COMPARISON OF THREE COMMON LIFE CYCLE ENVIRONMENTAL IMPACT ASSESSMENT METHODOLOGIES FOR POLYOLEFIN CRATES

by

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ABSTRACT

In this thesis, a comparative analysis of three different life cycle impact assessment methodologies has been carried out for polyolefin plastic crates. Additionally, improvement possibilities for the waste management of plastic crates have been investigated. In the study, GaBi 4 software tool was utilized for methodology comparison.

The three different life cycle impact analysis methodologies assessed in this study include: CML 2001, EDIP 2003 and Eco-Indicator (EI) 99 – "Hierarchist Approach". The differences and similarities of the methods were examined. While EI is an endpoint methodology, EDIP and CML are midpoint methods. In the first part of the study, polyethylene (PE) and polypropylene (PP) plastic crates were analyzed with these methods. In the second part, the CML methodology was selected and applied to observe the effect of recycling and incineration on the products' life cycles.

In the comparative analysis, differences of less than 1% were observed in the characterization stage for all methodologies. According to EDIP, the acidification and photo-oxidant formation results slightly favor the use of PP, however, the eutrophication results weakly support PE use. Based on the CML, acidification, photo-oxidant formation and toxicity results approve PP scenarios, whereas eutrophication and global warming results shows PE use as more advantageous. For EI, toxicity results indicate that PP may be favored, however resource depletion and global warming results highlight that PE may be preferred. Thus, it has been concluded that both plastic materials show similar performance. In addition, in global warming and ozone depletion the results do not vary with methodology selection. For other categories, similarities can again be observed. Results also indicate that incorporating recycling into waste management leads to a reduction in emissions. For the comparison of "40% recycling" and "only virgin raw material use" scenarios, it has been deducted that the "40% recycling" scenario achieves a reduction of approximately 39% is achieved in all CML categories. When considering the "60% recycling" scenario, a reduction of about 59% was observed relative to the "only virgin material use" scenario. The reuse of plastics was researched using CML. It has been assessed that a decrease in reuse from 350 times to 300 times led to a reduction of 25.19% in the weighting scores.

ÖZET

Bu tezde üç farklı "Yaşam Döngüsü Etki Analizi" metodolojisinin karşılaştırmalı analizi poliolefin plastik kasalar için gerçekleştirilmiştir. Ayrıca, kasaların atık yönetiminin iyileştirilmesi alanları araştırılmıştır. Çalışmada, GaBi 4 yazılımı kullanılmıştır.

Üç farklı yaşam döngüsü etki analizi metodu olarak bu çalışmada incelenen metodlar: "CML 2001 Kasım '09", "EDIP 2003" ve "Eco-indicator (EI) 99- Hierarchist yaklaşımı"dır. Metodların farklılık ve benzerlikleri incelenmiştir. EI bir son-nokta metodu iken, EDIP ve CML orta-nokta metodolojileridir. Çalışmanın ilk bölümünde, polietilen (PE) ve polipropilen (PP) plastik kasalar analiz edilmişlerdir. İkinci bölümde ise, CML metodu seçilmiş ve geridönüşüm ve yakmanın ürünün yaşam döngüsü içindeki etkilerini gözlemlemek için uygulanmıştır.

Hammaddelerin karşılaştırıldığı analizde, tüm metotlar için % 1 den az fark gözlemlenmiştir. EDIP'e göre, asidifikasyon ve fotooksidant oluşumu az farkla PP, ötrofikasyon sonuçları PE kullanımını savunmaktadır. CML metodu, asidifikasyon, fotooksidant oluşumu ve toksisite sonuçları PP, ötrofikasyon ve küresel ısınma sonuçları PE senaryolarının daha avantajlı olduğunu göstermektedir. EI ise, toksisite kategorisi sonuçlarının PP, ancak kaynak tüketme ve küresel ısınma kategorisi sonuçlarının PE kullanımını desteklediğini göstermektedir. Buradan hareketle, iki plastik malzemenin de benzer performans gösterdikleri sonucuna varılmıştır. Ayrıca küresel ısınma ve ozon incelmesinin sonuçlarının metot seçimi ile değişmedikleri görülmüştür. Diğer kategoriler için de benzerlikler gözlemlenebilmektedir. Sonuçlar ayrıca, geri dönüşümün atık yönetimine eklenmesinin emisyon düşüşlerine neden olduğunu göstermektedir. 40% geridönüşümden gelen malzeme ve sadece saf madde kullanımı senaryoları karşılaştırıldığında, 40 % oranda geri dönüşümden gelen malzemenin katıldığı senaryonun, yaklaşık 39% kadar emisyon düşüşüne neden olduğu görülmüştür. 60 % oranda geri dönüşümden gelen malzemenin katıldığı senaryonun, ise yaklaşık 59% kadar tüm emisyon düşüşüne neden olduğu görülmüştür. Tekrar kullanım senaryoları, CML ile incelenmiştir. 350 kereden 300 kereye düşürüldüğünde (%14'lük düşüş) ağırlıklandırılmış sonuçlarda 25.19 % azalmaya neden olduğu hesaplanmıştır.

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LIST OF SYMBOLS / ABBREVIATIONS

Symbol	Explanation	Units
BOD	Biological Oxygen Demand	(mg/L)
COD	Chemical Oxygen Demand	(mg/L)
kg CO_2	Carbon dioxide equivalents. Units for potential contribution to global warming	(kg CO_2- eq)
kg NO_3	Nitrate equivalents. Units for potential contribution to nutrient enrichment	(kg NO_3- eq)
m^2 UES	Unprotected EcoSystem. Units for potential contribution to eutrophication and acidification	(m^2 UES)
AP	Acidification Potential	
AF	Amplification factor	
BAF	Biological Amplification factor	
CARMEN	Cause effect Relation Model to support Environmental Negotiations	
CFC	Chloroflorocarbon gases	
CML	Centre of Environmental Science	
DALY	Disability Adjusted Life Years	
EDIP	Environmental Development of Industrial Products	
EI	Ecoindicator	
FAETP	Freshwater Aquatic Ecotoxicity Potantial	
FUND	The Climate Framework for Uncertainty, Negotiation and Distribution	
GWP	Global Warming Potential	
HDPE	High Density Polyethylene	
LCA	Life Cycle Analysis	
LCIA	Life Cycle Impact Analysis	
LCI	Life Cycle Inventory	
LDPE	Low Density Polyethylene	
IIASA	International Institute for Applied System Analysis	
IKP	Polymer Testing and Polymer Sciences	

IPCC	Intergovernmental Panel on Climate Change
IR	Incremental Reactivity
ISO	The International Organization for Standardization
MAETP	Marine Aquatic Ecotoxicity Potantial
NOEC	No Observed Effect Concentration
ODP	Ozone Depletion Potentials
PE	Polyethylene
PDF	Potentially Disappeared Fraction
POO	Probability of Occurrence
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinylchloride
RAF	Radiation amplification factor
RAINS	Regional Air Pollution Information and Simulation
RIVM	Netherlands Institute of Public Health and Environment
SETAC	The Society of Environmental Toxicology and Chemistry
T	length of time interval
TETP	Terrestrial Ecotoxicity Potantial
UNEP	The United Nations Environmental Programme
USES-LCA	Uniform System for the Evaluation of Substance
UV	Ultra Violet
VOC	Volatile Organic Compounds
WMO	World Meteorological Organization

1. INTRODUCTION

In the twentieth century, a rapid increase in population, a general improvement in living standards and the growth of cities caused an increased volume of production. According to Lundquist, as costs of waste management have risen, approaches for management techniques changed, as well. Therefore, terms like “sustainable development”, “life cycle engineering”, and “cradle to grave” have gained importance (Lundquist et al., 2000). Life Cycle Analysis (LCA) is an integrated tool for evaluation of the total life cycle impacts of products and services, leading industry and people towards more sustainable production and consumption.

In LCA, impact assessment that utilizes environmental information for various pollutants and resources and requires characterization indicators, calculations, etc. may be time and resource consuming. Therefore, ready-made methodologies are commonly preferred and each methodology has its own specific measurement principles (Baumann and Tillman, 2004).

In LCA methodologies, different aspects can be considered, such as midpoint and endpoint point of view. Endpoint modeling enables more structured and defined weighting. However, extending the models to endpoints reduces their level of comprehensiveness since a significant number of assumptions or values choices are used for extensions from mid-point to end-point methods. Moreover, that extensions may not reflect the viewpoint of other experts and/or the user (Hofstetter et al., 2000). A consensus was reached by the LCIA experts at Brighton workshop in May 2000. At the Brighton workshop it was suggested that the midpoint and endpoint indicators should be available in parallel. As a result, the user would be able to see the comparative results at the midpoint level, as well as at the endpoint level, and can provide both sets of information to decision makers within a consistent framework (Hofstetter et al., 2000). In literature, there are many life cycle impact assessment (LCIA) methods that can be used for LCA. In this study, three methods are considered, namely CML 2001 Nov. ’09, EDIP 2003 and Eco-Indicator (EI) 99 – Hierarchist Approach.

As a case study, polyolefin plastic crates were used for analysis. More specifically, polyethylene (PE) and polypropylene (PP) plastic crates were selected. The use of plastics has been important in the history of engineering and product design. However, the plastics industry also created a culture dependent upon disposable materials, due to the short lifespan of many plastic products. Therefore, today, municipal solid waste contains enormous amounts of plastic wastes due to the rapid increase in consumption. (Andrady, 2003; Lundquist et al., 2000). In order to evaluate plastic use and waste management, a "cradle to grave" approach was applied and analyzed. Cradle to grave includes the different stages of a plastic product's life cycle, such as extraction and processing of raw materials, manufacturing, transportation, distribution, use and reuse, recycling, and the final disposal.

The main goal of the study was to compare different methods used commonly in LCA. In this context, common assessment methods which are: CML 2001 Nov. '09 (mid-point), EDIP 2003 (mid-point) and the damage-oriented method Eco-Indicator 99 – Hierarchist Approach) were compared. The case study was used to illustrate the concepts behind the presented strategy. This evaluation contains the advantages of being able to calculate both mid and endpoint indicators.

Also, the environmental performance of polyolefin crates was researched. The environmental impacts of the life cycles of PE and PP crates that are produced in Turkey were investigated within this concept. This LCA model has been developed with the objective of identifying the main categories of environmental burdens with their weighted impacts throughout the life cycle of a plastic crate. Also, the study targeted to determine possible ways of achieving environmental improvements for the given type of the crate analyzed and for the current crate model used in industry. Present and future target scenarios were created for both materials. The current situation in Turkey incorporates 40 % recycled material content which meets the target for the year 2012, according to plastic packaging legislation. Future projections for plastic crates in Turkey are based on a 60 % recycling target for year 2020. Consequently, the environmental performance results for present and future systems have been compared.

Furthermore, performance given an applied recycling option was researched. Environmental performance data for three different enhanced capacity systems without a

recycling option were established and compared with scenarios that employ recycling. For enhanced capacities: only the CML method, present year capacity and PE material were selected for use. The enhanced production capacities (without a recycling option) considered for the study were enhanced capacity 1 - 1,400,000 items, and enhanced capacity 2 - 1,600,000 items. Also Base capacity - 1,000,000 items, scenario added for comparison. These capacities were compared with the present scenario of 1,400,000 items and the future target scenario of 1,600,000 items.

Lastly, since reuse of durable plastics is one of the main policies of solid waste management, reuse options for crates were analyzed, as well. Scenarios created for reuse occurrences of 350, 300, 200 and 100 times were compared.

2. LIFE CYCLE ASSESSMENT AND PLASTICS INDUSTRY

2.1. Life Cycle Assessment

Life Cycle Analysis (LCA) is a tool that provides information on the product's environmental impacts for decision making. The broad view of LCA is essential in order to avoid problem-shifting, for example, from one phase of the life-cycle to another, from one region to another, or from one environmental problem to another (Finnveden et al., 2009).

LCA studies may be used for;

- developing of environmental legislation and regulation or criteria for environmental taxes, standards, or eco-labeling programs,
- increasing the credibility of the company's environmental policy,
- developing a systematic evaluation of the environmental consequences associated with a given product and providing information to consumer,
- investigating the environmental trade-offs associated with one or more specific products/processes to help gain stakeholder (state, community, etc.) acceptance for a planned action,
- to guide the suppliers to act in an environmentally friendlier way,
- calculating emissions to air, water, and land in relation to each life cycle stage and/or major contributing process,
- examining the human and ecological effects of material consumption and environmental releases on local, region, and world base,
- comparing the health and ecological impacts between two or more rival products/processes or identify the impacts of a specific product or process (Miettinen and Hämäläinen, 1997; U.S. Environmental Protection Agency, 2006).

2.1.1 Principles and Methodological Framework

Since LCA has become a key subject for environmental management, it is closely linked to legislations, regulations, standards and guidelines which are related to the

environment. The procedures that are used for initiation, performing and reporting of LCA studies have been examined by several international organizations since 1990. As the most significant of them, a workshop was performed by The Society of Environmental Toxicology and Chemistry (SETAC) and Guidelines for Life Cycle Assessment: A "Code of Practice", published by SETAC in 1993. Guidelines laid the foundation for further development and as the most important outcome of this guideline, the LCA methodology was defined. SETAC's role was not to standardize methodology, but to improve the science and practice of LCA.

Primary responsibility for standardization lies with The International Organization for Standardization (ISO), which performs this function worldwide. The realization of an LCA is described in ISO International Standards and all assessments should follow the ISO 14040: 2006 series guidelines. Before the year 2006, ISO 14040-series have contained seven standards including;

- 14040: Principals and framework,
- 14041: Goal, scope and inventory analysis,
- 14042: Impact assessment,
- 14043: Life cycle interpretation,
- ISO 14047, 14048 and 14049: Examples on impact assessment and inventory and rules for documentation (Bey, 2000; Guinée and Heijungs, 2005).

At present ISO 14044:2006 together with ISO 14040:2006 replaces ISO 14040:1997, ISO 14041:1998, ISO 14042:2000 and ISO 14043:2000, which have been technically revised. The structure of current new ISO standards is illustrated in Figure 2.1.

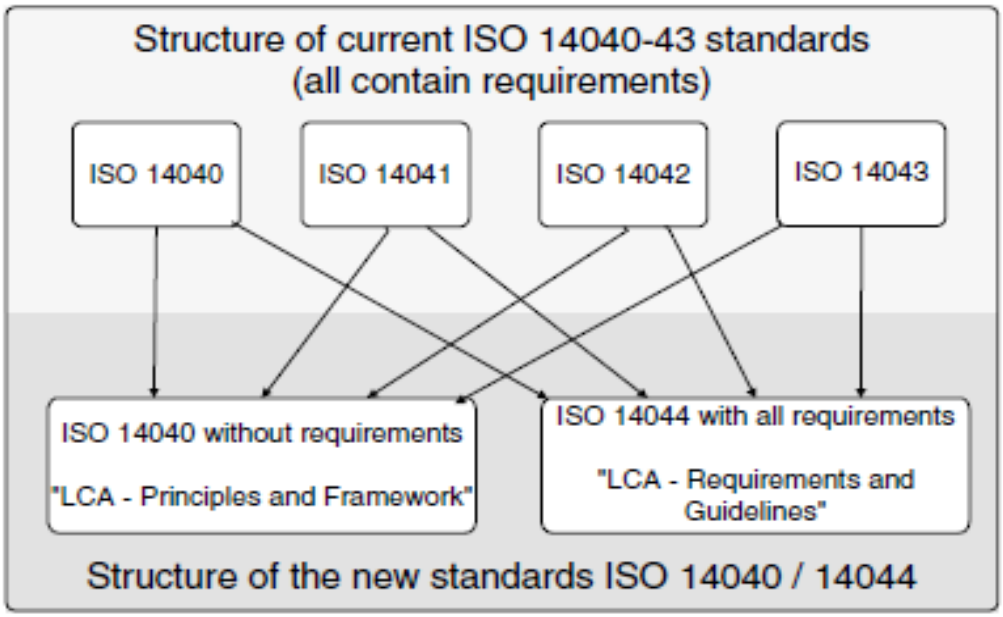

Figure 2.1. Structure of current ISO Standards (Finkbeiner et al., 2006).

The development of the international standards for life cycle assessment was an important step to consolidate procedures and methods of LCA. The ISO standards present an international reference in terms of principles, framework, and terminology for LCA studies. On the other hand, the standards themselves only cannot ensure a detailed operational guideline or does not present methods. Therefore many other guidebooks, decision trees, tables with conversion factors, and mathematical equations have been published to assist LCA analysts (Bey, 2000; Guinée and Heijungs, 2005). As recommended by ISO (2006) and SETAC (1993), LCA studies should be carried out as illustrated in Figure 2.2.

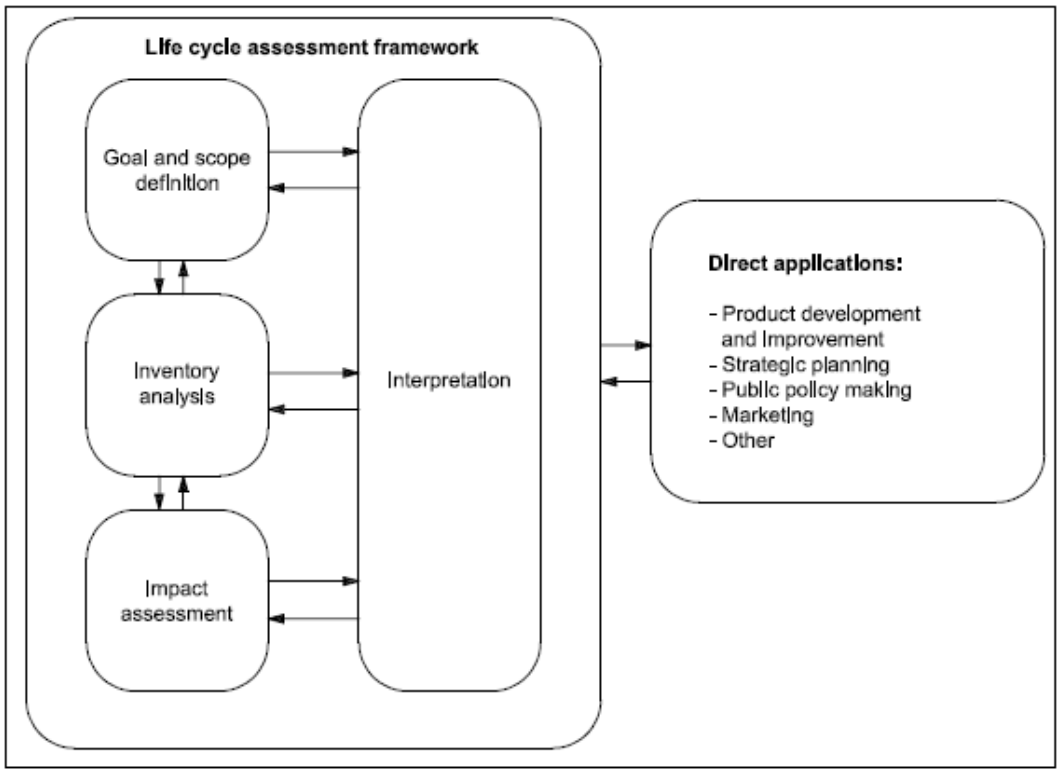

Figure 2.2. Stages of an LCA (ISO, 2006).

According to Figure 2.2. LCA process is a systematic, staged approach which consists of four main components: goal definition and scoping, inventory analysis, impact assessment, and interpretation. The stages follow an iterative procedure in which the level of detail may subsequently be increased.

2.1.2 Methods for Life Cycle Assessment

There are several different characterization methods for LCA performers to follow. The complex procedure of impact assessment steps, which involves environmental information of various pollutants and resources, characterization indicators and calculations etc. may be time and resource consuming. Hence, for analysts the most practical alternative way is to use “Ready-made” Life Cycle Impact Assessment (LCIA) methodologies, so that the practitioner does not have to go in depth into the procedure of the different impact assessment steps. Ready-made methodologies are packages of impact assessment

procedures. The harmful effects of a pollutant or a resource is determined in a measure of common scale and each methodology has its own specific measurement principle.

The different LCA methodologies present different views of the nature, human and society regarding LCA analysis. The answers for the following questions roughly determine the methods' points of view:

- *Views of the nature*: Is nature resistant or fragile? Do features of the nature show a constant flux model, or is it evolving towards a climax?
- *Views of the humans*: Do human beings belong to nature or are they subjected to cultural affairs? Does the freedom of action or limited possibility on acts define the path of humans?
- *Views of the society*: Does the growth of the society harm the environment? In case of economy, should the society be established as a market economy, in a decentralized small scale economy or in planned economy?

However, the most important aspect in using such methods is the viewpoint of the decision maker. With various LCA methods, the assessment offers an overview of smaller, greater and more controversial environmental problems on which decision makers shall choose and decree (Baumann and Tillman, 2004). In LCA methods, different aspects can be considered, such as:

- Overall impact classes (Resources, Natural environment, Working environment),
- Impact categories (Global warming, ozone depletion, acidification, etc.),
- Normalization references (average European values, average global values),
- Weighting factors (depend e.g. on national reduction targets) (Bey, 2000).

LCA methodologies can be divided into two groups due to the choice of an impact category indicator result. The result can be selected either at the midpoint or endpoint level.

- *Midpoint impact category* methodology is the problem-oriented approach, which converts impacts into environmental themes such as climate change, acidification,

human toxicity, etc. A midpoint indicator can be defined as a parameter in a cause-effect chain or network (environmental mechanism) for a particular impact category that is between the inventory data and the category endpoints. Although in general this definition will hold true, such as in categories like climate change and acidification, it may not be fully adequate in others (Bare et al., 2000).

- *Endpoint impact category* methodology, also known as the damage-oriented approach, converts environmental impacts into issues of concern such as human health, natural environment, and natural resources. Endpoint characterization factors (or indicators) are calculated to reflect differences between stressors at an endpoint in a cause-effect chain. This may be of direct relevance to society's understanding of the final effect, such as measures of biodiversity change. In some impact categories, more than one endpoint measure exists. For example, in the context of ecosystem effects, measures include the Potentially Affected Fraction (PAF) of species and the Potentially Disappeared Fraction (PDF) of species (Bare et al., 2000).

For evaluations, endpoint results have higher level of uncertainty compared to midpoint results, however the complexity of the analysis is lower than midpoint results (PE International, 2011). According to Bare et al., the overall opinion in LCAI shows that while endpoint models may be more relevant, but less certain (i.e., higher model and parameter uncertainty), midpoint modeling may be more certain (i.e., lower model and parameter uncertainty), but less relevant to what the decision makers really want to know. A consensus was reached by the LCIA experts at the Brighton workshop in May 2000 and it was acknowledged that both midpoint and endpoint level indicators have complimentary merits and limitations. It was also suggested that the midpoint and endpoint indicators should be available in parallel. The user can see the comparative results at the midpoint level, as well as at the endpoint level and can provide both sets of information to decision makers within a consistent framework (Bare et al., 2000).

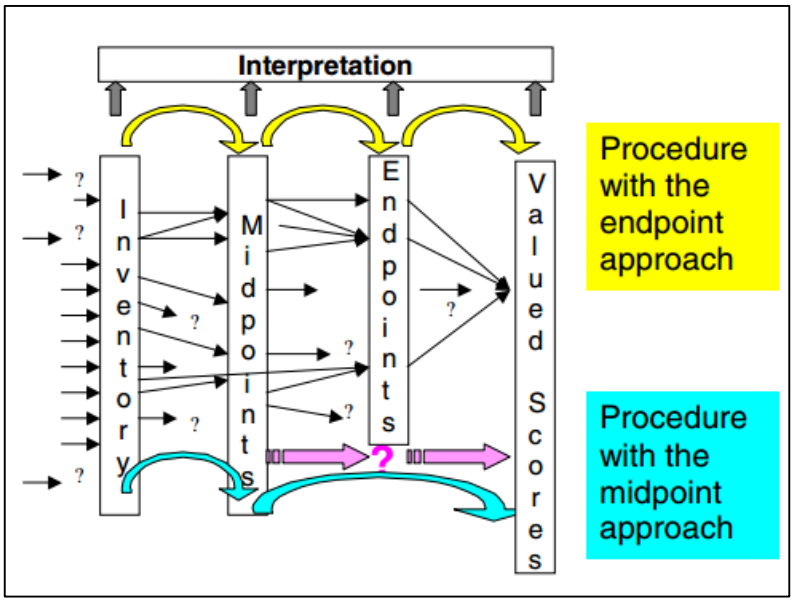

Figure 2.3. Graphical representation of some basic differences between the midpoint (lower row of swinging arrows) and the endpoint approach (upper row of swinging arrows) (Bare et al., 2000).

In literature there are many LCIA methods that can be used for LCA, in this study three methods –Eco Indicator 99, EDIP 2003 and CML 2001 – are chosen and described in the following.

2.1.2.1 Eco Indicator 99 Method

Eco-Indicator (EI) 95 was developed in a joint Project of companies, research institutes and the Dutch government. The most recent revised version is called Eco-Indicator 99. In Eco Indicator 99 manual, this method is simply described as "a damage oriented method for Life Cycle Impact Assessment". Hence the impact assessment methodology of Ecoindicator converts the data of the inventory table into damage scores which can be aggregated to particular damage scores per each of three damage categories (human health, ecosystem health and resources), or even to one single score (Cotetiu, 2006).

In the Eco-indicator 99 (EI 99), different perspectives can be chosen for LCA. Individualists approach uses age weighting, or the short time perspective (which is set at 100 years) in the calculation of Disability Adjusted Life Years (DALYs). Hierarchists approach

do not use age weighting, but would disregard the effect of displacements. The hierarchic perspective is a moderate perspective and generally accepted by the scientific community, assigning 40–40–20 % of weight to the three impact areas human health, ecosystem health and resources, respectively. Egalitarians approach also do not use age weighting, but they do include the effects of displacements (Goedkoop and Spriensma, 2000; Goedkoop et al., 2007). In the method, three types of damage categories is defined;

1. *Human Health:* This damage category represents the idea that all human beings, in present and future, should not be in danger of environmentally transmitted illnesses, disabilities or premature deaths. The number and duration of diseases, and life years lost due to premature death from environmental causes are involved in this category. Expressed as the "number of year life lost" and "the number of years lived disabled". These are combined as Disability Adjusted Life Years (DALYs), an index that is also used by the Worldbank and WHO. The effects are: climate change, ozone layer depletion, carcinogenic effects, respiratory effects and ionising (nuclear) radiation.

2. *Ecosystem Quality:* This damage category represents the idea that non-human species should not suffer from disruptive changes of their populations and geographical distribution. The effect on species diversity, especially for vascular plants and lower organisms are involved in this category. Expressed as "the loss of species over a certain area, during a certain time". The effects are: ecotoxicity, acidification, eutrophication and land-use.

3. *Resources:* This damage category represents the idea that the nature's supply of resources should also be available for future generations. The surplus energy needed in future to extract lower quality mineral and fossil resources are involved in this category. Expressed as "the surplus energy needed for future extractions of minerals and fossil fuels". The depletion of agricultural and bulk resource as sand and gravel is considered under land use. (Eco indicator 99, 2000; Goedkoop and Spriensma, 2000; Goedkoop, 2008).

Eco Indicator 99 method uses four different procedures to create a relation between inventory table and three types of damage categories:

1. *Procedures for human health:*
    a) Fate analysis procedure: Relating an emission (expressed as mass) to a temporary change in concentration.
    b) Exposure analysis procedure: Relating this temporary concentration to a dose.
    c) Effect analysis procedure: Relating the dose to a number of health effects, like the number and types of cancers, and respiratory effects.
    d) Damage analysis procedure: Relating health effects to the number of years lived disabled (YLD) and Years of Life Lost (YLL).

2. *Approaches for ecosystem health:*
    a) For toxic emissions and emissions that change acidity and nutrients levels.
    i) Fate analysis procedure: Concerning with emissions to concentrations.
    ii) Effect analysis procedure: Concerning with concentrations to toxic stress or increased nutrient or acidity levels.
    iii) Damage analysis procedure: Concerning with these effects to the increased potentially disappeared fraction for plants.
    b) For land-use and land transformation: Modeling on the basis of empirical data on the quality of ecosystems, as a function of the land-use type and the area size.

3. *Resource extraction:*
    a) Resource analysis step: Relating an extraction of a resource to a decrease of the resource concentration.
    b) Damage analysis step: Relating lower concentration to the increased efforts to extract the resource in the future (Goedkoop and Spriensma, 2000).

In Figure 2.4. these models are represented in a schematic way.

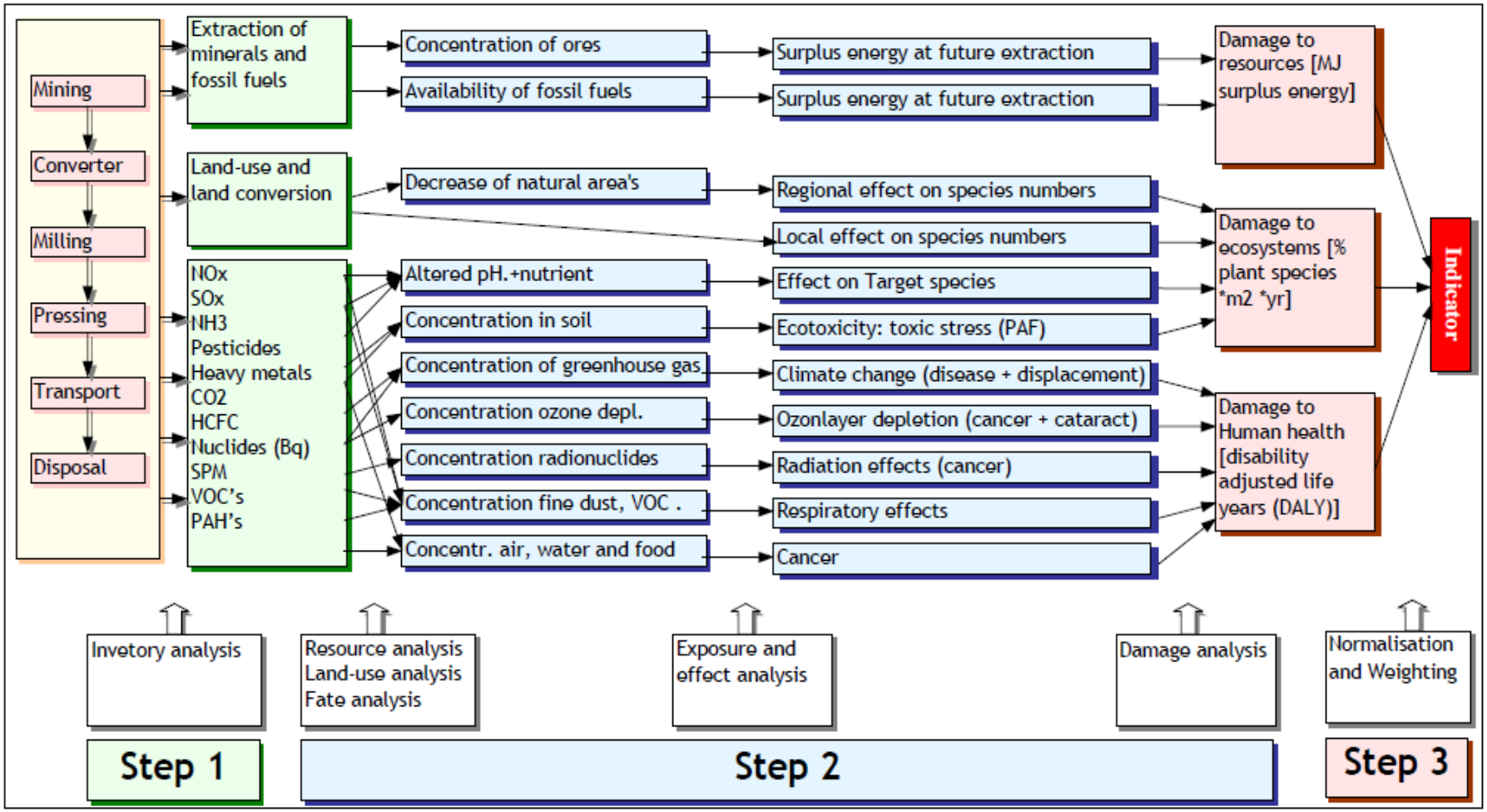

Figure 2.4. Detailed representation of the damage models (Goedkoop et al., 2008).

Since Eco Indicator 99 is the updated and more complete version developed for Europe, in order to find differences between cultural values, developers gathered a panel. In this panel 365 members of a Swiss LCA interest group has delivered their opinions about environmental damages and construction the set of indices has been done and now the methodology can be implemented to other parts of the world (Baumann and Tillman, 2004).

2.1.2.2 EDIP 2003

Between 1990 and 1996, a research project about environmental product development has been performed in Denmark. The project was entitled as EDIP which is an abbreviation for Environmental Development of Industrial Products. The EDIP 97 method was developed under the Danish Environmental Design of Industrial Products Programme by the Technical University of Denmark, five private sector companies, the confederation of Danish Industries and the Danish Environmental Protection Agency. In EDIP Project, a methodology for environmental assessment of products was formed. Within the scope, tools for product development procedures of new generation products were presented as well (Hauschild and Wenzel, 1998; Bey, 2000).After that, EDIP 2003 is presented as an update of the EDIP 97 methodology. In Figure 2.5 EDIP 2003 and EDIP 97 is being compared by means of coverage of causality chain. At each link, the descriptors indicate aspects to consider. The EDIP2003 method covers the major part of the chain and involves the spatial variations in the relevant parameters, while the EDIP 97 covers the first links and hence neglects spatial differentiation.

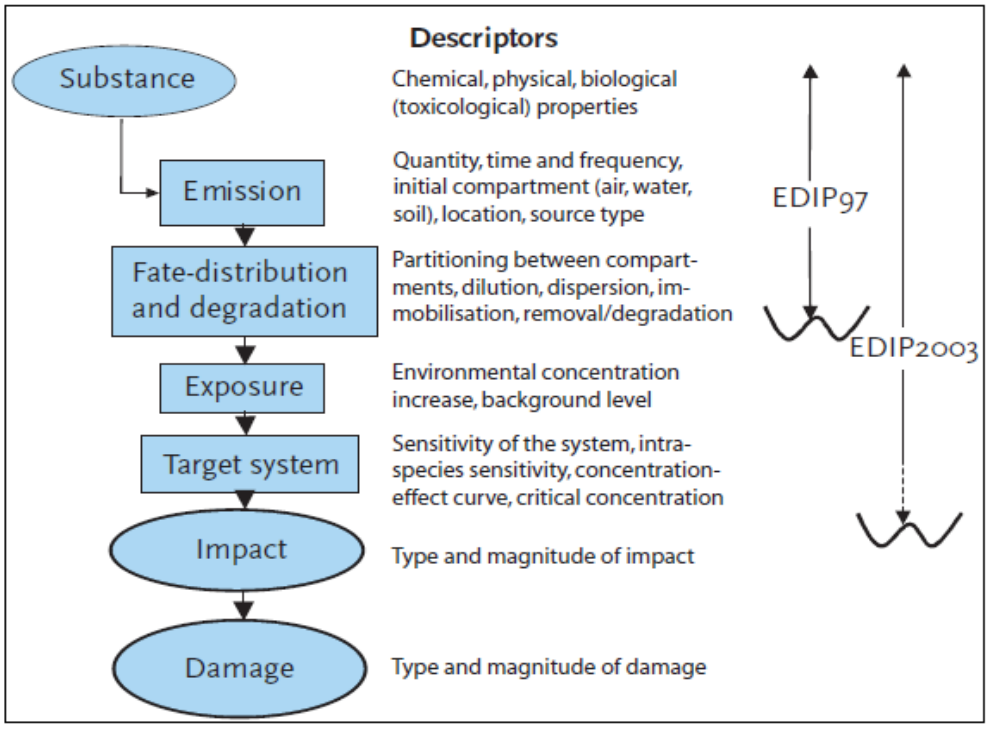

Figure 2.5. Causality chain, comparison of EDIP 97 and 2003 (Hauschild and Potting, 2005).

The EDIP 2003 method uses problem-oriented (midpoint) approach and incorporates 19 different impact categories: Global warming, Ozone depletion, Acidification, Terrestrial Eutrophication, Aquatic Eutrophication (N-eq), Aquatic Eutrophication (P-eq), Ozone Formation (human), Ozone formation (vegetation), Human toxicity (exposure route via air) Human toxicity (exposure route via water) , Human toxicity (exposure route via soil), Ecotoxicity (water acute), Ecotoxicity (water chronic), Ecotoxicity (soil chronic), Hazardous waste, Slags/ashes, Bulk waste, Radioactive waste (Goedkoop, 2008). However GaBi 4 version of the methodology does not cover resource consumption and toxicity group impact categories.

The most important improvement of EDIP 2003 (as it is indicated at the explanation of Figure 2.7) is that new update involved the exposure in the characterization modeling of the main non-global impact categories and both in a site-generic and a site-dependent form can be used (Goedkoop, 2008; Hauschild and Potting, 2005). For normalization stage, the average impact resulting from an average person is taken (Bey, 2000).

2.1.2.3 CML Method

Centre of Environmental Science is one of the three research groups at Leiden University- Netherlands who has developed the ready-made method of CML and CML is the abbreviation of the group name. The impact assessment method applied in CML methodology is defined as a midpoint approach.

In the method, the emission loads are aggregated due to their contribution to environmental effects. For each environmental category, a potential impact is calculated according to the equivalency factors proposed. The impact categories may have different scaling factors: global, continental, regional and local (Le Borgne and Feillard, 2011).In 2001, CML group members developed a new set of impact categories and characterization methods for the impact assessment step. From 2001 to present, different new versions of CML 2001 are still published by CML Center and the most recent two updates are December 2007 and November 2009 (Mølgaard, 1995).

The structure of CML method is very similar to EDIP method but differs in following ways;

- The CML method uses additional impact categories.
- At normalization step, CML method does not take into account regional conditions.
- Normalized data evaluation is different.

CML method uses the following environmental impacts: Global warming, ozone depletion, nutrient enrichment, acidification, photochemical ozone formation, toxic chemicals, local effects, waste. Both CML and EDIP methods may end up with only one numeric result for the environmental impact of a product (after weighing). At CML method the weighing can only be technical, while at EDIP method both technical and political factors are used (Mølgaard, 1995).

The CML method has various sets of normalization and weighing scores for spatial differentiation. For normalization “World, EU25, EU25+3, Western Europe and Netherlands” options can be used. The normalization calculation consists of dividing the

LCIA results of each impact category per the reference value (the total impact from emissions, extractions, radiation and land use, per impact category for Western Europe over a year) (Monteiro and Freire, 2011). On the other hand, for weighting only Europe based strategies are available. The approaches used in the method are “Experts IKP (Polymer testing and Polymer Sciences) for Central Europe”, “Experts IKP for Northern Europe” and “Experts IKP for Southern Europe”.

2.1.3 Tools Used for LCA Analysis

Since conducting LCA with all its stages and sub-stages would be time consuming and tedious, software applications are developed and mostly used to support calculations and evaluations. According to Brunner and Rechberger (2000), there are certain requirement categories which LCA software should be able to fulfill, including:

- *Documentation:* Documentation should be understandable and detailed with an installation guide, a user manual and an online help.
- *User Friendliness:* The application should be based on widely used operating systems and menus should be designed similar to popular software products. The software should be self-explanatory, easy to use and multilingual.
- *Support and Maintenance:* The software producers must present support (via email, telephone) and product maintenance and upgrades should be available via internet.
- *Stability:* Known bugs and conflicts with other applications must be cleared.
- *Cost benefit:* A trial or limited version should be available and price should be reasonable.
- *Calculation speed and accuracy:* Accurate calculation in an acceptable time span.
- *Compability with other software applications:* Importing and exporting data and figures from and to other applications.
- *Flexibility and automatization:* The program can be adopted without knowing a programming language (Brunner and Rechberger, 2004).

2.1.3.1. GaBi

The software was developed by Institute for Polymer Testing Science (IKP) at the University of Stuttgart in cooperation with PE Europe GmbH in Germany. GaBi stands for "ganzheitliche bilanzierung" in German which means life cycle engineering. The tool is used in industrial, academic and consultancy purposes. The multifunctional features of this software enable simple and quick modeling for complex analyses and data intensitive cases (Brunner and Rechberger, 2004). The tool can provide solutions for different problems regarding cost, environment, social and technical criteria, optimization of processes. Gabi can be used accordingly with the procedure for eco-balancing, which is standardized in ISO 14040 series. The databases which defined within the system contain life cycle balance data from the researches made by IKP University of Stuttgart and PE Europe GmbH (IKP and PE Europe, 2003).

2.1.3.2. Other Softwares

Umberto software system is developed by the Institute for Energy and Environmental Research Heidelberg Ltd. (IFEU) incorporation with Institute for Environmental Informatics Hamburg Ltd. (IFU). Umberto can be used to demonstrate material and energy flow systems. In addition environmental cost of the system can be calculated. This software can be used by companies that desire to establish an environmental management system (Brunner and Rechberger, 2004).

Simapro software system is developed by a private Dutch company named PRé Consultants. The software provides analysis and monitoring of the environmental performance of products and services. Simapro has direct linking to Excel or ASP databases and uses Monte Carlo analysis for data uncertainty evaluations. This software is widely used in LCA studies. SimaPro provides several inventory databases with thousands of processes and the most important impact assessment methods (PRé Consultants, 2011).

2.2. Characterization Step of LCIA

Since the results of an LCA study are influenced by the LCIA method applied, the main difference in LCIA methodologies lies in characterization methods. The impact categories that are calculated according to EDIP 2003, CML 2001 and EI 99 methodologies can be grouped into three main categories such as Material Welfare, Ecosystem Health and Ecotoxicity.

2.2.1. Material Welfare

This category impacts involve use of non-renewable and renewable sources. Abiotic Resources are defined as natural resources such as ores, oils, wind energy etc. However, depending on the problem or definition that the method uses, this impact category can include only natural resources or natural resources, human health and the natural environment, among its areas of protection (Oers et al, 2002; Guinée et al., 2002).

2.2.1.1 CML 2001 Nov '09 Method- Abiotic Depletion (ADP), Elements

The impact category is concerned with protection of human welfare, human health and ecosystem health and is related to extraction of minerals due to inputs in the system. For Abiotic Depletion (ADP) Factor, elements are determined for each extraction of minerals and is measured as "kg of Antimony equivalents / kg extraction". The classification method is originally developed by Heijungs. Antimony is used solely as a reference material to facilitate the use of an indicator for comparative purposes. The rate of extraction divided by the ultimate quantity of reserves for resources used in the system are always equated to the reference ratio for Antimony (Guinée et al., 2002). This model is based on concentration reserves and rate of de-accumulation. CML method's approach is suitable for depletion but not qualified for competitive use, i.e. use of resource that restricts the potential for others to use the same resource (Heijungs, 2002).

2.2.1.2. EI 99 HA Method- Resources- Minerals

In EI 99 method, the damages to resources are defined as MJ surplus energy. The surplus energy is stated as the difference between the energy needed to extract a resource now and at some point in the future. The point in the future has been chosen as the time at which 5 times the cumulative extraction of the resource before 1990 is occurred. Thus, factor of 5 is chosen arbitrary; however after normalization step this value has no further importance. For EI 99 method's approach the damage factors are expressed per kg of extracted metal or ore "in ore" refers to the metal content in the ore, i.e., 1kg iron (in ore) means one kg of pure iron (Goedkoop and Spriensma, 2000).

The relation between energy use and the lowering of ore grades for the most common minerals are affected by three factors:

- Energy is needed to change the chemical bonds. It is not possible to reduce this energy requirement by efficiency improvements or technological developments.
- The energy requirements needed to extract, grind and purify an ore goes up as the grade goes down.
- The energy requirements needed to extract, grind and purify an ore goes down with efficiency increases and technological developments Chapman and Roberts, 1983).

Chapman indicated that until now the 3rd mechanism is stronger than the second, which means that even though the grade of all ores decreases in time, the energy requirements also decrease. Chapman proposed that this trend will likely proceed many decades from now. However, it should be noted that, not taking possible remediation technologies into account is also common practice in LCA, thus future efficiency increases in mineral extractions are not considered (Chapman, 1983).

2.2.2. Acidification

Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials. Acid rain is only one famous form in which acid deposition is seen. Fog, snow and dew also capture and accumulate atmospheric

pollutants. Moreover, acidic particles and aerosols are converted to acids when they contacted surface water or moisted tissues (e.g. lungs). The major acidifying pollutants are SO_2, NO_x, HCl and NH_3. Acidifying pollutants form acidifying H^+ ions and this is used for determination of acidification in LCA. Therefore Acidification Potential impact category is defined as the number of H^+ ions produced per kg substance relative to SO_2 which reflects the maximum acidification a substance can cause. On the other hand, acidification potential changes depending on the accumulation area. Therefore, various approaches have been suggested for LCA (Baumann and Tillman, 2004).

2.2.2.1. EDIP 2003 Method- Acidification Potential

In EDIP 2003, the RAINS 7.2 model is used to establish acidification factors. Regional Air Pollution Information and Simulation (RAINS) model was developed by the International Institute for Applied System Analysis (IIASA) in Laxenburg, Austria. RAINS is an integrated assessment model which incorporates information on regional emission levels with information on long-range atmospheric transport. For acidification, eutrophication, and tropospheric ozone creation RAINS model is used in order to estimate patterns of deposition and concentration for comparison with critical loads and thresholds. The RAINS method was developed to support treaty decisions on acid precipitation in Europe. The 7.2 version of the RAINS model divides Europe into "grids" which consists of 612 elements covering all 44 European regions, including the European part of the former Soviet Union. RAINS evaluates the dispersion and accumulation of nitrogen and sulfur compounds on these grid elements. Total accumulation for one grid element is calculated by summing up the contributions from every region and the background contribution for that grid element. In RAINS, estimating dispersion and accumulation are based on a model developed by EMEP (cooperative Program for Monitoring and Evaluation of the long range transmission of air pollutants in Europe). The EMEP model is a trajectory model. The RAINS model compares the aggregated accumulation with the cumulative distribution curve of unprotected ecosystems in a grid element in order to determine the area of protected and unprotected ecosystem. The RAINS model generally focuses on the principal contributors to acidification emissions of sulfur dioxide, nitrogen oxide, and ammonia (Potting et al., 1998; Hauschild and Potting, 2005). In EDIP 2003 methodology, the unit of acidification potential expressed as the area of unprotected system (m^2 UES).

2.2.2.2. CML 2001 Nov '09 Method- Acidification Potential

In CML 2001 Nov '09 Method Acidification Potential for emissions to air is calculated with the adapted RAINS 10 model which describes the fate and deposition of acidifying substances. Acidification Potential is expressed as kg SO_2 equivalents/ kg emission. The time span is eternity and the geographical scale varies between local scale and continental scale (Wayman, 2009).

2.2.2.3. EI 99 HA Method- Acidification / Nutrification

In EI 99 method, Acidification / Nutrification is based on the computer model "Natuur Planner" (Nature Planner). The model is developed by RIVM (Netherlands Institute of Public Health and Environment) and used for both the fate modeling and the damage modeling for NO_x, SO_x and NH_3 depositions. The Natuur Planner utilizes a 250 by 250 meter grid for the Netherlands. The model, itself involves several databases with information on vegetation, soil conditions and fate models, which are combined directly with effect models. As EI methods are made for the damage calculations on human, plants or abiotic nature, Natuur Planner works different from RAINS. Natuur Planner examines observed effects of acidification and eutrophication on "plants". From these observations the probability that a plant species still occurs in an area can be determined, which is called the Probability of Occurrence or POO. For the calculations POO is translated into Potentially Disappeared Fraction (PDF), (PDF=1-POO). RIVM uses target species approach that should occur on a specific type of ecosystem if there would have been no man-made changes in the nutrient level or the acidity. The "Natuurplanner" uses a very detailed grid system with an exact description of the type of ecosystem and the associated set of target species (Goedkoop and Spriensma, 2000). The working principle behind model is computing the increment or decrement of target species if an additional accumulation is added to the background. The Natuur Planner incorporates two parts: a soil model (SMART) and a vegetation response model (MOVE). While SMART is a fate model and computes the pH and the nutrient level, expressed as Nitrogen availability, and the availability of water, MOVE is a damage model and it calculates the effects of the SMART results on the PDF for each grid-cell. Therefore the results from SMART form the input for the vegetation model MOVE. This model involves the response functions of more than 900 Dutch plant species. The response

functions identify the relationship between the PDF and the soil acidity and between nutrient condition and the moisture condition and their mutual interactions. Natuurplanner also covers a combined effect assessment of eutrophication, acidification, desiccation, fragmentation, climate change and pollution by toxic substances on ecosystems and species (multi-stress). The disadvantage of this model is, it is not possible to understand whether a damage is caused by changes in the nutrient level or the acidity, as a result the impact categories have been combined. Another problem of the model is that, it is still only available for the Netherlands. Netherlands is chosen as representative for Europe and a crude assumption is made. In addition to these, the model can only calculate the damages that occur through airborne depositions. Also aquatic ecosystems are not covered by the nature planner. Thus, it does not involve the effect of phosphate and other eutrophying emissions to water. The unit of the model is PDF (Goedkoop and Spriensma, 2000).

2.2.3. Eutrophication

Eutrophication involves deposition of high environmental levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may lead to unwanted shift in species composition and high biomass production in both aquatic and terrestrial ecosystems. Furthermore, elevated nutrient concentrations can find their ways into surface waters and is unacceptable in potable water (Guinée et al., 2002). In LCA, the eutrophication category, can sometimes be called nutrification, which also includes degradable organic pollution and sometimes waste heat since they all affect biological productivity. These pollutants all lead to oxygen consumption. Micro-organisms break down the degradable organic pollutant discharges into water and utilize oxygen. Nutrient flows and waste heat causes increased biological productivity and biomass formation that also causes high oxygen consumption when biomass is being degraded. There is not a method or model for involving impacts or waste heat to those of N and P substances and organic pollution. As it is stated, eutrophication can affect terrestrial ecosystems. The amount of nitrogen is the limiting nutrient for plant growth. The growths are stimulated with increase of nitrogen which leads to changes in function and species composition of nutrient-poor ecosystems in heathlands, dune vegetation, commons and raised bogs. While phosphorus is the limiting nutrient for freshwater ecosystems, for marine ecosystems nitrogen is the limiting nutrient (Baumann and Tillman; 2004; Guinée et al., 2002).

2.2.3.1. EDIP 2003 Method- Aquatic Eutrophication

In EDIP 2003 method, "CARMEN" (acronym for *CA*use effect *R*elation *M*odel to support *E*nvironmental *N*egotiations) model is used. The model establishes exposure factors for aquatic eutrophication to handle problems relating to the fate of nutrients. CARMEN model inputs are atmospheric deposition of nitrogen on soil and coastal seas, phosphorus and nitrogen supply to agricultural soils, and phosphorus and nitrogen discharged with municipal wastewater. The model does not contain an assessment of ecological effects. CARMEN models these inputs with a high regional resolution based on 124320 grid-elements of 100-250 km^2 areas. In CARMEN, Europe includes 32 countries where emission takes place. The area is subdivided into 101 river catchments. The nitrogen and phosphorus sources have been allocated to each grid-element on the basis of the distribution of land uses in the grid. The transport of nutrient by rivers to sea is modeled crudely using the assumption of fixed removal rates of N and P in freshwater systems. Nutrient transportation from soil to surface waters is carried out by water flow. Modeled routes are deep groundwater drainage (nitrogen), runoff (nitrogen) or topsoil erosion (phosphorus) followed by river transport to coastal waters. EDIP 2003 approach for CARMEN can be regarded as a realistic worst case because the fraction of nutrients that is not available for surface waters is excluded from the characterization (Hauschild and Potting, 2005). Furthermore, EDIP 2003 method do not assign BOD (or COD) or waste heat to the impacts for eutrophication (Guinée, 2002). In EDIP 2003 method, eutrophication potential is expressed in N- or P-equivalents however, GaBi 4 version uses kg NO_3 equivalents as unit.

2.2.3.2. CML 2001 Nov. '09 Method- Eutrophication Potential

No fate model is adapted in CML 2001 method. Characterization factors for aquatic eutrophication have been proposed by Heijungs et al. (1992) and this characterization approach is based on the stoichiometry given by the Redfield ratio between N and P (Guinée et al., 2002; Readman et al., 2008) According to Redfield et al. (1992), emissions of N or P can be converted into biomass on the basis of the molecular composition of algae (to the typical composition of aquatic phytoplankton: $C_{106}H_{263}O_{110}N_{16}P$) (1963). Excessive growth of phytoplanktons cause aquatic ecosystems to go out of balance and starts a chain of ecological effects. This concept provides summing up and having universal characterization

factors regardless of local environmental conditions (Goedkoop et al., 2009). In Heijungs' approach substances are assessed by their potential to produce organic matter relative to phosphate (Redfield et al., 1992).

Heijungs established these factors without further differentiation between the initial emission compartments and regions involved. Heijungs ignores that only a fraction of the eutrophying emissions will be transported to the aquatic environment; therefore, this approach can be regarded as the worst case. Eutrophication Potential is expressed as kg PO_4 equivalents/ kg emission. Fate and exposure are not included and time span is eternal (Readman et al., 2008). This approach has serious problems due to the ignorance of some factors, such as:

- The hydrogeological conditions in the region which determine the transport of nutrients from surface runoff/erosion (nitrogen and phosphorus), and groundwater drainage (nitrogen) to surface water.
- Phosphorus removal is not possible (at most temporarily stored in bottom sediment), but nitrogen may leave the aquatic system through denitrification and therefore the amount of nitrogen available for biomass growth over time is smaller than the amount entering the aquatic system.
- Remaining nutrients in the aquatic system will reach marine systems (Hauschild and Potting, 2005).

2.2.3.3. EI 99 HA Method- Acidification / Nutrification

In EI 99, there is no separate model for eutrophication potentials and a combined approach has been proposed. For eutrophication category, nutrification fate model is defined by "Natuur Planner" model as well. In LCA, the eutrophication category, can sometimes be called nutrification, which also includes degradable organic pollution and sometimes waste heat since they all affect biological productivity (Baumann and Tillman, 2004). The outputs of "Natuur Planner" define the acidity, nutrient condition and the moisture condition and their interactions at the same time (Goedkoop and Spriensma, 2000).

2.2.4. Global Warming

Global warming is the impact of human emissions on the radiative forcing of the atmosphere, adverse impacts may harm ecosystem health, human health and material atmosphere. Emissions to air increases radiative forcing which leads to temperature increases at the earth surface. This phenomenon also referred as "greenhouse effect". During the 20th century, the average global temperature increased by about 0.6 °C due to this increased greenhouse effect. The consequences may change climate patterns, cause a shift of vegetation zones and of the precipitation distribution, and the rise of the sea level due to the melting ice caps (Guinée et al., 2002).

Carbon dioxide is not the only gas that causes global warming. Methane, chlorofluorocarbons (CFCs), nitrous oxide and other trace gases also absorb infrared radiation and they absorb much more effectively. In order to compare the impacts of different greenhouse gases, potential contribution of a substance to climate change is expressed as its global warming potential (GWP). GWP of a substance is defined as the ratio between the increased infrared absorption due to the instantaneous emission of 1 kg of the substance and that increased infrared absorption of CO_2 due to an equal emission of a CO_2 (Baumann and Tillman, 2004).

2.2.4.1. EDIP 2003 Method- Global Warming

In EDIP 2003, IPCC (Intergovernmental Panel on Climate Change) model has been adapted to compute global warming factors. The United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) have arranged an international panel of meteorological researchers and atmospheric chemists which discussed the latest developments about greenhouse effect topic. This network forms the IPCC (Intergovernmental Panel on Climate Change) and issues regular status reports every fifth year. Special and additional reports are issued about every second year, updating data from the latest status report (Guinée et al., 2002).

According to IPCC, for a substance to be regarded as greenhouse gas, it must be a gas at normal temperatures in the atmosphere and;

- be able to absorb heat radiation and be stable in the IPCC model, or
- be of fossil origin and converted to CO_2 on breakdown in the atmosphere (Guinée et al., 2002).

In order to compare the effects of different greenhouse gases the IPCC uses the concept of global warming potentials (GWPs). This concept turns the effects of different gases into terms of carbon dioxide equivalent. The endpoint is chosen at the level of increase in the atmosphere's radiative forcing. The following procedure is recommended by IPCC for computing GWP of substances which contribute to an increase in global warming. This expected contribution is calculated on the basis of knowledge of its;

- specific IR absorption capacity (assuming that substance's concentration in the atmosphere does not rise further),
- expected lifetime in the atmosphere (Guinée et al., 2002).

EDIP method uses the 1994 GWP values from the IPCC. The adaptation of EDIP methodologies excludes indirect contributions (both positive and negative) to the greenhouse effect except for methane, i.e., contributions attributable to a gas affecting the atmospheric lives of other greenhouse gases already present. Moreover, EDIP method goes further than the IPCC's recommendation by including that contribution of organic compounds and carbon monoxide from petrochemical origin, which follows their degradation sooner or later to CO_2 in the atmosphere (Hauschild and Wenzel, 1997; Hauschild and Potting, 2005). IPCC has compiled a list of provisional best estimates for GWP with time horizons of 20, 100 and 500 years, based on the expert judgment of scientists worldwide (Guinée et al., 2002).

A substance's global warming effect is influenced by the length of time interval (T) during its lifetime in the atmosphere. How the GWP weights the relative effects of the various greenhouse gases is significant. If T is high, the entire quantity of substance emitted can be expected on the basis of average life time, to be broken down or converted within the time interval. The magnitude of the GWP will reflect the substance total cumulative contribution to warming. If T is shorter than the substance's average life, life time will be only partially covered and magnitude of the GWP will reflect the contribution accordingly. Therefore, a small T value (10-50 years) will weigh the short-lived gases relatively heavier.

Similarly, a large T value (200-1000 years) will weigh the long-lived greenhouse gases heavier. The choice of T is very important for those substances whose atmospheric lifetimes deviate significantly from CO_2 (Hauschild and Wenzel, 1997). For global warming a time horizon of 100 years is recommended by EDIP 2003, because certain substances gradually decompose and will become inactive in the long run (Goedkoop et al., 2008).

2.2.4.2. CML 2001 Nov. '09 Method- Global Warming Potential

In CML 2001 Nov. '09 Method Global Warming Potential is calculated with the adapted IPCC model. As in EDIP 2003 method, factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission. Geographic scope of this indicator is at global scale (Wayman et al., 2009).

2.2.4.3. EI 99 HA Method- Climate Change

In EI 99, model for global warming category is expressed as climate change and IPCC guidelines are adapted for this method as well as in EDIP 2003 and CML 2001 methods. There are some particular points that must be taken into account in modeling of health effects:

- At present climate change does not create much direct damage, but predictions according to the current emissions explain that considerable damages in the coming decades and thereafter would occur. This means that scenarios and models that could not be validated by experimental data will be conferred.
- The vulnerability of systems at risk is dependent on the development of the economy and society, as some effects can in principle be prevented, if proper actions are taken.
- Temperature change has many important positive health effects, as well as negative effects.
- The greenhouse emissions in Europe will cause damage all over the world (Goedkoop and Spriensma, 2000; Frischknecht et al., 2007).

Due to these reasons there are disagreements about consequences of the greenhouse effect. Damage to Human Health can occur via several impact pathways to multiple

endpoints. EI 99 used the FUND (The Climate Framework for Uncertainty, Negotiation and Distribution) model in order to convert IPCC model into damage oriented style. The procedure can be summarized as follows:

1. The model used IPCC I992 scenario, and calculated damages for each year between 2000 and 2200.
2. Model repeated this process three times and added a flow of 1Mt per year of CO_2, CH_4 and N_2O respectively.
3. The differences between these runs were interpreted as the marginal damage.

The results include change in deaths due to malaria, schistosomiasis, dengue fever, cardiovascular and respiratory disorders, all average temperature dependent modifications. Next to this, the number of people which have to be displaced due to sea level rise were calculated. All these parameters are calculated for nine world regions. In this model, unlike the other impact categories it is assumed that, the greenhouse gases emitted in Europe contribute to damages all over the world. The model also assumes that people with an income higher than $ 3100 can afford prevention and do not get malaria, dengue and schistosomiasis (Goedkoop and Spriensma, 2000; Frischknecht et al., 2007).

A time scale of 200 years is adapted in damage calculations. Moreover, the lifetime of the gases is not only responsible for the magnitude of the radiative forcing, but also causes health damages. Substances with a short lifetime appear to have greater benefits than substances with a longer lifetime. Normally the equivalency factors can lead to misleading results, therefore all gases need to be treated separately through the FUND model (Goedkoop and Spriensma, 2000; Frischknecht et al., 2007).

Because damage is not linear dependent on the atmospheric lifetime, The IPCC equivalence factors have been modified for modeling and a separate damage calculation is made for CO_2, CH_4 and N_2O. For other gases, it is assumed that:

- Gasses with an atmospheric lifetime below 20 years are assumed to behave like methane,
- Gasses with an atmospheric lifetime between 20 and 100 years behave like CO_2,

- Gasses with an atmospheric lifetime oh more than 100 years are assumed to behave like N_2O.

This also means that the IPCC factors are split into three groups. The damage factors are expressed per kg substance and the unit of damage is DALYs (disability adjusted life years).The endpoint damage factor for human damage due to climate change links the marginal changes in temperature to marginal changes in DALY (Goedkoop and Spriensma, 2000; Frischknecht et al., 2007).

2.2.5. Ozone Depletion

Ozone (O_3) becomes a harmful pollutant in the lower part of the atmosphere (troposphere) which damages plants, human health and built environment. However, it is an essential substance in the upper part of the atmosphere (stratosphere), where it filters more than 99 % of the dangerous ultraviolet radiation from the sun. Ozone, normally, appears in trace amounts throughout the atmosphere with a peak concentration between about 20 and 25 km altitude (lower stratosphere) as shown in Figure 2.6.

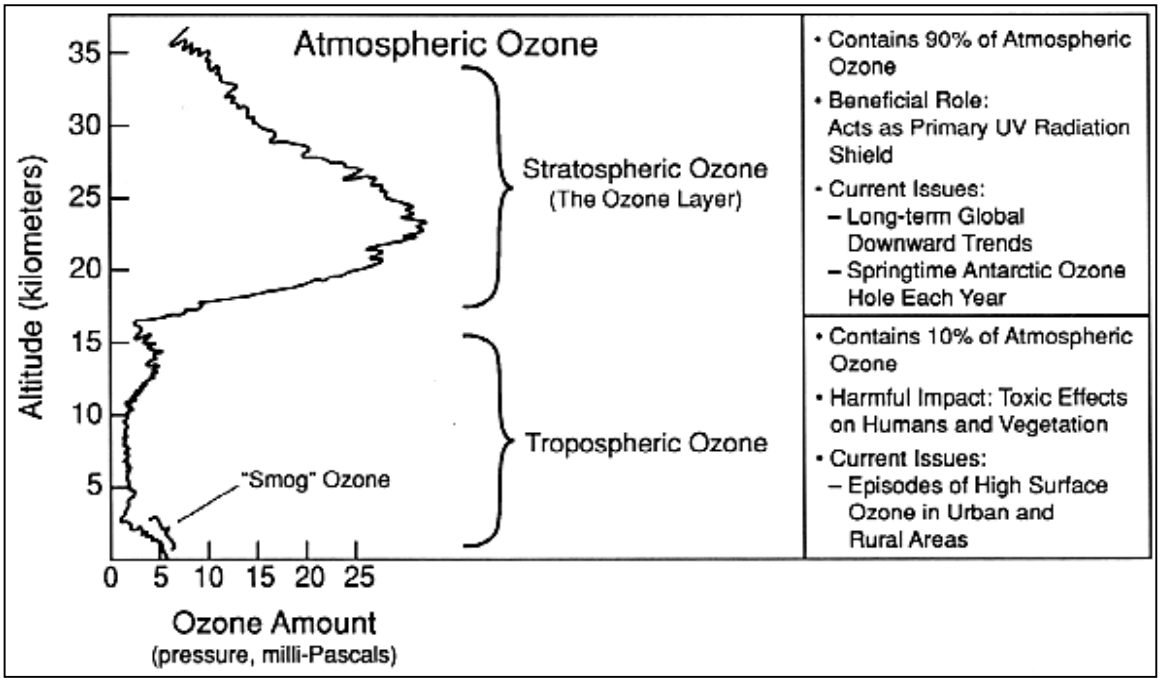

Figure 2.6. Graphic of ozone concentrations in the atmosphere (U.S. Department of Commerce, 1998).

The ozone layer is sustained through a complex series of chemical reactions. Ozone is produced by the absorption of ultraviolet (UV) radiation by oxygen molecules; it is destroyed by UV radiation, visible light and certain substances acting as catalysts, e.g. H, OH, NO, Cl and Br. The rate of destruction is enhanced with the increased concentrations of these substances while they remain in the stratosphere. On the other hand, with elevated CO_2 concentrations that cause lower stratospheric temperatures, ozone destruction reactions are slowed down. Ozone depletion refers to the thinning of the stratospheric ozone layer as a result of various chlorinated and bromated substances, such as Chlorofluorocarbon gases (CFCs) and halons (Baumann and Tillman, 2004).

The ozone content of the stratosphere is falling, and since 1985 this drastic thinning of the ozone layer has been, referred to as the "ozone hole", over the South Pole. In the last few years, the breakdown of ozone has also accelerated over the northern hemisphere. As a result of this, the intensity of harmful ultraviolet radiation at the earth's surface has increased over parts of the southern and northern hemispheres (Hauschild and Potting, 2005).

2.2.5.1. EDIP 2003 Method- Stratospheric Ozone Depletion

In EDIP 2003, World Meteorological Organization (WMO) approach has been adapted to compute stratospheric ozone depletion factors. WMO developed the ozone depletion potentials (ODPs) to be used in LCA and updates its list of ODPs periodically. The standard ODP represents the alteration in the stratospheric ozone layer in the steady state approach due to emission of CFC-11 (R 11) (Baumann and Tillman, 2004). A substance is regarded as ozone depleting, when it;

- is a gas at normal atmospheric temperatures,
- contains chlorine or bromine,
- is stable with a life in the atmosphere of a few years to centuries, so that it can be transported up into the stratosphere (Hauschild and Potting, 2005).

Since reaching steady state status may take hundreds of years, ODPs for shorter time spans can be chosen (Baumann and Tillman, 2004).Normally the factors provided by WMO describe the impact of an emission integrated over an infinitive time span and a typical LCIA

uses these factors. However, WMO advice to use factors integrated over a shorter time-span (Potting et al., 2001). ODP values from the WHO are calculated on the basis of two dimensional models. This model enables prediction of variation of ozone concentrations with both altitudes over the surface of the earth and with latitude over the earth (with zonal averages); on the other hand three dimensional models can also estimate concentrations at a chosen height (Hauschild and Wenzel, 1997).

In EDIP 2003 adaptation, the unit is taken as kg R11 equivalents (also known CFC 11 equivalents). EDIP 2003 method opts to use the steady state ODPs. The endpoint is chosen early in the environmental mechanism at the disturbance point of the ozone content of the stratosphere, and thus characterization factors are taken from recommendations of the latest version of the WMO status report (Guinée et al., 2002).

2.2.5.2. CML 2001 Nov. '09 Method- Ozone Layer Depletion

The characterization model of CML 2001 is based on the WMO's ODPs as well and defines ozone depletion potential of different gasses. The unit used is kg R11 equivalent/ kg emission. The geographic scope of this indicator is at global scale. The time span is infinite (Wayman et al., 2009).

2.2.5.3. EI 99 HA Method- Ozone Layer Depletion

While The ODPs are relative values, found by dividing the ozone destroying ability of specific gas by that of CFC-11, they can also be a characterization factor that specifies the midpoint level assessment (i.e. EDIP 2003 and CML 2001). In EI, ODP factors have been used for calculating the damage factors. However, the ODP does not have any information on the actual impacts on receptors due to ozone depletion and as an indicator only ODP is not a sufficient in a damage-oriented approach.

According to Goedkoop and Spriensma (2000), chlorine containing gases are diluted in the troposheric part of the atmosphere. In an average of 4 years they drift into the stratosphere where they cause ozone layer depletion by contributing to chemical processes. Therefore, the atmospheric residence time (about 1 to 1000 years) is an important factor for

ozone depletion. Substances that have a lower residence time than 4 years do not reach the stratosphere in significant amounts. Thus, the damage caused by a substance is depending on the time span. If the time span is only 100 years, part of the damage caused by substances with a residence time of more than 100 year will be neglected.

In fate analysis quantitative risk estimates are available for some of the UV-B-associated effects, e.g., cataract and skin cancer. The risk estimates has been determined in terms of the biological amplification factor (BAF). BAF is defined as the percentage increase in incidence that would result from a 1% increase in ambient UV radiation. For computing overall increase in incidence per percent ozone depletion, the radiation amplification factor (RAF) is defined. RAF is the percentage increase in effective UV per percent decrease in ozone. The overall percentage increased incidence per percentage ozone depletion is then represented by the amplification factor, which is AF = RAF x BAF. AF is used for damage analysis. Based on the AF and the world-wide skin cancer and cataract incidences in 1990, the excess incidence as a result of 1% ozone depletion during 1 year is calculated (Goedkoop and Spriensma, 2000).

Mortality is computed using fatal fraction base of the disease and the incidence. Incidences and mortality are converted to DALYs using the approach of Hofstetter's study and data from Murray's study for age, average duration of the disease and disability weighting. Three-quarters of all DALYs per percentage of ozone layer decrease are caused by cataracts. Most DALYs are caused by early death (years of life lost) due to increased mortality (Hofstetter, 1998; Murray and Lopez, 1996).

2.2.6. Photo-Oxidant Formation

Photo-oxidants are formed in the lower parts of the atmosphere through photochemical oxidation of NO_X, hydrocarbons (such as VOC) and CO in the presence of sunlight. They are reactive chemical compounds and very harmful to human health, ecosystems and crops. Ozone is considered the most significant of this category along with peroxyacetylnitrate. photooxidant formation is known as summer smog and characterized by high levels of inorganic compounds, mainly particles, carbon monoxide and sulphur compounds which

causes bronchial irritation, coughing, etc. (Guinee et al., 2002). Photochemical ozone formation follows these four steps below;

1. Reaction between VOCs or CO and OH to form peroxy radicals,
2. The peroxy radicals oxidize NO to NO_2,
3. NO_2 is split by sunlight with formation of NO and release of oxygen atoms,
4. Oxygen atoms react with molecular oxygen, O_2, to form ozone.

The substances formed in this process are strong oxidants and can react with every oxidizable molecule available. Therefore if these molecules are living cells, their functioning is disrupted and cells may be killed, especially human and plant tissues may be damaged (Hauschild and Wenzel, 1997).

Today, three methods are available for comparing the ozone creation potential of VOC, which are based on; POCPs, fate factors, and incremental reactivity (IR). The methods mostly focus on regional impacts. All methods compute the estimated quantity of ozone by a given substance (Guinee et al., 2002; Baumann and Tillman, 2004).

Different hydrocarbons react at different rates. In POCPs, the ozone formation caused by a substance is defined relative to that of a standard substance. On the other hand, IRs express the change in the quantity of ozone produced by a particular substance when this substance added to the system (base case pollution scenario). Also there are several types of IRs, e.g. maximum incremental reactivity or maximum ozone reactivity. Since POCPs and IRs are given for specific hydrocarbons, this raises problems in practicality for LCAs due to the presentation of hydrocarbon emissions as group parameters e.g. VOCs (volatile organic compounds) or HCs (hydrocarbons). LCA methods for this category either use average POCP or IR values for specific groups of substances (e.g. aromatics, non-methane hydrocarbons, etc.) or define which significant substance make up the “VOC mixture” during the inventory phase (Baumann and Tillman, 2004). On the other hand, in fate factor case, factors are based on DALYs for respiratory diseases due to air pollution (Guinee et al., 2002).

2.2.6.1. EDIP 2003 Method- Photochemical Ozone Formation

In EDIP 2003 method, characterization factors for photochemical ozone formation have been developed using the RAINS model which was also used for development of characterization factors for acidification and terrestrial eutrophication. Since RAINS is basically intended to support the development of cost-effective European abatement strategies for different types of air pollution, this approach has recently been broaden to include the precursors of photochemical ozone formation. According to EDIP 2003, main substances that contribute to photochemical ozone formation are: VOC, NO_X (the sum of NO and NO_2), CO and CH_4. (Hauschild and Potting, 2005).

EDIP methodology is based on the emission patterns of the European countries thus factors may change in time. Normally the numbers based on the 1995 emissions are chosen as the default EDIP2003 characterization factors however, for temporal variation, they are also calculated for the registered or projected emissions of two more reference years which are 1990 and 2010. Meteorological conditions also affect the ozone formation and may cause variations. In order to minimize the effects of fluctuations in meteorological conditions, characterization factors for each emission years 1990, 1995 and 2010 are used. The factors are derived as the average of five different calculations using the meteorological data for the years 1989, 1990, 1992, 1993 and 1994 respectively (Hauschild and Potting, 2005).

In this category, protection areas for EDIP 2003 are human and ecosystem health. Since observations showed human beings and vegetation are distinct in their sensitivity and thresholds to ozone exposure, the exposure of humans and vegetation is modeled separately and divided into two categories. According to Hauschild and Potting (2005) geographical distribution of man-made materials will follow the distribution pattern of humans. Damage to materials caused by ozone is not modeled separately and is regarded to be reflected like exposure on humans.

Human exposure: The impact potential for is expressed as the product of the number of persons exposed above the threshold of chronic effects, 60 ppb (pers), the annual duration of the exposure above the threshold (hours), and the exceeding of the threshold concentration

(ppb). The unit of the impact potential for human exposure is pers*ppm*hours. However, Gabi 4 version of the method uses the unit of pers*ppm.

Vegetation exposure: The impact potential for vegetation exposure is expressed as the product of the area of vegetation exposed above the threshold of chronic effects, 40 ppb (m^2), the annual duration of the exposure above the threshold (hours), and the exceeding of the threshold concentration (ppb). The unit of the impact potential for vegetation is m^2*ppm/hours (Hauschild and Potting, 2005). Gabi 4 version of the method uses the unit of m^2 UES.

2.2.6.2. CML 2001 Nov. '09 Method- Photochemical Ozone Creation Potential

The characterization model of CML 2001 is based on POCPs as well; however a different model has been used for the same approach. POCPs are calculated for the CML impact assessment method by a UN Economic Commission for Europe (UNECE) working group trajectory model. POCP of a VOC indicates the ratio between the change in ozone concentration due to a change in the emission of that VOC and the change in the ozone concentration due to a change in the emission of ethylene. POCPs are expressed in kg ethylene equivalents/kg emission. The time span of the model is 5 days and the geographical scale varies between local and continental scale (Guinée et al., 2002). Values have been published for a wide range of volatile organic substances. The value for ethylene has been set at 1. The values for most other substances are less than 1.

2.2.7. Ecotoxicity

In LCA Toxicity is a complicated impact category with various characterization methods since internationally many types of impacts and research and methodology development is in progress. Toxicity category is often divided into human toxicity and ecotoxicity. Important factors in characterization are fate, exposure or intake and effect. The main differences between methods are based on the definitions of effects and the extent of fate (Baumann and Tillman, 2004).

2.2.7.1. CML 2001 Nov. '09 Method- Freshwater Aquatic Ecotoxicity Potential, Marine Aquatic Ecotoxicity Potential and Terrestrial Ecotoxicity Potential

MAETP, FAETP and TETP Ecotoxicity categories deal with the harmful effects of toxic substances on marine and freshwater environments and terrestrial ecosystems. Therefore the indicators are created for emissions to air, water and soil.

The characterization factors used in the CML were calculated using the Uniform System for the Evaluation of Substance (USES-LCA). The model is based on the "(E)USES" model family which is used for risk assessment in the European Union. It is also one of the base models used for the development of LCIA toxicity consensus model, "USEtox". USES-LCA describes fate, exposure and effects of toxic substances. The time horizon defined for the model is infinite. For all factors, toxicity levels of substances are expressed as kg 1,4- dichlorobenzene equivalents /kg emission. USES-LCA model has recently been updated to USES-LCA 2.0 and contains a database of 3,396 chemicals (Huijbregts et al., 2009).

2.2.7.2. EI 99 HA Method- Ecotoxicity

For Ecotoxicity, EI 99 uses a model developed by Netherlands Institute of Public Health and Environment (RIVM) for the Dutch Environmental Outlook. This model calculates the Potentially Affected Fraction (PAF) of species in relation to the concentration of toxic substances. PAF shows the percentage of species that is exposed to a concentration above the No Observed Effect Concentration (NOEC). PAFs are computed based on toxicity data for terrestrial and aquatic organisms like micro-organisms, plants, worms, algae, amphibians, molluscs, crustaceans and fish. In this approach, it is stated that the higher the concentration, the larger the number of species is affected. As this is not an observable damage, a rather crude conversion factor is used to translate toxic stress into real observable damage by converting PAF into PDF. The unit of damage is PDF*m^2*yr (Goedkoop and Spriensma, 2000).

2.3. Plastics Industry

Plastics have been developed and used extensively after their invention in the later nineteenth century. Today, the plastic products have totally become an essential part of daily life. The increasing demand on plastics industry caused increases in production capacities. Every day an immense amount of plastic products are produced and consumed all over the world. According to the 9th Development Plan of State Planning Organization in 2005, the global plastics production numbers has reached 235 million tons (State Planning Organization, 2008). The increase between 1949 and 2005 in plastics production is shown in Figure 2.7.

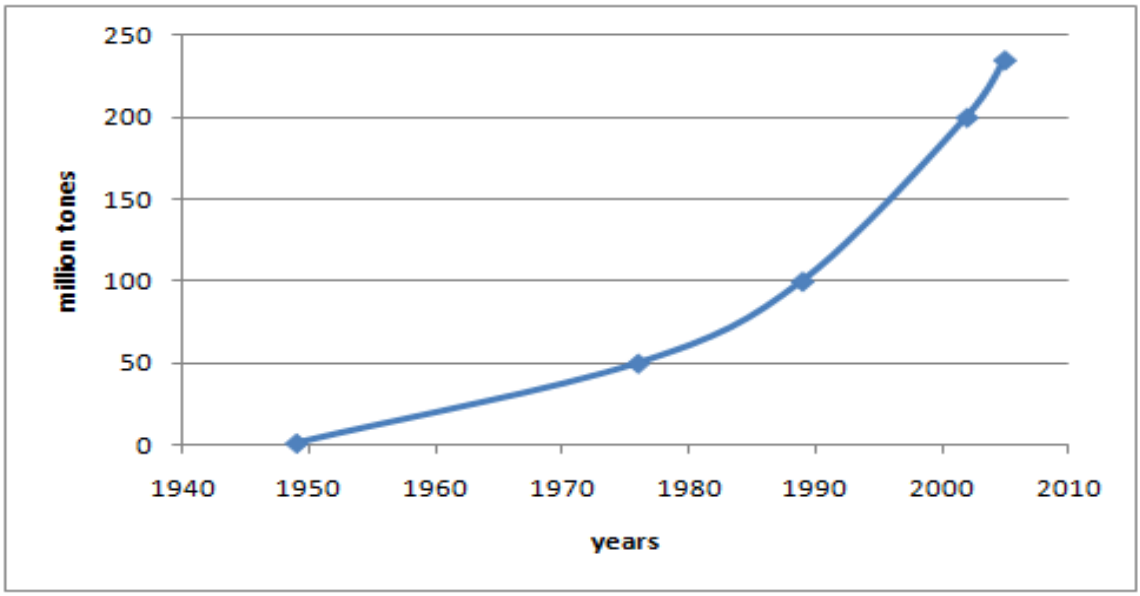

Figure 2.7. Global production of plastics between 1949 – 2005 (State Planning Organization, 2008).

Turkish Plastic Industry sector's share in the world of plastic market is at the level of 1.6 %. In 1999, production of 1.5 million tons of plastic products were produced and this production capacity increased by 150 %. According to the data of year 2004, Turkey has 3.7 million tons of plastic processing capacity which dominates the 6th place in the European countries ranks after Spain (State Planning Organization, 2008). In Figure 2.8, the increase in plastics production capacity of Turkey between years 1999-2005 is given.

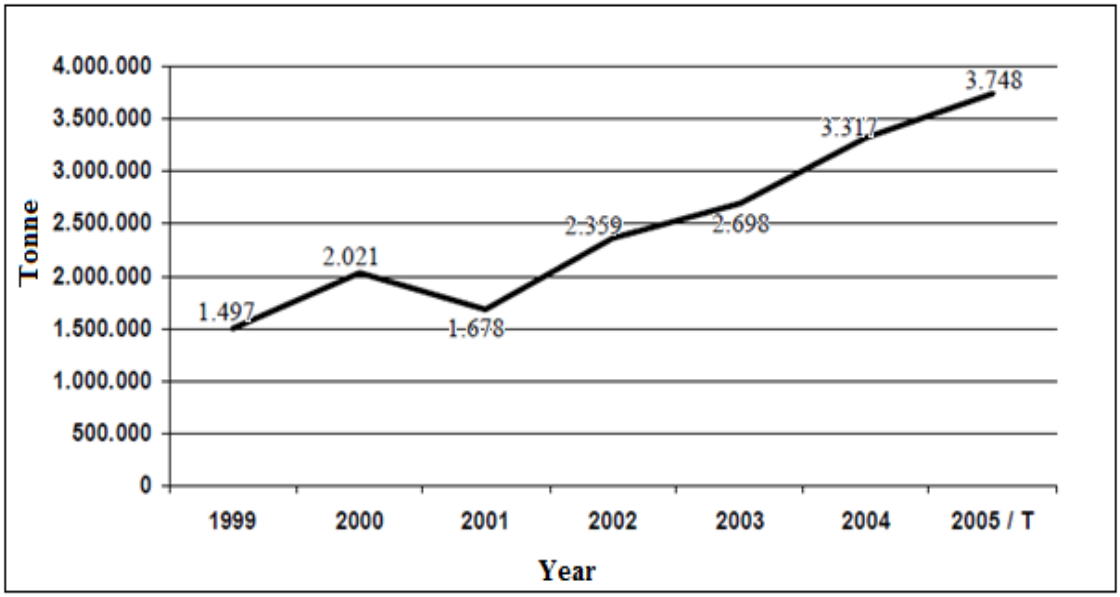

Figure 2.8. Increase in Production Capacity of Turkey between years 1999-2005 (State Planning Organization, 2008).

As it can also be seen in Table 2.1., plastics are predominantly used in packaging sector in Turkey.

Table 2.1. Percentage distribution of sectors (State Planning Organization, 2008).

Sector	**Distribution (%)**
Packaging	36
Construction materials	23
Electricity	10
Agriculture	6
Automotive	4
Clothing and chaussure	4
Others	17
Total	100

The plastics are divided in two main classes, thermoplastics (80 % of majority) and thermosets. Thermoplastics become viscous when they are heated to temperatures of few hundred degrees allowing shaping into products. This heating and cooling process can be repeated many times without significant degradation of the polymer. Therefore they are easily recycled into other products. (Andrady, 2003; Groover, 2010). Generally used thermoplastics are polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC) and

polystyrene (PS). These four types constitute more than 90 % of total consumption of thermoplastics (Lundquist et al., 2000). As of 2005, the shares of the plastic types in Turkey's plastics raw material capacity are given in Table 2.2.

Table 2.2. The shares of the plastic types in 2000 and 2005 in Turkey (State Planning Organization, 2008).

Plastic Type	**Percentages**	
	2000	**2005**
LDPE	30	37
PVC	28	18
PP	11	17
HDPE	9	11
Engineering plastics	9	9
PS	13	8
Total	100	100

Because plastics are easily processed, inexpensive (low-cost manufacturing techniques), lightweight and durable; they can replace use of metals in many applications. Plastic waste is one of the most visible components in municipal solid wastes due to use in packaging, construction and consumer products (Hoon, 2006). Moreover, many of these materials can be reused and are environment- friendly. However, due to the durability of plastics, these materials can cause problems at the end of products' lives. The life cycle of plastic products includes production, transportation, use and disposal which have contributed to the release of waste emissions.

2.3.1. Recovery and Disposal Techniques of the Plastics

Recovery can take the form of reuse, recycling or energy recovery, or a combination of these. Reuse should be considered the first option in managing plastic wastes. However, this strategy has limitations due to the introduction of impurities. Reusing plastic is preferable to recycling due to the following advantages;

- conservation of fossil fuels since plastic production uses 4–8 % of global oil production, i.e. 4 % as feedstock and 4 % during conversion,

- reduction of energy and municipal solid waste,
- reduction of carbon-dioxide, nitrogen-oxides and sulphur-dioxide emissions (Al-Salem et al., 2009).

Recycling is an important step in plastics life cycle, especially for plastic producers and processors. It is the second option in waste management hierarchy. Sorting is a fundamental part of polymer recycling due to many different types of plastics in use and compability problems with each other. Mixed plastics generally have lower value and produce low grade plastics with poor and variable properties (Scheirs, 1998).The most important benefit of plastic recycling is avoiding the reduction of oil refining, monomer manufacturing and polymerisation in its upstream processes (Rajendran et al., 2012).

Primary recycling (re-extrusion), is the processing of scrap, industrial or single-polymer plastic parts in the extrusion cycle. In a closed-loop recycling, products are recycled into products of the same type. Secondary recycling (mechanical recycling) is the process of converting used products into different products. Tertiary recycling (chemical recycling) involves chemical breakdown of materials with advanced technology processes. By converting plastic materials into smaller molecules, usually liquids or gases, they can be then reutilized further back in the feedstock chain for the production of new petrochemicals and plastics (Al-Salem et al., 2009).

Recycling of plastic into new high-quality plastic products requires clean recycled materials that consist of only one plastic type. If the recycled plastics are contaminated and/or are a mix of different plastic types, the quality of the produced plastic is lower and usually used for products such as fences; garden furniture and pallets that often could be made of other materials (Astrup et al., 2009). Moreover, detoration of materials occurs during recycling; the polymer chains are sheared and impact strength is reduced. Therefore, recycled product have to be used in less demanding applications than original product made of virgin material, else early break downs will be experienced. Mass loss during processing also limits recycling. With 90 % of efficiency, only three recycling process would reduce the material to 73 % of its initial quantity (Stevens, 2002). However, when recycling is compared to oil extraction and production of virgin resins, recycling requires less energy. In addition to this, using recycling instead of virgin material generates 30 % less CO_2 emissions

and littering problems arising from waste plastics would also decrease (European Commission, 2008).

Energy recovery takes place in waste incineration plants. Incineration (energy recycling) is defined as exploiting the calorific content of material, on the other hand, it destroys the polymer value and does not reduce the dependence on virgin raw plastics. Incineration is considered third option in the hierarchy of waste management. Latest life cycle assessment studies that compare recycling and incineration for different recyclable material fractions concluded that recycling in general is preferable to incineration. However, since plastics have high heat content, in plastic LCA studies incineration with energy reclamation results are more significant than other material fractions like glass, steel and aluminum and incineration is preferred. Depending on the country's view on size reduction, incineration options, management applications vary for municipal solid waste. While about 19 % is incinerated in Western Europe, 80 % is thermal processed in Denmark and 90 % in Japan, due to the land scarcity for landfills (Stevens, 2002; Merrild, 2012).

Landfills are the last option in the waste management hierarchy. They pose risks like leaching of toxins into water supplies and uncontrolled production of methane. Apart from other problems that have been discussed by authorities, plastics take up a lot of space even if there are compacted. In some European countries like Germany and Netherlands, landfilling of plastics is not allowed (Stevens, 2002).

2.3.2. Plastics in Container Packaging Applications

Packaging can be defined as the art, science and technology of ensuring the safe delivery of a product to the ultimate consumer in sound condition (Selin, 1977). Packaging is an important stage in transportation chain of goods and is closely related to the transport logistics, storage and packed goods themselves. Packaging is influenced by transport distance, transport duration, conservation techniques and handling conditions and affects economic and ecological efficiency of the distribution of goods (European Commission Environment Website, 2011).

Depending on the intended purpose, container packaging can be categorized as wholesale or bulk packaging, pre-packaging or retail packaging. In addition to this, a producer can choose either one-way or multi-way packaging practices. In one way packaging the product which packs the costumer's good cannot be refilled and reused, it may be deposited. In multi way packaging, the package is made as durable as possible to be reused several times (May, 2001). Since the viability of collecting and reprocessing of used products is a handicap, to compensate this additional cost, reusing package several times before the materials needed to be recycled is important (Ross and Evans, 2003).

An important branch of container packaging industry is food packaging applications, especially in fruit and vegetable production. For fruit and vegetable packaging generally sacks, bags, baskets and crates are utilized. A crate is a large shipping container, often made of plastics, wood or cardboard. Crates are used for the bulk packaging of fresh agricultural products. Many are designed to stack securely to be returned for reuse.

Cost analyses of different packaging containers for mango are shown that, the unit cost of packaging (packaging cost/kg) mangoes in plastic crates is lower than that of packaging them in either bamboo baskets or carton boxes. Although the cost of acquiring plastic crates is higher than acquiring baskets or carton boxes, plastic crates can be reused several times (Rapusas and Rolle, 2008). Also when wooden and cardboard crates are used contamination and durability problem arises. But, some countries, e.g. Australia, only permit the use of wood, if it is certified for not bearing forest illnesses or bugs (İstanbul Chamber of Commerce, 1968). Although wood, paper and cardboard cause less emissions in waste management, wood material is not a rapidly renewable source and using them cause accelerated deforestation (Stevens, 2002).

In many developing countries, there has been the rapid adoption of plastic crates for bulk packaging of fresh produce items. Plastic crate bulk packaging serves two main functions; for easy handling and efficient marketing and for protecting the produce from all forms of injury damage caused by rough handling (during loading, unloading and transport), pressure during stacking, moisture loss and heat (Rapusas and Rolle, 2008).

The raw materials used in plastic crates are based on PE and PP. PE is cheap, flexible, durable, chemically resistant and very suitable for crate's raw material. LDPE is used to make films and packaging materials like plastic bags, while HDPE is used more often to make containers. PP is the lightest material of the major plastics used for container practices and can be readily recycled provided that the criteria for control, quality and cost can be satisfied (Savaşçı et al., 2008). At Table 2.3. properties of HDPE and PP are shown.

Table 2.3. Properties of HDPE and PP (Savaşçı et al., 2008).

Property	**HDPE**	**PP**
Specific weight	0.941-0.965	0.90-0.91
Tensile strength, Mpa	22-39	30-40
Temperature strain, ^{0}C (ASTM- D 648)	60-82	100-110
Combustion velocity	Very slowly	Slowly
Impact of sun light	Effected	Effected
Effect of strong acid/base	Durable	Durable
Effect of organic solvent	80 ^{0}C < Durable	80 ^{0}C < Durable

2.3.3. Legislations and Regulations

According to European Parliament and Council Directive 94/62/EC of December, 20th (1994) on packaging and packaging waste, EU targets for recycling for 2008 is to recycle 55 to 80 % of weight of packaging waste. The EC directive aims the following targets for materials contained in packaging waste;

- 60 % for glass, paper and board,
- 50 % for metals,
- 22.5 % for plastics and,
- 15 % for wood.

However, the targets are exceeded with the involvement of European countries and each country has set their own national targets with respect to their economic and political views.

In Turkey, as an equivalent of Council Directive 94/62/EC, Packaging Waste Control Regulation is in force. In this regulation, it is indicated that authorized bodies and non-authorized bodies who are not a member of the authorized organization are responsible for recycling their packaging waste according to the targets which are specified in the Table 2.4. below (Ministry of Environment and Urban Planning, 2011).

Table 2.4. Annual targets for recycling according to Packaging Waste Control Regulation (Ministry of Environment and Urban Planning, 2011).

Year	**Annual targets for recycling**				
	Glass	**Plastics**	**Metal**	**Paper/Cardboard**	**Wood**
2008	35	35	35	35	-
2009	36	36	36	36	-
2010	37	37	37	37	-
2011	38	38	38	38	-
2012	40	40	40	40	-
2013	42	42	42	42	5
2014	44	44	44	44	5
2015	48	48	48	48	5
2016	52	52	52	52	7
2017	54	54	54	54	9
2018	56	56	56	56	11
2019	58	58	58	58	13
2020	60	60	60	60	15

In the Packaging and Packaging Waste Statistics, it is stated that in 2008, regulation targets were exceeded and 39 % of recycling ratio was achieved (Packaging Waste Division, 2008).

3. LIFE CYCLE ANALYSIS METHODOLOGYOF PLASTIC CRATES

3.1. Goal and Scope Definition

The goal of this study is comprised of two different parts:

1. Comparison of three common LCIA methods for plastic materials is studied. Therefore, the latest versions of the most commonly used LCA methodologies CML 2001 Nov. '09 and EDIP 2003 and damage oriented method Eco-indicator 99 (Hierarchist approach) are examined.

2. Plastic crates used for vegetable container are analyzed and potential environmental impacts of the production, utilization, transport and "end of life" options are researched. The term "end of life" proposed in this context is recycling, incineration and landfilling applications.

a. First of all, polypropylene and high density type polyethylene raw materials which are commonly used in plastic crates are evaluated on two different scenarios basis and compared. While PE raw material is assigned to A type Scenarios, PP is designated to B type Scenarios.

b. In this concept, future scenarios have been developed for both materials. EC directives and Turkish legislations are investigated for projection of future situation of plastic crates in Turkey. Year 2020 target limits are taken into account for these type of scenarios. Future and present target scenarios are compared.

c. Also, performance of recycling option is researched. For this reason, environmental performance of three new different capacity systems which only use raw material feedstock created and compared with scenarios which employs recycling. In this step only CML method and PE material is chosen. From the literature it is seen that, CML method are commonly used for LCA applications of plastic products (Borgne and Feillard, 2001; Harding et al., 2006; Department Life Cycle Engineering GaBi et al., 2009). The enhanced production capacities (without recycling option) considered for the study are: Base capacity

- 1,000,000 items, Enhanced capacity -1,400,000 items, Enhanced capacity - 1,600,000 items.

d. In addition, since reuse of durable plastics is one of the focus points of solid waste management, reuse options of crates are researched. Average reuse of plastic crates are found up to 300 times in the literature survey (Rapusas and Rolle, 2009) and scenarios which are created for 350, 300, 200 and 100 times reuse are compared.

All scenarios used in this study are summarized in Table 3.1.

Table 3.1. Life cycle scenarios.

Scenario	Raw material	Time span	Recycling rate	Number of crates	Reference flow (tons raw material)	Number of reuse
A.1	PE	Present	40%	$1.4.\ 10^6$	$1.4.\ 10^3$	300
B.1	PP	Present	40%	$1.4.\ 10^6$	$1.4.\ 10^3$	300
A.2	PE	2020 targets	60%	$1.6.\ 10^6$	$1.6.\ 10^3$	300
B.2	PP	2020 targets	60%	$1.6.\ 10^6$	$1.6.\ 10^3$	300
A.1.2	PE	Present	No recycling	$1.\ 10^6$	$1.\ 10^3$	300
A.1.3	PE	Present	No recycling	$1.4.\ 10^6$	$1.4.\ 10^3$	300
A.1.4	PE	Present	No recycling	$1.6.\ 10^6$	$1.6.\ 10^3$	300
A.1.5	PE	Present	40%	$1.4.\ 10^6$	$1.4.\ 10^3$	350
A.1.6	PE	Present	40%	$1.4.\ 10^6$	$1.4.\ 10^3$	200
A.1.7	PE	Present	40%	$1.4.\ 10^6$	$1.4.\ 10^3$	100

The plastic product of this case study is chosen as polyolefin crates and the functional unit is summarized in Table 3.2.

Table 3.2. Functional unit of the study.

Properties to define functional unit	**Attributes of the crates**
Number of items	1,000,000
Raw material	polyolefin pellets
Purity of raw material	Virgin, uncontaminated and free of heavy metal traces
Weight	1.5 kg
Dimensions	400 x 300 x 145 mm
Color	colorless
Duration - Life Time (year basis)	5 year life time (Rapusas and Rolle, 2009).
Duration - Reuse	up to 300 times (Rapusas and Rolle, 2009).
Service locations	Used in wholesale market and in tomato fields
Service conditions	The vegetable crates are used for tomato storage, filled by workers of fields and wholesale market

The life cycle of a plastic crate is not very complicated. The study covers crate production, use and transport, recycling and disposal stages. The system boundary of this project is summarized in Figure 3.1. The following boundaries are set for this study:

- The vegetable crates are used for tomato storage,
- *Geographical boundaries:* Turkey (from İstanbul to Antalya) is the geographical area for this LCA,
- The materials are considered to be uncontaminated and free of heavy metal traces.
- *Crate production:* The plant that crates are produced is located in İstanbul (near Gaziosmanpaşa Whole sale market),

- *Crate production loss:* It is assumed that 10 % loss of materials during recycling processing, however there is no loss in injection process. In literature recycling process efficiency is defined up to 90% (Stevens, 2002),
- *Washing processes in production stage:* It is assumed that there is no loss in water quantity in washing processes (inside pools),
- *General Transport:* Concerning all the transportation stages, 14-ton trucks have been chosen, and the GaBi 4 transport model has been used,
- *Crate transport from production plant to storage centers:* The storage centers are assumed to be placed along the way to the fields,
- *Crate transport from field and to wholesale market hall:* 740 km-long distance (From whole market of Gaziosmanpaşa, İstanbul to Antalya tomato fields in Kepez, Muratpaşa, Konyaaltı),
- *Broken crates transport:* The crates that has been broken during use stage is being sent to recycling, incineration and landfilling processes. A 60 km-long drive additional transport in İstanbul have been taken into account,
- *Washing processes in transport & use stage:* 10 % of water loss. In GaBi 4 directory, an existing washing process which incorporates 3 % of water loss is modified, due to assumptions that has been made for Turkey,
- *Use:* Use stage is only defined by transport processes. The filling of crates with vegetables are done by field workers and since there would be no emission from human work, only the transport process from field to whole sale market is taken into account for emission calculations,
- *Reuse:* Plastic crates can be used up to 300 times and have a 5 year life time period (Rapusas and Rolle, 2009),
- *Landfill:* Broken crates which cannot be collected back, are disposed in a landfill,
- *Incineration:* According to Tan and Khoo's (2006) LCA scenario studies for year 2004, 90% of plastic waste disposed will be incinerated. Considering Turkey's situation it is assumed that 80 % percent of items are sent for energy recovery. The incineration takes place in the furnaces of a cement factory in İstanbul. It is assumed that furnaces of a cement factory in İstanbul is used for incineration.

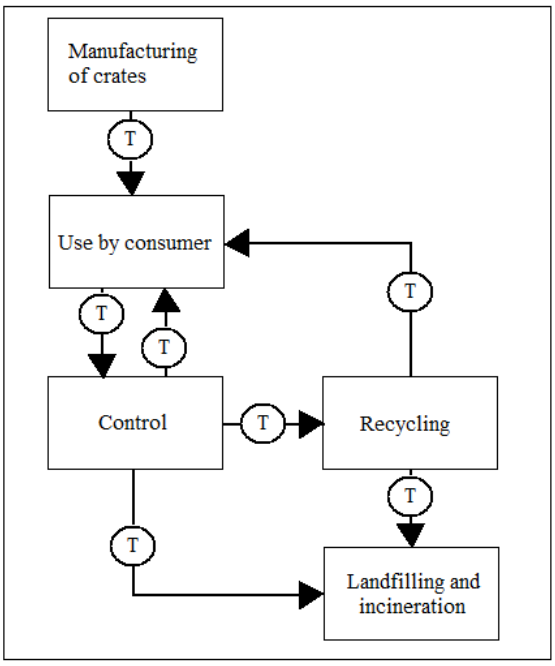

Figure 3.1. System boundaries.

3.2. Inventory

Data library of GaBi 4 consists of energy consumption, emission and materials data and relevant data were compiled for the defined functional unit. The additional data related to recycling processes were collected from a plastic crate producer company located in Güneşli, İstanbul (Birlik Metal Machines Manufacturing and Importation Co., 2011).

10 % of used plastic is considered to be lost during recycling processes. 1,500,000 kg, 2,100,000 kg and 2,400,000 kg of raw plastic are required to produce 1,000,000, 1,400,000 and 1,600,000 items of crates, respectively. Moreover, 600,000 kg and 900,000 kg of recycled plastic is required to reach 40 % and 60 % of situation targets, respectively.

Considering different LCA methodologies, the input data were evaluated by GaBi 4 software to compute emissions taking the defined functional unit as baseline. The models were generated for LCA through input-output balances of LCA stages. The diagram below is developed which can be used for a quick overview of mass and energy flows (Figure 3.2.).

The overall life cycle stages for Scenarios A.1, B.1, A.2 and B.2 are similar. The differences are modeled in recycling percentages, raw material preferences and reuse times. Crates are produced in a facility in İstanbul. They are sent to storage centers where they can be bought by farmers or whole market traders in order to be filled in fields. The crates are taken to Antalya- Kepez tomato fields and in the fields are filled with tomatoes. Then the crates are transported to whole sale market in Gaziosmanpaşa, İstanbul. In wholesale market the crates are emptied and sent back to Antalya. Depending on scenario, the crates are refilled up to 100, 200, 300 or 350 times and when they are broken they either recycled or incinerated and landfilled. Depending on scenario, 40 % or 60 % of the capacity are replenished by used plastic and incorporated to recycling process.

Life cycle stages for Scenarios A.1.2, A.1.3 and A.1.4 are similar as well, however they don't involve recycling applications. In Figures 3.2. and 3.3., life cycle of Scenarios A.1 and A.1.2 are given as an example for mass diagrams. Since the mass diagrams of other scenarios are similar, only raw materials or capacity changes are considered in the mass balances.

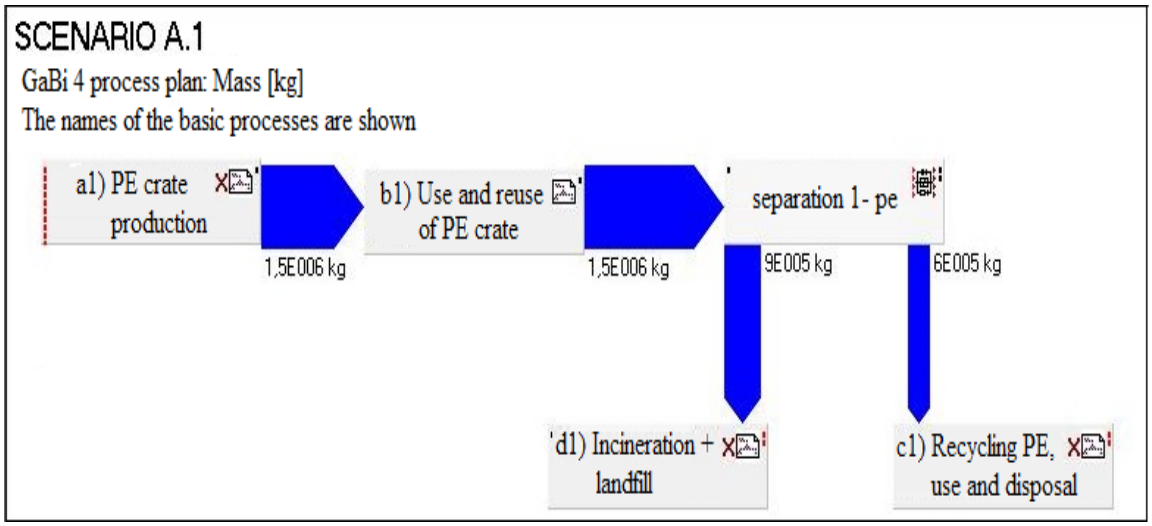

Figure 3.2. Life Cycle Analysis of Scenario A.1 (mass balance).

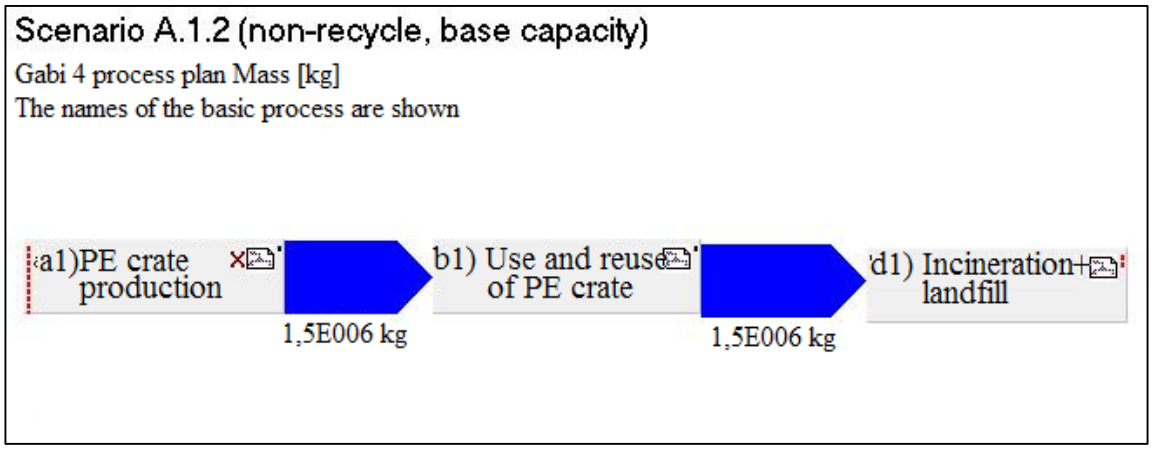

Figure 3.3. Life Cycle Analysis of Scenario A.1.2 (mass balance).

3.2.1. Production Stage

The production stage involves an input-output balance of "raw material manufacturing", "crate production", "power production" and "production of water for industrial use" and "wastewater treatment processes. In this study raw material production is based on plastic granulate manufacturing. Granulate form of plastics is preferred due to ease of transport. The Gabi 4 diagram of the Production stage for Scenario A.1 is given in Figure 3.4. The production stage is identical in all scenarios and quantities of energy and mass remain same.

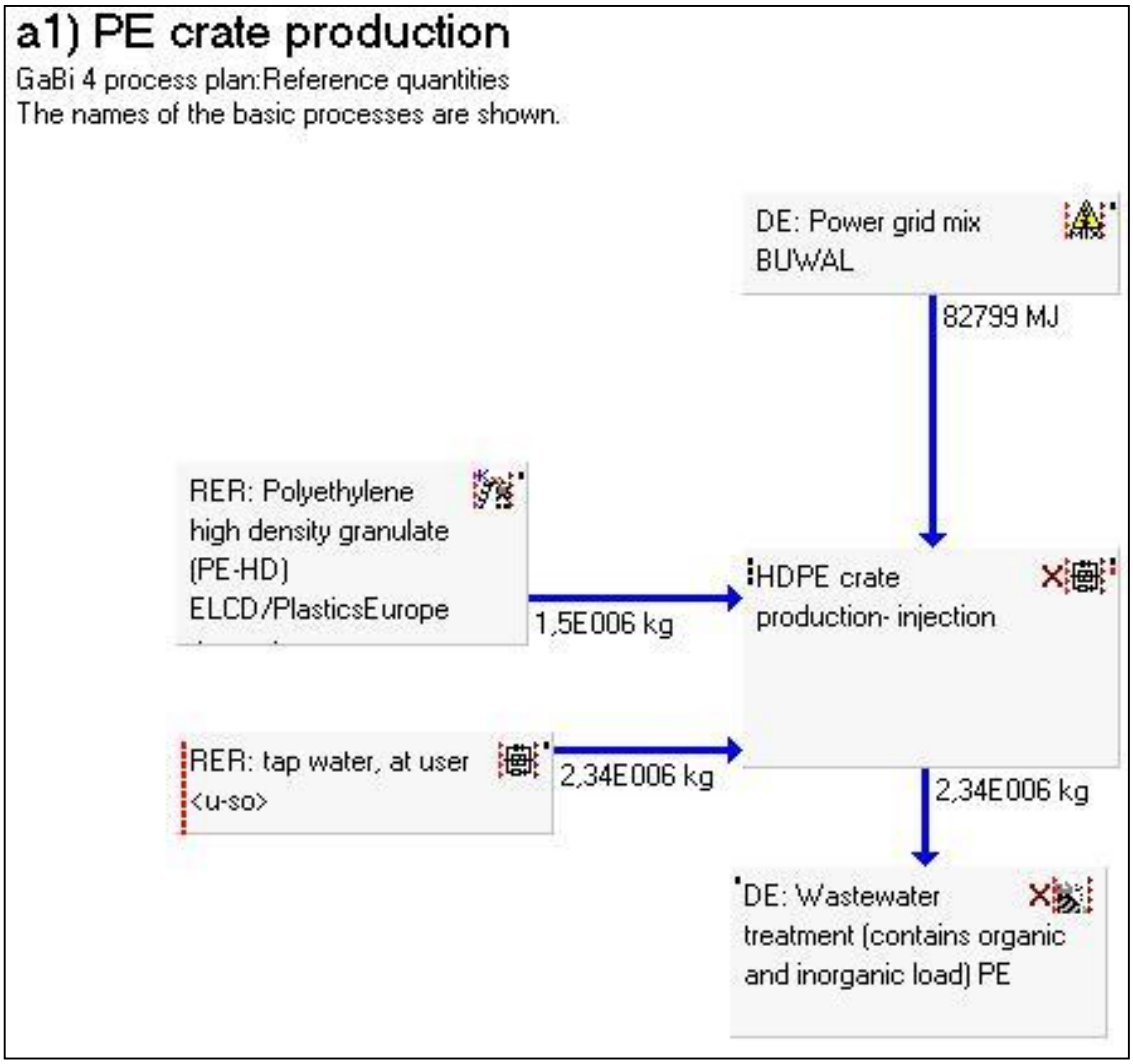

Figure 3.4. Mass balance of Production stage for Scenario A.1.

Considering the information obtained from the crate production facility in Güneşli, İstanbul, it is assumed that granulates have been supplied from Petkim Petrochemistry Co. The process for granulate manufacturing chosen from GaBi 4 database has been adapted from "ELCD/ Plastics Europe" database. HDPE granulate and PP granulate production process is utilized for raw material manufacturing. In Figure 3.5. crate production process which involves melting and injection has been restructured particularly and integrated into the GaBi 4 plans (Birlik Metal Machines Manufacturing and Importation Co., 2011). In this phase, the temperature is increased up to 380 °C. Granulate is melted and liquid plastic is injected into the crate mould. The finished products are sent to storage centers of the factory

in different cities. For tomato, the storage centers are assumed to be located in Antalya region.

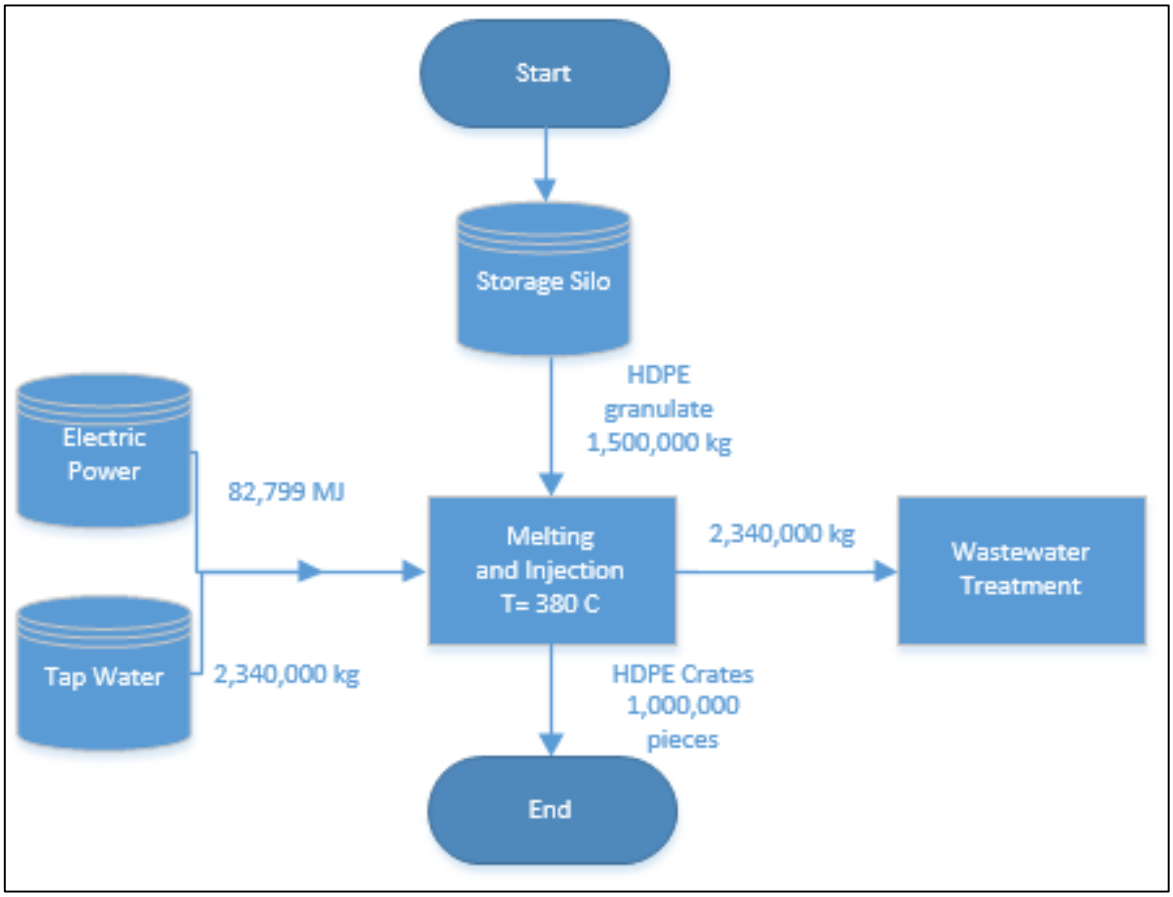

Figure 3.5. The flowchart of the crate production process (Birlik Metal Machines Manufacturing and Importation Co., 2011).

3.2.2. Transport & Use Stage

In transport & use stage; "transport", "production of water for industrial use", "thermal energy production", "diesel production", "power production", and "wastewater treatment" processes are used for inventory analysis. For these processes GaBi4 process models are applied. The plastic crates that are sent to storage center in Antalya. Here, they are purchased by whole market and transported to tomato fields in Kepez. Then the crates are sent to whole sale market in Gaziosmanpaşa, İstanbul. In wholesale market the crates are emptied and sent back to Antalya. "Transport" processes involves a 740 km-long drive from Gaziosmanpaşa,

İstanbul whole market to Antalya tomato fields in Kepez and 60 km-distance intercity drive. The rigidity and durability of PE and PP crates allows them to be reused for an extended period of time. According to Rapusas and Rolle (2009), plastic crates can be used up to 300 times and have a 5 year life time. One time use of crates is defined by the filling and transport between fields in Antalya and wholesale market in İstanbul, which covers 1600 km distance travelling. As crates are used for 300 times, 480,000 km of road transport is assumed to be traveled and this data is utilized for "transport process" calculations. Since physical and hygienic properties of plastic crates is very important in order to protect against chemical, physical and microbiological risks, they must be cleaned after each use (Rapusas and Rolle, 2009).For this reason a tailor made washing process is defined by modifying a current process existing in GaBi 4 directory. Around 10 % of water is assumed to be lost due to evaporation and water remnants on crates during washing. Due to 300 times use of the crates, the washing operation is repeated for 299 times and finally water is discharged to wastewater treatment process. The treatment process is chosen for organic and inorganic load of wastewater, thus crop residues, dirt and dust are additionally considered. It is assumed that after 300 times, all crates are sent to final disposal stages among which recycling, incineration and landfilling processes are considered. The Gabi 4 diagram of the Transport &Use Stage for Scenario A.1 is given in Figure 3.6.

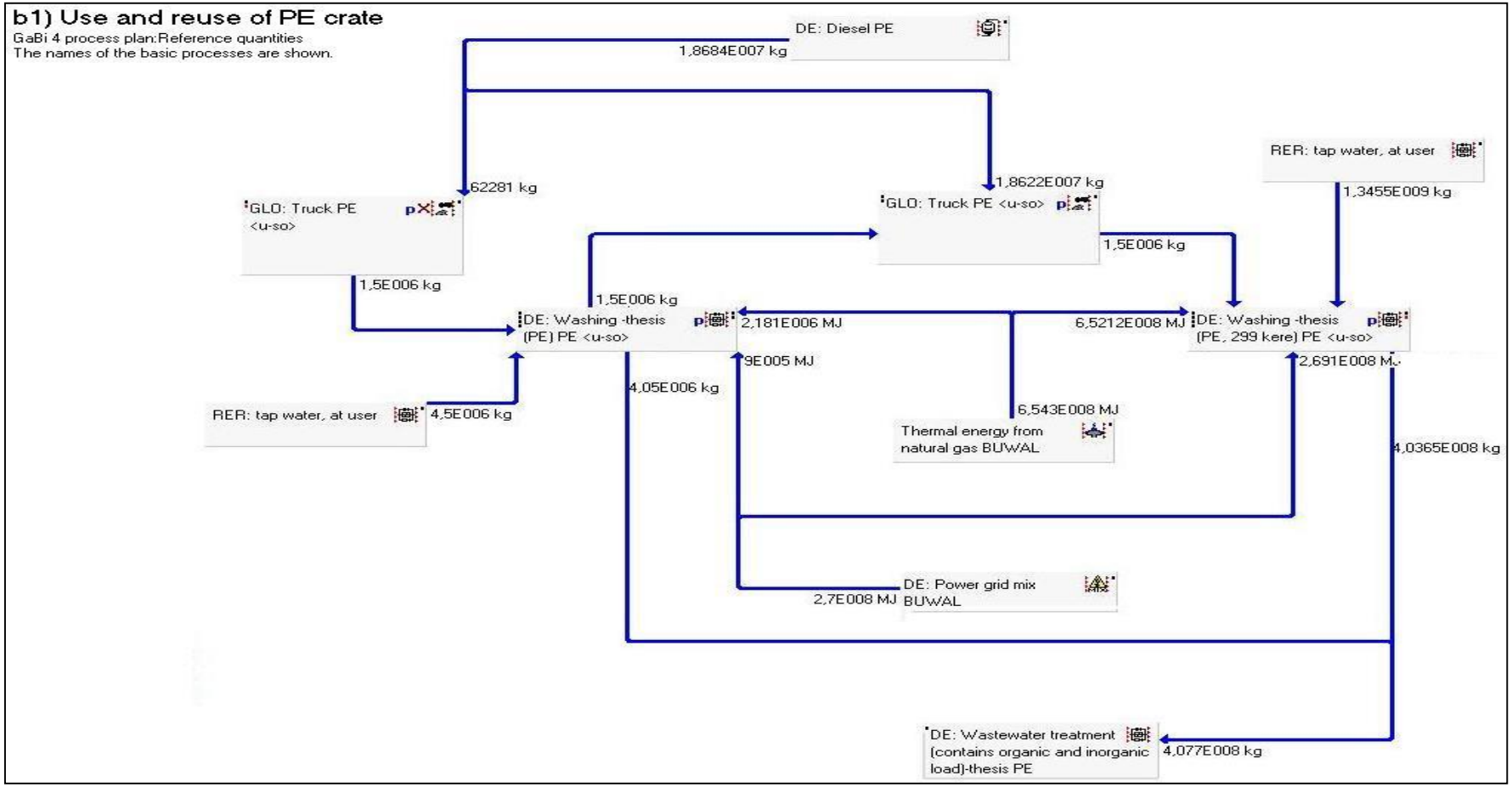

Figure 3.6. Mass Balance of Transport & Use stage for Scenario A.1.

3.2.3. Recycling Stage

Depending on scenario, 40 % or 60 % of used crates are sent to recycling. Recycling stage consists of “recycled granulate production”, “recycled crate production”, “transport”, “production of water for industrial use”, “diesel production”, “power production”, “landfill”, “incineration” and “wastewater treatment” processes.

The details of recycled granulate production processes are adopted from an existing crate recycling plant located in Güneşli, İstanbul. The layout of the recycling plant has been integrated to GaBi 4. Figure 3.7. shows the process flow diagram developed for Scenario A.1. As it is shown in this figure, re-granulation begins with mechanical crushing. This process generates dust and when the crushing is combined to washing, the dust is taken up by the water and it is eventually separated. According to the study of Rajendran et al. (2012), the plastic waste used as feedstock also contains mud, dust, waste metals and other volatile waste which contributed almost 25 % of the feedstock. Therefore the crates are washed in the two subsequent pools, where the dust and other impurities like sand, dirt, soil and vegetable remnants, etiquettes etc. are removed. Also, the water used for washing is treated at the end of washing. In this study it is assumed that recycled plastics do not incorporate with heavy metals. After washing, while the plastic crate is separated from water and dried (in aglomer machine), the material begins stretching and expanding like a rope with the impact of temperature. Then, granulation machine cuts the stretched and elongated plastic, creating small recycled granules. These granules are stored in a silo for future use or directly fed into injection stage. The recycling process efficiency is defined up to 90 % (Stevens, 2002). Recycled crate production is very similar to virgin crate production, the recycled granulates are melt and injected into crate mould. Even if recycled plastics used contained heavy metals, this process is not suitable for hazardous substance releases. The recycled products are gathered to storage centers and from there they are sent back to the croplands for tomato loading. In the fields they are filled with tomato and loaded to trucks for Antalya-İstanbul transportation. This phase incorporates 1600 km of distance (2 trips between Antalya and İstanbul).Since recycled crates are not durable and broken at first use. Broken recycled crates are either landfilled (20 %) or incinerated (80 %). The Gabi 4 diagram of the Recycling Stage for Scenario A.1 is depicted in Figure 3.8.

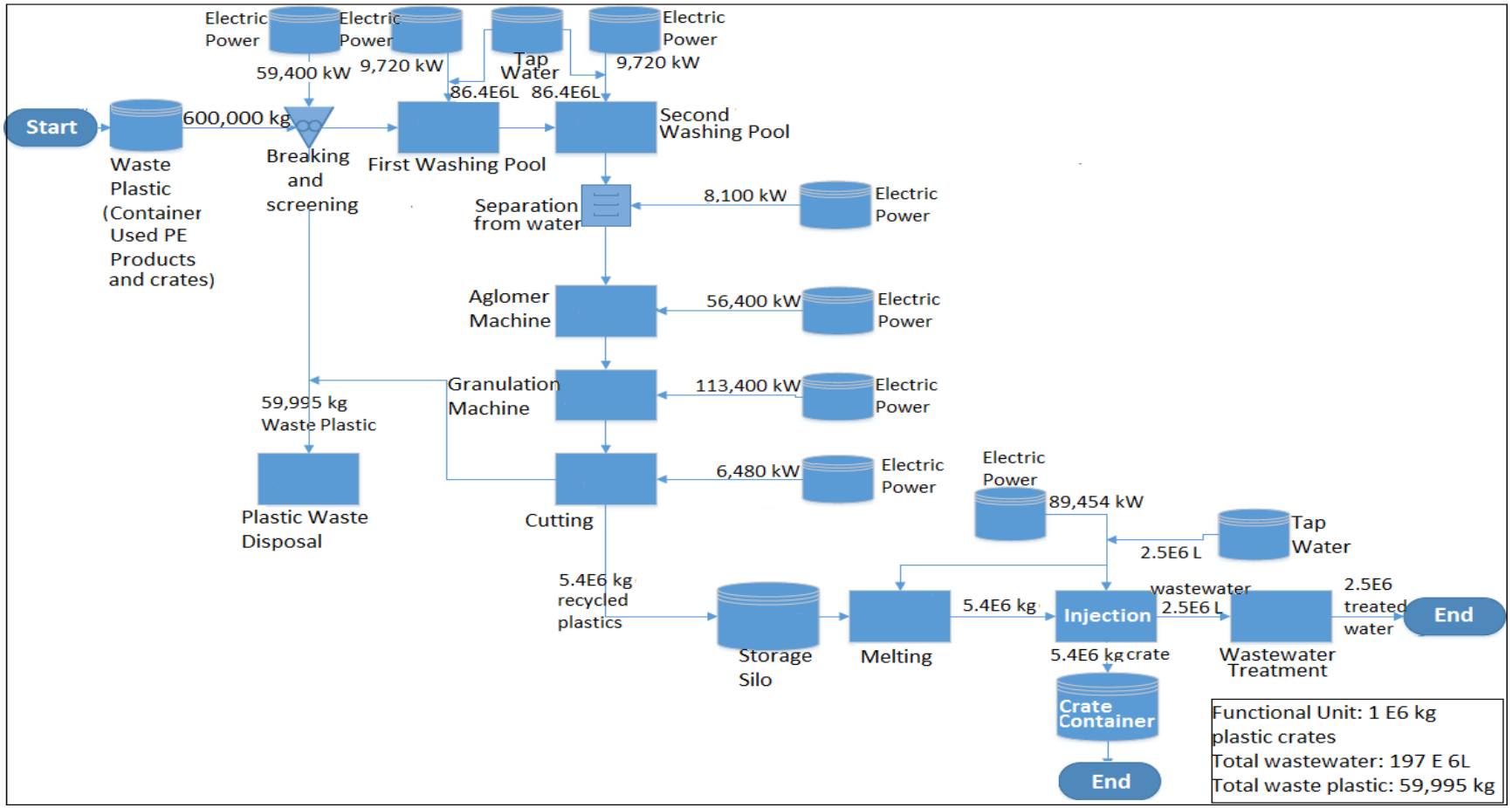

Figure 3.7. The flowchart of the recycling process.

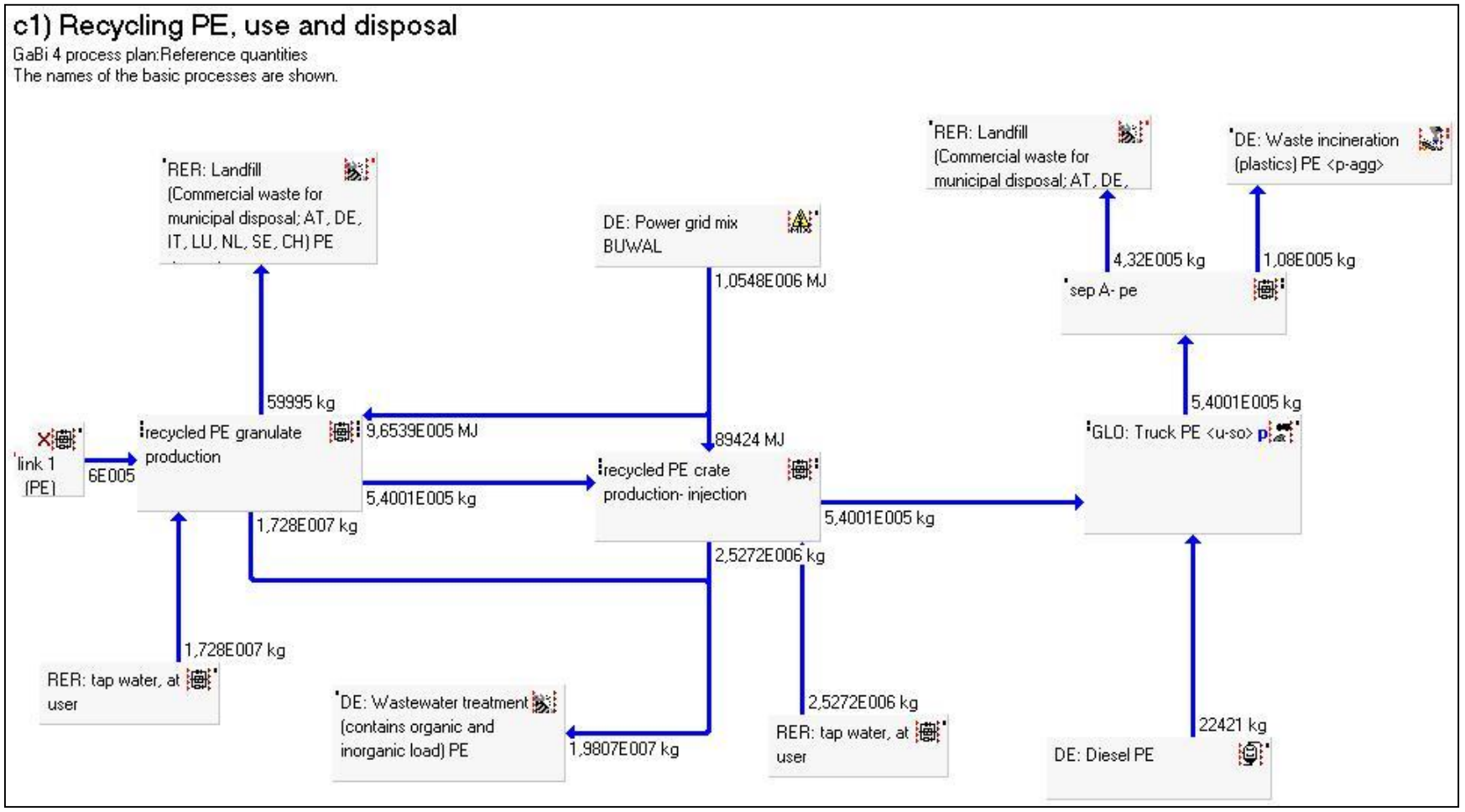

Figure 3.8. Mass balance of recycling stage for Scenario A.1.

3.2.4. Disposal Stage

Depending on the defined scenario, the remaining of the broken crates (60 % for A.1 and B.1, 40 % for A.2 and B.2) are sent to disposal stage from use stage. This stage only incorporates landfill and incineration processes. 20 % of the broken &recycled crates are landfilled and 80 % of them are incinerated. The incineration takes place in the furnaces of the selected cement factory. The GaBi 4 diagram of the Disposal stage for Scenario A.1 is given in Figure 3.9.

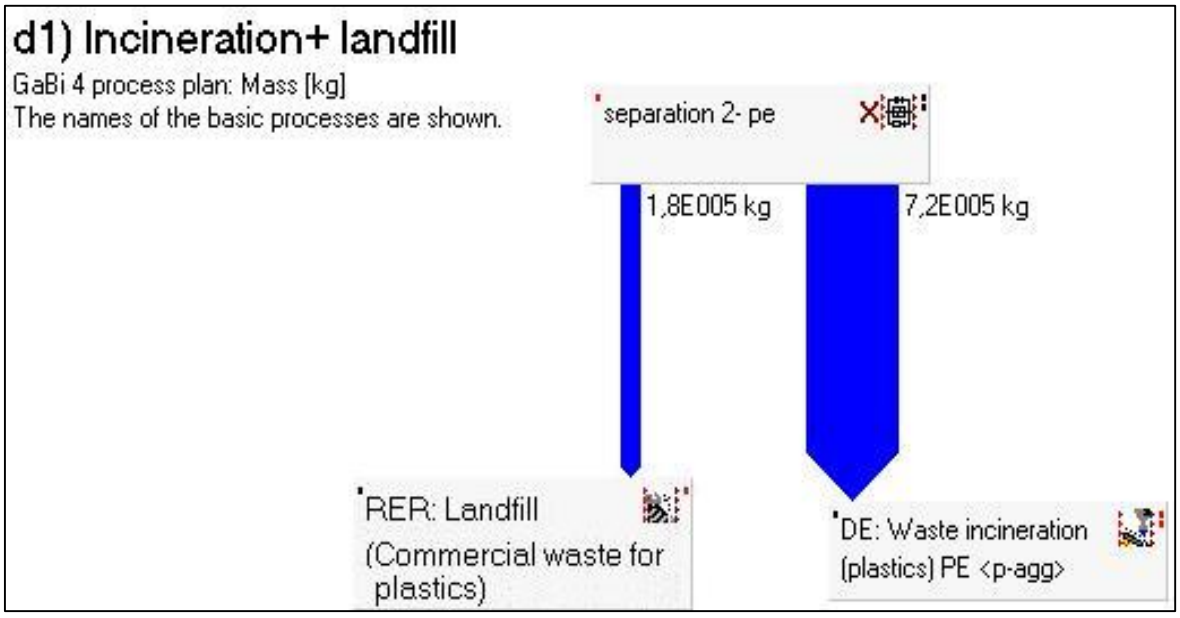

Figure 3.9. Mass balance of recycling stage for Scenario A.1.

4. RESULTS AND DISCUSSION

In this section of the study, energy and mass balance data that have been compiled in inventory phase are interpreted for potential environmental impacts. For this purpose, GaBi 4 software has been used in classification, characterization, normalization and weighting stages.

The relevant environmental impact categories for the selected product value chain, considering the overall input-output balance are summarized in Table 4.1. With respect to impact categories, the interpretation of EDIP 2003, CML 2001 and EI 99 methodologies are assessed. In the study the latest version of CML 2001 which is upgraded in November 2009 has been applied. Moreover, for EI 99 the Hierarchist (H) standard perspective is implemented.

In EDIP 2003 methodology, there exists no methods for material welfare and toxicity that have been interpreted in GaBi 4. Similarly, photo-oxidant formation is not available in EI 99 methodology. This study concentrates on global impact categories and excludes regional and local type impacts to an extent. Human health impacts are also excluded.

Table 4.1. Characterization of potential environmental impacts.

Potential impacts	**Characterization subcategory**	**Methodology for impact categories**		
		EDIP 2003	**CML 2001**	**EI 99**
Material welfare	Material welfare	No characterization approach for this method	Abiotic Depletion Elements	Resources-Minerals
Ecosystem Health	Acidification	Acidification potential	Acidification potential	Acidification/ Nitrification
	Eutrophication	Eutrophication potential	Eutrophication potential	Acidification/ Nitrification
	Global Warming	Global warming	Global warming potential	Climate Change
	Ozone Depletion	Stratospheric ozone depletion	Ozone layer depletion	Ozone layer depletion
	Photo-Oxidant Formation	Photochemical ozone formation - impact on human and vegetation	Photochemical ozone creation potential	No characterization approach for this method
Ecotoxicity	Ecotoxicity	No characterization approach for this method	Freshwater, marine water and terrestrial ecotoxicity potentials	Ecotoxicity

4.1. Characterization

In this stage, all potential contributions from the emissions in chosen impact categories are calculated according to EDIP 2003, CML 2001 and EI 99 methodologies. In Table 4.2 this comparison is summarized in terms of different units that has been used by three methodologies. The results from the life cycle inventory are used to assess the potential impacts of two types of plastics with different recycling ratios and capacities. The calculations have been illustrated by GaBi 4 graphs.

Table 4.2. Comparison of units in characterization subcategories.

Characterization subcategory	**Units**		
	EDIP 2003	**CML 2001**	**EI 99**
Material welfare	No characterization approach for this method	kg of Sb equivalents / kg extraction	MJ surplus energy
Acidification	m^2 UES	kg SO_2 equivalents/ kg emission	PDF*m^2*a
Eutrophication	m^2 UES	kg PO_4 equivalents/ kg emission	PDF*m^2*a
Global warming	kg CO_2 equivalent / kg emission	kg CO_2 equivalent / kg emission	DALY
Ozone depletion	kg R11 equivalents / kg emission	kg R11 equivalent/ kg emission	DALY
Photo-oxidant formation	*Human exposure:* pers.ppm	kg Ethylene equivalents/kg emission	No characterization approach for this method
	Vegetation exposure: m^2 UES		
Ecotoxicity	No characterization approach for this method	*FAETP:* kg DCB equivalents	pdf*m^2*a
		MAETP: kg DCB equivalents	
		TETP: kg DCB equivalents	

4.1.1. Material Welfare

4.1.1.1. CML 2001 Nov. ’09 Method- Abiotic Depletion (ADP), Elements

In Figures C.1., C.2., C.3. and C.4., Abiotic Depletion results for scenarios A.1, B.1, A.2 and B.2 are given, respectively. Abiotic Depletion score of Scenario A.1 is measured as 49.6266 kg Sb-Equiv. It is observed from the Figure C.1. that 71.85 % of resource depletions in Scenario A.1 comes from production stage, this is followed by transport & use stage with 27.38 %. In transport &use phase the relative contribution of the “diesel production”, “power generation” and “wastewater treatment” processes to depletion impacts are 4.57 and 21.67 %, respectively. In production stage, “wastewater treatment” process covers 71.75 % of the score. ADP impacts of Scenario A.1 is caused by the following non-renewable resources defined in GaBi. 53.3 % of score is caused by Lead - zinc ore (4.6 % - 0.6 %) depletion.

This is followed by Magnesium chloride leach (40 %), Sodium chloride (rock salt), Zinc - copper ore (4.07 % - 2.5 9 %) and Zinc - lead - copper ore (12 % - 3 % - 2 %) with 15.86, 20.79, 4.76 and 5.26 % of score, respectively.

Polyethylene (Scenario A.1) and polypropylene (Scenario B.1) raw material preferences are compared in Figures C.1. and C.2. It is calculated that ADP of Scenario B.1 is 49.7729 kg Sb-Equiv. and 0.29 % of difference is observed. It is concluded that, there would be no difference between utilization of PE and PP as raw material in terms of ADP impact category.

ADP results of Scenario A.2 and B.2 are 49.8285 and 49.7997 kg Sb-Equiv. are determined respectively, which corresponds to 0.06 % of difference. Since future target scenarios which are based on increased recycling rate utilization, uses the same production and transport &use stages, no significant difference is monitored between any scenarios generated (Figures C.3. and C.4.). In addition to these, in Figures C.3. and C.4., it is noticed that the emission scores of recycling stage is 46.31 % higher than “incineration and landfill” stage.

4.1.1.2. EI 99 HA Method- Resources- Minerals

In Figures C.5., C.6., C.7. and C.8. Resources- Minerals results of EI 99 Method for Scenarios A.1, B.1, A.2 and B.2 are given, respectively. The score of Scenario A.1 is found as 106,349 MJ surplus energy. Similar to CML method results, transport & use stage has the greatest impact score among all stages. According to Figure C.5, resource depletion is mostly seen in production and transport &use stages of the life cycle. Productions stage covers 65.45 % of total emissions and 13.56 % belongs to transport &use stage. In transport &use phase, the relative contribution of the “diesel production”, “wastewater treatment” and “tap water generation” processes to resource depletion impacts are 4.25, 19.74 and 10.32 %, respectively. “Wastewater treatment” process of crate production stage covers 65.21 % of score. Results of EI 99 method confirm that, the depletions are mostly resulted from” wastewater treatment” and “tap water” processes. According to GaBi 4 results depletions of Scenario A.1 is also caused by following nonrenewable elements and ores. Aluminum, Copper, Nickel (nonrenewable elements), Copper ore (0.14%), Iron ore (56.86%), Lead -

zinc ore (4. 6% - 0.6 %), Nickel ore (1.6 %), Zinc - copper ore (4.07 % - 2.5 9%) and Zinc - lead - copper ore (12 % - 3 % - 2 %) (non-renewable resources) share 2.09, 3.69, 3.1, 3.34, 6.39, 28.79, 1.82, 38.97 and 10.04 % of the score, respectively.

Resources- Minerals results of Scenario B.1 is determined as 106,352 MJ surplus energy. This result shows 0.002 % of difference with Scenario A.1, which is negligible. When raw material preferences are compared in Figures C.5. and C.6., no difference is observed, between utilization of PE and PP as well.

It is determined that, depletion results of Scenario A.2 and B.2 are 106,583 and 106,598 MJ surplus energy, respectively. Since recycling and disposal stage's depletion scores are negligible compared to production and transport & use stages, future target scenarios cannot be compared in graphs (Figures C.6. and C.7.). 0.01 % of difference is calculated between A.2 and B.2. However, it may be deduced that recycling stage result is 97.80 % higher than "incineration & landfill" stage. It is seen that the ratio of "incineration & landfill" stage to recycling stage varies with the chosen method.

4.1.2. Acidification

4.1.2.1. EDIP 2003 Method- Acidification Potential

In Figures C.9., C.10., C.11. and C.12. Acidification Potential impacts of EDIP 2003 Method for Scenarios A.1, B.1, A.2 and B.2 are given, respectively. Acidification potential of Scenario A.1 is measured as 15,923,666 m^2 UES. As it can be seen from the Figure C.9, 90% of Acidification Potential in Scenario A.1 comes from transport &use stage, this is followed by production stage with 9.2 %. In transport &use stage the relative contribution of the power generation and transport processes to the acidification potential are 35 % and 52 %, respectively. The acidification potential of Scenario A.1 is caused by the following inorganic emissions to air. 60.6 % of the acidification potential is caused by Nitrogen oxides, followed by 34.4 % of acidification potential because of Sulphur Dioxide and the rest 5 % is due to Hydrogen Fluoride and Hydrogen Chloride acids.

The raw material preferences Polyethylene (Scenario A.1) and polypropylene (Scenario B.1) are compared in Figures C.9. and C.10. It is determined that Acidification potential of Scenario B.1 is 15,921,211m^2 UES, which poses 0.015 % of difference on behalf of Scenario B.1. It is concluded that, there would be no difference between utilization of PE and PP as raw material in terms of Acidification potential.

Acidification Potential of Scenario A.2 and B.2 are calculated as 15,946,988 and 15,936,777 m^2 UES, respectively. 0.064 % of difference is observed and the result support Scenario B.2. Since future target scenarios (A.2 and B.2) which are based on alternative recycling rate utilization, incorporates the same production and use stages as well, it is observed that no significant difference is monitored between any scenarios generated (Figures C.11. and C.12.). In addition to these, in Figures C.11. and C.12., it is noticed that the emission scores of recycling stage is 84 % higher than "incineration & landfill" stage.

4.1.2.2. CML 2001 Nov. '09 Method- Acidification Potential

In Figures C.13., C.14., C.15. and C.16., CML 2001 Nov '09 Method Acidification Potential (AP) results for scenarios A.1, B.1, A.2 and B.2 are given, respectively. Acidification potential of Scenario A.1 is determined as 942,570 kg SO_2-Equiv. According to Figure C.13, AP is mainly observed in transport &use (89.96 % of total emissions) and production stages (9.78 % of total emissions) of the life cycle. In transport & use phase the relative contribution of "power generation" and "transport" processes to the acidification potential are 30.6 % and 46.6 %, respectively. Due to using the same model as EDIP 2003, AP of Scenario A.1 is also caused by the following inorganic emissions to air. Emissions that are responsible for AP are nitrogen oxides and sulphur dioxide, which covers 59 % and 39 % of total impact respectively.

In acidifying substances (acids) EDIP 2003 approach for RAINS Model causes visible impacts for HF and HCl compounds on graphs (Figures C.9., C.10., C.11. and C.12.). In CML 2001's approach, the emission of two acids are not regarded as much as EDIP 2003's. In EDIP 2003, interpretation for acidification potential (RAINS 7.2 version), Potting et al. (1998) stated that acidifying substances with very short lifetimes such as hydrochloric acid and hydrogen fluoride may be important and may dominate the total acidifying emissions in

the life cycle of products. The acidification factors from these substances with very short lifetimes have been approximated on the basis of sulfur dioxide, in order to enable quantification of the acidifying impact from these substances. Normally in Figures C.13 and C.14, HCl emission would be disregarded and ignored due to the magnitude of Nitrogen oxides and Sulphur dioxide, but in order to demonstrate the distinction, it has been added to the graph; on the other hand HF emissions cannot be seen even though it has been inserted due to its minority in magnitude.

Acidification potential of Scenario B.1 is determined as 942,186 kg SO_2-Equiv. This result creates 0.04 % of difference with Scenario A.1, which is negligible. In CML 2001 method, when raw material preferences are compared in Figures C.15. and C.16., no difference is determined, between utilization of PE and PP as well.

It is determined that, AP of Scenario A.2 and B.2 are 937,196 and 943,113 kg SO_2-Equiv., respectively. Since recycling and disposal stage scores are negligible when they are compared to use and production stage, differences cannot be monitored in graphs between future target scenarios for CML method and numerically these results create 0.067 % of difference between themselves. However, it may be deduced that recycling stage result is 92 % higher than "incineration & landfill" stage.

4.1.2.3. EI 99 HA Method- Acidification / Nutrification

In Figures C.17., C.18., C.19. and C.20. Acidification/Nutrification results for scenarios A.1, B.1, A.2 and B.2 are given, respectively. Acidification/Nutrification result of Scenario A.1 is found as 6,745,265 PDF*m^2*a. According to Figures C.17. and C.18., the Acidification / Nutrification is mostly seen in production and transport & use stages of the life cycle. Especially transport &use stage covers 92 % of total emissions and only 7.6 % belongs to production. Similar to EDIP 2003 and CML 2001 results, transport &use stage has the greatest impact score among all stages. In transport &use phase, contribution of the "transport" processes to the acidification potential is 80 % and the remaining is divided between "diesel production", "thermal energy production" and "wastewater treatment" processes.

Acidification/Nutrification caused by inorganic emissions to air like in CML and EDIP methods. While nitrogen oxides are responsible for 95.2 % of emissions, sulphur dioxide, covers 4.8 % of total impact. In acidification category, the models of EDIP 2003 and CML 2001 can adapt acids into their methodologies, however, EI 99's model Natuur Planner does not takes acids into account. Frischknecht et al. (2007) reported that EI 99 the methodology does neither provide damage factors for a range of acids like hydrogen chloride or hydrogen sulphide nor for the important nutrient phosphate. Thus, Hydrogen chloride (Inorganic emissions to air) and Hydrogen fluoride (Inorganic emissions to air) emissions are not observed in figures C.17., C.18., C.19. and C.20.

Another issue is, while in RAINS model, the impact of sulphur dioxide is approximately 60 % of nitrogen oxides score. Similar approach has been adopted in Natuur Planner model, however, the ratio of magnitude is greater (approximately 70 %). For Natuur Planner Goedkoop and Spriensma (2000) indicated that there is a strong relation between the deposition of NH_3 and an increased nutrient availability, while the deposition of SO_x results in an slight decrease of nutrient availability. This can be explained as nutrients become less available if the pH decreases, and as nutrient availability is expressed as nitrogen availability. There is a weak relation between the deposition of NH_3 and acidity, while the relation between acidity and NO_x deposition is strong. For these reasons, when Figures C.13. and C.17. are contrasted, it is seen the magnitude of nitrogen oxides is greater than sulphur dioxide in EI method results.

Acidification/Nutrification result of Scenario B.1 is calculated as 6,745,280 PDF*m^2*a, it is found that the difference with Scenario A.1 is totally negligible (0.0002 %). Therefore, according to EI 99, utilization of PE or PP as raw material does not cause any improvements in Acidification/Nutrification category (Figures C.15. and C.16).

Acidification/Nutrification scores of Scenario A.2 and B.2 are found as 6,751,249 and 6,750,513 PDF*m^2*a. Since main scores are only seen in production and use stages and recycling and disposal stage scores are ignored, differences cannot be monitored in graphs between future target scenarios and present scenarios. Numerically, 0.01 % of difference is found between Scenario A.2 and B.2 scores. Finally, it is also observed, that recycling stage

result is 94 % higher than “incineration & landfill” stage and this ratio is close to RAIN model approach of CML 2001 results.

4.1.3. Eutrophication

4.1.3.1. EDIP 2003 Method- Aquatic Eutrophication

In Figures C.21., C.22., C.23. and C.24. Aquatic Eutrophication impacts of EDIP 2003 Method for Scenarios A.1, B.1, A.2 and B.2 are given, respectively. Aquatic Eutrophication score of Scenario A.1 is calculated as 528,842 kg NO_3-Equiv.In Figure C.21., it is observed that, 90.44 % of Aquatic Eutrophication impacts in Scenario A.1 comes from transport &use stage, this is followed by production stage with 9.33 %. Aquatic Eutrophication is mainly seen in “transport” process of transport & use phase with a contribution of 72.9 % of total score and “power generation” process covers 10 %. “Wastewater treatment” process of production stage also contributes 9.32 % of the total impact.

Aquatic Eutrophication impact of Scenario A.1 is caused by the following inorganic emissions to air and freshwater. 90.3 % of the score is caused by nitrogen oxides (inorganic emission to air), followed by nitrate (emission to freshwater) and phosphate with 3.7 % and 2.3 % of total impact respectively.

Raw material preferences are compared according to Figures C.21. and C.22.. It is calculated that Aquatic Eutrophication impact of Scenario B.1 is 533,194 kg NO3-Equiv., which creates 0.73 % of difference on behalf of Scenario A.1. It is concluded that, utilization of PE or PE as raw material gives similar environmental performances in terms of Aquatic Eutrophication category.

It is calculated that, Eutrophication impacts of Scenario A.2 and B.2 are 529,078 and 533,194 kg NO_3-Equiv, which poses 0.77 % of difference on behalf of Scenario A.2. Since Scenarios A.2 and B.2 are based on enhanced recycling rate utilization and incorporates the same production and use stages of Scenarios A.1 and B.1, no significant difference is monitored between A.1 and A.2 or B.1 and B.2. (0.044% of difference between A.1 and A.2; 0.084 of difference between B.1 and B.2). In addition to these, in Figures C.23. and C.24., it

is noticed that the emission scores of recycling stage is 84 % higher than “incineration & landfill” stage.

4.1.3.2. CML 2001 Nov. ’09 Method- Eutrophication Potential

In Figures C.25., C.26., C.27. and C.28., Eutrophication Potential scores for Scenarios A.1, B.1, A.2 and B.2 are given, respectively. Eutrophication potential of Scenario A.1 is determined as 180,318 kg Phosphate-Equiv. According to Figure C.13., the main share to the emissions are caused by transport & use and production stages with 83.8 % and 16 % of total emissions, respectively. “Wastewater treatment” process of production stage contributes 16 % of the total impact, “transport” process and “power generation” processes of transport & use phase covers 67.64 % and 7 % of total score, respectively.

Eutrophication Potential impact of Scenario A.1 is caused by the following inorganic emissions to air and analytical measures to freshwater. Nitrogen oxides and Chemical oxygen demand (COD) are the main responsible for EP and cover 80.5 % and 12 % of total impact respectively. An interesting outcome of this results is that, nitrate and phosphate which are normally the main contributors of eutrophication by definition cannot be seen in the results. This should be regarded as a case sensitive situation due to the high emissions of Nitrogen oxides (inorganic emissions to air) and COD (Analytical measures to fresh water). Thus, even though CML method characterization factors for Nitrate (Inorganic emissions to fresh water) and Phosphate (Inorganic emissions to fresh water) are greater than Nitrogen oxides (Inorganic emissions to air) and COD, the calculated result are ignored in the graphical demonstration. This case is not the same in EDIP calculations because higher characterization factors are assigned for nitrate and phosphate (Figures C.21., C.22., C.23. and C.24). The only common emission for CML and EDIP methods is nitrogen oxides (Inorganic emissions to air).

Eutrophication Potential of Scenario B.1 is determined as 180,497 kg Phosphate-Equiv. This result creates 0.1 % of difference with Scenario A.1, which is negligible. Thus, when raw material preferences are compared in Figures C.25. and C.26., similar environmental performances is observed in terms of eutrophication.

It is calculated that, EP of Scenario A.2 and B.2 are 180,190 and 180,611 kg Phosphate-Equiv and this causes 0.23 % of difference between two future target scenarios. Since recycling and disposal stage scores are negligible compared to transport % use stage, differences cannot be observed in graphs (Figures C.27. and C.28.) as well. However, it may be deduced that recycling stage result is 92 % higher than "incineration & landfill" stage.

4.1.3.3. EI 99 HA Method- Acidification / Nutrification

Impact scores of the Acidification / Nutrification category have been covered in Acidification category in Figures C.17., C.18., C.19., C.20. Since Acidification / Nutrification model of EI define the acidity, nutrient condition and the moisture condition and their interactions at the same time, it is not possible to determine whether damage is caused by changes in the nutrient level or the acidity. Another problem of this approach is that it does not cover the effect of phosphate and other eutrophying emissions to water (Goedkoop and Spriensma, 2000). Therefore a direct comparison cannot be made between EDIP 2003 and CML 2001 with EI 99 for this category. For these three methodologies, the dominancy of nitrogen oxides which are also the common compounds in the results, are the only factors that may be commented on.

4.1.4. Global Warming

4.1.4.1. EDIP 2003 Method- Global Warming

In Figures C.29., C.30., C.31. and C.32. Global Warming scores for scenarios A.1, B.1, A.2 and B.2 are given, respectively. Global Warming result of Scenario A.1 is calculated as 212,122,279 kg CO_2-Equiv. As it is observed in Figure C.29., 78.7 % of Global Warming score in Scenario A.1 comes from transport &use stage, this is followed by production stage with 19,66 %.

In transport & use phase, the relative contributions of "power generation", "transport", "thermal energy production" and "wastewater treatment" processes to the global warming are 22 %, 28%, 19% and 5%, respectively. "Wastewater treatment" process of production stage covers 18.3 % of total impact. Global Warming score of Scenario A.1 is caused by

both organic and inorganic emissions to air. 93.2 % of the impact is caused by Carbon dioxide and 4 % of the score is due to methane emissions.

Global Warming result of Scenario B.1 is calculated as 212,776,591 kg CO2-Equiv., it is found that the difference with Scenario A.1 is 0.3 % and negligible. Therefore, according to EDIP 2003, utilization of PE or PP as raw material does not cause any improvements in terms of global warming category (Figures C.29 and C.30).

Global Warming scores of Scenario A.2 and B.2 are determined as 212,981,655 and 212,966,227 kg CO2-Equiv. 0.007 % of difference is found between Scenario A.2 and B.2 scores. Because main emission are observed only in production and use stages, recycling and disposal stage scores are ignored. Thus, differences between future target scenarios and present scenarios cannot be monitored in graphs. Between A.1 and A.2, 0.04 % and between B.1 and B.2 0.089 of difference is calculated. In Figures C.31. and C.32., it is noticed that emission scores of recycling stage is 48 % higher than "incineration & landfill" stage. According to Global Warming result of present scenario (Scenario A.1: 40 % of waste is recycled, 48 % is incinerated and remaining is landfilled), CH_4 and CO_2 emission scores of recycling stage equals to 45 % of "incineration & land filling" stage. When present case is compared to future target case, it is monitored that CH_4 and CO_2 emissions are increased.

4.1.4.2. CML 2001 Nov. '09 Method- Global Warming Potential

In Figures C.33., C.34., C.35. and C.36. Global Warming Potential results for scenarios A.1, B.1, A.2 and B.2 are given, respectively. Acidification potential of Scenario A.1 is measured as 211,204,762 kg CO_2-Equiv. According to Figure C.33., 78.6 % of Global Warming Potential in Scenario A.1 originated from transport & use stage, this is followed by production stage with 19.7 %.In production stage, contribution of "wastewater treatment" process to Global Warming potential is 18.35 %. In transport & use stage, the share of the "power generation", "transport", "thermal energy" production and "wastewater treatment" processes to Global Warming potential are 22.25 %, 28.12 %, 19 % and 5.5 %, respectively. These contributions are compatible with EDIP 2003 method's contribution of Global Warming results as well.

Global Warming potential of Scenario A.1 is caused by both organic and inorganic emissions to air. 94 % of the Global Warming potential is caused by Carbon dioxides, this is followed by methane with 4 % of contribution. Since the same model is implemented in both EDIP 2003 and CML 2001 methods for global warming potential calculations, the very same substance emissions made similar impacts in both methods' results.

Raw material preferences are compared according to Figures C.33. and C.34. It is calculated that Global Warming potential of Scenario B.1 is 211,871,405 kg CO_2-Equiv. 0.31 % of difference is observed compared to Scenario A.1. It is determined that, utilization of PE or PP as raw material shows similar environmental performance in terms of Global Warming potential.

Global Warming potential of Scenario A.2 and B.2 are calculated as 212,063,108 and 212,060,388 kg CO2-Equiv. respectively. Between future target scenarios for CML method 0.001 % of difference is determined. Since recycling and disposal stage scores are negligible when they are compared to transport &use and production stages, differences cannot be monitored in Figures C.35 and C.36. Therefore Scenario A.1 and A.2 or B.1 and B.2 cannot be compared. Between A.1 and A.2, 0.04 % and between B.1 and B.2, 0.089 of difference is calculated. It is noted that these values are exactly the same as EDIP 2003 results. According to Figures C.35. and C.36., it is noticed that emission scores of recycling stage is 48 % higher than "incineration & landfill" stage.

4.1.4.3. EI 99 HA Method- Climate Change

Apart from EDIP and CML, in EI 99 for climate change, a time scale of 200 years is adapted in damage calculations. In Figures C.37., C.38., C.39. and C.40., Climate Change results for Scenarios A.1, B.1, A.2 and B.2 are given, respectively. Climate Change scores of Scenario A.1 is determined as 44.0555 DALY. According to Figure C.37., the main share to the emissions are caused by transport &use and production stages with 79 % and 19.74 % of total emissions, respectively. "Wastewater treatment" process of production stage contributes 18.33 % of the total impact, "transport" process and "power generation" processes of transport & use phase covers 67.64 % and 7 % of total score respectively.

Climate change impact of Scenario A.1 is caused by both organic and inorganic emissions to air as in other two methods. Climate change is caused by carbon dioxides and methane with 95 % and 4 % of contribution, respectively.

Raw material preferences are compared according to Figures C.37. and C.38. It is calculated that Climate Change impact of Scenario B.1 is 44.205 DALY which creates 0.33 % of difference with Scenario A.1. It is determined that, utilization of PE or PE as raw material gives similar environmental performances in terms of Climate change category.

It is calculated that, Climate change impacts of Scenario A.2 and B.2 are 44.24 and 44.243 DALY, which creates 0.088 % of difference on behalf of Scenario A.2. Since Scenarios A.2 and B.2 are based on enhanced recycling rate utilization and incorporates the same production and transport & use stages of Scenarios A.1 and B.1, no significant difference is monitored between A.1 and A.2 or B.1 and B.2. (0.337 % of difference between A.1 and A.2; 0.009 of difference between B.1 and B.2). In addition to these, in Figures C.39. and C.40., it is noticed that the emission scores of recycling stage is 48.21 % higher than "incineration & landfill" stage.

In method comparison part, it is concluded that, the same emissions that have been seen in results of both EDIP 2003 and CML 2001 (Figures C.29. to C.36.) methods made similar impacts in EI 99 method as well (due to the utilization of the base IPCC model). Since, EI 99 converted the impacts into DALYs, a direct comparison cannot be made. However, it is observed that the ratio between these substances' impacts remained the same and conversion by FUND model protected the ratio. These results can be justified by the findings of the Brighton workshop, according to Hofstetter et al. (2000), theoretically, providing they are developed using a consistent framework, midpoint and endpoint characterization factors within some impact categories may display linear proportionality.

4.1.5. Ozone Depletion

4.1.5.1. EDIP 2003 Method- Stratospheric Ozone Depletion

In Figures C.41., C.42., C.43. and C.44., Stratospheric Ozone Depletion impacts of EDIP 2003 Method for scenarios A.1, B.1, A.2 and B.2 are given, respectively. Stratospheric Ozone Depletion score of Scenario A.1 is measured as 2.221 kg R-11 Equiv. As it is observed from the Figure C.41, 86.5 % of Stratospheric Ozone Depletion impacts in Scenario A.1 comes from transport & use stage, this is followed by production stage with 13 %. In transport &use stage the relative contribution of the "diesel production", "power generation", and "thermal energy generation" processes to Stratospheric Ozone Depletion impacts are 5 %, 61.5 % and 15.34 % respectively. In production stage, "wastewater treatment" process covers 13 % of the score. Stratospheric Ozone Depletion impacts of Scenario A.1 is caused by halogenated organic emissions to air. 77 % of depletion is caused by Halon. This is followed by R11, R114 and R 12 with 10.8 %, 9.53 % and 1.9 % of score, respectively.

Polyethylene (Scenario A.1) and polypropylene (Scenario B.1) raw material preferences are compared in Figures C.41. and C.42. It is calculated that Acidification potential of Scenario B.1 is 2.2226 kg R-11 Equiv., which poses 0.007 % of difference on behalf of Scenario A.1. It is concluded that, there would be no difference between utilization of PE and PP as raw material in terms of Stratospheric Ozone Depletion category.

It is determined that, Stratospheric Ozone Depletion of Scenario A.2 and B.2 are 2.2262 and 2.2257 kg R-11 Equiv., which creates 0.02 % of difference on behalf of Scenario B.2. Since future target scenarios (A.2 and B.2) which are based on alternative recycling rate utilization, incorporates the same production and transport & use stages as well, it is observed that no significant difference is monitored between any scenarios generated (Figures C.43. and C.44). In addition to these, in Figures C.43. and C.44., it is noticed that the emission scores of recycling stage is 77.78 % higher than "incineration & landfill" stage.

4.1.5.2. CML 2001 Nov. ’09 Method- Ozone Layer Depletion

In Figures C.45., C.46., C.47. and C.48. Ozone Layer Depletion results of CML 2001 Method for Scenarios A.1, B.1, A.2 and B.2 are given, respectively. The score of Scenario A.1 is found as 2.2578 kg R-11 Equiv. According to Figures C.45. Ozone layer depletion is mostly seen in production and transport & use stages of the life cycle. Especially transport & use stage covers 85.87 % of total emissions and only 13.56 % belongs to production. Similar to EDIP results, transport & use stage has the greatest impact score among all stages. In transport &use phase, the relative contribution of the “diesel production”, “power generation”, “wastewater treatment” and “thermal energy generation” processes to Stratospheric Ozone Depletion impacts are 5.21 %, 60.51 %, 4.08 % and 15.09 %, respectively. Wastewater treatment process of production stage covers 13.54 % of score. Since CML method uses the same model as EDIP 2003, Ozone Layer Depletion of Scenario A.1 is also caused by the same halogenated organic emissions to air. 76.67 % of depletion is caused by halon. This is followed by R11, R114 and R 12 with 10.64 %, 10.39 % and 2.29 % of score, respectively. In addition to this, the factors used by methods are similar in magnitude. For halon and R11 both approaches utilize the same factor and no difference has been seen on the results. In R 114 and R 12 results, only small differences are observed. For instance; in Scenario A.1 (Figure C.41.) for R 114 and R 12 emissions 9.6 % and 18 % of difference is noted. However, these differences may not be noticed in the graphs.

Ozone Layer Depletion of Scenario B.1 is determined as 2.2594 kg R-11 Equiv. This result creates 0.07 % of difference with Scenario A.1, which is negligible. In CML 2001 method, when raw material preferences are compared in Figures C.45. and C.46., no difference is observed, between utilization of PE and PP as well.

It is calculated that, Ozone Layer Depletion score of Scenario A.2 and B.2 are 2.2292 and 2.2257 kg R-11 Equiv., respectively. Numerically these results create 0.15 % of difference between themselves. Since recycling and disposal stage scores are negligible when they are compared to transport & use and production stage, differences cannot be observed in graphs (Figures C.47. and C.48.) between future target scenarios. However, it may be deduced that recycling stage result is 77.40 % higher than “incineration & landfill” stage.

4.1.5.3. EI 99 HA Method- Ozone Layer Depletion

In Figures C.49., C.50., C.51. and C.52. Ozone layer depletion results of EI 99 method for scenarios A.1, B.1, A.2 and B.2 are given, respectively. Ozone Layer Depletion score of Scenario A.1 is determined as 0.002336 DALY. According to Figure C.49., depletions are mainly observed in production (86.5 % of total emissions) and transport & use stages (12.94 % of total emissions) of the product. In transport &.use stage the relative contribution of "diesel production", "power generation" and "transport processes" to the depletions are 4.97 %, 61.4 % and 15.31 %, respectively. "Wastewater treatment" process of production stage also contributes 12.91 % of the total impact.

Ozone layer depletion of Scenario A.1 is originated from the same halogenated organic emissions to air. 77.64 % of depletion is caused by halon. This is followed by R11, R114 and R 12 with 10.77 %, 9.5 % and 1.9 % of score, respectively. As it is noticed, in EDIP 2003, CML 2001 and EI 99 the ozone layer Depletion impacts are made by same substances due to the use of same base ODP factors. Since EI 99 is a damage oriented method, these factors have been converted into damage factor. However, it is observed that even though, the results are modified for damage oriented forms; they keep their previous ratios for damage stage in EDIP and CML methods. These results can be justified by the findings of the Brighton workshop as well. According to Hofstetter et al. (2000), especially for the midpoint measure 'ozone depletion potentials' and the endpoint measure of 'DALYs' related to ozone depletion may be linearly proportional. Similar to EDIP and CML method's results, the magnitude of production stage result is 14.5 % of all depletion result.

Ozone layer depletion results of Scenario B.1 is calculated as 0.002338 DALY. This result creates 0.067 % of difference with Scenario A.1. In EI 99 method, when raw material preferences are compared in Figures C.49. and C.50. no difference is determined, between utilization of PE and PP as well.

It is determined that, Ozone Layer Depletion results of Scenario A.2 and B.2 are 0.002342 and 0.002341 DALY. Since recycling and disposal stage scores are negligible, future target scenarios cannot be compared in graphs (Figures C.51. and C.52.) and 0.02 %

of difference is calculated between A.2 and B.2. However, it may be deduced that recycling stage result is 40.3 % higher than “incineration & landfill” stage.

4.1.6. Photo-Oxidant Formation

4.1.6.1. EDIP 2003 Method- Photochemical ozone formation

In Figures C.53., C.54., C.55. and C.56. photochemical ozone formation - impact on human health scores for scenarios A.1, B.1, A.2 and B.2 are given, respectively. The score for Scenario A.1 is calculated as 154.78 pers*ppm*hours. As it is observed in Figure C.53, 92 % of the score in Scenario A.1 comes from transport & use stage, this is followed by production stage with 7.5 %. In transport &use phase, the relative contributions of “diesel production”, “power generation”, “wastewater treatment”, “transport”, “thermal energy production” processes to the score are 2.81 %, 9.29 %, 2 %, 72.1 % and 5.42 % respectively. “Wastewater treatment” process of production stage creates 6.77 % of total impact. The score of Scenario A.1 is caused by both organic and inorganic emissions to air. 87.46 % of depletion is caused by nitrogen oxides. This is followed by methane and non-methane volatile organic compounds with 6.91 % and 4.79 % of score, respectively.

Raw material preferences are compared according to Figures C.53. and C.44. It is calculated that Photochemical ozone formation - impact on human health results of Scenario B.1 is 154.4 pers*ppm*hours. 0.25 % of difference is observed compared to Scenario A.1. Thus, utilization of PE or PP as raw material showed similar environmental performances.

Photochemical ozone formation - impact on human health scores of Scenario A.2 and B.2 are determined as 154.76 and 154.52pers*ppm*hours. 0.155 % of difference is found between Scenario A.2 and B.2 scores. Because main emission are observed only in production and transport &use stages, recycling and disposal stage scores are ignored. Thus, differences between future target scenarios and present scenarios cannot be monitored in graphs. In Figures C.55. and C.56., it is noticed that emission scores of recycling stage is 71 % higher than “incineration & landfill” stage.

In Figures C.57., C.58., C.59. and C.60., photochemical ozone formation - impact on vegetation scores for scenarios A.1, B.1, A.2 and B.2 are given, respectively. The score for Scenario A.1 is calculated as 2,267,763,688 m^2 UES*ppm*hours. In Figure C.57., 92.15 % of the score in Scenario A.1 comes from transport & use stage, this is followed by production stage with 7.44 %. In transport &use phase, the relative contributions of "diesel production", "power generation", "wastewater treatment", "transport", "thermal energy production" processes to the score are 2.6 %, 9.11 %, 2 %, 72.97 % and 5.11 %, respectively. "Wastewater treatment" process of production stage covers 6.79 % of total impact. These contribution percentages also shows similarity with the percentages of impact on human health scores. Like in impact on human health result, the score of Scenario A.1 is caused by both organic and inorganic emissions to air. 89.41 % of depletion is caused by nitrogen oxides. This is followed by methane and non-methane volatile organic compounds with 5.85 % and 4.03 % of score, respectively. When the two EDIP 2003 method categories are compared (e.g. comparing figures C.53 and C.57), it is observed that all are common emissions with different scores due to the units that GaBi 4 uses. Therefore, even though the units differ, the same ratios between emission scores are reserved.

Raw material preferences are compared according to Figures C.59. and C.60. It is calculated the impact of Scenario B.1 is 2,263,024,189 m^2 UES*ppm*hours, which creates 0.2 % of difference with Scenario A.1. It is determined that, there is no difference in utilization of PE or PE as raw material in terms of vegetation exposure.

It is calculated that, Photochemical ozone formation - impact on vegetation scores of Scenario A.2 and B.2 are 2,267,830,408 and 2,264,817,422 m^2 UES*ppm*hours, which poses 0.13 % of difference on behalf of Scenario A.2. Since Scenarios A.2 and B.2 are based on enhanced recycling rate utilization and incorporates the same production and use stages of Scenarios A.1 and B.1, no significant difference is monitored between A.1 and A.2 or B.1 and B.2. In addition to these, in Figures C.59. and C.60., it is noticed that the emission scores of recycling stage is 72.96 % higher than "incineration & landfill" stage.

4.1.6.2. CML 2001 Nov. ’09 Method- Photochemical Ozone creation potential

In Figures C.61., C.62., C.63. and C.64., Photochemical ozone creation potential results for scenarios A.1, B.1, A.2 and B.2 are given, respectively. Score of Scenario A.1 is measured as 97,209 kg Ethene-Equiv. According to Figure C.61., 92.6 % of the score in Scenario A.1 originated from use stage, this is followed by production stage with 7.08 %. In production stage, contribution of wastewater treatment and polyethylene production processes to Photo-chemical ozone creation potential are 5.15 % and 1.91 %, respectively. In transport &use stage, the share of the “diesel production”, “power generation”, “wastewater treatment”, “transport” and “thermal energy generation” processes to Photo-chemical ozone creation potential are 5.83, %, 15.07 %, 1.55 %, 63.14 % and 6.57 %, respectively. However, these contributions are not compatible with EDIP 2003 method’s results. Especially, while polyethylene production process’ share to photochemical ozone creation is observed in CML 2001method’s scores, in EDIP it is under 1% and ignored.

Photochemical ozone creation potential of Scenario A.1 is caused by both organic and inorganic emissions to air. The contributions of carbon monoxide, nitrogen oxides, sulphur dioxide, non-methane volatile organic, propane, methane compounds and are 8.33 %, 33.45 %, 15.83 %, 38.68 %, 1.34 % and 2.34 % of score, respectively. When EDIP 2003 method results are compared to CML 2001 method’s, it is observed that most of the impacts are made by same substances, even if the models used for characterizations are different. Methane, nitrogen oxides and non-methane volatile organic compounds are the common emissions in two EDIP 2003 categories and CML 2001’s POCP approach and mainly expected in this category group. Unlike EDIP, in CML 2001 method, the emissions of carbon monoxide, propane and sulphur dioxide is monitored in the results. Although there are certain amount of carbon monoxide and sulphur dioxide results in EDIP’s two categories, they are ignored when compared to other emissions and cannot be observed in the graphs.

Raw material preferences are compared according to Figures C.61. and C.62. It is calculated that Global Warming potential of Scenario B.1 is 96,710 kg Ethene-Equiv., 0.5 % of difference is observed compared to Scenario A.1. It is determined that, utilization of PE or PP as raw material shows similar environmental performance in terms of Photochemical ozone creation potential.

Photochemical ozone formation - impact on vegetation scores of Scenario A.2 and B.2 are calculated as 97,259 and 96,783 kg Ethene-Equiv., which creates 0.5 % of difference on behalf of Scenario A.2. It is found that, there is no significant difference between A.1 and A.2 or B.1 and B.2. In Figures C.63. and C.64., it is noticed that the emission scores of recycling stage is 85.61 % higher than "incineration & landfill" stage.

4.1.7. Ecotoxicity

4.1.7.1. CML 2001 Nov. '09 Method- Freshwater Aquatic Ecotoxicity Potential, Marine Aquatic Ecotoxicity Potential and Terrestrial Ecotoxicity Potentials

In Figures C.65., C.66., C.67. and C.68., FAETP results of CML 2001Method for Scenarios A.1, B.1, A.2 and B.2 are given, respectively. FAETP score of Scenario A.1 is calculated as 1,594,525 kg DCB-Equiv. In Figure C.65., it is observed that, 25.45 % of FAETP impacts in Scenario A.1 comes from production stage and 74 % is resulted from transport &use stage. FAETP is mainly observed in "power generation" process of transport &use phase with a contribution of 59.31 % of total score and "diesel production" process covers 5.45 %. In production phase, "wastewater treatment" process and raw material production processes also contributes 9.42 % and 16 % of the total impact, respectively. FAETP impact of Scenario A.1 is caused by heavy metals, organic and inorganic emissions to freshwater. 14.60 % and 35.88 % of the score is caused by copper (+II) and nickel (+II) (heavy metals to fresh water), 31.2 % of the score comes from barium (+II) (Inorganic emissions to fresh water) and 13.3 % of it is resulted from polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) (halogenated organic emissions to fresh water).

Raw material preferences are compared according to Figures C.65. and C.66.. It is calculated that FAETP impact of Scenario B.1 is 1,339,127 kg DCB-Equiv., which creates 16.01 % of difference on behalf of Scenario B.1. In this category it is observed that it is concluded that, utilization of PP as raw material is advantageous in terms of FAETP performance. The underlying reason is that FAETP impact of Scenario B.1 is only caused by heavy metals and organic emissions to freshwater. The emissions of polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) which are originated from PE raw material production, are not present in PP based scenario. While, 17.85 and 43.93 % of the score is caused by

copper (+II) and nickel (+II) (heavy metals to fresh water), 38.21 % of the score comes from barium (+II) (Inorganic emissions to fresh water). Therefore, in Figure C.66., it is observed that, 11.31 % of impacts in Scenario A.1 comes from production stage and 88.23 % is resulted from transport & use stage.

Scores of Scenario A.2 and B.2 are calculated as 1,598,119 and 1,343,440 kg DCB-Equiv., respectively. Between future target scenarios for CML method 15.93 % of difference is determined. Consequently, Scenario A.2 become less environmentally friendly when compared to Scenario B.2. Since recycling and disposal stage scores are negligible when they are compared to transport & use and production stages, differences cannot be monitored in Figures C.71. and C.72. According to Figures C.67. and C.68., it is noticed that emission scores of recycling stage is 67.43 % higher than "incineration &landfill" stage.

In Figures C.69., C.70., C.71. and C.72., MAETP results of CML 2001 Method for Scenarios A.1, B.1, A.2 and B.2 are given, respectively. MAETP score of Scenario A.1 is calculated as 46,799,135,912 kg DCB-Equiv. In Figure C.69., it is observed that, only 1.07 % of MAETP impacts in Scenario A.1 comes from production stage and practically all emissions (98.51 %) are resulted from transport &use stage. It is noticed that this percentage share does not resemble to other categories' results. In transport &use phase, most of the contributions are caused by "power generation" with 93.15 % of the score. This is followed by "diesel production" and "thermal energy generation" processes which are 2.02 %, 2.27 % respectively. The score of Scenario A.1 is caused by both inorganic air and to fresh water. 96.5 % of the impact is caused by hydrogen fluoride (Inorganic emissions to air) and 3.49 % of the score is due to barium (Inorganic emissions to fresh water) emissions.

MAETP result of Scenario B.1 is calculated as 46,776,547,364 kg DCB-Equiv., it is found that the difference with Scenario A.1 is 0.05 % and negligible. Therefore, according to this category, utilization of PE or PP as raw material does not cause any improvements in Figures C.69. and C.70. However, it is also observed that, when PE is preferred as raw material, the impact of the hydrogen fluoride (Emission to marine water) emissions becomes more distinct and noticeable. PP raw material substitution causes 45 % loss in Hydrogen Fluoride scores.

MAETP scores of Scenario A.2 and B.2 are determined as 46,891,679,836 and 46,871,541,384 kg DCB-Equiv. 0.04 % of difference is found between Scenario A.2 and B.2 scores. Since main emission are seen only in production and transport &use stages, recycling and disposal stage scores are ignored. Thus, differences between future target scenarios and present scenarios cannot be monitored in graphs. In Figures C.71. and C.72., it is noticed that emission scores of recycling stage is 98.33 % higher than "incineration & landfill" stage.

In Figures C.73., C.74., C.75. and C.76. TETP results of CML 2001 Method for Scenarios A.1, B.1, A.2 and B.2 are given, respectively. TETP score of Scenario A.1 is calculated as 135,997 kg DCB-Equiv. In Figure C.77., it is observed that, 5.72 % of TETP impacts in Scenario A.1 comes from production stage and 93.56 % is resulted from transport & use stage. TETP is observed in "power generation", "diesel production" and "thermal energy generation" processes of transport & use phase covers 35.8 %, 28.94 % and 24.85 % of total score, respectively. In production phase, "wastewater treatment" process also contributes 5.62 % of the total impact. TETP impact of Scenario A.1 is caused by heavy metals to air and industrial soil. 68.3 % and 12.55 % of the score is caused by Mercury (+II) and Vanadium (+III) (heavy metals to air) and 19.13 % of it is resulted from Chromium (unspecified, Heavy metals to industrial soil).

TETP score of Scenario B.1 is calculated as 135,714 kg DCB-Equiv., it is found that the difference with Scenario A.1 is 0.2 % and negligible. Thus for TETP category, raw material changes does not cause differentiation in emission scores. (Figures C.73 and C.74).

It is calculated that, TETP impacts of Scenario A.2 and B.2 are 135,923 and 135,882 kg DCB-Equiv., which poses 0.03 % of difference. Since Scenarios A.2 and B.2 are based on enhanced recycling rate utilization and incorporates the same production and transport &use stages of Scenarios A.1 and B.1, no significant difference is monitored between A.1 and A.2 or B.1 and B.2. In addition to these, in Figures C.75 and C.76, it is noticed that the emission scores of recycling stage is 80.17 % higher than "incineration & landfill" stage.

4.1.7.2. EI 99 HA Method- Ecotoxicity

In Figures C.77., C.78., C.79. and C.80. Ecotoxicity scores for scenarios A.1, B.1, A.2 and B.2 are given, respectively. Ecotoxicity score of Scenario A.1 is calculated as 325,697 pdf*m^2*a. In Figure C.77., it is observed that, 91.77 % of impacts in Scenario A.1 comes from transport & use stage, this is followed by production stage with 7.35 %. Ecotoxicity is predominantly observed in "diesel production" and "transport" process of transport &use stage with a contribution of 14.99 % and 67.07 % of total score, respectively, on the other hand "thermal energy generation" and "wastewater treatment" process covers 5.08 and 2.43 %. "Wastewater treatment" process of production stage also contributes 7.22 % of the total impact.

Ecotoxicity impact of Scenario A.1 is caused by heavy metals to air, freshwater and industrial soil. 5.75 % and 43.4 % of the score is caused by Lead (+II) and Nickel (+II) (heavy metals to air), this followed by chromium (unspecified), copper (+II) and nickel (+II) (heavy metals to fresh water) with 4.98 %, 7.91 % and 6.76 % of total impact respectively. Chromium (unspecified) (heavy metals to industrial soil) also covers 4.98 % of the score.

Raw material preferences are compared according to Figures C.77. and C.78. It is calculated that impact of Scenario B.1 is 325,076 pdf*m^2*a., which creates 0.19 % of difference. It is realized that, raw material preferences do not affect environmental performance of crates in terms of ecotoxicity.

It is calculated that, Ecotoxicity impacts of Scenario A.2 and B.2 are 326,111 and 325,783 pdf*m^2*a., which poses 0.1 % of difference. Since Scenarios A.2 and B.2 are based on enhanced recycling rate utilization and incorporates the same production and use stages of Scenarios A.1 and B.1, no significant difference is monitored between A.1 and A.2 or B.1 and B.2. In addition to these, in Figures C.79. and C.80., it is noticed that the emission scores of recycling stage is 80.15 % higher than "incineration & landfill" stage.

According to results in Figures C.65. to C.76., in CML 2001 method for marine and freshwater toxicity there are less heavy metallic emissions than in EI 99 method. This result may be originated from USES-LCA model. According to Huijbregts et al. (2009), the oceanic compartment can be excluded for essential metals, i.e., cobalt, copper, manganese,

molybdenum, and zinc, as additional inputs of essential metals in the oceans may not lead to toxic effects.

All characterization results (for Scenarios A.1, B.1, A.2 and B.2) of Method Comparison Part is summarized in Table 4.3.

Table 4.3. Characterization results of Method Comparison Part.

Characterization	**Characterization results of Method Comparison Part**		
	EDIP 2003	**CML 2001**	**EI 99**
Material welfare	No characterization approach for this method	**A.1:** 49.6266 kg Sb-Equiv. **B.1:** 49.7729 kg Sb-Equiv. **A.2:** 49.8285 kg Sb-Equiv. **B.2:** 49.7997 kg Sb-Equiv.	**A.1:** 106,349 MJ surplus energy **B.1:** 106,352 MJ surplus energy **A.2:** 106,583 MJ surplus energy **B.2:** 106,598 MJ surplus energy
Acidification	**A.1:** 15,923,666 m^2 UES **B.1**: 15,921,211 m^2 UES **A.2:** 15,946,988 m^2 UES **B.2:** 15,936,777 m^2 UES	**A.1:** 942,570 kg SO2-Equiv **B.1:** 942,186 kg SO2-Equiv. **A.2:** 937,196 kg SO2-Equiv. **B.2:** 943,113 kg SO2-Equiv.	**A.1:** 6,745,265 PDF*m^2*a. **B.1:** 6,745,280 PDF*m^2*a **A.2:** 6,751,249 PDF*m^2*a **B.2:** 6,750,513 PDF*m^2*a
Eutrophication	**A.1:** 528,842 kg NO_3-Equiv. **B.1:** 533,194 kg NO3-Equiv. **A.2:** 529,078 kg NO_3-Equiv **B.2:** 533,194 kg NO_3-Equiv	**A.1:**180,318 kg Phosphate-Equiv. **B.1:**180,497 kg Phosphate-Equiv. **A.2:**180,190 kg Phosphate-Equiv **B.2:**180,611 kg Phosphate-Equiv	**A.1:** 6,745,265 PDF*m^2*a. **B.1:** 6,745,280 PDF*m^2*a **A.2:** 6,751,249 PDF*m^2*a **B.2:** 6,750,513 PDF*m^2*a
Global Warming	**A.1:** 212,122,279 kg CO_2-Equiv. **B.1:** 212,776,591 kg CO2-Equiv. **A.2:** 212,981,655 kg CO2-Equiv. **B.2:** 212,966,227 kg CO2-Equiv.	**A.1:** 211,204,762 kg CO_2-Equiv. **B.1:** 211,871,405 kg CO_2-Equiv. **A.2:** 212,063,108 kg CO2-Equiv. **B.2:** 212,060,388 kg CO2-Equiv.	**A.1:** 44.0555 DALY **B.1:** 44.2050 DALY **A.2:** 44.2400 DALY **B.2:** 44.2430 DALY

Table 4.3. Characterization results of Method Comparison Part (continued).

Characterization	EDIP 2003	CML 2001	EI 99
Ozone Depletion	**A.1:** 2.2210 kg R-11 Equiv. **B.1:** 2.2226 kg R-11 Equiv. **A.2:** 2.2262 kg R-11 Equiv. **B.2:** 2.2257 kg R-11 Equiv.	**A.1:** 2.2578 kg R-11 Equiv. **B.1:** 2.2594 kg R-11 Equiv. **A.2:** 2.2292 kg R-11 Equiv. **B.2:** 2.2257 kg R-11 Equiv.	**A.1:** 0.002336 DALY **B.1**: 0.002338 DALY **A.2:** 0.002342 DALY **B.2:** 0.002341 DALY
Photo-Oxidant Formation	***On Human*** **A.1:** 154.78 pers*ppm*hours **B.1:** 154.40 pers*ppm*hours **A.2:** 154.76 pers*ppm*hours **B.2:** 154.52 pers*ppm*hours ***On Vegetation*** **A.1:** 2,267,763,688 m^2 UES*ppm*hours **B.1:** 2,263,024,189 m^2 UES*ppm*hours. **A.2:** 2,267,830,408 m^2 UES*ppm*hours **B.2:** 2,264,817,422 m^2 UES*ppm*hours	**A.1:** 97,209 kg Ethene-Equiv. **B.1:** 96,710 kg Ethene-Equiv. **A.2:** 97,259 kg Ethene-Equiv. **B.2:** 96,783 kg Ethene-Equiv.	No characterization approach for this method
Ecotoxicity	No characterization approach for this method	***FAETP:*** **A.1:** 1,594,525 kg DCB-Equiv. **B.1:** 1,339,127 kg DCB-Equiv. **A.2:** 1,598,119 kg DCB-Equiv. **B.2:** 1,343,440 kg DCB-Equiv. ***MAETP:*** **A.1:** 46,799,135,912 kg DCB-Equiv. **B.1:** 46,776,547,364 kg DCB-Equiv. **A.2:** 46,891,679,836 kg DCB-Equiv. **B.2:** 46,871,541,384 kg DCB-Equiv.	**A.1:** 325,697 pdf*m2*a **B.1:** 325,076 pdf*m2*a **A.2:** 326,111 pdf*m2*a **B.2:** 325,783 pdf*m2*a

Table 4.3. Characterization results of Method Comparison Part (continued).

Characterization	EDIP 2003	CML 2001	EI 99
Ecotoxicity	No characterization approach for this method	***TETP:*** **A.1:** 135,997 kg DCB-Equiv. **B.1:** 135,714 kg DCB-Equiv. **A.2:** 135,923 kg DCB-Equiv. **B.2:** 135,882 kg DCB-Equiv.	No characterization approach for this method

4.1.8. Impact Categories for different capacities

In previous part, comparative method analysis is performed for Scenarios A.1, B.1, A.2 and B.2. It has been deduced that selection of PE or PP raw material, does not create significant difference in emissions, depletions and results. Therefore in this part of the analysis, PE raw material has been selected as a representative of polyolefin for further assessments. In this step, one out of three methods has been chosen for "LCIA of polyolefin crates". Impact categories are defined by the most recent expert revision (November 2009) of the CML 2001 characterization method. Scores of different capacities have been compared for the determination the effects of recycling, incineration and landfilling options in cradle to grave type LCA. The different capacities are defined as Scenarios A.1.2, A.1.3, A.1.4.For Scenarios A.1.2, A.1.3 and A.1.4, the following environmental impacts are studied: abiotic depletion, acidification, eutrophication, global warming, ozone depletion, photochemical ozone formation and ecotoxicity potentials.

4.1.8.1. CML 2001 Nov '09 Method- Abiotic Depletion (ADP), Elements

In Figures C.81., C.82. and C.83., ADP results for scenarios A.1.2, A.1.3 and A.1.4 are given, respectively. The score of Scenario A.1.2, A.1.3 and A.1.4 is calculated as 49.7055, 69.5877 and 79.5288 kg Sb-Equiv., respectively. In new scenarios, it is observed that, 71.74 % of depletions in Scenario A.1 comes from transport &use stage, this is followed by production stage with 27.33 %.

Comparative analysis of Scenarios A.1 and A.2 (Figures C.1. and C.3.) with Scenarios A.1.2, A.1.3 and A.1.4 (Figures C.81. to C.83.) showed that by adding recycle step to the life cycle, the utilization of raw materials in production stage is decreased. In use stage, less materials are sent to "washing" and "transport" processes. Therefore, reductions in resource depletion are achieved. While, the results of the base capacity (1,000,000 items) scenario (Scenario A.1.2) and A.1 are almost same, 40 % and 60 % of capacity enhancement without recycling cause 40.22 % and 59.6 % of depletion increase, respectively. The differences between scenarios are given in Table 4.4.

Table 4.4. Comparison of all ADP scores.

Comparison	% Difference
A.1 - A.2	0.40
A.1 - A.1.2	0.16
A.1 - A.1.3	40.22
A.2 - A.1.4	59.60

4.1.8.2. CML 2001 Nov '09 Method- Acidification Potential

In Figures C.84., C.85. and C.86. AP results for scenarios A.1.2, A.1.3 and A.1.4 are given, respectively. The score of Scenario A.1.2, A.1.3 and A.1.4 is calculated as 940,693 kg SO_2-Equiv., 1,316,971 kg SO_2-Equiv. and 1,505,110 kg SO_2-Equiv., respectively. In these scenarios, it is calculated that, 89.91 % of depletions in Scenario A.1 comes from use stage, this is followed by production stage with 10.01 %. Scenarios A.1 and A.2 (Figures C.13 and C.15) with Scenarios A.1.2, A.1.3 and A.1.4 (Figures C.84. to C.86.) are compared. 40 % and 60 % of capacity enhancement causes 39.72 % and 59.59 % emission increase, respectively. When Figures C.13. and C.84. are compared, it is observed that the scores of the Scenario A.1.2 (base capacity -1,000,000 items- scenario) and A.1 are similar (with 0.06 % difference). The differences between scenarios are given in Table 4.5.

Table 4.5. Comparison of all AP scores.

Comparison	% Difference
A.1 - A.2	0.06
A.1 - A.1.2	0.20
A.1 - A.1.3	39.72
A.2 - A.1.4	59.59

4.1.8.3. CML 2001 Nov '09 Method- Eutrophication Potential

In Figures C.87., C.88. and C.89. EP results for scenarios A.1.2, A.1.3 and A.1.4 are given, respectively. Scenarios A.1 and A.2 (Figures C.29. and C.31.) with Scenarios A.1.2, A.1.3 and A.1.4 (Figures C.87. to C.89.) are checked against each other. The score of Scenario A.1.2, A.1.3 and A.1.4 is calculated as 179,534 kg Phosphate-Equiv., 251,348 kg Phosphate-Equiv. and 287,255 kg Phosphate-Equiv., respectively. In these scenarios, it is observed that, 81.59 % of depletions in Scenario A.1 comes from use stage, this is followed by production stage with 18.14 %.

When Figures C.29. and C. 91. are compared, it is observed that the results of the base capacity (1,000,000 items) scenario (Scenario A.1.2) and A.1 are almost same. 40 % and 60 % of capacity enhancement causes 39.39 % and 59.42 % emission increase, respectively. The differences between scenarios are given in Table 4.6.

Table 4.6. Comparison of all EP scores.

Comparison	% Difference
A.1 - A.2	0.07
A.1 - A.1.2	0.43
A.1 - A.1.3	39.39
A.2 - A.1.4	59.42

4.1.8.4. CML 2001 Nov '09 Method- Global Warming Potential

In Figures C.90., C.91. and C.92. GWP results for scenarios A.1.2, A.1.3 and A.1.4 are given, respectively. The score of Scenario A.1.2, A.1.3 and A.1.4 is calculated as kg CO2-Equiv, respectively.

In order to compare Scenarios A.1 and A.2 with Scenarios A.1.2, A.1.3 and A.1.4 Figures C.33., C.34. and Figures C.90., C.91., C.92. are examined. The score of Scenario A.1.2, A.1.3 and A.1.4 is calculated as 211,437,295 kg CO_2-Equiv., 296,012,213 kg CO_2-Equiv. and 338,299,672 kg CO_2-Equiv., respectively. In these scenarios, it is determined that, 78.67 % of depletions in Scenario A.1 comes from transport &use stage, this is followed by production stage with 19.74 %. As it is expected due to the increase gas emissions transport processes, the results of "transport & use" stage again is higher than other stages when the capacity is increased. Thus, it is noted that when recycle stage added to the life cycle, GWPs are decreased accordingly.

When Figures C.33. and C. 90. are compared, it is noticed that the results of the base capacity (1,000,000 items) scenario (Scenario A.1.2) and A.1 are almost same. 40 % and 60 % of capacity enhancement causes 40.15 % and 59.53 % emission increase, respectively. The differences between scenarios are given in Table 4.7.

Table 4.7. Comparison of all GWP scores.

Comparison	% Difference
A.1 - A.2	0.40
A.1 - A.1.2	0.11
A.1 - A.1.3	40.15
A.2 - A.1.4	59.53

4.1.8.5. CML 2001 Nov '09 Method- Ozone Layer Depletion

In Figures C.93., C.94. and C.95., ODP scores for scenarios A.1.2, A.1.3 and A.1.4 are given, respectively. Scenarios A.1 and A.2 (Figures C.45. and C.47.) and Scenarios A.1.2, A.1.3, A.1.4 are contrasted. The score of Scenario A.1.2, A.1.3 and A.1.4 is calculated as, 2.2532 kg R11-Equiv., 3.1545 kg R11-Equiv. and 3.6052 kg R11-Equiv., respectively. In

new scenarios, it is observed that, 85.87 % of depletions in Scenario A.1 comes from transport & use stage, this is followed by production stage with 13.56 %.

When Figures C.45. and C.93. are compared, it is seen that the scores of the base capacity (1,000,000 items) scenario (Scenario A.1.2) and A.1 are almost same (0.11 % of difference). 40 % and 60 % of capacity enhancement causes 39.71 % and 61.73 % emission increase, respectively. The differences between scenarios are given in Table 4.8. As in other previous impact categories, it is observed that the utilization of more "raw materials" for capacity increase leads to higher emissions and scores rather than increasing capacity with recycle lines.

Table 4.8. Comparison of all ODP scores.

Comparison	% Difference
A.1 - A.2	1.28
A.1 - A.1.2	0.20
A.1 - A.1.3	40.15
A.2 - A.1.4	59.53

4.1.8.6. CML 2001 Nov '09 Method- Photochemical Ozone creation potential

In Figures C.96., C.97. and C.98. POCP results for scenarios A.1.2, A.1.3 and A.1.4 are given, respectively. The score of Scenario A.1.2, A.1.3 and A.1.4 is calculated as 97,012 kg Ethene-Equiv., 135,817 kg Ethene-Equiv. and 155,220 kg Ethene-Equiv., respectively. In these scenarios, it is calculated that, 92.79 % of depletions in Scenario A.1 comes from use stage, this is followed by production stage with 7.09 %.

For comparative analysis, Scenarios A.1 and A.2 (Figures C.61. and C.63.) and Scenarios A.1.2, A.1.3 and A.1.4 are examined. 40 % and 60 % of capacity enhancement causes 39.74 % and 59.59 % emission increase, respectively. When Figures C.61. and C.96 are compared, it is seen that the results of the base capacity (1,000,000 items) scenario (Scenario A.1.2) and A.1 are almost same. Consequently, it is attained that, increasing capacity by joining recycling facilities to the model rather than using supplement raw

material, creates less impacts in photochemical ozone creation potential category. The differences between scenarios are given in Table 4.9.

Table 4.9. Comparison of all POCP scores.

Comparison	% Difference
A.1 - A.2	0.07
A.1 - A.1.2	0.18
A.1 - A.1.3	39.74
A.2 - A.1.4	59.59

4.1.8.7. CML 2001 Nov '09 Method- Freshwater Aquatic Ecotoxicity, Marine Aquatic Ecotoxicity and Terrestrial Ecotoxicity Potentials

In Figures C.99., C.100. and C.101., FAETP results; in Figures C.102., C.103. and C.104., MAETP results; and in Figures C.105., C.106. and C.107., TETP results for Scenarios A.1.2, A.1.3 and A.1.4 are given, respectively.

FAETP: Scenarios A.1 and A.2 (Figures C.65. and C.67.) with Scenarios A.1.2, A.1.3 and A.1.4 (Figures C.99. to C.100.) are compared. The score of Scenario A.1.2, A.1.3 and A.1.4 is calculated as 1,587,656 kg DCB-Equiv., 2,222,718 kg DCB-Equiv., 2,540,249 kg DCB-Equiv., respectively. In these scenarios, it is determined that, 74.41 % of depletions in Scenario A.1 comes from transport & use stage, this is followed by production stage with 25.58 %. When Figures C.65. and C.99. are compared, it is noticed that the scores of the base capacity (1,000,000 items) scenario (Scenario A.1.2) is 0.43 % lower than Scenario A.1. 40 % and 60 % of capacity enhancement causes 39.39 % and 58.95 % emission increase, respectively. The differences between scenarios are given in Table 4.10.

Table 4.10. Comparison of all FAETP scores.

Comparison	% Difference
A.1 - A.2	0.22
A.1 - A.1.2	0.43
A.1 - A.1.3	39.39
A.2 - A.1.4	58.95

MAETP: In Figures C.102., C.103. and C.104., MAETP scores for scenarios A.1.2, A.1.3 and A.1.4 are given, respectively. Scenarios A.1 and A.2 (Figures C.69. and C.71.) and Scenarios A.1.2, A.1.3, A.1.4 are compared. The score of Scenario A.1.2, A.1.3 and A.1.4 is calculated as 46,614,014 kg DCB-Equiv., 65,259,620,598 kg DCB-Equiv. and 74,582,423,540 kg DCB-Equiv., respectively. In new scenarios, it is seen that, 98.9 % of depletions in Scenario A.1 comes from transport &use stage. When Figures C.69. and C.102 are compared, it is noticed that the results of the base capacity (1,000,000 items) scenario (Scenario A.1.2) and A.1 are almost same. 40 % and 60 % of capacity enhancement causes 39.45 % and 59.05 % emission increase, respectively. The differences between scenarios are given in Table 4.11.

Table 4.11. Comparison of all MAETP scores

Comparison	% Difference
A.1 - A.2	0.20
A.1 - A.1.2	0.40
A.1 - A.1.3	39.45
A.2 - A.1.4	59.05

TETP: In Figures C.105., C.106. and C.107., TETP scores for scenarios A.1.2, A.1.3 and A.1.4 are given, respectively. Scenarios A.1 and A.2 (Figures C.73. and C.75.) and Scenarios A.1.2, A.1.3, A.1.4 are compared. The score of Scenario A.1.2, A.1.3 and A.1.4 is calculated as, 135,395 kg DCB-Equiv., 189,553 kg DCB-Equiv. and 216,632 kg DCB-Equiv., respectively. In new scenarios, it is observed that, 93.98 % of depletions in Scenario A.1 comes from transport &use stage, this is followed by production stage with 5.75 %. When Figures C.73. and C.105. are compared, it is observed that the scores of the base

capacity (1,000,000 items) scenario (Scenario A.1.2) is 0.44 % lower than Scenario A.1. 40 % and 60 % of capacity enhancement causes 39.38 % and 59.38 % emission increase, respectively. The differences between scenarios are given in Table 4.12.

Table 4.12. Comparison of all TETP scores.

Comparison	% Difference
A.1 - A.2	0.05
A.1 - A.1.2	0.44
A.1 - A.1.3	39.38
A.2 - A.1.4	59.38

4.1.9. Impact Categories for different reuse options

In this part of the study, PE raw material and CML 2001 (November 2009) characterization method has been chosen for determination the effects of different reuse options. The options are defined as A.1.5, A.1.6 and A.1.7 which represents 350 times, 200 times and 100 times reuse of crates, respectively.

These scenarios is compared to Scenario A.1 which proposes 300 times reuse. For these scenarios the following environmental impacts are studied: abiotic depletion, acidification, eutrophication, global warming, ozone depletion, photochemical ozone formation and ecotoxicity potentials.

4.1.9.1. CML 2001 Nov ’09 Method- Abiotic Depletion (ADP), Elements

The scores of Scenarios A.1.5, A.1, A.1.6 and A.1.7 are calculated as 76.85322, 49.626587, 59.29446 and 40.6224 kg Sb-Equiv, respectively. In Scenarios A.1.5, A.1, A.1.6 and A.1.7, it is observed that, 53 %, 27 %, 39 % and 11 % of depletions comes from use stage, respectively. In addition to this, in Figure 4.1. change of ADP results with number of reuse are illustrated. A decrease in score of 300 times reuse model (Scenario A.1) is observed. The result of Scenario A.1 shows promising optimized performance in ADP category. In Figure C.108. comparative ADP results for Scenarios A.1.5, A.1.6 and A.1.7

are shown, respectively. The differences between transport & use stages of scenarios are also given in Table 4.13.

Table 4.13. Comparison of ADP scores.

Comparison	% Difference
A.1 - A.1.5	54.86 % of increase
A.1 - A.1.6	19.48 % of increase
A.1 - A.1.7	18.14 % of reduction

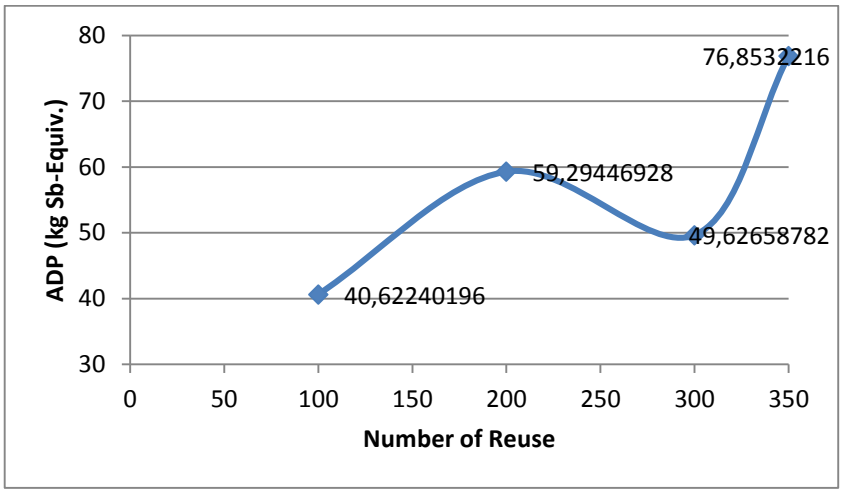

Figure 4.1. Change of ADP results with number of reuse.

Since the material used in Scenario A.1 does not change, percentage of scores caused by non-renewable resources is the same in Scenarios A.1.5, A.1.6 and A.1.7.

4.1.9.2. CML 2001 Nov '09 Method- Acidification Potential

The scores of Scenarios A.1.5, A.1.6 and A.1.7 are calculated as 1145359.95, 694231.64 and 380424.48 kg SO_2-Equiv., respectively. In Scenarios A.1.5, A.1, A.1.6 and A.1.7, it is observed that, 91.71 %, 86.31 % and 74.95 % of acidification scores comes from use stage, respectively. In Figure C.109. comparative AP results for Scenarios A.1.5, A.1.6 and A.1.7 are shown, respectively. It is observed that the scores increases when reuse times increases. Optimum number of reuse cannot be found in AP category. The differences between use stages of scenarios are given in Table 4.14.

Table 4.14. Comparison of AP scores

Comparison	% Difference
A.1 - A.1.5	21.51 % of increase
A.1 - A.1.6	26.34 % of reduction
A.1 - A.1.7	59.63 % of reduction

Since the material used in Scenario A.1 does not change, percentage of scores caused by inorganic emissions to air is the same in Scenarios A.1.5, A.1.6 and A.1.7.

4.1.9.3. CML 2001 Nov '09 Method- Eutrophication Potential

The scores of Scenarios A.1.5, A.1.6 and A.1.7 are calculated as 227557.76, 144210.8 and 83088.16 kg Phosphate-Equiv., respectively. In Scenarios A.1.5, A.1, A.1.6 and A.1.7, it is observed that, 76.55 %, 85.14 % and 59.29 % of eutrophication scores comes from transport &use stage, respectively. In Figure C.110. comparative EP results for Scenarios A.1.5, A.1.6 and A.1.7 are shown, respectively. It is observed that the scores increases when reuse times increases. Optimum number of reuse cannot be found in EP category. The differences between use stages of scenarios are given in Table 4.15.

Table 4.15. Comparison of EP scores.

Comparison	% Difference
A.1 - A.1.5	32,24 % of increase
A.1 - A.1.6	24,65 of reduction
A.1 - A.1.7	66,37 of reduction

Since the material used in Scenario A.1 does not change, percentage of scores caused by emissions is the same in Scenarios A.1.5, A.1.6 and A.1.7.

4.1.9.4 CML 2001 Nov '09 Method- Global Warming Potential

The scores of Scenarios A.1.5, A.1.6 and A.1.7 are calculated as 266639043.86, 171209693.33 and 100580538.43 kg CO_2-Equiv., respectively. In Scenarios A.1.5, A.1, A.1.6 and A.1.7, it is observed that, 83.18 %, 73.80 % and 55.40 % of global warming scores

comes from transport & use stage, respectively. In Figure C.111. comparative GWP results for Scenarios A.1.5, A.1.6 and A.1.7 are shown, respectively. It is observed that the scores increases when reuse times increases. Optimum number of reuse cannot be found in GWP category. The differences between use stages of scenarios are given in Table 4.16.

Table 4.16. Comparison of GWP scores.

Comparison	% Difference
A.1 - A.1.5	26.24 % of increase
A.1 - A.1.6	18.93 % of reduction
A.1 - A.1.7	52.38 % of reduction

Since the material used in Scenario A.1 does not change, percentage of scores caused by emissions is the same in Scenarios A.1.5, A.1.6 and A.1.7.

4.1.9.5 CML 2001 Nov '09 Method- Ozone Layer Depletion

The scores of Scenarios A.1.5, A.1.6 and A.1.7 are calculated as 2.80, 1.73 and 0.97 kg R11-Equiv., respectively. In Scenarios A.1.5, A.1, A.1.6 and A.1.7, it is observed that, 88.62 %, 81.60 % and 66.98 % of ozone layer depletion scores comes from transport &use stage, respectively. In Figure C.112. comparative ODP results for Scenarios A.1.5, A.1.6 and A.1.7 are shown, respectively. It is observed that the scores increases when reuse times increases. Optimum number of reuse cannot be found in ODP category. The differences between use stages of scenarios are given in Table 4.17.

Table 4.17. Comparison of ODP scores.

Comparison	% Difference
A.1 - A.1.5	24.08 % of increase
A.1 - A.1.6	23.23 % of reduction
A.1 - A.1.7	57.21 of reduction

Since the material used in Scenario A.1 does not change, percentage of scores caused by emissions is the same in Scenarios A.1.5, A.1.6 and A.1.7.

4.1.9.6. CML 2001 Nov '09 Method- Photochemical Ozone creation potential

The scores of Scenarios A.1.5, A.1.6 and A.1.7 are calculated as 116026.40, 69202.88 and 37428.55 kg Ethene-Equiv., respectively. In Scenarios A.1.5, A.1, A.1.6 and A.1.7, it is observed that, 93.80 %, 89.61 % and 80.79 % of scores comes from transport &use stage, respectively. It is observed that the scores increases when reuse times increases. Optimum number of reuse cannot be found in POCP category. In Figure C.113. comparative POCP results for Scenarios A.1.5, A.1.6 and A.1.7 are shown, respectively. The differences between transport & use stages of scenarios are calculated and given in Table 4.18.

Table 4.18. Comparison of POCP scores.

Comparison	% Difference
A.1 - A.1.5	19.36 % of increase
A.1 - A.1.6	28.81 % of reduction
A.1 - A.1.7	61.50 % of reduction

Since the material used in Scenario A.1 does not change, percentage of scores caused by emissions is the same in Scenarios A.1.5, A.1.6 and A.1.7.

4.1.9.7. CML 2001 Nov '09 Method- Freshwater Aquatic Ecotoxicity, Marine Aquatic Ecotoxicity and Terrestrial Ecotoxicity Potentials

FAETP scores of Scenarios A.1.5, A.1.6 and A.1.7 are calculated as 1,900,496 kg DCB-Equiv., 1,260,634 kg DCB-Equiv. and 807,455.5 kg DCB-Equiv., respectively. In Scenarios A.1.5, A.1, A.1.6 and A.1.7, it is observed that, 78.26, 67.22 and 48.83% of scores comes from transport & use stage, respectively. MAETP scores of Scenarios A.1.5, A.1.6 and A.1.7 are calculated as 54,902,728,479.95 kg DCB-Equiv., 31,583,157,936.88 kg DCB-Equiv. and 16,068,354,085 kg DCB-Equiv., respectively. In Scenarios A.1.5, A.1, A.1.6 and A.1.7, it is observed that, 98.73, 97.79 and 95.66 % of scores comes from transport & use stage, respectively. TETP scores of Scenarios A.1.5, A.1.6 and A.1.7 are calculated as 163010.3, 96630.46 and 51306.22 kg DCB-Equiv., respectively. In Scenarios A.1.5, A.1,

A.1.6 and A.1.7, it is observed that, 94.63 %, 90.95 % and 82.95 % of scores comes from transport &use stage, respectively. In Figure C.114. comparative ecotoxicity results for Scenarios A.1.5, A.1.6 and A.1.7 are shown, respectively. It is observed that the scores increases when reuse times increases. Optimum number of reuse cannot be found in ecotoxicity potentials category. The differences between transport & use stages of scenarios are given in Table 4.19.

Table 4.19. Comparison of ecotoxicity scores.

Comparison	**% Difference**		
	FAETP	**MAETP**	**TETP**
A.1 - A.1.5	25.90 % of increase	17.31 % of increase	19.86 % of increase
A.1 - A.1.6	28.26 of reduction	32.51 % of reduction	28.95 % of reduction
A.1 - A.1.7	66.62 of reduction	65.67 % of reduction	62.27 % of reduction

All characterization results (for Scenarios A.1, A.1.2, A.1.3, A1.4, A.1.5, A.1.6, A.1.7 and A.2) of Method Comparison Part is summarized in Table 4.20.

Table 4.20. Characterization results of Scenarios A.1, A.1.2, A.1.3 and A1.4.

	Characterization results of Method Comparison Part CML 2001	
Material welfare	**A.1:** 49.6266 kg Sb-Equiv. **A.1.2:**.49.7055 kg Sb-Equiv. **A.1.3:**69.5877 kg Sb-Equiv. **A.1.4:**79.5288 kg Sb-Equiv. **A.2:** 49.8285 kg Sb-Equiv.	**A.1:** 49.6266 kg Sb-Equiv. **A.1.5:** 76.85322kg Sb-Equiv. **A.1.6:** 59.29446 kg Sb-Equiv. **A.1.7:** 40.6224 kg Sb-Equiv.
Acidification	**A.1:** 942,570 kg SO_2-Equiv. **A.1.2:** 940,693 kg SO_2-Equiv., **A.1.3:** 1,316,971 kg SO_2-Equiv. **A.1.4:** 1,505,110 kg SO_2-Equiv. **A.2:** 937,196 kg SO_2-Equiv.	**A.1:** 942,570 kg S SO_2-Equiv. **A.1.5:** 1145359.95 kg SO_2-Equiv. **A.1.6:** 694231.64 kg SO_2-Equiv. **A.1.7:**380424.48 kg SO_2-Equiv.

Table 4.20. Characterization results of Scenarios A.1, A.1.2, A.1.3 and A1.4 (cont.).

	Characterization results of Method Comparison Part CML 2001	
Eutrophication	**A.1:**180,318 kg Phosphate-Equiv. **A.1.2:** 179,534 kg Phosphate-Equiv **A.1.3:**.51,348 kg Phosphate-Equiv. **A.1.4:**287,255 kg Phosphate-Equiv. **A.2:**180,190 kg Phosphate-Equiv.	**A.1:**180,318 kg Phosphate-Equiv. **A.1.5:** 227557.76 kg Phosphate-Equiv. **A.1.6:** 144210.8 kg Phosphate-Equiv. **A.1.7:**83088.16 kg Phosphate-Equiv.
Global warming	**A.1:** 211,204,762 kg CO_2-Equiv. **A.1.2:** 211,437,295 kg CO_2-Equiv. **A.1.3:**296,012,213 kg CO_2-Equiv. **A.1.4:**338,299,672 kg CO_2-Equiv. **A.2:** 212,063,108 kg CO2-Equiv.	**A.1:** 211,204,762 kg CO_2-Equiv. **A.1.5:** 266639043.86 kg CO_2-Equiv. **A.1.6:** 171209693.33 kg CO_2-Equiv. **A.1.7:**100580538.43 kg CO_2-Equiv.
Ozone depletion	**A.1:** 2.2578 kg R-11 Equiv. **A.1.2:** 2.2532 kg R11-Equiv. **A.1.3:**3.1545 kg R11-Equiv. **A.1.4:**3.6052 kg R11-Equiv. **A.2:** 2.2292 kg R-11 Equiv.	**A.1:** 2.2578 kg R-11 Equiv. **A.1.5:** 2.80 kg R-11 Equiv. **A.1.6:** 1.73 kg R-11 Equiv. **A.1.7:**0.97 kg R11-Equiv.
Photo-oxidant formation	**A.1:** 97,209 kg Ethene-Equiv. **A.1.2:**97,012 kg Ethene-Equiv. **A.1.3:**135,817 kg Ethene-Equiv. **A.1.4:**155,220 kg Ethene-Equiv. **A.2:** 97,259 kg Ethene-Equiv.	**A.1:** 97,209 kg Ethene-Equiv. **A.1.5:** 116,026.40 kg Ethene-Equiv. **A.1.6:** 69,202.88 kg Ethene-Equiv. **A.1.7:** 37,428.55 kg Ethene-Equiv.

Table 4.20. Characterization results of Scenarios A.1, A.1.2, A.1.3 and A1.4 (cont.).

	Characterization results of Method Comparison Part CML 2001	
Ecotoxicity	***FAETP:*** **A.1:** 1,594,525 kg DCB-Equiv. **A.1.2:** 1,587,656 kg DCB-Equiv., **A.1.3:** 2,222,718 kg DCB-Equiv. **A.1.4:** 2,540,249 kg DCB-Equiv. **A.2:** 1,598,119 kg DCB-Equiv.	***FAETP:*** **A.1:** 1,594,525 kg DCB-Equiv. **A.1.5:**1,900,496 kg DCB-Equiv. **A.1.6:** 1,260,634 kg DCB-Equiv. **A.1.7:** 807,455.5 kg DCB-Equiv.
	MAETP: **A.1:** 46,799,135,912 kg DCB-Equiv. **A.1.2:** 46,614,014 kg DCB-Equiv. **A.1.3:** 65,259,620,598 kg DCB-Equiv. **A.1.4:** 74,582,423,540 kg DCB-Equiv. **A.2:** 46,891,679,836 kg DCB-Equiv.	***MAETP:*** **A.1:** 46,799,135,912 kg DCB-Equiv. **A.1.5:** 54,902,728,479.95 kg DCB-Equiv. **A.1.6:** 31,583,157,936.88 kg DCB-Equiv. **A.1.7:** 16,068,354,085 kg DCB-Equiv.
	TETP: **A.1:** 135,997 kg DCB-Equiv. **A.1.2:** 135,395 kg DCB-Equiv. **A.1.3:** 189,553 kg DCB-Equiv. **A.1.4:**216,632 kg DCB-Equiv. **A.2:** 135,923 kg DCB-Equiv.	***TETP:*** **A.1:** 135,997 kg DCB-Equiv. **A.1.5:** 163010.3 kg DCB-Equiv. **A.1.6:** 96630.46 kg DCB-Equiv. **A.1.7:**51306.22 kg DCB-Equiv.

5. INTERPRETATION OF LCIA RESULTS

5.1. Normalization of Impact Assessment

Normalization is a procedure used for monitoring the contribution of one impact category to the overall environmental problem. In Figures C.115., C.116. and C.117. normalization results for Scenarios A.1, A.2, B.1 and B.2 are given for all three methodologies.

Normalized Environmental Impacts of Scenarios for EDIP 2003 method are given in Table 5.1. Normalized Environmental Impacts of Scenarios for EDIP 2003 method are shown in Figure C.117. According to EDIP 2003 methodology, it is noticed that Global Warming has the highest value above other impact categories for all scenarios. Photochemical ozone depletion- effects on vegetation category is the second highest in value (36 % lower than Global Warming). Photochemical ozone formation is in the third order. Moreover, it is seen that all scenarios have similar scores in normalized results.

Table 5.1. EDIP 2003 Method's Normalized Environmental Impacts of Scenarios.

	A.1	**B.1**	**A.2**	**B.2**
Acidification potential	7,238	7,236	7,248	7,243
Aquatic eutrophication	9,117	9,185	9,122	9,193
Global warming	24,381	24,457	24,480	24,478
Stratospheric ozone depletion	21.5638	21.5787	21.6138	21.6094
Photochemical ozone formation	Human: 15.4780	Human: 15.4400	Human: 15.4763	Human: 15.4523
	Vegetation: 16,198	Vegetation: 16,164	Vegetation: 16,198	Vegetation: 16,177

Like EDIP 2003's, CML values also prove that all scenarios have similar impacts in normalization. All comparable impact categories in the graphs (Figures C.117. and C.118.) have shown that ranking strategies of EDIP 2003 and CML 2001 differs in normalization stage. For example, the most distinct difference can be noticed in acidification impact results,

while CML 2001 favors acidification and ranks it to the third place, EDIP 2003 puts acidification in the 5th place order.

For CML 2001 Nov. ’09 methodology (Figure C.118.), the World context is adopted. Since CML method is only available for Europe, it is also selected for Turkey. In CML 2001 Nov. ’09 MAETP has the most severe impact when compared to other impact categories for all scenarios (all other impacts can be neglected when they are compared to MAETP) and Global Warming Potential comes in the second rank. It is found that this unusual appearance of MAETP in the result is due to the “energy grid process” in recycling stage. Normalized Environmental Impacts of Scenarios for CML 2001 Nov. ’09 method are given in Table 5.2.

Table 5.2. CML 2001 Method’s Normalized Environmental Impacts of Scenarios.

	A.1	**B.1**	**A.2**	**B.2**
Acidification potential	3.943821E-6	3.942203E-6	3,948721E-6	3,946082E-6
Eutrophication potential	1.138822E-6	1.139952E-6	1,138010E-6	1,140671E-6
Global warming potential	5.047866E-6	5.063799E-6	5,068381E-6	5,068316E-6
Ozone layer depletion potential	9.964503E-9	9.971504E-9	9,988095E-9	9,985937E-9
Photochemical ozone creation potential	3.348659E-6	3.331466E-6	3,350389E-6	3,333985E-6
Toxicity potential	FAETP: 4.592604E-7	FAETP: 3.856998E-7	FAETP: 4,602955E-7	FAETP: 3,869421E-7
	MAETP: 0.0002409854	MAETP: 0.00024086914	MAETP: 0,000241462	MAETP: 0,000241358
	TETP: 1.244270E-7	TETP: 1.241680E-7	TETP: 1,243595E-7	TETP: 1,243217E-7

Normalized Environmental Impacts of Scenarios for EI 99 method are given in Figure C.119 and Table 5.3. In EI 99 methodology, Climate Change and Acidification/Nutrification impacts have the highest significance in all scenarios and their values are very close to each other. As EDIP 2003 and CML 2001 normalizations results, all scenarios show similar impacts. However, unlike CML 2001 toxicity values, Ecotoxicity is not an important impact according to EI 99 methodology. On the other hand, when ozone depletion categories are

compared for CML 2001 and EI 99, it is seen that both methodologies ranks ozone depletion as least important therefore inputs are not visible in Figures C.117. and C.118.

Table 5.3. EI 99 Method's Normalized Environmental Impact Potential of Scenarios.

	A.1	**B.1**	**A.2**	**B.2**
Acidification/ nutrification	17,987	17,987	18,003	18,001
Climate change	18,433	18,495	18,510	18,512
Ozone layer depletion	10.6682	10.6754	10.6931	10.6909
Ecotoxicity	401.59	400.83	402.11	401.70

In Figure C.120. and Table 5.4. normalization results for Scenarios A.1.2, A.1.3 and A.1.4 are given for only CML 2001 '09 Nov methodology, for comparison of different capacities. For that reason Figures C.118. and C.120. are examined. According to normalization scores, the highest impact comes from MAETP and all and Global Warming Potential comes in the second rank.

Table 5.4. CML 2001 Method's Normalized Environmental Impacts of Scenarios.

	A.1.2	**A.1.3**	**A.1.4**
Acidification potential	3.935957E-6	5.510340E-6	6.297532E-6
Eutrophication potential	1.133868E-6	1.587415E-6	1.814188E-6
Global warming potential	5.053424E-6	7.074794E-6	8.085478E-6
Ozone layer depletion potential	9.944228E-9	1.392191E-8	1.591076E-8
Photochemical ozone creation potential	3.341874E-6	4.678623E-6	5.346998E-6
Toxicity potential	FAETP: 4.572821E-7	FAETP: 6.401950E-7	FAETP: 7.316514E-7
	MAETP: 0.000240032	MAETP: 0.000336045	MAETP: 0.000384051
	TETP: 1.238762E-7	TETP: 1.734267E-7	TETP: 1.982019E-7

In Figure C.121. normalization results for Scenarios A.1, A.1.5, A.1.6 and A.1.7 are given for only CML 2001 ’09 Nov methodology, for comparison of 300 times, 350 times, 200 times and 100 times reuses, respectively. According to normalization scores, MAETP category causes the highest impact and Global Warming Potential is the second.

5.2. Weighting

Weighting stage is used for evaluation of different environmental impacts according to each other. The results from the scenarios were all calculated as weighted potential impacts according to three methodologies and are given in Figures C.122., C.123. and C.124. for Scenarios A.1, A.2, B.1 and B.2.

In EDIP 2003 methodology, according to Figure C.122. for Scenario A.1, Global Warming category has the highest potential to cause significant impacts with 31.33 % of total score. This is followed by photochemical ozone depletion- impact on human with 24.71 %, Eutrophication potential with 12.76 %, Acidification potential with 10.54 %, Photochemical Ozone Formation - impact on vegetation with 1.55 % and Stratospheric Ozone depletion with 0.02 %. It is also determined that all scenarios have shown similar performances in weighting scores.

It is seen that 11.97 % of weighting scores result from production stage and the 87.33 % of emissions belong to transport & use stage. The highest environmental impact potential arises from “transportation process” in transport & use stage and has 55.76 % of the total score. 16.24 % of the score comes from “power generation process” in transport & use stage. “Thermal energy generation”, “wastewater treatment” and “diesel production” processes also causes 8.98 %, 3.36 % and 2.63 % of the score. On the other hand, most of the weighting scores of production stage (11.13 % of total score) are caused by “wastewater treatment” process.

At acidification potential category, production and transport & use stages causes 9.48 % and 78.83 % of weighting scores, respectively. While, “wastewater treatment process” of production stage has 8.49 % of the score, “diesel production”, “power generation”, “wastewater treatment”, “transport” and “thermal energy generation” processes of transport

& use stage result 4.33 %, 31.17 %, 2.56 %, 47.24 % and 4.51 % of the total score, respectively.

In terms of aquatic eutrophication, production and transport & use stage incorporate 10.77 % and 88.83 % of weighting scores, respectively. While, “wastewater treatment” process of production stage creates 10.35 % of the score, “power generation”, “wastewater treatment”, “transport” and “thermal energy generation” processes of transport & use stage result 4.35 %, 9.83 %, 70.11 %, 3.18 % of the score, respectively.

For global warming, production and transport & use stages possess 19.69 % and 78.83 % of weighting scores, respectively. While, “wastewater treatment” process of production stage causes 18.29 % of the score, “power generation”, “wastewater treatment”, “transport” and “thermal energy generation” processes of transport & use stage result 53.99 %, 5.52 %, 28.37 % and 18.98 % of the score, respectively.

At stratospheric ozone depletion results, production and transport & use stage have 12.94 % and 86.94 % of weighting scores, respectively. While, “wastewater treatment” process of production stage causes 12.92 % of the score, “power generation”, “wastewater treatment”, “transport” and “thermal energy generation” processes of transport & use stage result 4.98 %, 61.51 %, 3.90 % and 15.34 % of the score, respectively. The effect of wastewater treatment on ozone depletion was researched from the literature and deferred that any instantaneous or eventual N_2O emissions during biological wastewater treatment may cause an anthropogenic intrusion of global N_2O cycle and thus plays a decisive role in ozone depletion (Bhunia et al., 2010).

In photochemical ozone formation- effect on human category, production stage causes 7.55 % and transport & use stages leads 92.02 % of weighting scores. While, “wastewater treatment” process of production stage causes 6.77 % of the score, “power generation”, “diesel production”, “wastewater treatment”, “transport” and “thermal energy” generation processes of transport & use stage result 2.81 %, 9.29 %, 2.04 %, 72.10 and 5.42 % of the score, respectively.

In photochemical ozone formation- effect on vegetation category, production causes 7.44 % and transport & use stages creates 92.16 % of weighting scores. While, “wastewater treatment” process of production stage causes 6.79 % of the score, “power generation”, “diesel production”, “wastewater treatment”, “transport” and “thermal energy generation” processes of transport & use stage result 2.56 %, 9.11 %, 2.05 %, 72.10 % and 5.11 % of the score, respectively.

For Scenarios A.2, B.1 and B.2, similar percentages and scores are observed, as well (less than 0.01 % difference). Weighted Environmental Impacts of Scenarios A.1, A.2, B.1 and B.2 for EDIP 2003 methodology are given in Figure C.122. Weighted Environmental Impacts of Scenarios A.1, A.2, B.1 and B.2 for EDIP 2003 methodology are given in Table 5.5.

Table 5.5. EDIP 2003 Method’s Weighted Environmental Impacts of Scenarios A.1, A.2, B.1 and B.2.

	A.1	**B.1**	**A.2**	**B.2**
Acidification potential	9192	9190	9205	9199
Aquatic Eutrophication	11123	11205	11128	11215
Global warming	27307	27391	27418	27416
Stratospheric ozone depletion	1358	1359	1361	1361
Photochemical ozone formation	Human: 20.5858	Human: 20.5352	Human: 20.5835	Human: 20.5516
	Vegetation: 21543	Vegetation: 21498	Vegetation: 21544	Vegetation: 21515

For CML 2001 methodology the Southern Europe context is adopted. The reason for this assumption is the similarity of economical and climatic conditions between southern part of Europe and Turkey. In Figure C.123., CML methodology weighting results are given. In weighting results Global warming potential is found to be very distinct in other categories for all scenarios (Scenarios A.1, A.2, B.1 and B.2) and creates 81 % of all weighting score. In Scenario A.1 it is seen that Eutrophication potential and photochemical ozone depletion follow Global warming and weighting values are close to each other, which are 11 % and 10

% of the total weighting respectively. Acidification potential is the last category in order and contributes 7 % of the score.

17.57 % of weighting scores results from production stage and the 81.23 % of the score is caused by transport & use stage. The highest environmental impact potential arises from "transportation" process in transport & use stage and has 37.47 % of the total score. "Power generation", "thermal energy generation", "wastewater treatment" and "diesel production" processes of transport & use stage also causes 19.97 %, 15.05 %, 4.90 % and 3.53 % of the score. On the other hand, most of the weighting scores of production stage (16.25 % of total score) results from "wastewater treatment" process.

At acidification potential results, production and transport & use stages creates 9.19 % and 90.55 % of weighting scores, respectively. While, "wastewater treatment" process of production stage causes 8.32 % of the score, "diesel production", "power generation", "wastewater treatment", "transport" and "thermal energy generation" processes of transport & use stage result 3.76 %, 24.34 %, 2.51 %, 55.22 %, 4.34 % of the score, respectively.

In eutrophication potential category, production and transport & use stages has 18.06 % and 81.24 % of weighting scores, respectively. While, wastewater treatment process of production stage causes 17.69 % of the score, "power generation", "diesel production", "wastewater treatment", "transport" and "thermal energy generation" processes of transport & use stage result 1.72 %, 7.46 %, 5.34 %, 62.92 %, 3.47 % of the score, respectively.

For global warming potential, production and transport & use stages lead to 19.78 % and 78.74 % of weighting scores, respectively. While, wastewater treatment process of production stage causes 18.34 % of the score, "power generation", "diesel production", "wastewater treatment", "transport" and "thermal energy generation" processes of transport & use stage result 3.47 %, 22.23 %, 5.54 %, 28.14 % and 19.02 % of the score, respectively.

At stratospheric ozone depletion potential category, production and transport & use stages hold 12.92 % and 86.52 % of weighting scores, respectively. While, "wastewater treatment" process of production stage causes 12.90 % of the score, "power generation", "wastewater treatment", transport and "thermal energy generation" processes of transport &

use stage result 4.97 %, 61.43 %, 3.89 % and 15.32 % of the score, respectively. As EDIP 2001 weighting results indicated, it was noticed that "wastewater treatment" process has the highest impact in CML 2001 results, as well.

In photochemical ozone creation potential, 7.06 % and 92.61 % of weighting scores arise from production and transport & use stages, respectively. In production stage "wastewater treatment" and" polyethylene high density granulate production" processes cause 5.15 % and 1.90 % of the score, respectively. "Power generation", "diesel production", "wastewater treatment", "transport" and "thermal energy generation" processes of transport & use stage result 5.83 %, 15.07 %, 1.55 %, 63.15 % and 6.57 % of the score, respectively.

For Scenarios A.2, B.1 and B.2, similar percentages and scores are observed, as well. Weighted Environmental Impacts of Scenarios A.1, A.2, B.1 and B.2 for are given in Figure C.123. When Figures C.122. and C.123. are examined, it is seen that weighting strategies of EDIP 2003 and CML 2001 differs. However, in global warming potential and stratospheric ozone depletion potential categories it is observed that the percentages of the processes' scores show parallelism. Weighted Environmental Impacts of Scenarios A.1, A.2, B.1 and B.2 for are given in Table 5.6.

Table 5.6. CML 2001 Method's Weighted Environmental Impact Potential of Scenarios A.1, A.2, B.1 and B.2.

	A.1	**B.1**	**A.2**	**B.2**
Acidification potential	4,633030E-6	4,631819E-6	4,638332E-6	4,636070E-6
Eutrophication potential	7,988794E-6	7,996722E-6	7,983099E-6	8,001768E-6
Global warming potential	5,054032E-5	5,069795E-5	5,074566E-5	5,074316E-5
Ozone layer depletion potential	2,316643E-8	2,318199E-8	2,322038E-8	2,321559E-8
Photochemical ozone layer creation potential	7,271226E-6	7,233933E-6	7,274983E-6	7,239404E-6

In EI 99 methodology weighting results are given in Figure C.124. As in normalization stage, Climate Change and Acidification/ Nutrification impacts have the highest significance for Scenario A.1 with a share of 66 % and 31 %, respectively. Ecotoxicity results have the lowest score and only contribute to 7 % of the total weighting results. 10.57 % of weighting scores results from production stage and the 88.93 % of the score is caused by transport & use stage. The highest environmental impact potential (58.36 % of the total score) is caused by "transportation" process in transport & use stage. "Power generation", "thermal energy generation", "wastewater treatment" and "diesel production" processes of transport & use stage causes 17.70 %, 6.40 %, 2.62 % and 3.03 % of the score. In production stage, it is seen that 8.25 % and 2.19 % of total score results from "wastewater treatment" and "polyethylene granule production" processes, respectively. It is seen that in B type scenarios, the share of "polypropylene granule production processes" are 0.83 % of the total score.

At acidification/ nitrification category, production and transport & use stages contributes 7.61 % and 92.18 % of weighting scores, respectively. While, "wastewater treatment" process of production stage causes 7.10 % of the score, "power generation", "transport" processes of transport & use stage result 10.73% and 73.78 % of the score, respectively.

For ecotoxicity, 7.35 % and 91.77 % of weighting scores result from production and transport & use stages, respectively. While, "wastewater treatment" process of production stage causes 7.22 % of the score, "diesel production", "power generation", "tap water production" and "thermal energy generation" processes of transport & use stage result 14.99 %, 67.07 %, 2.43 %, 5.08 % of the score, respectively.

In climate change, production and transport & use stages covers 19.78 % and 78.75 % of weighting scores, respectively, which are similar to CML's weighting results, as well. While, "wastewater treatment" and "polyethylene granule production" processes of production stage causes 18.42 % and 1.33 % of the score, "diesel production", "power generation", "wastewater treatment", "transport" and "thermal energy generation" processes of transport & use stage result 3.36 %, 22.19 %, 5.56 %, 28.35 % and 18.96 % of the score, respectively.

In ozone layer depletion category, production and transport & use stages cause 12.94 % and 86.50 % of weighting scores, respectively. While, “wastewater treatment” process of production stage causes 12.92 % of the score, “diesel production”, “power generation”, “wastewater treatment” and “thermal energy generation” processes of transport & use stage result 4.97 %, 61.40 %, 3.90 % and 15.31 % of the score, respectively. Like in EDIP and CML methodology weighting results, in this category, the effect of “wastewater” process is observed.

Overall, it was noticed that the ratio and magnitude of these results resemble CML 2001 Nov ’09 methodologies’ scores. For Scenarios A.2, B.1 and B.2, similar percentages and scores are observed, as well (with less than 0.01 % difference). Weighted Environmental Impacts of Scenarios A.1, A.2, B.1 and B.2 for EI 99 methodology are given in Figure C.124 and in Table 5.7.

Table 5.7. EI 99 Method’s Weighted Environmental Impact Potential of Scenarios.

	A.1	**B.1**	**A.2**	**B.2**
Acidification/ nutrification	525,332	525,333	525,798	525,740
Climate change	1,143,987	1,147,858	1,148,775	1,148,876
Ozone depletion	60.6678	60.7086	60.8091	60.7966
Ecotoxicity	25,365	25,317	25,398	25,372

In Figure C.125. and Table 5.8., weighting results for Scenarios A.1.2, A.1.3 and A.1.4 are given for only CML 2001 ’09 Nov methodology, in order to compare different capacities. For Scenarios A.1.2, A.1.3 and A.1.4, while Global Warming category contributes 71.81% of the total score, Eutrophication potential, Photochemical ozone creation (impact on vegetation), Acidification and Ozone Layer Depletion Potentials has 11.29 %, 10.30 %, 6.56 %, 7 % and 0.03 % respectively.

Since most of the emissions are caused by production and transport & use phases, it is seen that weighting results of A.1 and A.1.2 are equal to each other. When Scenarios A.1 and A.1.3 compared, it is observed that 40 % of increment in virgin material (instead of recycled polyolefin) use also creates 40 % increase in weighting scores. Also comparison of

A.2 and A.1.4 showed that 60 % of increment in virgin material use creates 59.52 % increase in weighting results. In this final stage, it is deduced that capacity increase with recycling provides better results in terms of environmental impact categories in overall. Therefore Scenarios A.1, A.2, B.1 and B.2 should be favored rather than Scenarios A.1.2, A.1.3 and A.1.4.

Table 5.8. CML 2001 Method's Weighted Environmental Impact Potential of Scenarios.

	A.1	**A.1.2**	**A.1.3**	**A.1.4**	**A.2**
Acidification potential	4.633030E-6	4.624484E-6	6.474278E-6	7.399175E-6	4.638332E-6
Eutrophication potential	7.988794E-6	7.954040E-6	1.113565E-5	1.272646E-5	7.983099E-6
Global warming potential	5.054032E-5	5.059595E-5	7.083433E-5	8.095352E-5	5.074566E-5
Ozone layer depletion potential	2.316643E-8	2.311815E-8	3.236541E-8	3.698905E-8	2.322038E-8
Photochemical ozone layer creation potential	7.271226E-6	7.256490E-6	1.015908E-5	1.161038E-5	7.274983E-6

In Figure C.126. weighting results for Scenarios A.1.5, A.1.6 and A.1.7 are given (CML 2001 '09 Nov methodology used), for comparison of different reuse options. Weighted environmental impacts of scenarios are shown in Table 5.9. For all three scenarios, the highest weighted environmental impact potential comes from Global Warming and Eutrophication potentials.

Table 5.9. Contribution of Weighted Environmental Impact Potentials to weighting of Scenarios A.1.5, A.1.6 and A.1.7.

	Percentage of contribution (%) in reuse scenarios			
Category	**A.1.5**	**A.1**	**A.1.6**	**A.1.7**
Acidification potential	6.37	6.58	6.06	5.70
Eutrophication potential	11.43	11.34	11.42	11.36
Global warming potential	72.33	71.73	73.24	74.28
Ozone layer depletion potential	0.032501	0.03288	0.031597	0.030271
Photochemical ozone layer creation potential	9.84	10.32	9.25	8.64

Since most of the emissions in these scenarios are caused by production and transport & use phases, it is found that with higher reuse weighting results increase as well (Table 5.10.).

Table 5.10. Comparison of weighting scores.

	Acid-ification potential	**Eutroph-ication potential**	**Global warming potential**	**Ozone layer depletion potential**	**Photochem-ical ozone layer creation potential**	**% Total Difference**
A.1 - A.1.5	21.22 % increase	26.20 % increase	26.24 % increase	23.75 % increase	19.36 % increase	25.19 % increase
A.1 - A.1.6	26.87 % reduction	20.02 % reduction	18.93 % reduction	23.70 % reduction	28.82 % reduction	20.60 % reduction
A.1 - A.1.7	60.16 % reduction	53.92 % reduction	52.36 % reduction	57.65 % reduction	61.51 % reduction	54.00 % reduction

5.3. Comparison of Waste Management Strategies Used in the Study

In all cases it is observed that recycling phase does not provide more environmentally feasible reductions than incineration stage. The results are reflected in all Scenarios A.2 and B.2's graphs. The reason behind this deduction is the immerse energy generating from

incineration of waste plastics at the end of the life cycle. The energy is assumed to be used in cement factory in İstanbul for klinker production. The energy output from incineration phase of scenarios is summarized at Table 5.11 and Table 5.12. The data is taken from a cement factory in Karadeniz region.

Table 5.11. Energy used for klinker production (A.1., A.1.5, A.1.6, A.1.7, B.1, A.2, B.2).

	A.1., A.1.5, A.1.6, A.1.7	**B.1**	**A.2**	**B.2**
Raw material incinerated (tons)	1.4. 10^3	1.4. 10^3	1.6. 10^3	1.6. 10^3
Amount of energy output (kg coal equivalent)	581511.2	581497.4	41645.4	387674.1
Amount of energy output (kg-CO_2equivalent per unit)	2483499.6	2483441	177857.9	1655666.4
Amount of klinker produced (kg)	5123028	5122907	3415352	366840,5

Table 5.12. Energy used for klinker production (A.1.2, A.1.3, A.1.4).

	A.1.2	**A.1.3**	**A.1.4**
Raw material incinerated (tons)	$1.\ 10^3$	$1.4.\ 10^3$	$1.6.\ 10^3$
Amount of energy output (kg coal equivalent)	969185.3	1356859	1550696
Amount of energy output (kg-CO_2equivalent per unit)	4139166	5794832.4	6622665.7
Amount of klinker produced (kg)	8538379	11953731	13661407

Since same amount of plastic is used for all scenarios and scenarios A.1, A.1.5, A.1.6 and A.1.7 only differ in reuse section of the use phase, the energy output from incineration phase of these scenarios is same.

6. CONCLUSIONS

In this thesis, three commonly used LCA methodologies were compared, and analyses were carried out for polyolefin plastic crates. Additionally, improvement possibilities for the waste management of plastic crates were investigated. The scenarios were created based on using different: a) plastic raw materials, b) waste management alternatives and c) production capacities.

For analyses, EDIP 2003, CML 2001 Nov. ’09 and EI 99 were used in this study. Selected environmental impact categories were: “Resource Depletion”, “Acidification”, “Eutrophication”, “Global Warming”, “Ozone Depletion”, “Photo-Oxidant Formation” and “Toxicity”. The implementation and names of the categories depend on the methodology used. After the characterization stage, normalization and weighting stages were also included and presented.

According to results of the study, EDIP 2003 and CML 2001 Nov. ’09 (both of which are midpoint methodologies) showed similar performances, as it was presumed. It was also noticed that EI 99 method (an endpoint methodology) produced results parallel with the other two methodologies in some impact categories, as well. In the global warming and ozone depletion categories, the results of all three methods resemble each other, and related graphs (see Figures C.29. to C.52.) showed similar trends. For the global warming category emission scores, EDIP and CML yielded almost the same scores, with % 0.85 % of difference. In the same category, when comparing the results of CML and EI, a 1.05 % difference was observed. For the ozone depletion category emission scores, EDIP and CML showed a difference of 0.43 %; and, between CML and EI, the results indicated a 0.82% difference. Therefore, in the Global Warming and Ozone Depletion categories, the results did not show any significant variations with methodology selection. For other impact categories, similarities were also found. For resource depletion, acidification, eutrophication, photo-oxidant formation and toxicity categories, similarities in the distribution and magnitude of emissions and results with respect to stages are seen. The least significant resemblance was noticed in the toxicity category.

It was concluded that both midpoint and endpoint level indicators have their own merits and limitations and can be used in a complimentary way. The user can see the comparative results at the midpoint level, as well as at the endpoint level and utilize the information in decision making.

Crate production and transport & use stages are the main life cycle stages that contribute to the majority of emissions. Therefore, it was determined that raw material selection, variations in manufacturing technologies or in logistics strategies may change the magnitude of impact scores.

Two different raw materials (PE and PP) were used in this project, reflecting the reality in applications in the crate industry. Similar performances for PE and PP in terms of characterization, normalization and weighting were observed at the end of each LCA scenario for all methodologies. In a comparative analysis for all methodologies, differences of less than 1% were obtained between raw materials in characterization. According to EDIP 2003, results from the acidification and photo-oxidant formation categories' slightly favor the use of PP, however, the eutrophication category results weakly support PE use. Similar results were seen upon applying CML 2001 Nov. '09, as well; while acidification, photo-oxidant formation and toxicity category results support PP based scenarios, eutrophication and global warming category results show PE use is more advantageous. In the same manner, for EI 99, toxicity category results state that PP raw material may be favored on one hand, while on the other hand, resource depletion and global warming category results indicate that using PE may be preferred. However, none of these results are distinct and feasible for raw material selection; thus, it has been concluded that both materials showed parallel performances. Moreover, it has also been noted that, in midpoint methodologies, acidification and photo-oxidant formation are common categories for favoring PP use, and the eutrophication category commonly encourages PE use. There are also similarities between the EI 99 and CML 2001 methodologies. Toxicity and global warming categories are common indicating categories for the selection of raw material. It has been deduced that one of the mid-point methods may be used alongside an end-point method in order to fully evaluate the environmental performance of a product.

Since recycling systems are often incorporated in scenarios for compliance to regulations, the effects of recycling were researched. For evaluations of emissions the CML 2001 Nov ’09 methodology was used. It was clearly observed that including recycling instead of using only virgin raw materials is very advantageous. When Scenarios A.1 and A.1.3 were compared, a reduction of approximately 28 % was observed in all available CML 2001 Nov ’09 characterization categories. Similarly, a reduction of approximately 37 % in various categories was monitored when Scenarios A.2 and A.1.4 are compared. Consequently, it has been concluded that Scenarios A.1, A.2, B.1 and B.2 (scenarios with a recycling system which incorporates the use of recycled materials) should be favored over Scenarios A.1.2, A.1.3 and A.1.4 (scenarios that use only virgin raw material).Since most emissions are caused by production and transport &use phases, the results of Scenarios A.1 and A.1.2 were found to be equal to each other. When Scenarios A.1 and A.1.3 were compared, it was observed that a 40 % increment in virgin raw material use also generates a 40 % increase in weighting scores. Additionally, comparison of Scenarios A.2 and A.1.4 showed that a 60 % increment in virgin raw material use produces a 59.52 % increase in weighting results. In this final stage, it is was deduced that a capacity increase with recycling provides better results in terms of environmental impact categories and weighting overall. Therefore, Scenarios A.1, A.2, B.1 and B.2 should be favored rather than Scenarios A.1.2, A.1.3 and A.1.4. It is also observed that increasing the recycling rates from 40 % (present application) to 60 % (future target) enhances the emissions of the recycling stage. However, recycling stage emission scores are negligible compared to the results of production and transport & use stages. Further, the weighting stage of the impact assessment for Scenarios A.1, A.2, A.1.2, A.1.3 and A.1.4 proved that increasing the recycling rates in the future is a better alternative than using higher amounts of virgin raw materials (Figure C.125.).

In addition, with the exception of global warming, in most impact categories the “incineration & landfilling” strategy showed better performance relative to recycling. However, based on the global warming result of the present scenario (Scenario A.1.: 40 % of waste is recycled, 48 % is incinerated and the remainder is landfilled), CH_4 and CO_2 emission scores for the recycling stage were lower than for the “incineration & landfilling” stage (where the incineration portion is 45 %). When the present case was compared to the future target case, it was seen that CH_4 and CO_2 emissions increased. It was also observed that the incineration of waste plastics at the end of their life cycle generates high amounts of

energy. This energy can be used in cement factories in İstanbul as feedstock for clinker production.

Scenarios A.1, A.1.5, A.1.6 and A.1.7 were compared (CML 2001 Nov. ’09 methodology) for researching different reuse options. For these scenarios, it was observed that the highest weighted environmental impact potential comes from global warming and eutrophication potentials due to the “transport process” (which transports crates) and “wastewater processes” (which treat washing water each time the crates are reused). Since the majority of the emissions in all scenarios are caused by production and transport &use phases, it was found that reusing the same crate many times increases weighting results. It was calculated that when reuse decreases from 350 to 300 times (a decrease of 14 %), a reduction of between 19.36 % and 32.24 % in most of the CML’s impact categories is achieved, with the exception of ADP (which corresponds to a 25.19 % reduction in weighting scores). Only the result of Scenario A.1 (reuse of 300 times) shows a promising optimized performance in this category. It was seen that when reuse decreases from 350 to 300 times, a 54.86 % reduction in ADP scores is achieved.

Since transport & use stage contributes to the majority of emissions, transportation solutions may be sought for improvement. In this regard, using “Green Trucks” instead of conventional trucks is an option. The trucks for crate transportation can be analyzed and chosen according to “Green Scores and Class Rankings”. Furthermore, as most of the environmental damage occurs during driving, emissions are greatly associated with fuel consumption. It is suggested that choosing more fuel-efficient vehicles would reduce reliance on a world oil market. In this context, “Green Diesel” use may be considered. As determined by LCA studies, green diesel produced via the “ecofining” process has environmental benefits over petroleum diesel, biodiesel and fossil-derived syndiesel. Compared to biodiesel, green diesel shows higher savings in fossil energy per ton of biofuel. In addition to these, transportation capacity is another important parameter. Carrying an extra 100 pounds reduces fuel economy by about 1 percent. Another recommendation for transportation emission is to avoid "aggressive driving”. According to related studies, it is found that driving 75 mph instead of 65 mph can considerably increase emissions in many vehicles. (American Council for an Energy-Efficient Economy Official Web site, 2014; Kalnes et al., 2008). Moreover, another issue in crate transport is transportation of empty

crates to the fields from crate manufacturing facility. The crates are sent without vegetables and are not used as containers. As the issue was investigated and it was seen that for that reason, an optimized road map procedure for crate transportation has been used by crate manufacturers in Europe (Euro Pool System Official Web site, 2014). Similar arrangements may be planned for Turkey as well. Lastly, according to EPA (2008) vehicle age and accumulated mileage affects the rate at which vehicle emits air pollutants. Thus, replacing old trucks can reduce emissions.

It is recommended that in future scenarios for LCA projects, the number of times a polyolefin recycled can be increased up to three times (limited by material features), and as a result, virgin raw material use may be reduced. In addition, for a constant capacity, different recycle rates can be analyzed and various disposal management strategies may be researched. Ecotoxicity modelling for Turkey may also be researched using the EI 99 methodology.

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APPENDIX A

System Boundaries

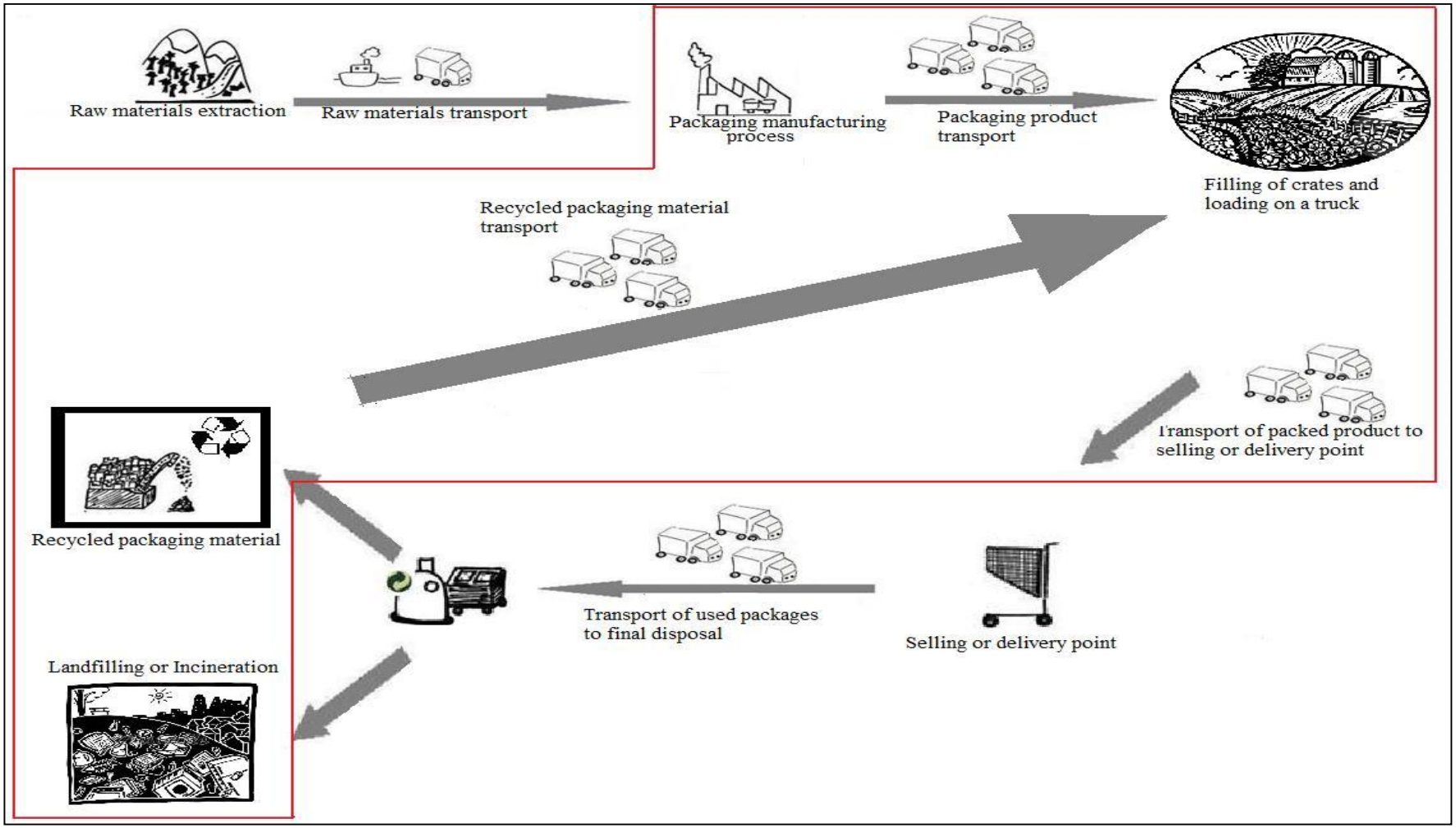

Figure A.1. System boundaries.

APPENDIX B

Inventory Tables

Table B.1. Inventory table for Scenario scenarios related to Polyethylene (continued on the next page).

	Input/ Output Values	Product				
		Polyethylene Crates				
LCA Stage	**Material (kg)**	**A-1**	**A-1.2**	**A-1.3**	**A-1.4**	**A-2**
Production Stage	**Crate Injection Process Inputs**					
	Polyethylene high density granulate (PE HD) [Plastics]	1500000	1500000	2100000	2400000	1500000
	Power [Electric power]	82799	82799	115919	132478	82800
	RER: tap water, at user	2340000	2340000	3276000	3744000	2340000
	Crate Injection Process Outputs					
	PE crate [Resources]	1500000	1500000	2100000	2400000	1500000
	Emissions to sea water					
	Waste water [Other emissions to sea water]	2340000	2340000	3276000	3744000	2340000
	Waste water [Other emissions to fresh water]	1,75E+11	1,7E+11	2,4E+11	2,8E+11	4,08E+08
	Cargo	1500000	1500000	2100000	2400000	1500000

Table B.1. (Continued).

Recycling Stage	**Recycled Granulate Production Inputs**					
	RER: tap water, at user	17280173	-	-	-	25920260
	Power [Electric power]	965392	-	-	-	1448089
	Polyethylene (PE) [Waste for Scenario recovery]	600000	-	-	-	900000
	Recycled Granulate Production Outputs					
	Waste water [Other emissions to sea water]	17280173	-	-	-	25920260
	Recycled PE granulate	540005	-	-	-	810008
	Waste for Scenario disposal (unspecified)	59995	-	-	-	89992
	Recycled Crate Production Process Inputs					
	RER: tap water, at user	2527225	-	-	-	3790838
	Recycled PE granulate	540005	-	-	-	810008
	Power [Electric power]	89424	-	-	-	134136
	Recycled Crate Production Process Outputs					
	Waste water [Other emissions to sea water]	2527225	-	-	-	3790838
	Recycled PE crate [Resources]	540005	-	-	-	810008

Table B.3. Inventory table for Scenario scenarios related to reuse of Polyethylene (continued on the next page).

	Input/ Output Values	**Product**		
		Polyethylene Crates		
LCA Stage	**Material (kg)**	**A.1.5**	**A.1.6**	**A.1.6**
Production Stage	**Crate Injection Process Inputs**			
	Polyethylene high density granulate (PE HD) [Plastics]	1500000	1500000	1500000
	Power [Electric power]	82799	82799	82799
	RER: tap water, at user [Appropriation]	2340000	2340000	2340000
	OUTPUTS			
	PE crate [Resources]	1500000	1500000	1500000
	Waste water [Other emissions to sea water]	2340000	2340000	2340000
Use Stage	**Washing Process Inputs**			
	RER: tap water, at user	1,58E+09	900000000	450000000
	Thermal energy (MJ) [Thermal energy]	766056000	436200000	218000000
	Cargo [Others]	1500000	1500000	1500000
	Power [Electric power]	315900000	180000000	90000000
	Washing Process Outputs			
	Waste water [Other emissions to fresh water]	1421550000	810000000	137700000
	Cargo[Others]	1500000	1500000	1500000

Table B.3. (Continued).

Recycling Stage	**Recycled Granulate Production Inputs**			
	RER: tap water, at user	17280173	17280173	17280173
	Power [Electric power]	965392	965392	965392
	Polyethylene (PE) [Waste for Scenario recovery]	600000	600000	600000
	Recycled Granulate Production Outputs			
	Waste water [Other emissions to sea water]	17280173	17280173	17280173
	Recycled PE granulate	540005	540005	540005
	Waste for Scenario disposal (unspecified)	59995	59995	59995
	Recycled Crate Production Inputs			
	RER: tap water, at user [Appropriation]	2527225	2527225	2527225
	Recycled PE granulate [Valuable substances]	540005	540005	540005
	Power [Electric power]	89424	89424	89424
	Recycled Crate Production Outputs			
	Waste water [Other emissions to sea water]	2527225	2527225	2527225
	Recycled PE crate [Resources]	540005	540005	540005

APPENDIX C

Characterization Results

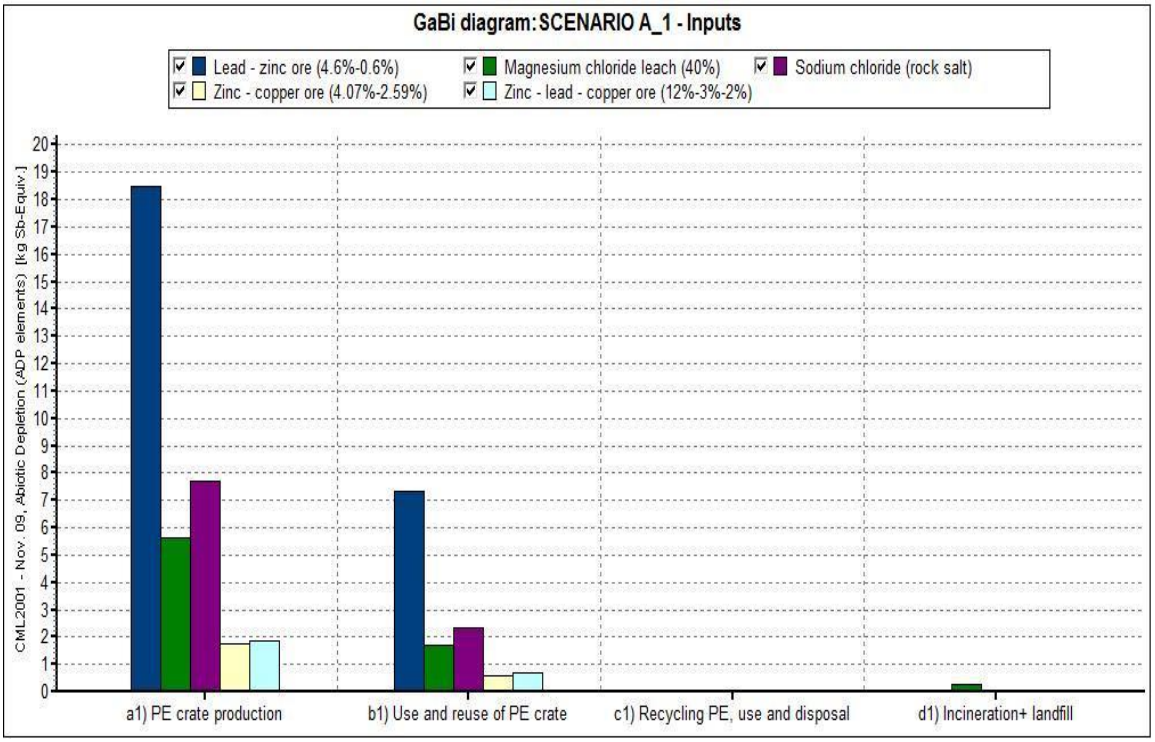

Figure C.1. CML Nov. ‘09 2001 Method. ADP results for Scenario A.1.

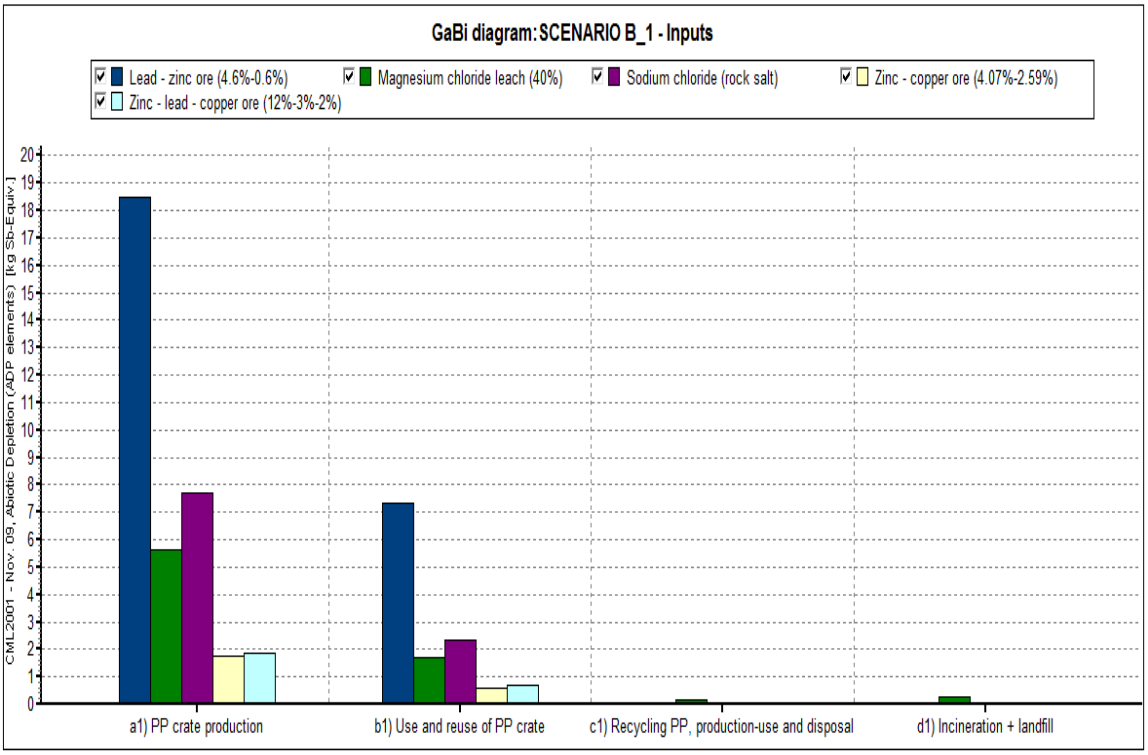

Figure C.2. CML 2001 Nov. ‘09 Method. ADP results for Scenario B.1.

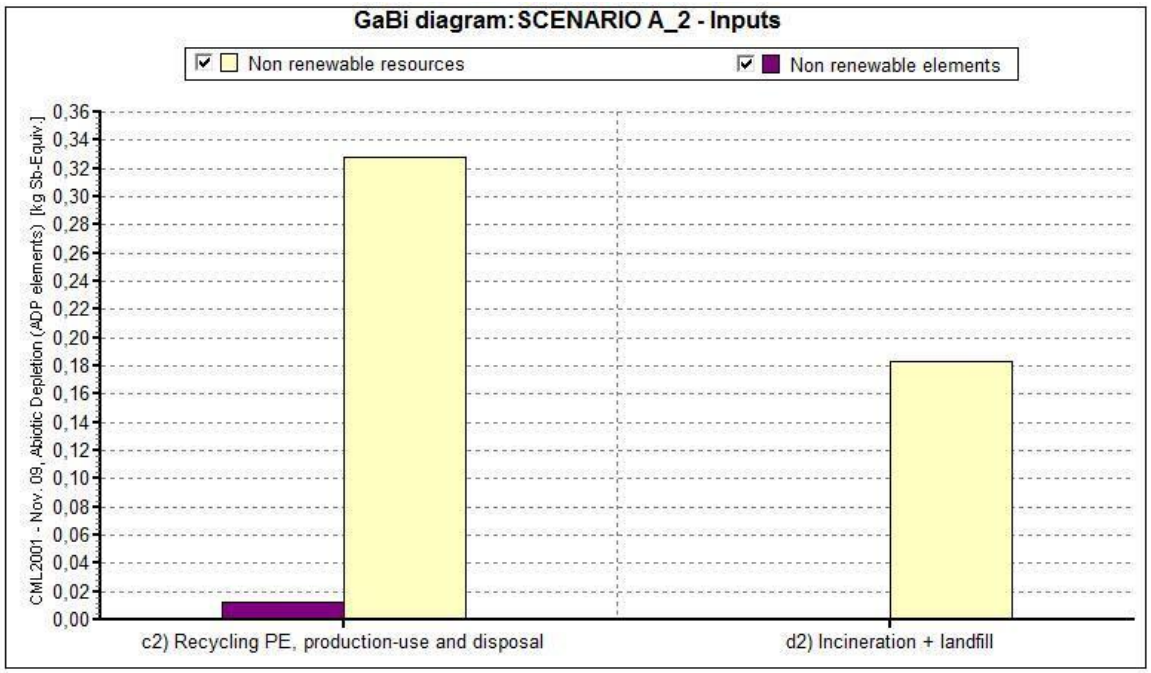

Figure C.3. CML 2001 Nov. ‘09 Method. ADP results for Scenario A.2.

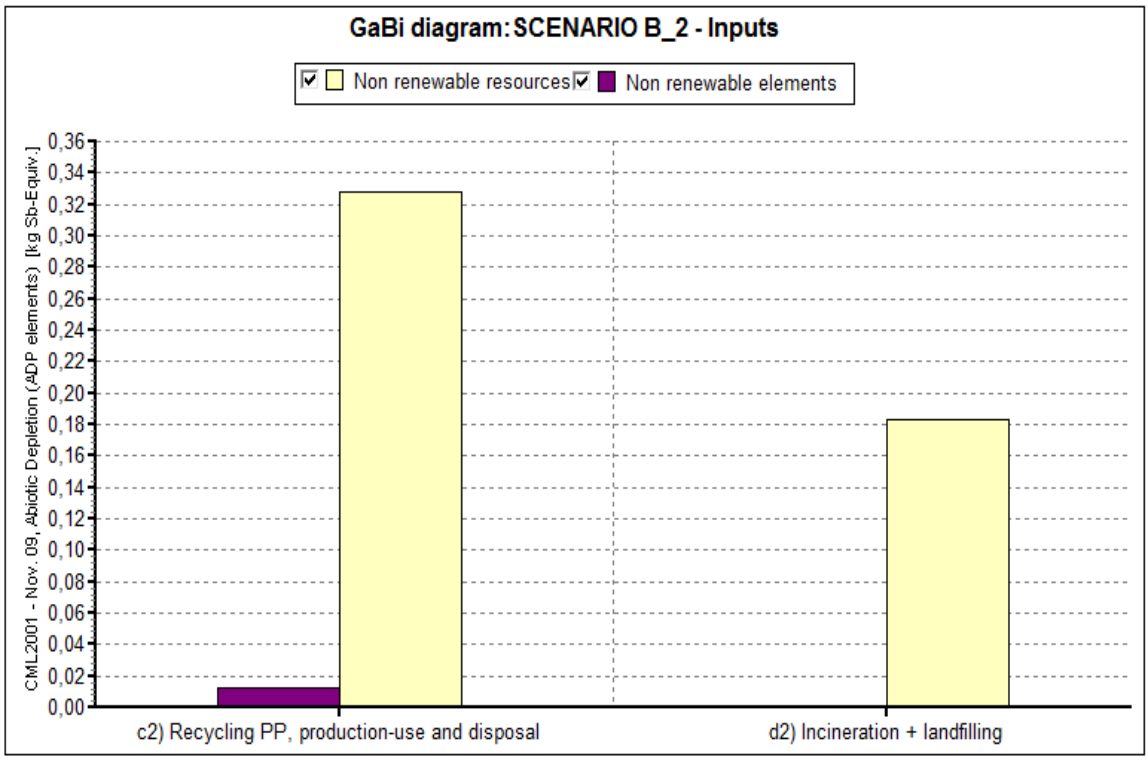

Figure C.4. CML 2001 Nov. ‘09 Method. ADP results for Scenario B.2.

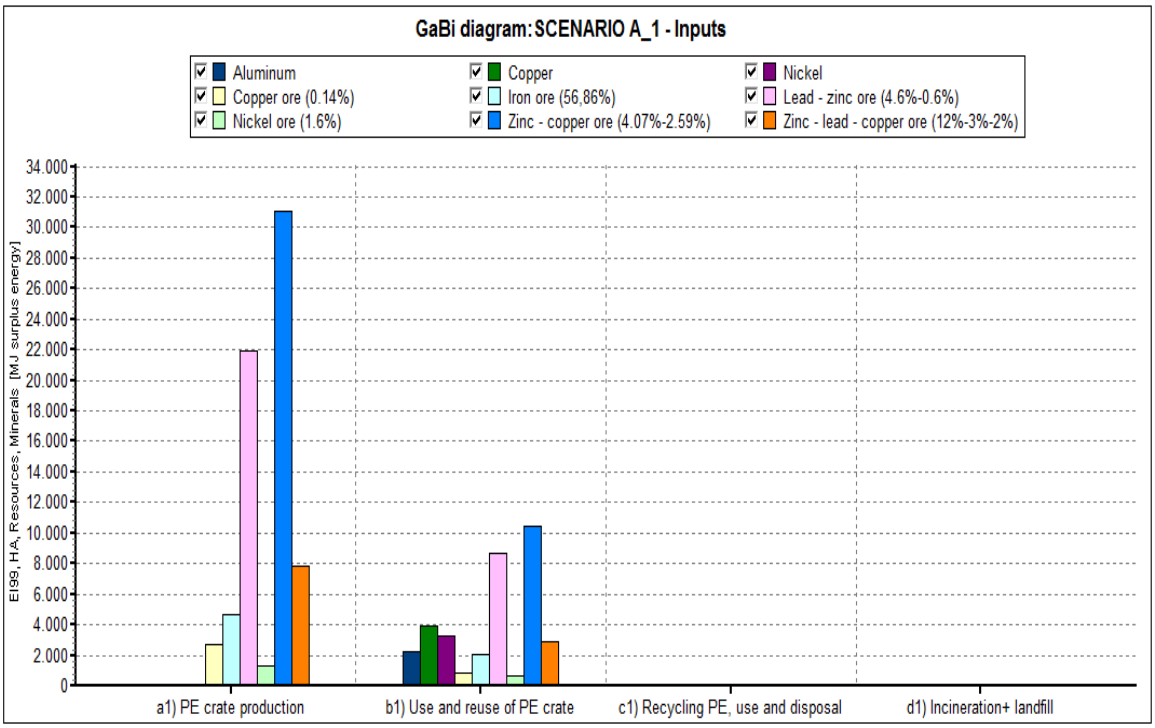

Figure C.5. EI 99 Method. Resources, Minerals results for Scenario A.1.

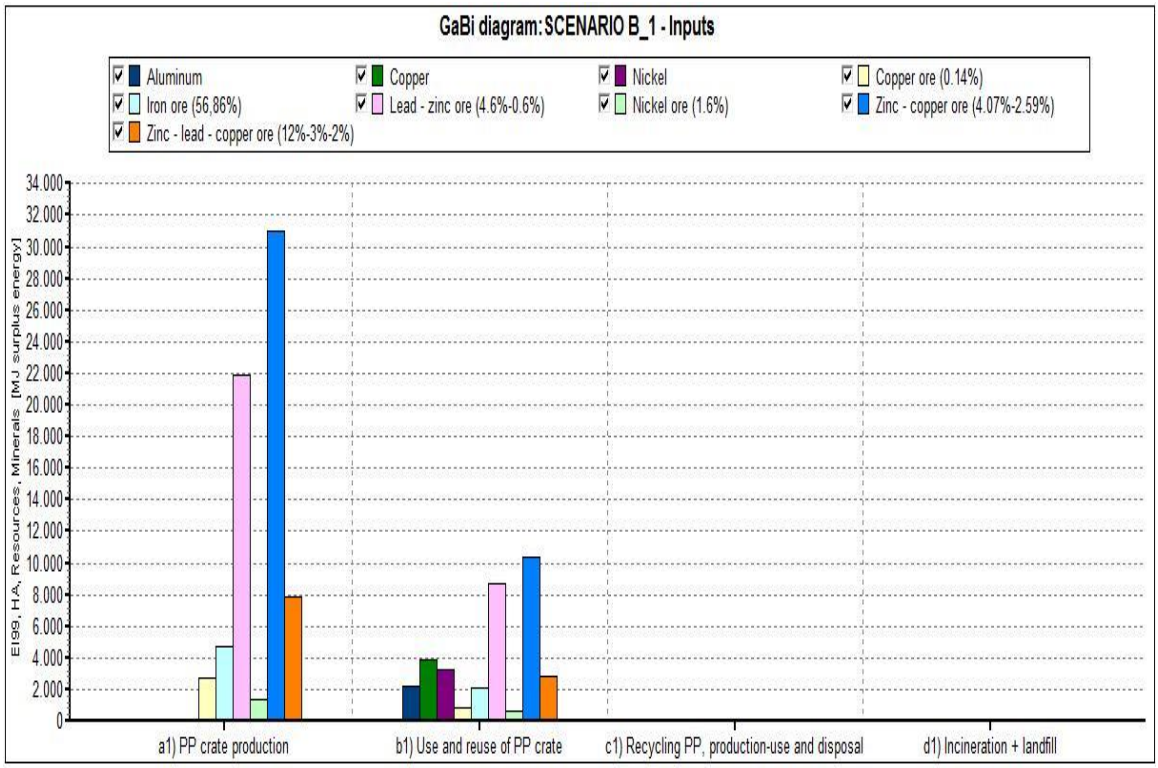

Figure C.6. EI 99 Method. Resources, Minerals results for Scenario B.1.

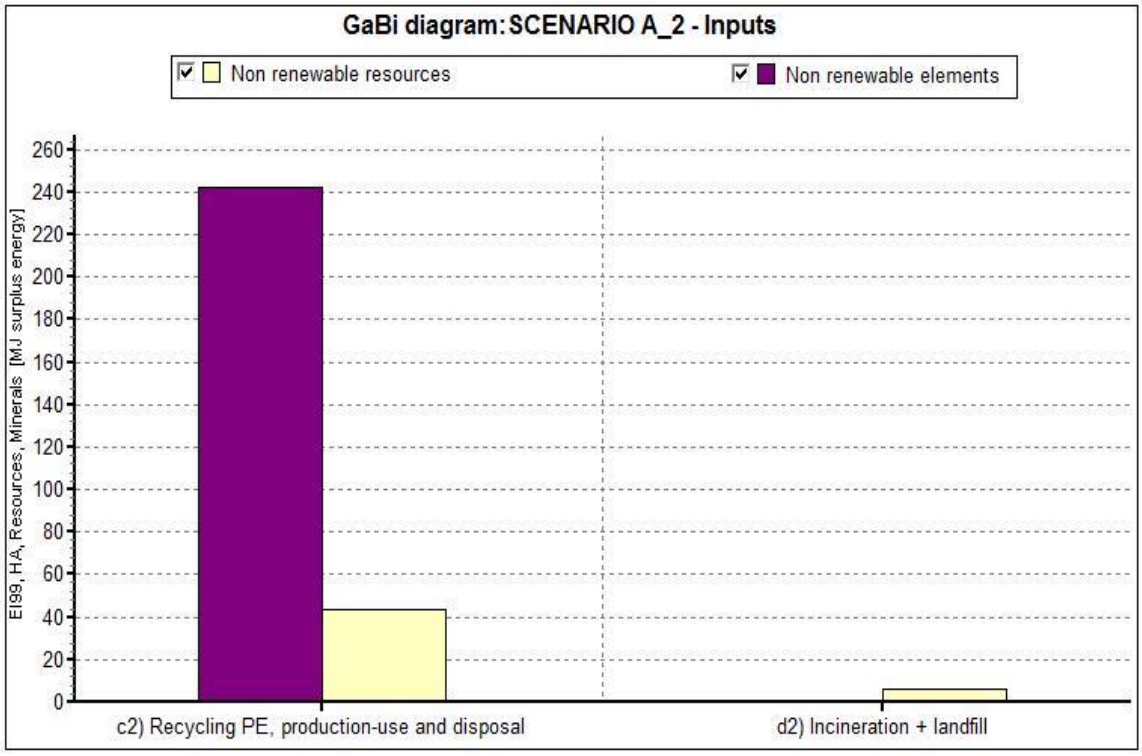

Figure C.7. EI 99 Method. Resources, Minerals results for Scenario A.2.

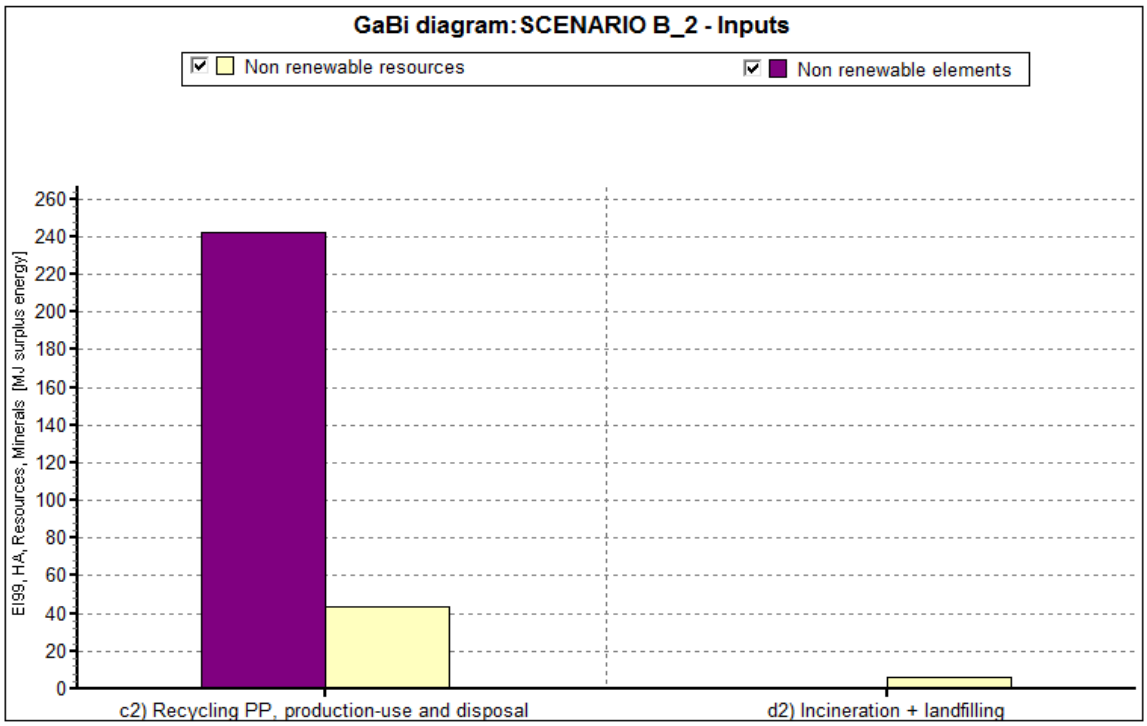

Figure C.8. EI 99 Method. Resources, Minerals results for Scenario B.2.

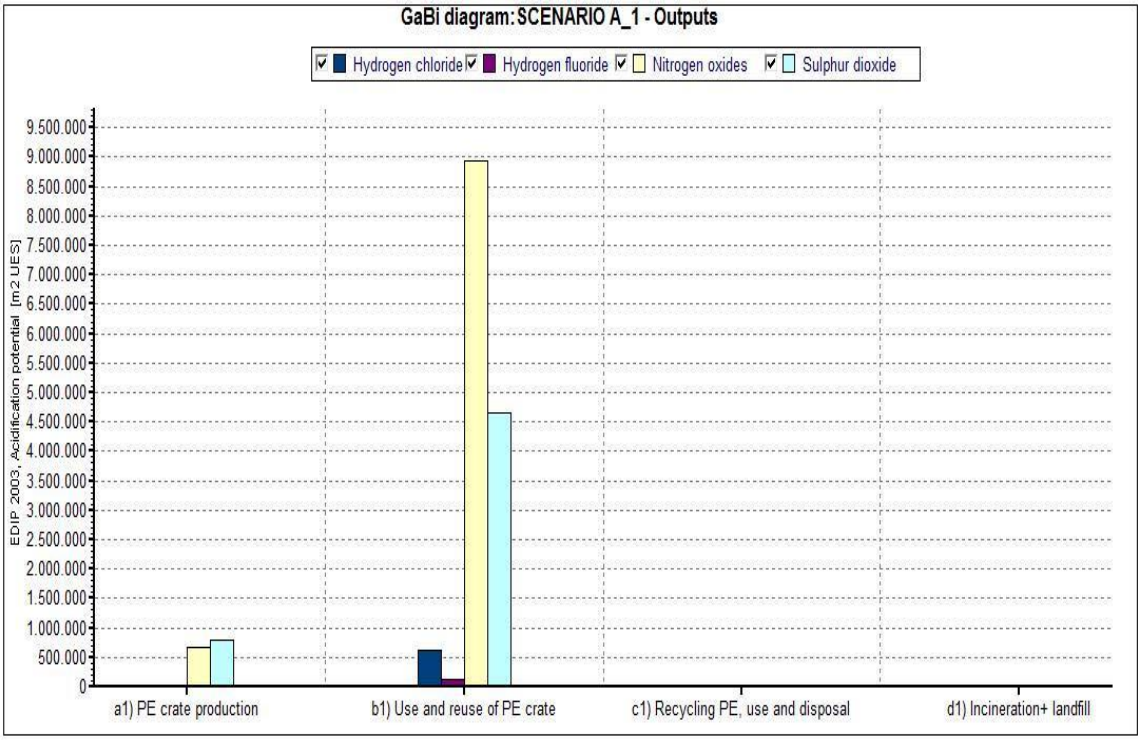

Figure C.9. EDIP 2003 Method. Acidification Potential results for Scenario A.1.

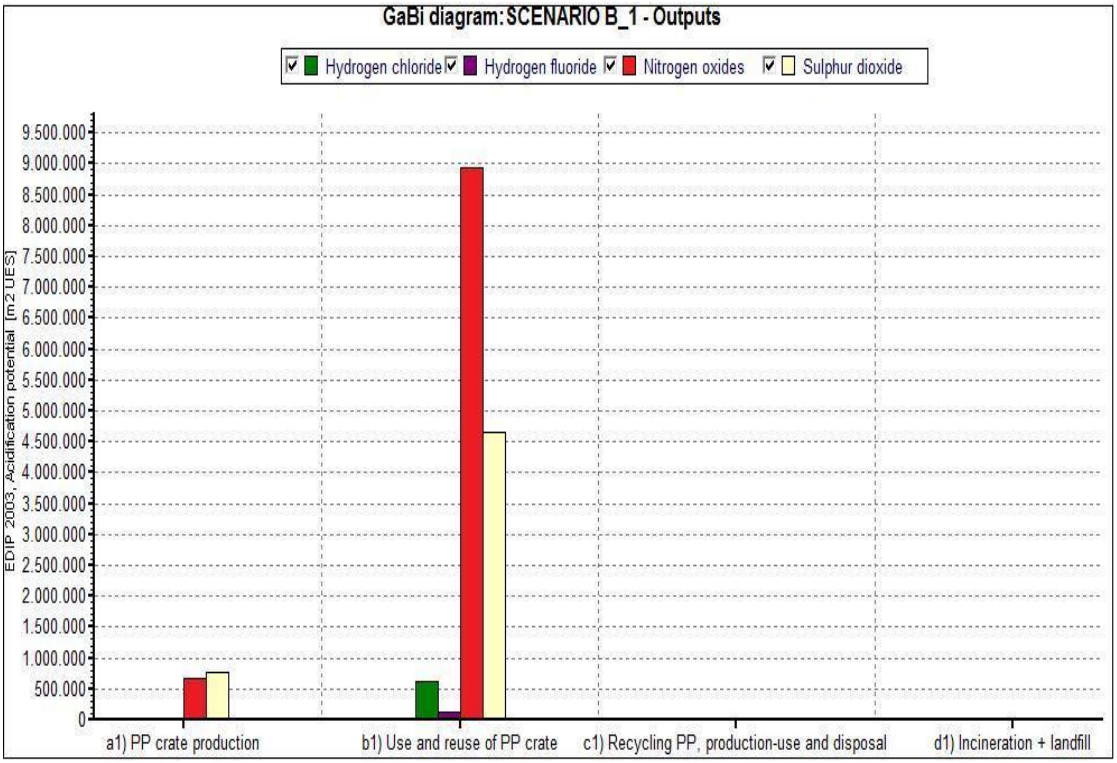

Figure C.10. EDIP 2003 Method. Acidification Potential results for Scenario B.1.

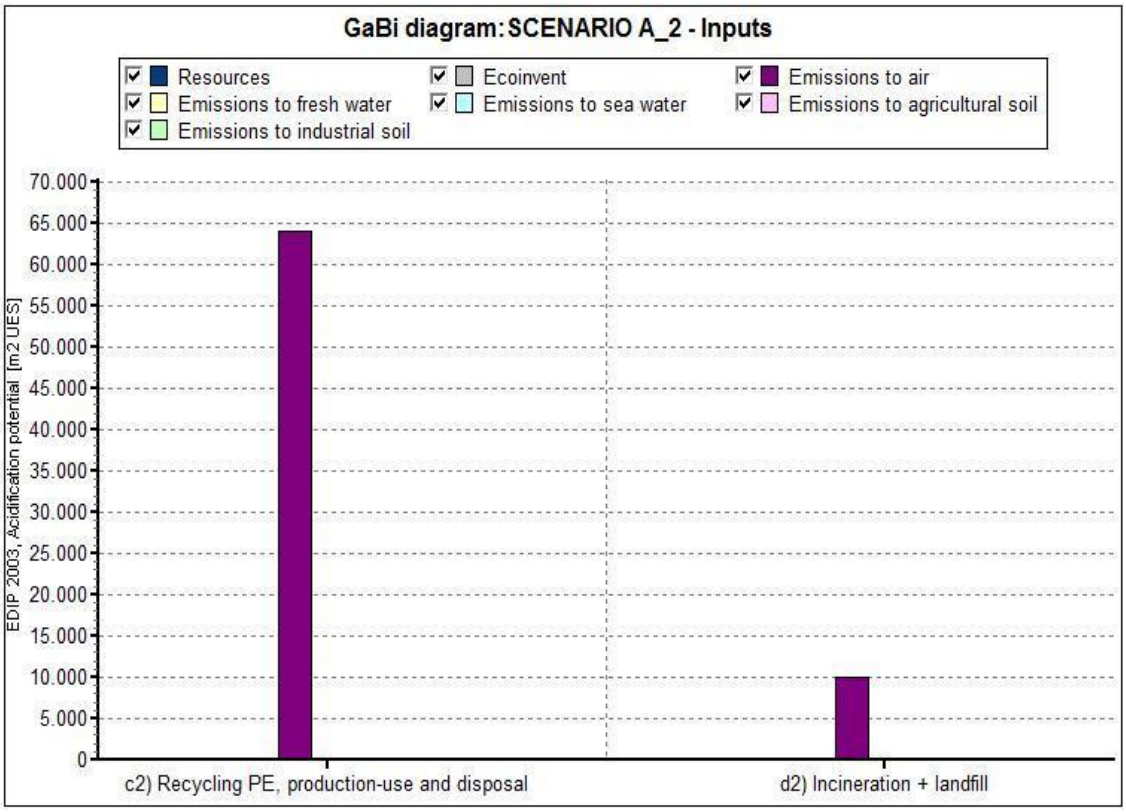

Figure C.11. EDIP 2003 Method. Acidification Potential results for Scenario A.2.

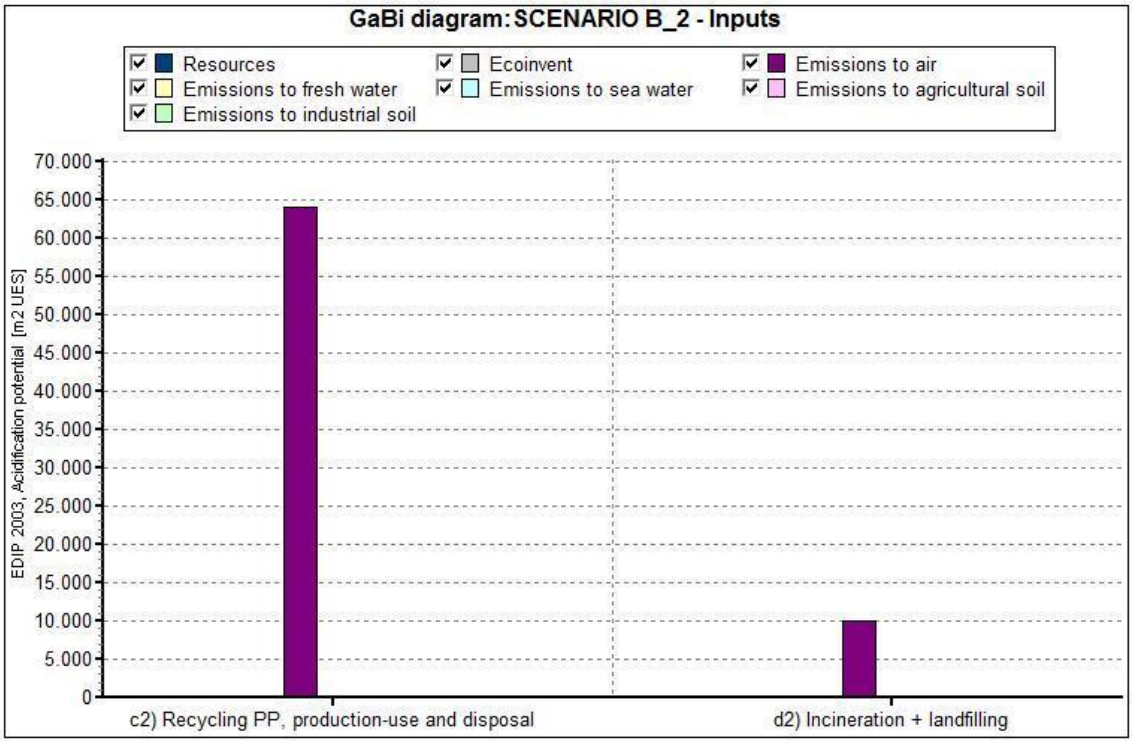

Figure C.12. EDIP 2003 Method. Acidification Potential results for Scenario B.2.

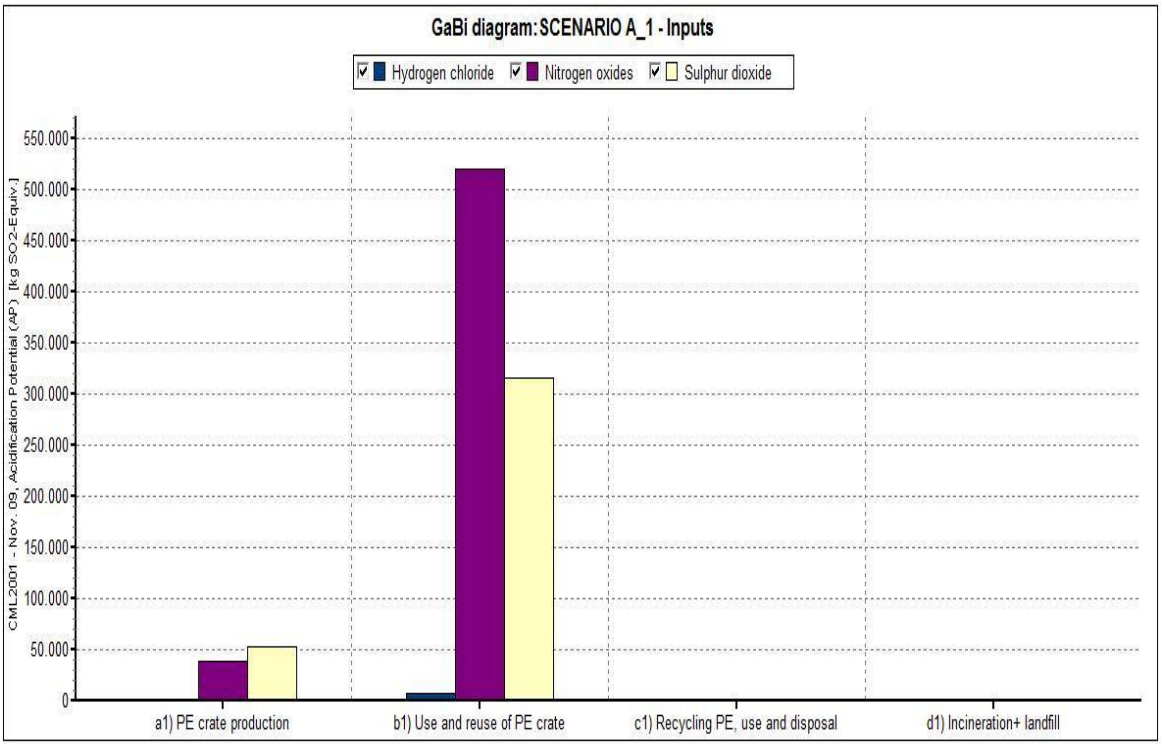

Figure C.13. CML 2001 Nov. ’09 Method. Acidification Potential results for Scenario A.1.

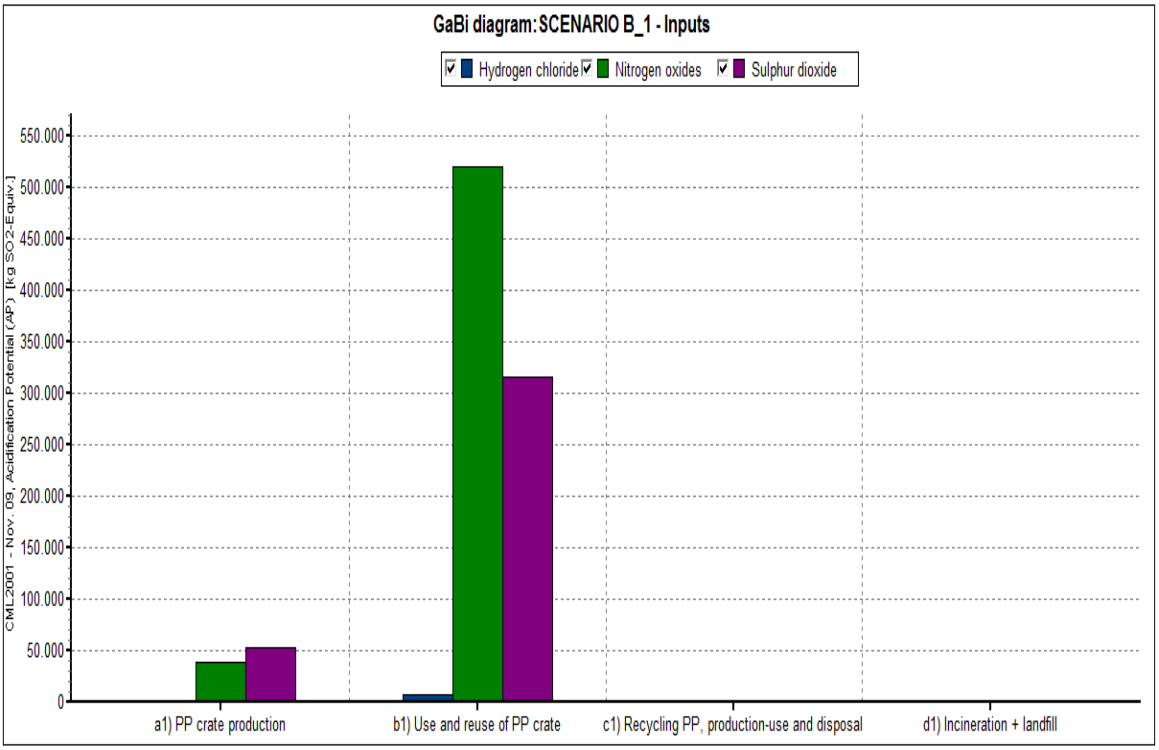

Figure C.14. CML 2001 Nov. ’09 Method. Acidification Potential results for Scenario B.1.

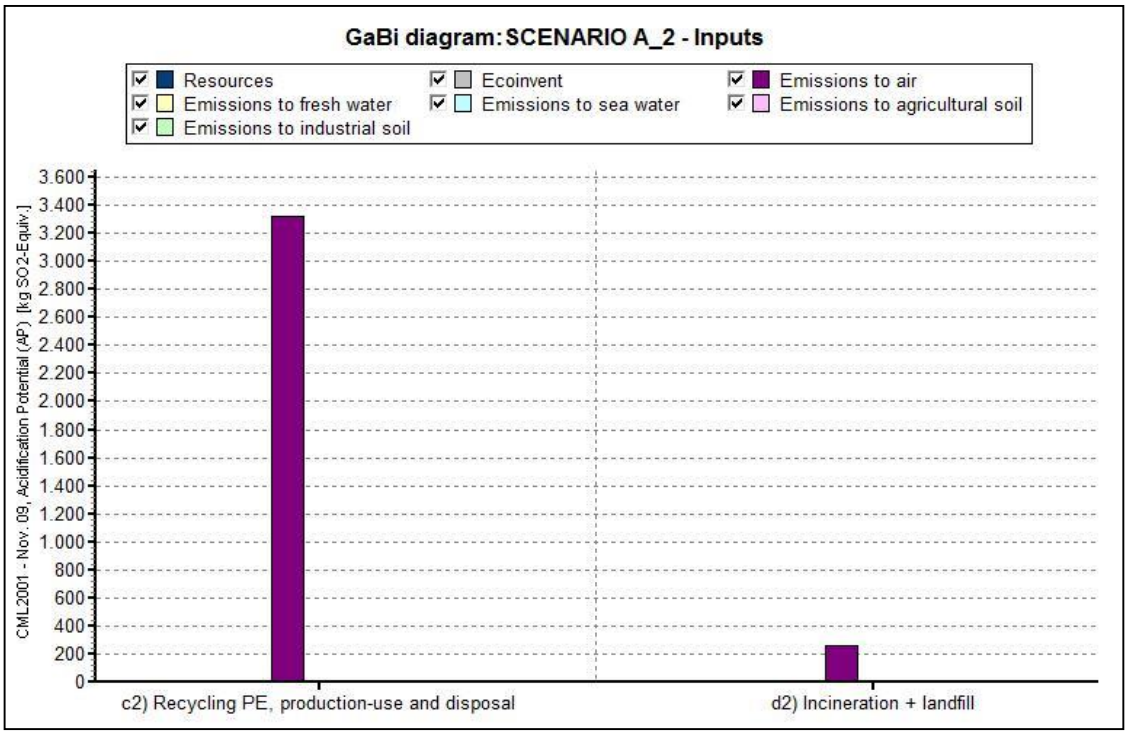

Figure C.15. CML 2001 Nov. ’09 Method. Acidification Potential results for Scenario A.2.

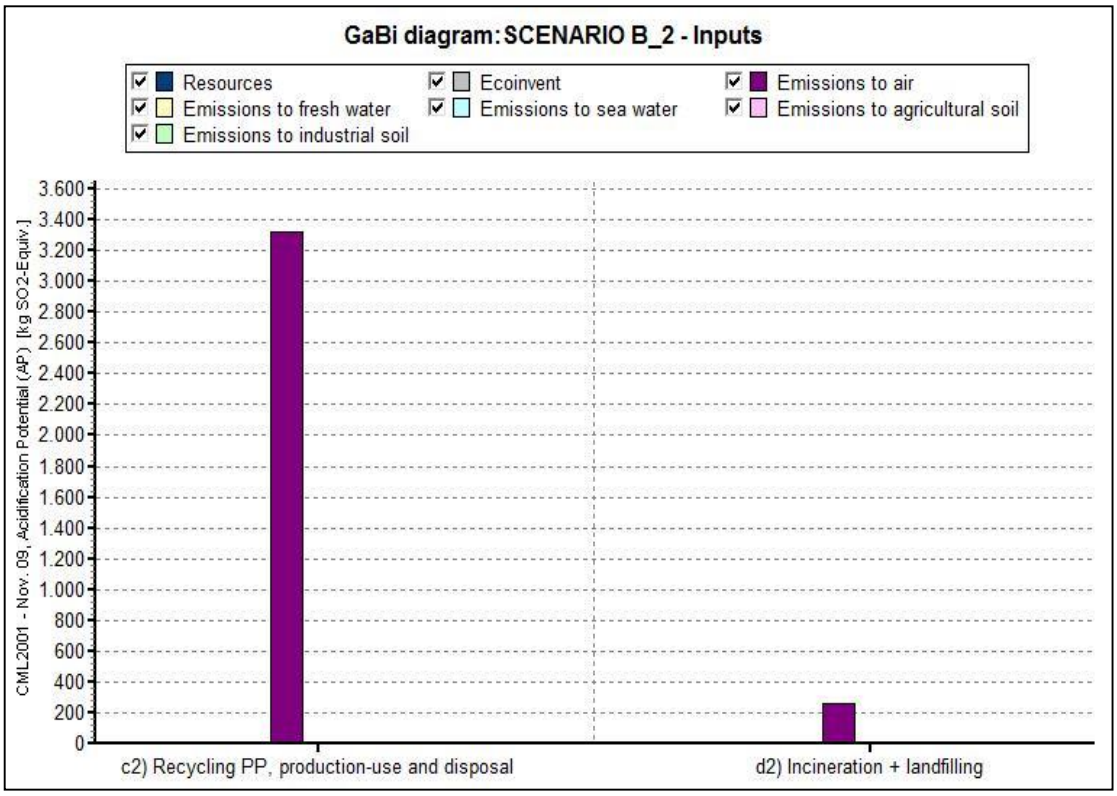

Figure C.16. CML 2001 Nov. ’09 Method. Acidification Potential results for Scenario B.2.

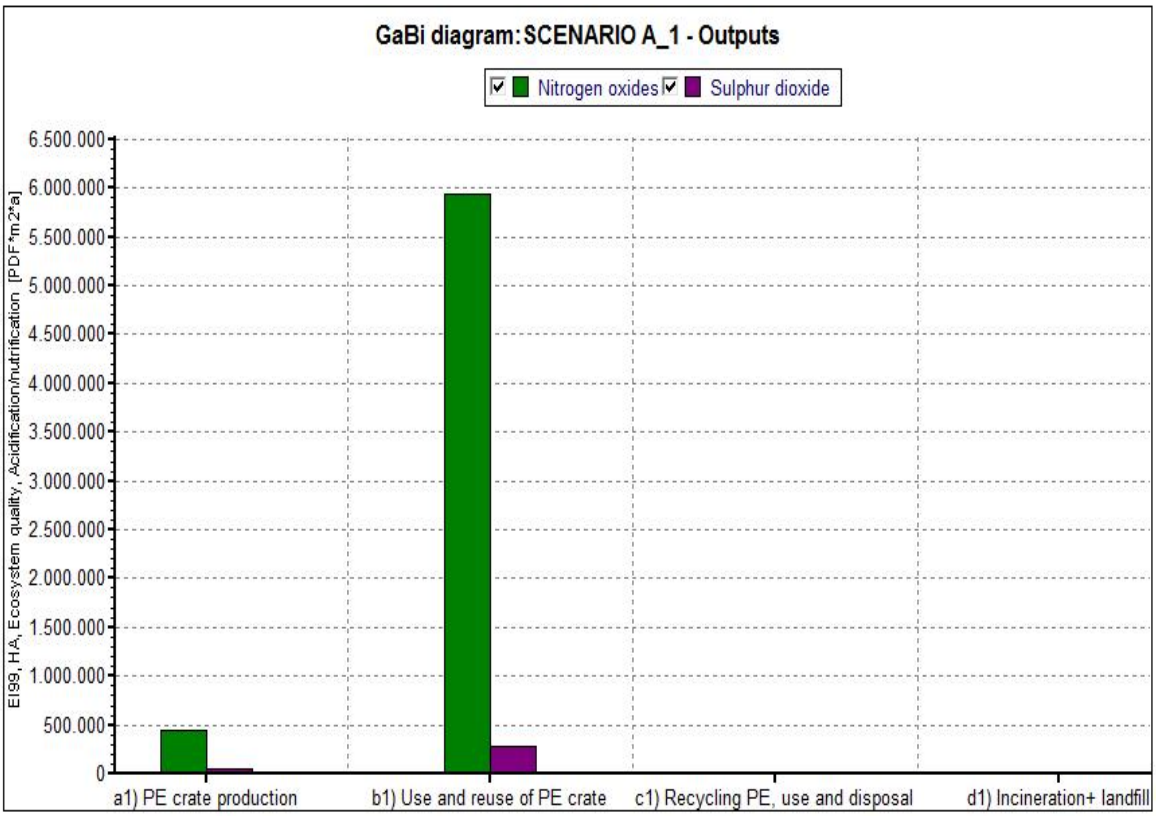

Figure C.17. EI 99 Method. Acidification / Nutrification results for Scenario A.1.

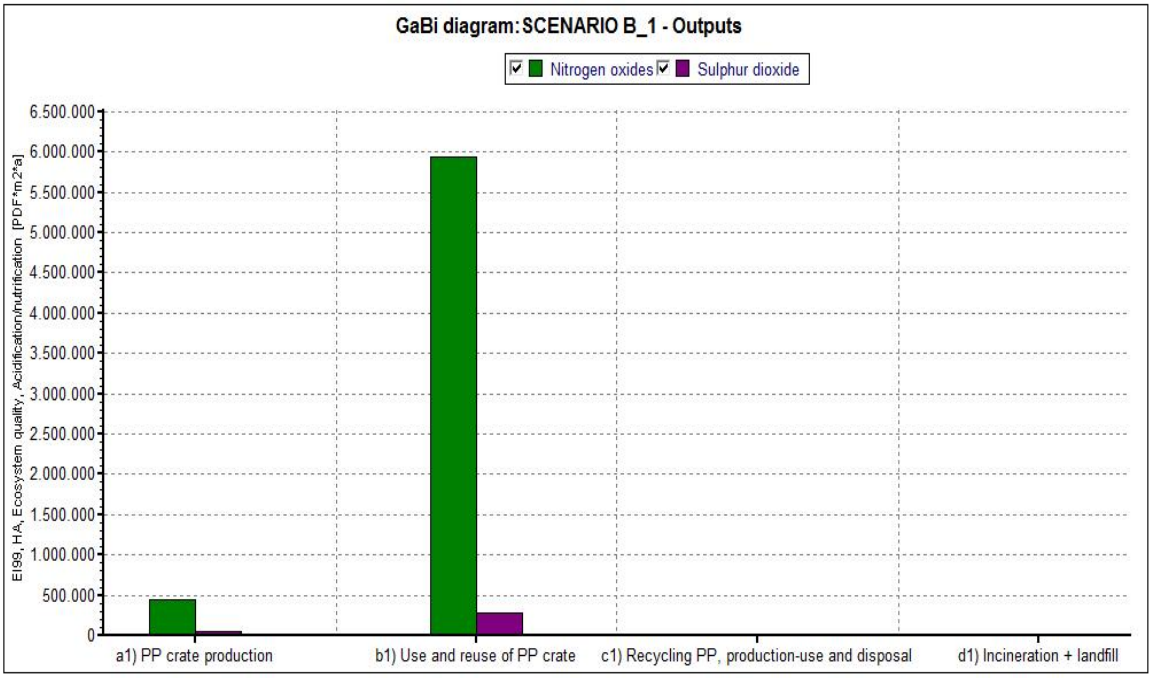

Figure C.18. EI 99 Method. Acidification / Nutrification results for Scenario B.1.

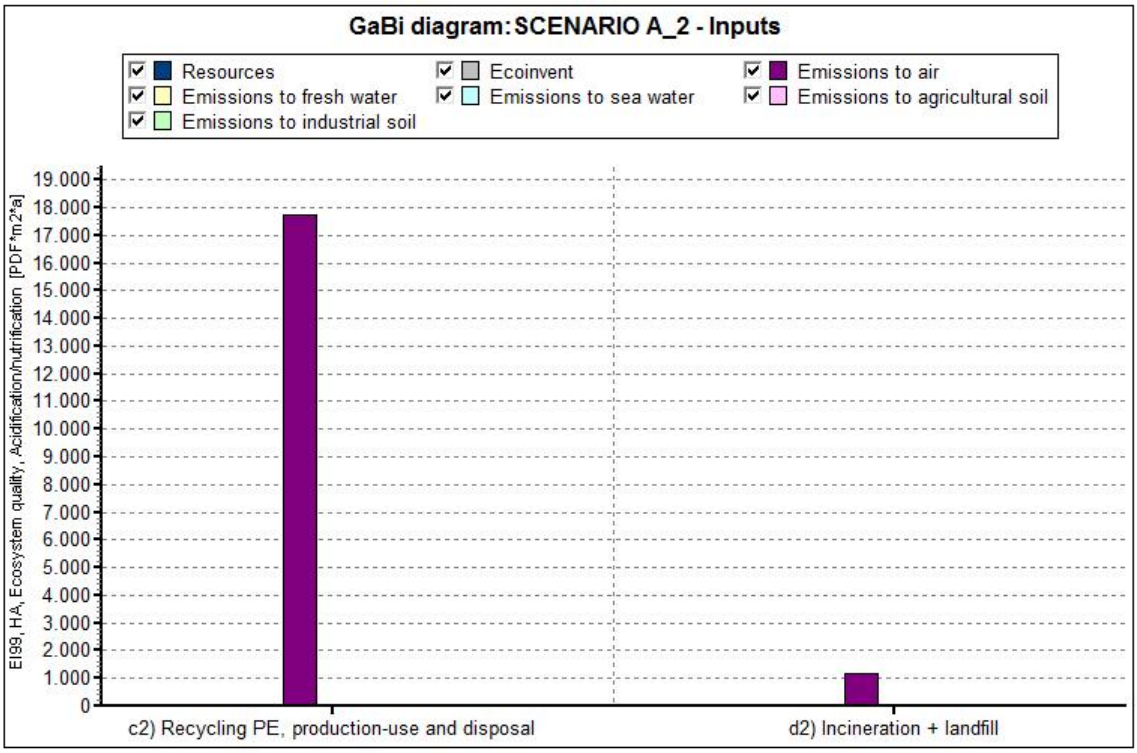

Figure C.19. EI 99 Method. Acidification / Nutrification results for Scenario A.2.

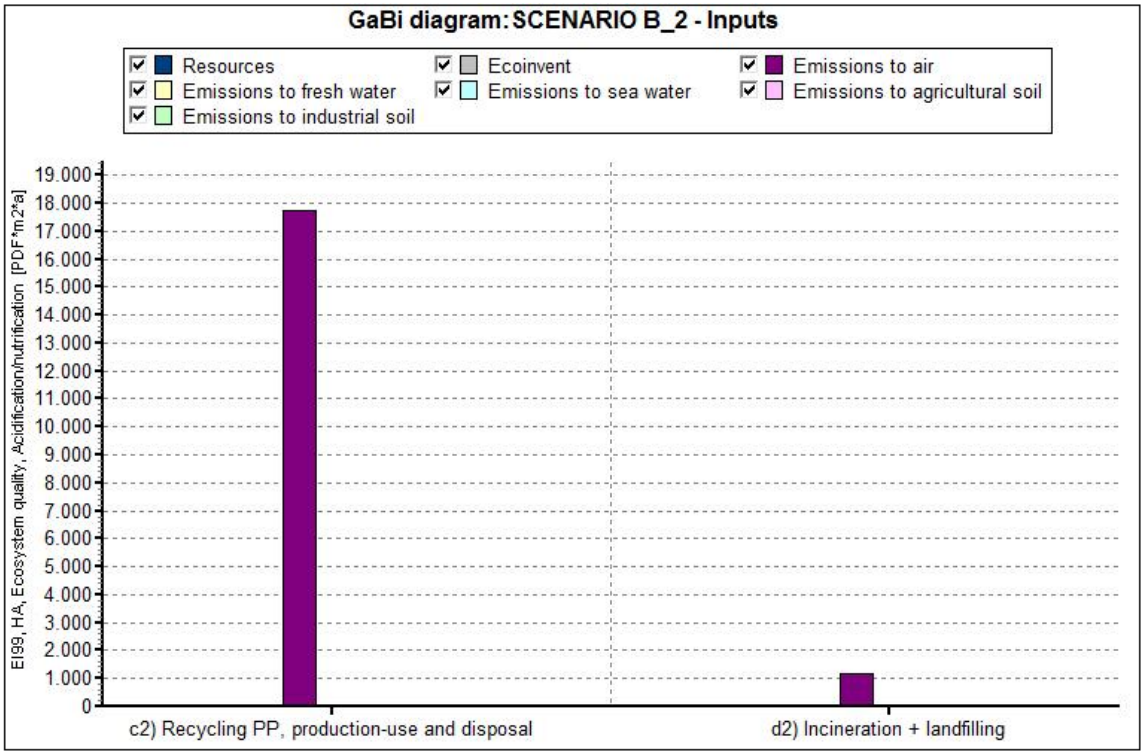

Figure C.20. EI 99 Method. Acidification / Nutrification results for Scenario A.2.

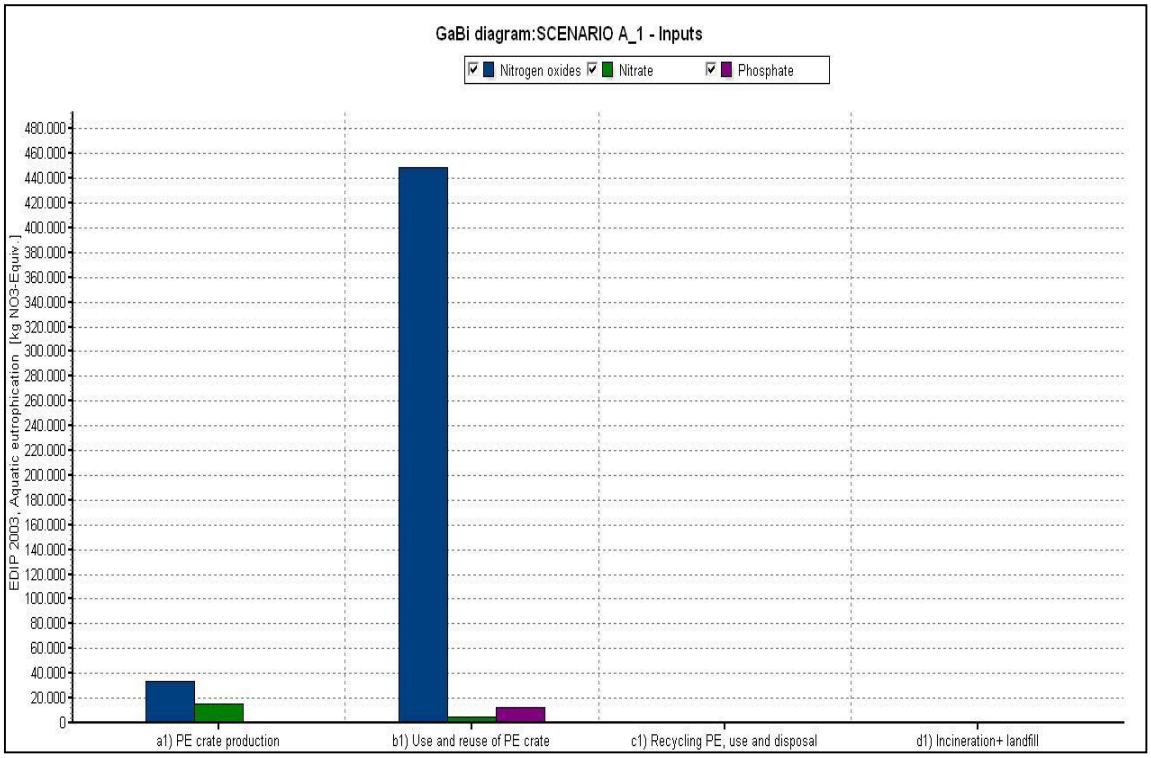

Figure C.21. EDIP 2003 Method. Aquatic Eutrophication results for Scenario A.1.

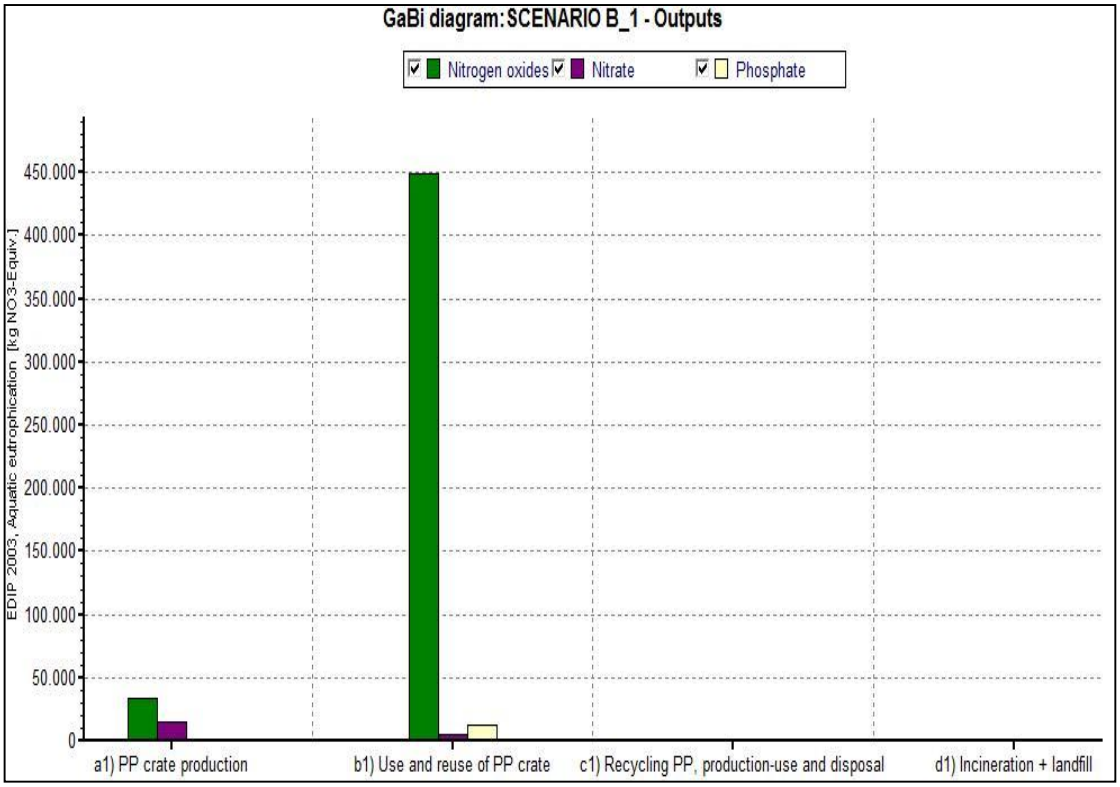

Figure C.22. EDIP 2003 Method. Aquatic Eutrophication results for Scenario B.1.

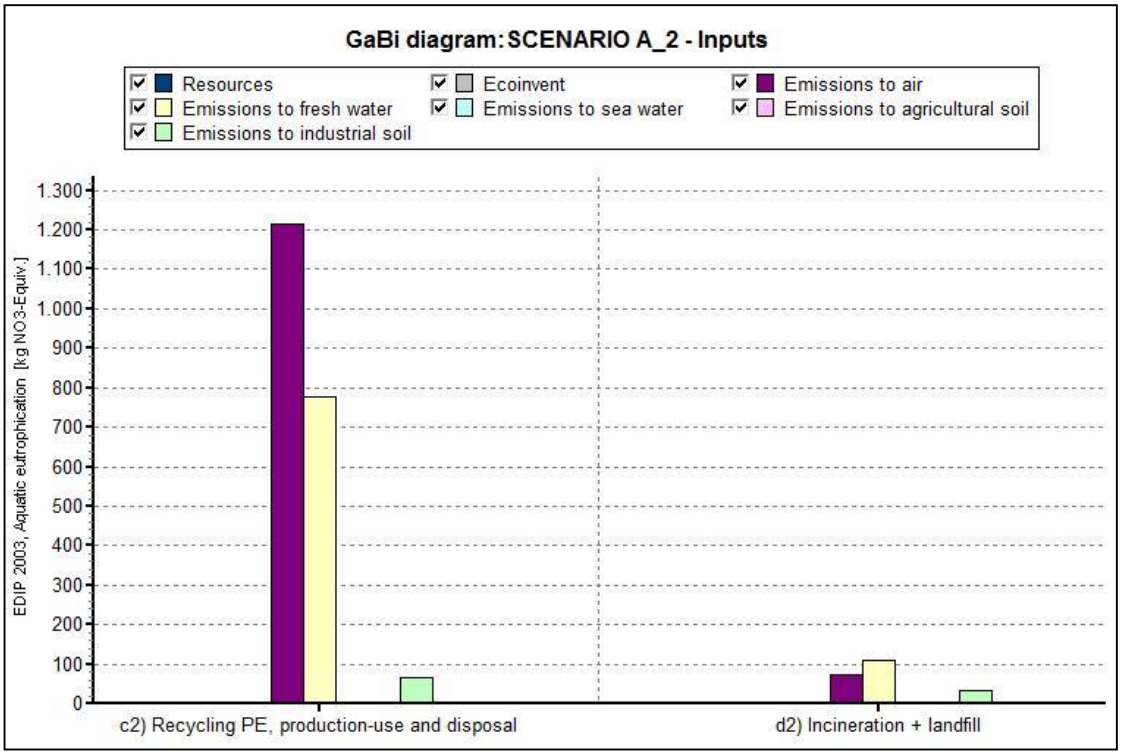

Figure C.23. EDIP 2003 Method. Aquatic Eutrophication results for Scenario A.2.

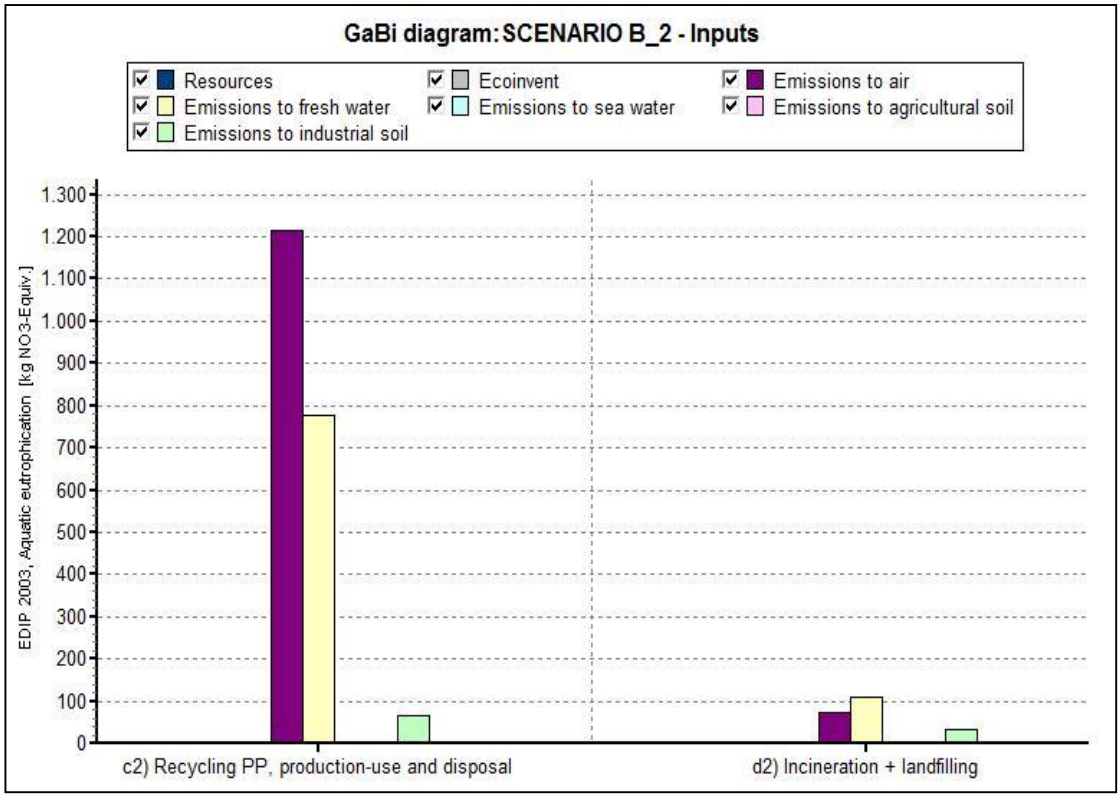

Figure C.24. EDIP 2003 Method. Aquatic Eutrophication results for Scenario B.2.

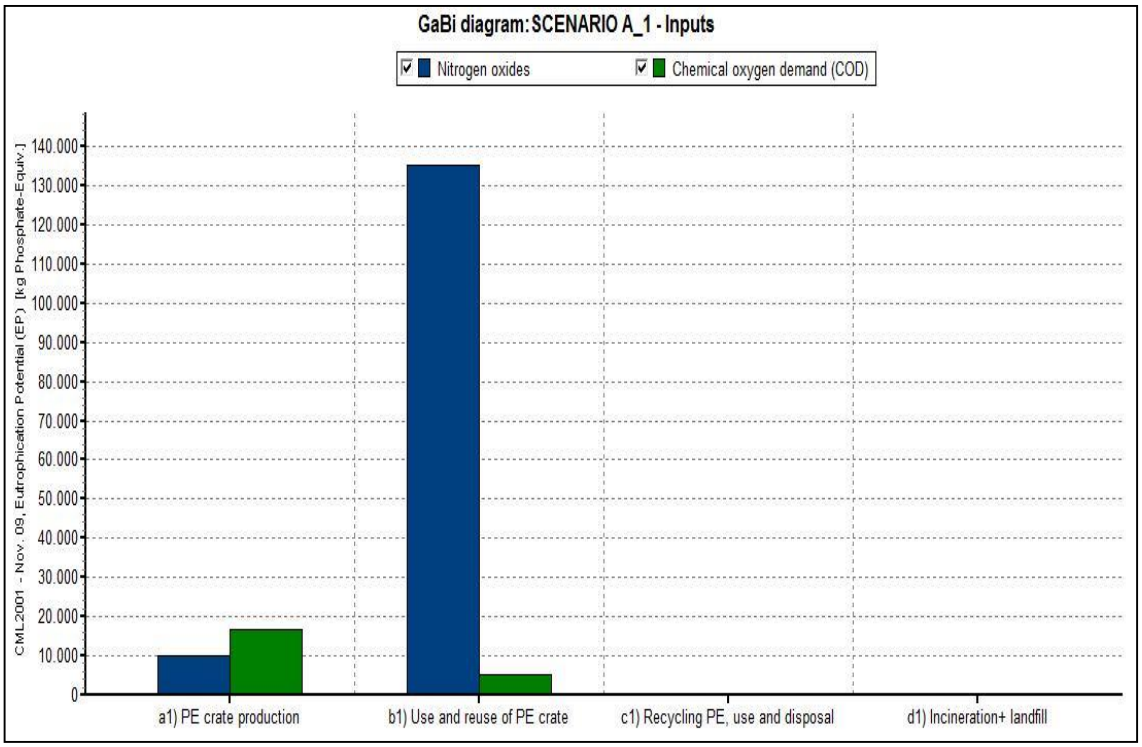

Figure C.25. CML 2001 Nov. ’09 Method. Eutrophication Potential results for Scenario A.1.

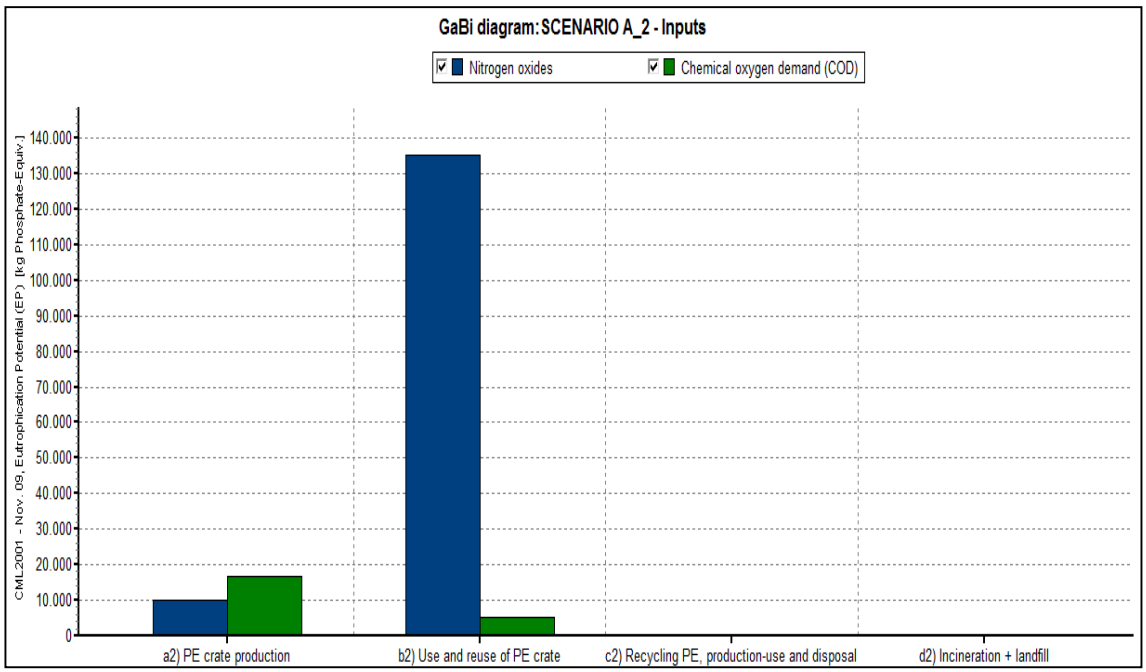

Figure C.26. CML 2001 Nov. ’09 Method. Eutrophication Potential results for Scenario B.1.

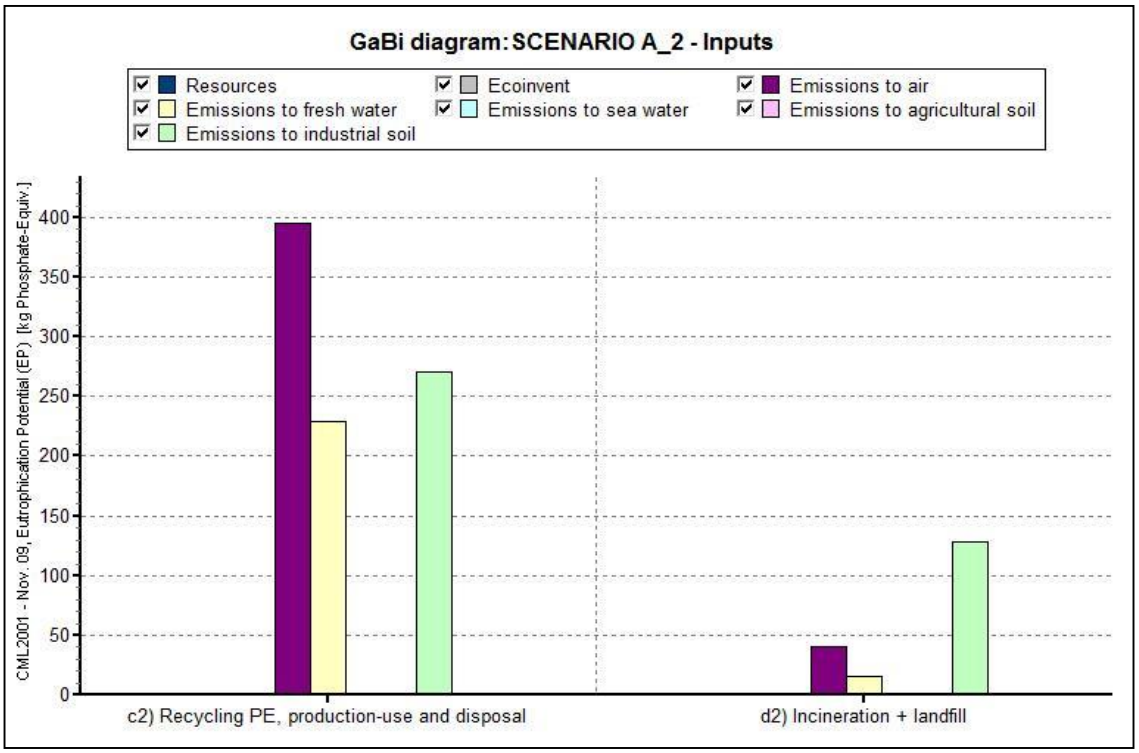

Figure C.27. CML 2001 Nov. ’09 Method. Eutrophication Potential results for Scenario A.2.

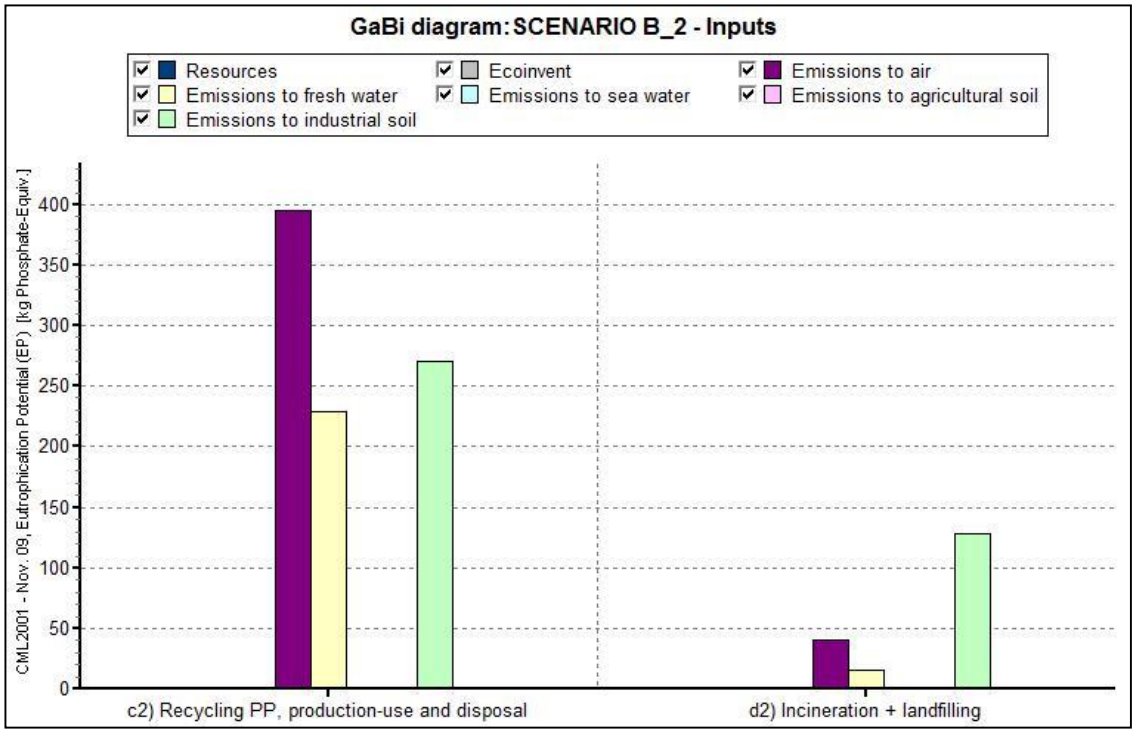

Figure C.28. CML 2001 Nov. ’09 Method. Eutrophication Potential results for Scenario B.2.

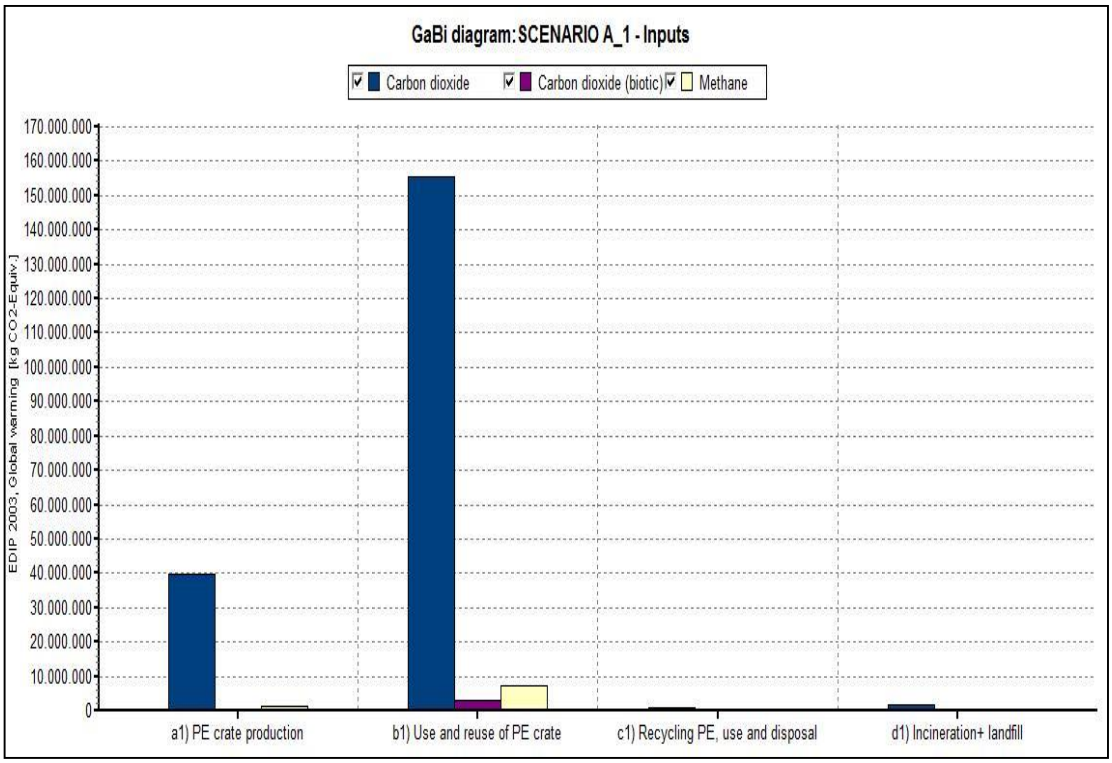

Figure C.29. EDIP 2003 Method. Global Warming results for Scenario A.1.

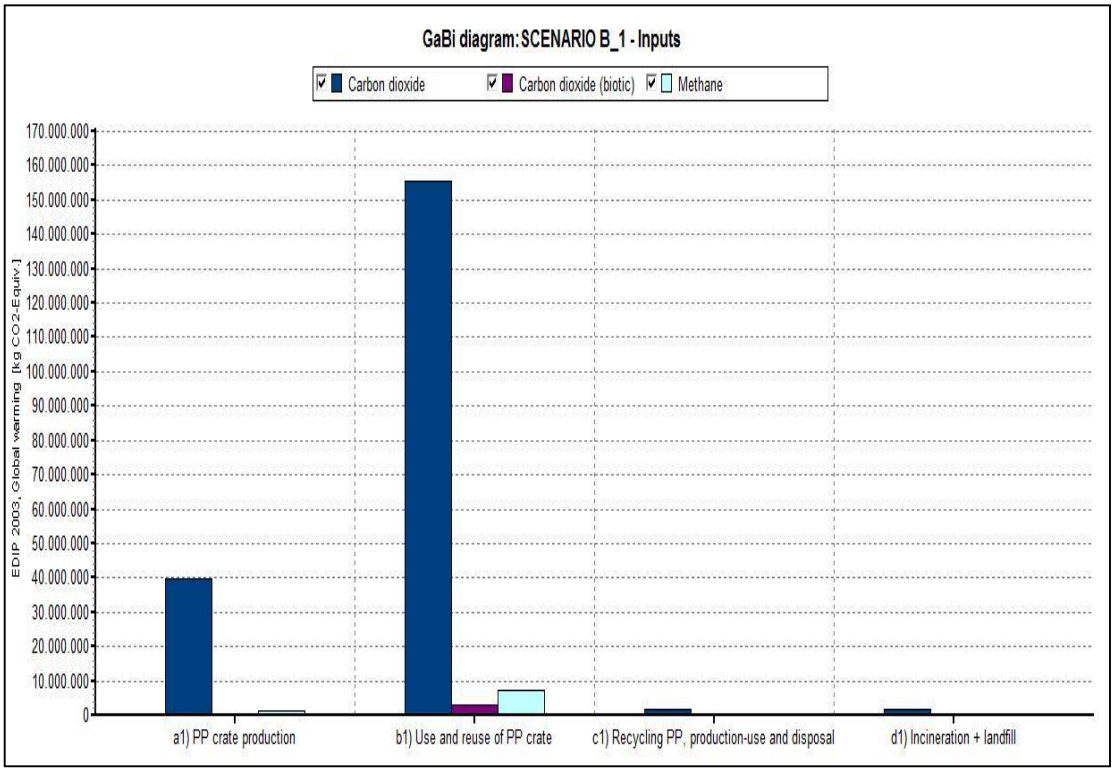

Figure C.30. EDIP 2003 Method. Global Warming results for Scenario B.1.

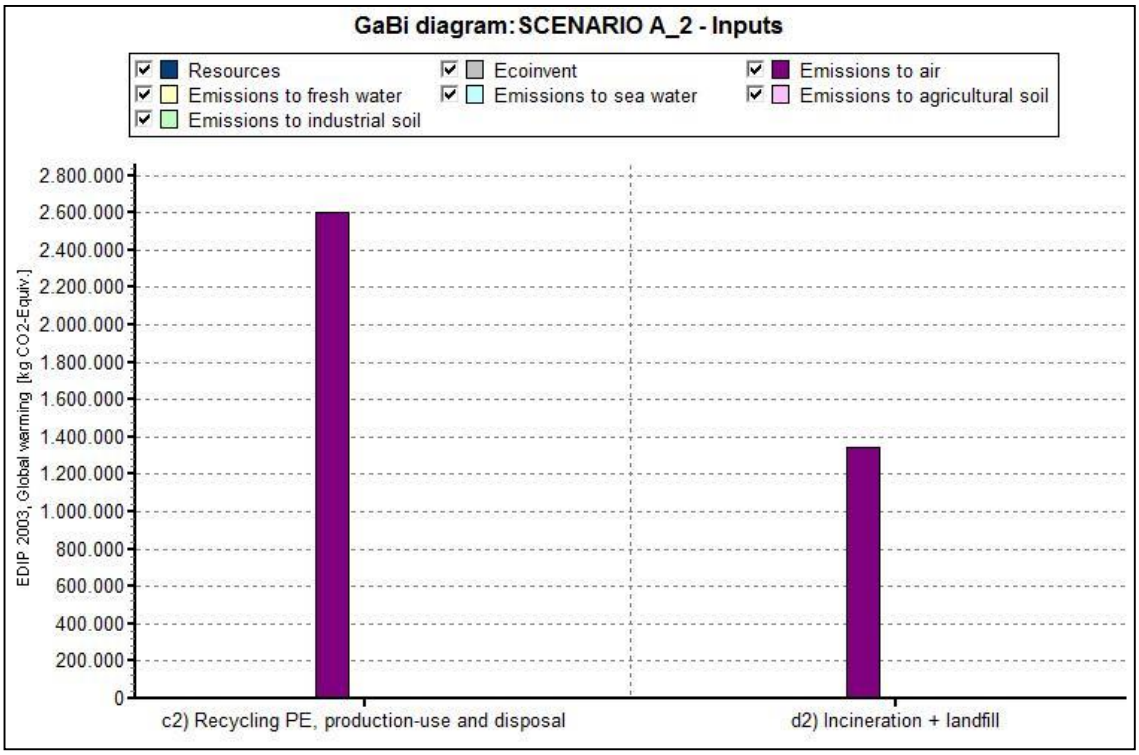

Figure C.31. EDIP 2003 Method. Global Warming results for Scenario A.2.

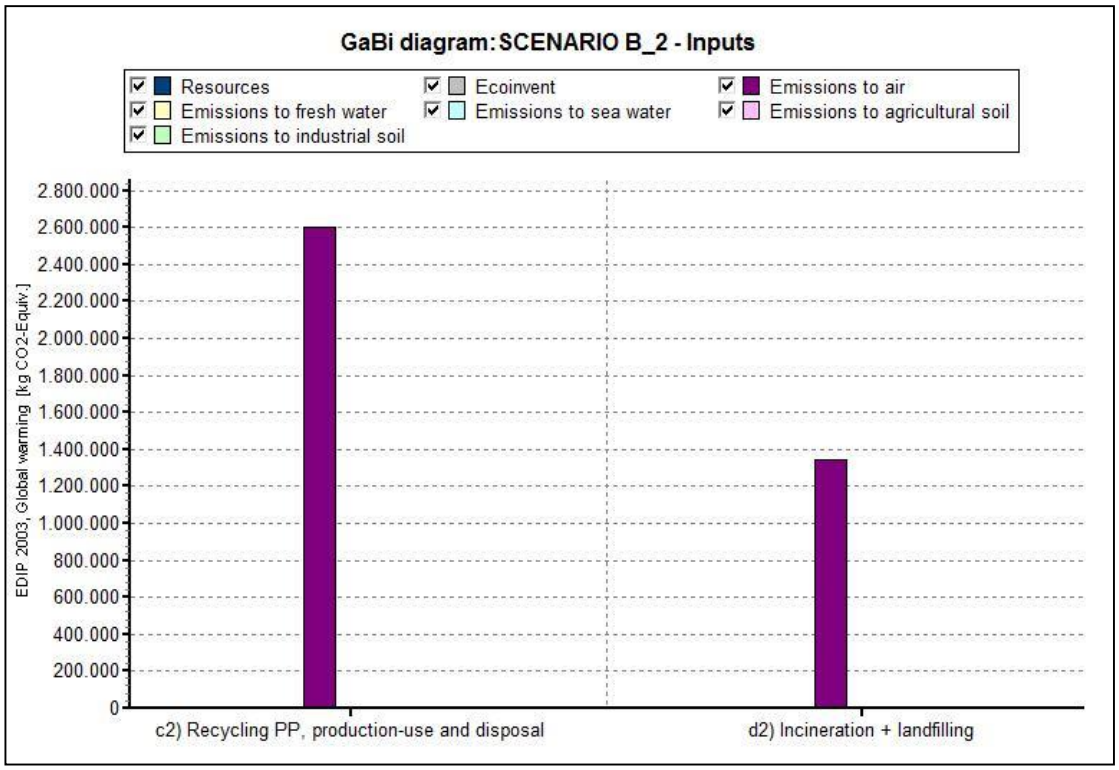

Figure C.32. EDIP 2003 Method. Global Warming results for Scenario B.2.

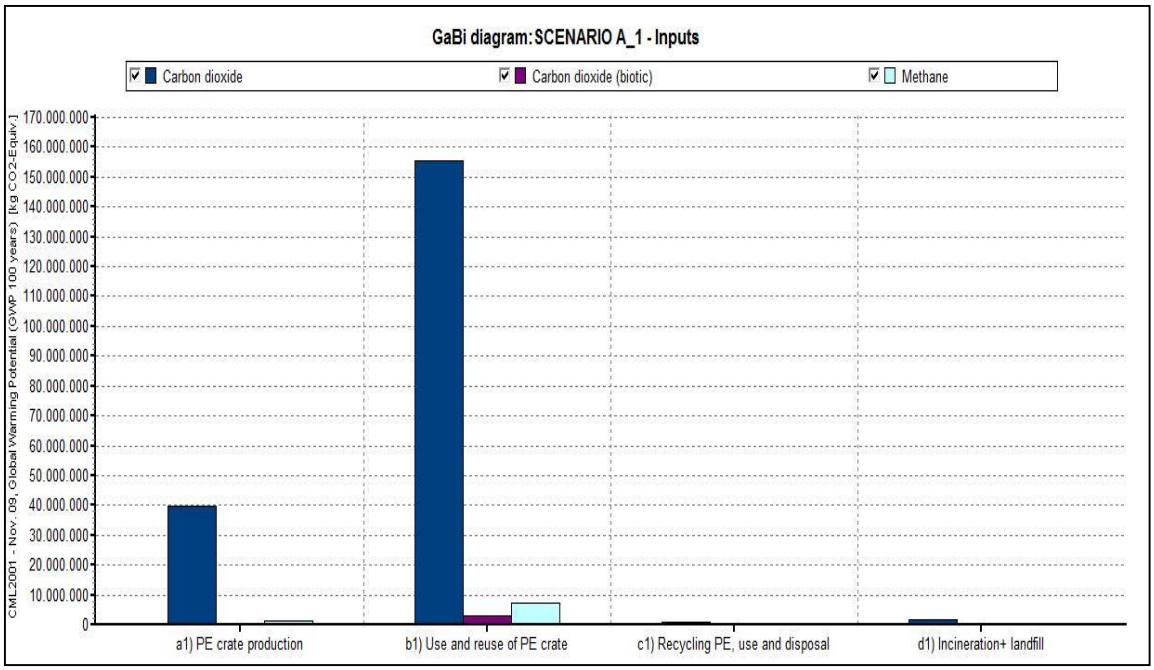

Figure C.33. CML 2001 Nov. ’09 Method. Global Warming Potential results for Scenario A.1.

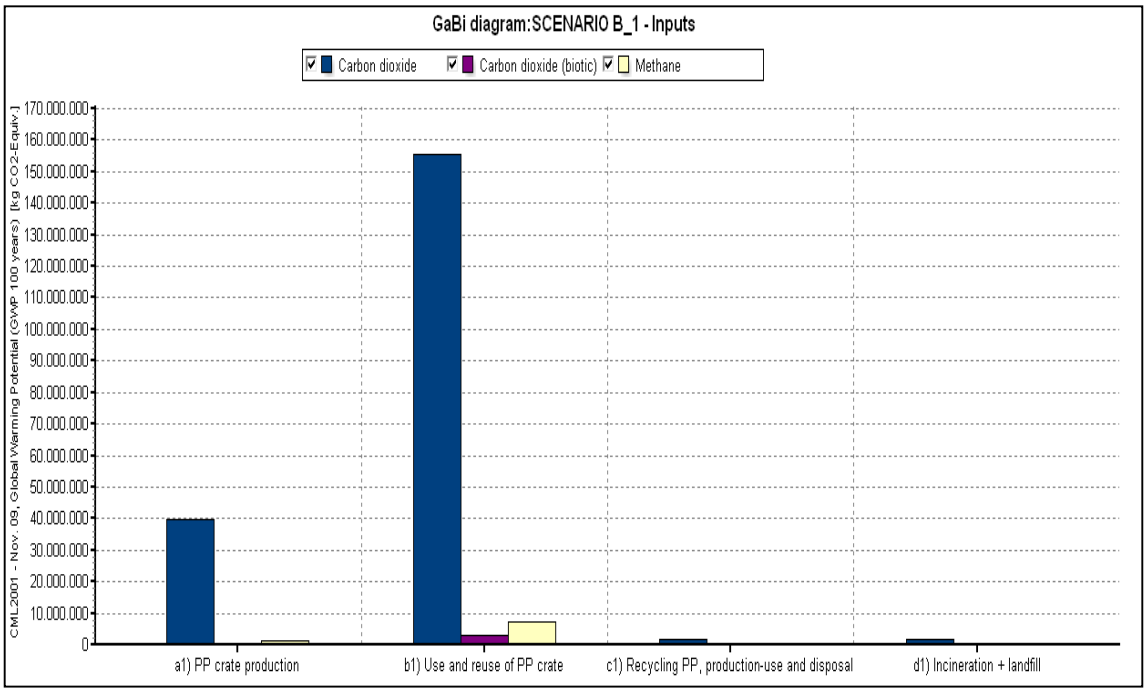

Figure C.34. CML 2001 Nov. ’09 Method. Global Warming Potential results for Scenario B.1.

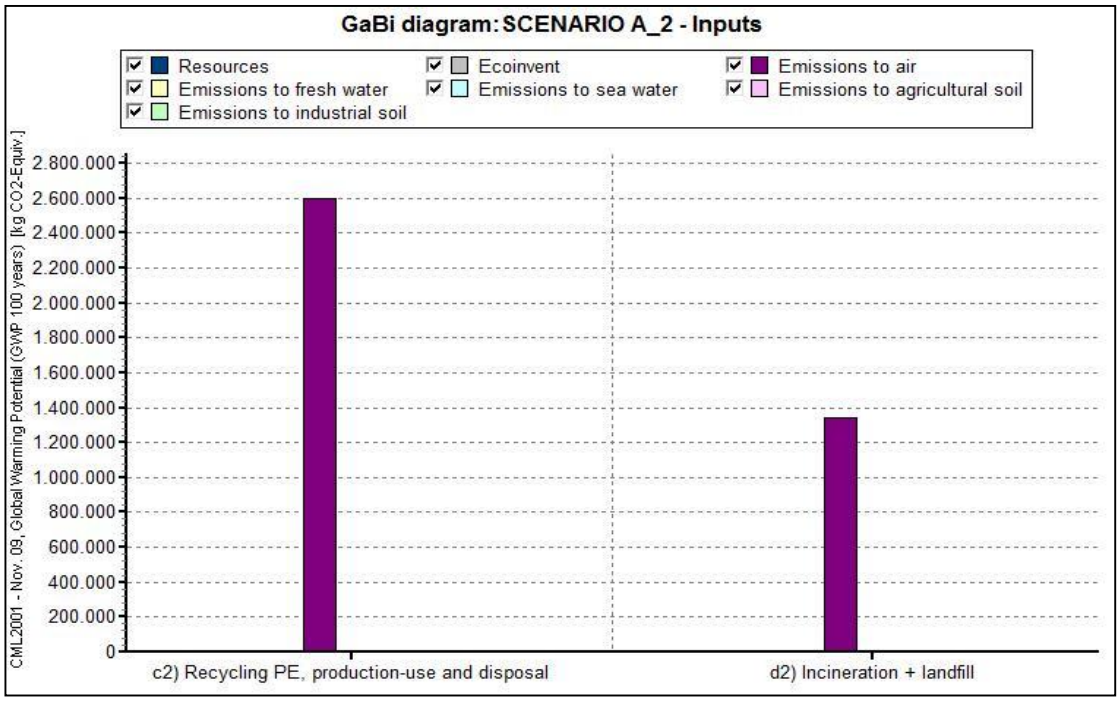

Figure C.35. CML 2001 Nov. ’09 Method. Global Warming Potential results for Scenario A.2.

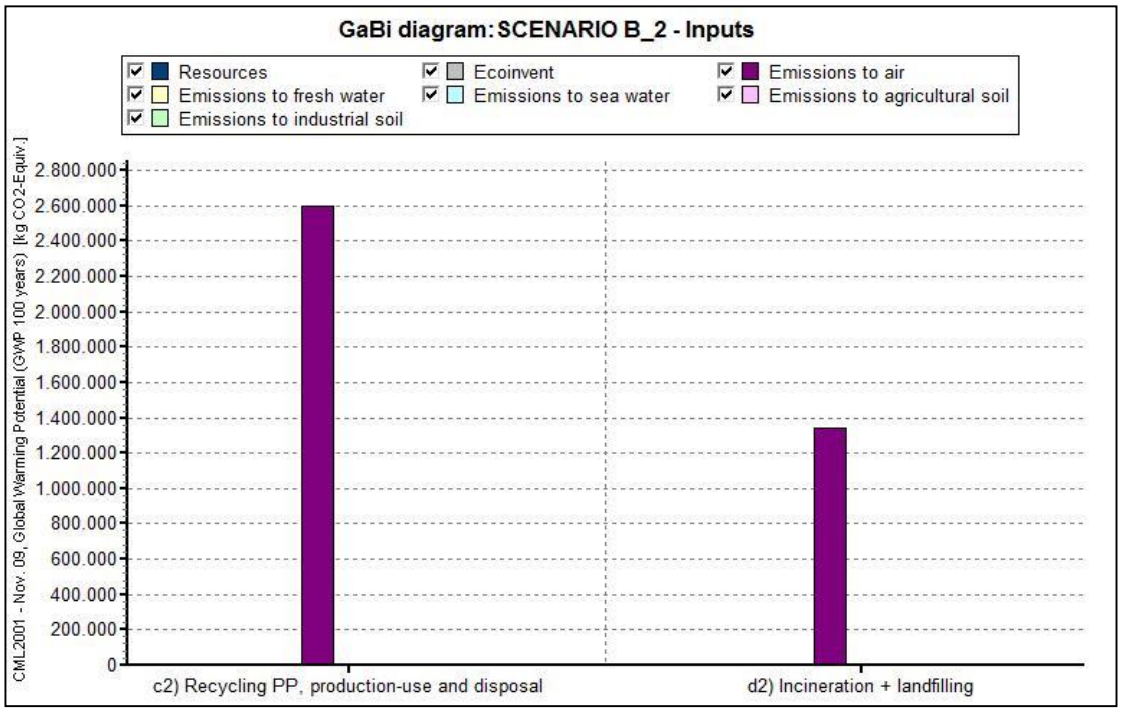

Figure C.36. CML 2001 Nov. ’09 Method. Global Warming Potential results for Scenario B.2.

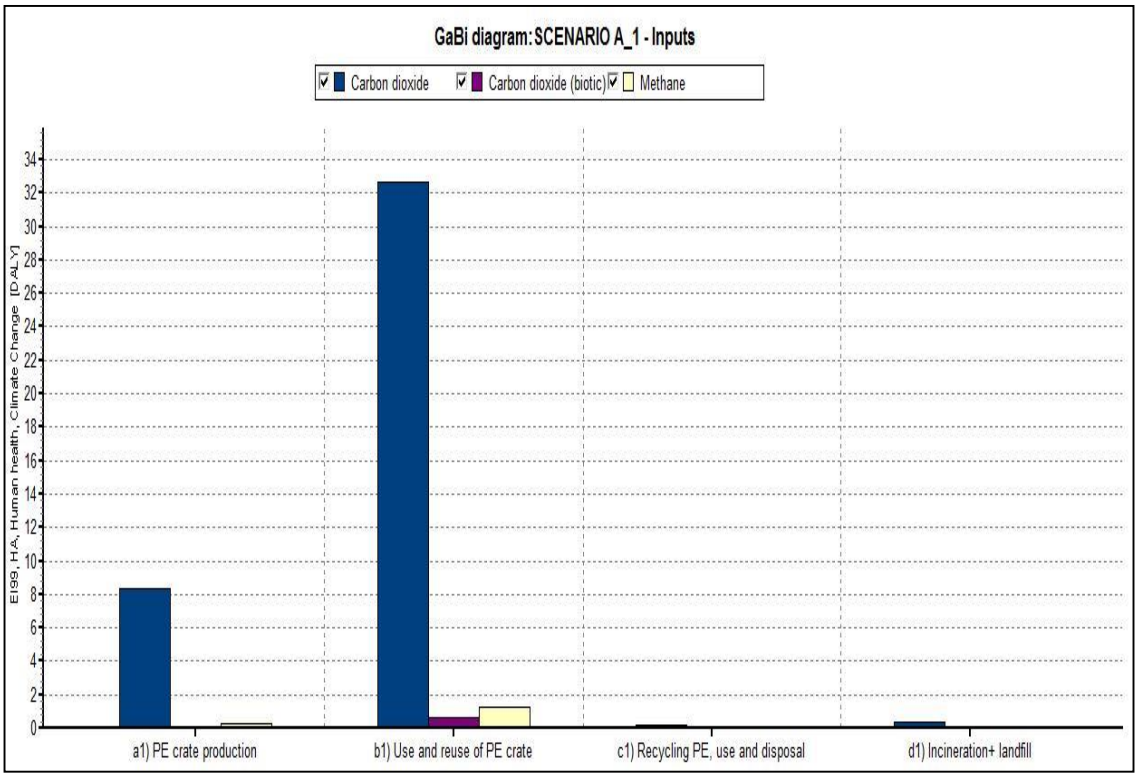

Figure C.37. EI 99 Method. Climate Change results for Scenario A.1.

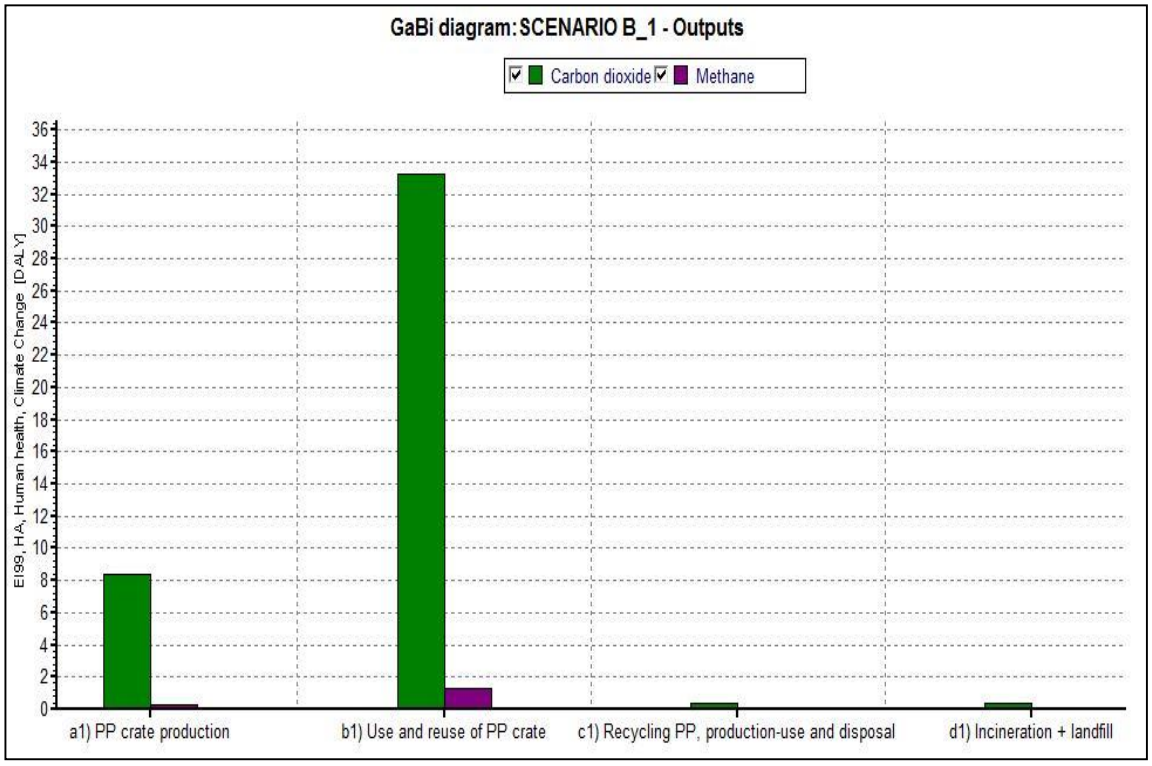

Figure C.38. EI 99 Method. Climate Change results for Scenario B.1.

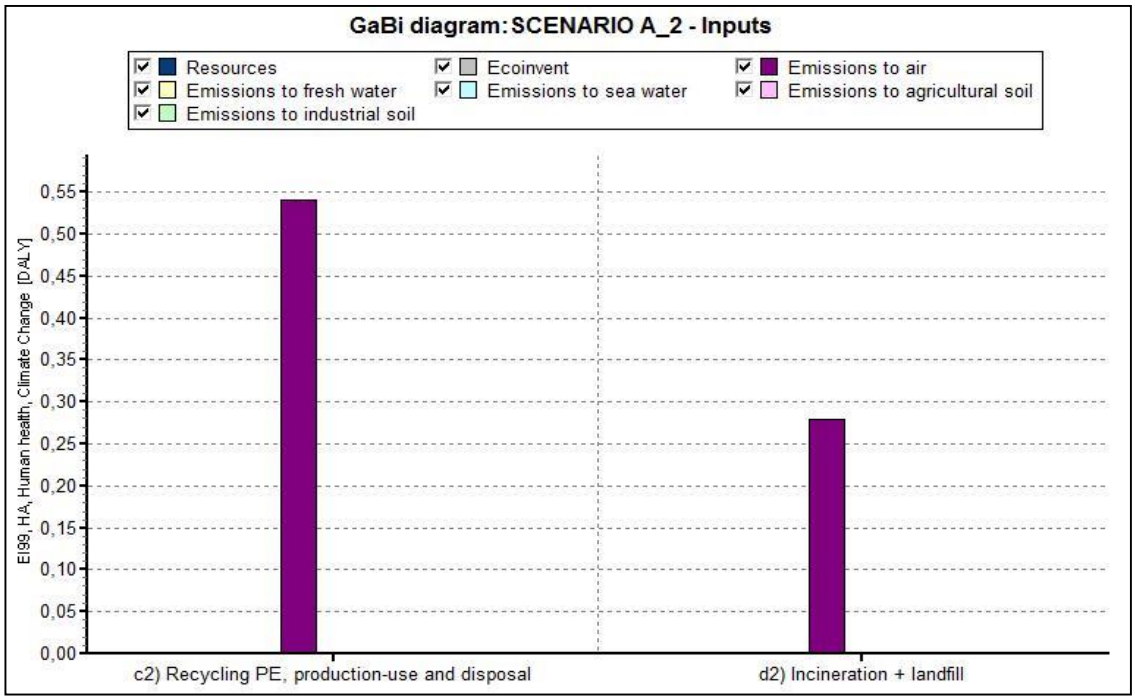

Figure C.39. EI 99 Method. Climate Change results for Scenario A.2.

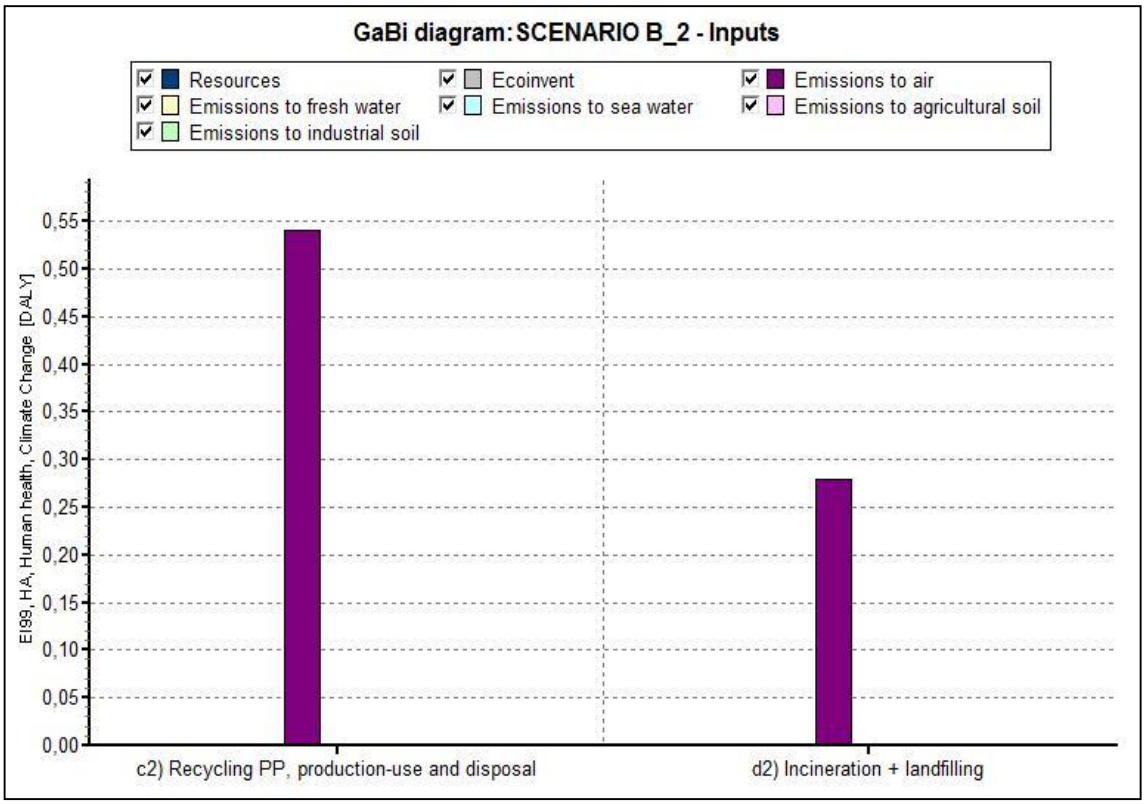

Figure C.40. EI 99 Method. Climate Change results for Scenario B.2.

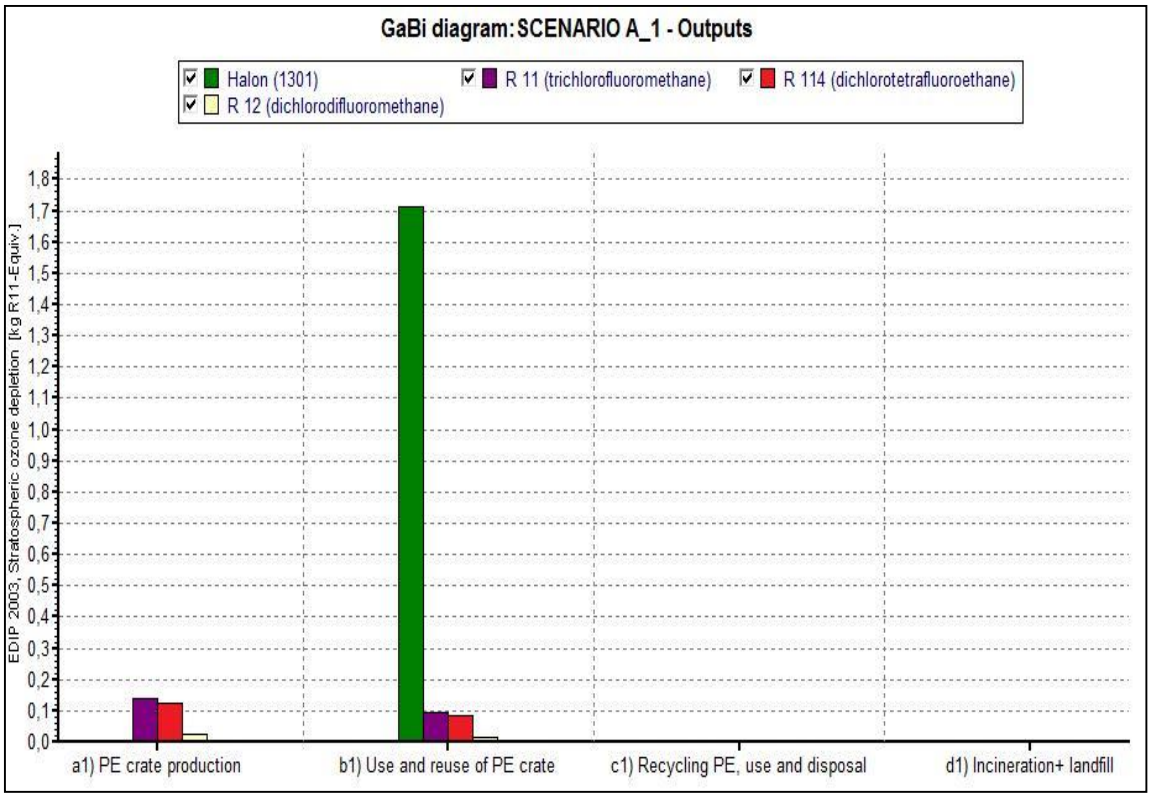

Figure C.41. EDIP 2003 Method. Stratospheric Ozone Depletion results for Scenario A.1.

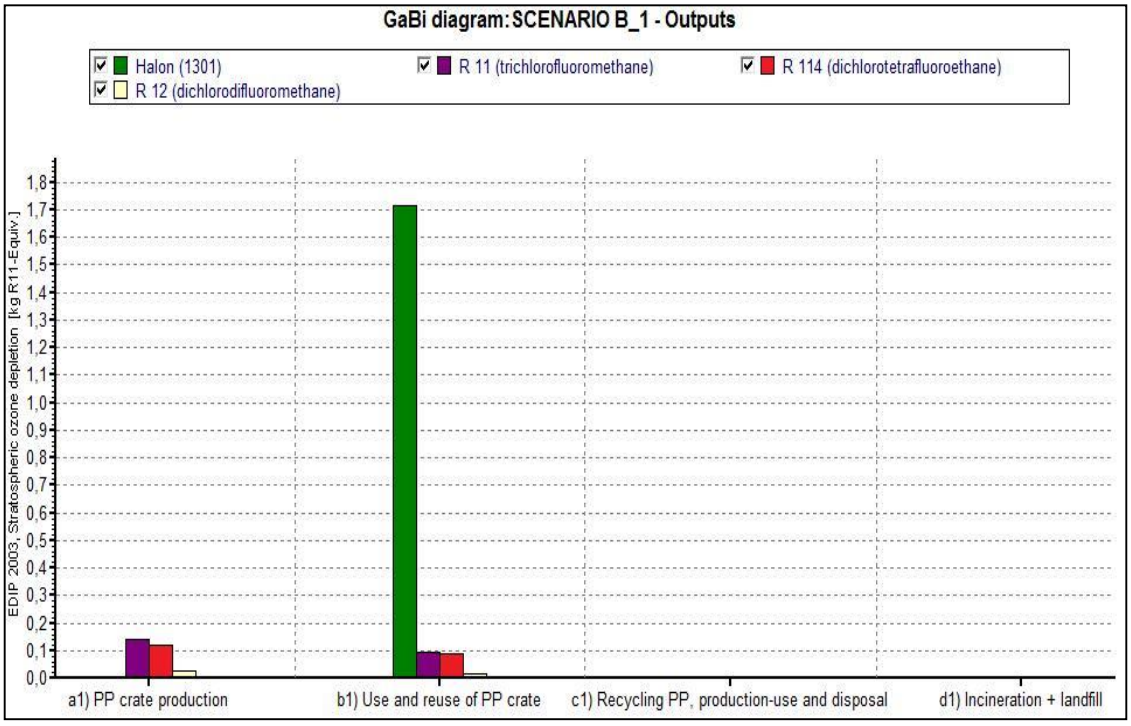

Figure C.42. EDIP 2003 Method. Stratospheric Ozone Depletion results for Scenario B.1.

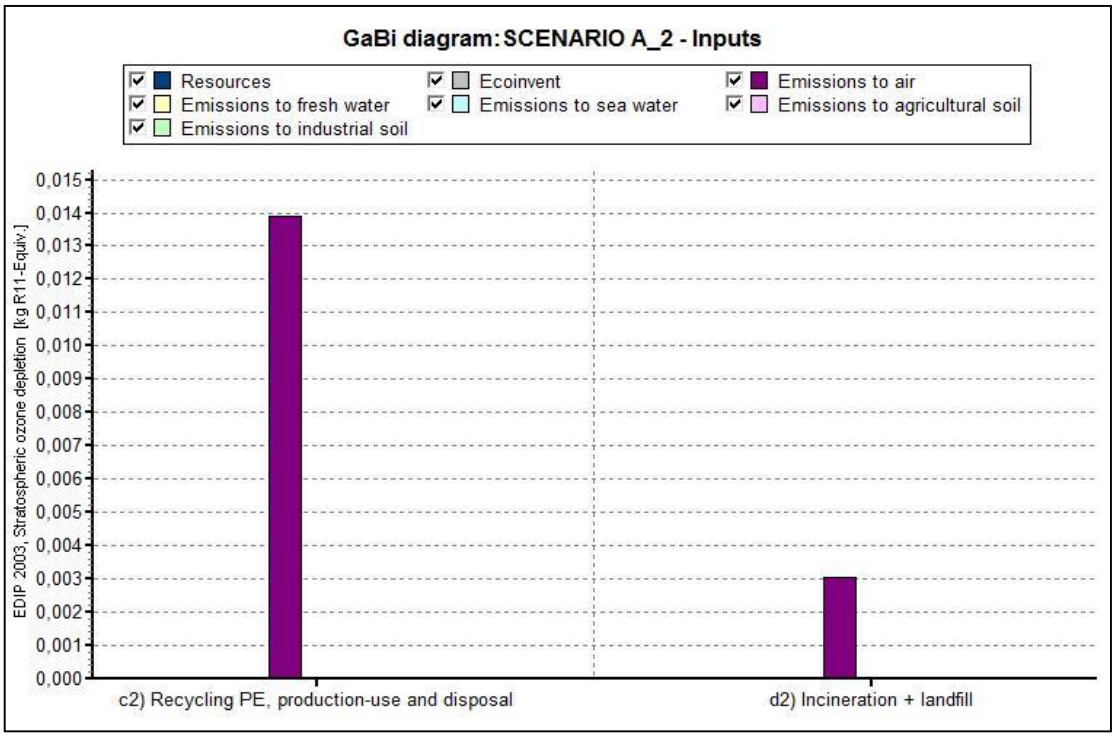

Figure C.43. EDIP 2003 Method. Stratospheric Ozone Depletion results for Scenario A.2.

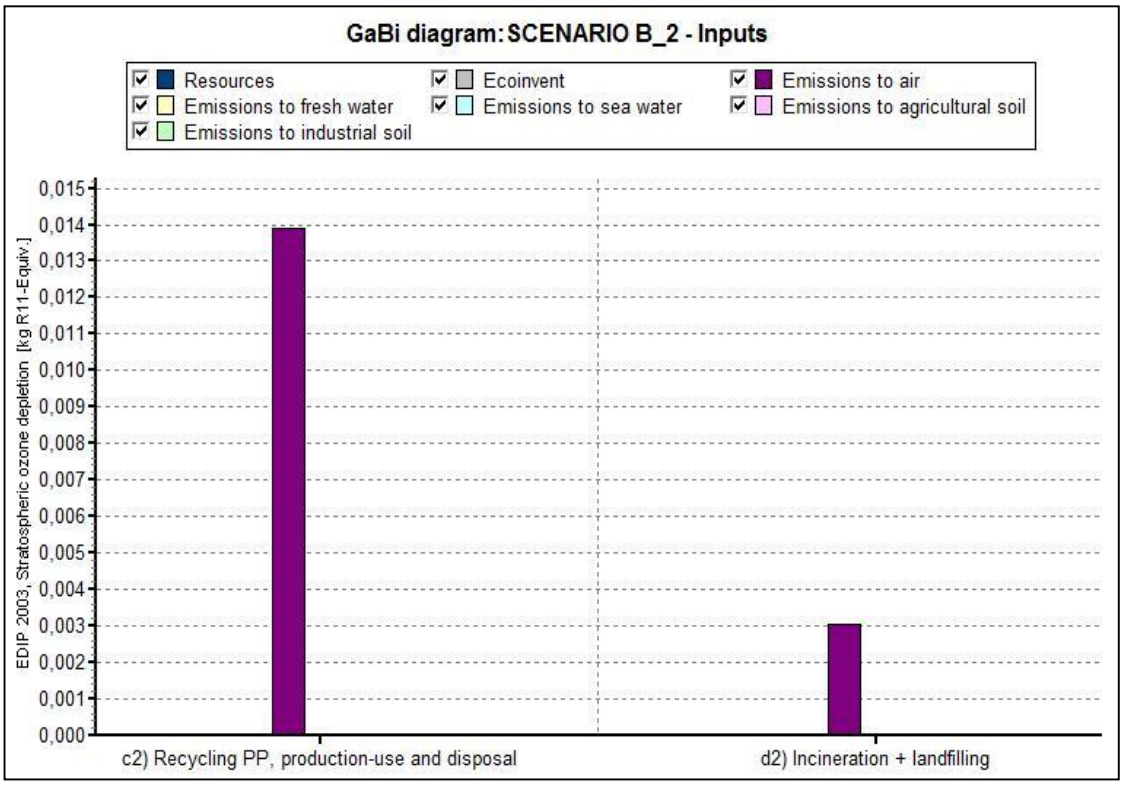

Figure C.44. EDIP 2003 Method. Stratospheric Ozone Depletion results for Scenario B.2.

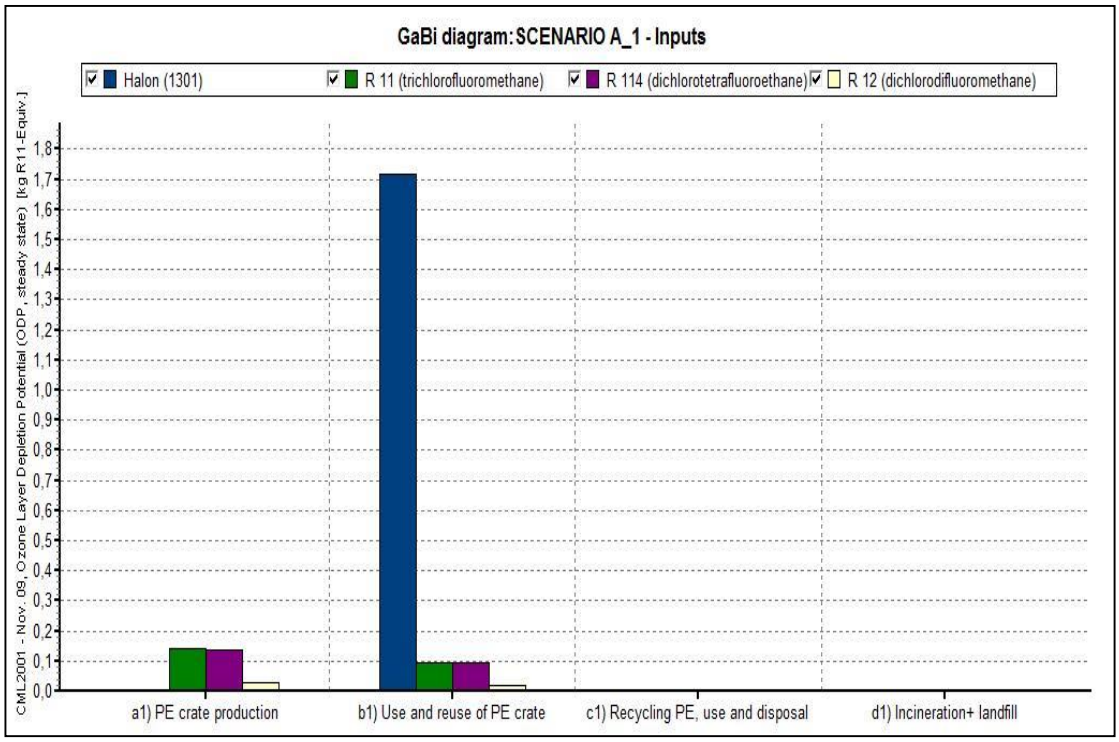

Figure C.45. CML 2001 Nov. ’09 Method. Ozone Layer Depletion results for Scenario A.1.

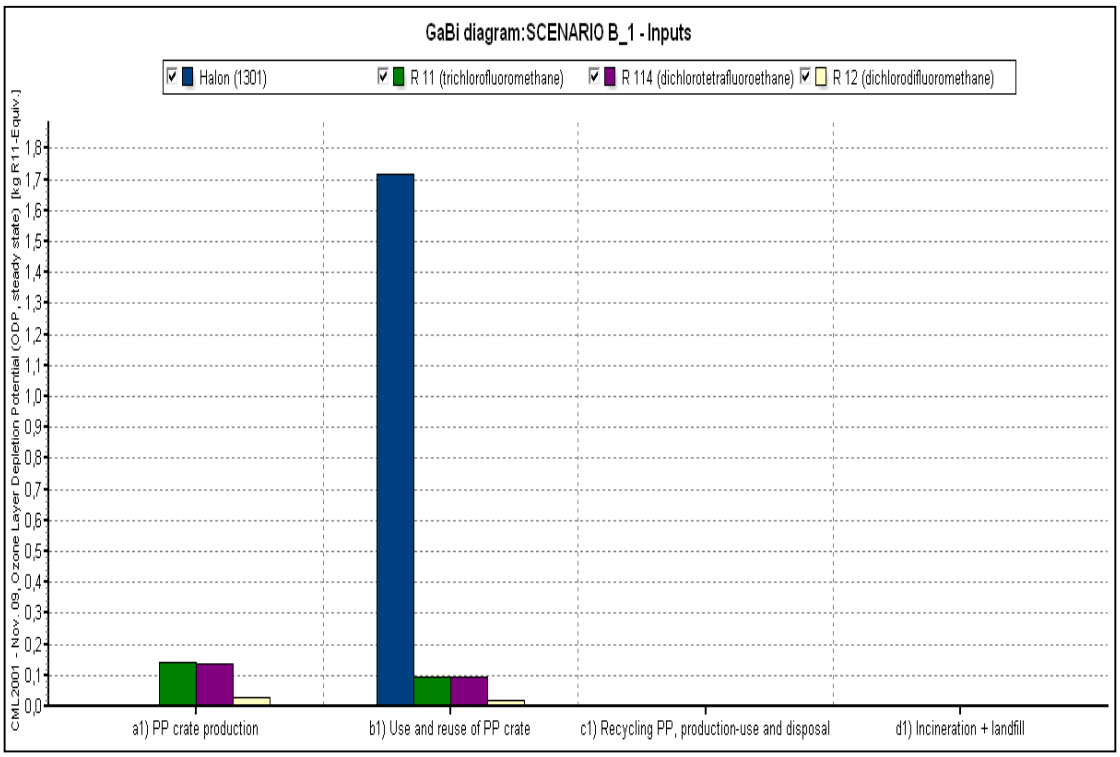

Figure C.46. CML 2001 Nov. ’09 Method. Ozone Layer Depletion results for Scenario B.1.

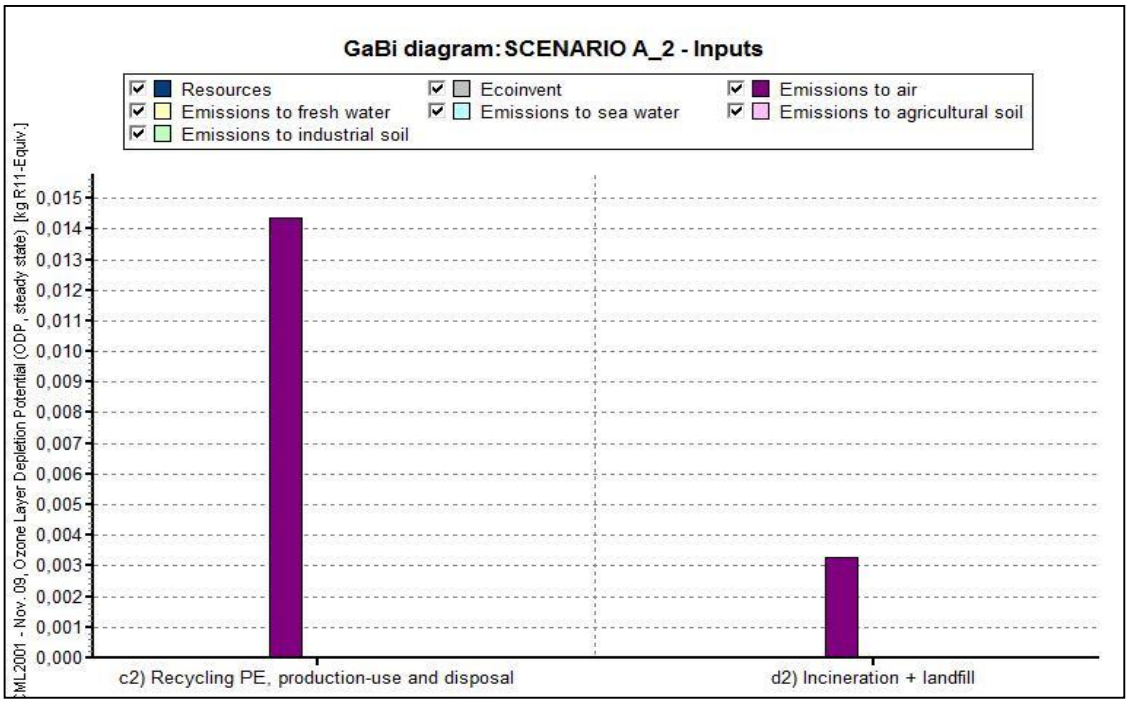

Figure C.47. CML 2001 Nov. ’09 Method. Ozone Layer Depletion results for Scenario A.2.

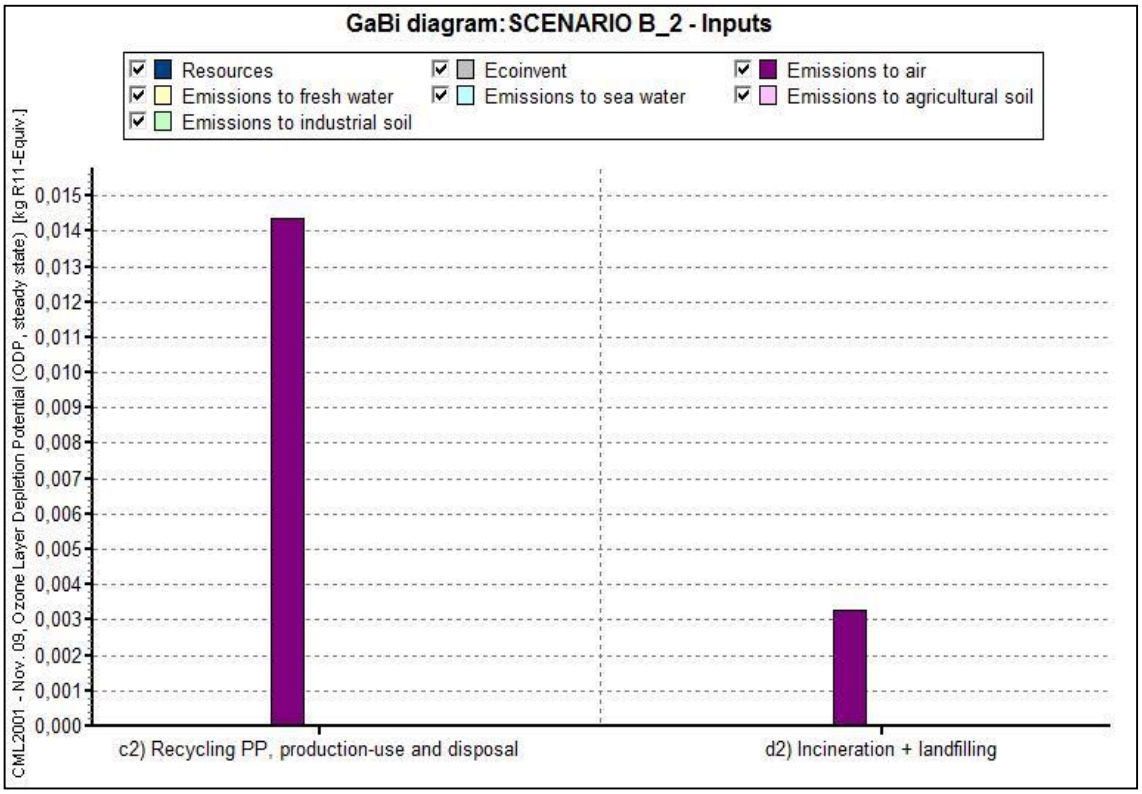

Figure C.48. CML 2001 Nov. ’09 Method. Ozone Layer Depletion results for Scenario B.2.

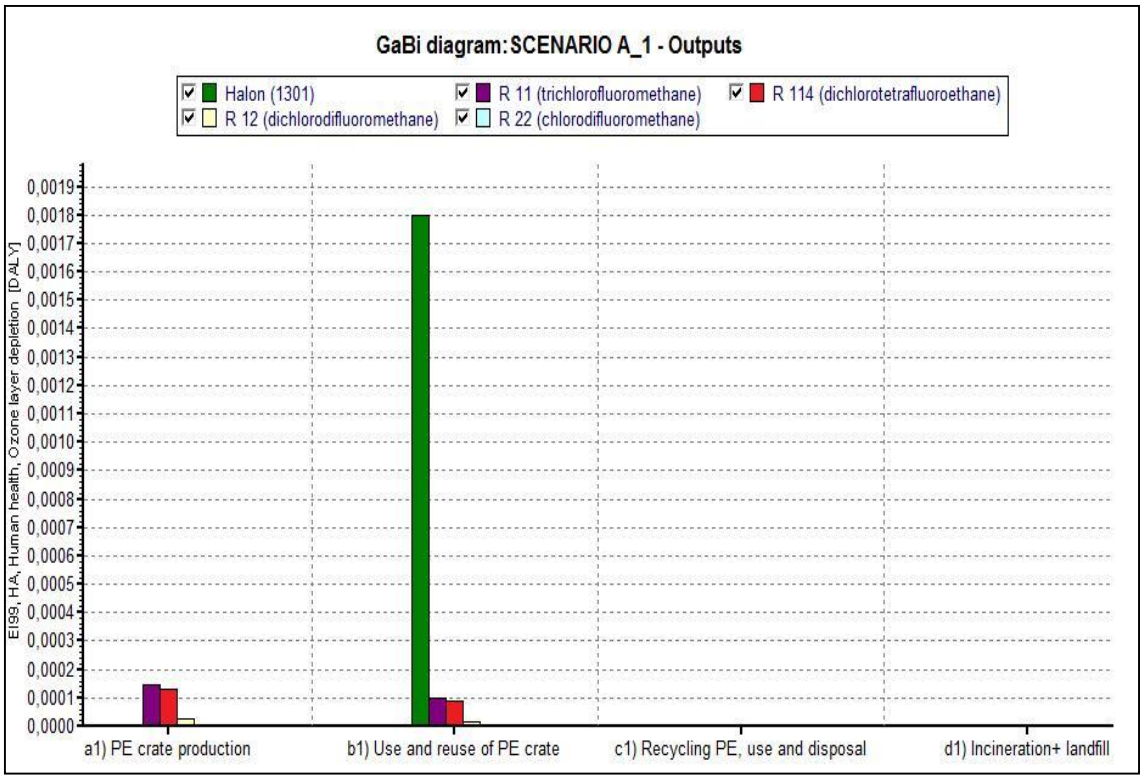

Figure C.49. EI 99 Method. Ozone Layer Depletion results for Scenario A.1.

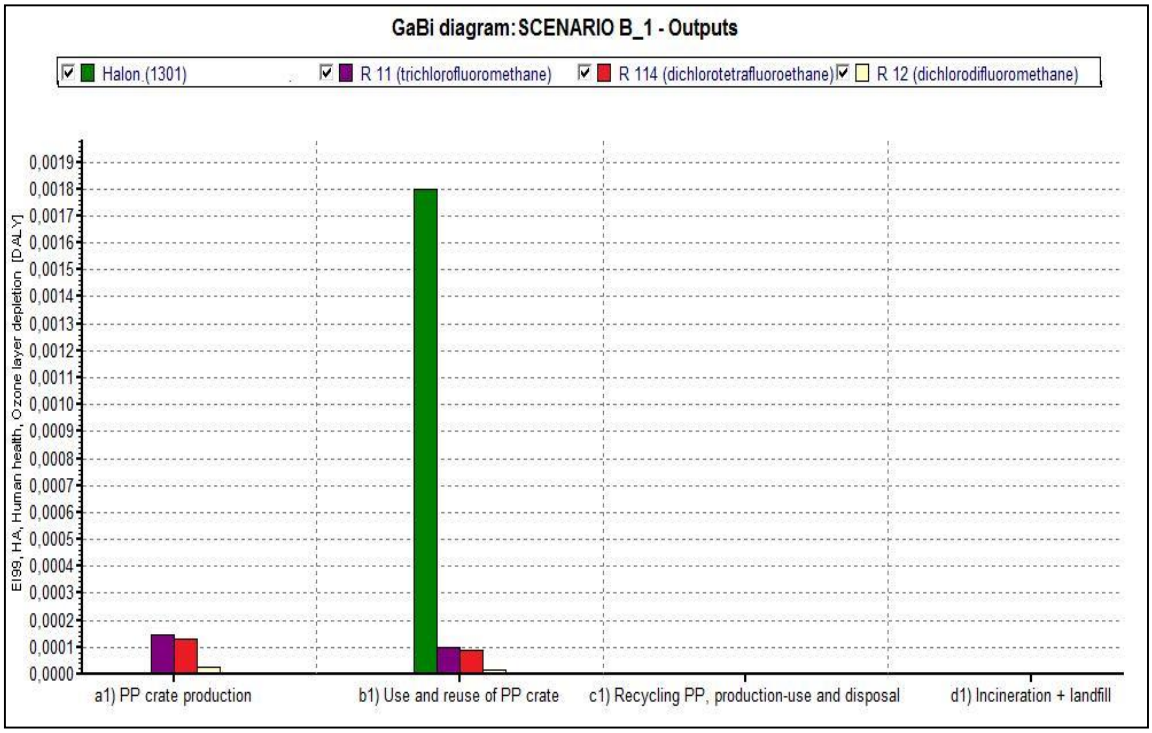

Figure C.50. EI 99 Method. Ozone Layer Depletion results for Scenario B.1.

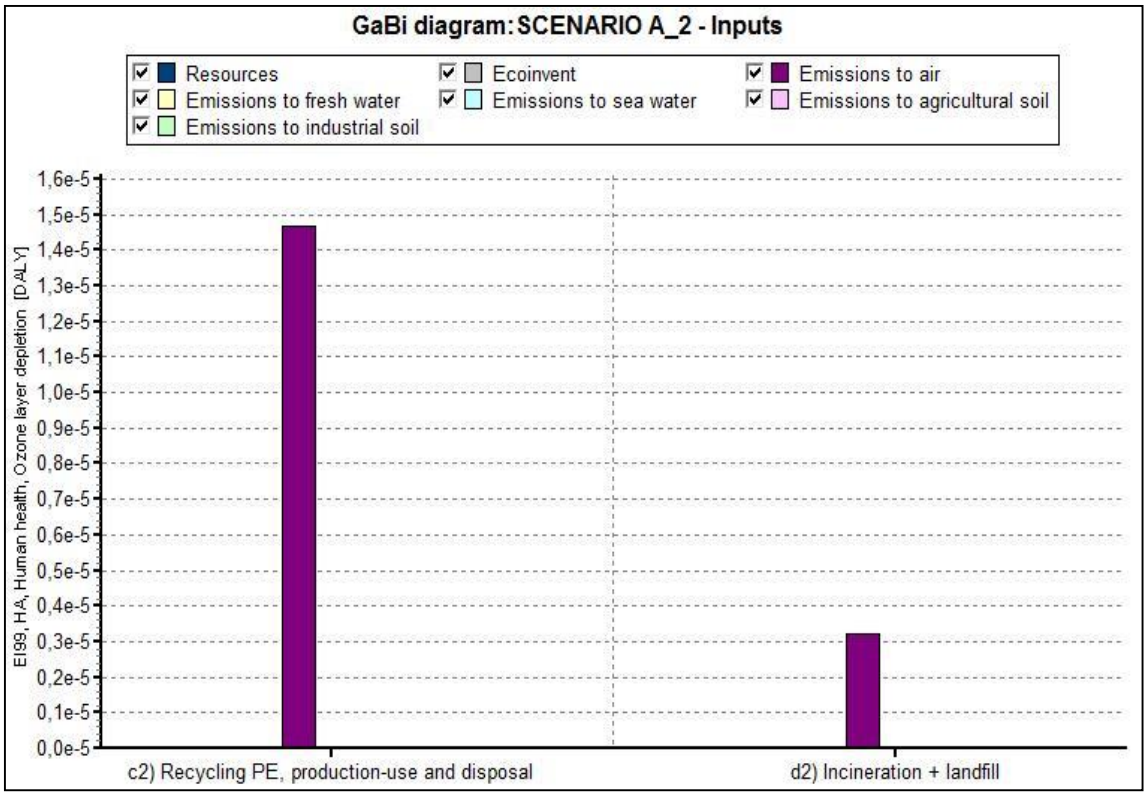

Figure C.51. EI 99 Method. Ozone Layer Depletion results for Scenario A.2.

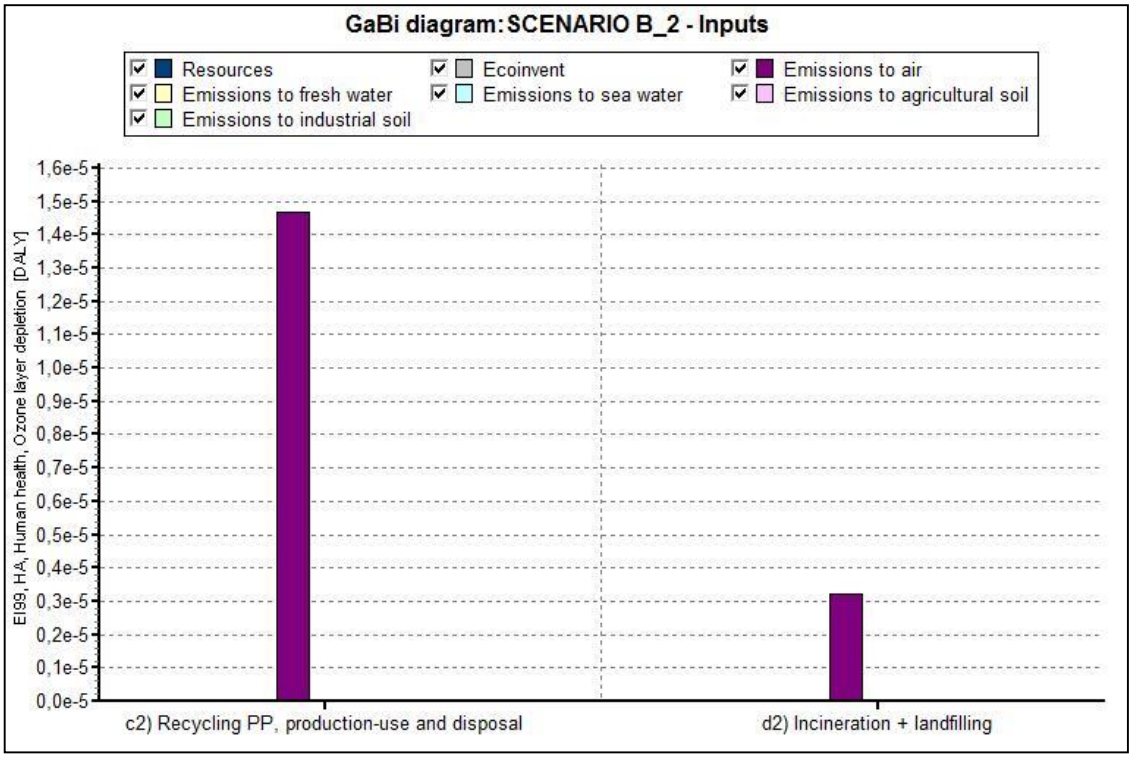

Figure C.52. EI 99 Method. Ozone Layer Depletion results for Scenario B.2.

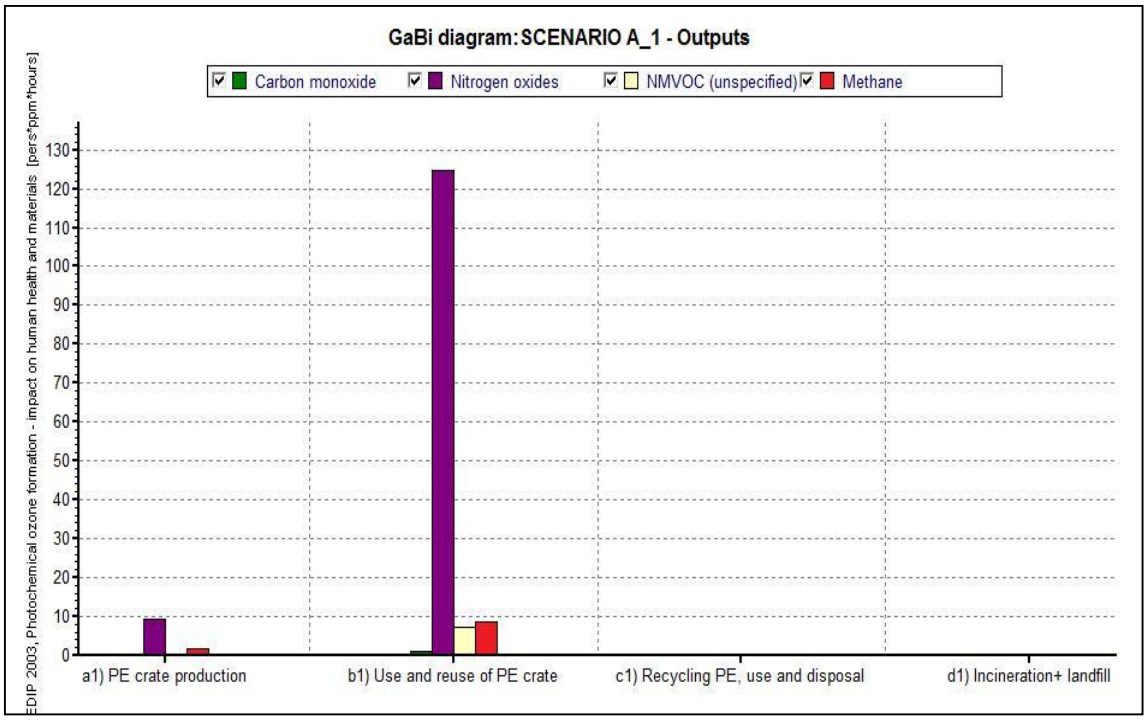

Figure C.53. EDIP 2003 Method. Photochemical ozone formation - impact on human health results for Scenario A.1.

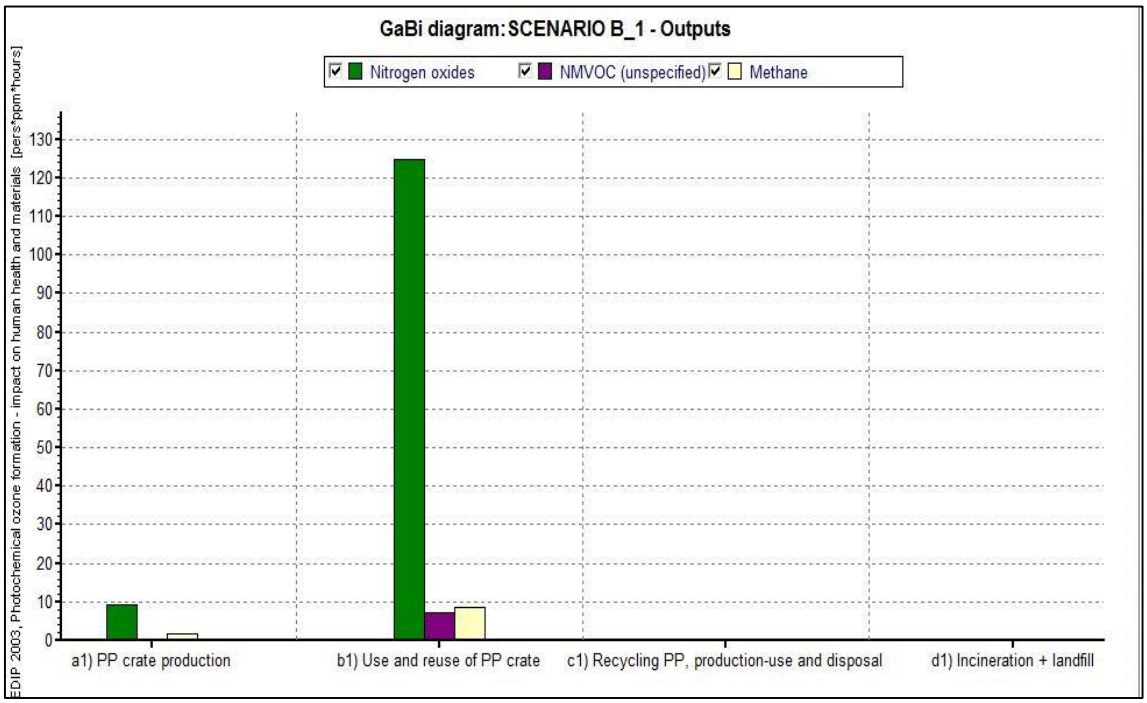

Figure C.54. EDIP 2003 Method. Photochemical ozone formation - impact on human health results for Scenario B.1.

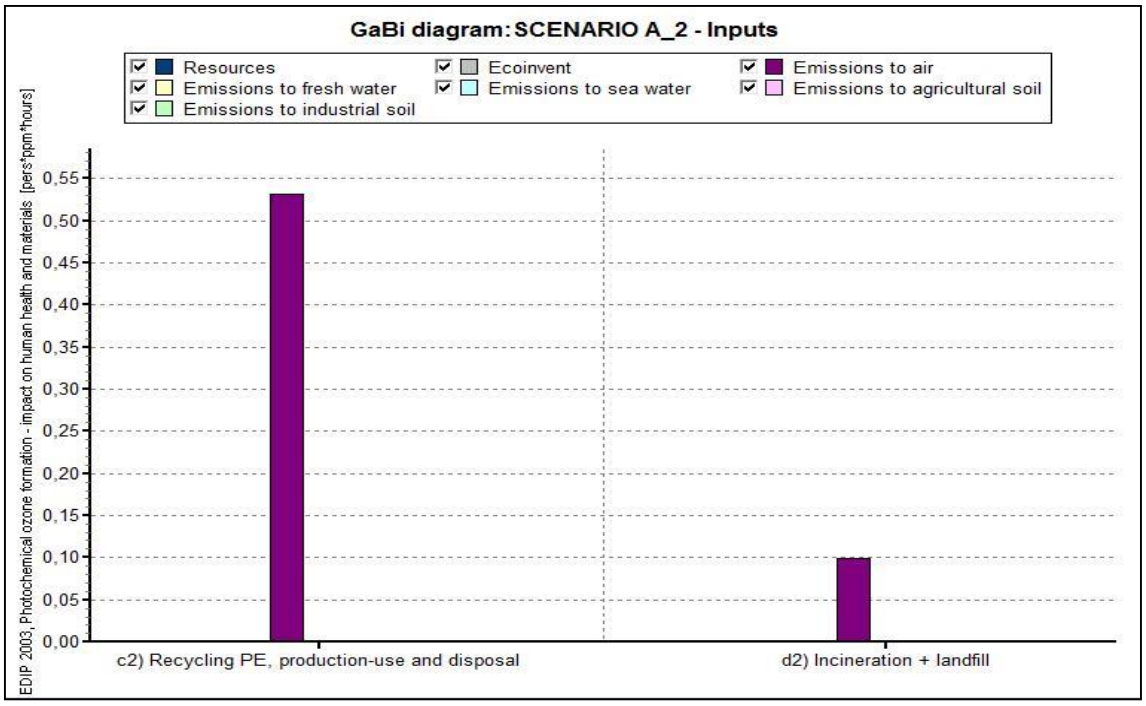

Figure C.55. EDIP 2003 Method. Photochemical ozone formation - impact on human health results for Scenario A.2.

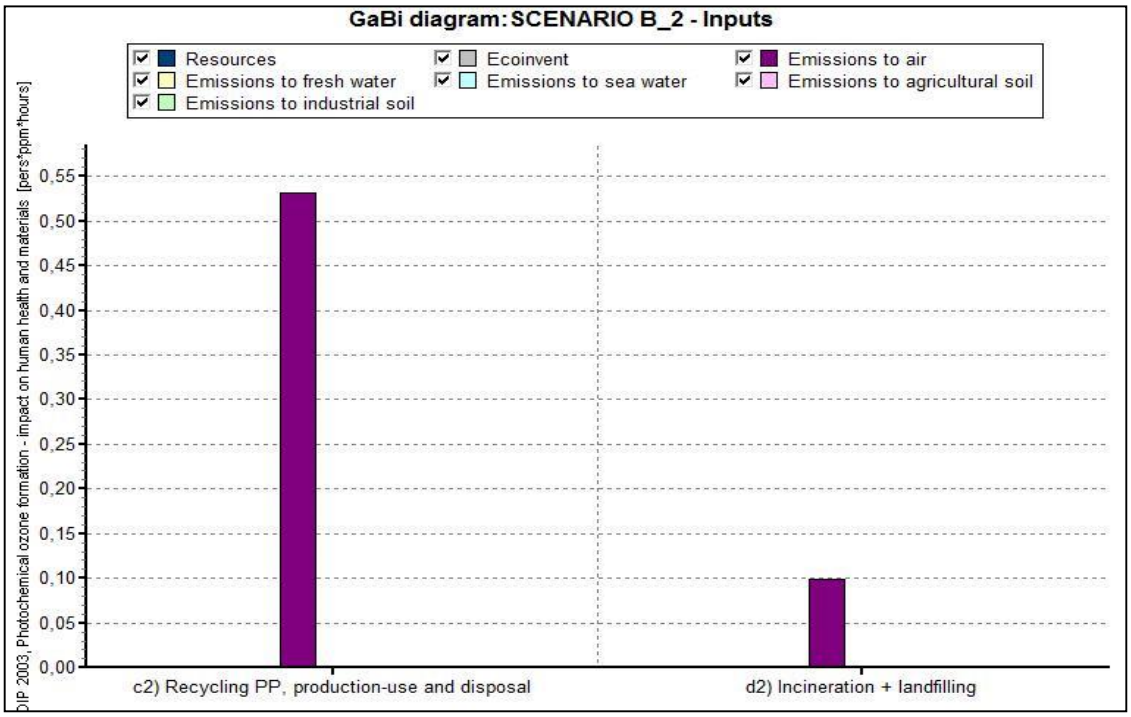

Figure C.56. EDIP 2003 Method. Photochemical ozone formation - impact on human health results for Scenario B.2.

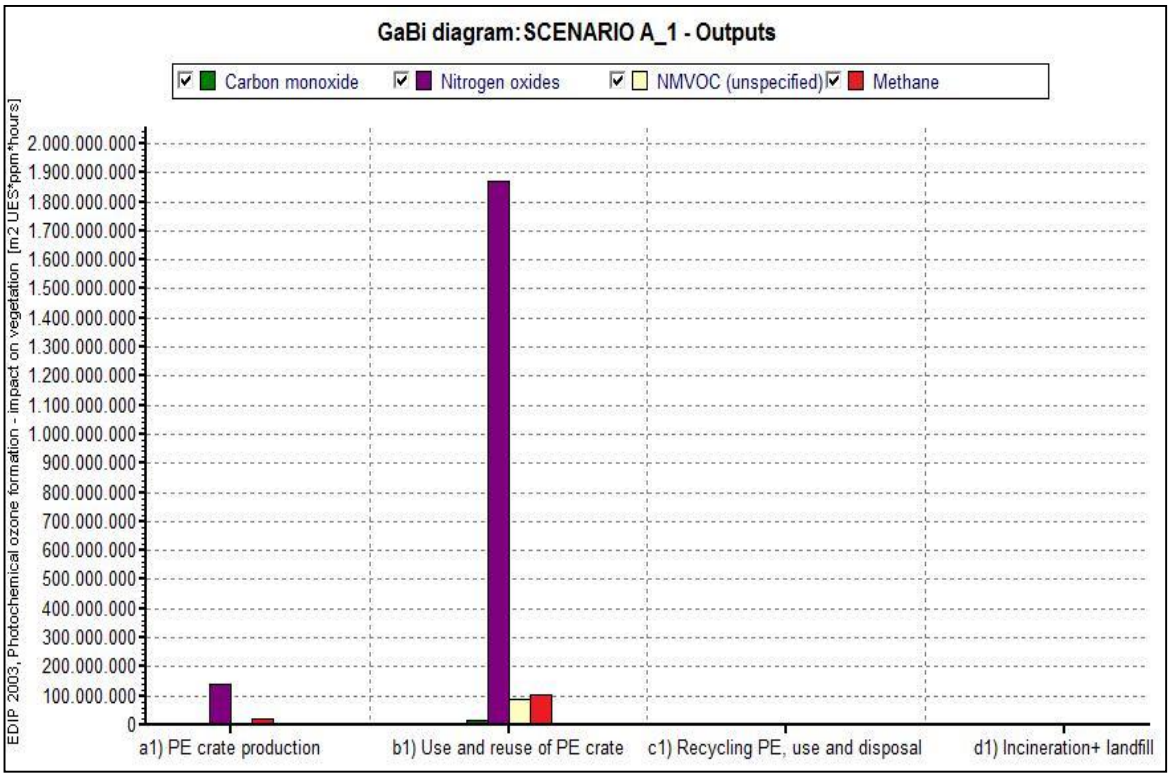

Figure C.57. EDIP 2003 Method. Photochemical ozone formation - impact on vegetation results for Scenario A.1.

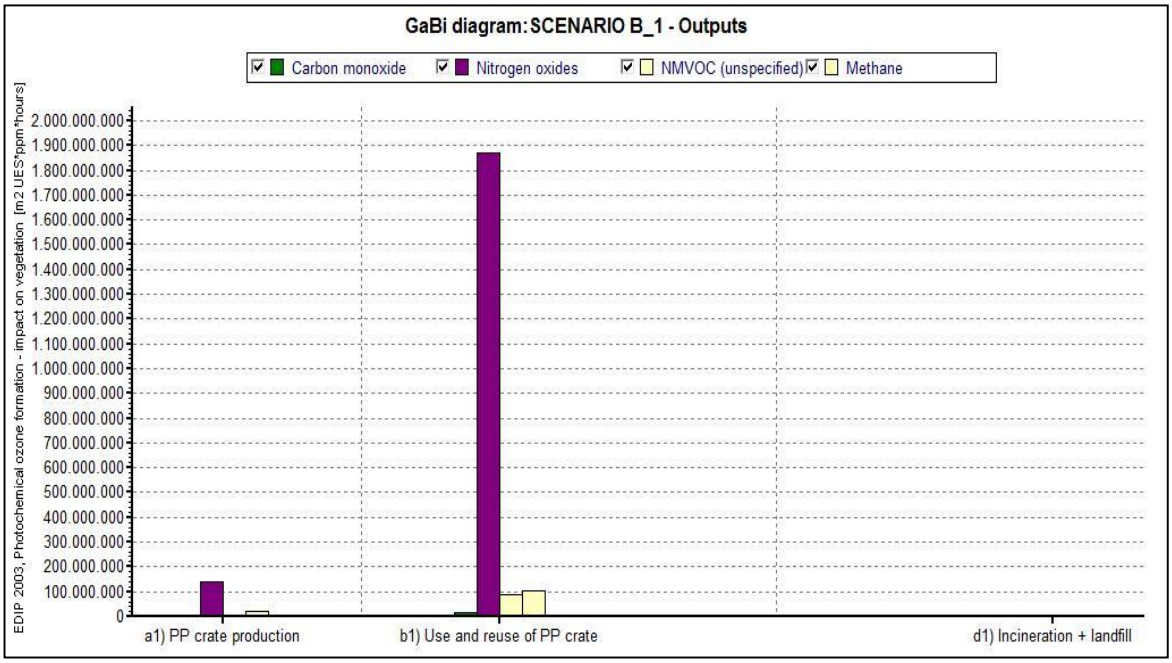

Figure C.58. EDIP 2003 Method. Photochemical ozone formation - impact on vegetation results for Scenario B.1.

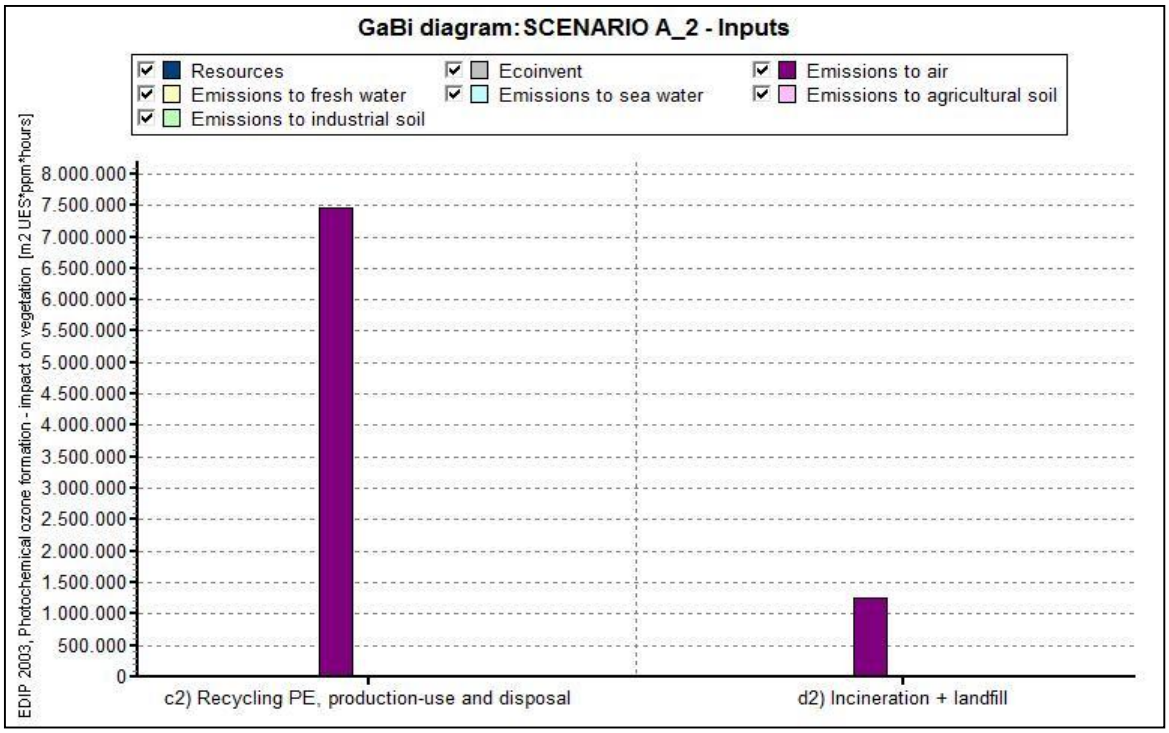

Figure C.59. EDIP 2003 Method. Photochemical ozone formation - impact on vegetation results for Scenario A.2.

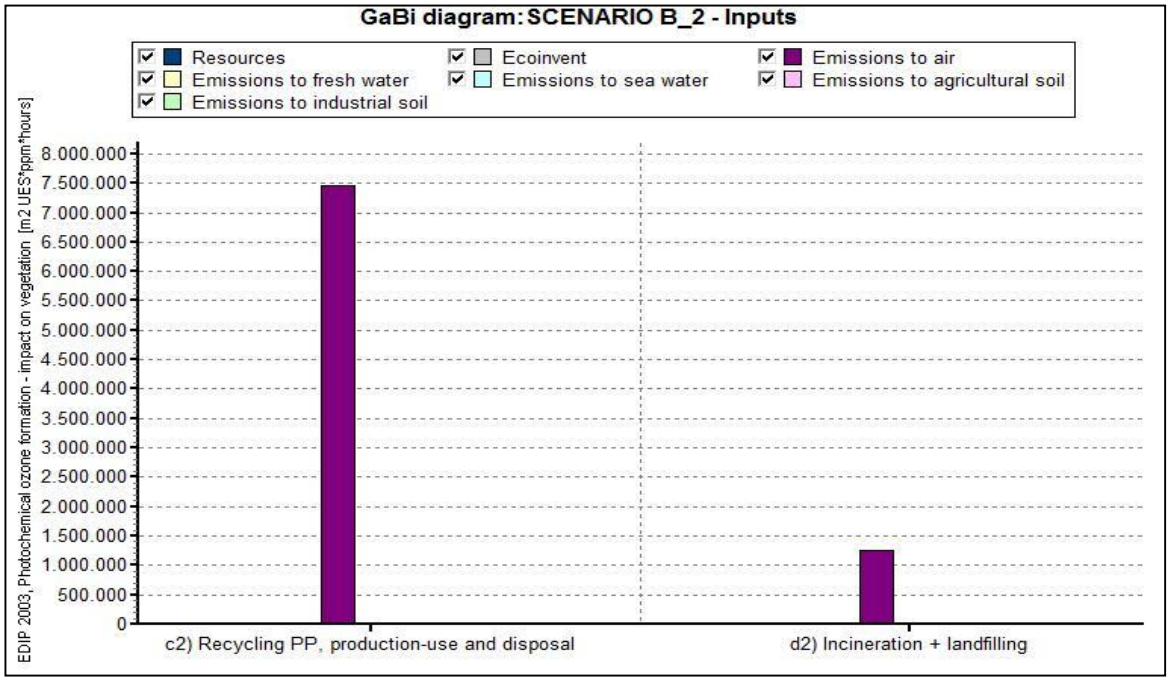

Figure C.60. EDIP 2003 Method. Photochemical ozone formation - impact on vegetation results for Scenario B.2.

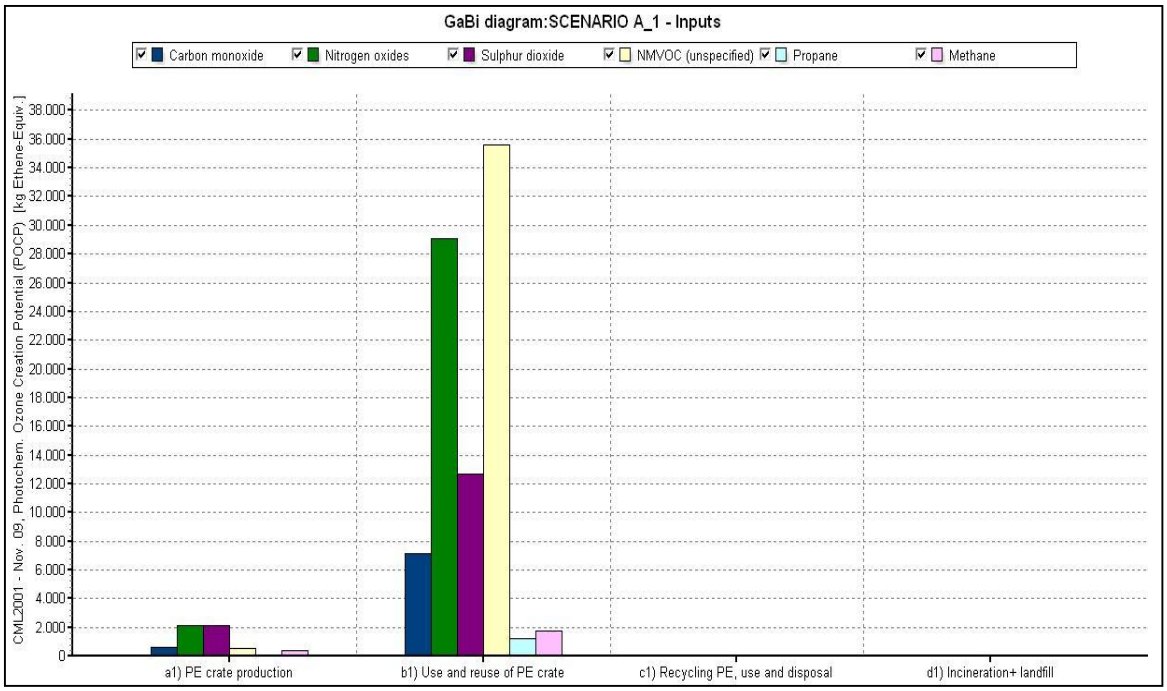

Figure C.61. CML 2001 Nov. ’09 Method. Photochemical Ozone creation potential results for Scenario A.1.

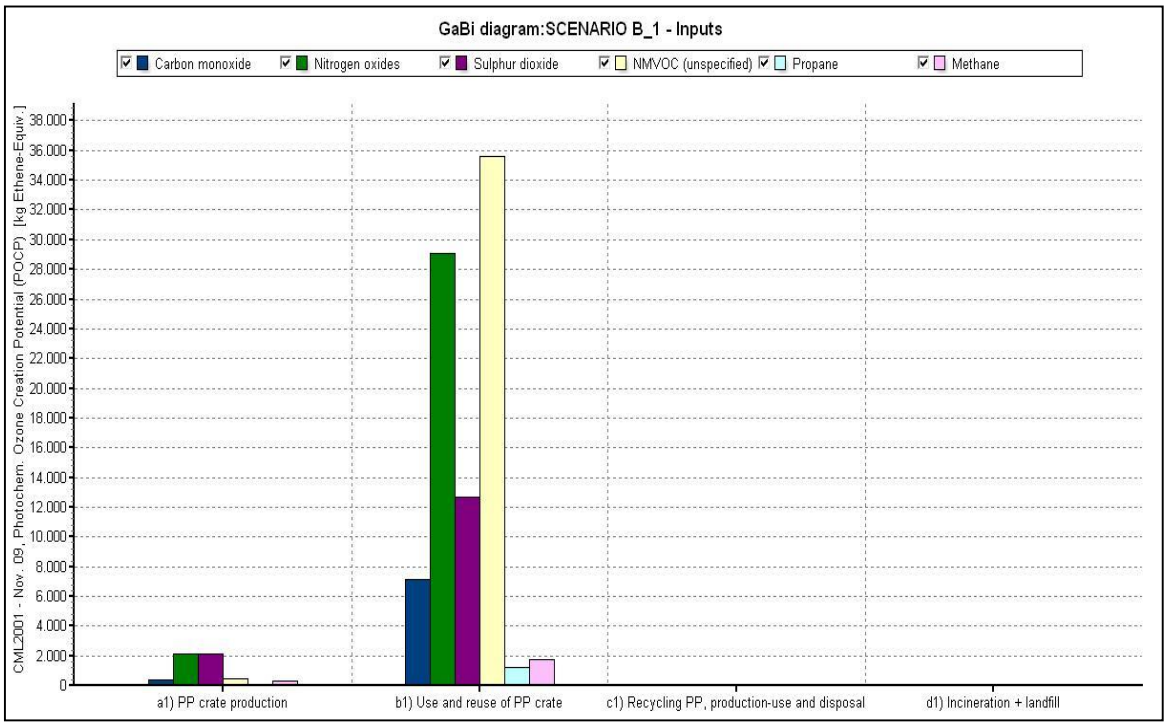

Figure C.62. CML 2001 Nov. ’09 Method. Photochemical Ozone creation potential results for Scenario B.1.

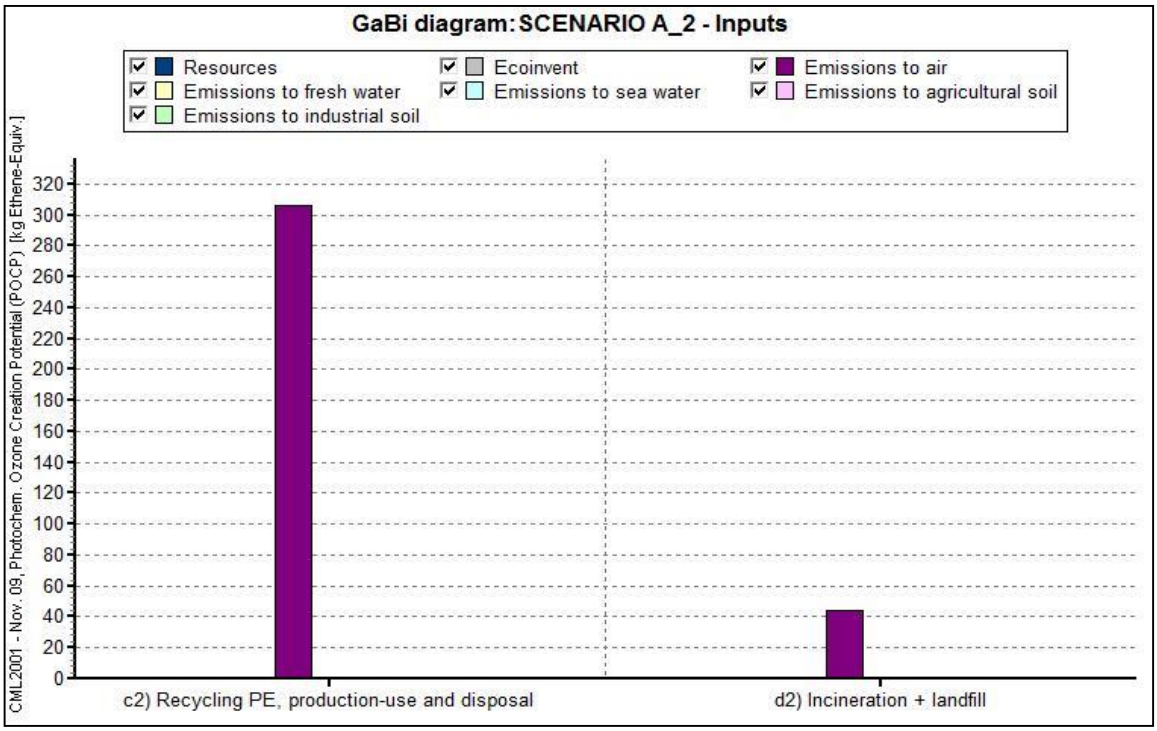

Figure C.63. CML 2001 Nov. ’09 Method. Photochemical Ozone creation potential results for Scenario A.2.

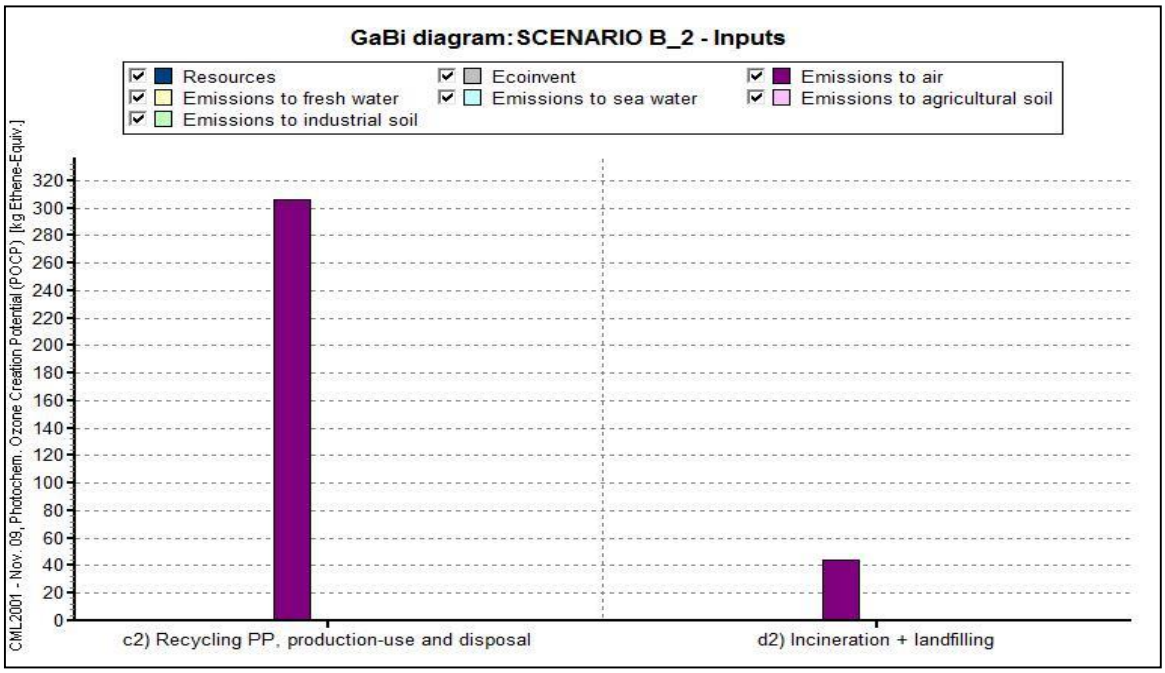

Figure C. 64. CML 2001 Nov. ’09 Method. Photochemical Ozone creation potential results for Scenario B.2.

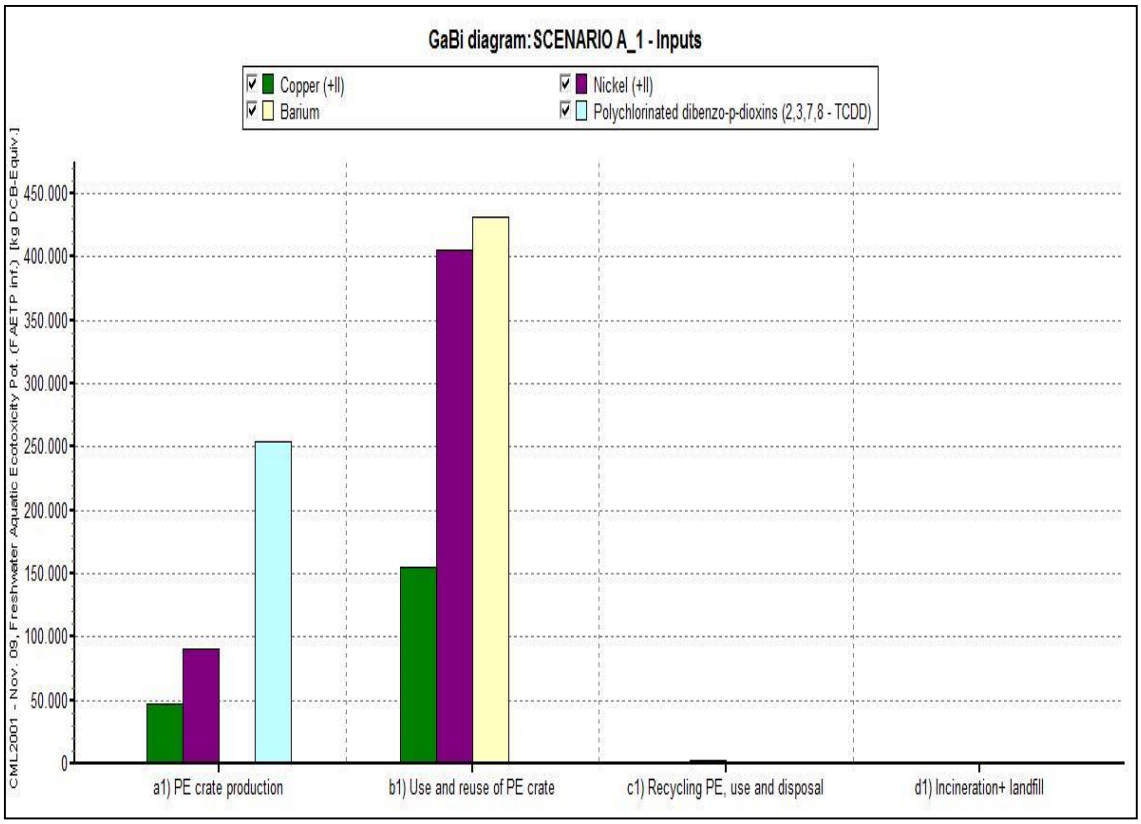

Figure C.65. CML 2001 Nov. ’09 Method. FAETP results for Scenario A.1.

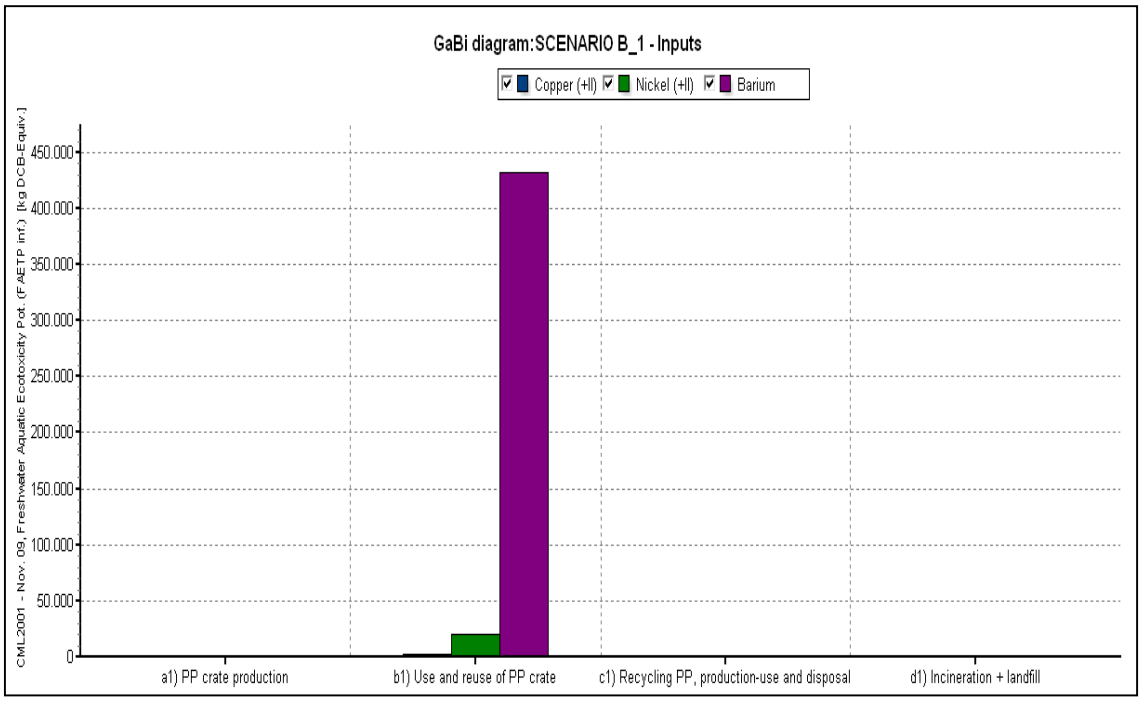

Figure C.66. CML 2001 Nov. ’09 Method. FAETP results for Scenario B.1.

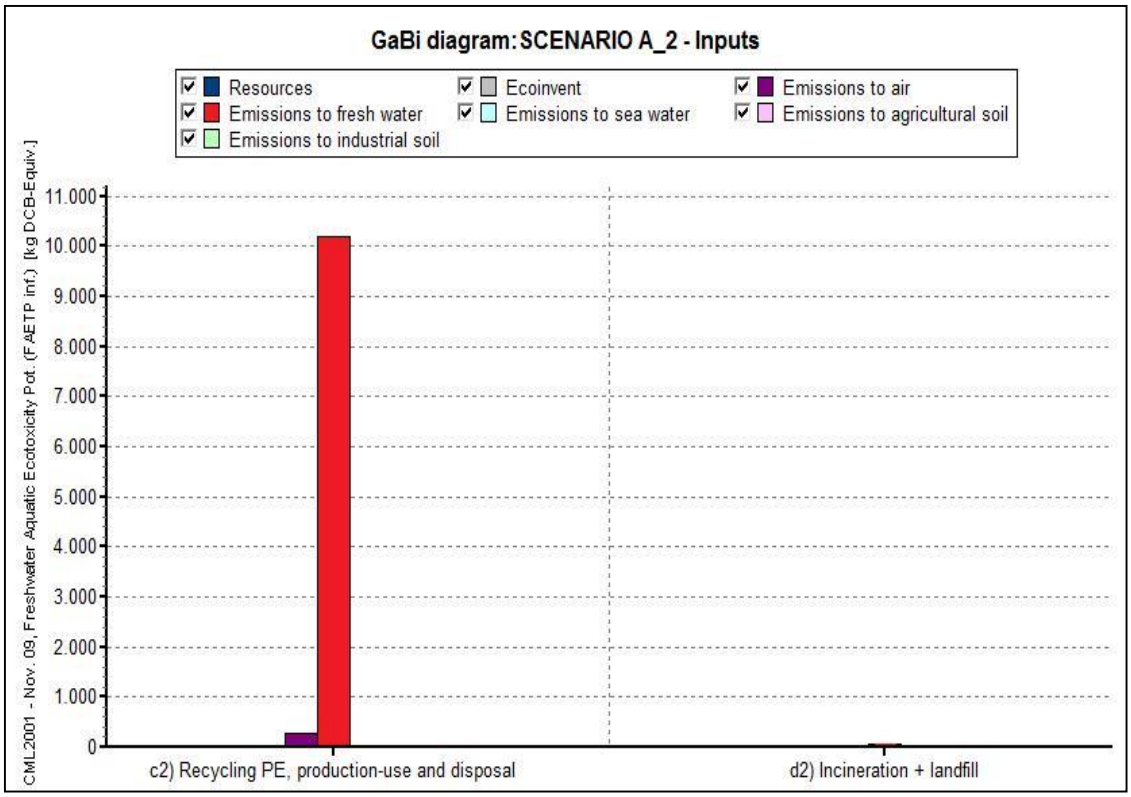

Figure C.67. CML 2001 Nov. ’09 Method. FAETP results for Scenario A.2.

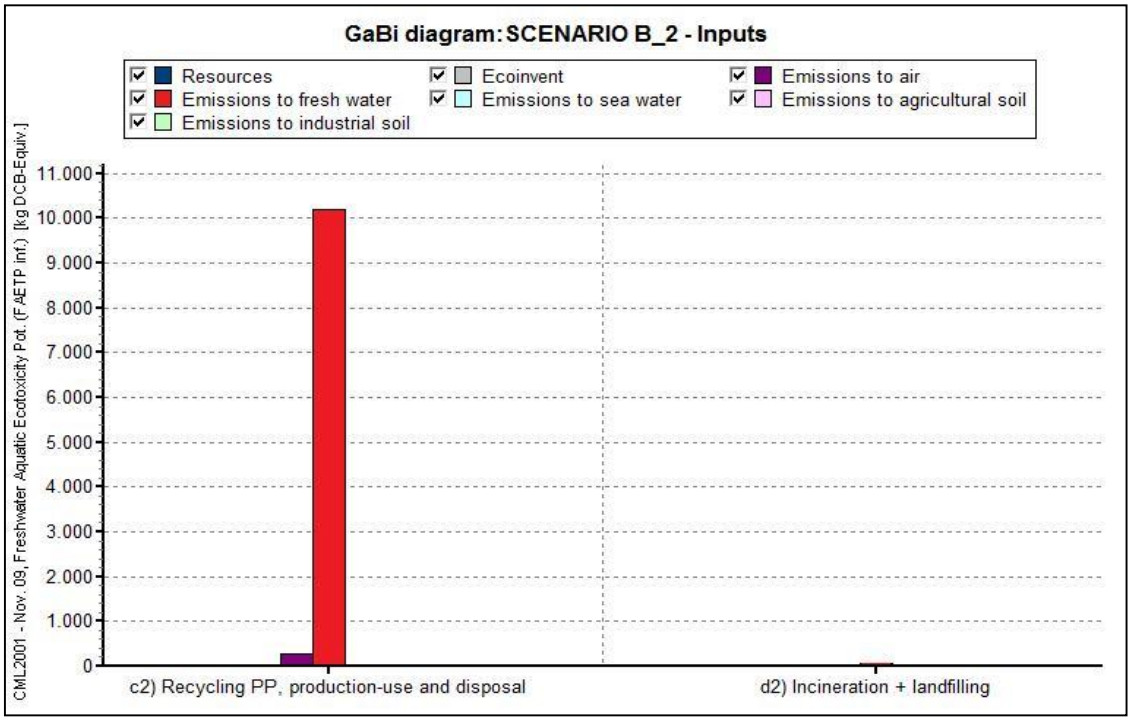

Figure C.68. CML 2001 Nov. ’09 Method. FAETP results for Scenario B.2.

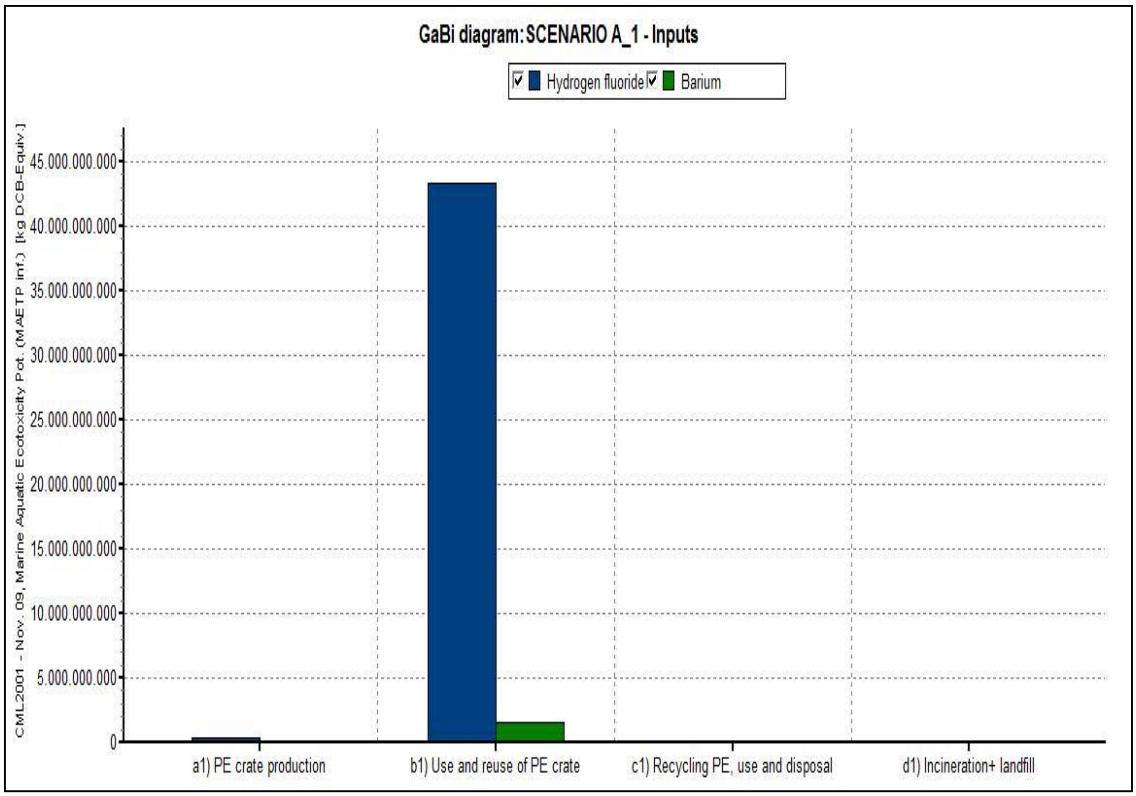

Figure C.69. CML 2001 Nov. ’09 Method. MAETP results for Scenario A.1.

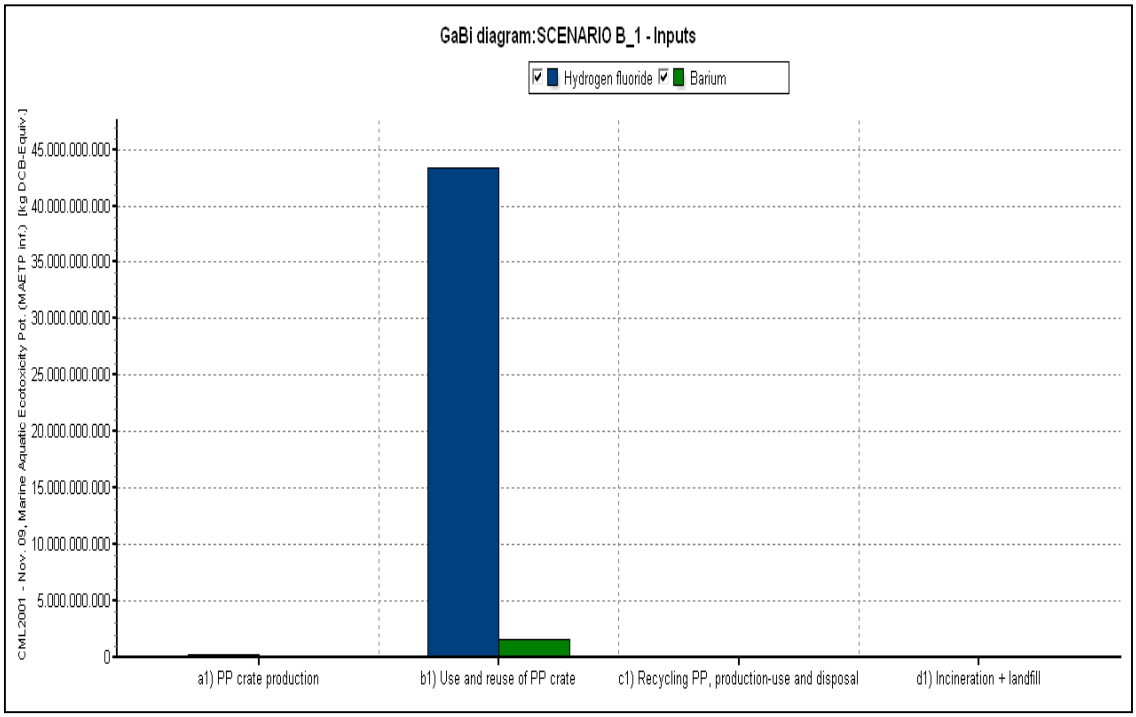

Figure C.70. CML 2001 Nov. ’09 Method. MAETP results for Scenario B.1.

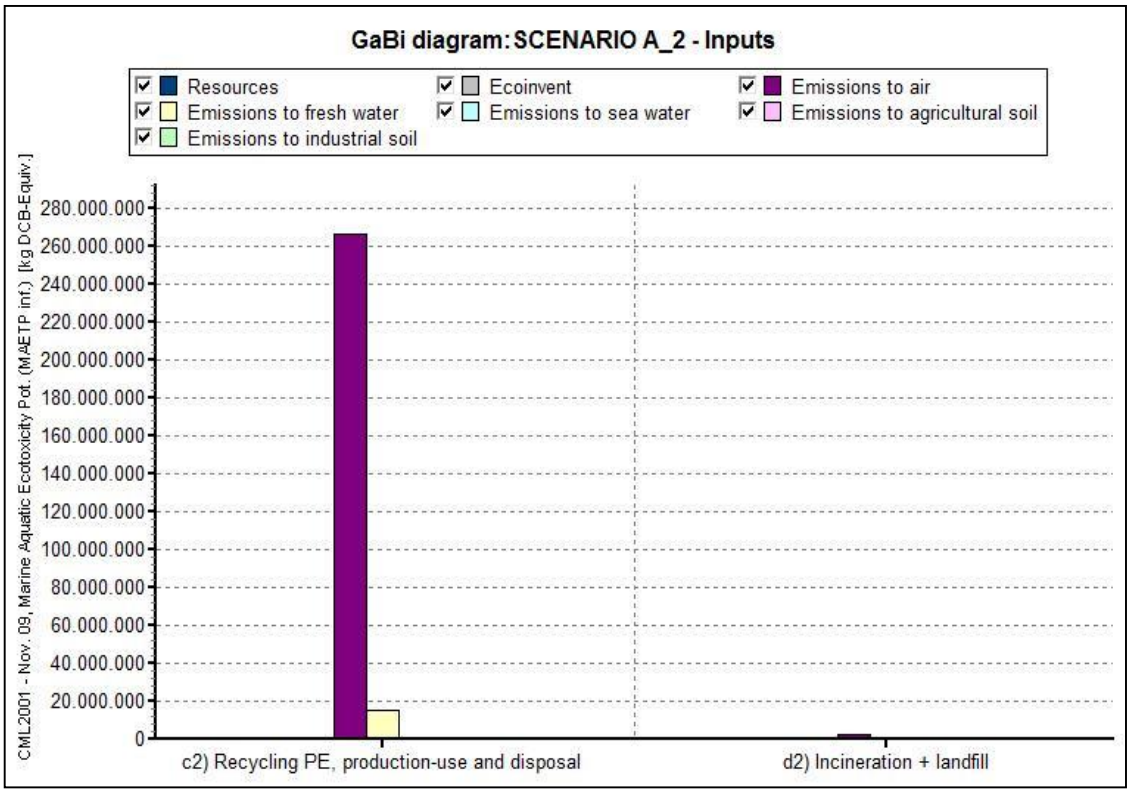

Figure C.71. CML 2001 Nov. ’09 Method. MAETP results for Scenario A.2.

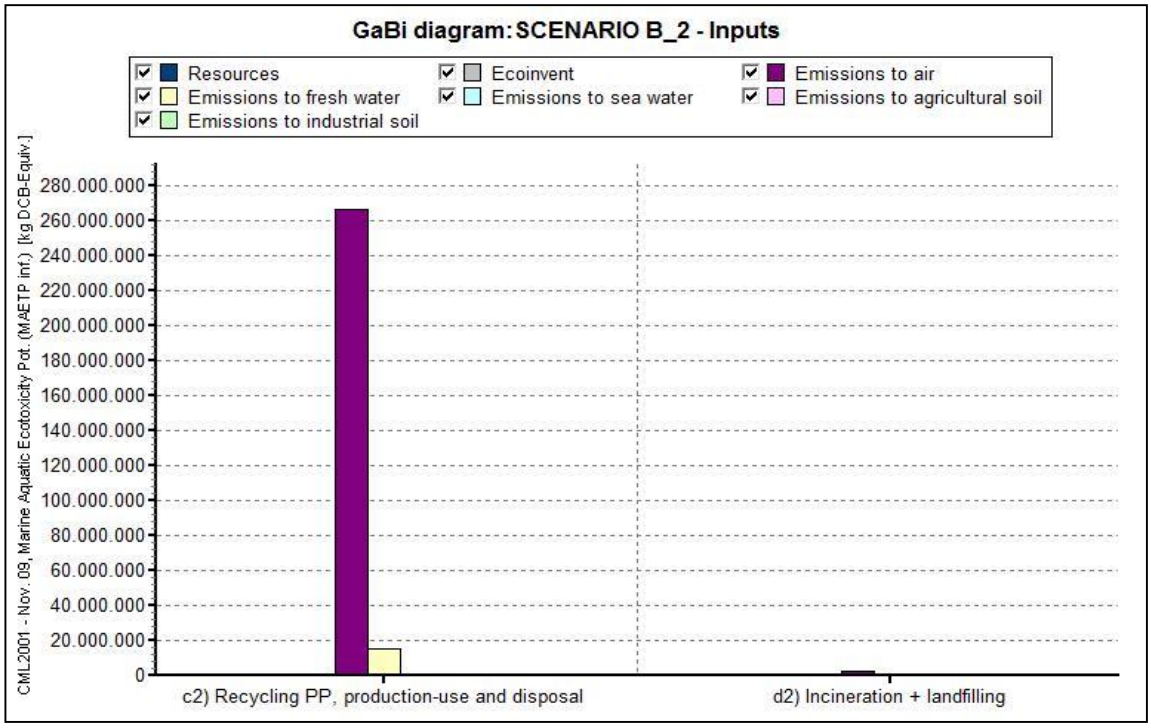

Figure C.72. CML 2001 Nov. ’09 Method. MAETP results for Scenario B.2.

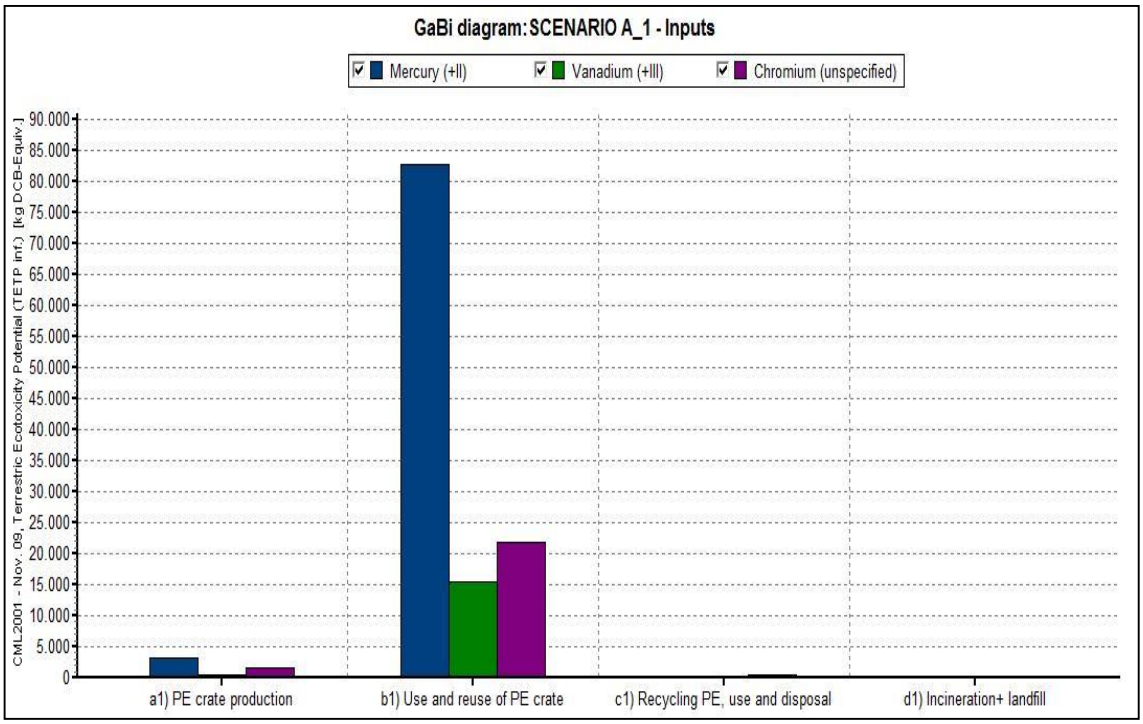

Figure C.73. CML 2001 Nov. ’09 Method. TETP results for Scenario A.1.

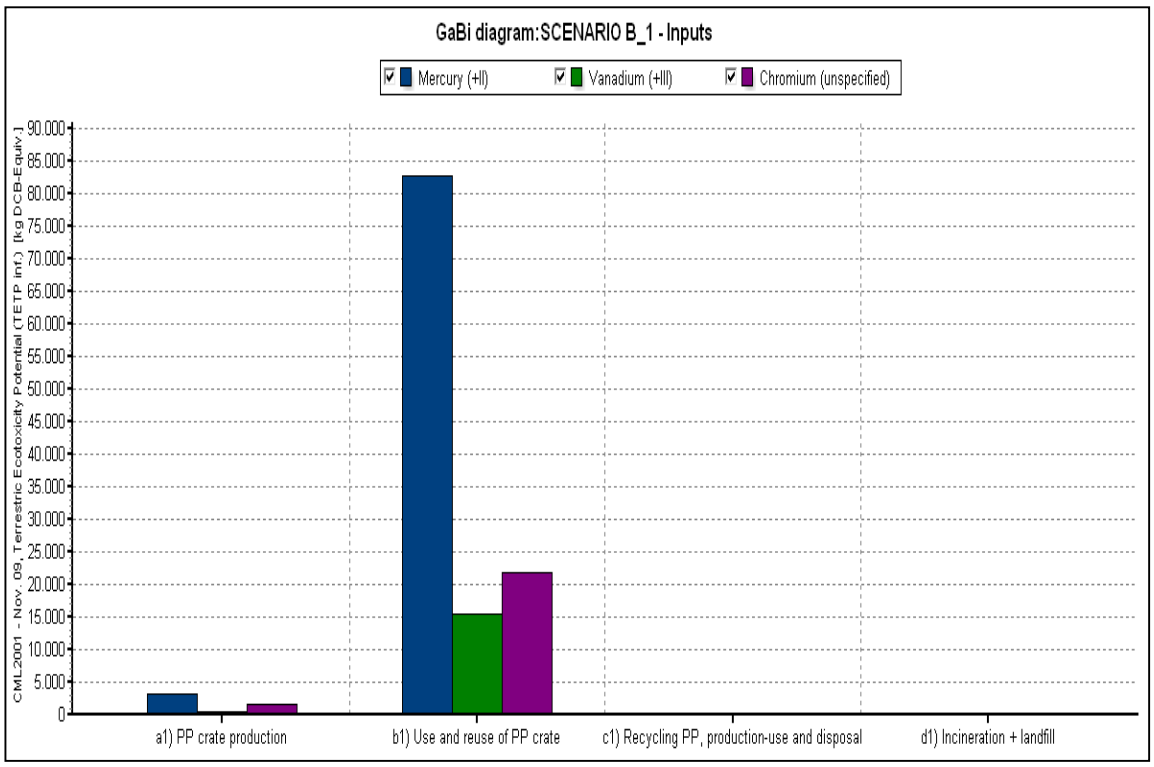

Figure C.74. CML 2001 Nov ’09 Method. TETP results for Scenario B.1.

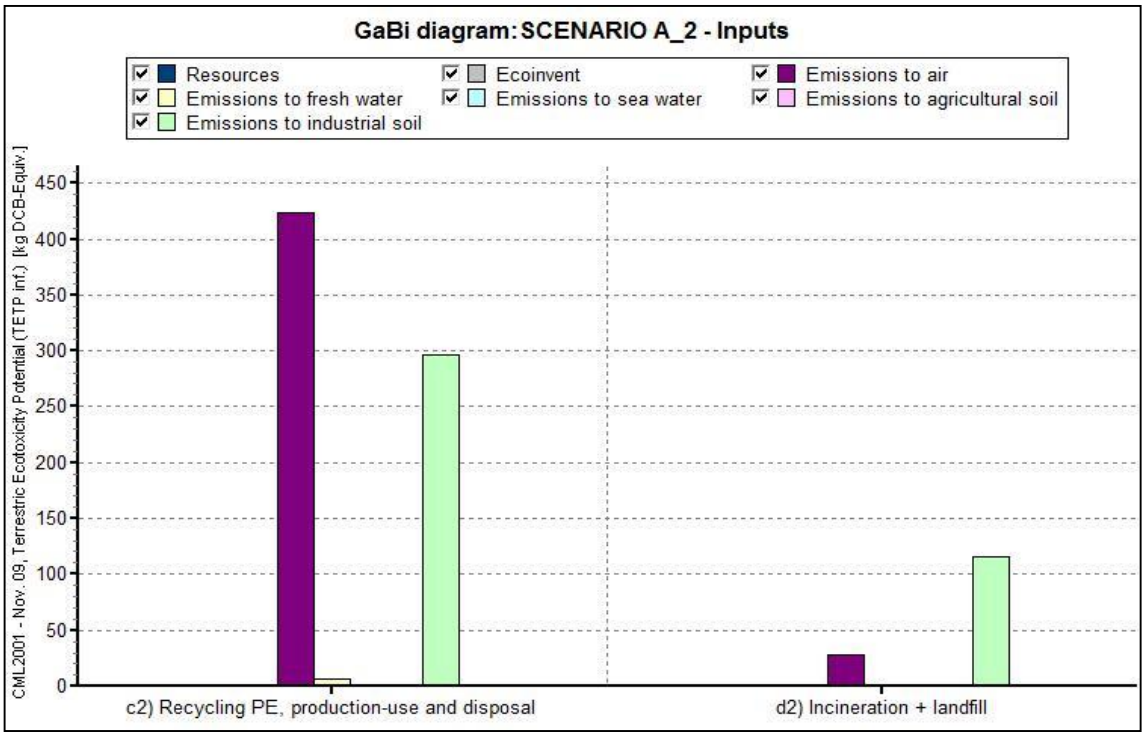

Figure C.75. CML 2001 Nov. ’09 Method. TETP results for Scenario A.2.

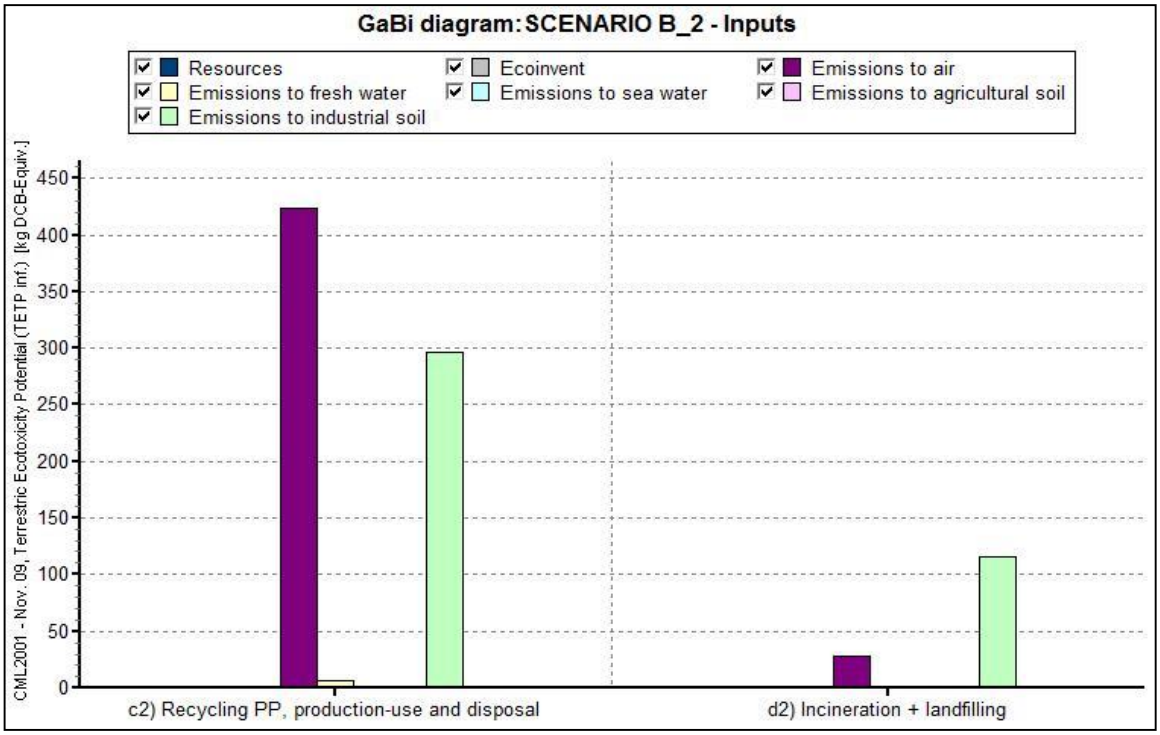

Figure C.76. CML 2001 Nov. ’09 Method. TETP results for Scenario B.2.

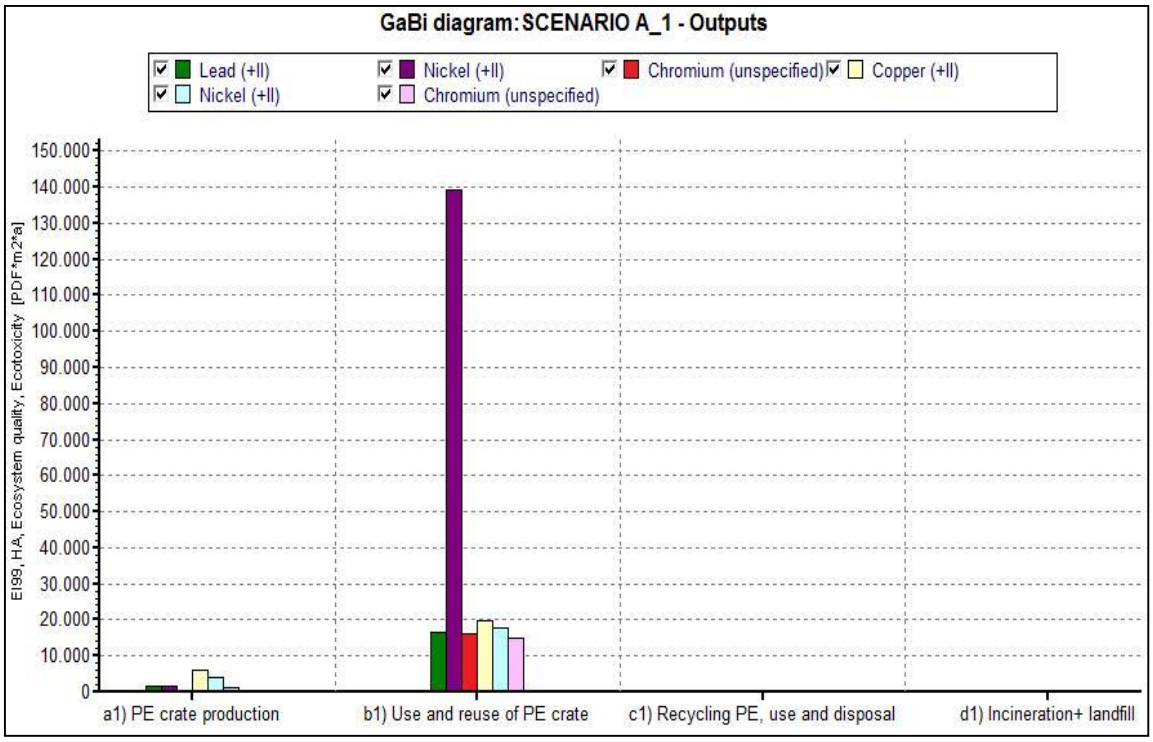

Figure C.77. EI 99 Method. Ecotoxicity results for Scenario A.1.

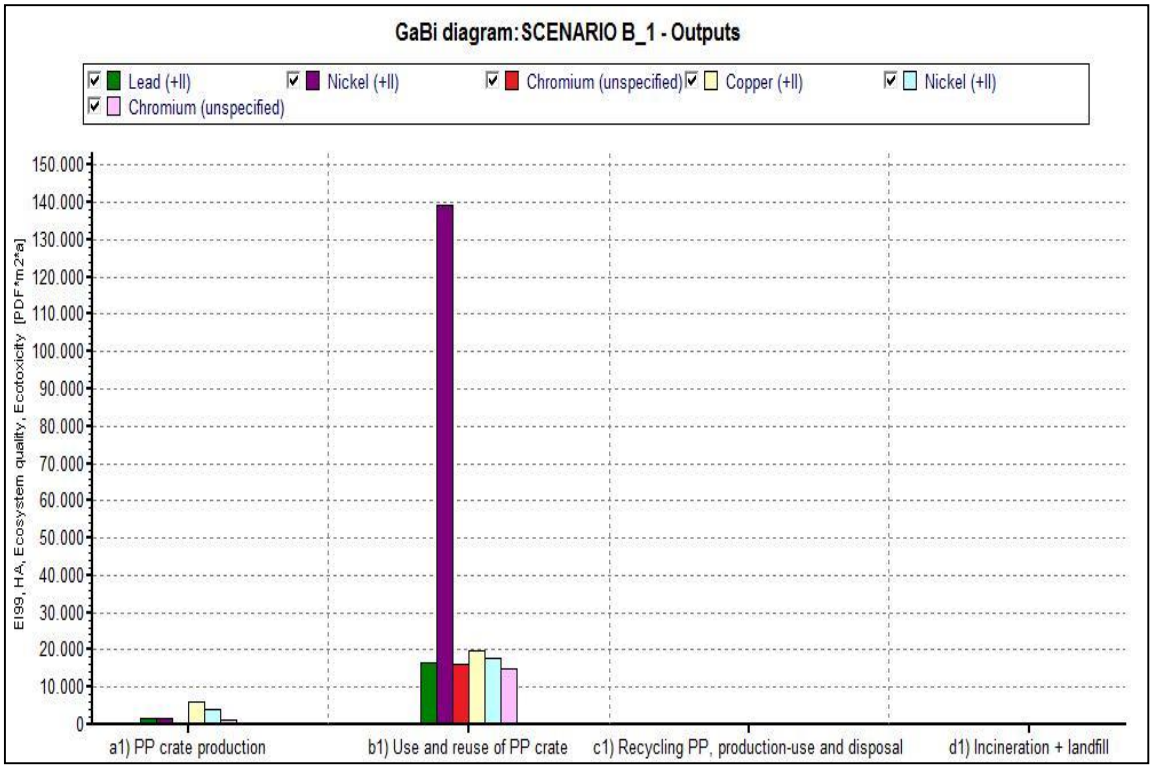

Figure C.78. EI 99 Method. Ecotoxicity results for Scenario B.1.

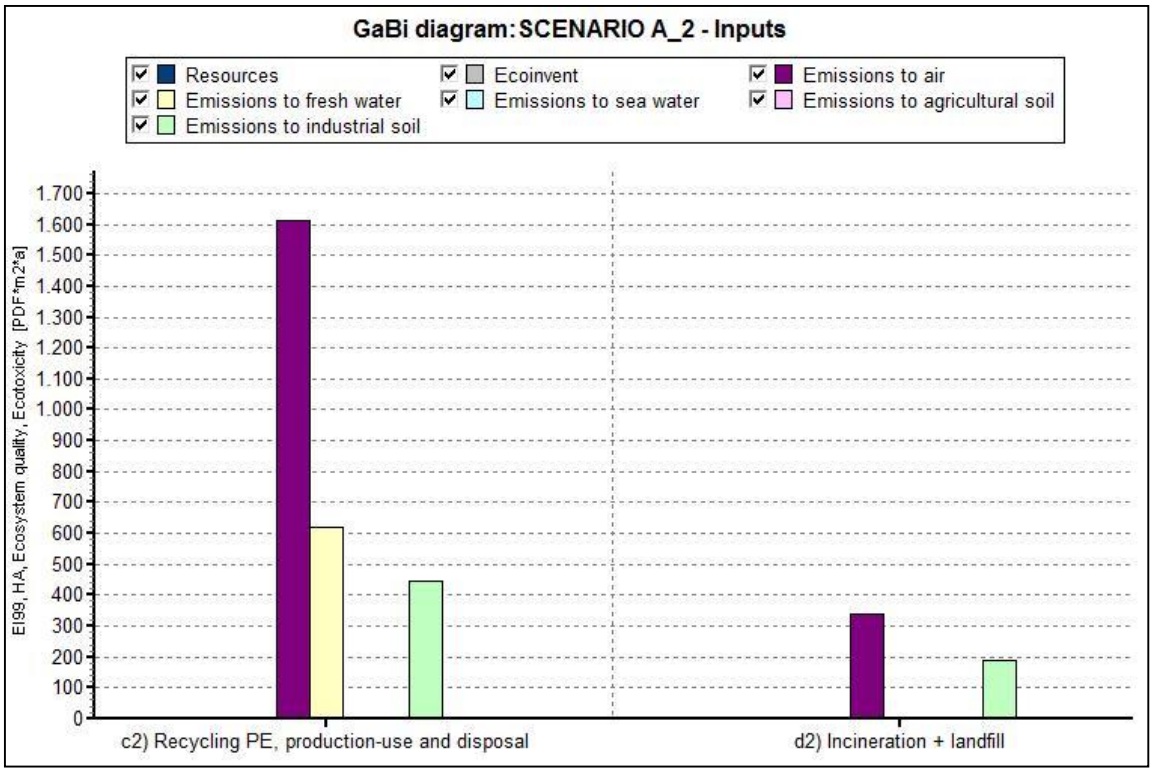

Figure C.79. EI 99 Method. Ecotoxicity results for Scenario A.2.

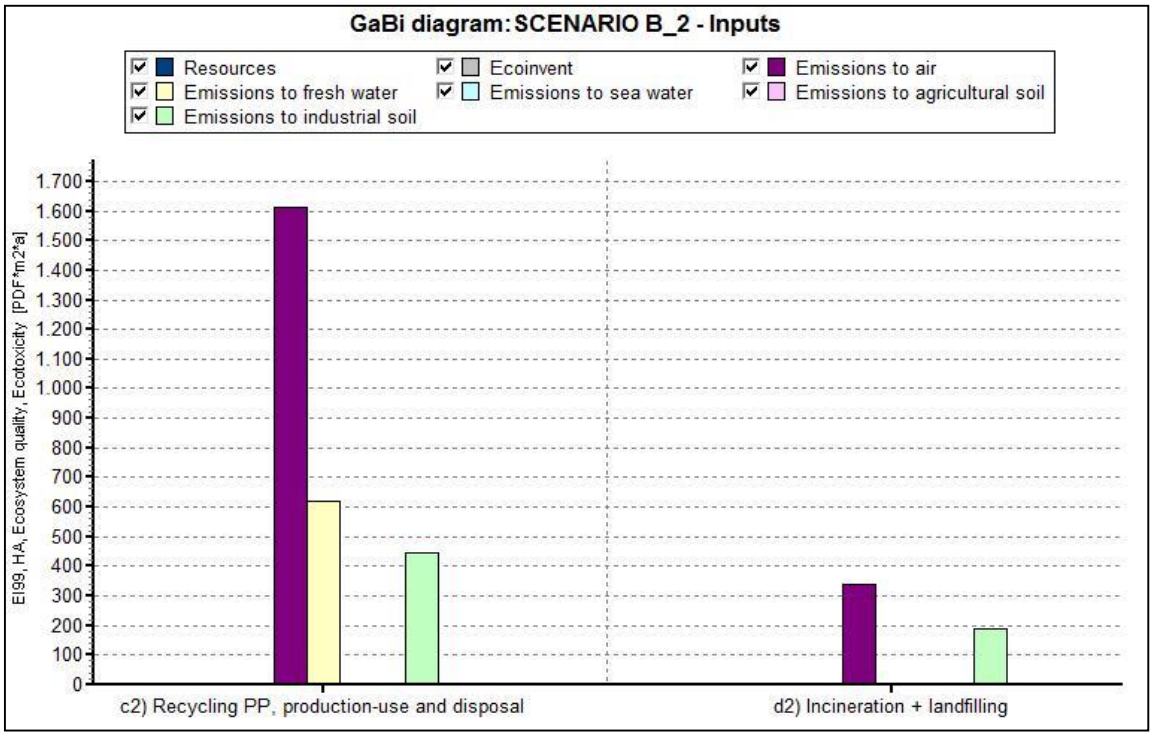

Figure C.80. EI 99 Method. Ecotoxicity results for Scenario B.2.

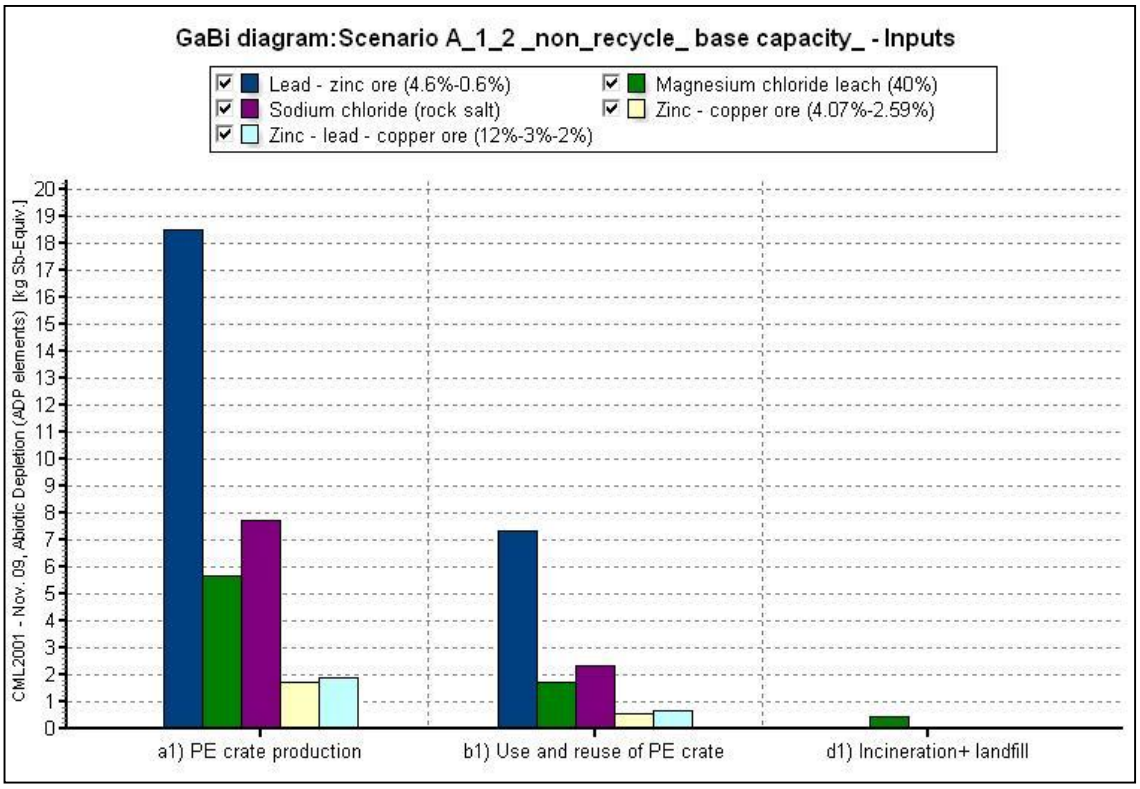

Figure C.81. CML 2001 Nov. ‘09 Method. ADP results for Scenario A.1.2.

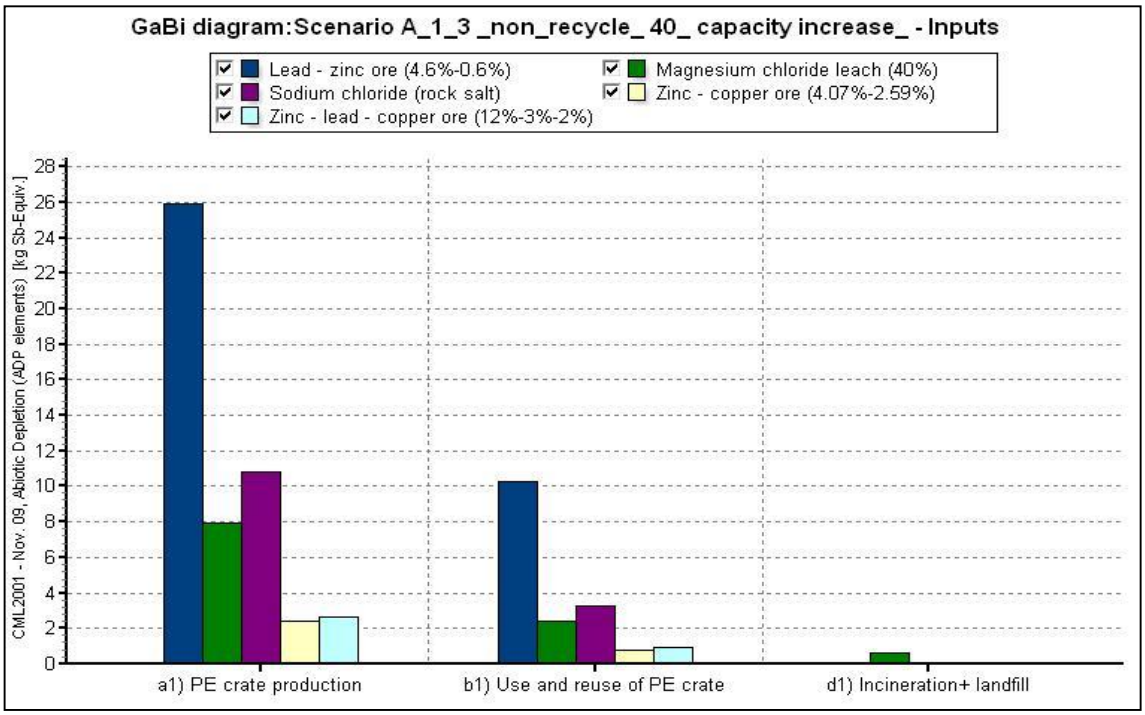

Figure C.82. CML Nov. ‘09 2001 Method. ADP results for Scenario A.1.3.

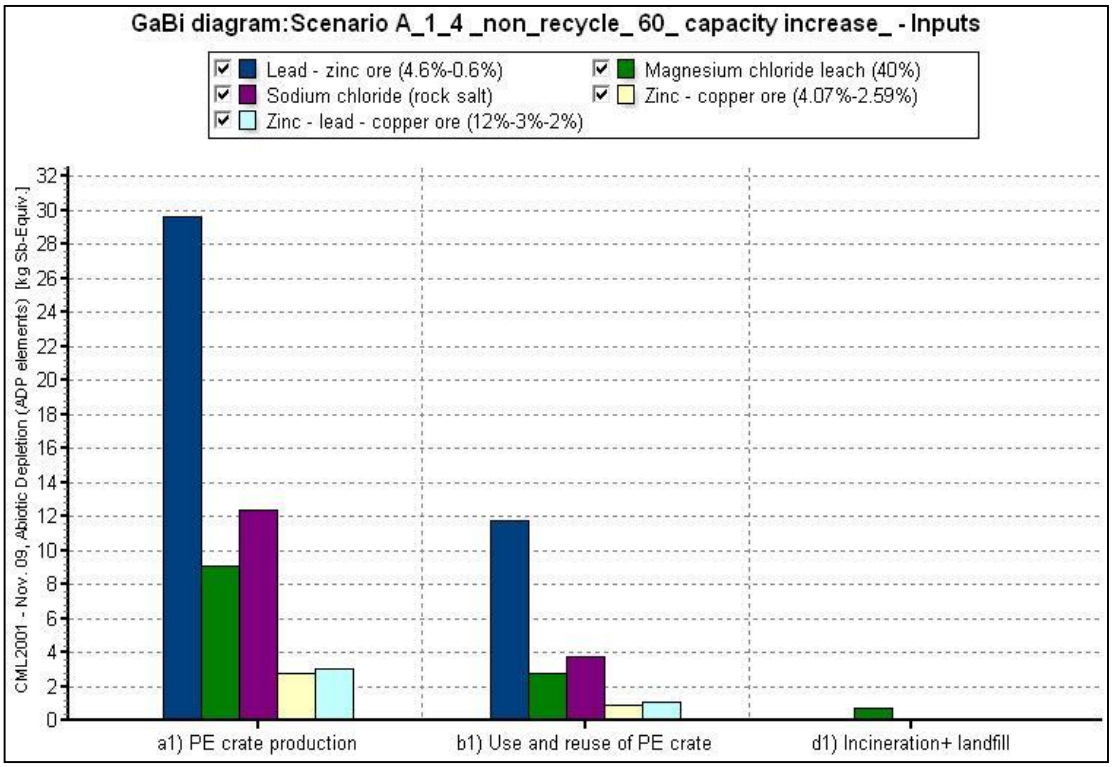

Figure C.83. CML 2001 Nov. ’09 Method. ADP results for Scenario A.1.4.

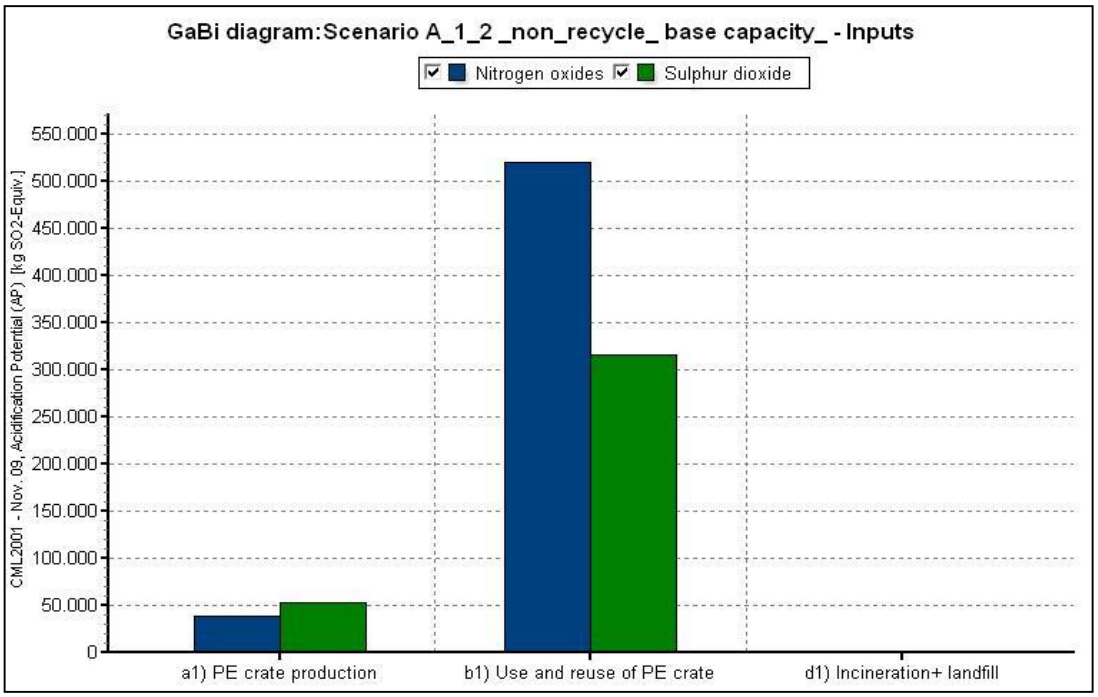

Figure C.84. CML 2001 Nov. ’09 Method. Acidification Potential results for Scenario A.1.2.

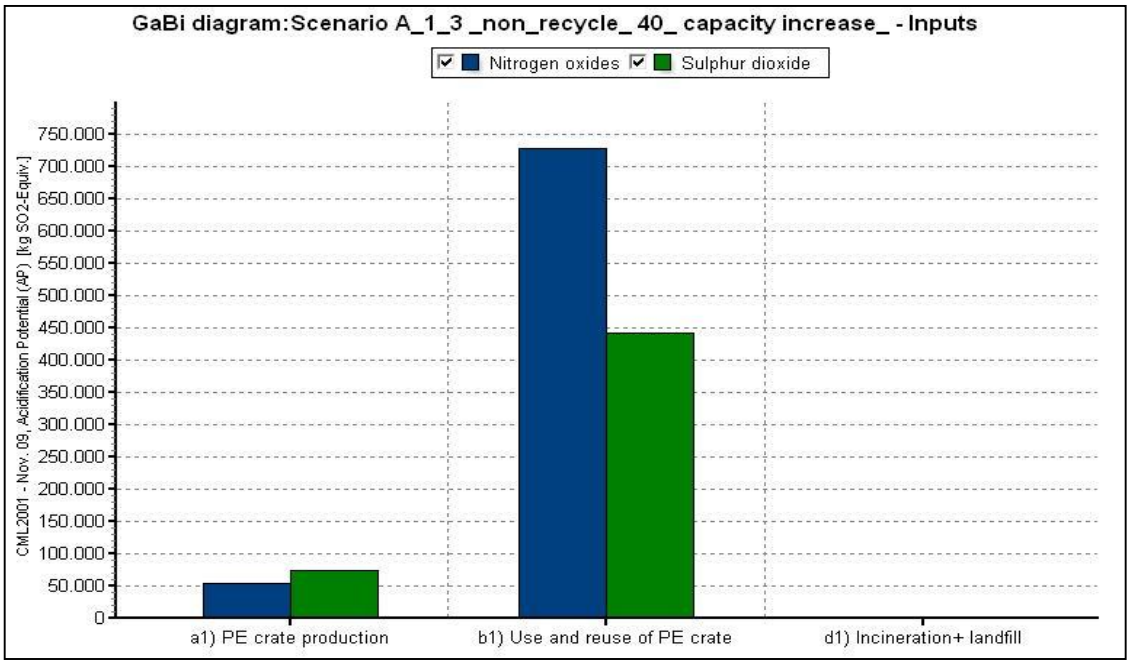

Figure C.85. CML 2001 Nov. ’09 Method. Acidification Potential results for Scenario A.1.3.

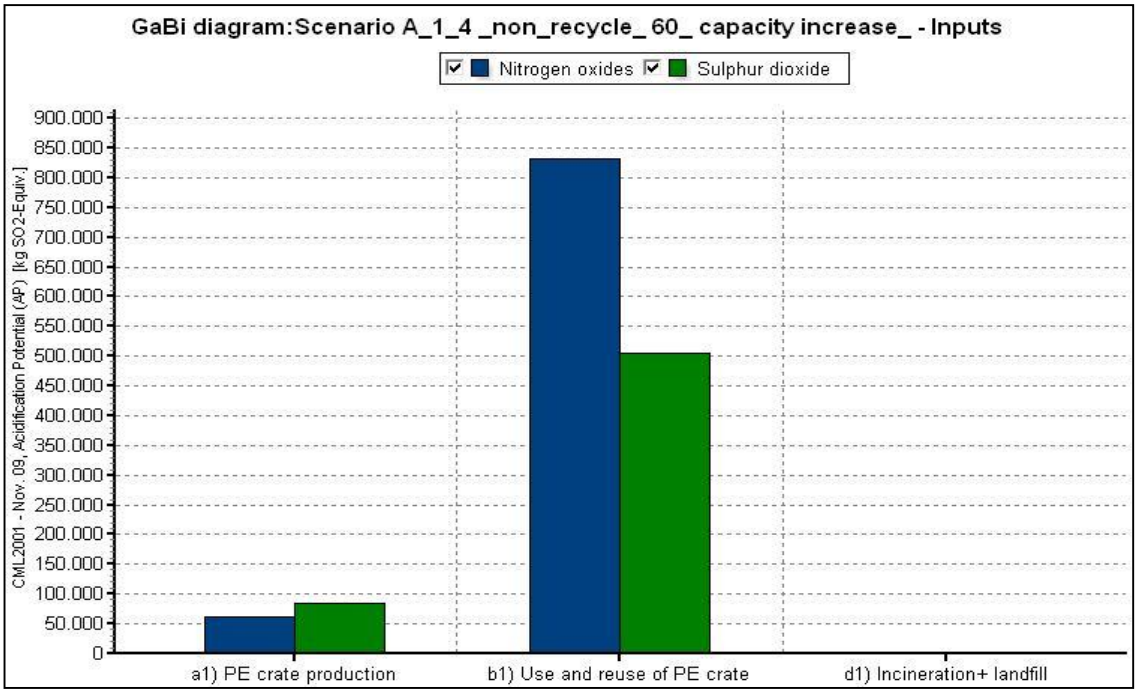

Figure C.86. CML 2001 Nov. ’09 Method. Acidification Potential results for Scenario A.1.4.

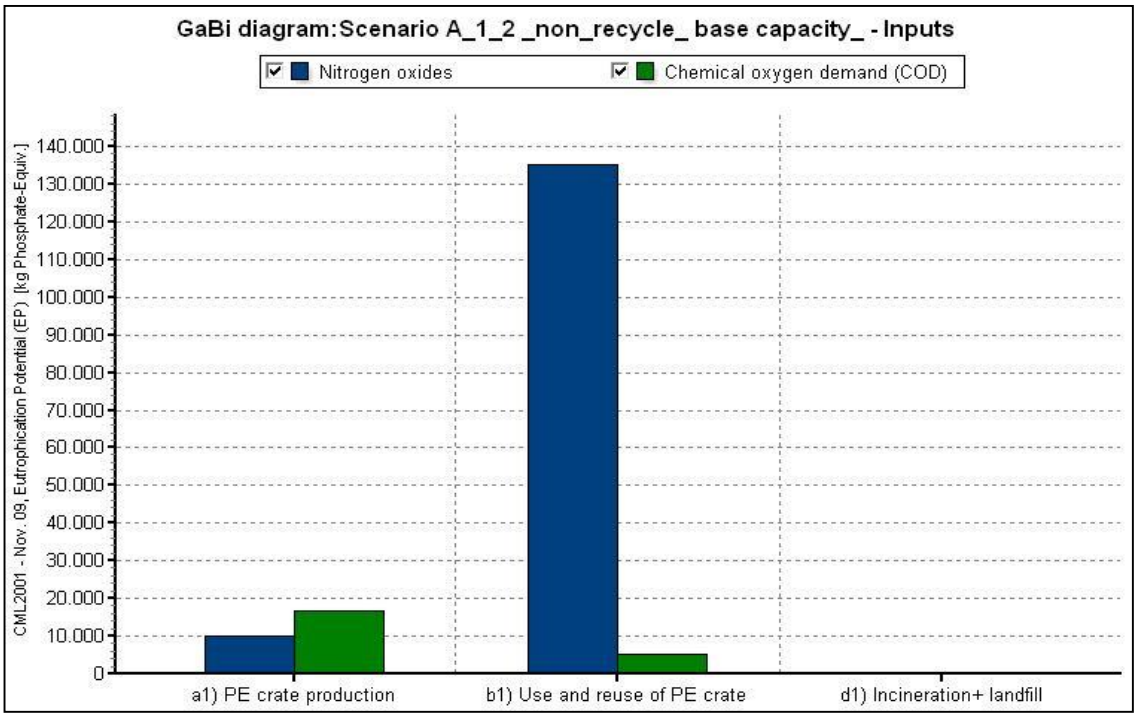

Figure C.87. CML 2001 Nov. ’09 Method. Eutrophication Potential results for Scenario A.1.2.

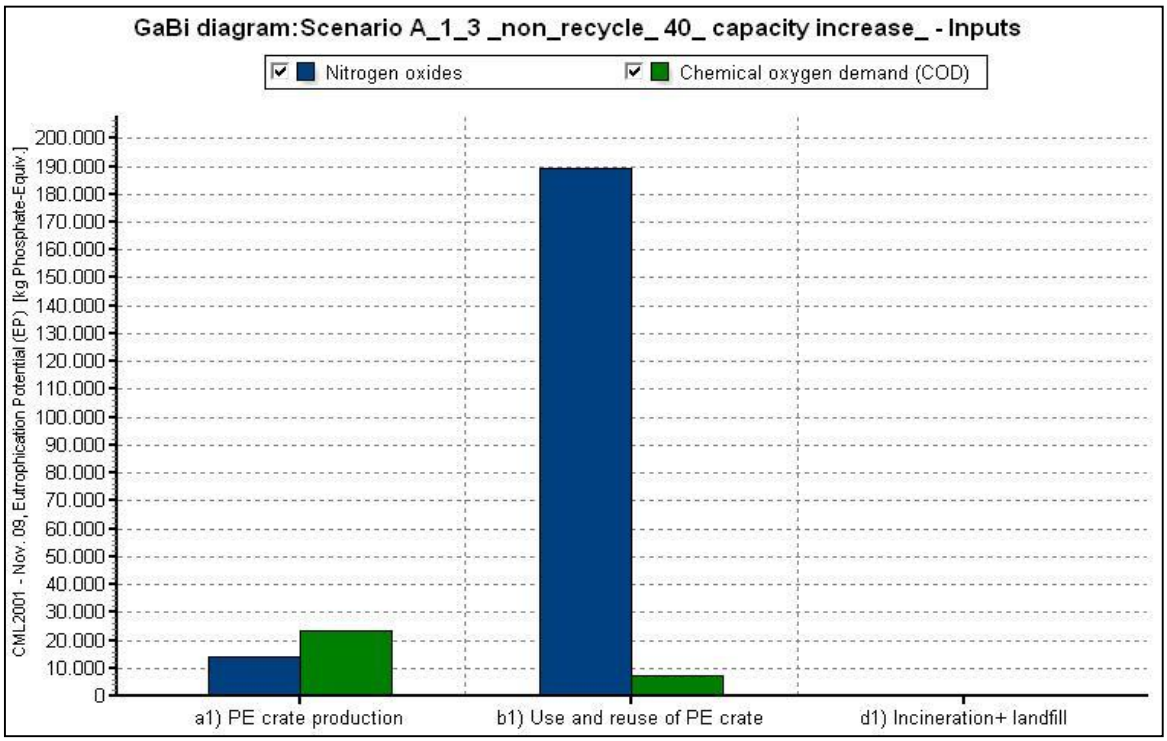

Figure C.88. CML 2001 Nov. ’09 Method. Eutrophication Potential results for Scenario A.1.3.

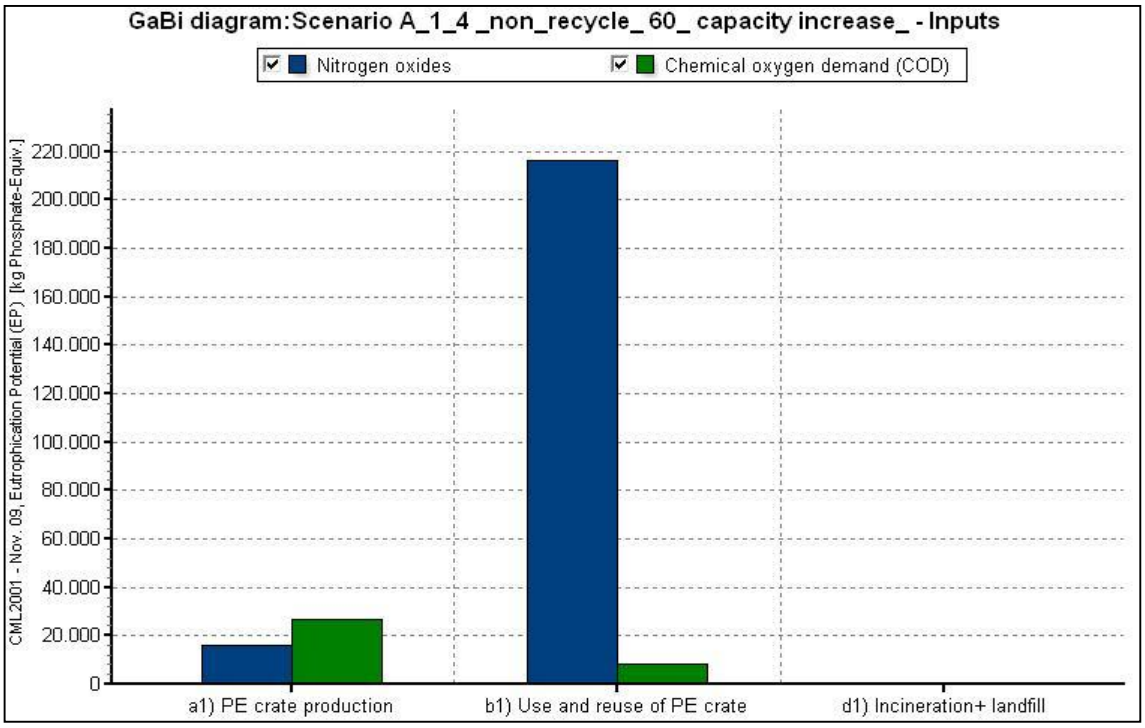

Figure C.89. CML 2001 Nov. ’09 Method. Eutrophication Potential results for Scenario A.1.4.

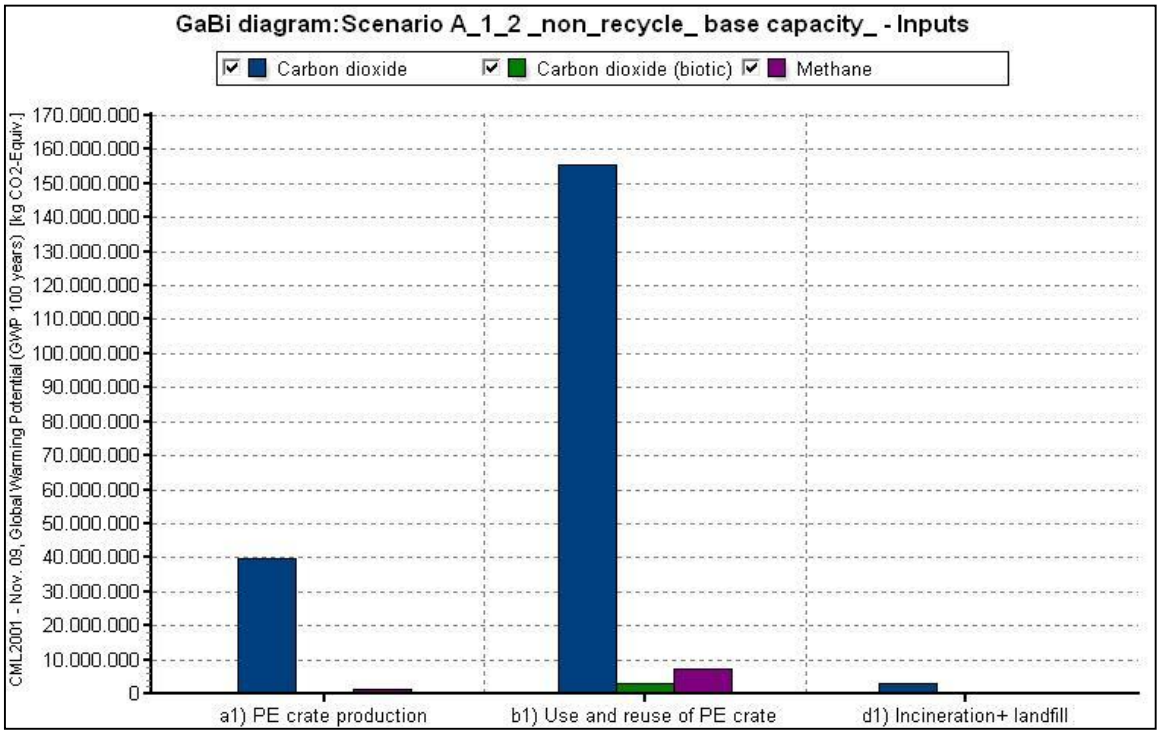

Figure C.90. CML 2001 Nov. ’09 Method. Global Warming Potential results for Scenario A.1.2.

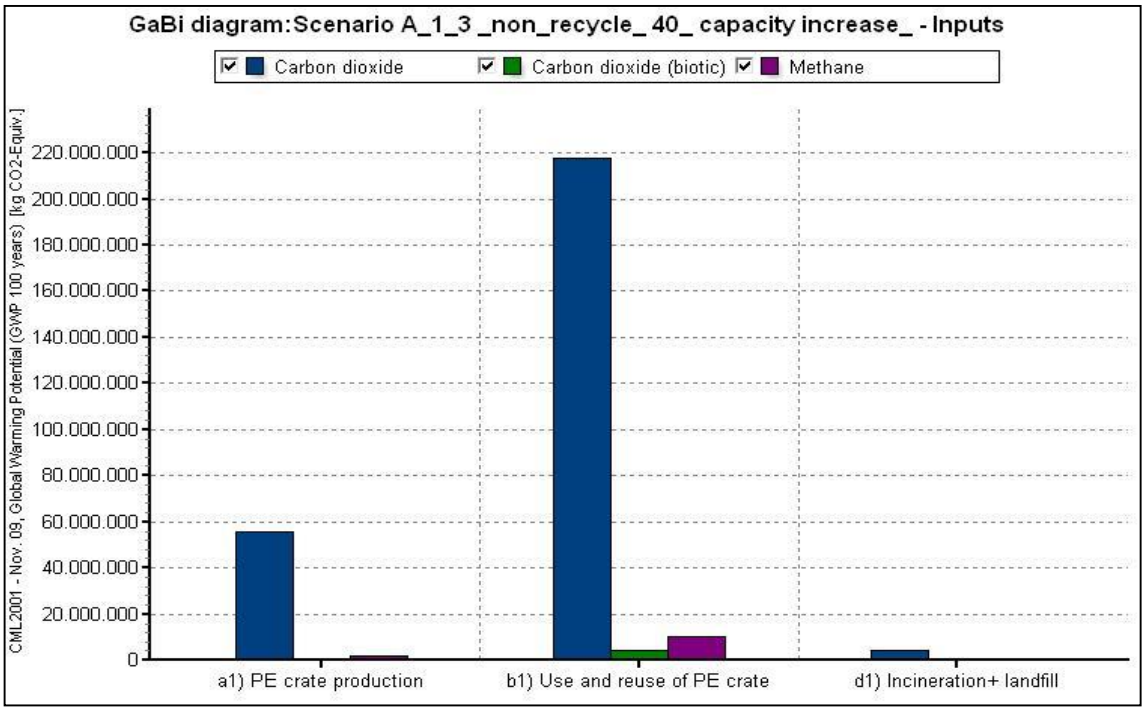

Figure C.91. CML 2001 Nov. ’09 Method. Global Warming Potential results for Scenario A.1.3.

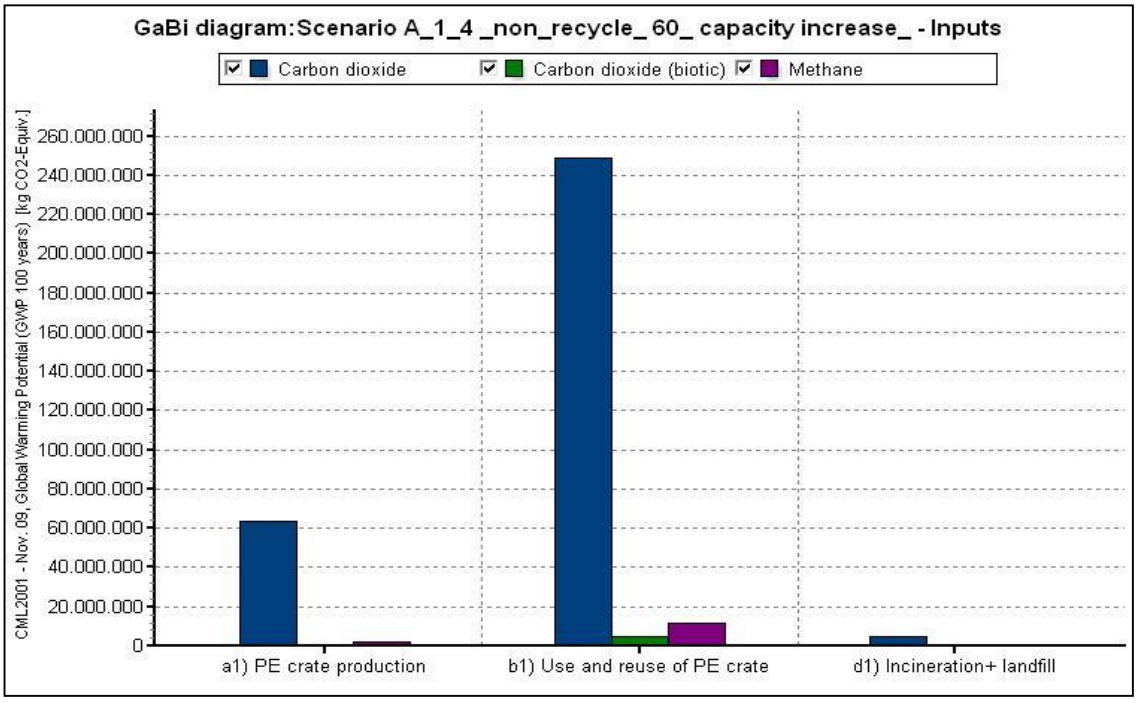

Figure C.92. CML 2001 Nov. ’09 Method. Global Warming Potential results for Scenario A.1.4.

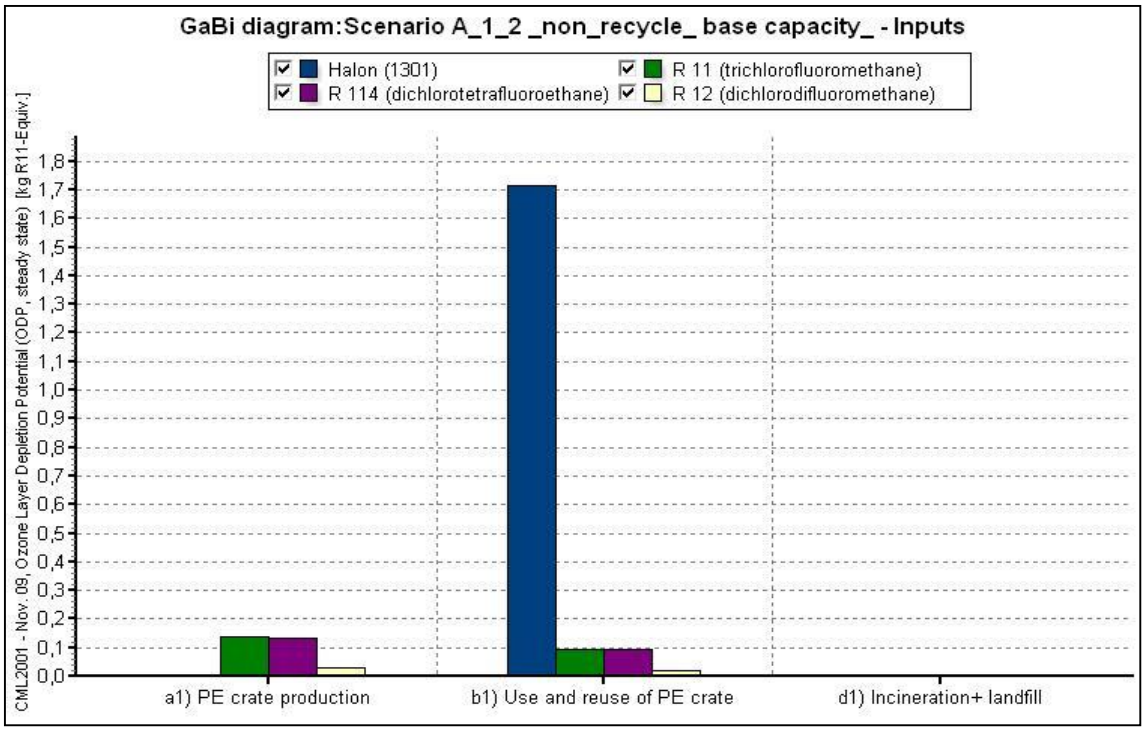

Figure C.93. CML 2001 Nov. ’09 Method. Ozone Layer Depletion results for Scenario A.1.2.

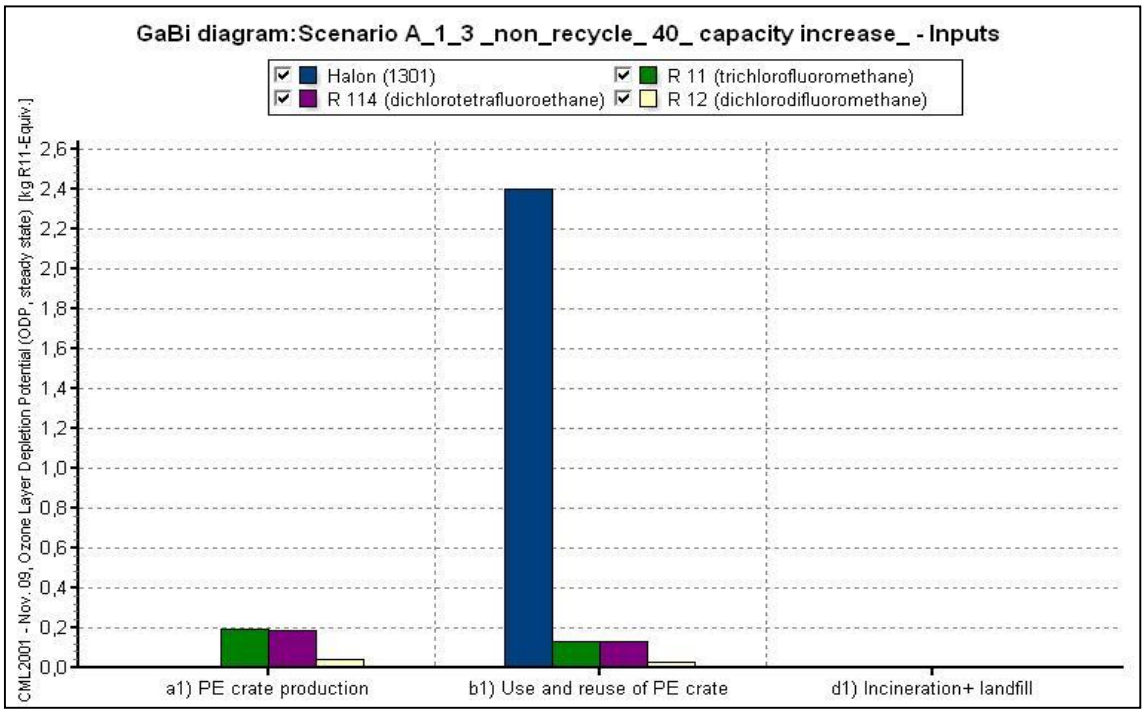

Figure C.94. CML 2001 Nov. ’09 Method. Ozone Layer Depletion results for Scenario A.1.3.

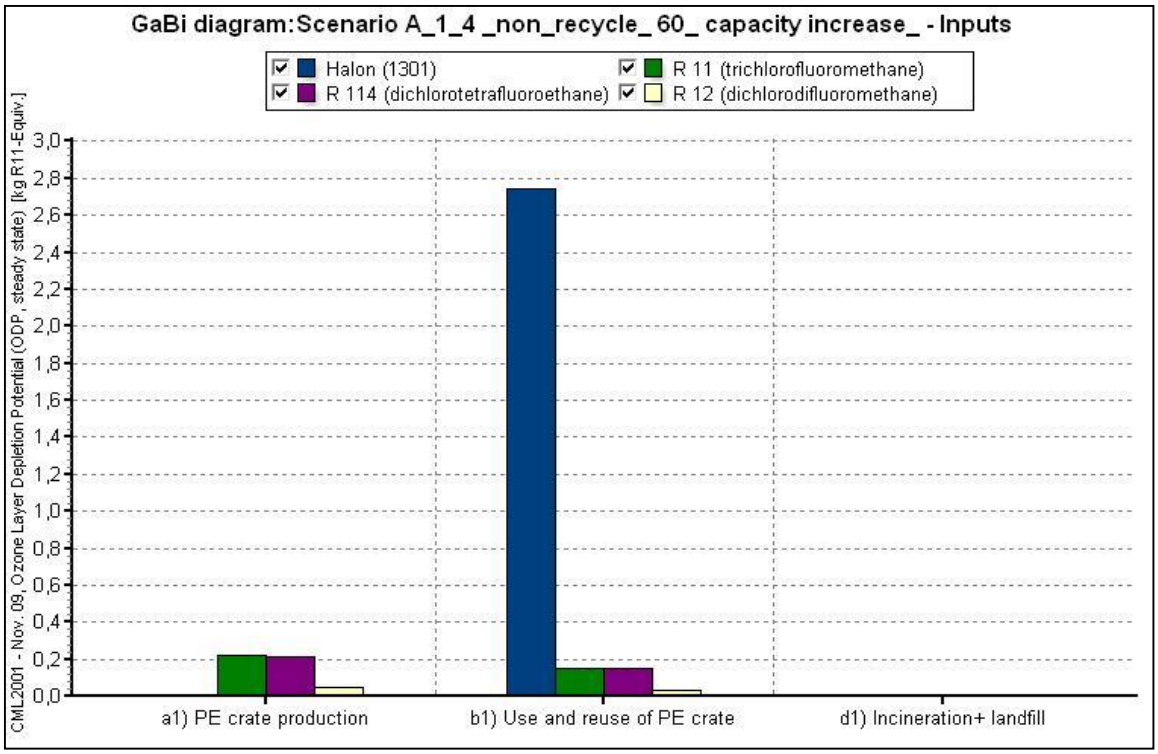

Figure C.95. CML 2001 Nov. ’09 Method. Ozone Layer Depletion results for Scenario A.1.4.

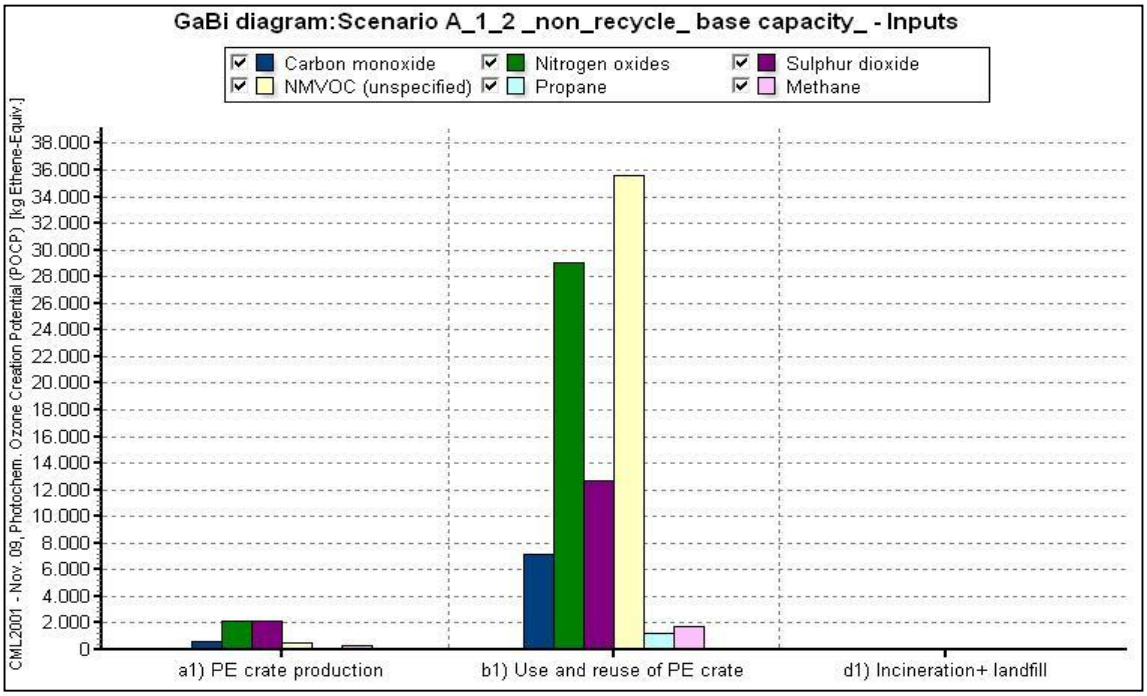

Figure C.96. CML 2001 Nov. ’09 Method. Photochemical Ozone creation potential results for Scenario A.1.2.

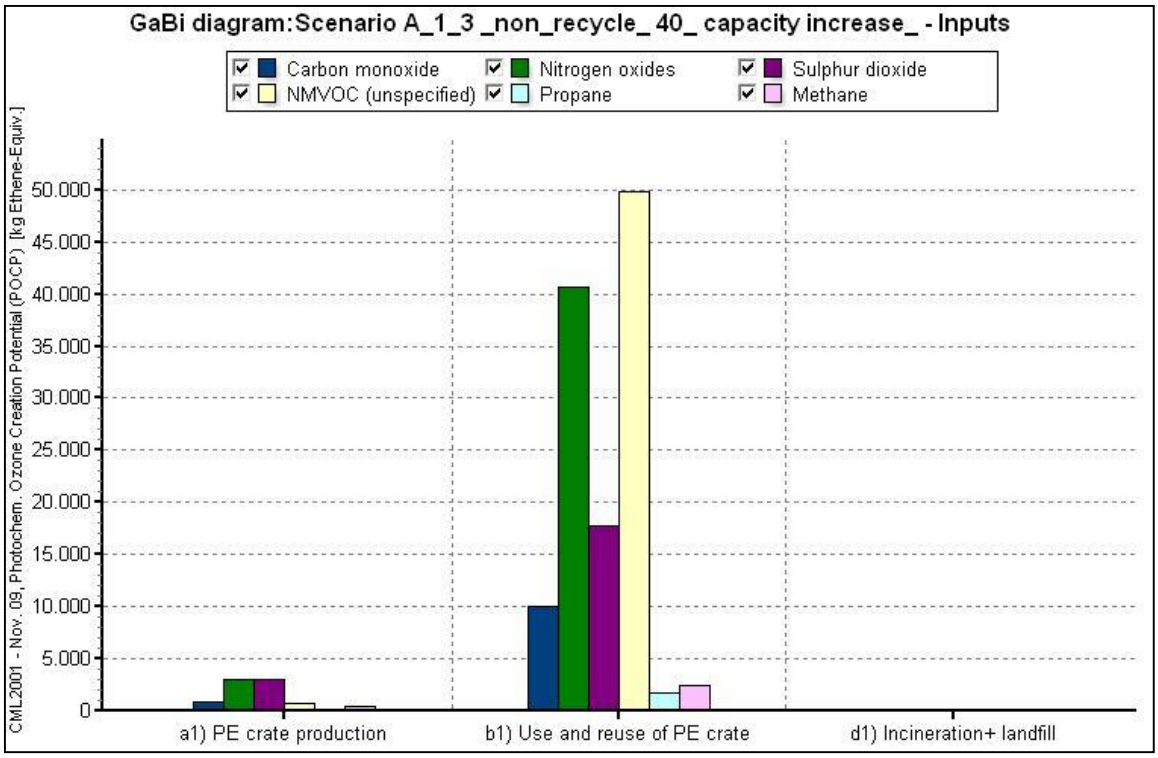

Figure C.97. CML 2001 Nov. ’09 Method. Photochemical Ozone creation potential results for Scenario A.1.3.

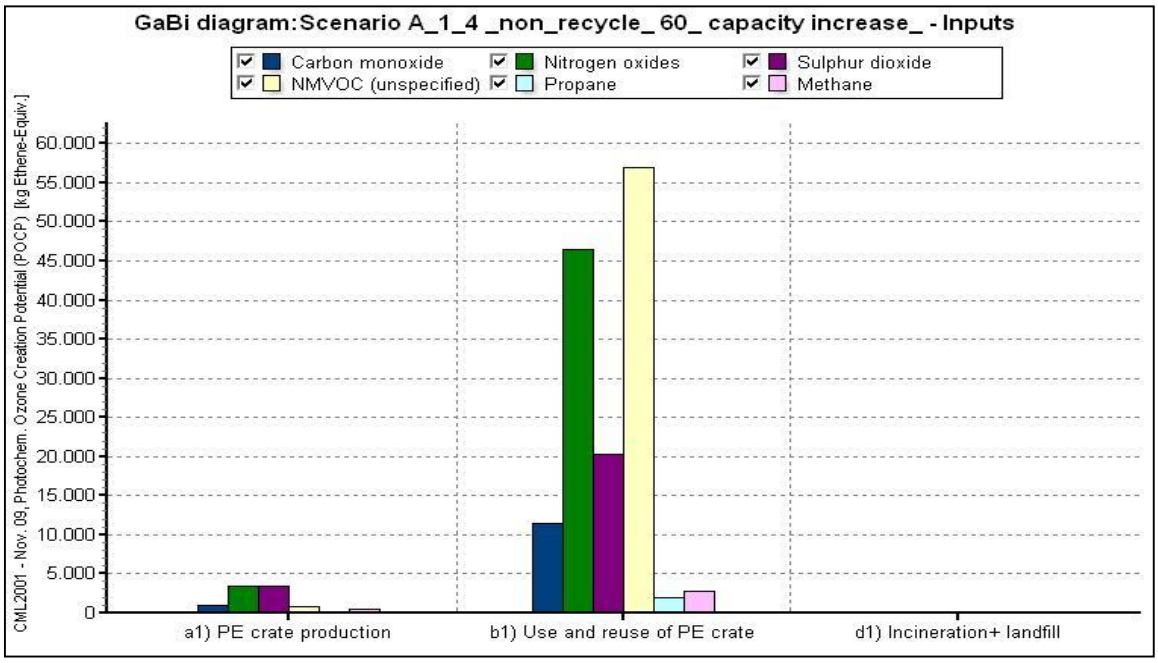

Figure C.98. CML 2001 Nov. ’09 Method. Photochemical Ozone creation potential results for Scenario A.1.4.

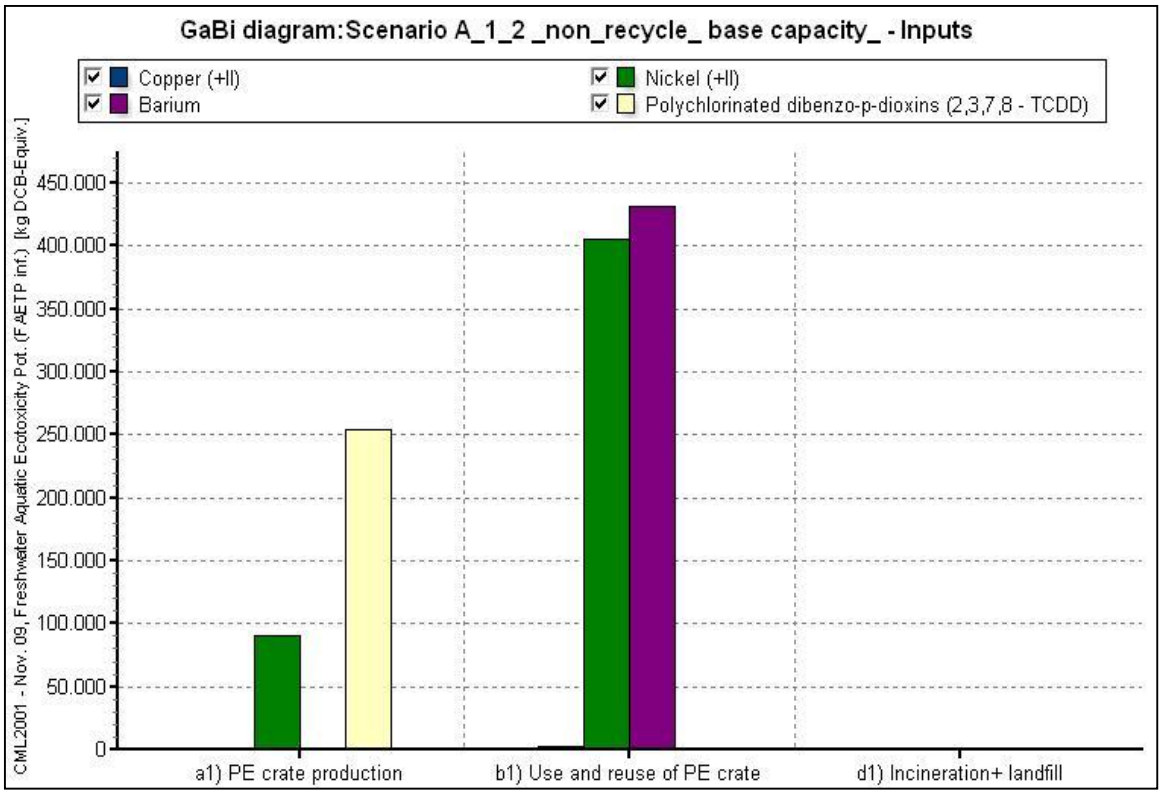

Figure C.99. CML 2001 Nov. ’09 Method. FAETP results for Scenario A.1.2.

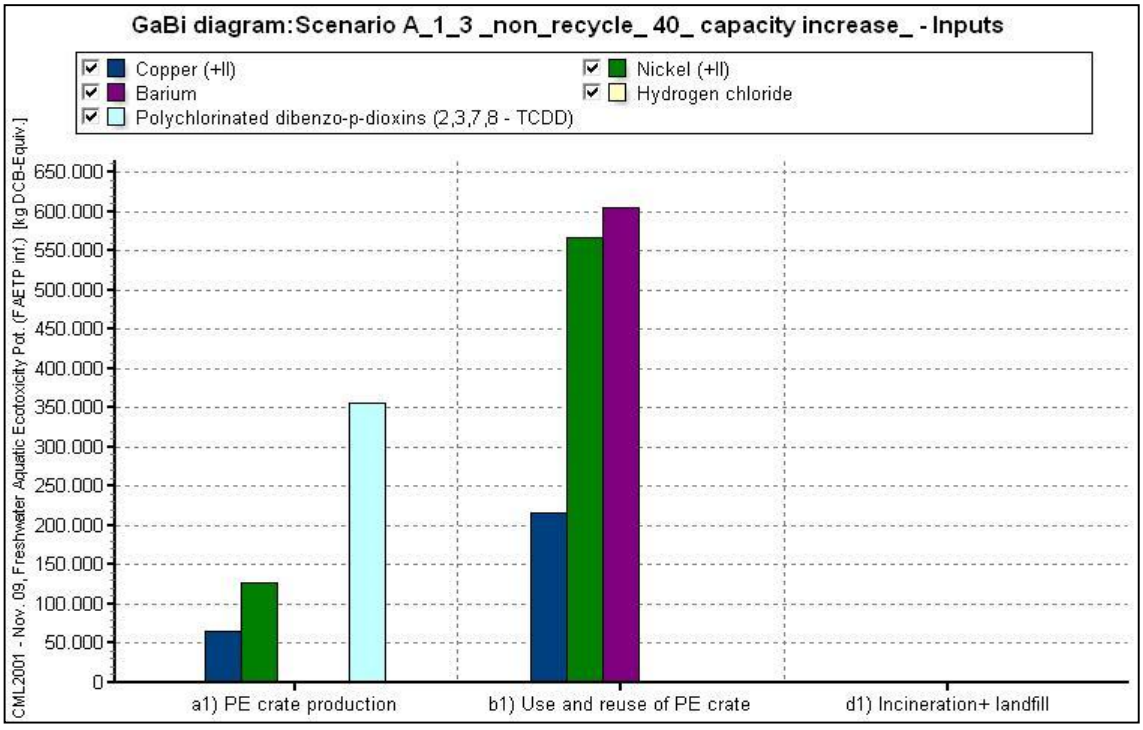

Figure C.100. CML 2001 Nov. ’09 Method. FAETP results for Scenario A.1.3.

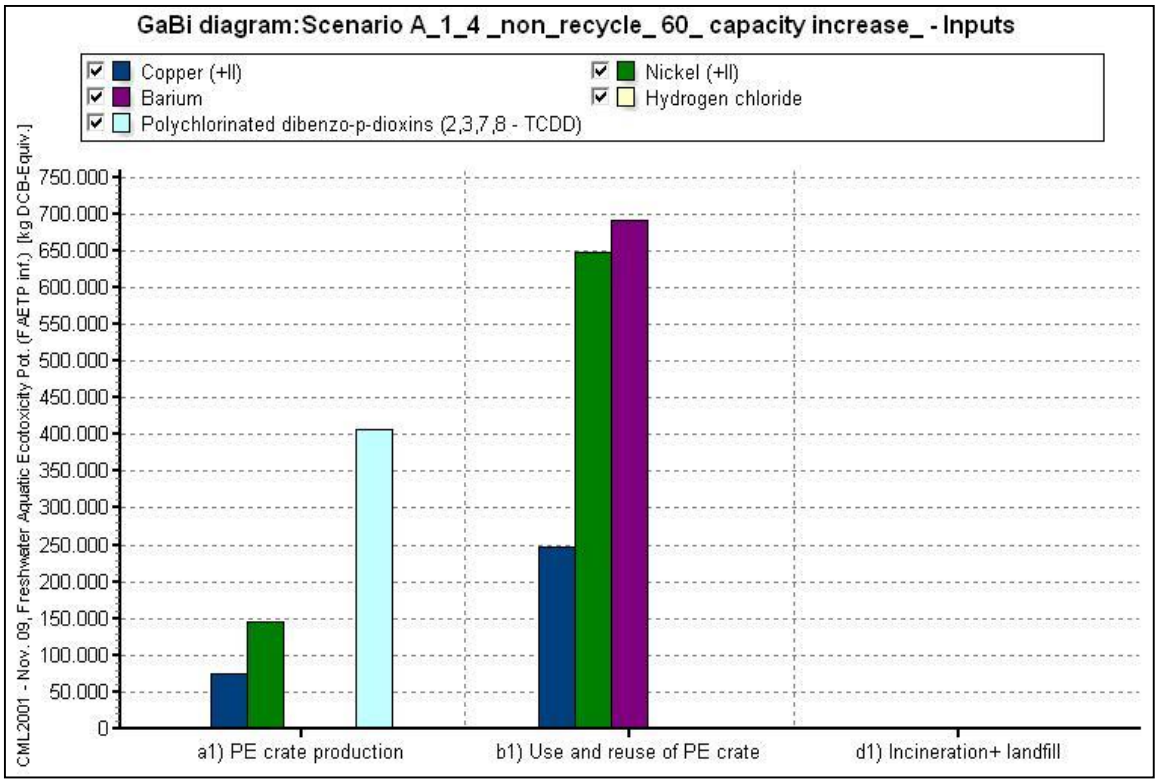

Figure C.101. CML 2001 Nov. ’09 Method. FAETP results for Scenario A.1.4.

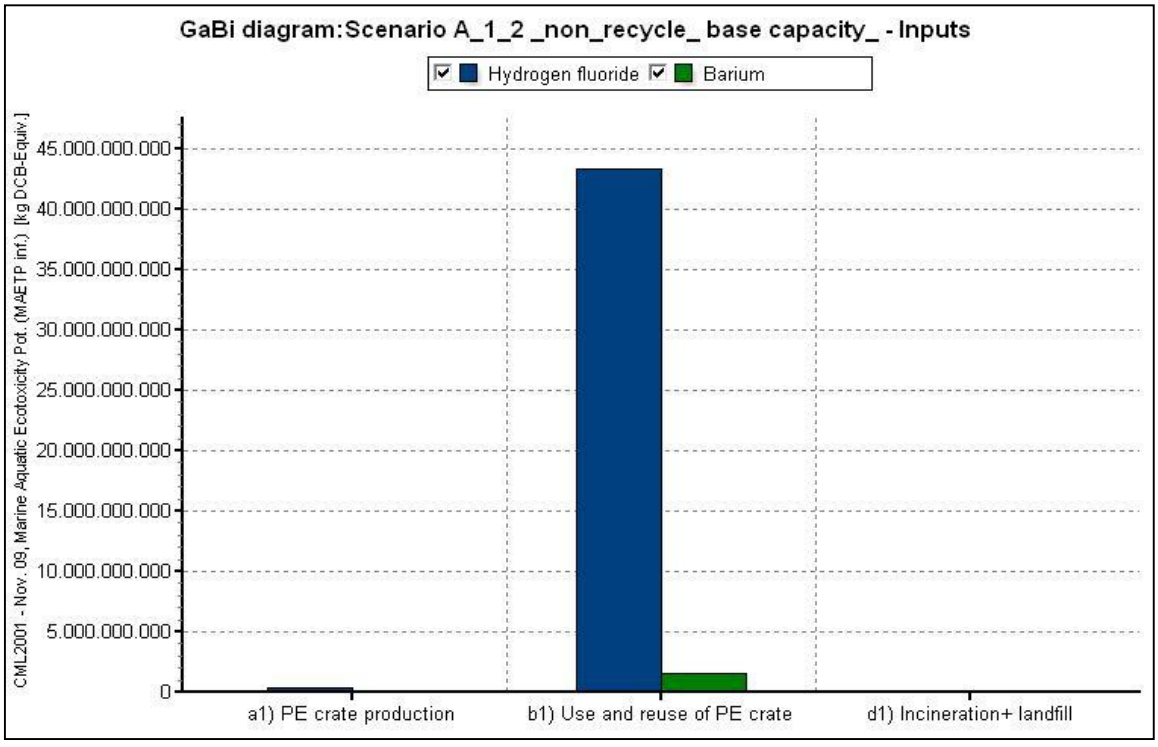

Figure C.102. CML 2001 Nov. ’09 Method. MAETP results for Scenario A.1.2.

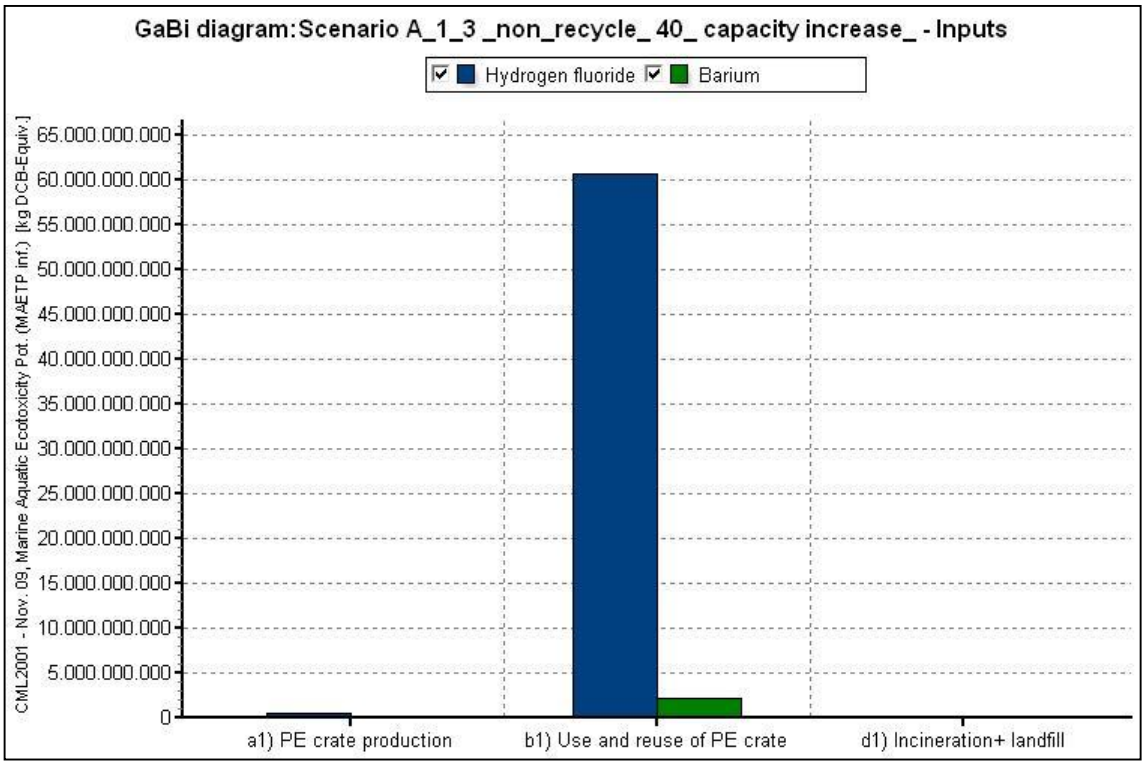

Figure C.103. CML 2001 Nov. ’09 Method. MAETP results for Scenario A.1.3.

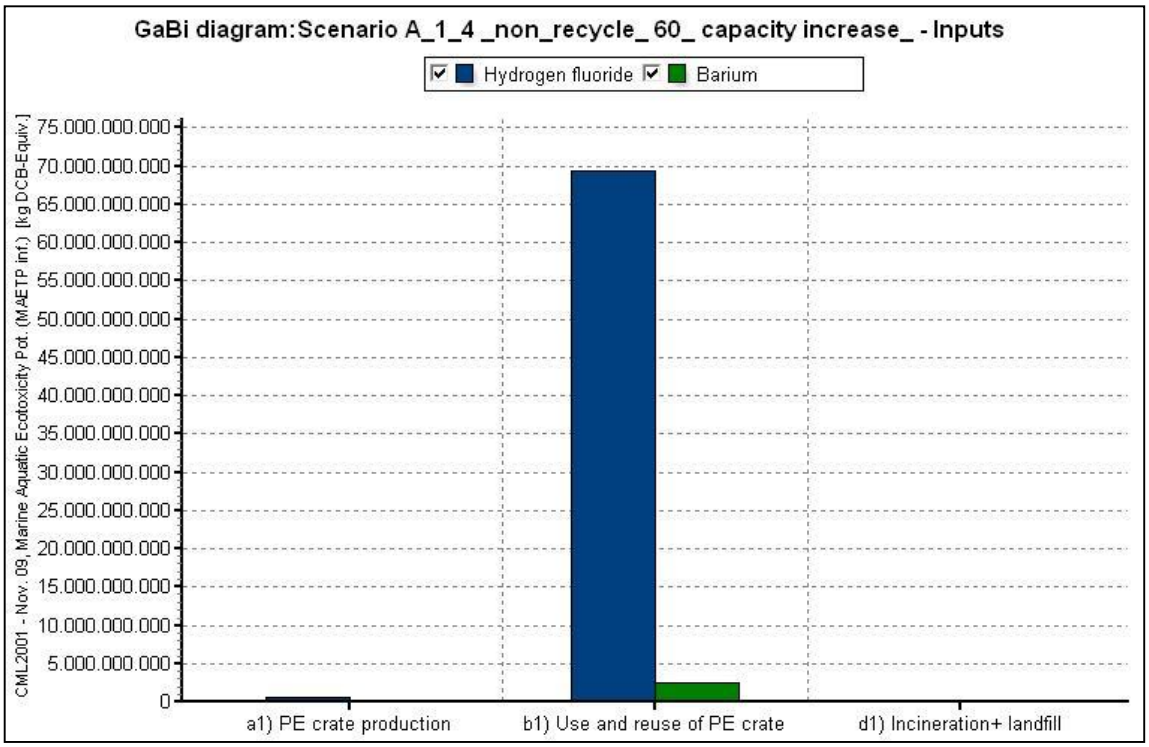

Figure C.104. CML 2001 Nov. ’09 Method. MAETP results for Scenario A.1.4.

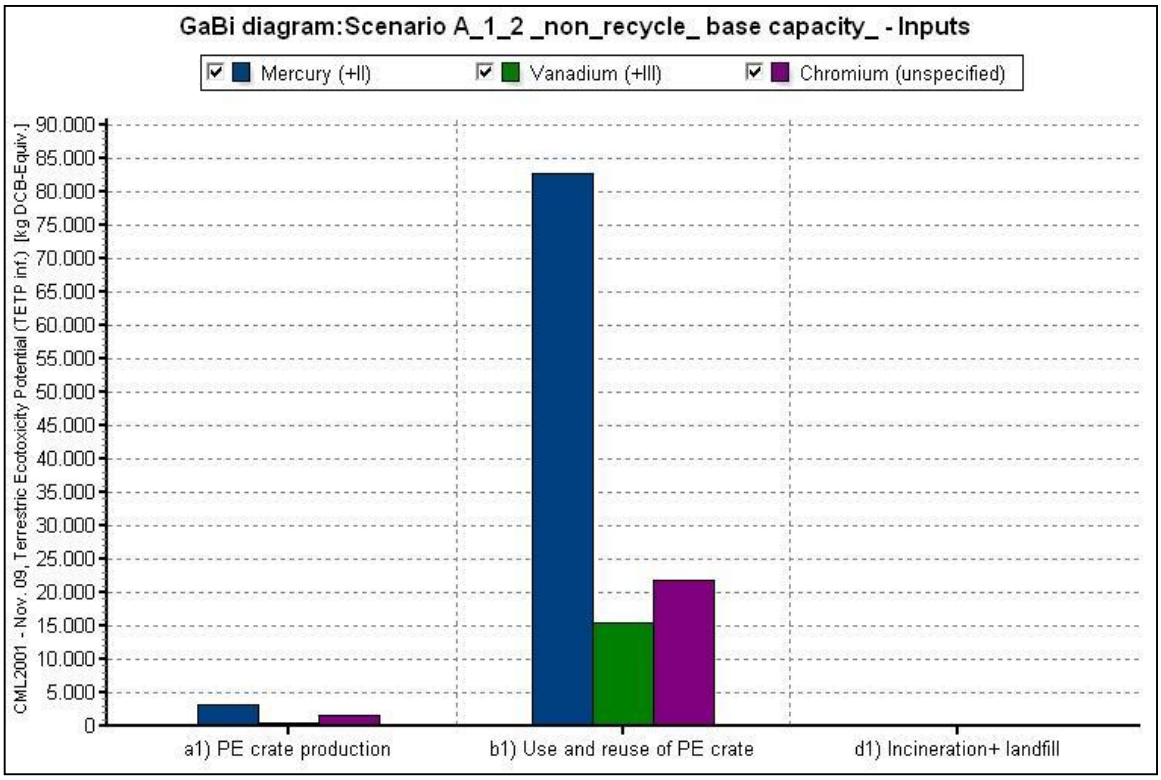

Figure C.105. CML 2001 Nov. ’09 Method. TETP results for Scenario A.1.2.

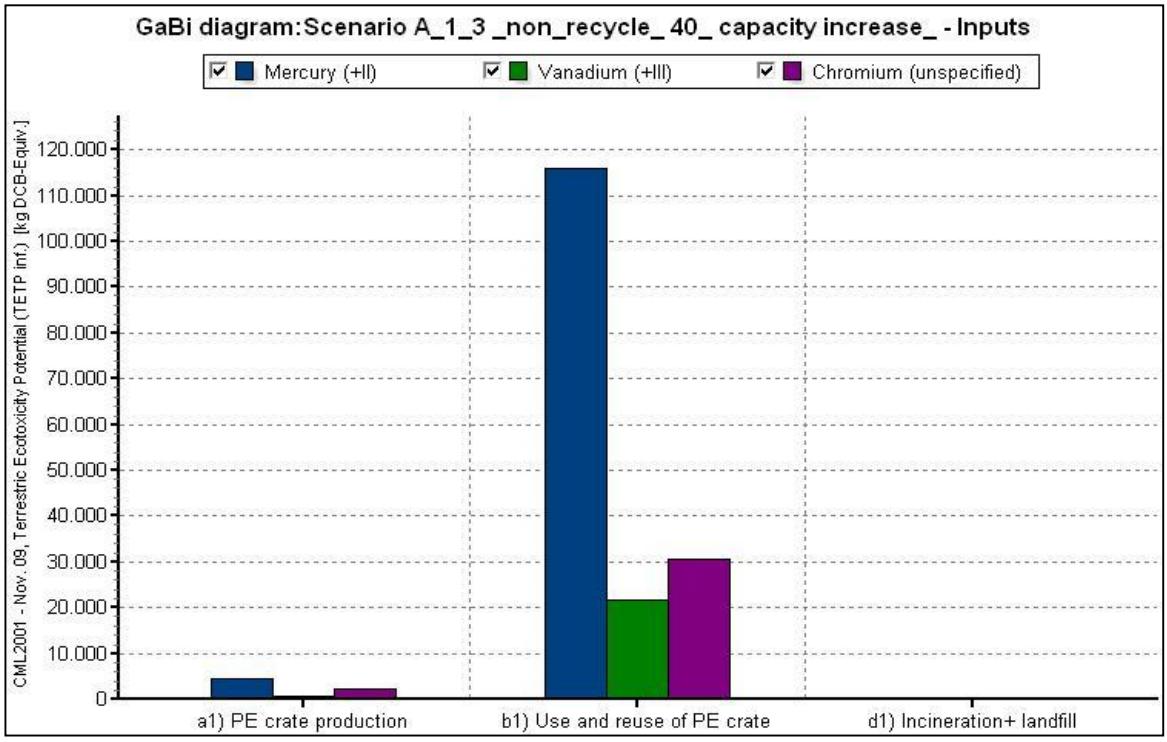

Figure C.106. CML 2001 Nov. ’09 Method. TETP results for Scenario A.1.3.

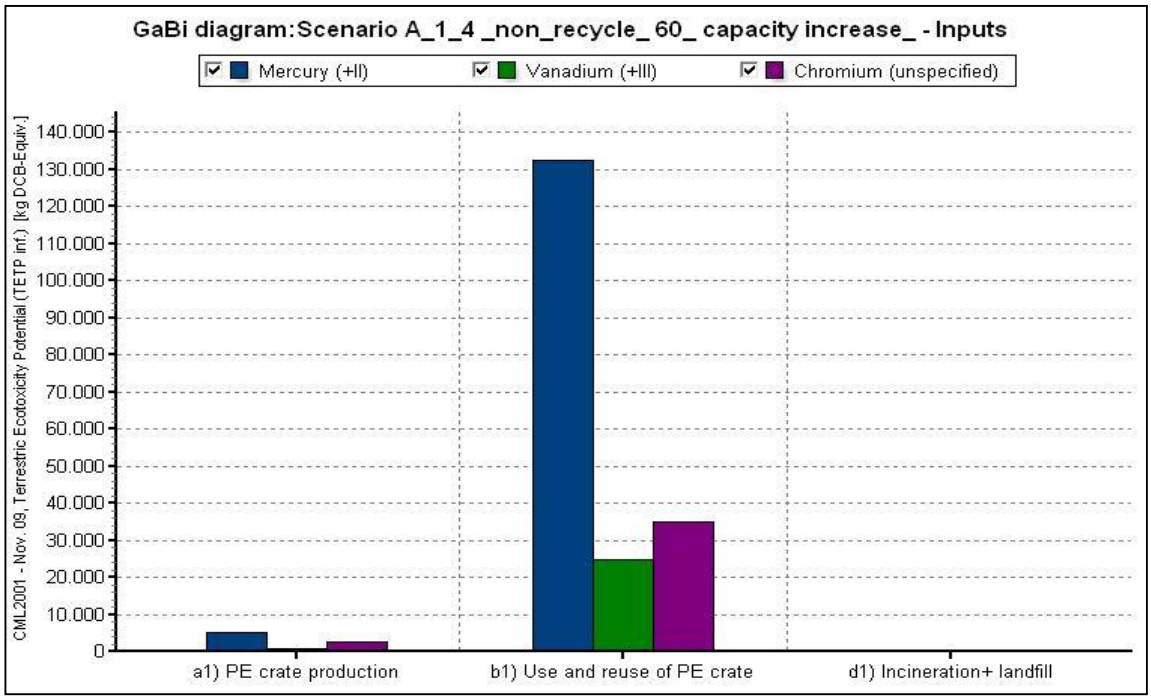

Figure C.107. CML 2001 Nov. ’09 Method. TETP results for Scenario A.1.4.

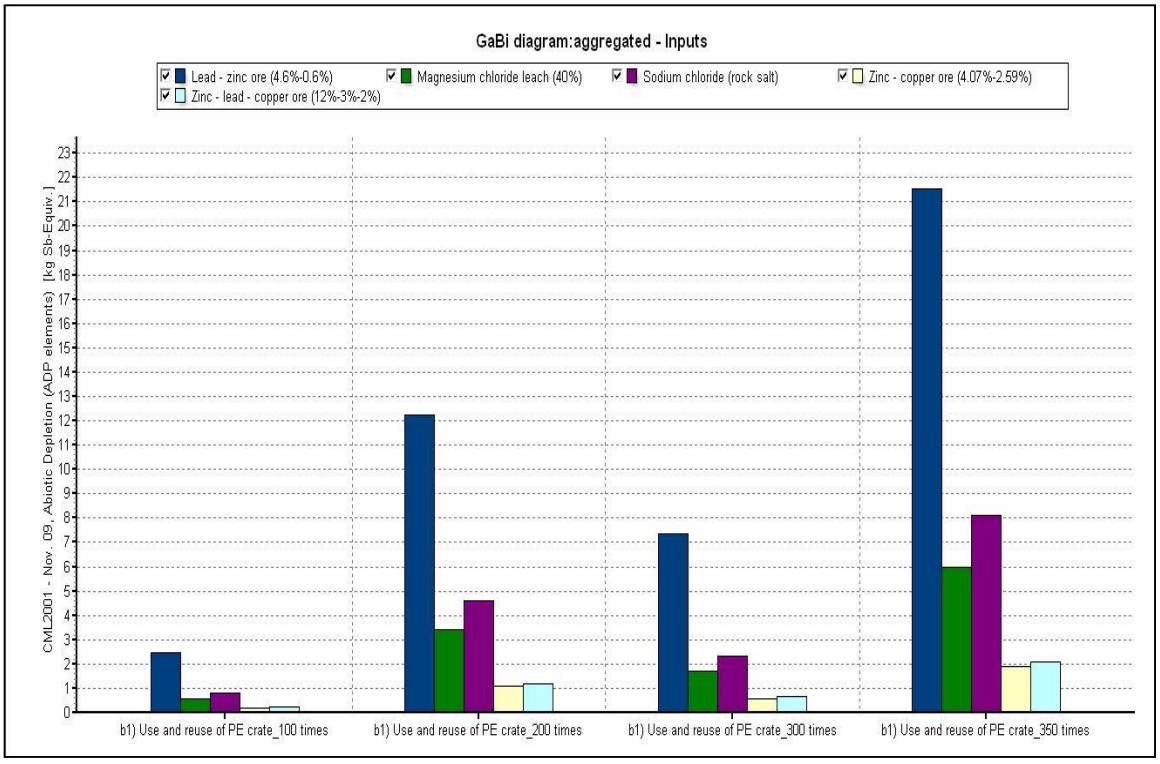

Figure C.108. CML 2001 Nov. ’09 Method. ADP results for Scenarios A.1, A.1.5, A.1.6, A.1.7

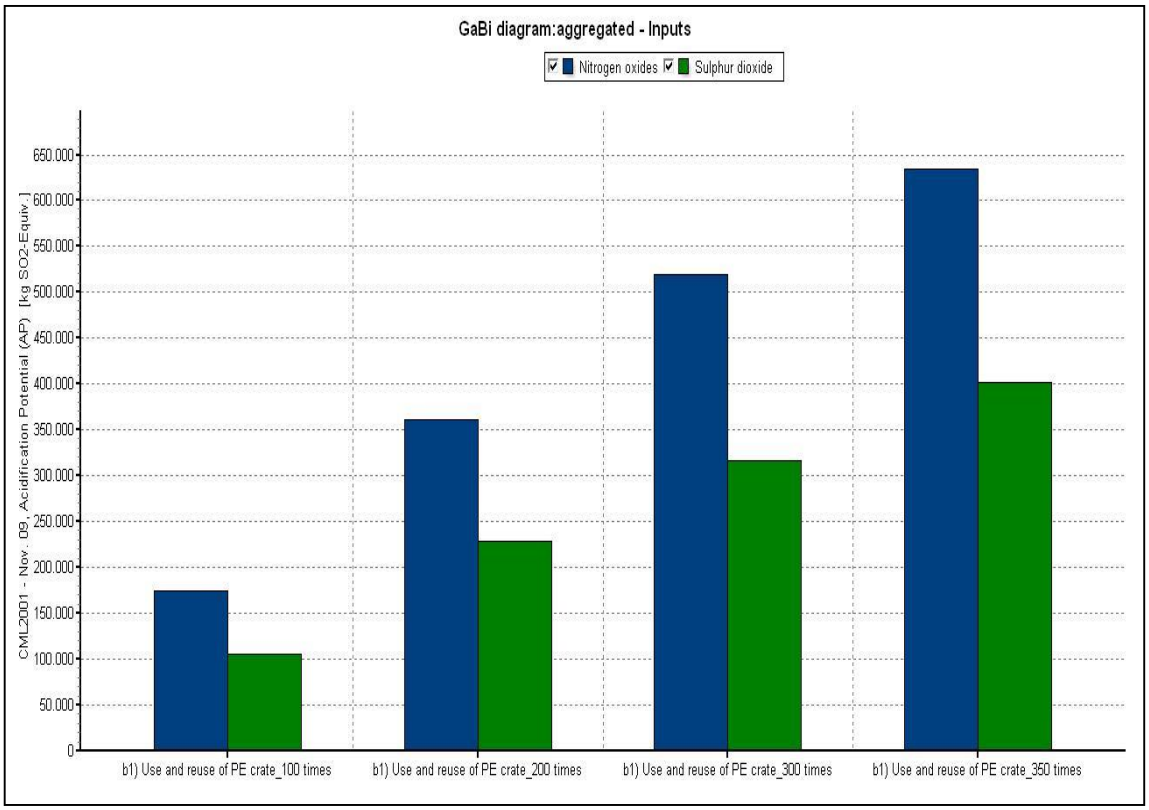

Figure C.109. CML 2001 Nov. ’09 Method. AP results for Scenarios A.1, A.1.5, A.1.6, A.1.7.

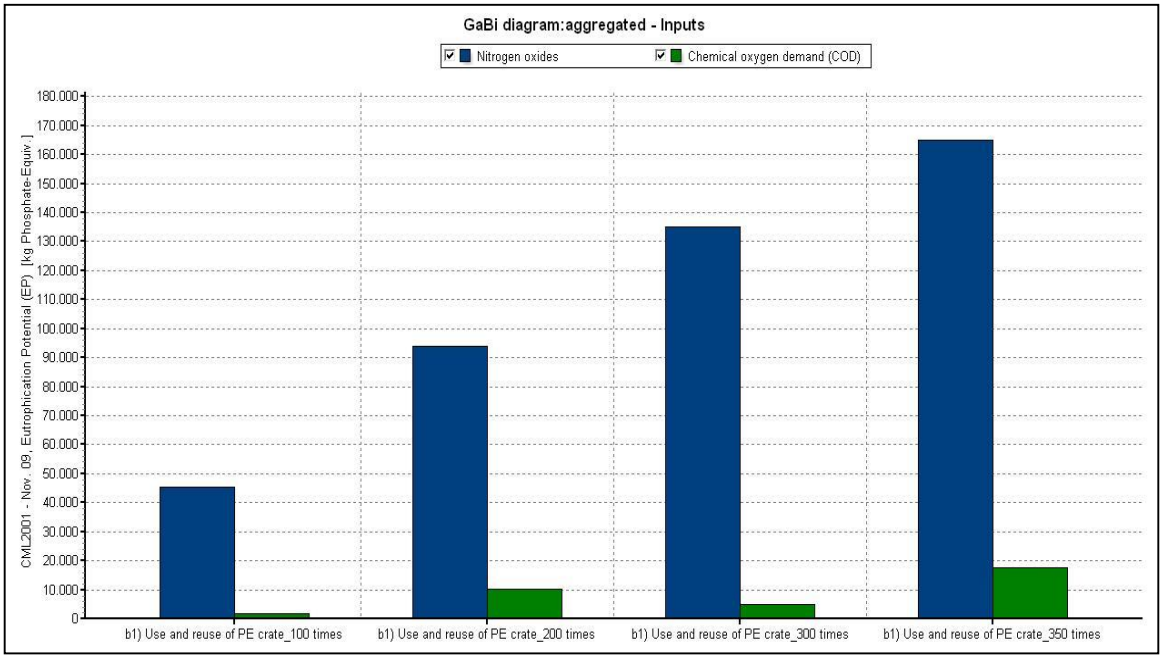

Figure C.110. CML 2001 Nov. ’09 Method. EP results for Scenarios A.1, A.1.5, A.1.6, A.1.7.

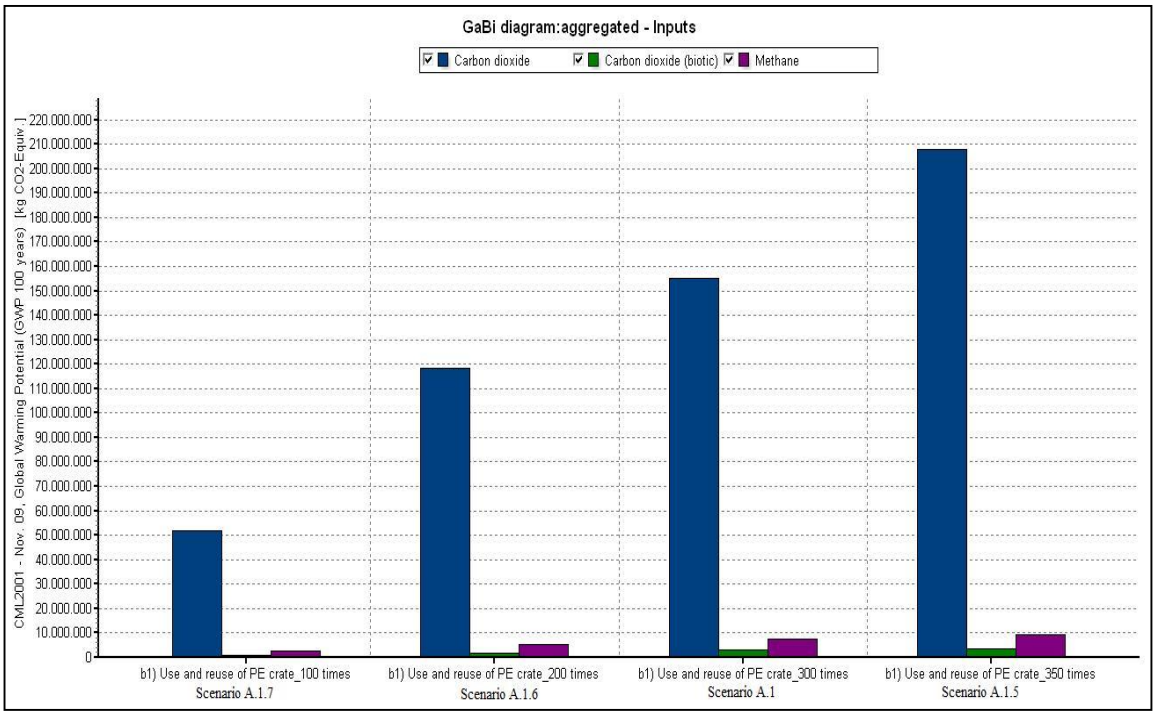

Figure C.111. CML 2001 Nov. ’09 Method. GWP results for Scenarios A.1, A.1.5, A.1.6, A.1.7

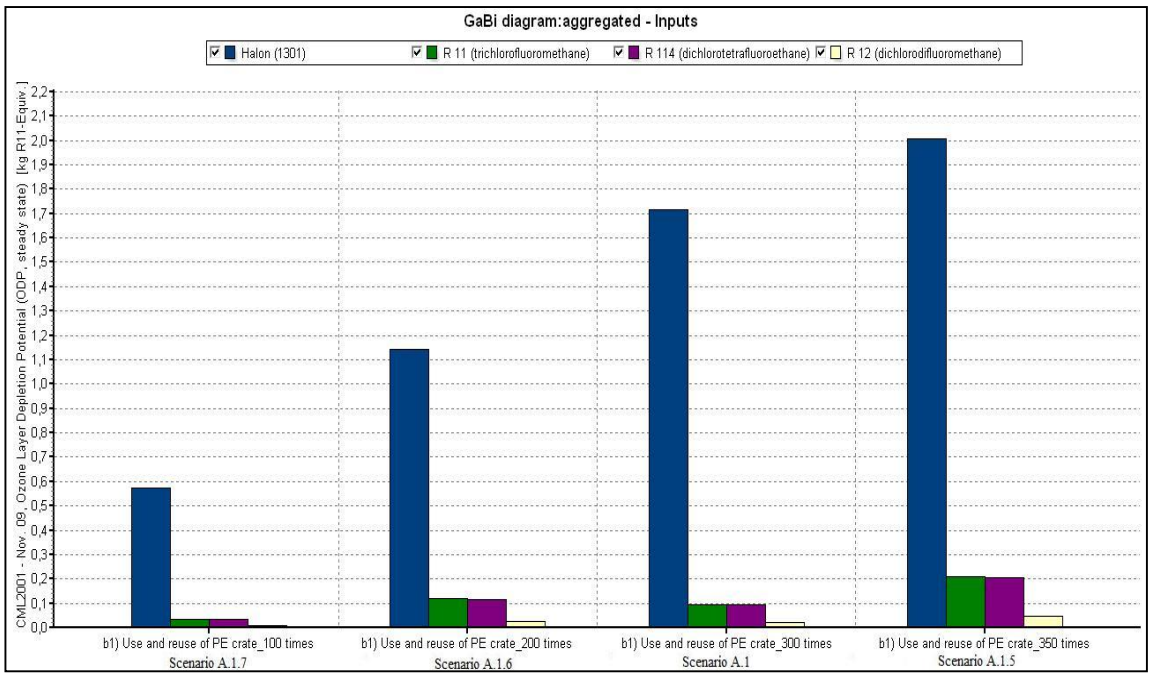

Figure C.112. CML 2001 Nov. ’09 Method. ODP results for Scenarios A.1, A.1.5, A.1.6, A.1.7

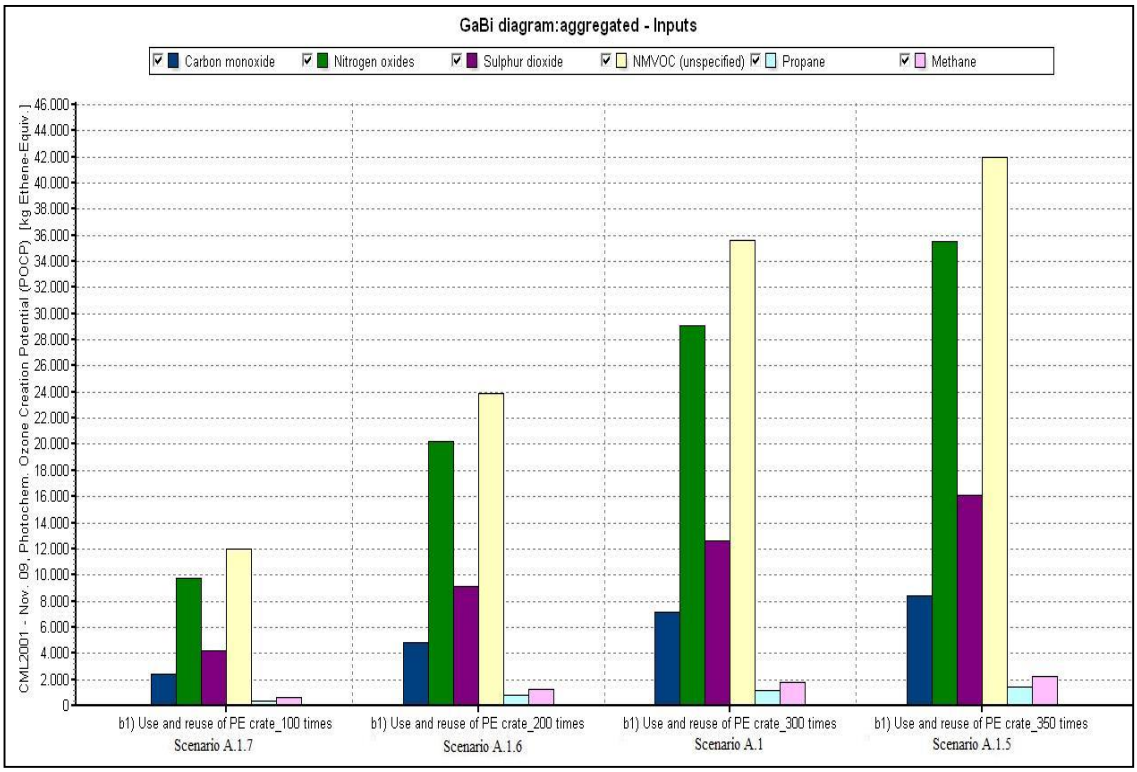

Figure C.113. CML 2001 Nov. ’09 Method. POCP results for Scenarios A.1, A.1.5, A.1.6, A.1.7

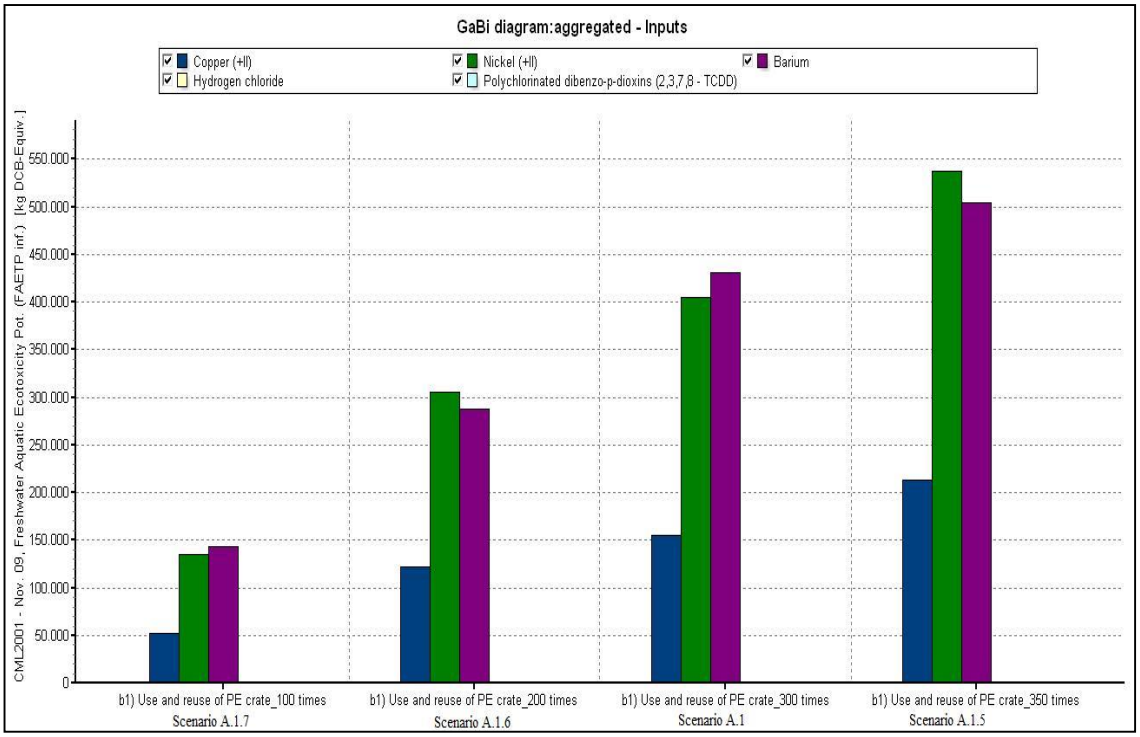

Figure C.114. CML 2001 Nov. ’09 Method. FAETP results for Scenarios A.1, A.1.5, A.1.6, A.1.7

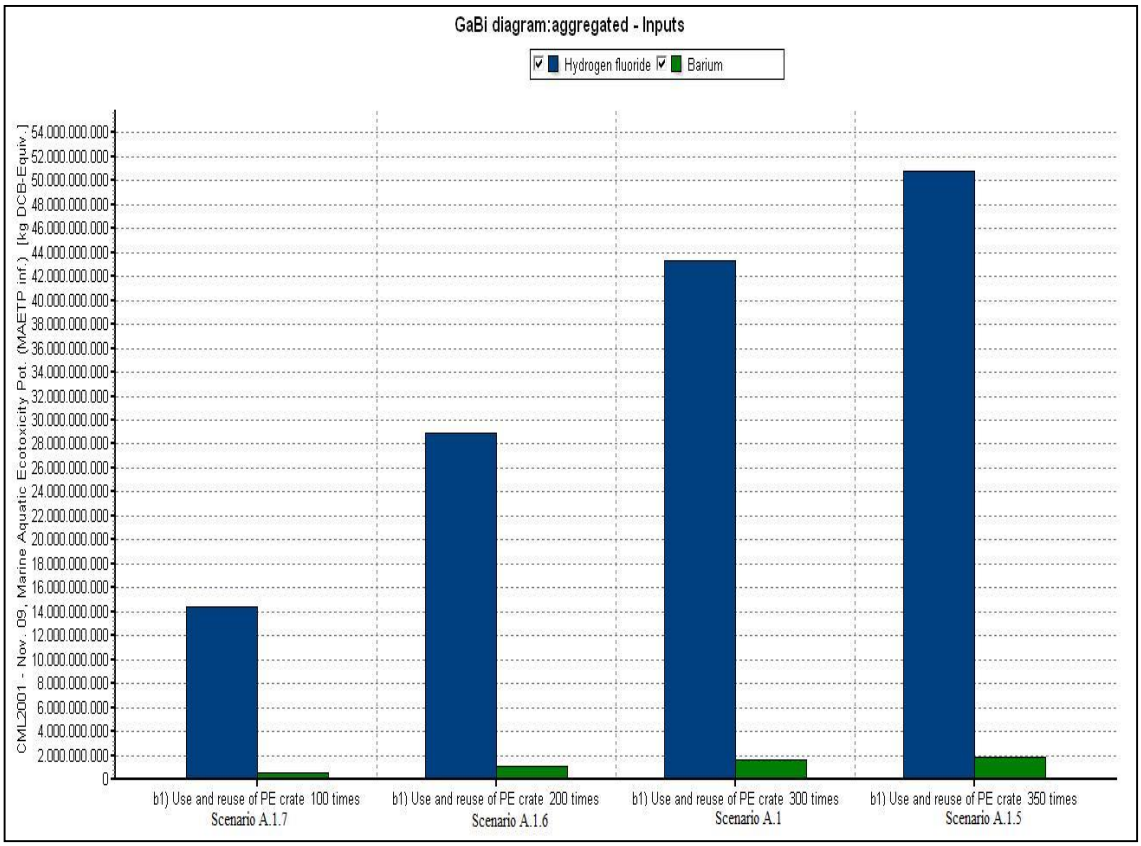

Figure C.115. CML 2001 Nov. ’09 Method. MAETP results for Scenarios A.1, A.1.5, A.1.6, A.1.7.

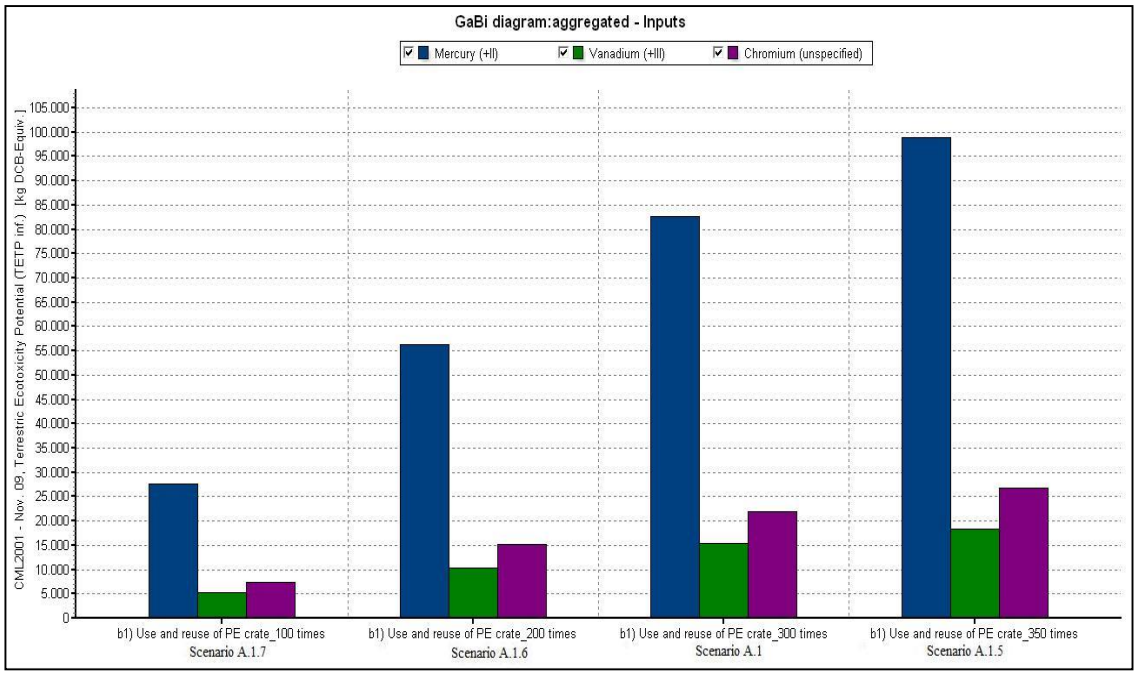

Figure C.116. CML 2001 Nov. ’09 Method. TETP results for Scenarios A.1, A.1.5, A.1.6, A.1.7.

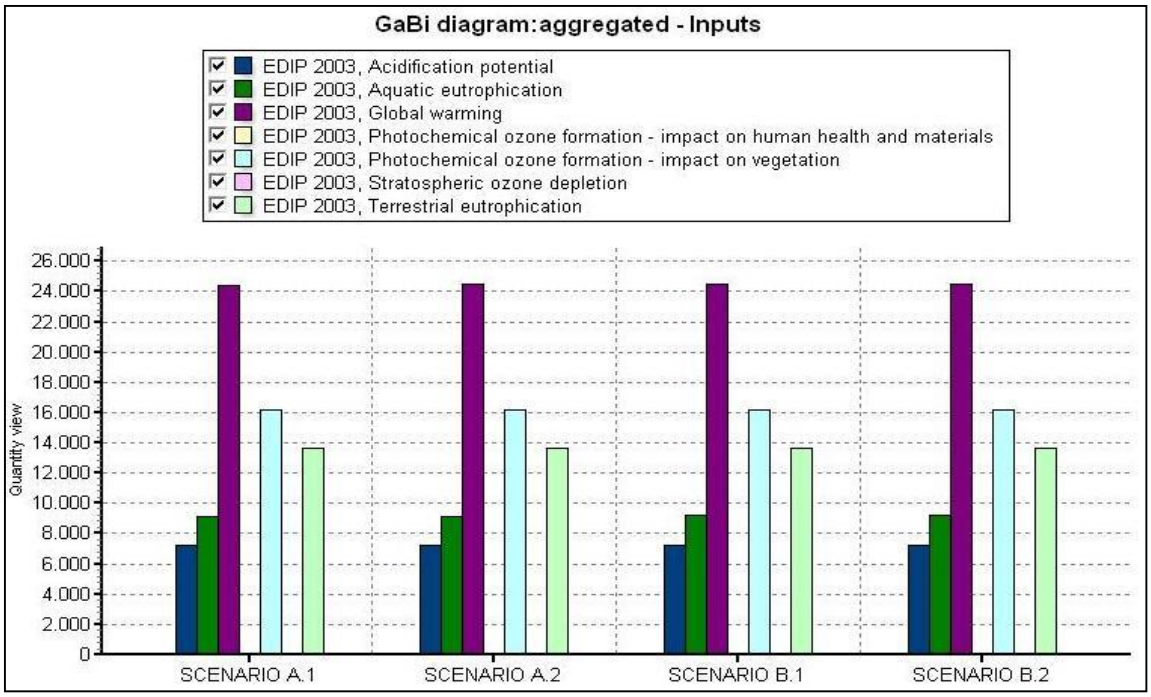

Figure C.117. The normalization results of EDIP 2003 for Scenarios A.1, A.2, B.1 and B.2.

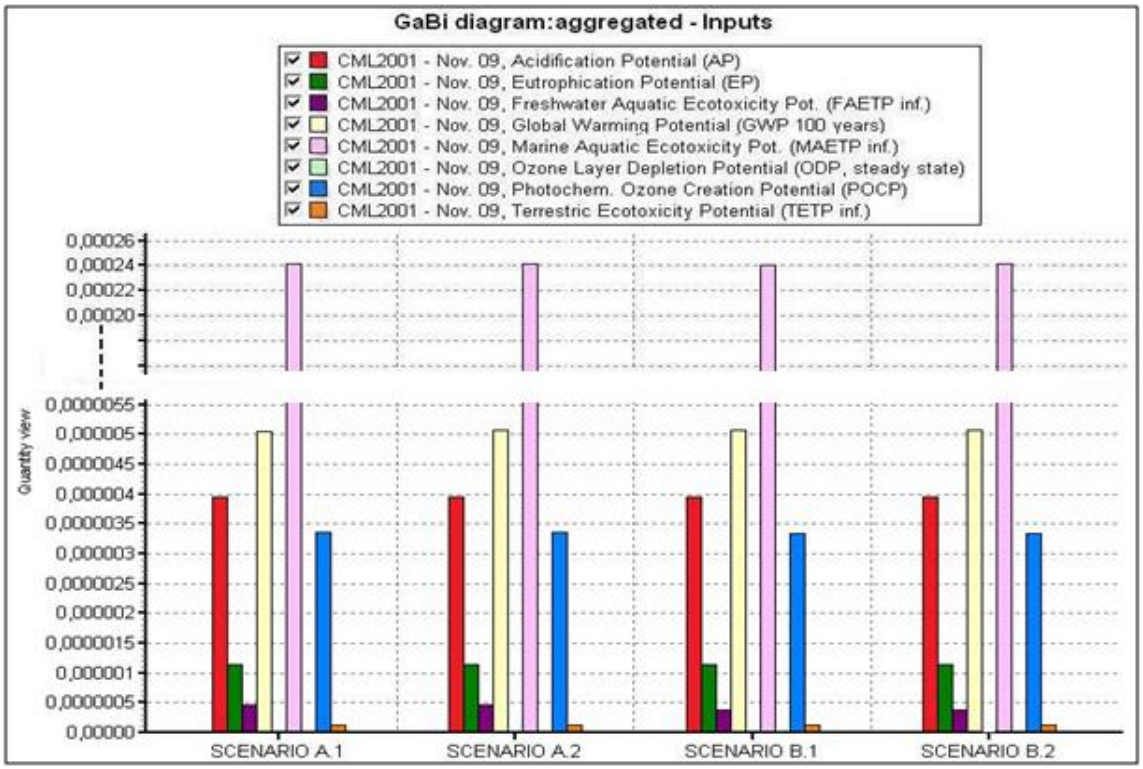

Figure C.118. The normalization results of CML 2001 Nov. ’09 Method for Scenarios A.1, A.2, B.1 and B.2.

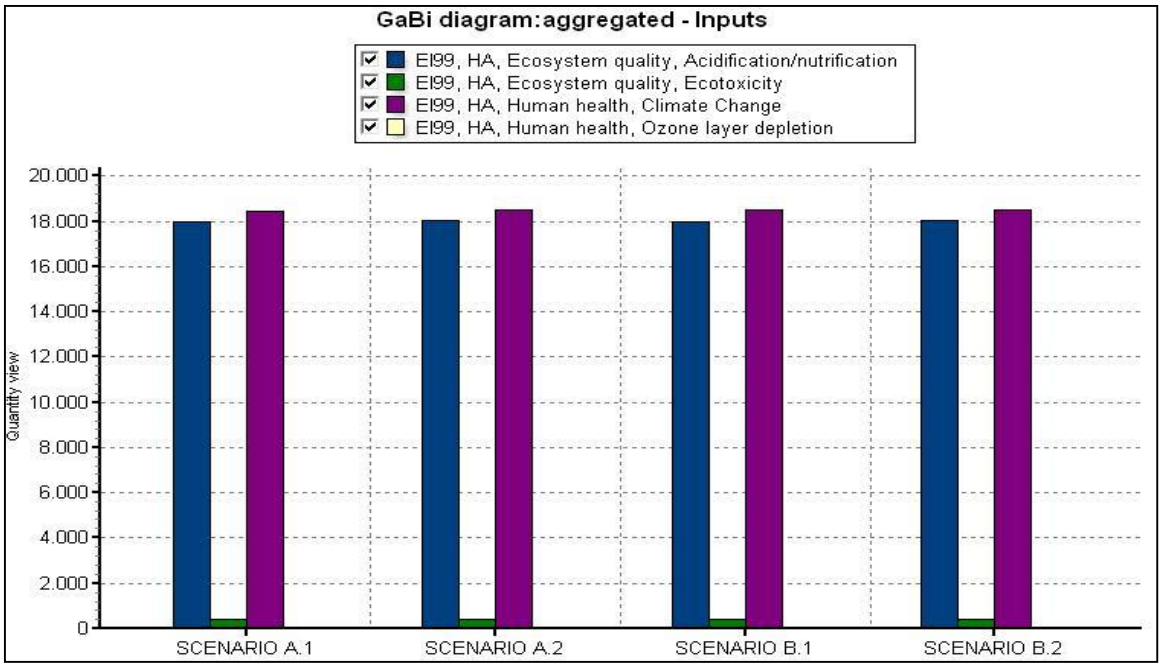

Figure C.119. The normalization results of EI 99 Method for Scenarios A.1, A.2, B.1 and B.2.

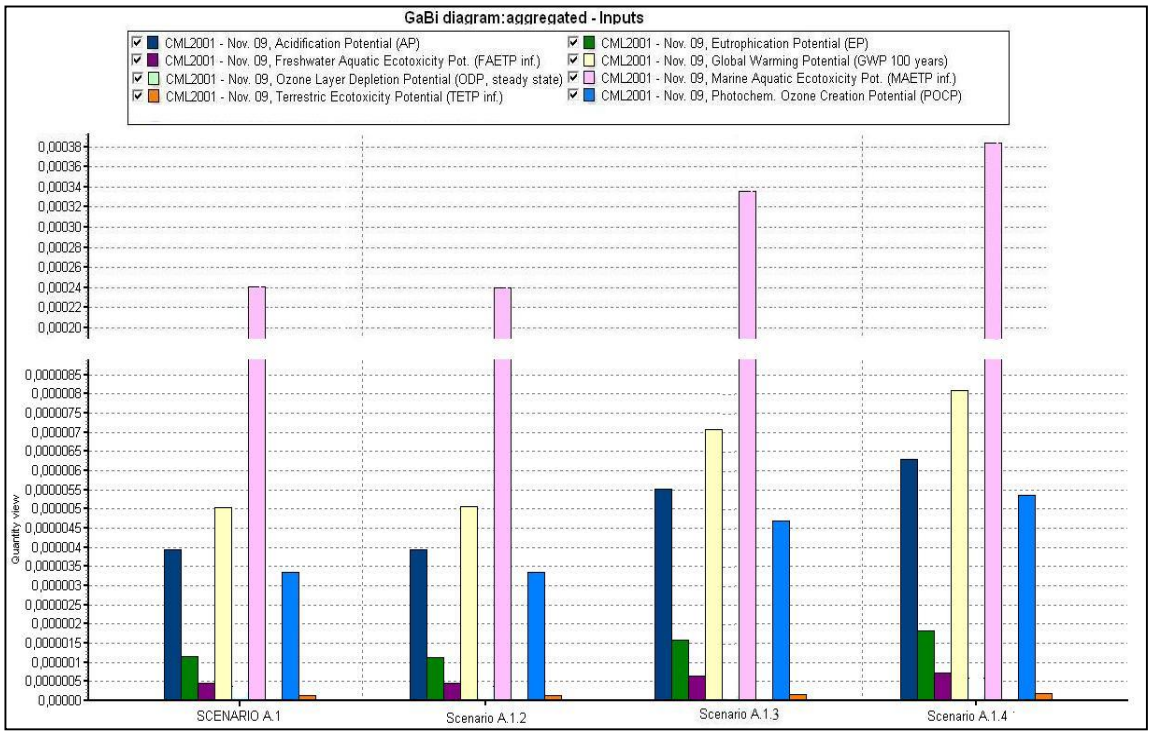

Figure C.120. The normalization results of CML 2001 Nov. ’09 Method for Scenarios A.1, A.1.2, A.1.3 and A.1.4.

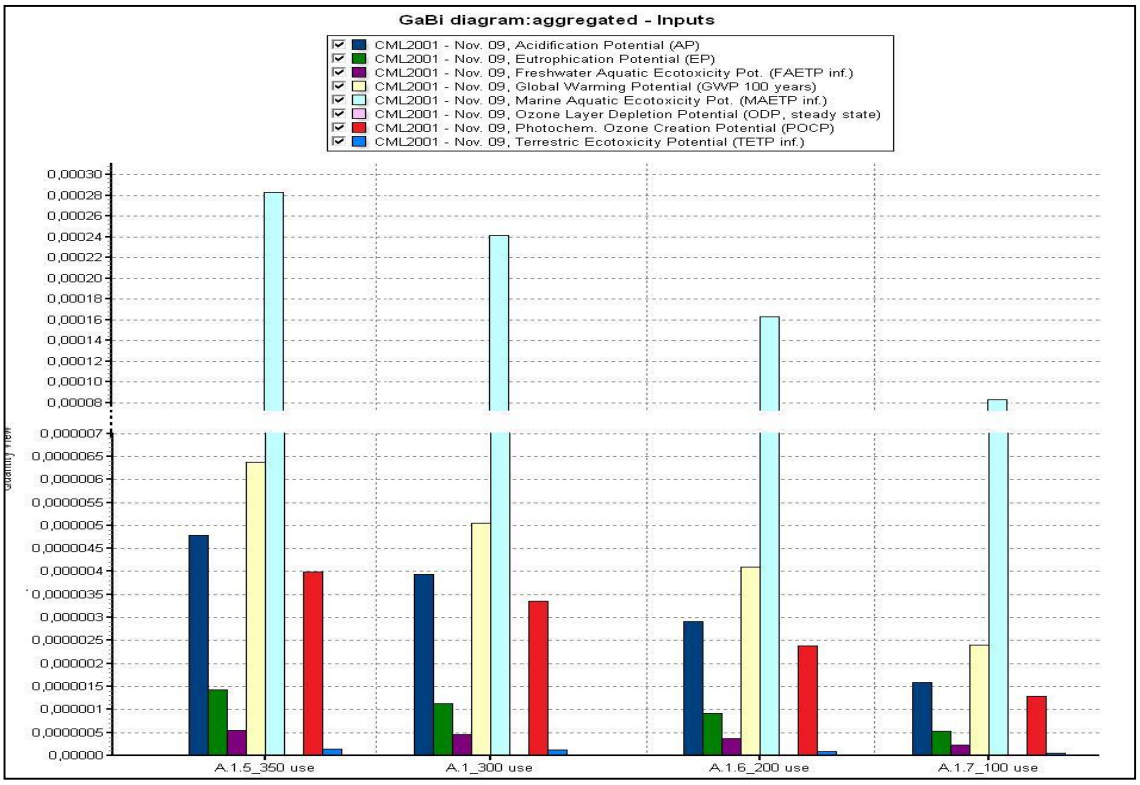

Figure C.121. The normalization results of CML 2001 Nov. ’09 Method for Scenarios A.1, A.1.5, A.1.6 and A.1.7.

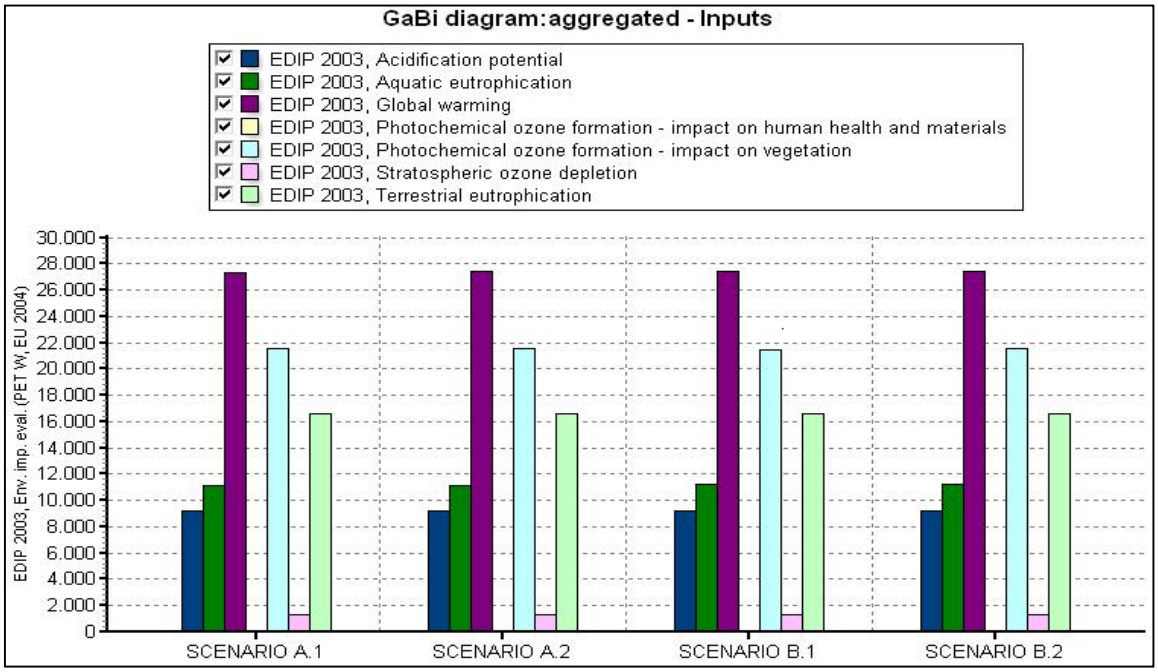

Figure C.122. The weighting results of EDIP 2003 for Scenarios A.1, A.2, B.1 and B.2.

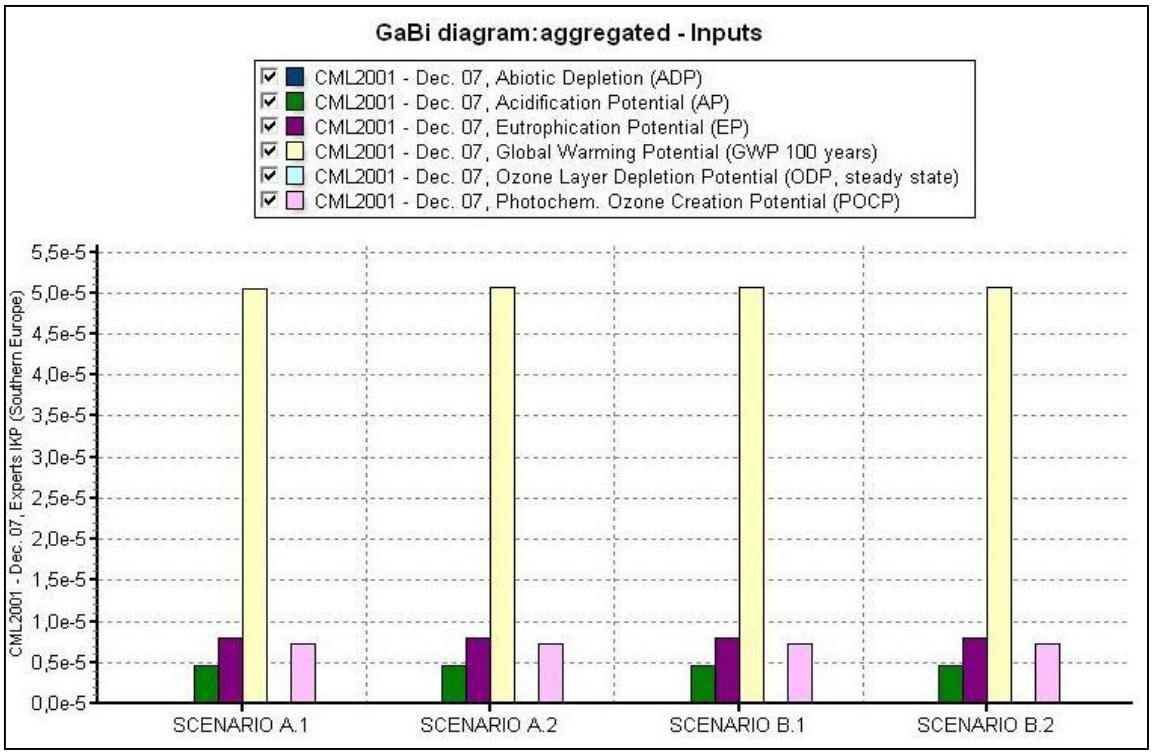

Figure C.123. The weighting results of CML 2001 Nov. ’09 Method for Scenarios A.1, A.2, B.1 and B.2.

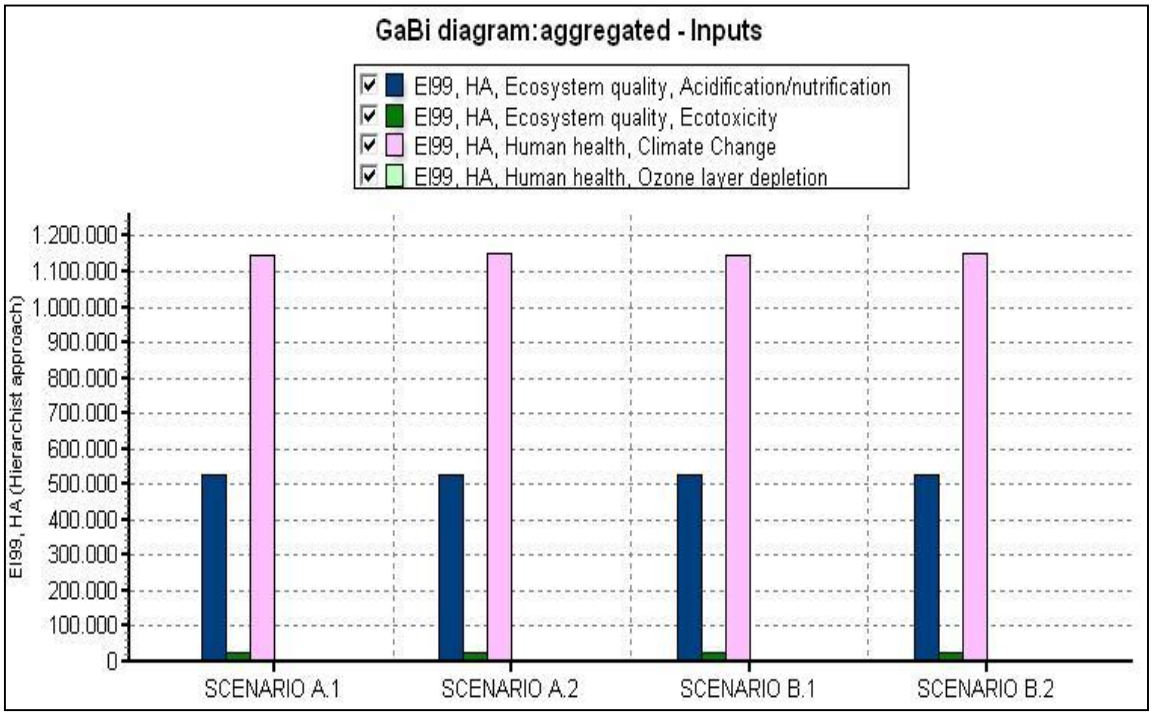

Figure C.124. The weighting results of EI 99 Method for Scenarios A.1, A.2, B.1 and B.2.

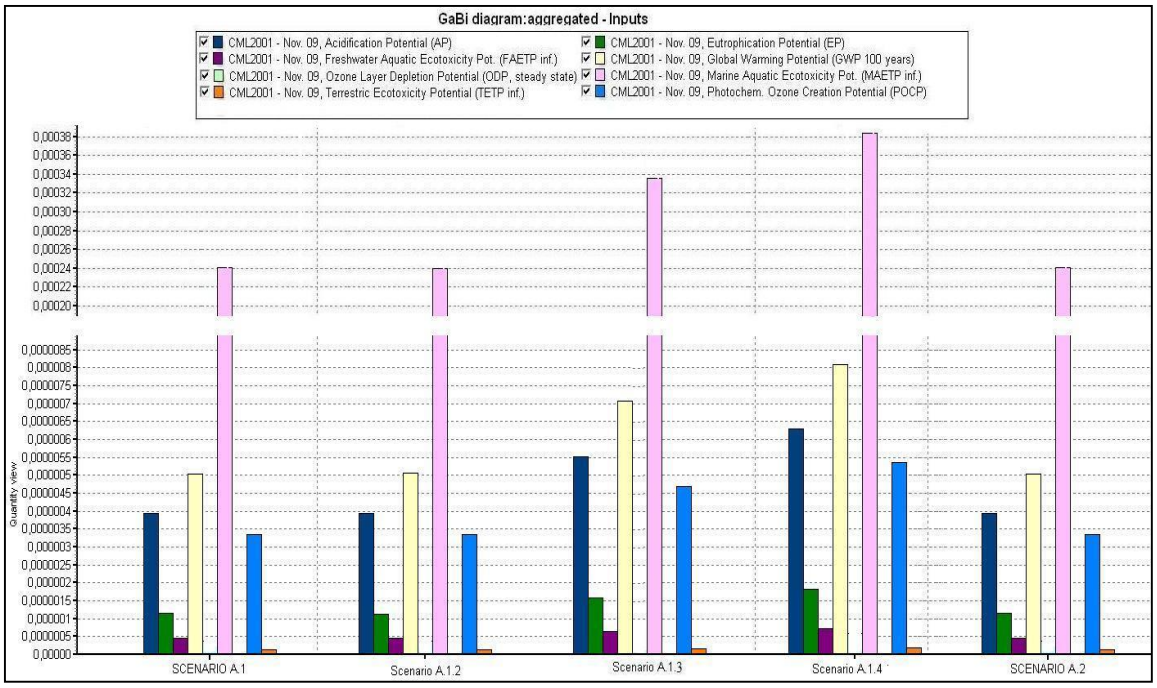

Figure C.125. The weighting results of CML 2001 Nov. ’09 Method for Scenarios A.1, A.1.2, A.1.3 and A.1.4., A.2.

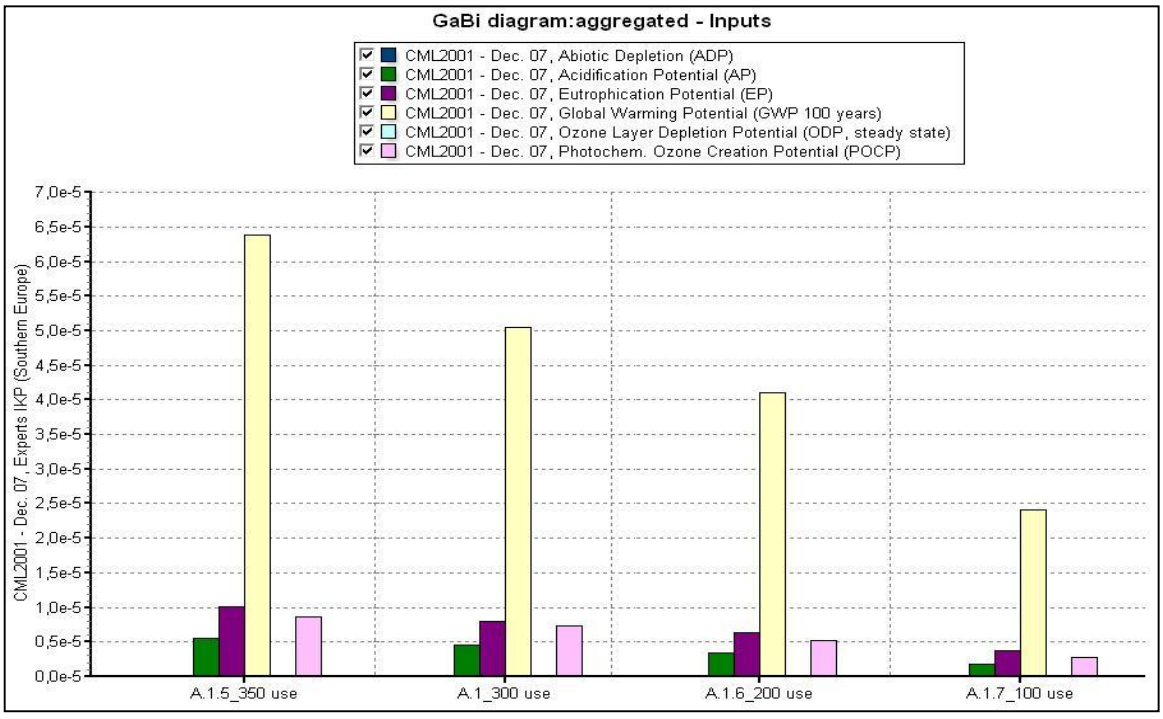

Figure C.126. The weighting results of CML 2001 Nov. ’09 Method for Scenarios A.1, A.1.5, A.1.6 and A.1.7.