For studying aggregation bias, original tables, which distinguish between 39
 196 and 133 sectors, were collapsed to 10 industries. They showed how
 197 aggregation to sector 'electricity, gas and water' causes a CO₂ trade deficit
 198 for Denmark ten times higher in the aggregate version. Su, Huang, Ang, &
 199 Zhou (2010) pioneered the systematic study of this issue and laid the
 200 foundations for a formal approach. Furthermore, they studied the effects of
 201 sector aggregation on CO₂ emissions embodied in China's and Singapore's
 202 exports and concluded that the optimal aggregation level is around 40
 203 sectors. Marin, Mazzanti, & Montini (2012) carried out a similar exercise,
 204 comparing different aggregation schemes using data for Spain and Italy for
 205 several air pollutants. They reported significant biases in results, in ways
 206 specific for each country. According to them, particularities of the economic
 207 structure of countries must also be taken into account when designing
 208 aggregation level. Lenzen (2011) concluded that, in case of divergence in

209 resolution between IO tables and environmental data, disaggregation of IO
 210 data rather than aggregation to the closest common level is preferable,
 211 because of sector aggregation bias. Bouwmeester & Oosterhaven, (2013)
 212 explored sector aggregation errors using a MRIO model, arising from
 213 estimating CO₂ emissions and embodied water use, and found that
 214 consequences for the latter are much larger than for the former. In addition,
 215 they also revealed noticeable differences across countries. Zhou et al. (2013)
 216 aggregated randomly a MRIO model for 10 selected Asian-Pacific 76-
 217 sectors economies, extended for carbon footprint analysis. Outcomes
 218 showed that even though on average aggregation has a moderate effect,
 219 grouping certain sectors can entail noticeable errors. Accordingly, they
 220 claimed that aggregation bias is rather a problem of which sectors are
 221 collapsed (e.g. 'iron and steel' or 'chemical fertilizers and pesticides' for
 222 China), than strictly speaking of number of sectors. Furthermore, they stated
 223 that grouping in general affects more aggregated industries than
 224 unaggregated, although there are cases in which unaggregated sectors can be
 225 seriously influenced as well (e.g. 'milled grain and flour' in Indonesia).
 226 Steen-Olsen et al. (2014) analyzed how sensitive CO₂ multipliers are to
 227 sector aggregation using four MRIO databases. They developed a common
 228 classification comprising 41 regions and 17 sectors and aggregated the
 229 databases to that level. Overall, significant errors were reported, more
 230 intense when higher is the disaggregation of original data. In addition, some
 231 examples about how bias is passed on the production chain are offered. For
 232 example, similarly to 'milled grain and flour' in Indonesia in Steen-Olsen et
 233 al. (2014), remarkable deviations appear in the 'construction sector', not
 234 aggregated in their experiment. Cement, a CO₂ intensive input whose effect
 235 is distorted when is grouped with less polluting products, is pointed out to
 236 be the reason.

237 Work on understanding the uncertainty in material footprint
 238 calculation with MRIO and the resolution in MRIO on material footprint is

in early stages, with a notable recent contribution by de Koning et al. (2015). They compared the EXIOBASE MRIO model most disaggregated version, 200 products by 163 industries, to an aggregated version of 60 by 60, for different raw materials categories and GHG emissions. They report that product and spatial aggregation has a larger effect on material footprints than for carbon footprint. Moreover, at product level, deviations might be of 100 % or more, which could limit usefulness of IO in Ew-MFA studies.

Another inherent grouping error to IO is spatial or regional aggregation. In this case, deviations might arise due to dissimilar technologies within a large region such as China (Su and Ang, 2014, 2010), or between countries in worldwide input output models (Andrew et al., 2009; Bouwmeester and Oosterhaven, 2013; de Koning et al., 2015). Although spatial and sector aggregation biases are related errors and can be the cause of the other (e.g. when linking data from different countries, modelers are forced to collapse industries), spatial aggregation is not discussed further in this paper.

4. The ENVIMAT₂₀₁₀ model

The ENVIMAT₂₀₁₀ model presents a structure of detailed EEIO combined with biophysical information from LCA Inventories and other sources. ENVIMAT₂₀₁₀ shows environmental and economic information of 230 product groups and 147 national industries for year 2010, based on the highest disaggregated public Supply and Use Tables (SUT) (Koskela, Mattila, Antikainen, & Mäenpää, 2013; Mattila, Koskela, Seppälä, & Mäenpää, 2013; Seppälä et al., 2011; Tuusjärvi et al., 2014). It updates the previous version of the model ENVIMAT₂₀₀₈, which had an even higher resolution, but confidentiality restrictions have become stricter recently. The environmental extension is represented by satellite accounts of waste emissions, material flows and energy transformation. Finally, to avoid the problems derived from the use of the domestic technology assumption for

269 goods, a hybrid approach mostly based on the Ecoinvent Database is
 270 adopted for the moment (Koskela et al., 2011). On the contrary, for services
 271 the domestic technology assumption is followed.

272 The ENVIMAT₂₀₁₀ industry classification is based on the Statistical
 273 classification of economic activities in the European Community (NACE)
 274 revision (Rev.) 2; while products classification relies on the European
 275 Classification of Products by Activity (CPA) version 2008. However, in
 276 order to avoid sector aggregation bias, some products and industries have
 277 been disaggregated using unpublished data or additional sources. Hereafter,
 278 digits correspond to international standard classifications CPA and NACE
 279 and the following lower case to the ENVIMAT₂₀₁₀ own classification
 280 system (full classification in Supporting Information (SI)). Thus, lower case
 281 always indicates a product or industry classification, which has been
 282 designed to satisfy both confidentiality restrictions and modelling purposes.
 283 NACE Rev. 2 and CPA are derived classifications of the International
 284 Standard Industrial Classification of all Economic Activities of the United
 285 Nations (ISIC) Rev. 4 and Central Product Classification of the United
 286 Nations (CPC) Rev. 2, respectively. Therefore, the results presented in this
 287 paper are applicable also outside the European Union (EU).

288 Table 1 illustrates how aggregation bias is prevented in
 289 ENVIMAT₂₀₁₀. Forestry activities are quite important for the Finnish
 290 economy in terms of output but, at the same time, are crucial drivers in
 291 material mobilization. A review of the dissimilarity of products and
 292 activities within the category informs about possible deviations due to
 293 aggregation bias. For example, within '021 Silviculture and other forestry
 294 activities', disparate products in material terms are included such as '02101a
 295 Forest nursery services' and '02103b Pulp wood'. The former, planting new
 296 trees to maintain the forestry sector, does not imply any substantial material
 297 extraction, whereas the latter is a primary input for the paper industry, which
 298 is the main driver in biomass removal in Finland. Aggregation would,

therefore, materialize forest nursery services causing distortions in results. Accordingly, to avoid biased allocation of RM, in the ENVIMAT₂₀₁₀, fine resolution for key forestry products has been adopted. Similar procedures are followed for divisions ‘01 Crop and animal production, hunting and related service activities’; ‘08 Other mining and quarrying’; and ‘35 Electricity, gas, steam and air conditioning supply’.

Table 1.

5. Description of the study

5.1. Aggregation schemes

To study sector aggregation bias in EEIO models, six different aggregation levels have been defined. Firstly, the benchmark scheme closest to a hypothetical reality is called the ‘ENVIMAT Reference Level’, which includes 147 industries and 230 products. The second level is the ‘ENVIMAT 147 by 147 industries’, in which reference products are aggregated to reference industry level. This procedure allows analyzing loss of information when allocation of environmental loads of first usage of goods is not carried out on a product level.

Further, two different aggregation schemes are set at 64-level, in order to study possible consequences of recent changes in EU accounting legislation. The new European System of National and Regional Accounts (ESA 2010), defined in the Annex B of the Council Regulation (EU) No 549/2013 of the European Parliament and of the Council of 21 May 2013, replaces ESA 1995 that has regulated the EU accounting framework until now. This regulation brings in two important changes: Firstly, it advocates the use of NACE Rev. 2 by EU members’ statistics offices, which incorporates noticeable novelties in comparison to the predecessor NACE Rev. 1.1. For instance, economic sectors in NACE Rev. 2 have been reorganized into 88 divisions, while in NACE rev.1.1 only 62 were recognized. Moreover, the aggregation system for the transmission of SUT has changed substantially. In ESA 1995, SUT were required on 60 by 60-

329 basis, which might be used from single country EEIO to more sophisticated
 330 MRIO models, such as the EORA model (see Lenzen, Moran, Kanemoto, &
 331 Geschke, 2013). Similarly, in ESA 2010, SUT are requested with dimension
 332 64 by 64. However, what is important for EEIO modeling, and especially
 333 for Ew-MFA studies, is that mining sectors are aggregated in ESA 1995 and
 334 2010 in diametrically opposed manners. In ESA 1995, five mining sectors
 335 are considered: extraction of coal, lignite and peat; crude petroleum and
 336 natural gas; uranium and thorium ores; metal ores; and other mining and
 337 quarrying. In contrast, in ESA 2010, the equivalent divisions are now
 338 required to be aggregated into a broad ‘Mining and quarrying’ category.
 339 While this choice might be sensible in terms of employment or value added,
 340 it might jeopardize their utility when studying material flows with EEIO
 341 models. Paradoxically, it might contradict official EU recommendations,
 342 where the study of material flows using EEIO is explicitly encouraged (e.g.
 343 European Environment Agency, 2013). In order to explore what would
 344 happen if ESA 2010’s 88 divisions were rearranged keeping the extractive
 345 sectors separate, an aggregation level inspired by ESA 1995 has been
 346 defined, called ‘Old 64 by 64 industries’ (O-64). The O-64 is based on
 347 NACE Rev. 2 and distinguishes 64 sectors, but its defining characteristic is
 348 that it implies more mining and quarrying industries and less services. It
 349 could be considered a NACE Rev. 2 version of the aggregated scheme
 350 utilized in de Koning et al. (2015). In a complementary manner, the other 64
 351 scheme, named ‘New 64 by 64 industries’ (N-64), is based on ESA 2010, in
 352 which all the mining sectors are aggregated.

353 Two more classifications have been added in order to analyze the
 354 sector aggregation effects more thoroughly. An aggregation scheme around
 355 40 industries has been set for two reasons: On one hand, on that level sector
 356 aggregation deviations for GHG embodied in exports seems to decrease
 357 considerably (Su et al., 2010). On the other hand, the MRIO model WIOD
 358 (World Input-Output Database) (Timmer, 2012; Timmer et al., 2015),

359 frequently used in environmental assessments, presents a 35 industries
 360 resolution. One hurdle to cross was that WIOD relies on NACE Rev. 1.1,
 361 while ENVIMAT₂₀₁₀ uses Rev. 2. Trying to convert ENVIMAT₂₀₁₀ to Rev.
 362 1.1 and then aggregate similar to WIOD would be futile, due to the large
 363 differences between the two systems. Therefore, it was decided to design a
 364 NACE Rev. 2 scheme inspired by the WIOD classification, which was
 365 denominated ‘WIOD 37 by 37 industries’ (W-37). The most interesting
 366 features of W-37 are that all biomass extractive sectors are now aggregated
 367 together. Finally, the results are presented at 25 industries level as well. This
 368 scheme, called ‘Presentation Level 25 by 25’ (P-25), is based on the EORA
 369 MRIO model (Lenzen et al., 2013), as this level is used in some cases.

370

371 5.2. The framework

372 The study consists of two complementary tasks for all aggregation
 373 schemes, the parallel estimations of RM and GHG emissions for each final
 374 use category distinguishing between domestic and imported products.
 375 Consequently, the technical coefficients matrix **A** and total final demand **F**
 376 are split into domestic and imported components, respectively, **A_d** and **A_m**;
 377 and **F_d** and **F_m** (henceforth, the subscripts **d** and **m** designate products’
 378 origin).

379 To explain how the ENVIMAT Reference Level (E-RL) is built, the
 380 starting points are the SUT. SUT can be transformed to IO tables by using
 381 assumptions or additional data. There are four methods to transform SUT to
 382 IO tables, each with drawbacks and advantages (EUROSTAT, 2008). In
 383 environmental analyses, the choice is dependent mainly upon the goals as
 384 well as the kind of data available (Rueda-Cantuche, 2013). In this respect, in
 385 the ENVIMAT₂₀₁₀ model, the so-called ‘fixed product sales structure
 386 assumption’ is followed. Deviations due to the method chosen are out of the
 387 scope of this paper, however, we support the conclusions drawn in Marin et

al. (2012), according to which little differences between the procedures are detected.

To describe the input requirements of products per unit of industry output, the use coefficient matrices for domestic products $\mathbf{Z}_d$ and imports $\mathbf{Z}_m$ can be expressed using equations $\mathbf{Z}_d = \mathbf{U}_d \hat{\mathbf{g}}^{-1}$ and $\mathbf{Z}_m = \mathbf{U}_m \hat{\mathbf{g}}^{-1}$, where $\mathbf{g}$ denotes total industry output, $\mathbf{m}$ total imports, $\mathbf{U}_d$ the domestic use matrix and $\mathbf{U}_m$ the use matrix of imports. Similarly, the market shares matrix $\mathbf{D}$ which depicts contribution of each industry to products' output, can be achieved through $\mathbf{D} = \mathbf{S}' \hat{\mathbf{q}}_d^{-1}$, where $\mathbf{S}$ is the supply matrix and $\mathbf{q}_d$ is total domestic products output. Accordingly, $\mathbf{A}_D$ and $\mathbf{F}_D$ can be obtained using $\mathbf{A}_d = \mathbf{DZ}_d$ and $\mathbf{F}_d = \mathbf{DY}_d$, where $\mathbf{Y}_d$ is the final use matrix for domestic products. For imports, the picture is more complex, because the market share matrix of each exporter nation is unknown. To overcome this limitation, instead of using the Finnish $\mathbf{D}$, it is assumed that foreign industries produce only one product type. In practice, it means that we define an aggregation matrix industry by product $\mathbf{N}$, whose elements are 1 or 0 appropriate placed, in such a manner that $\mathbf{A}_m$ and $\mathbf{F}_m$ can be estimated using $\mathbf{A}_m = \mathbf{NU}_m \hat{\mathbf{g}}^{-1}$ and $\mathbf{F}_m = \mathbf{NY}_m$, where $\mathbf{Y}_m$ is the final use matrix for imports.

In terms of environmental extension, in ENVIMAT₂₀₁₀ environmental information comes from fragmentary sources, therefore, at times it is preferable to build the intensity vector on a product basis and others on industry basis. For this reason, RM intensities are compiled on a product basis, whereas GHG are reported by the Finnish Environment Institute on an industry basis. For domestic products, RM direct coefficients $\mathbf{p}$ are calculated based on multiple national statistics (details in SI). In contrast, for imports a hybrid LCA perspective is adopted; that is to say, coefficients for imports also include environmental loads embodied in products. In order to highlight this method difference, hereafter imports are marked with the Greek alphabet. Thus, δ expresses indirect and direct loads

per euro of product imported. The intensity vector can refer to all RM flows or to some of them (e.g. minerals). Finally, the expression used to estimate RM in E-RL is presented in equation 3, in which the environmental loads are allocated to first users of products on a product basis.

$$\mathbf{l} = (\mathbf{p}'\mathbf{Z}_d + \boldsymbol{\delta}'\mathbf{Z}_m)(\mathbf{I} - \mathbf{A}_d)^{-1}\mathbf{F}_d + \mathbf{p}'\mathbf{Y}_d + \boldsymbol{\delta}'\mathbf{Y}_m \quad (3)$$

In order to study loads according to product origin, the latter equation can be split as shown in equation 4 and 5,

$$\mathbf{l}_d = (\mathbf{p}'\mathbf{Z}_d)(\mathbf{I} - \mathbf{A}_d)^{-1}\mathbf{F}_d + \mathbf{p}'\mathbf{Y}_d \quad (4)$$

$$\mathbf{l}_m = (\boldsymbol{\delta}'\mathbf{Z}_m)(\mathbf{I} - \mathbf{A}_d)^{-1}\mathbf{F}_d + \boldsymbol{\delta}'\mathbf{Y}_m \quad (5)$$

where $\mathbf{l}_d$ and $\mathbf{l}_m$ denote loads for domestic products and imports respectively. Because of different procedures utilized for their estimation, whenever possible, we present separate results for both. In this way, we can also analyze the effects of sector aggregation bias when using hybrid approaches. In contrast to RM, GHG emissions' allocation to first users is only possible for imported products, since domestic emissions are provided on an industry basis. Hence, E-RL for RM and GHG are different, the latter being closer to 'ENVIMAT 147 by 147 industries' (E-147) aggregation scheme.

To transform our E-RL to industry basis E-147, the intensities and final demands need to be converted using equations $\mathbf{e}' = \mathbf{p}'\hat{\mathbf{q}}_d\mathbf{N}'\hat{\mathbf{g}}^{-1}$ and $\boldsymbol{\alpha}' = \boldsymbol{\delta}'\hat{\mathbf{m}}\mathbf{N}'\hat{\mathbf{g}}^{-1}$. In addition, SUT are aggregated, and their components denoted with a dot superscript. The following are considered: the supply matrix $\dot{\mathbf{S}} = \mathbf{N}\mathbf{S}$; the use matrix of domestic products $\dot{\mathbf{U}}_d = \mathbf{N}\mathbf{U}_d$; the use matrix of imports $\dot{\mathbf{U}}_m = \mathbf{N}\mathbf{U}_m$; the final use matrix of domestic products $\dot{\mathbf{Y}}_d = \mathbf{N}\mathbf{Y}_d$, the final use matrix of imports $\dot{\mathbf{Y}}_m = \mathbf{N}\mathbf{Y}_m$; and, lastly, the total supply of products per industry $\dot{\mathbf{q}}_d = \mathbf{N}\mathbf{q}_d$. At this stage, total output per industry $\mathbf{g}$ in E-RL and E-147 is the same. Based on this, the use coefficient matrices can be defined as $\dot{\mathbf{Z}}_d = \dot{\mathbf{U}}_d\hat{\mathbf{g}}^{-1}$ and $\dot{\mathbf{Z}}_m = \dot{\mathbf{U}}_m\hat{\mathbf{g}}^{-1}$ and the market

443 shares matrix as $\dot{\mathbf{D}} = \hat{\mathbf{S}}'\hat{\mathbf{q}}_d^{-1}$ for the E-147 level. In the same way than for
 444 E-RL, it is possible to carry out $\dot{\mathbf{A}}_d = \dot{\mathbf{D}}\dot{\mathbf{Z}}_d$ and $\dot{\mathbf{F}}_d = \dot{\mathbf{D}}\dot{\mathbf{Y}}_d$; as well as
 445 $\dot{\mathbf{A}}_m = \dot{\mathbf{N}}\dot{\mathbf{Z}}_m$ and $\dot{\mathbf{F}}_m = \dot{\mathbf{N}}\dot{\mathbf{Y}}_m$. Equation 6 summarizes how the environmental
 446 loads per final use are estimated at the E-147 level¹.

$$\dot{\mathbf{I}} = (\mathbf{e}' + \alpha'\dot{\mathbf{A}}_m)(\mathbf{I} - \dot{\mathbf{A}}_d)^{-1}\dot{\mathbf{F}}_d + \alpha'\dot{\mathbf{F}}_m \quad (6)$$

447 For the following aggregate schemes, the procedure is analogous for
 448 all. For the sake of simplicity, components of O-64, N-64, W-37 and P-25
 449 are distinguished with an asterisk superscript.

450 To further aggregate the model, firstly, appropriate aggregation
 451 matrices $\mathbf{M}$ are designed. Further, the necessary aggregate components are
 452 calculated as follows: $\mathbf{U}_d^* = \mathbf{MNU}_d\mathbf{M}'$; $\mathbf{U}_m^* = \mathbf{MNU}_m\mathbf{M}'$ and $\mathbf{S}^* = \mathbf{MNSM}'$;
 453 $\mathbf{Y}_d^* = \mathbf{MNY}_d$; $\mathbf{Y}_m^* = \mathbf{MNY}_m$; $\mathbf{g}^* = \mathbf{Mg}$ and $\mathbf{q}_d^* = \mathbf{MNq}_d$. Lastly, for
 454 environmental intensities it is possible to carry out $\mathbf{e}^{*'} = \mathbf{e}'\hat{\mathbf{g}}\mathbf{M}'\hat{\mathbf{g}}^{*-1}$ and
 455 $\alpha^{*'} = \alpha'\hat{\mathbf{g}}\mathbf{M}'\hat{\mathbf{g}}^{*-1}$. The expression used to study loads induced by final
 456 users at more aggregated schemes is summarized in equation 7.

$$\mathbf{I}^* = (\mathbf{e}^{*'} + \alpha^{*'}\mathbf{A}_m^*)(\mathbf{I} - \mathbf{A}_d^*)^{-1}\mathbf{F}_d^* + \alpha^{*'}\mathbf{F}_m^* \quad (7)$$

457 Finally, sector aggregation bias τ can be defined as the difference in
 458 total environmental loads for each final use category, between a given
 459 aggregated scheme the reference level, as seen in equation 8. For deviations
 460 between E-RL and E-147, $\mathbf{I}^*$ is substituted with $\dot{\mathbf{I}}$.

$$\tau = \mathbf{I}^* - \mathbf{I} \quad (8)$$

461 Overall, biases can come from two sources: aggregation of IO data
 462 and aggregation of environmental information in the intensity vector. In the
 463 former case, more dissimilarity between the inputs' structure of each
 464 collapsed industry tend to cause higher biases. In the latter, aggregation of
 465 industries that hold dissimilar relationship with the environment can have an

¹ There is no point to keep now on separate products' first users, since considering the power series expansion:
 $\dot{\mathbf{I}}_d = \mathbf{e}'\dot{\mathbf{F}}_d + \mathbf{e}'\dot{\mathbf{F}}_d\dot{\mathbf{A}}_d + \mathbf{e}'\dot{\mathbf{F}}_d\dot{\mathbf{A}}_d^2\ldots = \mathbf{e}'(\mathbf{I} - \dot{\mathbf{A}}_d)^{-1}\dot{\mathbf{F}}_d$

analogous effect (Lenzen, 2011; Su et al., 2010), which is expected to be more pronounced for those environmental loads, such as raw material extraction, that are spread out unevenly among economic sectors (de Koning et al., 2015). To study this issue, environmental loads are estimated, combining aggregated environmental extensions with disaggregated SUT data, and the effects of aggregated Leontief inverses are combined with reference intensities. For environmental loads, $\bar{\mathbf{e}}^{*'} = \mathbf{e}^{*'} \mathbf{D}^* \mathbf{M} \mathbf{N}$; and $\bar{\boldsymbol{\alpha}}^{*'} = \boldsymbol{\alpha}^{*'} \mathbf{M} \mathbf{N}$; can be applied, which represents aggregated intensities rearranged on reference products classification level. Thus, environmental burdens to final uses $\tilde{\mathbf{I}}^*$ can be reattributed as shown in equation 9, in which the reference SUT skeleton is kept unaltered.

$$\tilde{\mathbf{I}}^* = (\bar{\mathbf{e}}^{*'} \mathbf{Z}_d + \bar{\boldsymbol{\alpha}}^{*'} \mathbf{Z}_m)(\mathbf{I} - \mathbf{A}_d)^{-1} \mathbf{F}_d + \bar{\mathbf{e}}^{*'} \mathbf{Y}_d + \bar{\boldsymbol{\alpha}}^{*'} \mathbf{Y}_m \quad (9)$$

The inverse exercise is also conducted for studying effects of aggregation of industries with different inputs $\tilde{\mathbf{I}}^*$. In this case, the weighting matrix $\mathbf{G} = \hat{\mathbf{g}} \mathbf{M}' \hat{\mathbf{g}}^{*-1}$ is used as shown in equation 10 (more details in SI).

$$\tilde{\mathbf{I}}^* = (\mathbf{p}' \mathbf{Z}_d \mathbf{G} + \boldsymbol{\delta}' \mathbf{Z}_m \mathbf{G})(\mathbf{I} - \mathbf{A}_d^*)^{-1} \mathbf{F}_d^* + \mathbf{p}' \mathbf{Y}_d + \boldsymbol{\delta}' \mathbf{Y}_m \quad (10)$$

480

481 6. Results and discussion

482 6.1. Comparing RM flows and GHG emissions

Figure 1 compares RM and GHG emissions embodied in final use bundles. At this level of analysis, aggregation causes more distortion in RM than in GHG estimates, in line with outcomes of de Koning et al. (2015). Grouping tends to overestimate RM requirements of private consumption at cost of investments for domestic products, and exports for imported products.

489 **Figure 1.**

In Figure 2, sector aggregation bias is presented in percentage² of the difference between E-RL and each scheme using a heat-map, so the higher the deviation for a given category, the deeper red the corresponding cell is. The bias can be an overestimation or an underestimation which is described by positive and negative values, respectively.

Figure 2.

Looking at these figures, some key messages emerge. Firstly, aggregation bias increases when moving from the reference level to more aggregated schemes, although in different ways and to a different extent, depending on the indicator. Additionally, in more aggregated schemes W-37 and P-25, there are similar deviations despite the significant decrease in the number of sectors. This backs the idea that sector aggregation bias depends on which sectors are aggregated, rather than purely on the number of economic branches, as pointed out in Zhou et al. (2013). Overall, there are no large differences between E-RL and E-147, since the deviations in all cases are below 5%. Therefore, E-147 is a suitable approach when more disaggregated information is not available.

Moreover, the O-64 scheme shows a superior performance in comparison to N-64 when studying RM, whereas these differences are not apparent in GHG emissions. This supports the notion that the new EU accounting framework can be detrimental for EEIO studies focusing on RM.

Figure 3 informs about the source of bias, for schemes O-64, N-64 and W-64 using equation 9 and 10 for RM.

Figure 3.

It is observed that the critical issue is the simplification of material intensities, since averaging them in the semi-aggregated scheme $\bar{\mathbf{I}}^*$ of N-64 and W-37, causes similar errors than in fully aggregated ones. On the other hand, in O-64 dissimilar inputs structure, assessed using semi-aggregated

² Aggregation bias in percentage τ (%) is obtained from $\tau \bar{\mathbf{I}}^{-1}$, multiply by 100.

518 scheme $\tilde{I}^*$, is relatively more important. To shed some light on this issue, a
 519 more careful study per RM type is presented in the next section.

520 Results for GHG are expected, and commented only briefly. In
 521 Finland, the main sectors releasing GHG are energy supply (38%),
 522 transportation (16%), agriculture (10%) and manufacturing (24%). In E-RL
 523 and E-147, energy supply encompass four sectors (electricity, gas, district
 524 heating and industrial steam), whereas it is represented by one sector in
 525 schemes O-64, N-64, W-37 and P-25. Grouping these four sectors is the
 526 main reason for differences observed between E-147 and forward. Notably,
 527 domestic consumption tends to be underestimated, when GHG emissions of
 528 district heating, one of the most polluting sectors essential due to cold
 529 weather are allocated to different users than households. At W-37 and P-25
 530 major relative deviations seen for domestic products are mostly due to
 531 aggregation of agriculture and forestry products. Accordingly, GHG
 532 emissions from growing crops and farming are passed on forestry, which
 533 holds high uses in investments. For imports, aggregation of chemical
 534 products with less GHG intensive pharmaceutical ones explains the
 535 deviation observed for public consumption. Overall, outcomes for GHG
 536 emissions are consistent with the literature (see results for Finland of
 537 Bouwmeester and Oosterhaven (2013)). However, finer comparisons are
 538 cumbersome because of varying aggregation schemes utilized among
 539 studies.

540

541 6.2. Raw Material Flows in detail

542 For a more detailed analysis, it is appropriate to distinguish between
 543 two broad groups of materials: biomass and minerals, since aggregation
 544 bias can affect distinctively according to such division. Figure 4 describes
 545 aggregation bias in absolute values (million tonnes, Mt) per final use
 546 category and type of RM.

547 **Figure 4.**

548 It is observed that grouping can bias even in contrary directions
 549 dependent on RM, as seen for investments and exports. The
 550 comprehensive nature of Ew-MFA seems to be the root of these
 551 divergences as well as its sensitivity to sector aggregation bias when
 552 relying on EEIO.

553 In the following, industries are referred to in two ways: when more
 554 precise classification is required, the ENVIMAT/NACE-CPA
 555 classification name is given in quotation marks. Alternatively, common
 556 synonyms without quoting marks are often used. Further information
 557 about the statements outlined below can be found in the SI.

558

559 6.2.1. Biomass Flows

560 There are three key sectors typically responsible for providing
 561 biomass to the economy: agriculture, forestry and fishing. Given its
 562 relevance, modifications of original ENVIMAT's forestry classification
 563 cause major deviations in biomass flows.

564 When aggregating from E-RL to E-147, only small deviations appear
 565 at final users' level. In absolute terms, the most remarkable deviations affect
 566 domestic products and take place in investments and exports, as seen in
 567 Figure 4. In particular, in E-147 biomass embodied in investments is
 568 overestimated by 4.9 Mt, whereas exports are underestimated by 5.4 Mt.
 569 The main reason is that in E-RL an averaging material intensity for the
 570 group '021 Silviculture and other forestry activities' of 14.9 kg/euro is
 571 assumed for all products within the category, as Table 1 indicates. This
 572 causes for example, that uses in E-147 of '02101a Forest nursery services'
 573 are attributed a mass of almost 3.5 Mt. An overestimation in one final use
 574 category implies a parallel underestimation in another bundle. In this case,
 575 the export-oriented sector '171 Manufacture of pulp, paper and paperboard'
 576 is the source of such biomass. The explanation is that reference material

intensity of paper industry's main input '02103b Pulp wood', is markedly reduced (see Table 1).

In O-64 and N-64, deviations for biomass remain low, although errors in investments and exports are exacerbated, mainly because all forestry activities are aggregated to division level '02 Forestry and logging'. The aggregation of these groups, whose material intensities are very low or null, causes an overall reduction of material intensity of other forestry products to 8.3 kg/euro (Table 1). At these levels, overestimations for domestic products in investments are accentuated by 3.6 Mt due to high uses of '025 Net growth of forests', which is assumed immaterial in more disaggregated schemes. As expected, the underestimation mentioned before for the exporting paper industry is at these levels even larger. Finally, aggregation to division '01 Crop and animal production, hunting and related services' also produces an overestimation of biomass embodied in crop products and an underestimation of animal products. Nevertheless, for Finland this deviation is of relatively little importance and is mostly offset within the private consumption bundle.

At levels W-37 and P-25, the aggregation of divisions 01 to 03 into a broad 'Agriculture, forestry and fishing' causes significant deviations for Finland. The reason is that aggregation of all biomass extractive sectors increases material intensity for agricultural and fishing products at the expense of forestry products, the biomass intensity of which falls to 4.7 kg/euro. As a consequence, a significant overestimation takes place in private consumption, since households are the major consumers of agricultural and fishing products. In addition, when calculating the biomass embodied in final products via Leontief inverse, this overestimation is also transferred to the food industry, a principal client of the agricultural sector (as it was foreseen in the example of section 3). Table 2 shows changes in domestic biomass multipliers³ of food products in comparison to those of

³ In this section the term 'multiplier' refers to indirect loads that is, upstream flow of RM.

wood and paper products. Overall, these variations cause that around 5 Mt are reallocated to private consumption in W-37 and P-25. As well, it can be recognized that another important compensating decrease happens in ‘Renting and operating of own or leased real estate’, which despite being a service with a low multiplier, has one of the largest shares of domestic final demand (see F_d^c in Table 2).

Table 2.

The underestimation is explained by inputs coming from the energy supply sector. In Finland, ‘02103d Forest chips’ is an important fuel in electricity generation, district heating and industrial steam. Further, considering they are produced mainly from the residues of logging activities, their price is quite low and their intensity high (Table 1). Underestimation begins at 64 industries level, but it is accentuated at W-37 and P-25, because the forest chips’ material intensity is considerably reduced (to 4.7 kg/euro). Accordingly, biomass requirements of renting real estate activities together with private consumption, drop when re-attribution of loads is carried out. In addition, aggregation to a heterogeneous biomass extractive sector causes that at these levels, previous deviations in investments are alleviated (see Figure 4). Lastly, it is worth noting that similar deviations arise for imported products as well, since Finland imports considerable amounts of pulp wood along with crop products, especially fruits.

6.2.2. Mineral Flows

Within this category, three broad groups are studied: fossil fuels, metals and non-metallic minerals. They are studied together because all are very sensitive to aggregation of mining sectors; taking into account that they hold different material intensities and are intended for a variety of purposes. Non-metallic minerals are primarily domestic, whereas in metals and fossil fuels imports predominate. The main fossil fuels used to power the Finnish

economy, crude oil, natural gas and coal are all extracted abroad. However, domestic extracted fuel peat plays a notable role as well. For metal ores, the most important product in terms of mass is iron ore, which was also imported in its entirety in 2010. Although the most remarkable deviations for these flows are caused at N-64 level and forward, there are other relevant outcomes to be mentioned.

In E-147, the most important complementary deviations appear in investments and exports for domestic products. Specifically, 3.3 Mt of minerals are transferred from investments to exports, as shown in Figure 4. Construction activities require a significant amount of ‘08121a Gravel, sand and crushed stone’ for making concrete and similar products, which holds a high material intensity (166.5 kg/euro). Nevertheless, at E-147 level, this allocation is done through a broader ‘08b Quarrying of gravel, sand and clay’, the material intensity of which results from averaging goods and services within the category, as indicated in Table 3. This allows biased allocation of material to some exporting industries, main users of the category’s services.

Table 3.

Regarding the O-64 level, noticeable deviations for domestic products take place in investments, exports, and public consumption (see Figure 4); mostly as a result of aggregating ‘08a Mining and quarrying of other minerals’ and ‘08b Quarrying of gravel, sand and clay’. It can be deduced from Table 3 that mineral requirements of users of gravel, sand and crushed stone are at this level even more underestimated, since the product group’s material intensity drops substantially by averaging. Next, this error is passed on along the production chain and as a result, multipliers of ‘41 Construction of buildings’ and ‘42 Civil engineering’ decrease, as shown in Table 4. This explains as well the fall observed in investments in Figure 1 and 4, since buildings are accounted as such (F_d^1 in Table 4). In a similar manner, Table 4 also reveals that lower multipliers in civil engineering and

road and railway maintenance cause a significant distortion, which explains the color intensity observed in government consumption in Figure 2 (deviation of -29.9 % from reference level). The other side of the coin is that mineral embodied in exports of some manufacturing increases, notably in the basic chemical industry, the iron industry and the paper industry (see Table 4). The problems described above illustrate why in the ENVIMAT₂₀₁₀'s classification system a distinction within other mining and quarrying is considered.

Table 4.

In N-64, W-37 and P-25, all mining sectors (divisions 05-09) are aggregated together into one heterogeneous 'Mining and quarrying' category. Table 5 complements Table 3, showing consequences in mining intensities of further aggregation. The effect is that it raises the intensity of those less material intensive mining industries (peat, non-ferrous metals and services) and vice versa. For domestic products, the most noticeable consequences are that construction activities are more underestimated, which exacerbates the decline in RM attributable to investments mentioned previously (observe fall of multipliers for N-64 and W-37 in Table 4). In parallel, RM embodied in exports of metal industries increases, although in a different manner than between N-64 and the two more aggregated schemes. In N-64, mineral requirements are mostly re-allocated to exports of '241 Manufacture of basic iron and steel and of ferro-alloys'. In contrast, in W-27 and P-25, due to coarse manufacturing classification, the overestimation is also spread out within '25 Manufacture of fabricated metal products, except machinery and equipment'. As a result equal multipliers are obtained (1.86 kg/euro in Table 4).

Table 5.

Moreover, at N-64 and forward bias is especially problematic for imports. In Table 6, aggregated values for minerals embodied per euro of product imported, obtained following a LCA approach, are presented. A

product-industry table as presented for domestic products is not disclosed due to imports data protection issues. Table 6 suggests that grouping causes a rearrangement of material embodied, from metal minerals to fossil fuels. Furthermore, bias is passed on via Leontief inverse causing a reduction of RM embodied in exports of '244 Manufacture of basic precious and other non-ferrous metals', as seen in multipliers in Table 7. Interestingly, bias helps to decrease the multiplier of the basic iron and steel industry to reach almost reference levels. Underestimation in metals is mainly counterweighted by increases in RM allocated in exports of '192 Manufacture of refined petroleum products' (see Table 7). Thus, these two changes are mostly mutually cancelled at final use level. However, because households use a significant amount of petroleum refining products, some metal mineral requirements end up in private consumption.

Table 6.

Finally, inputs of the electricity supply industries (hard coal, natural gas and fuel peat) are also overestimated. Deviations in electricity supply are in turn transmitted to other final use categories, mostly via '682 Renting and operating of own or leased real estate' in private consumption; and public administration, education and human health activities in public consumption (see multipliers and final uses in Table 7).

Table 7.

6.3. Deviations in Ew-MFA's indicators

Regarding Ew-MFA indicators, Figure 5 shows changes in RMC and RME of exports according to RM type. As expected for an open economy with important manufacturing and extractive sectors, high differences between RME and direct exports appear. Considering the particularities of the Finnish economy, it is not surprising that aggregation bias affects relatively more to RME of biomass flows. For RMC, aggregation bias begins being relevant at W-37 and P-25, causing the variance between RMC and DMC to disappear along with gains of using RME of trade products.

Figure 5.

Figure 6 shows changes in RMC and RME of exports, according to product origin. For domestic products, deviations are offset between biomass and minerals flows and as a result, RMC and RME of exports fluctuate slightly. For instance, for W-37, there is an underestimation of Finland's RMC of domestic products of about 11 Mt. This is because around 21 Mt of mineral flows are underestimated, partially counteracted by 10 Mt biomass overestimation. For imports, the picture is significantly different since, in this case, both flows influence in the same way and RME of exports are remarkably underestimated. Considering the same example again, in W-37 the RMC of imports increased up to 22 Mt, 18 coming from mineral flows and almost 4 from biomass flows. However, because deviations happen in opposite directions for domestic products and imports, overall RMC and RME of exports are not much affected, sharing around 50% each of total RM in all schemes.

Figure 6.

Conclusions

In this paper, EEIO's sector aggregation bias has been studied focusing on raw material (RM) flows using Finland's data. The results demonstrate that grouping extractive sectors creates significant errors when studying RM, whilst the bias is less significant for GHG emissions. Similar results have been reported by de Koning et al. (2015), which indicated that both reduced material and spatial resolution have a larger effect on material than carbon footprint. Therefore, recent changes in the EU accounting framework —towards aggregation of all mining activities together— would be heading in the wrong direction and will likely be fueling errors in studies based on these data. Similar patterns were observed for domestic products and imports, even when the model's input data were estimated in a different manner.

755 Comparing sources of bias, it was shown that what grouping pattern
 756 is followed in the RM intensity vector is crucial. Hence, careful attention
 757 should be paid to its design when using EEIO models in Ew-MFA. For
 758 Finland, particularly problematic is the aggregation of forestry activities
 759 with other biomass extractive sectors. This could cause problems in input
 760 output models, in which such distinction is not considered. In general,
 761 similar errors must be expected in economies with high extractive profiles
 762 (e.g. oil exporting countries) coarse categorized in EEIO models. To
 763 overcome this situation, examples about how aggregation bias is prevented
 764 in the ENVIMAT₂₀₁₀ model were offered. As a rule of thumb, materials
 765 which hold clear distinctive uses and intensities must be considered
 766 separately (e.g. sand and gravel from metal minerals).

767 The bias originates from the aggregation of forestry, agriculture and
 768 fishing, and from the aggregation of mining sectors. Also de Koning et al.
 769 (2015) found that, worldwide, aggregation bias is highest for agricultural
 770 products, and mining and quarrying products. Further, it was found that
 771 errors are passed along the whole supply chain via Leontief inverse,
 772 affecting estimation on RM embodied in final products. However,
 773 consequences of the bias depend upon the level of analysis. At industry
 774 level, bias causes important deviations in RM estimates, especially in
 775 construction and manufacturing sectors (e.g. food, paper, iron and chemical
 776 industries) but also in services with high final demand (e.g. real estate
 777 activities, public services). Thus, cross-checking results with bottom-up
 778 approaches, such as LCA, is advisable at this level. In contrast, at the macro
 779 spheres, deviations are often offset and consequently, not appreciated.
 780 Nonetheless, errors can also result in imprecise attribution of environmental
 781 loads to final use categories (e.g. biomass of forest products from exports to
 782 households), an important issue when discussing mitigation responsibilities
 783 or resource management strategies. Lastly, MFA macro indicators (RMC,
 784 RMI) are a step further in broadness and, accordingly, less affected by

grouping errors. Only in more aggregated schemes grouping shows noticeable effects for Finland.

More research will be needed to help EEIO modelers in designing adequate IO classification schemes. To this effect, studying aggregation bias in EEIO focusing on other environmental dimensions should be performed.

Acknowledgements

Pablo Piñero thanks the University of Oulu Graduate School, the AURORA Doctoral Programme, the Tauno Tönni Research Foundation and the Oulu University Scholarship Foundation for the financial support of this research. Mari Heikkinen and Ilmo Mäenpää acknowledge the funding of the Academy of Finland for the Sustainable Use of Natural Resources and the Finnish Economy (SURE) project (Decision nro. 258559) The authors also acknowledge the work carried out by the researches of the SURE project, in which the ENVIMAT model is updated and improved. We also thank the members of the SURE international scientific advisory board and Iñaki Arto for their comments on the early versions of this paper. Finally, we are also very grateful to the three anonymous reviewers, whose comments have substantially contributed to improve the article.

References

- Andrew, R., Peters, G.P., Lennox, J., 2009. Approximation and Regional Aggregation in Multi-Regional Input–Output Analysis for National Carbon Footprint Accounting. *Econ. Syst. Res.* 21, 311–335. doi:10.1080/09535310903541751
- Ayres, R.U., Kneese, A.V., D’Arge, R., 1970. *Economics and the Environment. A Materials balance Approach.* Resources For The Future, Baltimore.
- Bouwmeester, M.C., Oosterhaven, J., 2013. Specification and Aggregation Errors in Environmentally Extended Input–Output Models. *Environ. Resour. Econ.* 56, 307–335. doi:10.1007/s10640-013-9649-8

- 817 Bringezu, S., Schütz, H., Moll, S., 2003. Rationale for and interpretation of
818 economy-wide materials flow analysis and derived indicators. *J. Ind.*
819 *Ecol.* 7, 43–64. doi:10.1162/108819803322564343
- 820 De Koning, A., Bruckner, M., Lutter, S., Wood, R., Stadler, K., Tukker, A.,
821 2015. Effect of aggregation and disaggregation on embodied material
822 use of products in input–output analysis. *Ecol. Econ.* 116, 289–299.
823 doi:10.1016/j.ecolecon.2015.05.008
- 824 Eisenmenger, N., Schaffartzik, A., Wiedenhofer, D., 2013. How many
825 materials does Austria globally use? A comparison of seven methods
826 to calculate Raw Material Equivalents (RME), in: *Ecological*
827 *Economics and Institutional Dynamics. 10th International Conference*
828 *of the European Society for Ecological Economics.*
- 829 European Commission, Food and Agriculture Organization of the United
830 Nations, Organisation for Economic Co-operation and Development,
831 United Nations, World Bank, 2014. *System of Environmental-*
832 *Economic Accounting 2012. Applications and Extensions. White*
833 *cover publication, pre-edited text subject to official editing.*
- 834 European Environment Agency, 2013. *Environmental pressures from*
835 *European consumption and production.*
- 836 EUROSTAT, 2008. *Eurostat Manual of Supply, Use and Input-Output*
837 *Tables.*
- 838 EUROSTAT, 2001. *Economy-wide material flows accounts and*
839 *development indicators. A methodological guide. Office for Official*
840 *Publications of the European Communities, Luxembourg.*
- 841 Fischer-Kowalski, M., Krausmann, F., Giljum, S., Lutter, S., Mayer, A.,
842 Bringezu, S., Moriguchi, Y., Schütz, H., Schandl, H., Weisz, H., 2011.
843 *Methodology and Indicators of Economy-wide Material Flow*
844 *Accounting. J. Ind. Ecol.* 15, 855–876. doi:10.1111/j.1530-
845 9290.2011.00366.x
- 846 Hirschitz-Gabers, M., Srebotnjak, T., Gradmann, A., Lutter, S., Giljum, S.,
847 2014. Further Development of Material and Raw Material Input
848 Indicators – Methodological Discussion and Approaches for
849 Consistent Data Sets. Input paper for expert workshop.
- 850 Koskela, S., Mattila, T., Antikainen, R., Mäenpää, I., 2013. Identifying Key
851 Sectors and Measures for a Transition towards a Low Resource
852 Economy. *Resources* 2, 151–166. doi:10.3390/resources2030151
- 853 Koskela, S., Mäenpää, I., Seppälä, J., Mattila, T., Korhonen, M.-R., 2011.
854 EE-IO modeling of the environmental impacts of Finnish imports
855 using different data sources. *Ecol. Econ.* 70, 2341–2349.
856 doi:10.1016/j.ecolecon.2011.07.012
- 857 Kovanda, J., Weinzettel, J., 2013. The importance of raw material
858 equivalents in economy-wide material flow accounting and its policy
859 dimension. *Environ. Sci. Policy* 29, 71–80.
860 doi:10.1016/j.envsci.2013.01.005

- 861 Kovanda, J., Weinzettel, J., Hák, T., 2010. Material Flow Indicators in the
862 Czech Republic in Light of the Accession to the European Union. *J.*
863 *Ind. Ecol.* 14, 650–665. doi:10.1111/j.1530-9290.2010.00253.x
- 864 Kymn, K.O., Norsworthy, J.R., 1976. A review of industry aggregation in
865 input-output models. *Am. Econ.*
- 866 Lenzen, M., 2011. Aggregation Versus Disaggregation in Input–Output
867 Analysis of the Environment. *Econ. Syst. Res.* 23, 73–89.
868 doi:10.1080/09535314.2010.548793
- 869 Lenzen, M., 2000. Errors in Conventional and Input-Output—based Life—
870 Cycle Inventories. *J. Ind. Ecol.* 4, 127–148.
871 doi:10.1162/10881980052541981
- 872 Lenzen, M., Moran, D., Kanemoto, K., Geschke, A., 2013. Building Eora: a
873 Global Multi-Region Input–Output Database At High Country and
874 Sector Resolution. *Econ. Syst. Res.* 25, 20–49.
875 doi:10.1080/09535314.2013.769938
- 876 Lenzen, M., Pade, L.-L., Munksgaard, J., 2004. CO2 Multipliers in Multi-
877 region Input-Output Models. *Econ. Syst. Res.* 16, 391–412.
878 doi:10.1080/0953531042000304272
- 879 Leontief, W., 1936. Quantitative Input and Output Relations in the
880 Economic Systems of the United States. *Rev. Econ. Stat.* 18, 105–125.
- 881 Majeau-Bettez, G., Strømman, A.H., Hertwich, E.G., 2011. Evaluation of
882 process- and input-output-based life cycle inventory data with regard
883 to truncation and aggregation issues. *Environ. Sci. Technol.* 45,
884 10170–7. doi:10.1021/es201308x
- 885 Marin, G., Mazzanti, M., Montini, A., 2012. Linking NAMEA and Input
886 output for “consumption vs. production perspective” analyses. *Ecol.*
887 *Econ.* 74, 71–84. doi:10.1016/j.ecolecon.2011.11.005
- 888 Mattila, T., Koskela, S., Seppälä, J., Mäenpää, I., 2013. Sensitivity analysis
889 of environmentally extended input–output models as a tool for
890 building scenarios of sustainable development. *Ecol. Econ.* 86, 148–
891 155. doi:10.1016/j.ecolecon.2012.11.021
- 892 Miller, R.E., Blair, P.D., 2009. Input–Output Analysis: Foundations and
893 extensions. Cambridge University Press, Cambridge.
- 894 Muñoz, P., Giljum, S., Roca, J., 2009. The Raw Material Equivalents of
895 International Trade. *J. Ind. Ecol.* 13, 881–897. doi:10.1111/j.1530-
896 9290.2009.00154.x
- 897 Peters, G.P., 2008. From production-based to consumption-based national
898 emission inventories. *Ecol. Econ.* 65, 13–23.
899 doi:10.1016/j.ecolecon.2007.10.014
- 900 Rueda-Cantuche, J.M., 2013. The choice of type of input-output table
901 revisited : moving towards the use of supply-use tables in impact
902 analysis. *SORT* 35, 21–38.

- 903 Schaffartzik, A., Eisenmenger, N., Krausmann, F., Weisz, H., 2014.
904 Consumption-based Material Flow Accounting. *J. Ind. Ecol.* 18, 102–
905 112. doi:10.1111/jiec.12055
- 906 Schoer, K., Weinzettel, J., Kovanda, J., Giegrich, J., Lauwigi, C., 2012. Raw
907 material consumption of the European Union - Concept, Calculation
908 Method, and Results. *Environ. Sci. Technol.* 46, 8903–9.
909 doi:10.1021/es300434c
- 910 Schoer, K., Wood, R., Arto, I., Weinzettel, J., 2013. Estimating raw material
911 equivalents on a macro-level: comparison of multi-regional input-
912 output analysis and hybrid LCI-IO. *Environ. Sci. Technol.* 47, 14282–
913 9. doi:10.1021/es404166f
- 914 Seppälä, J., Mäenpää, I., Koskela, S., Mattila, T., Nissinen, A., Katajajuuri,
915 J.M., Härmä, T., Korhonen, M.R., Saarinen, M., Virtanen, Y., 2011.
916 An assessment of greenhouse gas emissions and material flows caused
917 by the Finnish economy using the ENVIMAT model. *J. Clean. Prod.*
918 19, 1833–1841. doi:10.1016/j.jclepro.2011.04.021
- 919 Steen-Olsen, K., Owen, A., Hertwich, E.G., Lenzen, M., 2014. Effects of
920 Sector Aggregation on Co2 Multipliers in Multiregional Input–Output
921 Analyses. *Econ. Syst. Res.* 26, 284–302.
922 doi:10.1080/09535314.2014.934325
- 923 Su, B., Ang, B.W., 2014. Input-output analysis of CO2 emissions embodied
924 in trade: A multi-region model for China. *Appl. Energy* 114, 377–384.
925 doi:10.1016/j.apenergy.2013.09.036
- 926 Su, B., Ang, B.W., 2013. Input–output analysis of CO2 emissions embodied
927 in trade: Competitive versus non-competitive imports. *Energy Policy*
928 56, 83–87. doi:10.1016/j.enpol.2013.01.041
- 929 Su, B., Ang, B.W., 2011. Multi-region input–output analysis of CO2
930 emissions embodied in trade: The feedback effects. *Ecol. Econ.* 71,
931 42–53. doi:10.1016/j.ecolecon.2011.08.024
- 932 Su, B., Ang, B.W., 2010. Input-output analysis of CO2 emissions embodied
933 in trade: The effects of spatial aggregation. *Ecol. Econ.* 70, 10–18.
934 doi:10.1016/j.ecolecon.2010.08.016
- 935 Su, B., Huang, H.C., Ang, B.W., Zhou, P., 2010. Input–output analysis of
936 CO2 emissions embodied in trade: The effects of sector aggregation.
937 *Energy Econ.* 32, 166–175. doi:10.1016/j.eneco.2009.07.010
- 938 Timmer, M., 2012. The World Input - Output Database (WIOD): Contents ,
939 Sources and Methods (No. 10), World Input-Output Database (WIOD)
940 Working Paper Series.
- 941 Timmer, M.P., Dietzenbacher, E., Los, B., Stehrer, R., de Vries, G.J., 2015.
942 An Illustrated User Guide to the World Input-Output Database: the
943 Case of Global Automotive Production. *Rev. Int. Econ.* 23, n/a–n/a.
944 doi:10.1111/roie.12178
- 945 Tukker, A., Bulavskaya, T., Giljum, S., Koning, A. De, 2014. The Global
946 Resource Footprint of Nations The Global Resource Footprint of
947 Nations.

- 948 Tuusjärvi, M., Mäenpää, I., Vuori, S., Eilu, P., Kihlman, S., Koskela, S.,
 949 2014. Metal mining industry in Finland - development scenarios to
 950 2030. *J. Clean. Prod.* 84, 271–280. doi:10.1016/j.jclepro.2014.03.038
- 951 Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J.,
 952 Kanemoto, K., 2013. The material footprint of nations. *Proc. Natl.*
 953 *Acad. Sci. U. S. A.* doi:10.1073/pnas.1220362110
- 954 Wyckoff, A.W., Roop, J.M., 1994. The embodiment of carbon in imports of
 955 manufactured products. *Energy Policy*. doi:10.1016/0301-
 956 4215(94)90158-9
- 957 Zhou, X., Shirakawa, H., Lenzen, M., 2013. Aggregation Effects in Carbon
 958 Footprint Accounting Using Multi- Region Input – Output Analysis,
 959 in: Yu, T., Chawla, N., Simoff, S. (Eds.), *Computational Intelligent*
 960 *Data Analysis for Sustainable Development*. Chapman & Hall/CRC
 961 *Data Mining and Knowledge Discovery Series*, Abingdon, UK, p.
 962 440.
- 963

Table 1. Supply, Domestic Extraction and biomass intensity of forestry and logging products for Finland in year 2010				
Code	Product	Domestic Supply (Million euros)	DE (Million kg)	Biomass intensity (kg/euro)
02101a	Forest nursery services	415	0	0.0
02103a	Logs	1,014	10,881	10.7
02103b	Pulp wood	410	15,029	36.6
02103c	Fuel wood	200	2,905	14.5
02103d	Forest chips	120	3,498	29.2
02103e	Other wood in the rough	0	0	0.0
02103f	Other products incidental to forestry and logging	8	0	0.0
021	Silviculture and other forestry activities	2,166	32,312	14.9
022	Logging	903	0	0.0
023	Gathering of wild growing non-wood products	80	33	0.0
024	Support services to forestry	404	1,139	0.4
025	Net growth of forests	460	0	2.8
02	Forestry and logging	4,013	33,485	8.3
Code = product code used in the model. Digits corresponds to CPA version 2008/NACE Rev.2 and the following lower case to the ENVIMAT ₂₀₁₀ own classification system. DE = Domestic Extraction.				

Table 2. Multipliers of biomass for food products, forestry products and real estate activities (kg/euro) for Finland in year 2010								
Code	Sector	E-RL $p'Z_dL$	E-147 $e'A_dL$	O-64 $e''A_dL^*$	W-37 $e'''A_dL^*$	F_d^c (M€)	F_d^i (M€)	F_d^e (M€)
101	Processing and preserving of meat and production of meat products	0.66	0.72	0.57	1.38	990	8	194
105	Manufacture of dairy products	0.90	0.97	0.57	1.38	1,086	-2	494
107	Manufacture of bakery and farinaceous products	0.15	0.13	0.57	1.38	525	1	100
108	Manufacture of other food products	0.54	0.27	0.57	1.38	659	7	267
11-12	Manufacture of beverages, Manufacture of tobacco products	0.25	0.20	0.57	1.38	670	0	203
161	Sawmilling and planing of wood	3.33	4.71	2.84	1.65	10	3	1184
162	Manufacture of products of wood, cork, straw and plaiting materials	1.06	1.48	2.84	1.65	10	18	868
171	Manufacture of pulp, paper and paperboard	1.70	0.91	0.78	0.42	45	72	8455
172	Manufacture of articles of paper and paperboard	0.53	0.30	0.78	0.42	117	2	286
682	Renting and operating of own or leased real estate	0.20	0.19	0.13	0.08	23,910	0	0
Code = sector code used in the model. Digits corresponds to NACE Rev.2 and the following lower case to the ENVIMAT ₂₀₁₀ own classification system. F_d^c denotes final consumption expenditure of domestic products (Households + Government), F_d^i investments and changes in stocks of domestic products, F_d^e exports of domestic products, L the Leontief Inverse $L = (I - A_d)^{-1}$ and M€ indicates million euros.								

Table 3. Supply, Domestic Extraction and material intensity of construction minerals for Finland in year 2010				
Code	Product	Domestic Supply (Million euros)	DE (Million kg)	Material intensity (kg/euro)
08111	Ornamental or building stone	35	611	17.5
08112	Limestone and gypsum	78	3,970	51.1
089a	Other mining and quarrying products n.e.c.	260	11,401	43.9
08a	Mining and quarrying of other minerals	373	15,982	42.9
0810	Quarrying, sorting, grinding etc. Services of gravel or sand ¹⁾	157	0	0
08121a	Gravel and sand, crushed stone	383	63,818	166.5
08122	Clays and kaolin	8	20	2.7
08b	Quarrying of gravel, sand and clay	548	63,838	116.6
08	Other mining and quarrying	920	79,820	86.8
Code = product code used in the model. Digits corresponds to CPA version 2008/NACE Rev.2 and the following lower case to the ENVIMAT ₂₀₁₀ own classification system. ¹⁾ Classification considered in Statistics Finland. DE = Domestic Extraction.				

Table 4. Mineral multipliers of construction and selected manufacturing and services (kg/euro) for Finland in year 2010

Code	Sector	E-RL $\mathbf{p}'\mathbf{Z}_d\mathbf{L}$	E-147 $\mathbf{e}'\mathbf{A}_d\mathbf{L}$	O-64 $\mathbf{e}''\mathbf{A}_d^*\mathbf{L}^*$	N-64 $\mathbf{e}''\mathbf{A}_d^*\mathbf{L}^*$	W-37 $\mathbf{e}''\mathbf{A}_d^*\mathbf{L}^*$	$\mathbf{F}_d^c$ (M€)	$\mathbf{F}_d^i$ (M€)	$\mathbf{F}_d^e$ (M€)
171	Manufacture of pulp, paper and paperboard	0.54	0.53	0.77	0.72	0.66	44	72	8,455
201a	Manufacture of basic chemicals, plastics and synthetic rubber in primary forms	0.89	0.85	2.70	2.09	1.72	54	-62	2,655
241	Manufacture of basic iron and steel and of ferro-alloys	0.73	0.72	1.84	2.78	1.86	22	156	3,380
244	Manufacture of basic precious and other non-ferrous metals	3.26	3.45	1.84	2.78	1.86	3	65	2,615
251	Manufacture of structural metal products	0.30	0.30	0.37	0.48	1.86	18	1	347
256	Treatment and coating of metals; machining	0.29	0.28	0.37	0.48	1.86	8	-75	664
41	Construction of buildings	2.22	2.03	1.67	1.24	1.30	0	16,863	3
42	Civil engineering	4.97	4.57	1.67	1.24	1.30	437	3,087	13
845	Road maintenance ¹⁾	2.03	1.90	0.16	0.17	0.17	451	0	4
846	Railway maintenance ¹⁾	0.85	0.80	0.16	0.17	0.17	1718	0	4

Code = sector code used in the model. Digits corresponds to NACE Rev. 2 and the following lower case to the ENVIMAT₂₀₁₀ own classification system.

$\mathbf{F}_d^c$ denotes final consumption expenditure of domestic products (Households + Government), $\mathbf{F}_d^i$ investments and changes in stocks of domestic products, $\mathbf{F}_d^e$ exports of domestic products, $\mathbf{L}$ the Leontief inverse $\mathbf{L} = (\mathbf{I} - \mathbf{A}_d)^{-1}$ and M€ indicates million euros.

¹⁾ Classification considered in Statistics Finland.

Table 5. Supply, Domestic Extraction and material intensity of fuel and metal minerals for Finland in year 2010

Code	Product	Domestic Supply (Million euros)	DE (Million kg)	Material intensity (kg/euro)
058a	Fuel peat	301	7,533	25.1
058b	Other peat	70	866	12.3
072	Non-ferrous metal ores and concentrates	570	18,191	31.9
08	Other mining and quarrying products ²⁾	920	79,820	86.8
099	Support activities for other mining and quarrying	38	0	0.0
B	Mining and quarrying	1,899	106,410	56.0

Code = product code used in the model. Digits corresponds to CPA version 2008/NACE Rev.2 and the following lower case to the ENVIMAT₂₀₁₀ own classification system. **DE** = Domestic Extraction. **B** = corresponding section in CPA 2008/NACE Rev.2.

²⁾ Data from Table 3.

Table 6. Minerals embodied in imports α obtained using LCA

Code	Sector	E-147 (kg/euro)	O-64 (kg/euro)	N-64 (kg/euro)	Intermediate Imports (Million euros)
05a	Extraction of fossil fuels	4.1	4.1	9.1	5,975
07	Mining of metal ores	24.4	24.4	9.1	1,706
08a	Mining and quarrying of other minerals	48.3	38.8	9.1	73
08b	Quarrying of gravel, sand and clay	34.0	38.8	9.1	143
099	Support activities for other mining and quarrying ³⁾	1.9	1.9	9.1	3

Code = product code used in the model. Digits corresponds to NACE Rev.2 and the following lower case to the ENVIMAT₂₀₁₀ own classification system. ³⁾ Obtained following the domestic technology assumption.

Table 7. Mineral multipliers of imports for selected manufacturing and services (kg/euro) for Finland in year 2010

Code	Sector	E-RL $\delta'\mathbf{Z}_m\mathbf{L}$	E-147 $\alpha'\mathbf{A}_m\mathbf{L}$	O-64 $\alpha''\mathbf{A}_m^*\mathbf{L}^*$	N-64 $\alpha''\mathbf{A}_m^*\mathbf{L}^*$	W-37 $\alpha''\mathbf{A}_m^*\mathbf{L}^*$	$\mathbf{F}_d^c$ (M€)	$\mathbf{F}_d^i$ (M€)	$\mathbf{F}_d^e$ (M€)
192	Manufacture of refined petroleum products	2.61	3.15	3.15	6.46	6.44	994	-283	3,819
241	Manufacture of basic iron and steel and of ferro-alloys	3.70	4.16	6.57	3.62	2.80	22	156	3,380
244	Manufacture of basic precious and other non-ferrous metals	13.23	12.07	6.57	3.62	2.80	3	65	2,615
682	Renting and operating of own or leased real estate	0.34	0.30	0.28	0.33	0.29	23,910	0	0
841	Administration of the State and the economic and social policy of the community	0.14	0.23	0.25	0.28	0.29	10,483	84	171
86	Human health activities	0.13	0.13	0.15	0.17	0.24	12,562	1	16

Code = sector code used in the model. Digits corresponds to NACE Rev. 2 and the following lower case to the ENVIMAT₂₀₁₀ own classification system.

$\mathbf{F}_d^c$ denotes final consumption expenditure of domestic products (Households + Government), $\mathbf{F}_d^i$ investments and changes in stocks of domestic products, $\mathbf{F}_d^e$ exports of domestic products, $\mathbf{L}$ the Leontief Inverse $\mathbf{L} = (\mathbf{I} - \mathbf{A}_d)^{-1}$ and M€ indicates million euros.

Figure

[Click here to download Figure Figures_High Resolution_color.pdf](#)

RM Domestic products (Mt)

RM Imports (Mt)

GHG Domestic products (Mkg)

GHG Imports (Mkg)

RM Domestic products

Priv.Cons	0.1	−2.8	8.1	33.7	37.6
Pub.Cons	3.8	−29.9	−25.6	−14.7	−16.8
Investments	2.6	−11.8	−26.4	−30.0	−30.0
Exports	−3.0	16.4	24.7	16.3	15.0
	E−147	O−64	N−64	W−37	P−25

RM Imports

Priv.Cons	−1.6	5.1	22.6	31.1	35.4
Pub.Cons	1.4	9.9	21.6	55.3	51.5
Investments	4.6	4.5	4.1	11.2	11.4
Exports	−0.3	−3.4	−10.6	−17.4	−18.8
	E−147	O−64	N−64	W−37	P−25

Total RM

Priv.Cons	−1.0	2.2	17.2	32.0	36.2
Pub.Cons	2.7	−11.5	−3.8	17.6	14.8
Investments	3.1	−7.4	−18.1	−18.9	−18.8
Exports	−1.3	3.6	1.8	−5.6	−6.9
	E−147	O−64	N−64	W−37	P−25

RM Aggregation Bias τ (million tonnes)

Raw Material Equivalents (RME) of Exports (Mt)

Figure

[Click here to download Figure Figures_High Resolution_bw.pdf](#)

RM Domestic products (Mt)

RM Imports (Mt)

GHG Domestic products (Mkg)

GHG Imports (Mkg)

RM Domestic products

Priv.Cons	0.1	−2.8	8.1	33.7	37.6
Pub.Cons	3.8	−29.9	−25.6	−14.7	−16.8
Investments	2.6	−11.8	−26.4	−30.0	−30.0
Exports	−3.0	16.4	24.7	16.3	15.0
	E−147	O−64	N−64	W−37	P−25

RM Imports

Priv.Cons	−1.6	5.1	22.6	31.1	35.4
Pub.Cons	1.4	9.9	21.6	55.3	51.5
Investments	4.6	4.5	4.1	11.2	11.4
Exports	−0.3	−3.4	−10.6	−17.4	−18.8
	E−147	O−64	N−64	W−37	P−25

Total RM

Priv.Cons	−1.0	2.2	17.2	32.0	36.2
Pub.Cons	2.7	−11.5	−3.8	17.6	14.8
Investments	3.1	−7.4	−18.1	−18.9	−18.8
Exports	−1.3	3.6	1.8	−5.6	−6.9
	E−147	O−64	N−64	W−37	P−25

RM Aggregation Bias τ (million tonnes)

Direct Material Consumption (DMC)

187.8 Mt

Raw Material Consumption (RMC) (Mt)

200
150
100
50
0

E-RL

E-147

O-64

N-64

W-37

P-25

Biomass Minerals

152.8

25.6

149.5

31.4

136.8

34.7

140.2

34.7

149.7

39.7

152

39.9

Raw Material Equivalents (RME) of Exports (Mt)

Figure 1. RM requirements and GHG emissions embodied per final use category

Figure 2. Sector aggregation bias in percentage $\tau(\%)$

Figure 3. Total aggregation bias per source of error
(schemes O-64, N-64 and W-37)

Figure 4. Total aggregation bias per type of raw material
(values appear when bias is over 1.5 Mt)

Figure 5. RMC and RME of exports per type of raw material

Figure 6. RMC and RME of exports according to origin of products (y-axis represents % of Raw Material Input)

Supplementary Material

[Click here to download Supplementary Material: Explanatory_Tables.xlsx](#)