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A mixed-method approach for environmental life cycle assessment in the single-serve coffee value

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Integrating resource efficiency in business strategies: A mixed-method approach for environmental life cycle assessment in the single-serve coffee value chain

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Abstract

Businesses are under increasing pressure to improve the resource efficiency of their products and services. There is a need for practical tools that enable businesses to implement resource efficiency in their value chains. In this paper, a mixed-method approach for assessing the life-cycle-wide use of natural resources in products and services is applied in a case study on a coffee value chain of the company Mars Incorporated. Material inputs along the entire chain were assessed quantitatively using the Material Input Per unit of Service method, while a semi-quantitative Hot Spot Analysis was performed to identify environmental hot spots. This mixed-method approach has been implemented for the first time in practice to assess the value-chain-wide resource consumption and environmental impacts within a specific value chain of Mars Incorporated. The paper concludes that combining the methods provides better insights into the value chain than using just one of either of the methods alone. For the company, the approach has proven to be practicable because it identifies improvement options and their value-chain-wide resource efficiency potential.

Key words: MIPS, Hot Spot Analysis, resource efficiency, environmental sustainability, LCA, coffee

Highlights

- A mixed-method approach for environmental life cycle assessment is developed.
- It combines Hot Spot Analysis and Material Input Per unit of Service analysis.
- The resource efficiency potential of identified improvement options can be modelled.
- The approach is practicable for the focal company in the coffee case study.
- Easy-to-understand results facilitate communication and implementation.

List of Acronyms

DPSIR - Driver-Pressure-State-Impact-Response

EOL – End-of-Life

HSA - Hot Spot Analysis

LCA – Life Cycle Assessment

MI – Material Input

MIPS - Material Input Per unit of Service

OECD - Organisation for Economic Co-operation and Development

PP - Polypropylene

TMR - Total Material Requirement

UK – United Kingdom

1 Introduction

The increasing use of natural resources such as materials, land and energy in the value chains of companies and products is a key driving force behind current environmental problems (Nelson et al., 2005; Geibler et al., 2010; Watson et al. 2013). Estimates illustrate that, in a "business as usual" scenario for 2050 and if all countries reached per capita consumption levels as currently in OECD countries, humans would require 180 billion tonnes of natural raw-materials, which is a 2.7-fold increase compared to today's levels (Dittrich et al., 2012). It has been proposed that the resource use from household consumption in industrialised countries should be reduced from the current level of approximately 40 tonnes to 8 tonnes per capita per year (Lettenmeier et al., 2014). The pressure that industrialized countries are putting on global land use is still increasing rather than decreasing (e.g. Bringezu et al., 2009). Hence, the relevance of sustainable management and efficient use of natural resources is growing globally.

Resource efficiency has been rising on political agendas worldwide, both at national (Lilja, 2009 or BMU, 2012) and international level (European Commission, 2012a; UNEP, 2011; EEA, 2011). For instance, the European Commission's "Roadmap to a Resource Efficient Europe" defines the vision of a competitive and inclusive economy growing in a way that respects resource constraints and planetary boundaries (European Commission, 2011). According to this roadmap, by 2020 all companies and their investors should be able to measure and benchmark life-cycle-wide resource efficiency. However, the environmental footprint proposed by the European Commission as an indicator set for companies has been criticised for increasing confusion and reducing the compatibility of approaches (Finkbeiner 2013).

Maximising material and energy efficiency has been identified as an archetype of a sustainable business model (Bocken et al., 2014; Krarup & Ramesohl, 2002). Consequently, resource efficiency should be integrated more intensively in tools and instruments supporting improved business decision-making. Many companies have started to analyse and reduce the environmental impacts of their processes, products and services, which led to the development of various tools and instruments (Hervaa et al., 2011). Commonly used approaches by companies are Life Cycle Assessment (LCA) (Mattsson, 1999; Humbert et al., 2009; Clune & Lockrey, 2014), energy and carbon footprinting (Plassmann et al., 2010;

Bolwig and Gibbon, 2009), water footprinting (De Fraiture et al., 2001; Hoekstra et al., 2009), product environmental footprinting (European Commission, 2012b) or material footprinting (Giljum et al., 2011; Lettenmeier et al., 2012; Lettenmeier, Liedtke, Rohn, 2014). LCA has been developed to integrate the whole value chain of products into the assessment and impact reduction instead of focusing on, for example, single production plants (ISO 14044, 2006; Rebitzer et al., 2004; Jeswani et al., 2010). However, the numerous categories of environmental impacts used in LCA focus mostly on output-based aspects, while the use of natural resources is not covered comprehensively (e.g. Wiesen et al., 2014). Additionally, results from this range of environmental categories are not easy to understand and to communicate, which is a key requirement for a comprehensive ecological indicator (Giljum et al., 2011). Furthermore, experience from carbon accounting highlights that increased collaboration between academic accounting and professional (business) practice is crucial "for evolution of the relationship between research and practice of sustainability embedded carbon accounting in order to forge ahead towards cleaner production" (Burritt and Tingey-Holyoak, 2012, 39).

Against this background, this paper describes a mixed-method approach for assessing the use of natural resources in products and services, and its practical application in the case of a coffee value-chain of Mars Incorporated. This paper describes the conceptual background and steps of two environmental LCA methods: the quantitative Material Input Per unit of Service (MIPS) method for assessing natural resource use in value chains (Hinterberger and Schmidt-Bleek, 1999), and the qualitative Hot Spot Analysis (HSA) for environmental impact assessments (Liedtke et al., 2010). The application of both methods is illustrated in a practical case study based on collaboration between representatives of Mars Incorporated and the Wuppertal Institute.

2 Mixed-method approach for assessing natural resource use of products

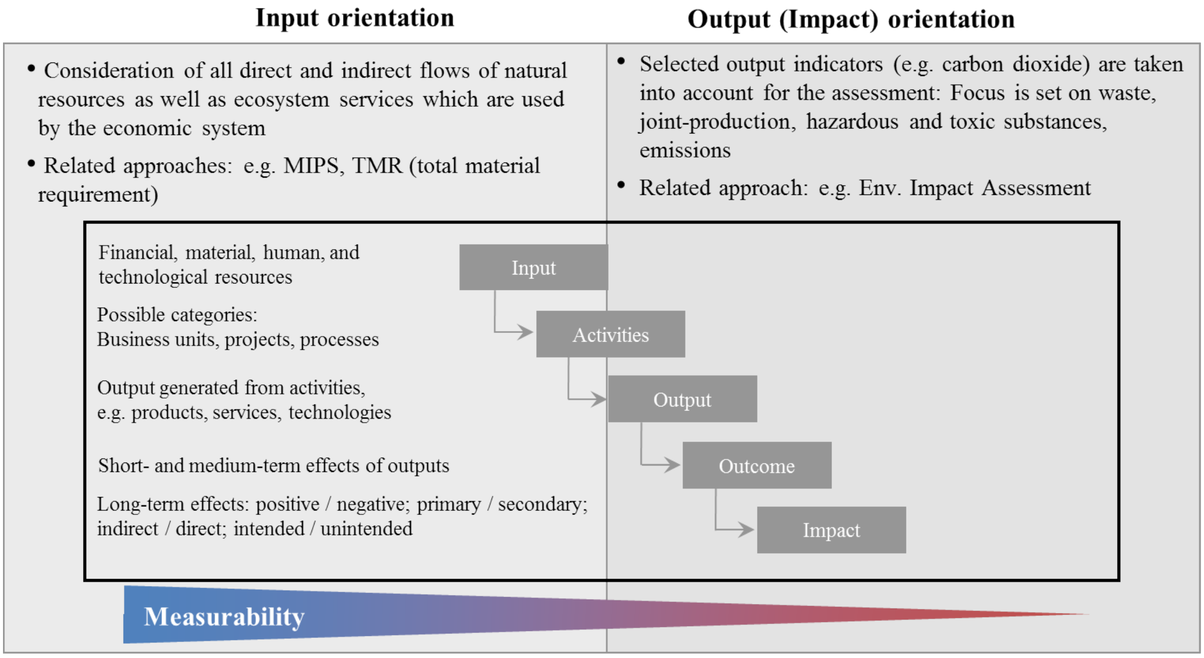
This section outlines the rationale behind the mixed-method approach used in the case study and describes each step used in the methods: from defining the scope definition to interpreting the results.

2.1 Assessing resource use in the industrial metabolism

All industrial processes require natural resources as an input (e.g. raw-materials, water) and produce outputs, both desired (the products) and non-desirable (e.g. emissions and wastes). Additionally, indirect inputs and outputs occur throughout the value chain, for instance the raw materials required to supply the electrical power used, and the emissions and wastes caused by producing that power. The direct and indirect input flows are the prerequisite for any output or impact to the environment caused by the product, including outputs and impacts that are not yet known. Hence, reducing the inputs is much more effective in reducing the overall environmental burden than individual measures on the output side (e.g. filtering emissions). By reducing the natural resource use in the manufacturing processes, environmental aspects can be adressed at source (Lettenmeier et al., 2009; Spangenberg and Lorek, 2002).

The differences between focussing on inputs or outputs when assessing resource consumption and its effects in the industrial metabolism can be illustrated using the model of causal chain analysis developed by the OECD (2002). In this model, "input" refers to all resources that are used for a specific activity and "outputs" are all direct effects of the activity. "Outcomes" are the short- to mid-term effects caused by the outputs, while "impacts" are defined as long-term effects of the outcomes. The measurability decreases along the causal chain from input to impact (Figure 1). This theoretical model can be illustrated using a simple example: to generate electricity, fossil energy carriers are used as an input. The quantity of energy carriers needed to produce one kWh of electricity is easy to measure and known to the electricity company. A direct output of the electricity generation activity is CO_2 emissions. They are also relatively easy to measure if appropriate technology is in place or accurate models are used. An outcome of the CO_2 emission is the enhanced greenhouse effect in the earth's atmosphere, while the impact of this enhanced greenhouse effect is global warming. Outcome and impact are difficult to measure, and even complex scientific investigations and modelling can only deliver estimations.

Figure 1: Description of the relationship between input and output orientation alongside the representation of the causal chain from input to impact with a decrease in measurability



Source: own figure, based on ISEAL Alliance (2009: 11) and Beisheim et al. (2007: 4, 8).

2.2 The mixed-method approach: Combining MIPS and HSA

MIPS (Material Input Per unit of Service) has been developed as a material flow-based indicator for assessing product life cycles at the micro-economic level (Schmidt-Bleek, 1994; Ritthoff et al., 2002; Liedtke et al., 2014).[1] MIPS allows the estimation of the input-oriented environmental impact potential of a product (e.g. a cup) used for providing a specific service or benefit (e.g. drinking 200 ml of tea), and thus provides a measure of eco-efficiency. With respect to the most widely used environmental indicators, i.e. the carbon footprint (e.g. Plassmann and Jones, 2009), it provides a more comprehensive view and is suitable for outlining possible trade-offs in the use of different resources. Compared to specific environmental evaluations like LCA, MIPS has a lower level of detail and a quantitative evaluation of environmental pressure only, and is thus less labour-intensive (Ritthoff et al., 2002; Schmidt-Bleek et al., 1998; Saurat and Ritthoff, 2013). Moreover, MIPS results can be

[1] MIPS is based on the idea, expressed in the 1960s, that sufficient management of environmental problems will not be possible without dematerialisation, i.e. without a general reduction of the material flows used by the human economy (Ayres and Kneese, 1969).

combined with economic and social data (e.g. Hirvilammi et al., 2013, Hirvilammi et al., 2014).

MIPS gives the amount of materials (including energy in terms of the material required) needed for a specific benefit (the so-called 'service') in mass units (kg or tonne). By using MIPS, companies can control the life-cycle-wide environmental pressure potential of the materials they use, their processes, logistics, and products in real time. The key difference to output-based indicators (e.g. emissions) is the active focus on the inputs certain products and services require instead of a focus on reducing emissions by technical means.

The Hot Spot Analysis (HSA) was developed as a qualitative screening method of product life cycles (Wallbaum and Kummer, 2006) and has been applied in the food sector (Liedtke et al., 2010; Bienge et al., 2010; Rohn et al., 2014). Its goal is to identify key ecological challenges along the entire value chains in a quick and reliable way. The results highlight so called "hot spots" in the product's value chain: Aspects of its life cycle with highly relevant resource use and environmental impact, which can be starting points for making improvements. Both methods have been selected based on a review and intensive discussion of various methods between representatives of Mars Incorporated and the Wuppertal Institute.

Table 1 summarises the steps needed to perform MIPS and HSA analyses. Both methods will be combined in the subsequent analysis. In the following sections, the steps for both MIPS and HSA are described, while the outcomes are presented in the results section (see sub-section 3.2 for MIPS and 3.3 for HSA).

2.2.1 Scope definition

For both methods, the first step is to define the aim, scope and system boundaries of the analysis. Similar to LCA, this begins with the definition of the functional unit. The functional unit is the product or service that is to be analysed, and to which all results relate. Within MIPS terminology, this is the "service unit" (S) in MIPS. The S in MIPS "designates the service, the benefit, the value created with technical systems [...]" (Lettenmeier et al., 2009). Its dimension is not predefined but depends on the individual case.

For both MIPS and HSA, once the service unit or product has been defined, the framework of the analysis must be specified. For this purpose, the life cycle of the product is investigated. Generically, it is divided into four main phases:

1. Raw-material procurement (such as mining or agriculture)
2. Processing (all processing and manufacturing processes)
3. Use (the use of the product or service, incl. retail and distribution)
4. End-of-Life (disposal and recycling processes after use)

Furthermore, all transports within and between these life cycle phases are considered. Depending on the complexity of the product life cycle and the level of detail desired, more sub-phases may be defined. Figure 2 in sub-section 3.1 shows the life cycle of coffee as analysed in this case study.

Next, the categories or aspects to be assessed for each life cycle phase need to be defined. In MIPS assessment, resource inputs are assessed for five categories of resources: abiotic raw-materials, biotic raw-materials, water, air, and earth movement in agriculture and forestry (Table 2). These categories allow the assessment of the resource intensity of the product under investigation, which is a valuable proxy of the environmental impact potential associated with the product, as discussed in sub-section 2.1 (Schmidt-Bleek, 2009; Ritthoff et al., 2002; Lettenmeier et al., 2009).

The environmental categories analysed in HSA were chosen to capture the environmental impacts of the product life cycle in a comprehensive way (Table 2). The input categories raw-materials, energy, water and land use allow the assessment of the resource intensity of the product under investigation, analogous to the MIPS-method. In addition to these input-oriented indicators, important outputs are also considered: These are solid wastes and emissions to air and water. The area of land occupied by certain activities in relation to the product life cycle such as mining, agricultural production or processing plants and transport infrastructure is considered as a resource input. Impacts on biodiversity and soil degradation can be seen as an effect or output of this land occupation.

2.2.2 Data gathering and inventory

The second step for both MIPS and HSA is data gathering to perform the analyses. For MIPS, data on all inputs in all process steps (such as agrochemicals for cultivation, energy carriers and electricity for processing, packaging materials, transport kilometres including vehicles and infrastructure, electricity, and water for brewing the coffee, etc.) is needed. Sources of information can be direct measurements providing specific data, expert assessments, literature references, and qualified estimations covering remaining information gaps, e.g. on the basis of theoretical calculations or general data from sector or national averages (Ritthoff et al., 2002).

The basis of a HSA is data from scientific literature that provides facts about ecological impacts in the value chain or parts of thereof. When performing data gathering from secondary sources, it is important to consider their scientific quality. Wherever possible, only sources that can be regarded as scientifically reliable are used, such as peer-reviewed journal publications, statistics agencies, or publications of recognised scientific or international institutions. The relevance of the data regarding the product life cycle under investigation is determined by the scope of the analysis.

2.2.3 Calculations and data evaluation

MIPS Step 3 - Calculating Material Input: The material input (MI) is measured in mass units. Since calculating the material input for each individual material and process over the entire life cycle would be time-consuming, usually precalculated, average material intensity factors, the "MI factors", are used (Ritthoff et al., 2002). MI factors give the material intensity values of specific input materials and energy quantities. They are expressed in kg / kg (kg of resources per kg of the material used) or respectively in kg / kWh in the case of electric power. For example, the abiotic MI factor is 540,000 kg for an average kilogram of primary gold, 350 kg for a kilogram of primary copper, and 8 kg for a kilogram of steel plate. The most comprehensive set of MI factors is provided by the Wuppertal Institute (2011). The material input (MI) is calculated by multiplying the individual input quantities for each process assessed in Step 2 by the specific material intensities of the inputs. MI calculation is done separately for each individual category of natural resources (abiotic resources, biotic resources, soil, air, water).

MIPS Step 4 - From Material Input to MIPS: In this final step of calculations, the Material Inputs generated in Step 3 are related to the service they provide. The initial calculations are often based on data relating to annual resource consumption of the product chain, or per kilogram resource inputs for specific materials and processes. To calculate MIPS, these MI values are divided by the number of service units (Ritthoff et al., 2002).

HSA Step 3 - Category significance assessment: Once the data has been analysed, the categories listed in Table 2 are rated based on the relative severity of the associated impacts. This is done separately for each life cycle phase. The rating is performed on a scale of 1 to 3 as follows:

- High relevance (3 points) is assigned to those categories that have the most severe environmental impacts within the life cycle phase.
- Medium relevance (2 points) is assigned to categories where impacts are significant but less severe in comparison to those impacts rated highly relevant.
- Low relevance (1 point) is assigned to no or minor impacts.

If no data is available and thus assessment is not possible, this is documented and treated as a 0 in calculations (see Table 3 for detailed results and Table 5, column 3, for results overview).

HSA Step 4 - Life cycle phase weighting of significance: Once the assessment of the different categories is completed, step four is performed in order to compare the environmental impacts of one phase to another. In this step the different life cycle phases are ranked by their importance in relation to the complete life cycle, again on a scale from 1 to 3. The weighting of the different life cycle phases can be done based on available LCA studies comparing the importance of the raw-material procurement, processing, use and waste treatment phases (Table 4 and Table 5, column 4).

2.2.4 Interpretation of results

MIPS Step 5 - Interpretation and evaluation of results: Once the Material Input for each process in every life cycle phase has been calculated, results are added up per resource category and life cycle phase. The results show how many kilograms of abiotic and biotic resources, water, air and soil are used in each phase and over the entire value chain of the product. In this case study, the interpretation and evaluation of the results included the following aspects:

- Comparison of the relevance of the different life cycle phases in each resource category including TMR[2].

[2] The sum of biotic and abiotic material inputs and erosion are sometimes considered together as the "Total Material Requirement" (TMR), which is then equivalent to the resource categories used when calculating TMR or TMC (Total Material Consumption) on a macroeconomic level. Water must be calculated and displayed separately, because the quantity of water used to generate a specific service is typically at least ten times higher than the amount of other resources (Lettenmeier et al. 2009). Air consumption (i.e. the part of the air transformed chemically, mainly the oxygen used in combustion processes) has also been calculated and displayed separately, but in principle it could be added to the TMR. This would make sense in the light of the CO_2 output of processes, which derives from the consumption of abiotic or biotic carbon resources and air.

- Assessing the relevance of the results of the different resource categories by relating the results to the average daily resource consumption by a European of food and drinks.
- Comparing the results of the case study to MIPS results from earlier studies on other drinks.
- Developing options for reducing the natural resource consumption of coffee and assessing their benefits in relation to dematerialisation targets like Factor 4 or Factor 10.
- Assessing the quality of the data used for the different life cycle phases.
- Comparing the MIPS results to the results of the HSA.

HSA Step 5 - Identification of environmental hot spots: For better visibility of the hot spots, the scores of the different environmental categories (Step 3) are multiplied by the score of the respective life cycle phase (Step 4), yielding scores from 0 to 9. Hot spots are defined as scores of 9 and 6 points, the highest and second highest scores possible (based on Wallbaum and Kummer, 2006) (Table 5, column 5).

HSA Step 6 - Stakeholder verification (optional): Especially in cases where the availability of reliable data is weak, stakeholder verification is recommended. This can be done in a workshop including stakeholders and experts from all phases of the product life cycle.

3 Applying the mixed-method approach to the Mars Coffee Case

Based on discussions between representatives from Mars Incorporated and the Wuppertal Institute, the following objectives for the study were defined:

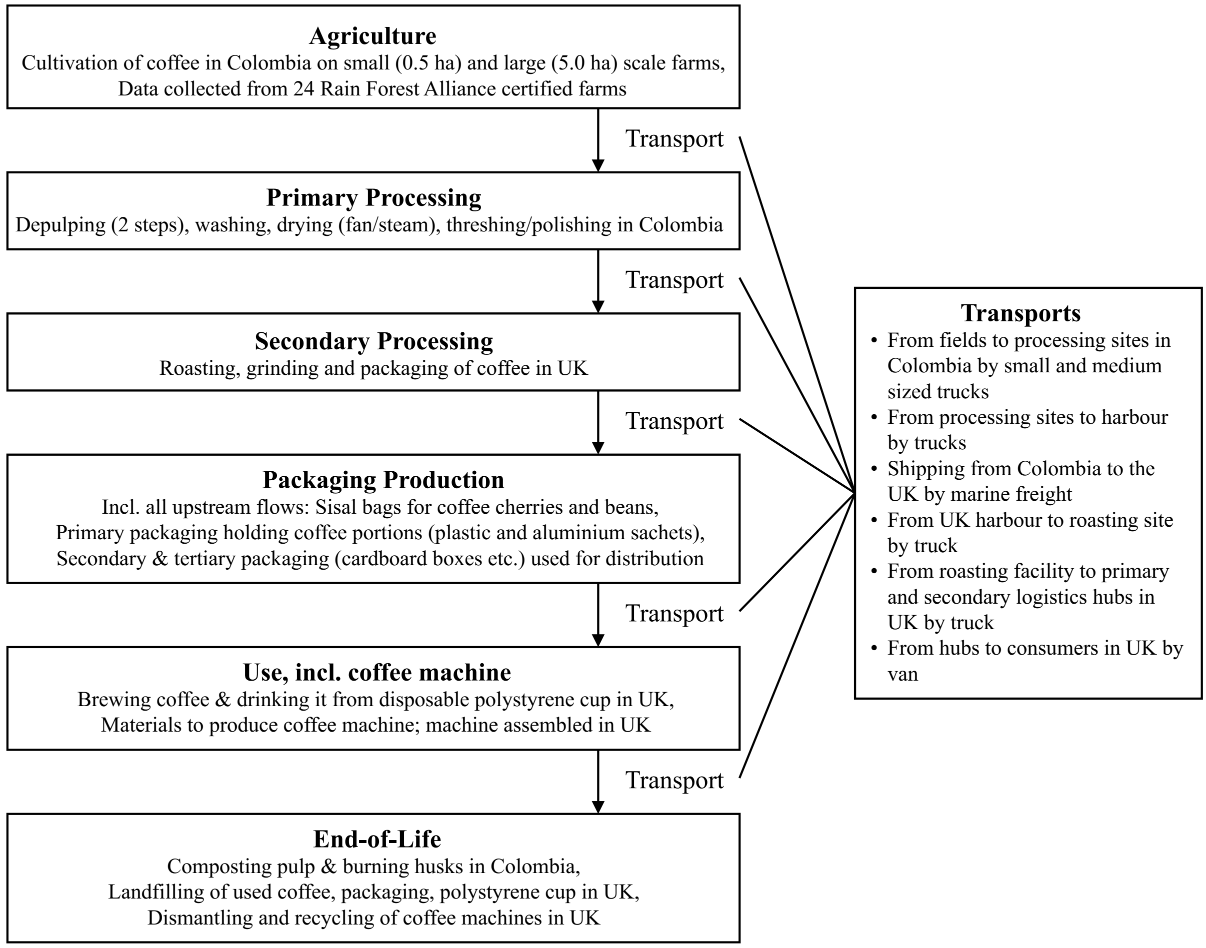
1. Quantify the material inputs of a specific coffee value chain of Mars based on the MIPS concept
2. Identify environmental hot spots in the life cycle of the coffee product based on HSA
3. Highlight the specific phases in the coffee life cycle, which require the highest input of materials and have the highest number of hot spots
4. Identify options for reducing the material inputs and hot spots based on literature

For the purpose of the MIPS analysis, the service unit ("S" in MIPS) was defined as drinking one cup of Mars coffee. "One cup of coffee" was adopted as product unit for the HSA.

3.1 System-boundaries and scope: Mars and the coffee case

The life cycle of the single-serve coffee we considered in this study is structured as follows. The coffee arrives at the manufacturing site after being roasted and blended to accommodate specific flavours and is then ground at the manufacturing site. The packaging materials are further treated and assembled in the production line. The final result is a single serve of coffee in a sachet. The coffee from the sachet can only be brewed with a specific coffee machine. The coffee sachets are then shipped to the final consumers. As the purpose of this paper is to assess resource efficiency methods in a business operations context, we focused on a specific flavour (obtained from a coffee variety harvested in Colombia) to illustrate the overall process throughout the product life cycle. Figure 2 summarises the system boundaries of this coffee product's life cycle (i.e. from the agricultural phase to the landfill).

Figure 2: System boundaries of MIPS with the definition of the different life cycle phases.



The main difference in the determination of life cycle phases for the MIPS and HSA analyses in this case study is the higher level of detail in MIPS. MIPS has two separate phases for cultivation and primary processing of the coffee, whereas in HSA primary processing of the coffee in Colombia is considered within the agriculture phase. The transports between the different life cycle phases are summarised in a separate distribution phase in MIPS. In HSA, transports were not considered separately but within the life cycle phase that follows the transport (i.e. transport of green beans to the roaster are considered in the processing phase, transports from the roaster via distribution hubs to the consumer are considered in the use phase, etc.). The simpler structure of the assessment framework for HSA is due to the fact that the secondary literature used as data source provided a lower level of detail than the numerical data used for the MIPS assessment.

3.2 MIPS Analysis Results

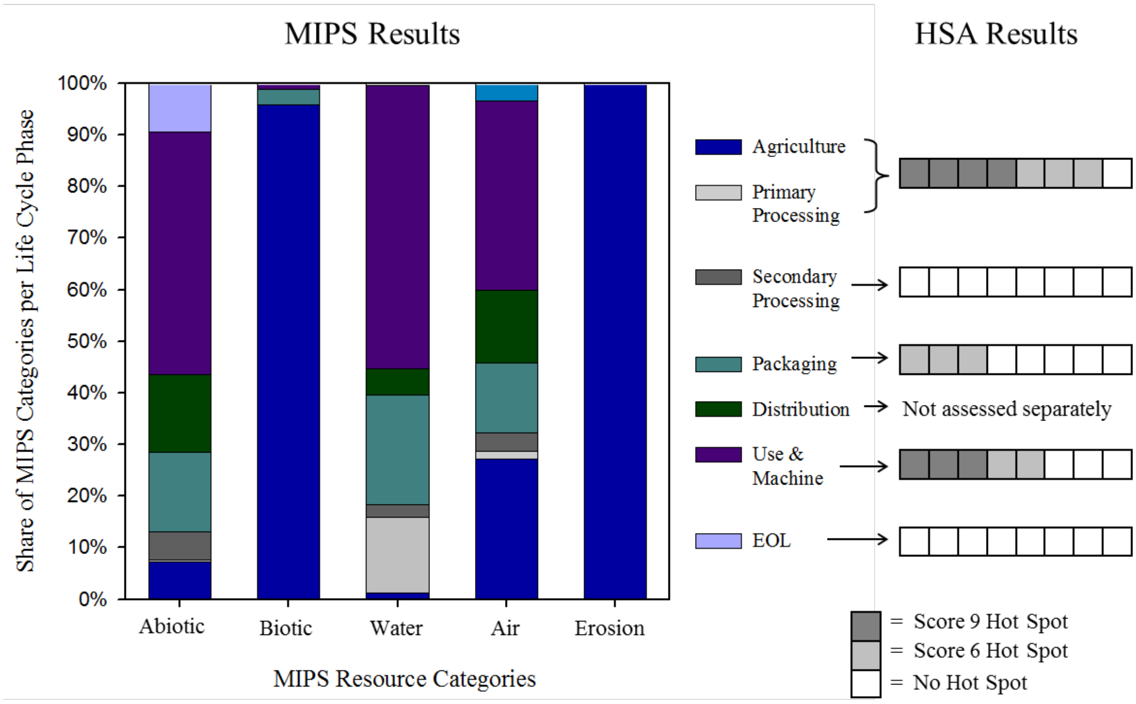
For Step 2, *data gathering and inventory*, part of the data was initially available from a previous LCA study. To this data we added the input materials of the coffee machine, which was excluded from the scope of the previous LCA study. The working dataset was then completed by iterative communication between the research unit at Mars Incorporated and the Wuppertal Institute. For example, data gaps in the agricultural phase were filled using internal data sources and published references (e.g. Coltro et al., 2006; Ataroff and Monasterio, 1997). The final dataset covered the whole input material information used for the MIPS calculations. Most of the data on processing, packaging, transport and the coffee machine were case-specific. Agricultural data were mostly based on literature concerning the countries neighbouring Colombia. Data on the use phase and the end-of-life phase were based on the average or most common situation in the UK. The unit of service consisted of a single serve of coffee represented by a sachet with a total weight of 6 gr (including the sachet packaging material and the coffee powder) providing 150 ml of coffee. The outcome of Step 2 was a detailed list of resource inputs showing the quantities of inputs used in each process step along the life cycle.

Step 3: The material input (MI) was calculated by multiplying the input quantities of the different resources collected in Step 2 by the specific MI factors of these materials. Most MI factors were taken from Wuppertal Institute (2011). MI calculations were done separately for each individual category of natural resources (abiotic resources, biotic resources, soil, air, water).

Step 4: Based on the definition of the service unit as one cup of coffee, in this step the annual material inputs for coffee cultivation is divided by the number of servings produced in that year; the material input values for the coffee machine are divided by the number of servings that the machine produces; the material inputs for distribution are divided by the number of portions transported etc. MIPS is recorded for each of the five resource categories in each process step of the life cycle.

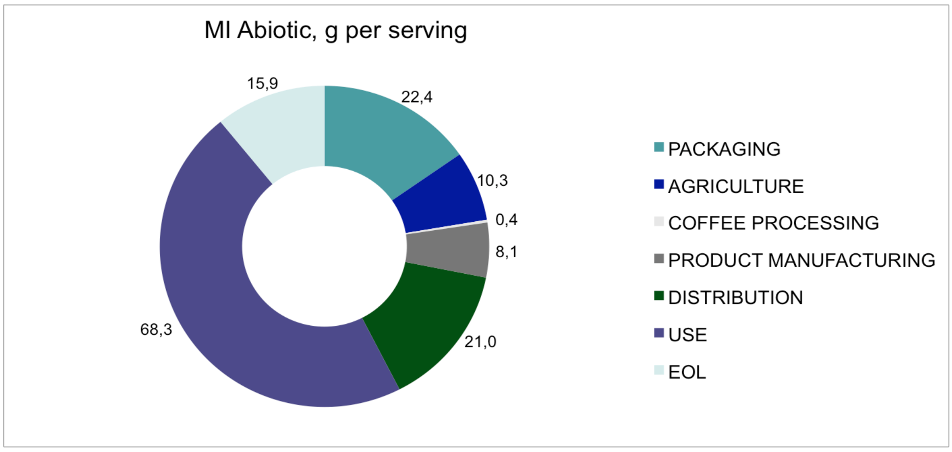
The high-level MIPS results are summarised in the left part of Figure 3.

Figure 3: Results of the MIPS analysis of all life cycle phases for Colombian coffee according to the five categories as well as results from the analogous HSA.



Detailed results for all MIPS catergories are presented in the supplementary material (Part 2: Figures 6 - 9). As an illustration, the MIPS results for the metric of abiotic materials are summarised in Figure 4. Here the use of abiotic material input has been split across all the life cycle phases . The results show how the 146 g of abiotic materials from a single serving of coffee (6 g, 150 ml of brewed coffee) are distributed across the life cycle. Packaging, Use and Distribution are the most relevant phases contributing, accounting for 75% of abiotic materials together. More detailed analysis within each phase identifies the individual contribution to the MI of each process step and facilitates the identification of reduction potentials.

Figure 4: Detailed results for the abiotic resources material input (MI) along the whole coffee lifecycle.



3.3 Hot Spot Analysis Results

The results of Step 1 are displayed in sub-section 3.1 above. Step 2 refers to data gathering. The HSA of Colombia Coffee was performed on the basis of published scientific literature. Only studies focussing on similar production systems and geographical regions were considered. Additionally, results from the MIPS analysis presented in sub-section 3.2, as well as results from an internal LCA by Mars Incorporated were considered. The following sub-section presents the results of the HSA relating to Steps 3-5 as described in sub-sections 2.2.3 and 2.2.4. Step 6, stakeholder verification, was not performed in this case study.

Results from step 3: Category significance assessment

To assess the environmental relevance of each category in every life cycle phase, data on these categories are summarised in a separate table for each life cycle phase. Table 3 shows how this was done for the agriculture phase. Agricultural practices for coffee cultivation range from large-scale unshaded monoculture to small scale farming using traditional agroforestry practices. For the evaluation of results, it was assumed that 85% of the coffee was sourced from large-scale farms and 15% from small-scale farms (personal communication Drinks Division, Mars Incorporated, 2010). The described inputs and outputs vary significantly between these management systems. Tables for the other life cycle phases can be found in Part 1 of the supplementary material (Tables 6 - 9).

To enable a quick overview, only the most significant inputs and outputs are listed as bullet points in Table 3. The left column lists the category assessed (e.g. emissions to air). The middle column summarises the processes or substances that dominate that category (e.g. the use of nitrogen fertilisers leads to emissions of greenhouse gases and pollutants from the soil to the air). The column on the right shows the relevance rating given to that specific category, e.g. the emissions to air are one of the most severe impacts in the agricultural phase and are therefore given a score of 3 (i.e. highly relevant). The scores of the categories for each life cycle phase are summarised in Table 5.

Results from step 4: Life cycle phase weighting of significance

To compare the relevance of each life cycle phase with one another, the contribution from the different impact categories within the life cycle phases is expressed as a percentage of the total resource use or emissions along the entire life cycle. Table 4 provides an example of such comparisons. In terms of secondary sources, only studies that had a similar assessment framework as our MIPS and HSA analyses could be considered, otherwise the percentage calculations would not be comparable. Thus, only the studies by Humbert et al. (2009) and Büsser et al. (2009) were used for this, as they assessed the whole life cycle of coffee products, including packaging. Initially, this synopsis was limited to energy and water consumption and air emissions, as these were the only three categories that were consistently covered by the LCA studies cited. Contributions from transportation were considered only where they showed a significant contribution and the MIPS category air consumption was used as a proxy for CO_2-eq. emissions.

This synopsis shows the largest impacts are in the use phase, with most selected metrics exceeding 30% of life cycle impacts, and some even exceed 50%. Agriculture and packaging show medium impacts, with most metrics in the range of approximately 10-30% of total life cycle impacts. Processing and end-of-life both show only small fractions of total life cycle impact for most metrics. However, this synopsis shows only three out of the eight categories analysed in the HSA. Thus, to rate the different life cycle phases in relation to each other, close attention must be also be paid to the results for the categories raw-materials, land use, impacts on biodiversity, waste and emissions to water.

Results for the consumption phase (Table 8 in supplementary material) note significant impacts for many of the categories. Thus, this phase was given the highest significance rating (3) in accordance with results from Table 4. Impacts in the phases agriculture and packaging appear to be in a similar range when only the assessment of energy, water and air emissions are considered (Table 4). However, agriculture also shows significant impacts with regard to materials, land use, biodiversity and emissions to water. Packaging also has significant impacts in these categories, especially associated with aluminium production. The scale of these effects is different though: a rough estimation on the basis of the MIPS analysis shows that 87% of the life cycle land use takes place in the agricultural phase and only 12.5% of total land use is associated with the packaging materials. This means that effects of land use, impacts on biodiversity and effects of water pollution for the cultivation of coffee affect a much larger area than the effects of aluminium mining, plastic and paper production with regard to the specific product analysed here. Therefore, the agriculture phase was rated as highly significant (3), whereas packaging was considered to be of medium significance (2). Processing and end-of-life did not show highly significant impacts compared to the other life cycle phases and were considered to be less significant (1). This weighting of the life cycle phases is summarised in column 4 of Table 5.

Results from step 5: Hot Spot identification

Hot spots were identified by multiplying the scores of the individual categories of each life cycle phase (column 3 in Table 5 below) by the relevance of the respective life cycle phase (column 4 in Table 5 below). All categories with 9 or 6 points are defined as hot spots and are highlighted in dark and light grey, respectively (column 6 in Table 5 below).

The results show that most hot spots, and thus the most relevant environmental impacts, are found in the agriculture and use phases (see also figure 3). The most significant impacts in each phase are summarised below; for more details please refer to Table 3, as well as Table 6 to Table 9 in the supplementary material.

In the agriculture phase, raw-materials, air emissions, impacts on biodiversity and land use are highly relevant. This is mainly due to the production and use of fertilisers (particularly synthetic and to a lesser degree organic) and unsustainable agricultural practices, such as intensive monoculture systems. Energy, water use and water emissions are also relevant in the agricultural phase. For energy consumption, the production of artificial fertilisers and other agrochemicals is highly relevant, as well as the drying of the coffee beans. Water consumption is dominated by inefficient wet processing of coffee cherries. Emissions to water stem from polluted wastewater from this process, as well as nitrogen leaching from fertilised soils and runoff of nutrients and pesticides from plantations.

In the use phase, the categories raw-materials, energy, and air emissions are particularly critical: all these impacts are related to energy consumption, mainly in form of electricity generated from fossil energy carriers, which is used to heat water to brew the coffee. Water use and waste production are also of relevance in the use phase. Water use mainly relates to electricity production (cooling and process water), while only a relatively small proportion is used to brew the coffee and wash the cup. Waste consists of packaging and used coffee grounds. Consumer behaviour, e.g. regarding wastage of brewed coffee and stand-by times of the coffee machine, is a major influence in this phase.

The packaging phase shows hot spots in the raw-materials, water and air emissions categories. The most significant impacts are caused by the production of aluminium and to a lesser degree plastic. The high amount of packaging (individually wrapped portions) and the use of primary materials that are difficult to recycle are important influences in this phase.

There are no hot spots in the processing and end-of-life phases. However, this does not mean that there is no resource consumption or environmental impact: in terms of processing, the energy consumed in the grinding process is relevant, as well as air emissions from transport and logistics and electricity generation. End-of-life impacts stem from landfilling of wastes and could be reduced by recycling packaging and using coffee grounds for compost or biogas production.

3.4 Significant aspects and improvement options

Both the MIPS analysis and the HSA show the most significant resource use and environmental impacts in the agriculture and consumption phases (Figure 3). These results are in agreement with output-oriented LCA analyses found in literature, which also place the largest fractions of environmental effects in these two phases (e.g. Büsser et al., 2009; Humbert et al., 2009; Salomone, 2003).

The HSA identified a broad range of theoretical improvement options from literature for all life cycle phases. In this paper, only those improvement options that relate to identified hot spots are briefly summarised. In the **agriculture phase**, identified improvement options include:

- **Reduction of agrochemical inputs, improved planning of nitrogen fertiliser applications and better fertiliser use efficiency:** A number of detailed studies have shown that this will reduce energy and raw-material consumption, emissions of NO, N_2O, NH_3, as well as contamination of groundwater and eutrophication of surface water (Coltro et al., 2006; Noponen et al., 2012; Salomone, 2003; Diers et al., 1999; Beer et al., 1998).

- **Improved agricultural practices,** e.g. traditional shaded agroforestry systems, organic agriculture, integrated agriculture, optimised use of different types of pesticides, best available technologies, regionally adapted practices, etc. Such practices can reduce erosion and biodiversity loss, reduce evapotranspiration and plant water needs and foster regional water cycles (Beer et al., 1998; Rappole et al., 2003; Perfecto et al., 2007).

- **Alternative wet processing and coffee drying technologies and techniques:** Innovative water saving processing machinery has been developed in Colombia and reduces water consumption by 10% (Van der Vossen, 2005). Solar coffee drying units as well as coupled solar/biomass units exist and can replace diesel or wood fuels for drying coffee. Traditional sun drying and dry processing of coffee beans requires no energy or water inputs (Diers et al., 1999; Van der Vossen, 2005; Mesoamerican Development Institute, 2011b).

For the **packaging phase**, the following main options were identified:

- **Use of recycled materials and/or reduction of packaging amount:** This reduces the demand for primary materials and thus reduces material, energy, and water consumption, impacts on biodiversity from mining, forestry etc. as well as emissions to air and water due to the production of packaging materials. Recycling is less resource-intensive and produces fewer emissions than the production of primary materials (Arena et al., 2003; Leroy, 2009; Ross et al., 2003).

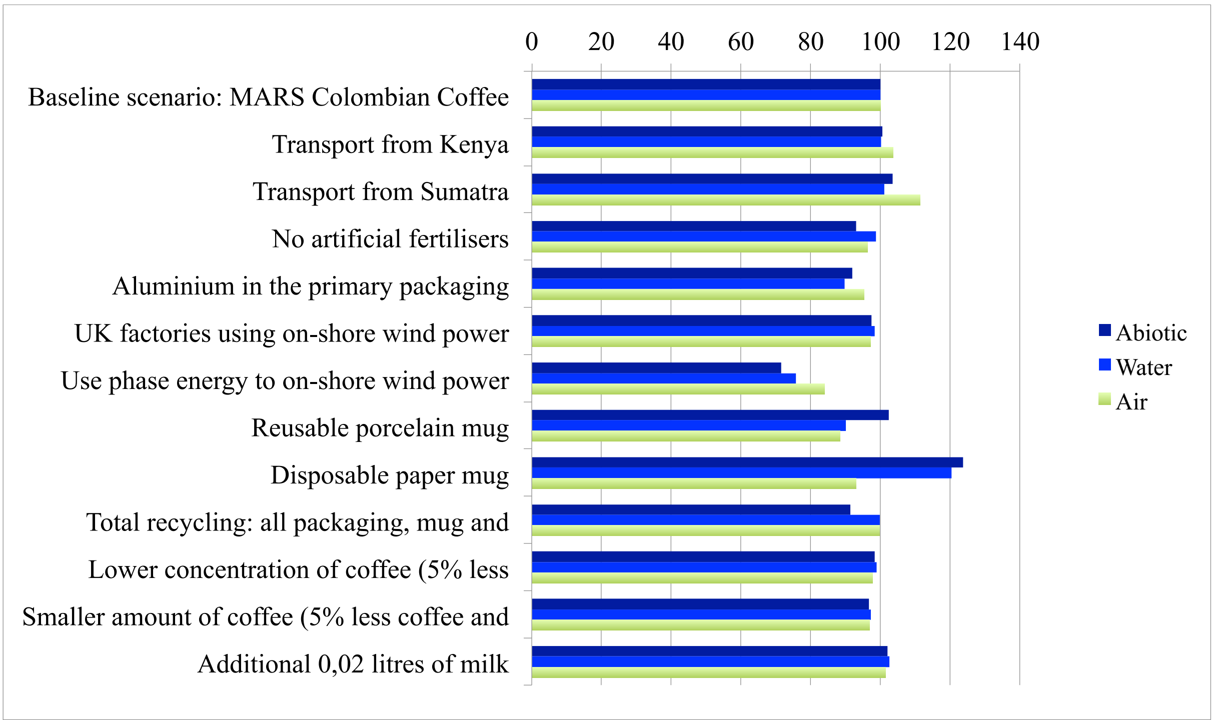
Improvement options in the **use phase** include**:**

- **Water heating:** Since most hot spots in the use phase relate to the consumption of energy to brew the coffee, more efficient water heating technologies as well as energy efficient consumer behaviour (e.g. regarding stand-by times of the coffee machine, wastage of hot water and coffee) can make a big difference.

- **Electricity from renewable energy sources** saves large amounts of material-intensive fossil energy carriers in electricity generation**.** Air emissions relating to fossil energy generation are also a significant environmental impact along the entire coffee life cycle (Salomone, 2003).

Once the resource inputs for the coffee product have been identified along the entire life cycle, MIPS can also be used to test the theoretical effects of different improvement options on the life-cycle-wide resource consumption of the product. To achieve this, several scenarios of change were defined, such as sourcing the coffee from a different country, using alternative power supply, altering the packaging of the coffee portions, using a porcelain or paper cup instead of the plastic cup, and others. The resource inputs for these alternative scenarios were then calculated and the effect on the total resource consumption along the life cycle of the altered coffee product was compared to the original coffee product. Figure 5 shows the changes in the consumption of abiotic resources, water and air for some alternative scenarios.

Figure 5: The results of MIPS-based scenario assessment for improvement options



In the quantitative scenario assessment (Figure 5), the first row shows the original product assessed in this study, Mars coffee from Colombia. As this is the baseline against which the scenarios are compared, abiotic resources, water and air consumption of this original product are set to 100%. The MIPS scenario assessment showed that sourcing the coffee from Kenya or Sumatra instead of Colombia had a small negative effect on resource consumption, especially in the case of Sumatra. In contrast, if no more artificial fertilisers were used, the consumption of all three metrics could be reduced; the same is true if the aluminium in the coffee sachet was replaced by polypropylene (PP). Of the different scenarios tested in this study, the greatest positive effect in terms of resource savings could be achieved by changing the energy supply in the use phase: if the fossil-fuel based electricity used to brew the coffee was substituted by electricity from on-shore wind power, significantly less abiotic resources, water and air would be consumed.

Such quantitative scenario assessments based on MIPS are useful to gain an overview of the effects of various improvement options. However, it must be noted that the results presented here are indicative only as they are based on rough theoretical estimates. Nonetheless, they provide a valuable starting point to select improvement options with potential to reduce the natural resource consumption of products, which can then be investigated in more detail before implementation.

4 Discussing the practicality of the approach

The combined approach of MIPS and Hot Spot Analysis introduced in this paper primarily focuses on the assessment of resource inputs and selected key outputs. MIPS quantitatively captures pressures induced on the environment by a specific production-consumption system and can thus serve as a pressure or efficiency indicator within the DPSIR[3] framework as used by the European Environment Agency (EEA, 2005; ETC/SCP, 2010). By focussing on pressures (such as resource consumption, wastes, emissions) rather than impacts (such as acidification, global warming etc.), the MIPS approach is geared towards measuring and improving the resource efficiency of products. Reducing resource use and emissions generated by a product effectively reduces the pressure a product exerts on the environment. Through increasing the resource efficiency of production-consumption systems, environmental pressures can be decoupled from their drivers (such as economic growth, consumer demand etc.). As a consequence, the purpose of a MIPS analysis is not to replace the reduction of specific toxic substances, but to further dematerialisation by achieving a system-wide reduction of environmental impacts, e.g. with respect to the resource use of companies and the value chains of their products.

As far as the process of analysis was concerned, the results were discussed during several interim meetings between the researchers at Mars Incorporated and the Wuppertal Institute, allowing the integration of other data sources and ensuring transparency of the MIPS calculations in full detail. Regarding interactions with the management team, the Mars researchers gained company management endorsement after running several interim meetings, in which the Wuppertal Institute team was introduced and the proposed input approach and its complementarity with the output-based LCA approach was illustrated.

[3] DPSIR stands for Driver-Pressure-State-Impact-Response and is a conceptual framework used by the EEA and others to analyse the interactions between societies and the environment (EEA 2005; ETC/SCP 2010).

The final results of the MIPS analysis and the HSA were presented by the research teams of Mars and the Wuppertal Institute to the management team of the Mars Drinks Division in the form of an interactive workshop with the goal of obtaining feedback and discussing possible items for future interventions to reduce the material inputs in their coffee product's life cycle. Experts at Mars verified the results regarding their plausibility and practical relevance. The innovative approach of using a combination of two screening LCA methods has proven to be practicable in the given case. MIPS and HSA are less time consuming than a full LCA. While both MIPS and HSA by themselves offer a lower level of detail, the combination of these two methods provides comprehensive results of important resource inputs and environmental effects.

The LCA performed previously has been a very useful and its input data was sufficient in most cases for the MIPS analysis. To assess the constituent materials of the coffee-machine, however, additional data had to be provided. In addition, the assessment of the agricultural production cannot, in the long run, be considered sufficient on the basis of the secondary data available in this study. Future value chain data collection and management should put a stronger focus on the agricultural production. Despite this insufficiency in terms of data, the MIPS approach turned out to be useful. It discovered relevant areas of resource use and was able to provide improvement options. Given the basic connection between biotic and abiotic material inputs and cost, the MIPS approach appears useful for developing business strategies to achieve more sustainable resource use.

The combination of MIPS with the HSA allows for inclusion of a broader range of data from scientific literature. Aspects for which specific numerical data was not available can be considered in a qualitative way; this also applies to aspects that are difficult to express numerically with the current state of science, such as impacts on biodiversity (Curran et al., 2011). The inclusion of broader scientific literature on similar product value chains can also serve as a cross-check for the MIPS analysis, which is primarily based on company-internal data and precalculated general MI-factors. The fact that similar results are attained through MIPS and HSA provides some measure of cross-verification. The results of both MIPS and HSA are easy to understand and effectively highlight the areas where improvement efforts should be prioritised.

The work presented in this paper focusses on measuring and improving the environmental sustainability of this coffee product. However, within the broader context of sustainability, the social and economic aspects are also relevant. For example, like many other products produced in developing countries, coffee has been associated with low incomes and poor working conditions for farmers, as well as an unequitable distribution of value added along the supply chain (see e.g. Macdonald, 2007; Stamm et al., 2002; Oxfam International, 2003). Devisscher et al. (2008) have shown that the integration of product-service systems can be a successful tool for a holistic approach to sustainability in the case of coffee production. To specifically assess social sustainability issues, the Wuppertal Institute developed Social Hot Spot Analysis. This method follows the same approach as the environmental HSA presented in this paper, but focusses on social aspects including working conditions, wages, human rights, health and safety, and such (Bienge et al, 2010). While beyond the scope of this study, social HSA can be coupled with environmental HSA or MIPS to allow the integrated assessment of environmental and social hot spots along product life cycles.

5 Conclusions

The study shows that the combination of the two methodologies for evaluating a product's life cycle is useful. As a qualitative to semi-quantitative approach including both input and output aspects, the environmental Hot Spot Analysis (HSA) is a useful addition to the Material Input Per unit of Service (MIPS) analysis in order to provide a broader, yet still comprehensive analysis of life-cycle-wide environmental impacts. MIPS provides detailed resource use values that can serve as a basis for quantifying improvement options while the HSA can deliver meaningful information on issues to focus on where specific and comprehensive numerical data of the company's value-chain is not available. At the same time, the HSA can benefit from the detailed quantitative results of the MIPS analysis.

In the case study presented, this mixed-method approach was applied for the first time to a coffee value-chain of Mars Incorporated. For the company, the approach of combining MIPS and HSA has proven a practical, easy-to-apply way of both finding out value-chain-wide resource consumption and environmental impacts, and identifying options to improve resource efficiency. While the HSA identifies specific improvement options documented in scientific literature, the quantitative scenario assessment with MIPS provides resource efficiency potentials and improvement options in the actual company-specific case. In addition, results of this mixed-method approach are easy to understand by non-specialist audiences, which facilitates their communication and implementation within a company.

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Disclaimer

The opinions expressed in this paper by the authors are the personal opinions of the authors alone and do not necessarily represent the views of the organisations they work for.

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Tables

Table 1: Overview of the methodological steps of the mixed method approach (based on Ritthoff et al. 2002 and Wallbaum and Kummer 2006, adopted).

Assessment elements	Methodological steps of MIPS	Methodological steps of HSA
Scope definition	1. Defining system boundaries, scope and service unit (life cycle phases, resource categories, service unit)	1. Defining system boundaries and scope (incl. life cycle phases, categories, product unit)
Data gathering and Inventory	2. Data gathering	2. Data gathering
	3. Calculating Material Input	3. Category significance assessment
	4. From Material Input to MIPS	4. Life cycle phase significance weighting
Interpretation of results	5. Interpretation and evaluation of results	5. Identification of Hot Spots
		6. Stakeholder verification (optional)

Table 2: Environmental categories to be assessed in MIPS and Hot Spot Analysis.

Resource categories of MIPS	Environmental categories of the HSA
Abiotic raw-materials: non-renewable resources (e.g. minerals, fossil energy carriers), unused extraction (e.g. overburden, soil excavation)	**Raw-materials (abiotic and biotic resources):** All materials used in the phase, non-renewable and renewable (e.g. agrochemicals, all input materials and process chemicals where relevant)
Biotic raw-materials: renewable resources, plant and animal biomass	
Air: Air consumed/chemically transformed in combustion and other processes	**Energy:** Energy used in the phase in terms of electricity and fuel
Water: All water consumed, e.g. processing and cooling water	**Water:** The amount of water used (for example in cultivation, mining, processing, use, cleaning etc.)
Earth movement in agriculture and forestry: The consumption (erosion) and alteration of earth	**Land use:** The amount of land used. Includes soil degradation
	Impacts on Biodiversity: Impacts or potential impacts on biodiversity resulting from activities in the phase
	Waste: All solid wastes in the different life cycle phases
	Emissions to air (incl. GHG emissions): Pollutants & GHG released to air, resulting from electricity usage, transport and other sources
	Emissions to water: E.g. chemicals and nutrients used for crop growing, pollutants and chemicals emitted during processing and landfilling

Source: adapted from Ritthoff et al. 2002, Wallbaum and Kummer 2006

Table 3: Results of the Hot Spot Analysis for the agriculture phase.

Category	Key inputs and outputs	Score*
Raw-materials (abiotic/biotic)	• Agrochemicals (fertilizers, pesticides) and organic fertilizers • Fossil fuels and wood used for energy generation	**3**
Energy	• Energy-intensive processes: production of artificial fertilizers, drying and processing of coffee beans, powering agricultural machinery and transportation vehicles • Energy consumption reduced if coffee beans are sun dried (common for small scale growers) or if solar powered drying equipment is used.	**2**
Water	• High water consumption: wet processing of cherries, production of inorganic fertilizers, coffee plants; Columbia no water stressed region • Production of large amounts of wastewater during wet processing	**2**
Land use	• Soil degradation and erosion increased in monocultures: maximized on sloping land and following plantation establishment; largest area in entire life cycle • Better soil fertility and reduced erosion possible in shaded agroforestry	**3**
Impacts on Biodiversity	• Colombia: "Mega-diverse country", high biodiversity: adverse effects esp. when natural forests are cleared to establish coffee plantations and from emissions and effluents from coffee production and processing • Traditional shaded coffee plantations can be high in biodiversity, but not comparable to a native forest; large differences also in these systems: from organic "rustic" plantations (high biodiversity) to low density monocultural specific shade trees (low biodiversity)	**3**
Waste	• Organic residues/ fruit pulp produced during coffee processing; can be used as fertilizer, fed to biogas digesters or remain an unused waste	**1**
Emissions: air	• Nitrogen fertilizer use (inorganic and organic): emissions of GHG and pollutants from soil to air (N_2O, NO, NH_3); Effects: air acidification, climate change • GHGs and pollutants from fertilizer manufacture, electricity generation, burning of diesel and wood, composting/incineration of pulp/husks	**3**
Emissions: water	• Nitrogen fertilizer use: risk of nitrate/nitrite contamination. Nitrogen leaching much lower under shaded coffee plantations compared to unshaded plantations • Excessive use of fertilizers: eutrophication of adjacent water bodies • Runoff from coffee plantations can carry pesticides to water bodies • Wastewater from coffee processing polluted with organic matter and other compounds (e.g. pesticides): if not treated, serious environmental risk to water bodies and health risk to humans	**2**

* Significance scoring: 1 = low relevance; 2 = medium relevance; 3 = high relevance; 0 = no data; Results are based on: Armbrecht et al., 2005; Ataroff et al., 1997; Beer et al., 1998; Chapagain et al., 2007; Coltro et al., 2006; Conservation International, 2007; EDE (Consulting for Coffee, International Coffee Organization), 2001; Giannetti et al., 2011; GTZ, 2002; Haddis et al., 2008; Humbert et al., 2009; Kondo et al., 2010; Lettenmeier, 2010; Liedtke et al., 2010; Mars drinks/WSP, 2009; Mesoamerican Development Institute, 2011; Noponen et al., 2012; Perfecto et al., 2005; Perfecto et al., 2007; Rappole et al., 2003; Salomone, 2003; Van der Vossen, 2005; Viere et al., 2011; WWF, 2010

Table 4: Distribution of resource consumption and environmental impacts over the life cycle phases.

Life cycle phase	Category	MIPS*	Mars LCA**	Secondary sources (LCAs)***
Agriculture	Energy		12%	10% (H)
	Water	18.5% (incl. transport)	15%	15% (H)
	Air emissions	33.4% (air consumption, incl. transports)	23% CO_2 eq.	10% of GHG (H)
Processing	Energy		Processing: 9%	
	Water	Manufacture & transports: 4% abiotic	Processing: 6%	
	Air emissions	Processing & transports: 14% (air consumption)	Processing: 3% CO_2 eq.	
Packaging	Energy		7%	4 – 30% (B; H)
	Water	21.3%	27%	15% (H)
	Air emissions	13.6% (air consumption)	23% CO_2 eq.	25% of GHG (H)
Use	Energy		75%	Largest fraction (B) 50% (H)
	Water	55.7% (incl. transports, machine, disposable plastic cups)	49% (mainly cooling water)	60% (H)
	Air emissions	38.3% (air consumption, incl. transports, machine, disposable plastic cups)	29% CO_2 eq.	12-40% of GHG (B) 30% of GHG (H)
End-of-Life	Energy		insignificant	
	Water	0.4%	insignificant	
	Air emissions	0.6% (air consumption)	14%	

* See sub-section 3.2; ** Mars drinks/WSP, 2009 ***B = Büsser et al., 2009; H = Humbert et al., 2009; GHG = Greenhouse gases

Table 5: Summary of Hot Spot results, steps 3-5.

Life cycle phase	Category	Step 3: Category significance (a)	Step 4: Life cycle phase significance (b)	Step 5: Hot Spot identification (c=a*b)
Agriculture	Raw-materials (abiotic & biotic)	**3**	**3**	**9**
	Energy	**2**		**6**
	Water	**2**		**6**
	Land use	**3**		**9**
	Impacts on Biodiversity	**3**		**9**
	Waste	**1**		**3**
	Air emissions	**3**		**9**
	Water emissions	**2**		**6**
Processing	Raw-materials (abiotic & biotic)	**2**	**1**	**2**
	Energy	**2**		**2**
	Water	**1**		**1**
	Land use	**1**		**1**
	Impacts on Biodiversity	**1**		**1**
	Waste	**0**		**0**
	Air emissions	**2**		**2**
	Water emissions	**1**		**1**
Packaging	Raw-materials (abiotic & biotic)	**3**	**2**	**6**
	Energy	**2**		**4**
	Water	**3**		**6**
	Land use	**2**		**4**
	Impacts on Biodiversity	**2**		**4**
	Waste	**2**		**4**
	Air emissions	**3**		**6**
	Water emissions	**1**		**2**
Use	Raw-materials (abiotic & biotic)	**3**	**3**	**9**
	Energy	**3**		**9**
	Water	**2**		**6**
	Land use	**1**		**3**
	Impacts on Biodiversity	**1**		**3**
	Waste	**2**		**6**
	Air emissions	**3**		**9**
	Water emissions	1		3
End-of-Life	Raw-materials (abiotic & biotic)	2	1	2
	Energy	1		1
	Water	1		1
	Land use	3		3
	Impacts on Biodiversity	0		0
	Waste	2		2
	Air emissions	3		3
	Water emissions	2		2

Supplementary Material

Part 1: Category significance assessment tables for the Hot Spot Analysis

Table 6: HSA Results for the processing/ manufacturing phase

Category	**Key inputs and outputs**	**Score***
Raw-materials (abiotic/biotic)	• Coffee beans • Fossil energy carriers for electricity generation	**2**
Energy	• Roasting is an energy efficient process; grinding and packaging consume more, but still only moderate amounts of energy • Production of instant coffee more energy-intensive	**2**
Water	• Low water consumption: water use mainly in electricity generation	**1**
Land use	• Industrial estates contribute to sealed areas and loss of soils; area is relatively small	**1**
Impacts on Biodiversity	• Destruction and fragmentation of habitats by sealed areas, change of species composition, limited gene flow; but area is relatively small	**1**
Waste	• No data	**0**
Emissions: air	• CO_2 emissions from transport and manufacture	**2**
Emissions: water	• Insignificant emissions to water	**1**

* Significance scoring: 1 = low relevance; 2 = medium relevance; 3 = high relevance; 0 = no data; Results are based on: EUA, 2002; Humbert et al., 2009; Lawton et al., 2010; Lettenmeier et al., 2010; Liedtke et al., 2010; Mars drinks/WSP, 2009; Salomone, 2003; Umweltbundesamt Österreich, 2011.

Table 7: HSA Results for the packaging phase

Category	Key inputs and outputs	Score*
Raw-materials (abiotic/biotic)	• Fossil energy carriers for electricity generation and transports • Plastic and aluminium for primary packaging, incl. pre-materials: bauxite, lime, caustic soda, anodes, process chemicals, oil, crude oil, natural gas • Wood and cardboard for secondary and tertiary packaging	**3**
Energy	• Production of packaging (including raw-material extraction and materials processing) is energy-intensive, esp. Aluminium foil production	**2**
Water	• Production of packaging (including raw-material extraction and materials processing) consumes significant amounts of water	**3**
Land use	• Open cast mining for bauxite: results in soil erosion and degradation of land • Forest areas for paper and cardboard production • Sealed areas of industrial estates: irreversible loss of soils; area relatively small in relation to life cycle land use	**2**
Impacts on Biodiversity	• Bauxite mining in tropical areas, incl. rainforests: disturbance/ destruction of areas of high biodiversity value • Forests for paper and cardboard production: biodiversity impact can be high • Sealed areas (factory infrastructure) destroy and dissect habitats. Adverse effects on habitat, species and genetic diversity	**2**
Waste	• Variety of solid wastes produced during aluminium and aluminium foil production; red mud problematic: toxic, alkaline, difficult to dispose of, large landfill areas	**2**
Emissions: air	• Raw-material extraction and production of primary packaging contributes significantly to life cycle GHG emissions, mainly due to burning fossil fuels (energy and electricity). • Further emissions from the production of plastics and aluminium include SO_2, NOx, particulates, perfluorocarbons, fluorides, organics (VOCs), NOx, ethane and small quantities of metals	**3**
Emissions: water	• During the production of plastic, toxic substances and pollutants are emitted to water, such as dissolved organics, organic compounds, suspended solids • Water emissions in this phase are only a small part of total water emissions	**1**

* Significance scoring: 1 = low relevance; 2 = medium relevance; 3 = high relevance; 0 = no data; Results are based on: Arena et al., 2003; Büsser et al., 2009; EAA, 2007; EUA, 2002; Harding et al., 2007; Humbert et al., 2009; Lawton et al., 2010; Leroy, 2009; Lettenmeier, 2010; Mars drinks/WSP, 2009; Momani, 2009; Ross et al., 2003; Salomone, 2003; Schmitz, 2006; Umweltbundesamt Österreich, 2011.

Table 8: HSA Results for the consumption phase

Category	Key inputs and outputs	Score*
Raw-materials (abiotic/biotic)	• Large amount of materials for energy generation (mainly fossil energy carriers); largest part used to generate electricity for water heating; smaller fractions for machine and plastic cup manufacture and transports of coffee and machine • Various materials for machine: plastics/ synthetic materials, steel, aluminium, brass, silicon, wirings (copper), etc.	**3**
Energy	• Largest fraction of life cycle energy consumed in this phase: mainly for water heating to brew coffee and wash cup; large variations in energy use due to implements used (kettle, various types of coffee machines, dishwasher), type of coffee (amount of water and coffee used, milk or not) and consumer behaviour (excess water and coffee, standby times, cup washing) • Energy used for machine manufacture and transports less significant	**3**
Water	• Significant water use in relation to energy generation; also for coffee brewing and cup cleaning or disposable plastic cup production • Water used for machine manufacture is less significant	**2**
Land use	• Mining of metals, fossil energy carriers and other materials (for electricity generation, the production of the machine and cup) are potentially high-impact land uses. • Irreversible loss of soils due to continuous expansion of transport infrastructure, creating more sealed areas • On a per-cup basis, the manufacturing of the coffee machine and ceramic cup as well as the transport infrastructure make only a small contribution to the total land use over the life cycle of one cup of coffee.	**1**
Impacts on Biodiversity	• Mining of metals, fossil energy carriers and other materials: potentially negative impacts on biodiversity • Sealed areas of transport infrastructure destroy and dissect habitats. Roads: barriers to wildlife, fragmentation of habitats. Adverse effects on habitat, species and genetic diversity • On a per-cup basis, the manufacturing of the coffee machine and ceramic cup as well as the transport infrastructure make only a small contribution to the total impacts on biodiversity over the life cycle of one cup of coffee.	**1**
Waste	• Coffee grounds and packaging. The use of 6 g of coffee per portion generates 12 g of coffee waste.	**2**
Emissions: air	• Significant emissions of GHG and other pollutants (SOx, NOx, hydrocarbons) due to energy generation: contribute to air acidification, global warming, ozone depletion, smog formation • Significant emissions also from disposable plastic cup production • Similar emissions from transports, but much smaller amount	**3**
Emissions: water	• Runoff from roads can carry pollutants (fuel oil, de-icing substances etc.) to water bodies • Use of ceramic cups: detergent emissions from washing	**1**

* Significance scoring: 1 = low relevance; 2 = medium relevance; 3 = high relevance; 0 = no data; Results are based on: Büsser et al., 2009; Environment Agency UK, 2010; EUA, 2002; Humbert et al., 2009; Lawton et al., 2010; Lettenmeier, 2010; Liedtke, et al. 2010; Mars drinks/WSP, 2009; Salomone, 2003; Umweltbundesamt Österreich, 2011.

Table 9: HSA Results for the end-of-life phase

Category	Key inputs and outputs	Score*
Raw-materials (abiotic/biotic)	• Material consumption of landfilling of coffee grounds and packaging low; materials for construction of landfills	**2**
Energy	• Energy consumption of landfilling low • Incineration of plastic allows some energy recovery; when landfilled, the energy content of plastic is lost	**1**
Water	• Very low water consumption for landfilling	**1**
Land use	• Landfilling consumes land that cannot be used for other purposes; surroundings also negatively affected	**3**
Impacts on Biodiversity	• No data	**0**
Waste	• Plastic packaging not degradable: persists in environment, accumulating waste • Incineration with energy recovery environmentally preferable, only waste ashes	**2**
Emissions: air	• Landfilling produces GHG emissions: methane, CO_2 • Plastic incineration: CO_2, SOx, HCl, heavy metals	**3**
Emissions: water	• Landfilling can lead to pollution of water bodies	**2**

* Significance scoring: 1 = low relevance; 2 = medium relevance; 3 = high relevance; 0 = no data; Results are based on: Arena et al., 2003; Lettenmeier, 2010; Liedtke et al., 2010; Mars drinks/WSP, 2009; Salomone, 2003.

Supplementary Material

Part 2: Results from the MIPS analysis on Biotic MI, Water, Air and Top-Soil Erosion.

Figure 6: Abiotic MI. One single serving of coffee requires 41 g of abiotic resources, almost entirely from the Agricultural phase.

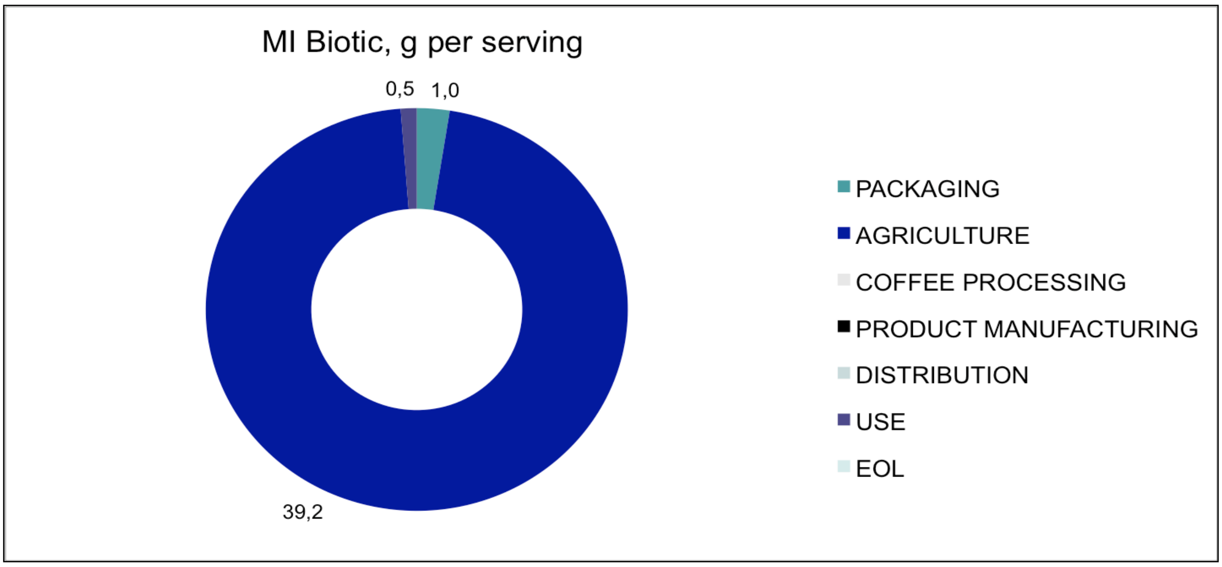

Figure 7: Water input. Producing a single serve requires 3.4 l of water. The three most contributing phases are Packaging, Coffee processing and Use, accounting for 85% of the total water consumption.

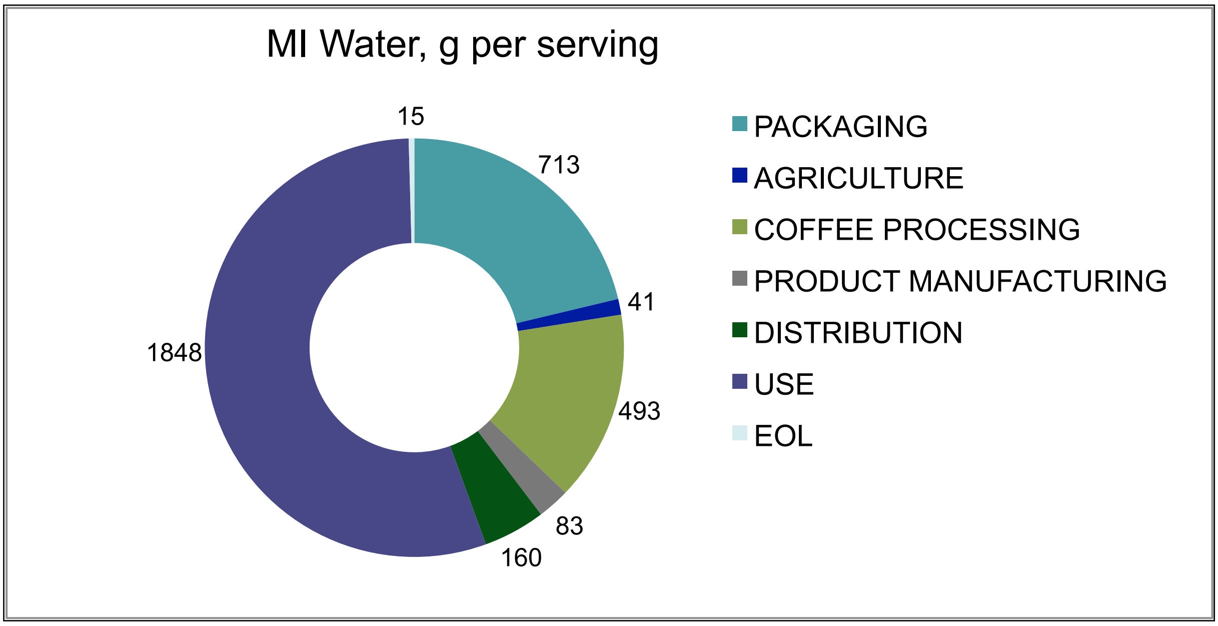

Figure 8: Air Input. Producing a single serve requires 69 g of air. The most relevant phases contributing to this metric are Agriculture and Use, representing altogether 68% of the total air consumption.

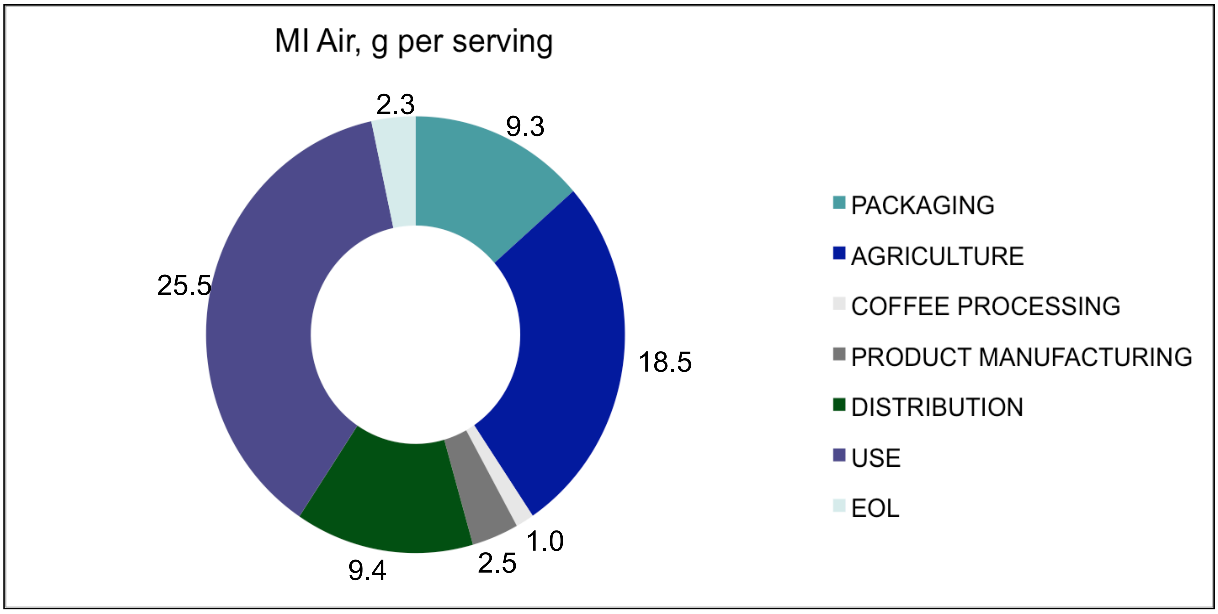

Figure 9: Erosion. Producing a single serve induces 12 g erosion, occurring naturally only in agricultural life cycle phase.