Development of the Product Environmental Footprint (PEF) Category Rules for Synthetic Turf Surfaces

PEF analysis of the PEFCR Representative Product – Landscaping Applications

May 2024

SYNTHETIC TURF COUNCIL EMEA

www.estc.info

Table of contents

Acronyms 1

Definitions 4

Summary 16

1 General 19

2 Goal of the study 19

3 Scope of the study 20

3.1 Representative product 20

3.2 Functional/declared unit and reference flow 21

3.3 System boundary 22

3.4 Environmental Footprint impact categories 24

3.5 Additional information 25

3.6 Assumptions and limitations 25

4 Life cycle inventory analysis 27

4.1 List and description of life cycle stages 27

4.2 Modelling choices 27

4.3 Handling multi-functional processes 30

4.4 Data collection 30

4.5 Data quality requirements and rating 34

5 Impact assessment results 35

5.1 PEF results 35

5.2 Additional information 36

6 Interpreting PEF results 37

6.1 Assessment of the robustness of the PEF study 37

6.2 Identification of most relevant impact categories, life cycle stages and processes 37

6.3 Limitations and relationship of the EF results relative to the defined goal and scope of the PEF study 44

6.4 Conclusions, recommendations, limitations and improvement potentials 44

7 Validation statement 46

8 References 48

ANNEX I – List of EF normalisation and weighting factors 51

ANNEX II – Confidential report 51

ANNEX III – EF compliant dataset 52

ANNEX IV – PEF results per life cycle stage and alternative scenarios 53

Acronyms

AD	activity data
AF	allocation factor
AR	allocation ratio
AU	Australia
B2B	business to business
B2C	business to consumer
BoC	bill of components
BoM	bill of materials
$CaCO_3$	calcium carbonate
CF	characterisation factor
CFF	Circular Footprint Formula
CN	China
CPA	Classification of Products by Activity
DC	distribution centre
DNM	Data Needs Matrix
DQR	Data Quality Rating
EC	European Commission
EF	Environmental Footprint
EFTA	European Free Trade Association
ELT	end-of-life tires
EoL	End of life
ESTC	EMEA Synthetic Turf Council
FU	functional unit
GHG	greenhouse gas
GR	geographical representativeness
GWP	global warming potential
HDPE	high density polyethylene
ILCD	International Reference Life Cycle Data System
ILCD-EL	International Reference Life Cycle Data System – Entry Level

IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCDN	Life Cycle Data Network
LCI	life cycle inventory
LCIA	life cycle impact assessment
LDPE	low density polyethylene
LLDPE	linear low-density polyethylene
m^2a	square metre x year
NDA	non-disclosure agreement
NGO	non-governmental organisation
NH_3	**a**mmonia
NMVOC	non-methane volatile compounds
NO_x	nitrogen oxides
NZ	New Zealand
P	precision
PA	polyamide
PAS	Publicly Available Specification
PE	polyethylene
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PEF-RP	PEF study of the representative product
PP	polypropylene
PU	polyurethane
RAF	Africa
RAS	Asia and the Pacific
RF	reference flow
RNA	North America
RoW	Rest of the World
RP	representative product

RSA	Region South Africa
RU	Russian Federation
SB	system boundary
SD	secondary dataset
SO_x	sulphur oxides
SS	supporting study
STS	synthetic turf system
TeR	technological representativeness
TiR	time representativeness
TS	Technical Secretariat
UK	United Kingdom
UNEP	United Nations Environment Programme
UUID	Universally Unique Identifier
w/o	without

Definitions

Activity data – This term refers to information which is associated with processes while modelling Life Cycle Inventories (LCI). The aggregated LCI results of the process chains that represent the activities of a process are each multiplied by the corresponding activity data[1] and then combined to derive the environmental footprint associated with that process. Examples of activity data include quantity of kilowatt-hours of electricity used, quantity of fuel used, output of a process (e.g. waste), number of hours equipment is operated, distance travelled, floor area of a building, etc. Synonym of non-elementary flow.

Acidification – EF impact category that addresses impacts due to acidifying substances in the environment. Emissions of NO_x, NH_3 and SO_x lead to releases of hydrogen ions (H^+) when the gases are mineralised. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.

Additional environmental information – Environmental information outside the EF impact categories that is calculated and communicated alongside PEF results.

Additional technical information – Non-environmental information that is calculated and communicated alongside PEF results.

Aggregated dataset – Complete or partial life cycle of a product system that next to the elementary flows (and possibly not relevant amounts of waste flows and radioactive wastes) lists in the input/output list exclusively the product(s) of the process as reference flow(s), but no other goods or services. Aggregated datasets are also called "LCI results" datasets. The aggregated dataset may have been aggregated horizontally and/or vertically.

Allocation – An approach to solving multi-functionality problems. It refers to "partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006).

Application specific – It refers to the generic aspect of the specific application in which a material is used. For example, the average recycling rate of PET in bottles.

Attributional – Refers to process-based modelling intended to provide a static representation of average conditions, excluding market-mediated effects.

Average data – Refers to a production-weighted average of specific data.

Background processes – Refers to those processes in the product life cycle for which no direct access to information is possible. For example, most of the upstream life-cycle processes and generally all processes further downstream will be considered part of the background processes.

Base – All elements of construction beneath the synthetic turf sports surfacing system (CEN/TR 17519:2020).

[1] Based on GHG protocol scope 3 definition from the Corporate Accounting and Reporting Standard (World resources institute, 2011).

Benchmark – A standard or point of reference against which any comparison may be made. In the context of PEF, the term 'benchmark' refers to the average environmental performance of the representative product sold in the EU market.

Bill of materials (BoM) – A bill of materials or product structure (sometimes bill of material, BOM or associated list) is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture the product in scope of the PEF study. In some sectors it is equivalent to the bill of components.

Business to Business (B2B) – Describes transactions between businesses, such as between a manufacturer and a wholesaler, or between a wholesaler and a retailer.

Business to Consumers (B2C) – Describes transactions between business and consumers, such as between retailers and consumers. According to (ISO 14025:2006), a consumer is defined as "an individual member of the general public purchasing or using goods, property or services for private purposes".

Characterisation – Calculation of the magnitude of the contribution of each classified input/output to their respective EF impact categories, and aggregation of contributions within each category. This requires a linear multiplication of the inventory data with characterisation factors for each substance and EF impact category of concern. For example, with respect to the EF impact category "climate change", CO_2 is chosen as the reference substance and kg CO_2-equivalents as the reference unit.

Characterisation factor – Factor derived from a characterisation model which is applied to convert an assigned life cycle inventory result to the common unit of the EF impact category indicator (based on ISO 14040:2006).

Classification – Assigning the material/energy inputs and outputs tabulated in the life cycle inventory to EF impact categories according to each substance's potential to contribute to each of the EF impact categories considered.

Climate change – All inputs or outputs that result in greenhouse gas emissions. The consequences include increased average global temperatures and sudden regional climatic changes. Climate change is an impact affecting the environment on a global scale.

Commissioner of the EF study – Organisation (or group of organisations) that finances the EF study in accordance with the PEF method and the relevant PEFCR, if available (definition adapted from ISO 14071:2014, point 3.4).

Company-specific data – It refers to directly measured or collected data from one or multiple facilities (site-specific data) that are representative for the activities of the company. It is synonymous to "primary data". To determine the level of representativeness a sampling procedure may be applied.

Company-specific dataset – It refers to a dataset (disaggregated or aggregated) compiled with company-specific data. In most cases the activity data is company-specific while the underlying sub-processes are datasets derived from background databases.

Comparative Assertion – An environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function (including the benchmark of the product category) (adapted from ISO 14044:2006).

Comparison – A comparison, not including a comparative assertion, (graphic or otherwise) of two or more products based on the results of a PEF study and supporting PEFCRs.

Co-product – Any of two or more products resulting from the same unit process or product system (ISO 14040:2006).

Cradle to Gate – A partial product supply chain, from the extraction of raw materials (cradle) up to the manufacturer's "gate". The distribution, storage, use stage and end of life stages of the supply chain are omitted.

Cradle to Grave – A product's life cycle that includes raw material extraction, processing, distribution, storage, use, and disposal or recycling stages. All relevant inputs and outputs are considered for all of the stages of the life cycle.

Critical review – Process intended to ensure consistency between a PEFCR and the principles and requirements of the PEF method.

Data Quality – Characteristics of data that relate to their ability to satisfy stated requirements (ISO 14040:2006). Data quality covers various aspects, such as technological, geographical, and time-related representativeness, as well as completeness and precision of the inventory data.

Data Quality Rating (DQR) – Semi-quantitative assessment of the quality criteria of a dataset based on Technological representativeness, Geographical representativeness, Time-related representativeness, and Precision. The data quality shall be considered as the quality of the dataset as documented.

Delayed emissions – Emissions that are released over time, e.g. through long use or final disposal stages, versus a single emission at time t.

Direct elementary flows (also named elementary flows) – All output emissions and input resource use that arise directly in the context of a process. Examples are emissions from a chemical process, or fugitive emissions from a boiler directly onsite.

Direct land use change (dLUC) – The transformation from one land use type into another, which takes place in a unique land area and does not lead to a change in another system.

Directly attributable – Refers to a process, activity or impact occurring within the defined system boundary.

Disaggregation – The process that breaks down an aggregated dataset into smaller unit process datasets (horizontal or vertical). The disaggregation may help making data more specific. The process of disaggregation should never compromise or threat to compromise the quality and consistency of the original aggregated dataset

Downstream – Occurring along a product supply chain after the point of referral.

Ecotoxicity, freshwater – Environmental footprint impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem.

EF communication vehicles – It includes all the possible ways that may be used to communicate the results of the EF study to the stakeholders (e.g. labels, environmental product declarations, green claims, websites, infographics, etc.).

EF compliant dataset – Dataset developed in compliance with the EF requirements provided at http://eplca.jrc.ec.europa.eu/LCDN/developer.xhtml.

Electricity tracking[2] – Electricity tracking is the process of assigning electricity generation attributes to electricity consumption.

Elementary flows – In the life cycle inventory, elementary flows include "material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation" (ISO 14040, 3.12). Elementary flows include, for example, resources taken from nature or emissions into air, water, soil that are directly linked to the characterisation factors of the EF impact categories.

Environmental aspect – Element of an organisation's activities or products or services that interacts or can interact with the environment (ISO 14001:2015).

Environmental Footprint (EF) Impact Assessment – Phase of the PEF analysis aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (based on ISO 14044:2006). The impact assessment methods provide impact characterization factors for elementary flows in order to aggregate the impact to obtain a limited number of midpoint indicators.

Environmental Footprint (EF) Impact Assessment method – Protocol for quantitative translation of life cycle inventory data into contributions to an environmental impact of concern.

Environmental Footprint (EF) Impact Category – Class of resource use or environmental impact to which the life cycle inventory data are related.

Environmental Footprint (EF) impact category indicator – Quantifiable representation of an EF impact category (based on ISO 14040:2006).

Environmental impact – Any change to the environment, whether adverse or beneficial, that wholly or partially results from an organisation's activities, products or services (EMAS regulation).

Environmental mechanism – System of physical, chemical and biological processes for a given EF impact category linking the life cycle inventory results to EF category indicators (based on ISO 14040:2006).

Eutrophication – Nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilised farmland accelerate the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen resulting in oxygen deficiency and, in some cases, fish death. Eutrophication translates the quantity of substances emitted into a common measure expressed as the oxygen required for the degradation of dead biomass. Three EF

[2] https://ec.europa.eu/energy/intelligent/projects/en/projects/e-track-ii

impact categories are used to assess the impacts due to eutrophication: Eutrophication, terrestrial; Eutrophication, freshwater; Eutrophication, marine.

External communication – Communication to any interested party other than the commissioner or the practitioner of the study.

Extrapolated data – Refers to data from a given process that is used to represent a similar process for which data is not available, on the assumption that it is reasonably representative.

Filled synthetic turf – Synthetic turf surface whose pile is either totally filled or partly filled with an unbound particulate material, typically sand, rubber or sand and rubber mixes (EN 15330-1:2013).

Flow diagram – Schematic representation of the flows occurring during one or more process stages within the life cycle of the product being assessed.

Foreground elementary flows - Direct elementary flows (emissions and resources) for which access to primary data (or company-specific information) is available.

Foreground Processes – Refer to those processes in the product life cycle for which direct access to information is available. For example, the producer's site and other processes operated by the producer or its contractors (e.g. goods transport, head-office services, etc.) belong to the foreground processes.

Functional unit – The functional unit defines the qualitative and quantitative aspects of the function(s) and/or service(s) provided by the product being evaluated. The functional unit definition answers the questions "what?", "how much?", "how well?", and "for how long?".

Gate to gate – A partial product supply chain that includes only the processes carried out on a product within a specific organisation or site.

Gate to grave – A partial product supply chain that includes only the distribution, storage, use, and disposal or recycling stages.

Global warming potential – Capacity of a greenhouse gas to influence radiative forcing, expressed in terms of a reference substance (for example, CO2-equivalent units) and specified time horizon **(**e.g. GWP 20, GWP 100, GWP 500, for 20, 100, and 500 years respectively)**.** It relates to the capacity to influence changes in the global average surface-air temperature and subsequent change in various climate parameters and their effects, such as storm frequency and intensity, rainfall intensity and frequency of flooding, etc.

Horizontal averaging – It is the action of aggregating multiple unit process datasets or aggregated process datasets in which each provides the same reference flow in order to create a new process dataset (UN Environment 2011).

Human toxicity - cancer – EF impact category that accounts for adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to cancer.

Human toxicity - non cancer – EF impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation.

Independent external expert – Competent person, not employed in a full-time or part-time role by the commissioner of the EF study or the user of the EF method, and not involved in defining the scope or conducting the EF study (adapted from ISO 14071:2014, point 3.2).

Indirect land use change (iLUC) – It occurs when a demand for a certain land use leads to changes, outside the system boundary, i.e. in other land use types. These indirect effects may be mainly assessed by means of economic modelling of the demand for land or by modelling the relocation of activities on a global scale.

Infill – Particulate materials used to infill the synthetic turf pile to provide support and aid the provision of the required performance characteristics (EN15330-1:2013).

Input flows – Product, material or energy flow that enters a unit process. Products and materials include raw materials, intermediate products and co-products (ISO 14040:2006).

Intermediate product – Output form a unit process that is input to other unit processes that require further transformation within the system (ISO 14040:2006). An intermediate product is a product that requires further processing before it is saleable to the final consumer.

Ionising radiation, human health – EF impact category that accounts for the adverse health effects on human health caused by radioactive releases.

Land use – EF impact category related to use (occupation) and conversion (transformation) of land area by activities such as agriculture, forestry, roads, housing, mining, etc. Land occupation considers the effects of the land use, the amount of area involved and the duration of its occupation (changes in quality multiplied by area and duration). Land transformation considers the extent of changes in land properties and the area affected (changes in quality multiplied by the area).

Lead verifier – Verifier taking part in a verification team with additional responsibilities compared to the other verifiers in the team.

Life cycle – Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal (ISO 14040:2006).

Life cycle approach – Takes into consideration the spectrum of resource flows and environmental interventions associated with a product from a supply-chain perspective, including all stages from raw material acquisition through processing, distribution, use, and end of life processes, and all relevant related environmental impacts (instead of focusing on a single issue).

Life cycle Assessment (LCA) – Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040:2006).

Life cycle impact assessment (LCIA) – Phase of life cycle assessment that aims at understanding and evaluating the magnitude and significance of the potential environmental impacts for a system throughout the life cycle (ISO 14040:2006). The LCIA methods used provide impact characterisation factors for elementary flows to in order to aggregate the impact to obtain a limited number of midpoint and/or damage indicators.

Life cycle inventory (LCI) – The combined set of exchanges of elementary, waste and product flows in a LCI dataset.

Life cycle inventory (LCI) dataset – A document or file with life cycle information of a specified product or other reference (e.g., site, process), covering descriptive metadata and quantitative life cycle inventory. A LCI dataset could be a unit process dataset, partially aggregated or an aggregated dataset.

Material-specific – It refers to a generic aspect of a material. For example, the recycling rate of PET.

Multi-functionality – If a process or facility provides more than one function, i.e. it delivers several goods and/or services ("co-products"), then it is "multifunctional". In these situations, all inputs and emissions linked to the process will be partitioned between the product of interest and the other co-products according to clearly stated procedures.

Non-elementary (or complex) flows – In the life cycle inventory, non-elementary flows include all the inputs (e.g. electricity, materials, transport processes) and outputs (e.g. waste, by-products) in a system that need further modelling efforts to be transformed into elementary flows. Synonym of activity data.

Non-filled synthetic turf – Synthetic turf surface that does not contain any form of unbound particulate fill within the pile of the carpet (EN15330-1:20130).

Normalisation – After the characterisation step, normalisation is the step in which the life cycle impact assessment results are multiplied by normalisation factors that represent the overall inventory of a reference unit (e.g. a whole country or an average citizen). Normalised life cycle impact assessment results express the relative shares of the impacts of the analysed system in terms of the total contributions to each impact category per reference unit. When displaying the normalised life cycle impact assessment results of the different impact topics next to each other, it becomes evident which impact categories are affected most and least by the analysed system. Normalised life cycle impact assessment results reflect only the contribution of the analysed system to the total impact potential, not the severity/relevance of the respective total impact. Normalised results are dimensionless, but not additive.

Output flows – Product, material or energy flow that leaves a unit process. Products and materials include raw materials, intermediate products, co-products and releases (ISO 14040:2006).

Ozone depletion – EF impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example long-lived chlorine and bromine containing gases (e.g. CFCs, HCFCs, Halons).

Partially disaggregated dataset – A dataset with a LCI that contains elementary flows and activity data, and that only in combination with its complementing underlying datasets yield a complete aggregated LCI data set.

Partially disaggregated dataset at level-1 – A partially disaggregated dataset at level-1 contains elementary flows and activity data of one level down in the supply chain, while all complementing underlying datasets are in their aggregated form.

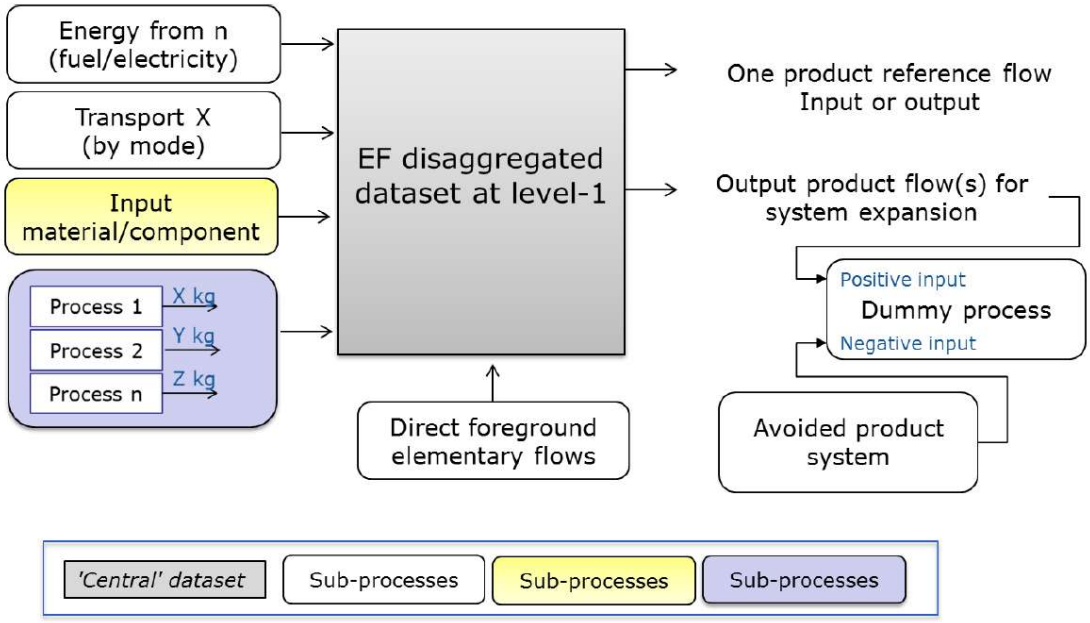


Figure 1: Example of a dataset partially disaggregated at level-1

Particulate matter – EF impact category that accounts for the adverse health effects on human health caused by emissions of Particulate Matter (PM) and its precursors (NO_x, SO_x, NH_3).

PEFCR supporting study – PEF study based on a draft PEFCR. It is used to confirm the decisions taken in the draft PEFCR before the final PEFCR is released.

PEF profile – The quantified results of a PEF study. It includes the quantification of the impacts for the various impact categories and the additional environmental information considered necessary to report.

PEF report – Document that summarises the results of the PEF study.

PEF study of the representative product (PEF-RP) – PEF study carried out on the representative product(s) and intended to identify the most relevant life cycle stages, processes, elementary flows, impact categories and any other major requirements needed for the definition of the benchmark for the product category/ sub-categories in scope of the PEFCR.

PEF study – Term used to identify the totality of actions needed to calculate the PEF results. It includes the modelling, the data collection, and the analysis of the results. It excludes the PEF report and the verification of the PEF study and report.

Photochemical ozone formation – EF impact category that accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of volatile organic compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and manmade materials through reaction with organic materials.

Population – Any finite or infinite aggregation of individuals, not necessarily animate, subject to a statistical study.

Primary data[3] – This term refers to data from specific processes within the supply chain of the user of the PEF method or user of the PEFCR. Such data may take the form of activity data, or foreground elementary flows (life cycle inventory). Primary data are site-specific, company-specific (if multiple sites for the same product) or supply chain specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, material/product balances, stoichiometry, or other methods for obtaining data from specific processes in the value chain of the user of the PEF method or user of the PEFCR. In this method, primary data is synonym of "company-specific data" or "supply-chain specific data".

Product – Any goods or services (ISO 14040:2006).

Product category – Group of products (or services) that can fulfil equivalent functions (ISO 14025:2006).

Product Environmental Footprint Category Rules (PEFCRs) – Product category specific, life cycle-based rules that complement general methodological guidance for PEF studies by providing further specification at the level of a specific product category. PEFCRs help to shift the focus of the PEF study towards those aspects and parameters that matter the most, and hence contribute to increased relevance, reproducibility and consistency of the results by reducing costs versus a study based on the comprehensive requirements of the PEF method. Only the PEFCRs listed on the European Commission website (http://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm) are recognised as in line with this method.

Product flow – Products entering from or leaving to another product system (ISO 14040:2006).

Product system – Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product (ISO 14040:2006).

Raw material – Primary or secondary material that is used to produce a product (ISO 14040:2006).

Reference flow – Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit (based on ISO 14040:2006).

Refurbishment – It is the process of restoring components to a functional and/ or satisfactory state to the original specification (providing the same function), using methods such as resurfacing, repainting, etc. Refurbished products may have been tested and verified to function properly.

Releases – Emissions to air and discharges to water and soil (ISO 14040:2006).

Representative product (model) – The RP may be a real or a virtual (non-existing) product. The virtual product should be calculated based on average European market sales-weighted characteristics of all existing technologies/materials covered by the product category or sub-category. Other weighting sets may be used, if justified, for example weighted average based on mass (ton of material) or weighted average based on product units (pieces).

[3] Based on GHG protocol scope 3 definition from the Corporate Accounting and Reporting Standard (World resources institute, 2011).

Representative sample – A representative sample with respect to one or more variables is a sample in which the distribution of these variables is exactly the same (or similar) as in the population from which the sample is a subset.

Repurpose – A discarded material or product is used in its original form, but for a different function than when it was new. The discarded material or product may be processed, typically by cleaning, repairing or otherwise refurbishing; inspection and/or testing to confirm that it is suitable for continued use. Example: A portion of the discarded turf is recovered from a synthetic turf field during the deconstruction phase. It is cleaned, repaired and used in a commercial or residential landscaping application, batting cage, or soil amendment. (Synthetic Turf Council, 2017)

Resource use, fossil – EF impact category that addresses the use of non-renewable fossil natural resources (e.g. natural gas, coal, oil).

Resource use, minerals and metals – EF impact category that addresses the use of non-renewable abiotic natural resources (minerals and metals).

Sample – A sample is a subset containing the characteristics of a larger population. Samples are used in statistical testing when population sizes are too large for the test to include all possible members or observations. A sample should represent the whole population and not reflect bias toward a specific attribute.

Secondary data[4] – It refers to data not from a specific process within the supply-chain of the company performing a PEF study. This refers to data that is not directly collected, measured, or estimated by the company, but sourced from a third party LCI database or other sources. Secondary data includes industry average data (e.g., from published production data, government statistics, and industry associations), literature studies, engineering studies and patents, and may also be based on financial data, and contain proxy data, and other generic data. Primary data that go through a horizontal aggregation step are considered as secondary data.

Sensitivity analysis – Systematic procedures for estimating the effects of the choices made regarding methods and data on the results of a PEF study (based on ISO 14040: 2006).

Shockpad – Elastic material placed beneath a synthetic turf sports surface that is designed to aid the provision of the performance properties of the sports surfacing system. Shockpads are also known as elastic layers (CEN/TR 175190).

Site-specific data – It refers to directly measured or collected data from one facility (production site). It is synonymous to "primary data".

Specific data – Refers to directly measured or collected data representative of activities at a specific facility or set of facilities. Synonymous with "primary data."

Stabilising infill – Particulate materials used to infill the lower portion of the synthetic turf surface to provide support to the carpet pile and ballast to hold the carpet in place and help prevent dimensional movement" (CEN/TR 17519).

[4] Based on GHG protocol scope 3 definition from the Corporate Accounting and Reporting Standard (World resources institute, 2011)

Stitch rate – Number of tufts per square meter, which is a function of the number of stitches per linear length multiplied by the spacing (gauge) of the tufting needles (CEN/TR 17519).

Subdivision – Subdivision refers to disaggregating multifunctional processes or facilities to isolate the input flows directly associated with each process or facility output. The process is investigated to see whether it may be subdivided. Where subdivision is possible, inventory data should be collected only for those unit processes directly attributable to the products/services of concern.

Sub-processes – Those processes used to represent the activities of the level 1 processes (=building blocks). Sub-processes may be presented in their (partially) aggregated form (see Figure 1).

Supply chain – It refers to all of the upstream and downstream activities associated with the operations of the user of the PEF method, including the use of sold products by consumers and the end-of-life treatment of sold products after consumer use.

Supply chain specific – It refers to a specific aspect of the specific supply chain of a company. For example the recycled content value of an aluminium may produced by a specific company.

Synthetic turf carpet – Sports surface comprised of a carpet of tufted, knitted or woven construction whose pile is designed to replicate the appearance of natural grass (EN15330-1:2013).

Synthetic turf surfacing system – All components of the surface that influence its sports performance or bio-mechanical characteristics including the synthetic turf carpet, infill, and shockpad, together with any supporting layers designed to contribute to the performance of the surface (EN15330-1:2013).

System boundary – Definition of aspects included or excluded from the study. For example, for a "cradle-to-grave" EF analysis, the system boundary includes all activities from the extraction of raw materials through the processing, distribution, storage, use, and disposal or recycling stages.

System boundary diagram – Graphic representation of the system boundary defined for the PEF study.

Uncertainty analysis – Procedure to assess the uncertainty in the results of a PEF study due to data variability and choice-related uncertainty.

Unit process – Smallest element considered in the LCI for which input and output data are quantified (based on ISO 14040:2006).

Unit process, black box – Process chain or plant level unit process. This covers horizontally averaged unit processes across different sites. Covers also those multi-functional unit processes, where the different co-products undergo different processing steps within the black box, hence causing allocation problems for this dataset.

Unit process, single operation – Unit operation type unit process that cannot be further subdivided. Covers multi-functional processes of unit operation type.

Upstream – Occurring along the supply chain of purchased goods/ services prior to entering the system boundary.

User of the PEFCR – A stakeholder producing a PEF study based on a PEFCR.

User of the PEF method – A stakeholder producing a PEF study based on the PEF method.

User of the PEF results – A stakeholder using the PEF results for any internal or external purpose.

Utilisation ratio – Ratio of actual load to the full load or capacity (e.g. mass or volume) that a vehicle carries per trip.

Verification – Conformity assessment process carried out by an environmental footprint verifier to demonstrate whether the PEF study has been carried out in compliance with the most updated version of the PEF method adopted by the Commission.

Validation – Confirmation by the environmental footprint verifier, that the information and data included in the PEF study, PEF report and the communication vehicles are reliable, credible and correct.

Validation statement – Conclusive document aggregating the conclusions from the verifiers or the verification team regarding the EF study. This document is mandatory and shall carry the electronic or handwritten signature of the verifier or, in case of a verification panel, of the lead verifier.

Verification report – Documentation of the verification process and findings, including detailed comments from the verifier(s), as well as the corresponding responses. This document is mandatory, but it may be confidential. The document shall carry the electronic or handwritten signature of the verifier, or in case of a verification panel, of the lead verifier.

Verification team – Team of verifiers that will perform the verification of the EF study, of the EF report and the EF communication vehicles.

Verifier – Independent external expert performing a verification of the EF study and eventually taking part in a verification team.

Vertical aggregation – Technical- or engineering-based aggregation refers to vertical aggregation of unit processes that are directly linked within a single facility or process

train. Vertical aggregation involves combining unit process datasets (or aggregated process datasets) together linked by a flow (UN Environment, 2011).

Waste – Substances or objects which the holder intends or is required to dispose of (ISO 14040:2006).

Water use – It represents the relative available water remaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met. It assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived (see also http://www.wulca-waterlca.org/aware.html).

Weighting – Weighting is a step that supports the interpretation and communication of the results of the analysis. PEF results are multiplied by a set of weighting factors, which reflect the perceived relative importance of the impact categories considered. Weighted EF results may be directly compared across impact categories, and also summed across impact categories to obtain a single overall score.

Summary

This report documents the PEF-RP study for **a representative product (RP) of synthetic turf systems for landscaping applications**. Only a limited number of companies in Europe produce synthetic turf for landscaping applications. For this reason, the TS has decided to model a virtual representative product based on the arithmetic average of the four most common sold landscaping synthetic turf systems of one Technical Secretariat member.

The **goal of the study** is to assess the environmental footprint of a representative product of synthetic turf for landscaping applications, identify the most relevant impact categories, life cycle stages, processes and elementary flows, and to develop a benchmark for synthetic turf for landscaping applications products.

The **intended application** is to provide guidance to the synthetic turf Technical Secretariat about the environmental performance of the representative product of synthetic turf for landscaping applications and set the starting point for the PEFCR development of the synthetic turf products.

The **functional unit** is 1 m^2 of synthetic turf system installed, used for 8 years, assuming reasonable usage and adequate maintenance (i.e. 8 m^2a). The system boundary includes the following life cycle stages:

- LCS 1.1 Yarn production
- LCS 1.2 Primary backing production
- LCS 1.3 Secondary backing production
- LCS 2.1 Carpet manufacturing
- LCS 3.1 Storage and distribution of carpet
- LCS 4.1 Installation
- LCS 4.2 Operation
- LCS 5.1 End of life of carpet

The characterised **PEF results** of the representative synthetic turf system used for landscaping applications are reported in Table 1 and normalised and weighted results in Table 2.

Table 1: Characterized results of life cycle of 8 m^2a of synthetic turf system

Impact category	Unit	Complete life cycle	Complete life cycle excluding use stage
Acidification	mol H^+ eq	7.78E-02	7.83E-02
Climate change	kg CO_2 eq	1.23E+01	1.20E+01
Ecotoxicity, freshwater	CTU_e	1.46E+02	1.47E+02
Particulate matter	disease inc.	1.50E-06	1.51E-06
Eutrophication, marine	kg N eq	1.98E-02	1.99E-02
Eutrophication, freshwater	kg P eq	3.04E-04	3.01E-04
Eutrophication, terrestrial	mol N eq	2.10E-01	2.11E-01
Human toxicity, cancer	CTU_h	8.29E-09	8.31E-09
Human toxicity, non-cancer	CTU_h	7.50E-08	7.49E-08
Ionising radiation	kBq ^{235}U eq	4.96E-01	5.44E-01
Land use	Pt	2.14E+01	2.15E+01
Ozone depletion	kg CFC-11 eq	1.62E-06	1.62E-06
Photochemical ozone formation	kg NMVOC eq	5.60E-02	5.63E-02
Resource use, fossils	MJ	2.06E+02	2.10E+02
Resource use, minerals and metals	kg Sb eq	6.36E-05	6.36E-05
Water use	m^3 depriv.	8.81E-01	8.53E-01

Table 2: Normalized and weighted results in absolute values of life cycle of 8 m^2a of synthetic turf system

Impact category	Complete life cycle Normalized results [person eq.]	Complete life cycle Weighted results	Complete life cycle excluding use stage Normalized results [person eq.]	Complete life cycle excluding use stage Weighted results
Acidification	1.40E-03	8.68E-05	1.41E-03	8.74E-05
Climate change	1.62E-03	3.42E-04	1.59E-03	3.35E-04
Ecotoxicity, freshwater	2.58E-03	4.95E-05	2.59E-03	4.97E-05
Particulate matter	2.52E-03	2.26E-04	2.53E-03	2.27E-04
Eutrophication, marine	1.01E-03	3.00E-05	1.02E-03	3.02E-05
Eutrophication, freshwater	1.89E-04	5.30E-06	1.87E-04	5.24E-06
Eutrophication, terrestrial	1.19E-03	4.41E-05	1.19E-03	4.43E-05
Human toxicity, cancer	4.80E-04	1.02E-05	4.81E-04	1.03E-05
Human toxicity, non-cancer	5.83E-04	1.07E-05	5.82E-04	1.07E-05
Ionising radiation	1.17E-04	5.88E-06	1.29E-04	6.46E-06
Land use	2.61E-05	2.07E-06	2.63E-05	2.09E-06
Ozone depletion	3.09E-05	1.95E-06	3.09E-05	1.95E-06
Photochemical ozone formation	1.37E-03	6.55E-05	1.38E-03	6.58E-05
Resource use, fossils	3.17E-03	2.64E-04	3.24E-03	2.69E-04
Resource use, minerals and metals	1.00E-03	7.55E-05	1.00E-03	7.55E-05
Water use	7.68E-05	6.54E-06	7.44E-05	6.33E-06
Weighted results as single score		1.23E-03		1.23E-03

The **most relevant impact categories** for the synthetic turf system used in landscaping applications include Climate change (27.9%); Resource use, fossils (21.5%); Particulate matter (18.4%); Acidification (7.1%); and Resource use, minerals and metals (6.2%). Additionally, the TS selected Water use (0.5%) as an impact category of special interest for the sector. Therefore, that category was included in the identification of the most relevant life cycle stages and processes.

Within these impact categories, the **most relevant life cycle stages** are:

- LCS 1.1 Yarn production
- LCS1.2 Primary backing production
- LCS 1.3 Secondary backing production
- LCS 3.1 Storage and distribution of carpet
- LCS 5.1 End of life of carpet

The environmental impacts in most relevant impact categories are primarily driven by the use of plastics in carpet manufacturing and its waste treatment at the end of life. The list **of most relevant processes** includes (in alphabetical order):

- Electricity grid mix 1kV-60kV {CN} > *LCS 2.1 Carpet manufacturing*
- Green pigment {GLO} > *LCS 1.1 Yarn production*
- In-line extrusion of mono-filament yarn {EU+EFTA+UK} | straight yarn | LCI result > *LCS 1.1 Yarn production*
- In-line extrusion of mono-filament yarn {EU+EFTA+UK} | texturized yarn | LCI result > *LCS 1.1 Yarn production*
- Incineration of styrene-butadiene-styrene (SBS) latex {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | SBS latex | LCI result > *LCS 5.1 EOL of carpet*
- Off-line extrusion of mono-filament {EU+EFTA+UK} | texturized yarn | LCI result > *LCS 1.1 Yarn production*
- PE granulates {EU+EFTA+UK} > *LCS 1.1 Yarn production*
- Polyethylene (PE), petrochemical based {GLO} > *LCS 1.1 Yarn production*
- Polypropylene (PP), petrochemical based {GLO} > *LCS 1.1 Yarn production & LCS1.2 Primary backing production*
- PP granulates {EU+EFTA+UK > *LCS 1.1 Yarn production*
- Styrene-butadiene-styrene (SBS) latex, petrochemical based {GLO} > *LCS 1.3 Secondary backing production*
- Transoceanic ship, containers {GLO} > *LCS3.1 S&D of carpet & LCS 1.1 Yarn production*
- Waste incineration of PE {EU+EFTA+UK} > *LCS 5.1 EOL of carpet*
- Waste incineration of PP {EU+EFTA+UK} > *LCS 5.1 EOL of carpet*
- Weaving of primary backing {EU+EFTA+UK} > *LCS 1.2 Primary backing production*

There were no direct elementary flows modelled in the RP model and there were only fully disaggregated datasets, hence there were no **most relevant elementary flows** identified.

As **additional environmental information**, the microplastics leakage to the environment due to fibre wear is calculated to be 0.05112 kg per functional unit (i.e., per 8m^2a). This corresponds to 4% of the total yarn mass. The freshwater ecotoxicity impact due to the microplastic pollutants in the environment is calculated to be 164 PAF.m^3.day.

Impacts are mainly driven by plastic production, plastic treatment at the end of life as well as treatment of plastic losses and international transportation. There are several **recommendations** and **improvement potentials**:

- Using renewable electricity for the plastic carpet components manufacturing as well as for the carpet manufacturing if it fulfils the PEF criteria;
- Reducing waste losses during manufacturing and installation;
- Recycling of the carpet at the end of life;
- Recycling of the manufacturing losses;
- Increasing local production of plastics and carpet components to reduce international transportation;
- Reduction of impacts related to the supply chain of the plastic raw materials;
- Further research on using alternatives to plastic materials.
-

1 General

This is the second version of the PEF-RP study. It incorporates the findings of the supporting studies, and the feedback collected from the stakeholder consultation and the panel review.

- Name of the product: Representative product of synthetic turf systems for landscaping applications
- Product identification: N/A
- Product classification (CPA): 13.93.13 Carpets and other textile floor coverings, tufted
- Company presentation: N/A
- Date of publication of the PEF study: April 2024
- Geographic validity of the PEF study: European Union + EFTA + UK
- Compliance with PEF method: Commission recommendation on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisation, Annexes 1-2 (European Commission 2021)
- Conformance to other documents: N/A
- Name and affiliation of the verifiers: PEFCR review panel composed of Max Sonnen (Ecomatters), Céline Alexandre (RDC Environment), and Mickael Benetti (Fédération Internationale de Football Association (FIFA))

2 Goal of the study

The goal of the study is to assess the environmental footprint of a representative product (RP) of synthetic turf for landscaping applications, identify the most relevant impact categories, life cycle stages, processes and elementary flows and develop a benchmark for synthetic turf for landscaping applications products. Table 3 summarizes the main elements of the goal of the study.

Table 3: Main elements of the goal of the study

Aspects	Detail
Intended applications	Provide guidance to the synthetic turf Technical Secretariat (TS) about the environmental performance of the representative product of synthetic turf for landscaping applications. Set the starting point for the PEFCR development of the synthetic turf systems.
Methodological limitations	The representative product is modelled for the four most common sold landscaping synthetic turf systems of one TS members. Supporting studies will assess the use of additional components of the synthetic turf system, namely with stabilizing infill and shockpad.
Reasons for carrying out the study	PEF-RP studies are the first step in the development of the PEFCR for synthetic turf systems
Target audience	TS of the synthetic turf PEFCR, synthetic turf producers, users (residential, commercial, and public)
Commissioner of the study	EMEA Synthetic Turf Council (ESTC) on behalf of the TS of synthetic turf systems
Identification of the verifier	External review panel appointed to review the PEFCR of synthetic turf systems which is composed of Max Sonnen (Ecomatters), Céline Alexandre (RDC Environment), and Mickael Benetti (FIFA)

3 Scope of the study

3.1 Representative product

To develop a PEFCR, PEF studies of so-called representative products (PEF-RP studies) shall be carried out. The PEFCR of synthetic turf will include two sub-categories: for sport surfacing and for landscaping applications. Each sub-category requires individual PEF-RP study and this report documents the PEF-RP study for landscaping applications.

European Commission (2021) define the representative product (model) as follows: “The RP may be a real or a virtual (non-existing) product. The virtual product should be calculated based on average European market sales-weighted characteristics of all existing technologies/materials covered by the product category or sub-category. Other weighting sets may be used, if justified, for example weighted average based on mass (ton of material) or weighted average based on product units (pieces).”

Only a limited number of companies in Europe produce synthetic turf for landscaping applications. For this reason, the TS has decided to model a virtual representative product based on the arithmetic average of the four most common sold landscaping synthetic turf systems of one TS members. The RP for landscaping applications only includes the carpet, which consists of yarn, primary and secondary backing. Additional STS components like stabilizing infill and shockpad are not commonly used though they can be used in some landscaping applications, such as recreational. This configuration with extra components will be assessed in a supporting study.

Table 4: Most common configuration of the four most sold landscape systems produced by a TS member used to model the representative product

Component	Most common landscape configurations				Representative product
Pile yarn	PE: 60% PP: 40%	PE: 75% PP: 25%	PE: 70% PP: 30%	PE: 65% PP: 35%	PE: 67.5% PP: 32.5%
Pile height	30 mm	40 mm	38 mm	29 mm	34 mm
Pile weight	1335 g/m^2	1320 g/m^2	1876 g/m^2	581 g/m^2	1278 g/m^2
Primary backing	Polypropylene 161 g/m^2	Polypropylene 183 g/m^2	Polypropylene 183 g/m^2	Polypropylene 183 g/m^2	Polypropylene 177.5 g/m^2
Secondary backing (dry)	SBS latex (60%) and $CaCO_3$ filler (40%) 800 g/m^2	SBS latex (60%) and $CaCO_3$ filler (40%) 800 g/m^2	SBS latex (60%) and $CaCO_3$ filler (40%) 800 g/m^2	SBS latex (60%) and $CaCO_3$ filler (40%) 800 g/m^2	SBS latex (60%) and $CaCO_3$ filler (40%) 800 g/m^2

Similarly to the RP for sports surfacing, also for this RP, the base construction during installation is not included because that is site-specific and not product dependent. Installation materials, such as adhesives or tape, have negligible contribution and thus have not been included in the scope of this PEFCR. Tape and adhesives cumulatively contribute to less than 1% of the single score impact as reported in the supporting studies. Cutting losses during turf carpet installation are significant and thus are considered in the PEFCR. The cutting losses are much larger for landscaping compared to sports, about 20% according to the Technical Secretariat. This is due to the random shapes of landscape areas, whereas sports fields & courts are rectangular. Turf carpet is produced in rolls, that need to be manufactured/cut to shape. The losses during installation are treated the same way to end of life of the system.

A lifetime of 8 years for the STS is assumed, following the length of warranty offered by the producers. Other than land occupation, there are no activities foreseen in the use stage, so this life cycle stage does not include any processes for this representative product.

It is assumed that synthetic turf systems used in landscaping applications are not recycled at the end of life. Main markets in landscaping are domestic use (homeowners) with small areas. Most of these will dispose the product in a similar way to household carpets, i.e., as curbside collection of municipal solid waste. In consequence, the synthetic turf systems are either landfilled or incinerated. The waste treatment at the end of life of the representative product for landscape surfacing is based on municipal waste treatment incineration and landfill shares on EU, following the values in Annex C (European Commission 2020)[5].

3.2 Functional/declared unit and reference flow

The functional unit (FU) is 1 m^2 of synthetic turf system installed, used for 8 years assuming reasonable usage and adequate maintenance (i.e. 8 m^{2}a). Table 5 defines the key aspects used to define the FU.

Following the definition of reference flow in European Commission (2021), it is the "measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit (based on ISO 14040:2006)." In this study, the reference flow is 8 m^2*yr of installed synthetic turf system based on the four most common sold landscape

[5] https://eplca.jrc.ec.europa.eu/permalink/Annex_C_V2.1_May2020.xlsx

synthetic turf systems of one TS member. The lifetime in landscaping is based on the length of the warranties offered by synthetic turf producers.

Table 5: Key aspects of the functional unit

What	How much	How long	How well
Synthetic turf landscaping surface	1m x 1m ($1m^2$)	8 years subject to appropriate usage and maintenance[6]	In good condition with no significant wear, colour change, or pile flattening[7]

Next to the functional unit, a **declared unit** can be used, which represents the size of an entire area. For an entire synthetic turf system, the declared unit could be an installed STS of x m^2. For instance, if the STS will be installed in a $100m^2$ area, the declared unit can be calculated as: 100 m^2 x 8 years = 800 m^2a. Results per declared unit can be provided to improve the usability of the PEF study – the recipients of the results can learn about the impacts of a complete system that they will purchase and install.

3.3 System boundary

The system diagram of synthetic turf systems for landscaping applications is shown in Figure 2. Table 6 provides information on all life cycle stages that are part of the product system.

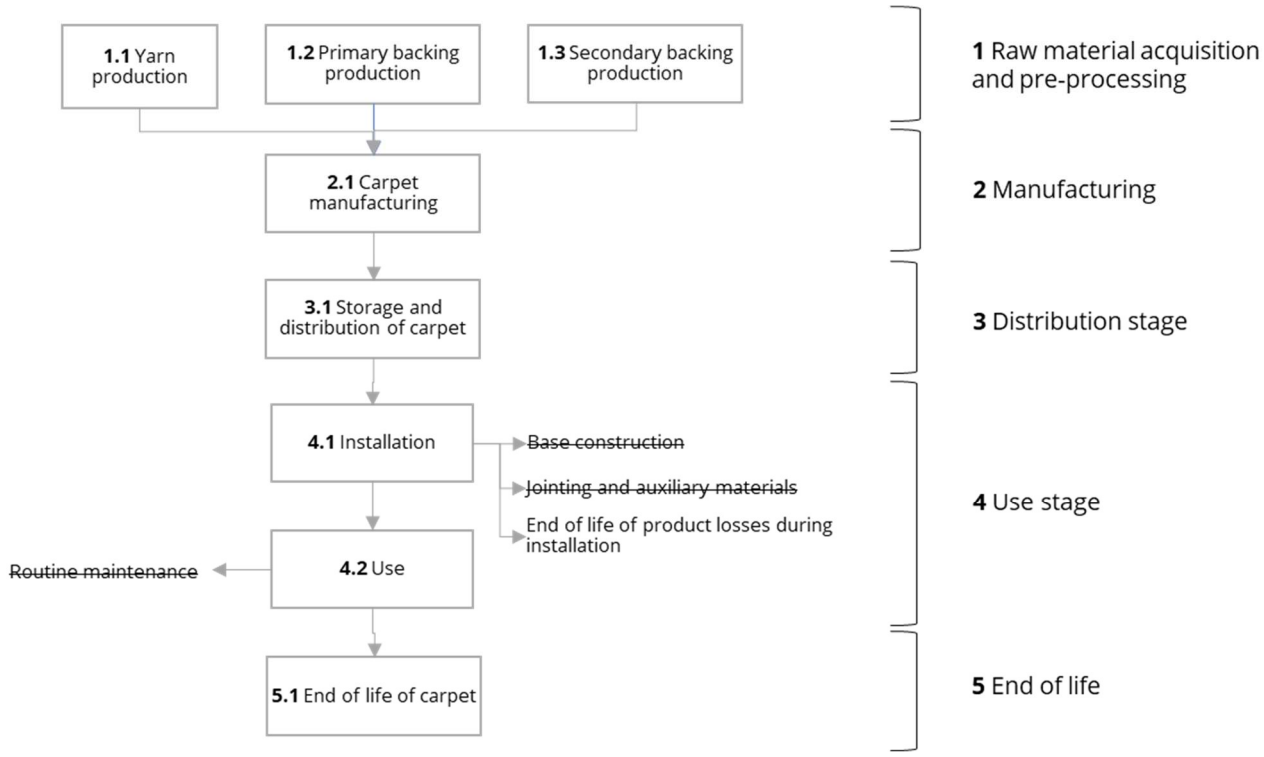


Figure 2: System diagram of the representative product of synthetic turf systems for landscaping applications. Every box constitutes a separate life cycle stage. On the right are the five default life cycle

[6] Appropriate maintenance of the synthetic turf depends on expectations of owner. In some cases it is purely decorative so no maintenance needed. In other cases loss of appearance is a consequence of use. Commercial use (resorts, etc.) may vacuum-clean to keep clean. Since this is a product-independent activity, vacuum cleaning shall be excluded in PEF calculation according to the PEFCR.

[7] There are no specific standards to measure good condition; this has to do with the expectations/perception of the owner.

stages to show how each was split. ~~Strikethrough text~~, i.e., base construction, jointing and auxiliary materials and routine maintenance, are excluded from the system boundary. The processes requiring company-specific data depend on the scope of the study and on the influence the company has over them.

Table 6: Life cycle stages of the RP model for landscaping applications

Default life cycle stage	Detailed life cycle stage	Short description of the processes included
1. Raw material acquisition and pre-processing	1.1 Yarn production	Includes the production of yarn, the input materials needed and their transport to the yarn manufacturing site. It also includes the transport of the yarn to the carpet manufacturing site.
	1.2 Primary backing production	Includes the manufacturing of primary backing, the input materials needed, their transport to backing manufacturing site. It also covers the transport of the primary backing to the carpet manufacturing site.
	1.3 Secondary backing production	Includes the manufacturing of secondary backing, the input materials needed, their transport to backing manufacturing site, and the transport of secondary backing to the carpet manufacturing site.
2. Manufacturing	2.1 Carpet manufacturing	The yarn is integrated into the artificial turf by being tufted (or woven) into a primary backing sheet. Secondary backing (often called coating) is added to the previous and helps hold the carpet yarns in place. The life cycle stage includes the production of carpet and treatment of carpet manufacturing waste.
3. Distribution stage	3.1 Storage and distribution of carpet	It includes transport from the carpet manufacturing site to the installation site (final user). Distribution centres and/or retail are also included.
4. Use stage	4.1 Installation	It includes turf carpet cutting losses during installation. The construction of the base (to prepare the site for the installation of the STS) is site-specific and not product dependent. The installation machinery is also considered product independent. Jointing and other auxiliary installation materials have a negligible contribution and are excluded based on the cut-off rule. For this reason, the base, installation machinery and jointing materials are excluded from the scope of this PEFCR.
	4.2 Operation	There are no activities included in the operation phase of landscaping applications.
5. End of life	5.1 End of life of carpet	Includes the removal of the carpet from the site and its respective waste treatments allocated to the yarn, primary backing and secondary backing weights.

3.4 Environmental Footprint impact categories

See below a list of EF impact categories, units and characterisation models used in this study.

Table 7: EF impact categories (European Commission 2021)

EF impact category	Impact category indicator	Unit	Characterisation model
Climate change[8]	Global Warming Potential (GWP100)	kg CO_2 eq	Baseline model of 100 years of the IPCC (based on IPCC 2021)
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11 eq	EDIP model based on the ODPs of the World Meteorological Organisation (WMO) over an infinite time horizon (WMO 2014 + integrations)
Human toxicity, cancer	Comparative Toxic Unit for humans (CTU_h)	CTU_h	Based on USEtox 2.1 model (Fantke et al. 2017), adapted as in (Saouter et al. 2018)
Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTU_h)	CTU_h	Based on USEtox 2.1 model (Fantke et al. 2017), adapted as in (Saouter et al. 2018)
Particulate matter	Impact on human health	disease incidence	PM model (Fantke et al. 2016) in (UNEP 2016)
Ionising radiation, human health	Human exposure efficiency relative to U^{235}	kBq ^{235}U eq	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al. 2000)
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg NMVOC eq	LOTOS-EUROS model (van Zelm et al. 2008) as applied in ReCiPe 2008
Acidification	Accumulated Exceedance (AE)	mol H^+ eq	Accumulated Exceedance (Seppälä et al. 2006; Posch et al. 2008)
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N eq	Accumulated Exceedance (Seppälä et al. 2006; Posch et al. 2008)
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model (Struijs et al. 2009) as applied in ReCiPe
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq	EUTREND model (Struijs et al. 2009) as applied in ReCiPe
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems (CTU_e)	CTU_e	Based on USEtox 2.1 model (Fantke et al. 2017), adapted as in (Saouter et al. 2018)
Land use[9]	Soil quality index[10]	Dimensionless (pt)	Soil quality index based on LANCA model (De Laurentiis et al. 2019) and on LANCA CF version 2.5 (Horn and Maier 2018)

[8] The indicator "Climate Change, total" is constituted by three sub-indicators: Climate Change, fossil; Climate Change, biogenic; Climate Change, land use and land use change. The sub-categories 'Climate change –fossil', 'Climate change – biogenic' and 'Climate change - land use and land use change', shall be reported separately if they show a contribution of more than 5% each to the total score of climate change.

[9] Refers to occupation and transformation.

[10] This index is the result of the aggregation, performed by JRC, of 4 indicators (biotic production, erosion resistance, mechanical filtration, and groundwater replenishment) provided by the LANCA model for assessing impacts due to land use as reported in De Laurentiis et al, 2019.

EF impact category	Impact category indicator	Unit	Characterisation model
Water use	User deprivation potential (deprivation-weighted water consumption)	m^3 water eq of deprived water	Available WAter REmaining (AWARE) model (Boulay et al. 2018; UNEP 2016)
Resource use, minerals and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	van Oers et al. 2002 as in CML 2002 method v4.8
Resource use, fossils	Abiotic resource depletion – fossil fuels (ADP-fossil)[11]	MJ	van Oers et al. 2002 as in CML 2002 method v4.8

The full list of normalization factors and weighting factors are available in ANNEX I – List of EF normalisation and weighting factors. The EF reference package v3.1 (https://eplca.jrc.ec.europa.eu/permalink/EF3_1/EF-v3.1.zip) shall be used.

The full list of characterization factors is available at this link: http://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml.

3.5 Additional information

As a minimum, the user shall estimate the amount of carpet fibres and polymeric infill, if applicable, lost to the environment, with the help of primary or secondary data. As an additional, but voluntary, exercise, the user can calculate the potential impact of the microplastic pollutant to freshwater ecotoxicity to estimate the magnitude of environmental impact currently not considered in the assessment. Further instructions can be found in section 3.7 of the 2nd draft PEFCR.

3.6 Assumptions and limitations

Any **assumptions** made in the RP study are an outcome of discussions and consensus within TS and reflect the best of our expert knowledge. The list of assumptions includes:

- The European average and the Global average transport distances have been used, as defined in section 4.4.3.4 European Commission (2021);
- Assumptions on the transportation of carpet from the factory to final client:
  - one third of carpet is transported directly to final client;
  - one third of carpet is transported to retail and then to final client;
  - one third of carpet is transported to distribution centre and then to final client;
  - The European and Global average default transport distances have been used, as defined in section 4.4.3.5 of European Commission (2021);
  - The ratio of transport within Europe is assumed to be 100% intracontinental (0% local);
  - Data on suppliers for carpet consumed in Europe were not available. Data on the global supply of synthetic turf carpet for landscaping and leisure applications from 2017 have been used to model the carpet manufacturing and the transportation of carpet to Europe (AMI Consulting 2018). Details of the

[11] In the EF flow list, and for the current recommendation, Uranium is included in the list of energy carriers, and it is measured in MJ.

global supply report are provided in section 4.2.5 for the energy use in carpet manufacturing and in section 4.4.5 for the storage and distribution of the carpet;
    - The mode of transportation of carpet from the distribution centre and retail to final client needs to modelled as a van (lorry of <1.2 t with a default utilisation ratio of 50% shall be used; if unavailable, a lorry of <7.5 t shall be used as approximation with a utilisation ratio of 20% shall be used). The utilization rate could not be modified in the EF 3.1 datasets and thus the default utilisation rate of 64% of lorry <7.5t, EURO 3 has been used(European Commission 2021);
- Assumptions on storage at distribution centre or retail:
    - The default energy consumption values, as defined in section 4.4.5 of (European Commission 2021) have been used;
    - Additional assumptions on storage have been used; height of storage: 2 meters; amount of time carpet is stored at retail: 0.5 months; amount of time carpet is stored at distribution centre: 1 month;
- The carpet might be cut into smaller pieces at the factory or by a middle company before is sent to retail. A middle company has not been modelled due to lack of relevant data. It is assumed that any potential cutting takes place directly at the factory;
- Packaging was excluded since its impact was negligible in the first version of the RP and thus it falls under the 3% cut-off criteria;
- Disassembly of the carpet at the end of life is expected to have a negligible impact, thus, it was excluded, falling under the 3% cut-off criteria;
- Transport of end-of-life carpet from use stage to waste treatment is expected to have a negligible impact, thus, it was excluded, falling under the 3% cut-off criteria.

The **limitations** of the RP study are:

- The representative product is based on the arithmetic average of the four most common sold landscape synthetic turf systems of one TS member. It includes the carpet, which consists of yarn, primary and secondary backing. The STS components stabilizing infill and shockpad are only used in some landscaping applications, such as recreational. The PEFCR is intended to cover all types of the synthetic turf systems. Therefore, a supporting study will assess the STS configuration with the additional components.
- Yarn composition is based on the arithmetic average of three common yarn compositions provided by three TS members for STS for sports and landscaping applications. Thus, the average yarn composition is a mix of yarn that is used in sports and landscaping applications.
- Yarn fibre losses to the environment due to wear during operation of the carpet have been calculated and provided in the additional information. However, due to the uncertainty in the amount of wear, it is assumed that all yarn fibres is reaching EoL treatment. Thus, the EoL impact of yarn is slightly overestimated.
- Few industry-specific secondary datasets were not available, thus, proxies from the existing EF-compliant datasets were used (all proxies are documented in Table 8):
    - Landfilling treatment processes of plastics were modelled using proxies because polymer-specific EF-compliant datasets were not available. This mainly affects the installation losses treatment and end of life stage.

- Yarn production, the PE part, requires monofilament, straight PE yarn produced by 50% in-line and 50% off-line extrusion. Because off-line extrusion of straight yarn was not available, 100% in-line extrusion was used.

Table 8: List of proxy datasets used in this study

Life cycle stage	Intended process	Proxy	Most relevant [Y/N]
LCS 1.1. Yarn production	Yarn manufacturing: 50% in-line and 50% off-line extrusion, mono-filament, straight yarn PE and 50% in-line and 50% off-line extrusion, mono-filament, texturized yarn PP	100% in-line extrusion, monofilament, straight yarn PE 50% in-line extrusion, monofilament, texturized yarn PP 50% off-line extrusion, monofilament, texturized yarn PP	Y
	Fluoroelastomer production	Fluoropolymer production	N
LCS 5.1. End of life	Landfilling of polyethylene	Landfilling of plastic waste	N
	Landfilling of polypropylene		N
	Landfilling of $CaCO_3$	Landfilling of inert material	N
	Incineration of $CaCO_3$	Incineration of inert material	N

A **data gap** is still present in this study: Manufacturing of the secondary backing was not included, due to lack of data.

4 Life cycle inventory analysis

4.1 List and description of life cycle stages

The list and description of life cycle stages was already documented in Table 6 in section 3.3.

4.2 Modelling choices

4.2.1 Yarn production

Yarn composition is based on the arithmetic average of three common yarn compositions provided by three TS members for STS for sports and landscaping applications. Yarn is modelled as:

- Yarn polymer for landscaping applications, petrochemical: 90%
- Masterbatch: 8%
- Processing aid: 2%

The percentage composition is summarized in the following Table 9.

Table 9: Average yarn product based on the arithmetic average of three common yarn compositions for sports and landscaping applications

Material	Average composition	
Yarn polymer	90%	PE: 67.5%
		PP: 32.5%
Masterbatch	8%	PE: 61.7%
		$CaCO_3$ filler: 4.2%
		UV stabilizer HALS: 4.9%
		Green pigment: 29.3%
Processing aid	2%	PE: 97.6% + Flouroelastomer: 2.4%

In a number of places in the model transport from supplier of raw materials to manufacturing site was based on the European average data (as defined in section 4.4.3.4 of European Commission (2021)). Processes where European average transport was used are listed in the PEFCR, Annex 4.1.

According to the TS, there are three distribution channels of the finished carpet for landscaping applications:

- Transporting of finished carpet from the manufacturing site directly to the customer;
- Cutting of the carpet in smaller pieces in the manufacturing site and transporting to retail;
- Transporting from the manufacturing site to a middle company that performs the carpet cutting into smaller pieces and then transporting to retail. For this case, a middle company has not been modelled due to lack of relevant data.

Distribution routes were modelled according to section 4.4.3.5 of European Commission (2021). These are further documented in section 4.4.5.

4.2.2 Storage and retail

In the PEF-RP study for landscaping applications the energy usage of distribution centres and retail was modelled using default values as defined in section 4.4.5 of European Commission (2021). Specifically, the storage energy consumption values provided at European Commission (2021) are:

- Distribution centre: 30 kWh/m^2 x year of electricity use and 360 MJ/m^2 x year of thermal energy use from natural gas;
- Retail: 150 kWh/m^2 x year of electricity use.

4.2.3 Use stage

The use of the STS was modelled using the main function approach. That means, all impacts related to the main function of the product, which is the "1 m^2 of synthetic turf system installed, used for 8 years assuming reasonable usage and adequate maintenance", have been modelled.

The use stage includes installation and operation of the STS. Product-independent processes were excluded. During installation, the installation losses treatment was modelled. All other activities of installation, i.e., the base, adhesives and machinery are product-independent activities and thus were excluded. No activities were modelled in operation. The only activity that takes place during operation is the "reasonable usage and adequate maintenance" which is a product-independent activity.

4.2.4 End of life modelling

The end of life was modelled using the Circular Footprint Formula and rules provided in section 5.10 of the PEFCR and in the PEF method. Table 10 contains parameter values used in the RP study.

The end-of-life scenario was determined based on expert judgement of the TS members and represents the average situation in Europe, i.e., 55% landfill and 45% incineration for all components. Additional scenarios were modelled to assess the effect of different EoL destinations on the overall environmental footprint of STS: 100% recycling, 100% incineration,

and 100% landfill (for results see ANNEX IV – PEF results per life cycle stage and alternative scenarios).

Table 10: Values used in Circular Footprint Formula parameters

Component	Destination shares			
	Repurposing	Recycling (R_2)	Incineration (R_3)	Landfill
Yarn	0	0	0.45	0.55
Primary backing				
Secondary backing				

4.2.5 Energy use

Carpet manufacturing

Data on the global supply of synthetic turf carpet for landscaping and leisure applications from 2017 (AMI Consulting 2018) have been used to model the global carpet production electricity and thermal energy use.

Electricity production:

- China: 64%
- Europe: 13%
- North America (RNA): 4%
- Rest: 19%. Specifically, using the PEF method global electricity mix shares, the remaining 19% is split into:
    - Australia (AU): 1.6%
    - New Zealand (NZ): 0.3%
    - Russian Federation (RU): 6.9%
    - Africa (RAF): 5.2%
    - Asia and the Pacific without China (RAS w/o CN): 74.3%
    - Region South Africa (RSA): 11.7%

Thermal energy:

- Europe: 13%
- Rest of the world (RoW): 87%

Table 11 summarizes the electricity and thermal energy use per m^2 of carpet manufacturing.

Table 11: Synthetic turf carpet manufacturing energy use for 1 m^2 of carpet

Process	**Unit**	**Amount per m^2 of carpet**	**Dataset**
Electricity	kWh	0.0503	Electricity grid mix 1kV-60kV {EU+EFTA+UK} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result
Electricity	kWh	0.248	Electricity grid mix 1kV-60kV {CN} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result
Electricity	kWh	0.0155	Electricity grid mix 1kV-60kV {RNA} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result
Electricity	kWh	0.0012	Electricity grid mix 1kV-60kV {AU} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result
Electricity	kWh	0.00022	Electricity grid mix 1kV-60kV {NZ} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result

Electricity	kWh	0.0051	Electricity grid mix 1kV-60kV {RU} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result
Electricity	kWh	0.0038	Electricity grid mix 1kV-60kV {RAF} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result
Electricity	kWh	0.0546	Electricity grid mix 1kV-60kV {RAS w/o CN} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result
Electricity	kWh	0.0086	Electricity grid mix 1kV-60kV {RSA} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result
Thermal energy	MJ	0.149	Thermal energy from natural gas {EU+EFTA+UK} | technology mix regarding firing and flue gas cleaning | production mix, at heat plant | MJ, 100% efficiency | LCI result
Thermal energy	MJ	1	Thermal energy from natural gas {ROW} | technology mix regarding firing and flue gas cleaning | production mix, at heat plant | MJ, 100% efficiency | LCI result

4.3 Handling multi-functional processes

The life cycle of the synthetic turf system does not include any multi-functional processes. The only case of allocation is associated with the water, energy and outputs of solid waste and wastewater at carpet manufacturing site, which are allocated to the products.

Table 12: Allocation rules

Process	Allocation rule	Modelling instructions
Manufacturing process	Physical allocation	The mass or area of output products shall be used.

4.4 Data collection

The PEF-RP model was developed by averaging the data of the four most common sold landscape synthetic turf systems provided by one member of the Technical Secretariat which manufactures synthetic turf products for landscaping. Below we describe all assumptions, data gaps and proxies used in modelling of each life cycle stage. Default values used in Circular Footprint Formula are documented in Table 10.

There was no explicit cut-off applied to this study, except for packaging , the EoL disassembly of the carpet, as well as the transport to EoL treatment) because these were found to be below the 3% cut-off. Since this is a representative product study, it provides evidence to cut-off future activities in the scope of the synthetic turf PEFCR.

Data collection tables are provided in the supporting excel Annex.

4.4.1 Yarn production

In the PEF-RP model for landscaping applications, yarn production is modelled as monofilament yarn, texturized PP and straight PE, 50% in-line and 50% off-line extrusion. The yarn composition has been modelled using the average data provided by three companies of the TS and is a mix of yarn for sports and landscaping applications.

Yarn was modelled using:

- 100% virgin fossil-based polyethylene resin and polypropylene resin;
- 100% in-line extrusion, monofilament, straight yarn for PE (50% off-line was not available, thus 100% in-line extrusion was assumed);
- 50% in-line extrusion, monofilament, texturized yarn for PP;

- 50% off-line extrusion, monofilament, texturized yarn for PP;
- Polyethylene and polypropylene losses were accounted for, as defined in the *Extrusion (in-line and off-line) datasets* (0.5%);
- Fluoropolymer was used as a proxy for fluoroelastomer;
- Transport of yarn incoming materials from supplier to the yarn manufacturing plant was modelled as a mix of average European transport and average non-European transport, based on the market shares of polyethylene and polypropylene documented in Ecoinvent;
- Transport of yarn from the yarn manufacturing plant to the carpet manufacturing plant was modelled using the average European transport.

Table 1 (Excel Annex) documents the inventory of yarn production, parameter values applied in Circular Footprint Formula and datasets used in the model. Table 7 (Excel Annex) includes all transport of yarn to carpet manufacturing sites.

4.4.2 Primary backing production

Primary backing, woven, is not manufactured by the companies participating in the PEF-RP study. It was modelled as:

- Fossil-based polypropylene;
- Manufactured from 100% virgin material;
- Polypropylene was modelled as a mix of European and non-European dataset, based on their market shares documented in Ecoinvent;
- Manufacturing process weaving was modelled using the EF dataset;
- Polypropylene 1.5% losses were accounted for from weaving;
- Transport of polypropylene from supplier to primary backing manufacturing plant was modelled as a mix of average European transport and average non-European transport, based on the market shares of polyethylene and polypropylene documented in Ecoinvent.
- Transport to carpet plant was included based on average European data.

Table 2 (Excel Annex) documents the inventory of primary backing production, parameter values applied in Circular Footprint Formula and datasets used in the model. Table 8 (Excel Annex) documents the transport of incoming materials and the transport of primary backing to carpet plant.

4.4.3 Secondary backing production

Secondary backing is not manufactured by companies participating in the PEF-RP study. It was modelled as:

- Fossil-based SBS latex;
- Manufactured from 100% virgin material;
- $CaCO_3$ was used as filler;
- Manufacturing inputs were not included, due to lack of data;
- Manufacturing losses were not included, due to lack of data;
- Transport of incoming materials SBS latex and $CaCO_3$ filler from supplier to primary backing manufacturing plant was modelled as a mix of average European transport and average non-European transport, based on the market shares of polyethylene and polypropylene documented in Ecoinvent;

- Transport to carpet plant was included based on average European data.

Table 3 (Excel Annex) documents the inventory of secondary backing production, parameter values applied in Circular Footprint Formula and datasets used in the model. Table 9 (Excel Annex) documents the transport of incoming materials and the transport of secondary backing to carpet plant.

4.4.4 Carpet manufacturing

For the PEF-RP model, carpet manufacturing was entirely based on company-specific information and represents tufting technology, followed by liquid roll coating and in-line oven drying. The assumptions in this life cycle stage include:

- Cumulative electricity consumption for tufting, coating and drying was provided, thus it is not possible to identify the individual contribution of each manufacturing step;
- Manufacturing waste and their transport to treatment are accounted, based on primary data;
- Treatment of manufacturing waste was modelled as landfill and incineration.

Table 4 (Excel Annex) documents the inventory of carpet manufacturing, parameter values applied in Circular Footprint Formula and datasets used in the model. Table 10 (Excel Annex) documents the transport of carpet manufacturing waste to treatment.

4.4.5 Storage and distribution of carpet

In the PEF-RP study for landscaping applications the energy usage of distribution centres and retail was modelled using default values as defined in section 4.4.5 of European Commission (2021) as discussed earlier. According to the TS, there are three distribution channels of the finished carpet for landscaping applications:

- Transporting of finished carpet from the manufacturing site directly to the customer;
- Cutting of the carpet in smaller pieces in the manufacturing site and transporting to retail;
- Transporting from the manufacturing site to a middle company that performs the carpet cutting into smaller pieces and then transporting to retail. Operations of a potential middle company have not been modelled due to lack of relevant data. Any potential cutting is assumed to take place at the factory.

The following have been modelled:

- Ratio between products sold through retail, distribution centre (DC) and directly to the final client; the following ratios have been assumed:
    - Products sold through retail: one third
    - Products sold through DC: one third
    - Products sold directly to the client: one third
- For factory to final client: Ratio between local, intracontinental and international supply chains; the following ratios have been assumed:
    - Intracontinental: 13% (EU artificial turf supply share - AMI Consulting 2018)
    - International: 87% (Global artificial turf supply share)
- For factory to retail: distribution between intracontinental and international supply chains; the following ratios have been assumed:
    - Intracontinental: 13% (EU artificial turf supply share - AMI Consulting 2018)

- International: 87% (Global artificial turf supply share)

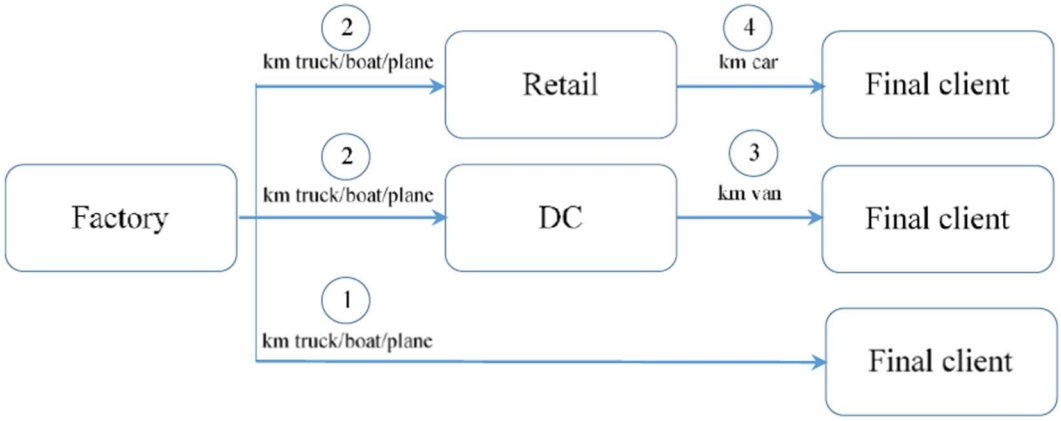


Figure 3: Diagram of transport routes of STS components from factory to final client, i.e., installation site

For direct distribution from factory to final client (route 1 in Figure 3), to retail or DC (route 2 in Figure 3), the following apply:

- local supply chain: 1,200 km by truck (>32 t, EURO 4, 0.64 utilisation ratio),
- intracontinental supply chain: 3,500 km by truck (>32 t, EURO 4, 0.64 utilisation ratio), and
- international supply chain: 1,000 km by truck (>32 t, EURO 4, 0.64 utilisation ratio) and 18,000 km by ship (transoceanic container). Note that for specific cases, plane or train may be used instead of ship.

For distribution from DC to final client (route 3 in Figure 3), a round trip of 250 km by van (lorry <7.5t, EURO 3, utilisation ratio of 20%).

For distribution from retail to final client (route 4 in Figure 3), the following apply:

- 62%: 5 km, by passenger car (average),
- 5%: 5 km round trip, by van (lorry <7.5t, EURO 3 with utilisation ratio of 20%), and
- 33%: no impact modelled.

Inventory data are summarized in Table 11 (Excel Annex).

No losses of carpet during cutting have been specified. It is assumed that any potential cutting losses are already included within the carpet waste that is produced during the carpet manufacturing at the factory. Nevertheless, a large percentage of installation losses has been modelled (see next section 4.4.6).

4.4.6 Installation

The following assumptions were made in the PEF-RP study:

- The construction of the base and the materials needed for that were not considered because these are location-specific and product-independent;
- Adhesives and jointing film materials were not included because they are product independent;
- Installation machinery was not included because it is product independent;
- 20% carpet installation losses;

- Based on information provided by the TS, the waste (losses) from installation is assumed to end up in municipal waste curbside collection (using European shares).
- Waste treatment of cutting losses which were modelled the same as final disposal at the end of life of the STS (see section 4.4.8 for further details).

Table 5 (Excel Annex) documents the inventory of carpet installation, parameter values applied in Circular Footprint Formula and datasets used in the model. Table 12 (Excel Annex) includes the data used for the transport of installation waste to waste treatment facilities.

4.4.7 Use

In landscaping applications, the use stage depends on the expectations of owner. In some cases it is purely decorative so no maintenance needed. In commercial use (resorts, etc.), users may vacuum-clean. However, since this is a product-independent activity, this shall be excluded from PEF calculations. Land occupation is also product independent and shall, for this reason and according to European Commission (2021), be excluded from the system boundary. Consequently, no activities are modelled in the use stage of STSs used in landscaping applications.

Further, it was assumed that the lifetime of the synthetic turf system is 8 years, as per the functional unit.

4.4.8 End of life of carpet

The main markets in landscaping are domestic use (homeowners) with small areas. Most of these will dispose the product in a similar way to household carpets, i.e., as curbside collection of municipal solid waste. For this reason, it is assumed that the majority of synthetic turf systems are not recycled or repurposed at the end of life. The waste destination at the end of life of STS used for landscaping is based on municipal waste treatment incineration and landfill shares on EU, 45% and 55% respectively, following the values in Annex C (European Commission 2020). EOL treatment processes impacts have been allocated to the weight of the different components (yarn, primary and secondary backing) per m2 of carpet.

The following assumptions were made in the RP study:

- For yarn, *Landfilling of plastic waste* was used as a proxy for landfilling of polyethylene and polypropylene;
- For primary backing, *Landfilling of plastic waste* was used as a proxy for landfilling of polypropylene;
- For secondary backing:
    - *Incineration of inert materials* was used as a proxy for the $CaCO_3$ filler; and
    - *Landfilling of inert materials* was used as a proxy for the $CaCO_3$ filler.

The inventories of end-of-life treatment of carpet (yarn, primary packing and secondary backing), parameter values applied in Circular Footprint Formula and datasets used in the model are documented in Table 6 (Excel Annex).

4.5 Data quality requirements and rating

Since the representative product was not modelled as a real product, the situation of all processes according to the Data Needs Matrix (DNM) cannot be done. The DQR of the PEF

study can also not be calculated. This was confirmed by the Environmental Footprint team by email on July 7th, 2023.

5 Impact assessment results

5.1 PEF results

This section includes the PEF results for the benchmark results of the representative synthetic turf system used for landscaping applications. The characterised, normalised and weighted results are reported in Table 13 and Table 14.

The TS expressed interest in analysing the detailed PEF results of the representative STS per life cycle stage as well as in quantifying environmental impacts for alternative end-of-life scenarios. Specifically, in addition to the end-of-life scenario incorporated in the benchmark results – which consists of incineration (45%) and landfill (55%) – the environmental impacts of **individual waste treatment options**: 100% incineration, 100% landfill, and 100% recycling. The detailed PEF results per life cycle stage and the alternative scenarios are provided in ANNEX IV – PEF results per life cycle stage and alternative scenarios.

Table 13: Characterised results for 8 m^2a of the RP for landscaping applications

Impact category	Unit	Complete life cycle	Complete life cycle excluding use stage
Acidification	mol H^+ eq	7.78E-02	7.83E-02
Climate change	kg CO_2 eq	1.23E+01	1.20E+01
Ecotoxicity, freshwater	CTU_e	1.46E+02	1.47E+02
Particulate matter	disease inc.	1.50E-06	1.51E-06
Eutrophication, marine	kg N eq	1.98E-02	1.99E-02
Eutrophication, freshwater	kg P eq	3.04E-04	3.01E-04
Eutrophication, terrestrial	mol N eq	2.10E-01	2.11E-01
Human toxicity, cancer	CTU_h	8.29E-09	8.31E-09
Human toxicity, non-cancer	CTU_h	7.50E-08	7.49E-08
Ionising radiation	kBq ^{235}U eq	4.96E-01	5.44E-01
Land use	Pt	2.14E+01	2.15E+01
Ozone depletion	kg CFC-11 eq	1.62E-06	1.62E-06
Photochemical ozone formation	kg NMVOC eq	5.60E-02	5.63E-02
Resource use, fossils	MJ	2.06E+02	2.10E+02
Resource use, minerals and metals	kg Sb eq	6.36E-05	6.36E-05
Water use	m^3 depriv.	8.81E-01	8.53E-01

Table 14: Normalised and weighted results in absolute values of 8 m^2a of the RP for landscaping applications

Impact category	Complete life cycle Normalized results [person eq.]	Complete life cycle Weighted results	Complete life cycle excluding use stage Normalized results [person eq.]	Complete life cycle excluding use stage Weighted results
Acidification	1.40E-03	8.68E-05	1.41E-03	8.74E-05
Climate change	1.62E-03	3.42E-04	1.59E-03	3.35E-04
Ecotoxicity, freshwater	2.58E-03	4.95E-05	2.59E-03	4.97E-05
Particulate matter	2.52E-03	2.26E-04	2.53E-03	2.27E-04
Eutrophication, marine	1.01E-03	3.00E-05	1.02E-03	3.02E-05
Eutrophication, freshwater	1.89E-04	5.30E-06	1.87E-04	5.24E-06
Eutrophication, terrestrial	1.19E-03	4.41E-05	1.19E-03	4.43E-05
Human toxicity, cancer	4.80E-04	1.02E-05	4.81E-04	1.03E-05
Human toxicity, non-cancer	5.83E-04	1.07E-05	5.82E-04	1.07E-05
Ionising radiation	1.17E-04	5.88E-06	1.29E-04	6.46E-06
Land use	2.61E-05	2.07E-06	2.63E-05	2.09E-06
Ozone depletion	3.09E-05	1.95E-06	3.09E-05	1.95E-06
Photochemical ozone formation	1.37E-03	6.55E-05	1.38E-03	6.58E-05
Resource use, fossils	3.17E-03	2.64E-04	3.24E-03	2.69E-04
Resource use, minerals and metals	1.00E-03	7.55E-05	1.00E-03	7.55E-05
Water use	7.68E-05	6.54E-06	7.44E-05	6.33E-06
Weighted results as single score		1.23E-03		1.23E-03

5.2 Additional information

This section includes the additional environmental information for the yarn fibre losses to the environment and the voluntary calculation of the freshwater ecotoxicity impact due to the microplastic pollutants. The requirements of what shall and should be reported are specified in section 3.5.

The fibre wear is calculated as 0.032 and 0.047 kg per FU (i.e., per 8m^2a), for residential and recreational use, respectively. Specifically:

- Amount of fibres (yarn) per FU: 1.278 kg
- Wear rate of fibres for residential application (less wear) over entire use: 2.5%
- Wear rate of fibres for recreational application (more wear) over entire use: 5%

$$\text{Loss of fibres to environment (for residential)} = 1.278 \times 2.5\% = 0.032 \text{ kg per FU}$$

$$\text{Loss of fibres to environment (for recreational)} = 1.278 \times 5\% = 0.064 \text{ kg per FU}$$

That means that between 2.5-5% of fibre yarn is lost to the environment during the 8 years lifetime of the STS for landscaping applications. As stated in the limitations, the whole amount of yarn fibres reaches EoL treatment.

The freshwater ecotoxicity impact of the microplastics from fibre losses in the environment is calculated as:

$$\text{Freshwater ecotoxicity microplastics (for residential)} = 0.0032 \times 3209 = 103 \text{ PAF.m}^3\text{.day per FU}$$

$$\text{Freshwater ecotoxicity microplastics (for recreational)} = 0.0064 \times 3209 = 205 \text{ PAF.m}^3\text{.day per FU}$$

6 Interpreting PEF results

6.1 Assessment of the robustness of the PEF study

The current version of the PEF-RP study contains a few proxies. The lack of material-specific datasets for landfilling of yarn and primary backing is not expected to affect the robustness of the study. None of the landfilling processes was identified to be a most relevant processes. Off-line extrusion for straight PE yarn was not available and thus 100% in-line extrusion has only been used (instead of 50% in-line and 50% off-line extrusion for the PE part of the yarn). In-line extrusion of straight yarn has been identified as a most relevant process. Moreover, in-line and off-line extrusion of texturized PP yarn have also been modelled and identified as most relevant processes. The lack of off-line extrusion of straight yarn is not expected to noticeably affect the results and trends identified, as it is expected to have a similar impact to the in-line extrusion of straight yarn. The study should be considered robust.

When it comes to the coverage of the representative product, it was modelled by averaging data of the four most common sold landscaping synthetic turf systems of one TS member, which ensures a fair representation of the product. Any industry average information was defined based on consensus with the TS.

Finally, yarn was also modelled by averaging the data of three companies of the TS, and it's modelled as a mix of yarn for sports and landscaping applications.

6.2 Identification of most relevant impact categories, life cycle stages and processes

In this section, the most relevant impact categories, life cycle stages and processes are identified according to the rules stipulated in Table 15. The summary of the results is provided in Table 16.

Table 15: Hotspot analysis. Source: European Commission (2021)

Item	At what level does relevance need to be identified?	Threshold
Most relevant impact categories	Single overall score	Impact categories that together contribute to at least 80% of the single overall score.
Most relevant life cycle stages	For each most-relevant impact category	All life-cycle stages that together contribute more than 80% to that impact category. If the use stage accounts for more than 50% of the total impact of a most-relevant impact category, the procedure shall be re-run, excluding the use stage.

Most relevant processes	For each most-relevant impact category	All processes that together contribute (along the entire life cycle) more than 80% to that impact category, considering absolute values.
Most relevant elementary flows[12]	For each most-relevant process considering the most-relevant impact categories	All elementary flows that together contribute to at least 80% of the total impact of a most-relevant impact category for each most-relevant process. If disaggregated data are available: for each most-relevant process, all direct elementary flows that together contribute at least 80% to that impact category (caused by the direct elementary flows only).

The **most relevant impact categories** (see Figure 4) identified in this study using the rules stipulated in Table 15 are:

- Climate change (27.9%)
- Resource use, fossils (21.5%)
- Particulate matter (18.4%)
- Acidification (7.1%)
- Resource use, minerals and metals (6.2%)

Additionally, the TS identified Water use (0.53%) as an impact category of special interest for the sector. Although Water use was not identified as most relevant in the PEF-RP study for sports surfacing, we expect it to become a hotspot for STS that need watering during the use stage. Water use is particularly relevant for systems: i) using organic infills, which need to be kept moist to prevent them from wind erosion; ii) designed to be used with water, e.g. to reduce the risk of carpet burns. Therefore, this category was included in the identification of the most relevant life cycle stages and processes.

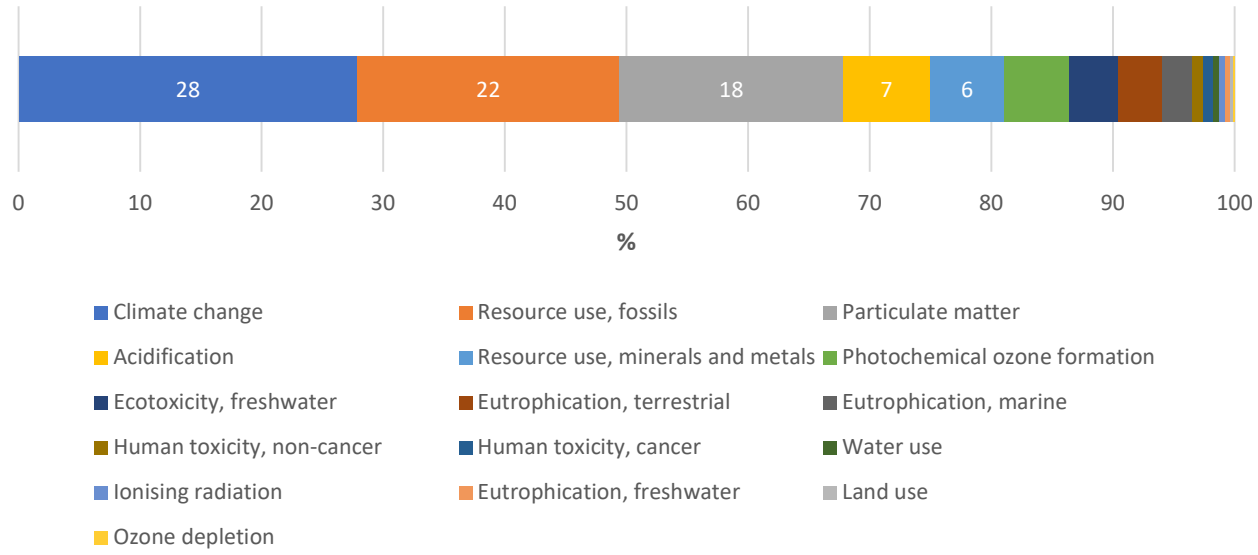


Figure 4: Normalized and weighted impact results of RP for landscaping, sorted from high to low contribution per impact category

[12] Since no disaggregated datasets were available when this study was carried out, only most relevant direct elementary flows were identified, if applicable. More information is provided at the end of this chapter.

The **most relevant life cycle stages** are:

- LCS 1.1 Yarn production
- LCS 1.3 Secondary backing production
- LCS 3.1 Storage and distribution of carpet
- LCS 5.1 End of life of carpet

For the impact category identified by the TS, i.e., water use, there is one additional life cycle stage that is identified as most relevant, that is:

- LCS 1.2 Primary backing production

The **most relevant processes** are listed below (in alphabetical order and with specification of the life cycle stage where they occur):

- Electricity grid mix 1kV-60kV {CN} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result > *LCS 2.1 Carpet manufacturing*
- Green pigment {GLO} | production mix, at plant | Pigment for colouration of plastic granules prior to spinning for yarn production. | LCI result > *LCS 1.1 Yarn production*
- In-line extrusion of mono-filament yarn {EU+EFTA+UK} | Processing dataset, parameterized | straight yarn | LCI result > *LCS 1.1 Yarn production*
- In-line extrusion of mono-filament yarn {EU+EFTA+UK} | Processing dataset, parameterized | texturized yarn | LCI result > *LCS 1.1 Yarn production*
- Incineration of styrene-butadiene-styrene (SBS) latex {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | SBS latex | LCI result > *LCS 5.1 EOL of carpet*
- Off-line extrusion of mono-filament {EU+EFTA+UK} | Processing dataset, parameterized | texturized yarn | LCI result > *LCS 1.1 Yarn production*
- PE granulates {EU+EFTA+UK} | Polymerisation of ethylene | production mix, at plant | 0.91- 0.96 g/cm3, 28 g/mol per repeating unit | LCI result > *LCS 1.1 Yarn production*
- Polyethylene (PE), petrochemical based {GLO} | mix of fossil-based HDPE, LDPE and LLDPE | production mix, at plant | 100% fossil-based | LCI result > *LCS 1.1 Yarn production*
- Polypropylene (PP), petrochemical based {GLO} | polymerisation of bio-fossil propylene | production mix, at plant | petrochemical based | LCI result > *LCS 1.1 Yarn production* & *LCS 1.2 Primary backing production*
- PP granulates {EU+EFTA+UK} | polymerisation of propene | production mix, at plant | 0.91 g/cm3, 42.08 g/mol per repeating unit | LCI result > *LCS 1.1 Yarn production*
- Styrene-butadiene-styrene (SBS) latex, petrochemical based {GLO} | emulsion polymerisation of styrene, and 1,3-butadiene | production mix, at plant | petrochemical based | LCI result > *LCS 1.3 Secondary backing production*
- Transoceanic ship, containers {GLO} | heavy fuel oil driven, cargo | consumption mix, to consumer | 27.500 dwt payload capacity, ocean going | LCI result > *LCS 3.1 S&D of carpet & LCS 1.1 Yarn production*
- Waste incineration of PE {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | polyethylene waste | LCI result > *LCS 5.1 EOL of carpet*
- Waste incineration of PP {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | polypropylene waste | LCI result > *LCS 5.1 EOL of carpet*

For the water use impact category, identified by the TS, an additional **most relevant process** has been identified. That is:

- Weaving of primary backing {EU+EFTA+UK} | service, Backing fabric, weaved | production mix, at plant | service, Backing fabric, weaved | LCI result > *LCS 1.2 Primary backing production*

There were no direct elementary flows modelled in the RP model and there were only fully disaggregated datasets, hence there were no most relevant elementary flows identified.

The EF3.1 datasets are fully aggregated and thus no direct elementary flows are available. Specifically, the European Commission (2021) states that "Elementary flows belonging to the background system of a most relevant process may dominate the total impact, therefore, if disaggregated datasets are available, the user of the PEF method should in addition identify the most relevant direct elementary flows for each most relevant process."

It should be noted that when the disaggregated EF3.1 datasets become available the identification of the most relevant direct elementary flows should be performed by the user of the PEFCR.

Table 16: Summary of most relevant impact categories, life cycle stages, and processes

Most relevant impact category	[%]	Most relevant life cycle stages	[%]	Most relevant processes	[%]
Climate change	27.9	LCS1.1 Yarn production	47.7	Polyethylene (PE), petrochemical based {GLO} | mix of fossil-based HDPE, LDPE and LLDPE | production mix, at plant | 100% fossil-based | LCI result	17.6
				In-line extrusion of mono-filament yarn {EU+EFTA+UK} | Processing dataset, parameterized | straight yarn | LCI result	8.0
				Polypropylene (PP), petrochemical based {GLO} | polymerisation of bio-fossil propylene | production mix, at plant | petrochemical based | LCI result	7.7
				PE granulates {EU+EFTA+UK} | Polymerisation of ethylene | production mix, at plant | 0.91-0.96 g/cm3, 28 g/mol per repeating unit | LCI result	3.2
				In-line extrusion of mono-filament yarn {EU+EFTA+UK} | Processing dataset, parameterized | texturized yarn | LCI result	2.7
				Off-line extrusion of mono-filament {EU+EFTA+UK} | Processing dataset, parameterized | texturized yarn | LCI result	2.5
		LCS1.3 Secondary backing production	21.9	Styrene-butadiene-styrene (SBS) latex, petrochemical based {GLO} | emulsion polymerisation of styrene, and 1,3-butadiene | production mix, at plant | petrochemical based | LCI result	21.5
		LCS5.1 EOL of carpet	9.8	Waste incineration of PE {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | polyethylene waste | LCI result	3.9
				Incineration of styrene-butadiene-styrene (SBS) latex {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | SBS latex | LCI result	2.7
				Waste incineration of PP {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | polypropylene waste | LCI result	2.6
		LCS3.1 S&D of carpet	7.6	Transoceanic ship, containers {GLO} | heavy fuel oil driven, cargo | consumption mix, to consumer | 27.500 dwt payload capacity, ocean going | LCI result	3.0
		Other		Polypropylene (PP), petrochemical based {GLO} | polymerisation of bio-fossil propylene | production mix, at plant | petrochemical based | LCI result - LCS1.2 Primary backing production	3.8
				Electricity grid mix 1kV-60kV {CN} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result - LCS2.1 Carpet manufacturing	2.3
Resource use, fossils	21.5	LCS1.1 Yarn production	66.2	Polyethylene (PE), petrochemical based {GLO} | mix of fossil-based HDPE, LDPE and LLDPE | production mix, at plant | 100% fossil-based | LCI result	21.4
				Polypropylene (PP), petrochemical based {GLO} | polymerisation of bio-fossil propylene | production mix, at plant | petrochemical based | LCI result	9.1
				In-line extrusion of mono-filament yarn {EU+EFTA+UK} | Processing dataset, parameterized | straight yarn | LCI result	6.7

				PE granulates {EU+EFTA+UK} | Polymerisation of ethylene | production mix, at plant | 0.91-0.96 g/cm3, 28 g/mol per repeating unit | LCI result	5.6
				PP granulates {EU+EFTA+UK} | polymerisation of propene | production mix, at plant | 0.91 g/cm3, 42.08 g/mol per repeating unit | LCI result	2.3
				In-line extrusion of mono-filament yarn {EU+EFTA+UK} | Processing dataset, parameterized | texturized yarn | LCI result	2.2
		LCS1.3 Secondary backing production	28.4	Styrene-butadiene-styrene (SBS) latex, petrochemical based {GLO} | emulsion polymerisation of styrene, and 1,3-butadiene | production mix, at plant | petrochemical based | LCI result	22.1
		Other		Polypropylene (PP), petrochemical based {GLO} | polymerisation of bio-fossil propylene | production mix, at plant | petrochemical based | LCI result - LCS1.2 Primary backing production	4.5
				Waste incineration of PE {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | polyethylene waste | LCI result - LCS5.1 EOL of carpet	3.9
				Waste incineration of PP {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | polypropylene waste | LCI result - LCS5.1 EOL of carpet	2.6
Particulate matter	18.4	LCS1.1 Yarn production	43.4	Polyethylene (PE), petrochemical based {GLO} | mix of fossil-based HDPE, LDPE and LLDPE | production mix, at plant | 100% fossil-based | LCI result	20.3
				Transoceanic ship, containers {GLO} | heavy fuel oil driven, cargo | consumption mix, to consumer | 27.500 dwt payload capacity, ocean going | LCI result	7.6
				Polypropylene (PP), petrochemical based {GLO} | polymerisation of bio-fossil propylene | production mix, at plant | petrochemical based | LCI result	7.4
		LCS1.3 Secondary backing production	25.9	Styrene-butadiene-styrene (SBS) latex, petrochemical based {GLO} | emulsion polymerisation of styrene, and 1,3-butadiene | production mix, at plant | petrochemical based | LCI result	24.4
		LCS3.1 S&D of carpet	16.0	Transoceanic ship, containers {GLO} | heavy fuel oil driven, cargo | consumption mix, to consumer | 27.500 dwt payload capacity, ocean going | LCI result	14.3
		Other		Electricity grid mix 1kV-60kV {CN} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result - LCS2.1 Carpet manufacturing	9.5
Acidification	7.1	LCS1.1 Yarn production	48.5	Polyethylene (PE), petrochemical based {GLO} | mix of fossil-based HDPE, LDPE and LLDPE | production mix, at plant | 100% fossil-based | LCI result	18.8
				Transoceanic ship, containers {GLO} | heavy fuel oil driven, cargo | consumption mix, to consumer | 27.500 dwt payload capacity, ocean going | LCI result	8.3
				Polypropylene (PP), petrochemical based {GLO} | polymerisation of bio-fossil propylene | production mix, at plant | petrochemical based | LCI result	7.8
				In-line extrusion of mono-filament yarn {EU+EFTA+UK} | Processing dataset, parameterized | straight yarn | LCI result	3.2
		LCS1.3 Secondary backing production	25.0	Styrene-butadiene-styrene (SBS) latex, petrochemical based {GLO} | emulsion polymerisation of styrene, and 1,3-butadiene | production mix, at plant | petrochemical based | LCI result	22.5

		LCS3.1 S&D of carpet	20.6	Transoceanic ship, containers {GLO} | heavy fuel oil driven, cargo | consumption mix, to consumer | 27.500 dwt payload capacity, ocean going | LCI result	15.6
		Other		Polypropylene (PP), petrochemical based {GLO} | polymerisation of bio-fossil propylene | production mix, at plant | petrochemical based | LCI result - LCS1.2 Primary backing production	3.9
Resource use, minerals and metals	6.2	LCS1.1 Yarn production	62.2	Polyethylene (PE), petrochemical based {GLO} | mix of fossil-based HDPE, LDPE and LLDPE | production mix, at plant | 100% fossil-based | LCI result	37.5
				Green pigment {GLO} | production mix, at plant | Pigment for colouration of plastic granules prior to spinning for yarn production. | LCI result	14.6
		LCS1.3 Secondary backing production	29.3	Styrene-butadiene-styrene (SBS) latex, petrochemical based {GLO} | emulsion polymerisation of styrene, and 1,3-butadiene | production mix, at plant | petrochemical based | LCI result	29.1
Water use	0.5	LCS1.2 Primary backing production	52.3	Polypropylene (PP), petrochemical based {GLO} | polymerisation of bio-fossil propylene | production mix, at plant | petrochemical based | LCI result	8.1
				Weaving of primary backing {EU+EFTA+UK} | service, Backing fabric, weaved | production mix, at plant | service, Backing fabric, weaved | LCI result	2.9
		LCS1.3 Secondary backing production	28.9	Styrene-butadiene-styrene (SBS) latex, petrochemical based {GLO} | emulsion polymerisation of styrene, and 1,3-butadiene | production mix, at plant | petrochemical based | LCI result	5.9
		Other		Polyethylene (PE), petrochemical based {GLO} | mix of fossil-based HDPE, LDPE and LLDPE | production mix, at plant | 100% fossil-based | LCI result - LCS1.1 Yarn production	39.2
				Polypropylene (PP), petrochemical based {GLO} | polymerisation of bio-fossil propylene | production mix, at plant | petrochemical based | LCI result - LCS1.1 Yarn production	16.4
				In-line extrusion of mono-filament yarn {EU+EFTA+UK} | Processing dataset, parameterized | straight yarn | LCI result - LCS1.1 Yarn production	7.9

2

6.3 Limitations and relationship of the EF results relative to the defined goal and scope of the PEF study

As described in section 3.6, the limitations of this RP study relevant in the context of goal and scope are:

- The representative product is based on the arithmetic average of the four most common sold landscape synthetic turf systems of one TS member. It includes the carpet, which consists of yarn, primary and secondary backing. The STS components stabilizing infill and shockpad are only used in some landscaping applications, such as recreational. The PEFCR is intended to cover all final applications of the synthetic turf systems. Therefore, the supporting studies will assess a synthetic turf system with the additional components.
- Yarn composition is based on the arithmetic average of three common yarn compositions provided by three TS members for STS for sports and landscaping applications. Thus, the average yarn product is a mix of yarn used in sports and landscaping applications.
- Yarn fibre losses to the environment due to wear during operation of the carpet have been calculated and provided in the additional information. However, due to the uncertainty in the amount of wear, it is assumed that the whole amount of yarn fibres is reaching EoL treatment. Thus, the EoL impact of yarn is slightly overestimated.
- Few industry-specific secondary datasets were not available, thus, proxies from the existing EF-compliant datasets were used (detailed list of proxies is provided in Table 8). These are:
    - Landfilling treatment processes of plastics were modelled using proxies because polymer-specific EF-compliant datasets were not available. This mainly affects the installation losses treatment and end of life stage.
    - Yarn production, the PE part, requires monofilament, straight yarn 50% in-line and 50% off-line extrusion. Because off-line extrusion of straight yarn was not available, 100% in-line extrusion was used.
- Manufacturing of secondary backing only account for the input materials, not for the processing into the backing, due to lack of relevant data.

6.4 Conclusions, recommendations, limitations and improvement potentials

The **most relevant impact categories** for the synthetic turf system used in landscaping applications include Climate change (27.9%), Resource use, fossils (21.5%), Particulate matter (18.4%), Acidification (7.1%), Resource use, minerals and metals (6.2%). Additionally, the TS selected Water use (0.5%) as an impact category of special interest for the sector. Therefore, that category was included in the identification of the most relevant life cycle stages and processes.

Within the most relevant impact categories, the **most relevant life cycle stages** are: LCS 1.1 Yarn production; LCS1.2 Primary backing production; LCS 1.3 Secondary backing production; LCS 3.1 Storage and distribution of carpet; and LCS 5.1 End of life of carpet.

The environmental impacts in most relevant impact categories are primarily driven by the use of plastics in carpet manufacturing and its waste treatment at the end of life. The list **of most relevant processes** includes (in alphabetical order):

- Electricity grid mix 1kV-60kV {CN} > LCS2.1 Carpet manufacturing
- Green pigment {GLO} > *LCS1.1 Yarn production*
- In-line extrusion of mono-filament yarn {EU+EFTA+UK} | straight yarn | LCI result > *LCS1.1 Yarn production*
- In-line extrusion of mono-filament yarn {EU+EFTA+UK} | texturized yarn | LCI result > *LCS1.1 Yarn production*
- Incineration of styrene-butadiene-styrene (SBS) latex {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | SBS latex | LCI result > *LCS5.1 EOL of carpet*
- Off-line extrusion of mono-filament {EU+EFTA+UK} | texturized yarn | LCI result > *LCS1.1 Yarn production*
- PE granulates {EU+EFTA+UK} > *LCS1.1 Yarn production*
- Polyethylene (PE), petrochemical based {GLO} > *LCS1.1 Yarn production*
- Polypropylene (PP), petrochemical based {GLO} > LCS1.1 Yarn production & LCS1.2 Primary backing production
- PP granulates {EU+EFTA+UK > *LCS1.1 Yarn production*
- Styrene-butadiene-styrene (SBS) latex, petrochemical based {GLO} > *LCS1.3 Secondary backing production*
- Transoceanic ship, containers {GLO} > LCS3.1 S&D of carpet & LCS1.1 Yarn production
- Waste incineration of PE {EU+EFTA+UK} > *LCS5.1 EOL of carpet*
- Waste incineration of PP {EU+EFTA+UK} > *LCS5.1 EOL of carpet*
- Weaving of primary backing {EU+EFTA+UK} > *LCS1.2 Primary backing production*

While the product under study is a virtual product, we still believe it can be useful to document a few recommendations and improvement potentials, since these would probably be applicable for other synthetic turf systems with similar hotspots. Impacts are mainly driven by plastic production, plastic treatment at the end of life as well as treatment of plastic losses and international transportation. There are several **recommendations** and **improvement potentials**:

- Using renewable electricity for the plastic carpet components manufacturing as well as for the carpet manufacturing if it fulfils the PEF criteria,
- Reducing waste losses during manufacturing and installation,
- Recycling of the carpet at the end of life,
- Recycling of the manufacturing losses,
- Supporting local production of plastics and carpet components to reduce international transportation,
- Reduction of impacts related to the supply chain of the plastic raw materials,
- Further research on using alternatives to plastic materials.

7 Validation statement

Representative Product (RP) "Synthetic Turf Sports & Landscape Surfaces"

CRITICAL REVIEW REPORT

Review Panel

Name of the member	Affiliation	Role
Max Sonnen	Ecomatters BV	Chair and LCA/PEF expert
Céline Alexandre	RDC Environment	LCA/PEF expert
Mickael Benetti	Fédération Internationale de Football Association (FIFA)	Synthetic turf expert

Review Scope

The task of the review panel was to assess the compliance of the RP reports (RP sports and RP landscaping) against the following requirements.

- The PEF-RP and related PEF-RP report are in compliance with the requirements in section 8.4 of Annex I of the PEF method;
- That the review comments on the first PEF-RP and supporting studies are addressed, reasons for non-implementation are provided;
- That any new dataset, updated default activity data and all assumptions that are at the basis of the requirements in the second draft PEFCR are implemented correctly;
- That the instructions given in sections A.2.4., A.3.2.7., A.4.2, A.4.3., A.4.4.3, A.6.1. and 4.4.9.4 are followed;
- That the GHG emissions and removals are calculated and reported following the rules of section A.4.2.9.

Review Process

The review has been performed in three distinct rounds: first, second, final.

The first round was carried out in July and August 2021 on a first version of the RP report and against the requirements of the PEF method. The panel made several comments, most of which were satisfactorily addressed by the Technical Secretariat in an updated PEFCR version.

The second round was performed between October and November 2023 on the second RP report. This version applies the requirements or the PEF method 2021. The panel made other comments which were promptly addressed by the Technical Secretariat in the final RP reports.

The final round was performed in December 2023 and January 2024 on the final RP reports. In this version, some smaller corrective actions were made in response to the remaining comments from the second review. All corrective actions were reviewed and approved.

The full list of the comments made in the two review rounds and the related responses and corrective actions from the Technical Secretariat are documented in the enclosed spreadsheet "RP Synthetic Turf Review Panel Comments Responses Final".

Review Statement

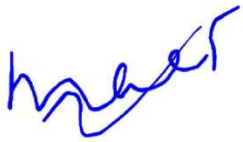
We hereby confirm that, following the RP examination, we have not established any relevant deviations by the above-referenced RP reports with respect to the requirements identified in the review scope.

We confirm we have been independent in our roles as reviewers, we have not been involved in the preparation of the PEFCR, RP, or related supporting studies and we have no conflicts of interest regarding this review.

We acknowledge the commitment undertaken by Technical Secretariat in developing this RP and the good and constructive collaboration with the TS members during the review

Yours sincerely,

January 24th, 2024

Max Sonnen	Céline Alexandre	Mickael Benetti
		Mickaël BENETTI

8 References

AMI Consulting. 2018. Artificial grass – The Global Market – 2018.

Boulay, A.-M., J. Bare, L. Benini, M. Berger, M.J. Lathuillière, A. Manzardo, M. Margni, M. Motoshita, M. Núñez, and A.V. Pastor. 2018. The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). *The International Journal of Life Cycle Assessment* 23(2): 368–378.

CEN/TR 17519:2020. Surfaces for sports areas – Synthetic turf sports facilities – Guidance on how to minimize infill dispersion into the environment. European Committee for Standardization, 2020.

Crenna, E., M. Secchi, L. Benini, and S. Sala. 2019. Global environmental impacts: data sources and methodological choices for calculating normalization factors for LCA. *The International Journal of Life Cycle Assessment* 24(10): 1851–1877.

Dreicer, M., V. Tort, and P. Manen. 1995. Nuclear fuel cycle: estimation of physical impacts and monetary valuation for priority pathways.

EN 15330-1:2013. Surfaces for sports areas. Synthetic turf and needle-punched surfaces primarily designed for outdoor use. Specification for synthetic turf surfaces for football, hockey, rugby union training, tennis and multi-sports use. https://shop.bsigroup.com/ProductDetail/?pid=000000000030262918.

European Commission. 2020. Annex C to the PEF method. https://eplca.jrc.ec.europa.eu/permalink/Annex_C_V2.1_May2020.xlsx.

European Commission. 2021. Commission recommendation on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisation, Annex 1-2. *Official Journal of the European Union, C(2021)9332 Final*.

Fantke, P., M. Bijster, C. Guignard, M. Hauschild, M. Huijbregts, O. Jolliet, A. Kounina, et al. 2017. USEtox 2.0 Documentation (Version 1). © USEtox® International Center. http://usetox.org.

Fantke, P., J.R. Evans, N. Hodas, J.S. Apte, M.J. Jantunen, O. Jolliet, and T.E. McKone. 2016. Health impacts of fine particulate matter. In *Global Guidance for Life Cycle Impact Assessment Indicators*, 76–99. SETAC.

Frischknecht, R., A. Braunschweig, P. Hofstetter, and P. Suter. 2000. Human health damages due to ionising radiation in life cycle impact assessment. *Environmental Impact Assessment Review* 20(2): 159–189.

Horn, R. and S. Maier. 2018. LANCA®-Characterization Factors for Life Cycle Impact Assessment, Version 2.5. *Fraunhofer: Stuttgart, Germany*.

ISO 14001:2015. Environmental management systems — Requirements with guidance for use. https://www.iso.org/standard/60857.html.

ISO 14025:2006. Environmental labels and declarations — Type III environmental declarations — Principles and procedures. https://www.iso.org/standard/38131.html.

ISO 14040:2006. Environmental management — Life cycle assessment — Principles and framework. https://www.iso.org/standard/37456.html.

ISO 14044:2006. Environmental management — Life cycle assessment — Requirements and guidelines. https://www.iso.org/standard/38498.html.

ISO 14071:2014. Environmental management — Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006. https://www.iso.org/standard/61103.html.

Laurentiis, V. De, M. Secchi, U. Bos, R. Horn, A. Laurent, and S. Sala. 2019. Soil quality index: Exploring options for a comprehensive assessment of land use impacts in LCA. *Journal of Cleaner Production* 215: 63–74.

Oers, L. van, A. de Koning, J.B. Guinée, and G. Huppes. 2002. Abiotic resource depletion in LCA - As an illustrative the extraction rates of 14 minerals were compared to their stocks in the natural environment (thus excluding stocks in the economy). Mineral stocks were here defined in three different ways:(June): 75.

Posch, M., J. Seppälä, J.-P. Hettelingh, M. Johansson, M. Margni, and O. Jolliet. 2008. The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterisation factors for acidifying and eutrophying emissions in LCIA. *The International Journal of Life Cycle Assessment* 13(6): 477–486. https://doi.org/10.1007/s11367-008-0025-9.

Sala, S., A. Alessandro Kim Cerutti, and Rana Pant. 2018. *Development of a weighting approach for the Environmental Footprint*. Luxembourg. https://ec.europa.eu/environment/eussd/smgp/documents/2018_JRC_Weighting_EF.pdf. Accessed January 6, 2023.

Saouter, E., F. Biganzoli, L. Ceriani, D. Versteeg, E. Crenna, L. Zampori, S. Sala, and R. Pant. 2018. Environmental Footprint: Update of Life Cycle Impact Assessment methods–Ecotoxicity freshwater, human toxicity cancer, and non-cancer. *European Union, Luxembourg*.

Seppälä, J., M. Posch, M. Johansson, and J.-P. Hettelingh. 2006. Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator (14 pp). *The International Journal of Life Cycle Assessment* 11(6): 403–416. https://doi.org/10.1065/lca2005.06.215.

Struijs, J., A. Beusen, H. van Jaarsveld, M.A.J. Huijbregts, M. Goedkoop, R. Heijungs, M.A.J. Huijbregts, A. De Schryver, J. Struijs, and R. Van Zelm. 2009. ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. *Report I: Characterisation Factors,*: 59–67.

UN Environment. 2011. Annual report 2011. https://www.unep.org/resources/annual-report/unep-2011-annual-report.

UNEP. 2016. *Global Guidance on Environmental Life Cycle Impact Assessment Indicators Volume 1*. http://www.lifecycleinitiative.org/life-cycle-impact-assessment-indicators-and-characterization-factors/.

WMO (World Meteorological Organization). 2014. *Assessment for Decision-Makers World Meteorological Organization United Nations Environment Programme WMO Global Ozone Research and Monitoring Project-Report No. 56*. http://ozone.unep.org/Assessment_Panels/SAP/SAP2014_Assessment_for_Decision-Makers.pdf.

Zelm, R. van, M.A.J. Huijbregts, H.A. den Hollander, H.A. van Jaarsveld, F.J. Sauter, J. Struijs, H.J. van Wijnen, and D. van de Meent. 2008. European characterization factors for human health damage of PM10 and ozone in life cycle impact assessment. *Atmospheric Environment* 42(3): 441–453. https://www.sciencedirect.com/science/article/pii/S1352231007008667.

ANNEX I – List of EF normalisation and weighting factors

Global normalisation factors are applied within the EF. The normalisation factors as the global impact per person are used in the EF calculations.

Table 17: List of normalisation and weighting factors for adopted in this study. Sources: (Crenna et al. 2019; Sala et al. 2018); https://eplca.jrc.ec.europa.eu/permalink/EF3_1/Normalisation_Weighting_Factors_EF_3.1.xlsx

Impact category	Unit	Normalisation factors [person eq.]	Weighting factors [%]
Acidification	mol H^+ eq.	5.56E+01	6.20%
Climate change	kg CO_2 eq.	7.55E+03	21.06%
Ecotoxicity, freshwater	CTU_e	5.67E+04	1.92%
EF-particulate matter	disease incidences	5.95E-04	8.96%
Eutrophication, freshwater	kg P eq.	1.61E+00	2.80%
Eutrophication, marine	kg N eq.	1.95E+01	2.96%
Eutrophication, terrestrial	mol N eq.	1.77E+02	3.71%
Human toxicity, cancer	CTU_h	1.73E-05	2.13%
Human toxicity, non-cancer	CTU_h	1.29E-04	1.84%
Ionising radiation	kBq U^{235} eq.	4.22E+03	5.01%
Land use	pt	8.19E+05	7.94%
Ozone depletion	kg CFC-11 eq.	5.23E-02	6.31%
Photochemical ozone formation	kg NMVOC eq.	4.09E+01	4.78%
Resource depletion, fossils	MJ	6.50E+04	8.32%
Resource depletion, minerals and metals	kg Sb eq.	6.36E-02	7.55%
Water use	m^3 water eq of deprived water	1.15E+04	8.51%

ANNEX II – Confidential report

Not needed since no data is regarded as confidential.

ANNEX III – EF compliant dataset

See ILCD package attached.

RP model landscaping.zip

ANNEX IV – PEF results per life cycle stage and alternative scenarios

Table 18: Detailed characterized results of life cycle of 8 m^2a of synthetic turf system per life cycle stage

Impact category	Unit	LCS1.1 Yarn production	LCS1.2 Primary backing production	LCS1.3 Secondary backing production	LCS2.1 Carpet manufacturing	LCS3.1 S&D of carpet	LCS4.1 Installation	LCS4.2 Operation	LCS5.1 EOL of carpet
Acidification	mol H^+ eq	3.77E-02	5.54E-03	1.94E-02	2.19E-03	1.60E-02	-5.19E-04	0	-2.63E-03
Climate change	kg CO_2 eq	5.84E+00	8.62E-01	2.69E+00	4.96E-01	9.30E-01	2.40E-01	0	1.19E+00
Ecotoxicity, freshwater	CTU_e	8.35E+01	1.23E+01	4.20E+01	1.13E+00	1.05E+01	-5.10E-01	0	-2.59E+00
Particulate matter	disease inc.	6.51E-07	9.03E-08	3.89E-07	1.62E-07	2.41E-07	-5.07E-09	0	-2.55E-08
Eutrophication, marine	kg N eq	9.39E-03	1.46E-03	4.56E-03	3.66E-04	4.65E-03	-9.77E-05	0	-5.03E-04
Eutrophication, freshwater	kg P eq	1.70E-04	4.78E-05	6.21E-05	5.18E-07	3.24E-06	3.40E-06	0	1.70E-05
Eutrophication, terrestrial	mol N eq	9.59E-02	1.46E-02	4.95E-02	4.01E-03	5.15E-02	-8.52E-04	0	-4.42E-03
Human toxicity, cancer	CTU_h	5.18E-09	5.95E-10	2.03E-09	3.48E-10	2.52E-10	-2.00E-11	0	-1.01E-10
Human toxicity, non-cancer	CTU_h	4.10E-08	7.04E-09	1.91E-08	3.33E-09	4.19E-09	7.60E-11	0	3.48E-10
Ionising radiation	kBq ^{235}U eq	6.52E-01	7.11E-02	4.00E-02	1.20E-02	1.05E-02	-4.84E-02	0	-2.42E-01
Land use	Pt	1.20E+01	1.43E+00	5.53E+00	3.71E-01	3.16E+00	-1.73E-01	0	-9.06E-01
Ozone depletion	kg CF-C11 eq	1.60E-06	4.40E-09	1.31E-08	1.31E-11	5.08E-12	-3.84E-11	0	-1.92E-10
Photochemical ozone formation	kg NMVOC eq	2.73E-02	3.95E-03	1.33E-02	1.11E-03	1.21E-02	-3.04E-04	0	-1.55E-03
Resource use, fossils	MJ	1.36E+02	1.91E+01	5.86E+01	5.62E+00	1.24E+01	-4.34E+00	0	-2.18E+01
Resource use, minerals and metals	kg Sb eq	3.96E-05	3.70E-06	1.86E-05	5.41E-08	1.64E-06	4.09E-09	0	1.84E-08
Water use	m^3 depriv.	-1.76E-01	4.61E-01	2.54E-01	1.17E-01	5.93E-02	2.76E-02	0	1.38E-01

In addition to the benchmark results, a number of alternative scenarios were calculated in the scope of the RP study. Since the purpose of these scenarios was to determine environmental impacts of different end of life destinations, a set of characterized results was sufficient and no hotspot analysis was performed.

In addition to the end-of-life scenario incorporated in the benchmark results – which consists of incineration (45%) and landfill (55%) – the TS expressed interest in quantifying environmental impacts of **individual waste treatment options**. The comparison of three distinct end-of-life destinations – 100% incineration, 100% landfill, and 100% recycling – to the benchmark (per functional unit of 8 m^2a of STS) is presented in Figure 5. The characterized results for the different scenarios are presented in Table 19.

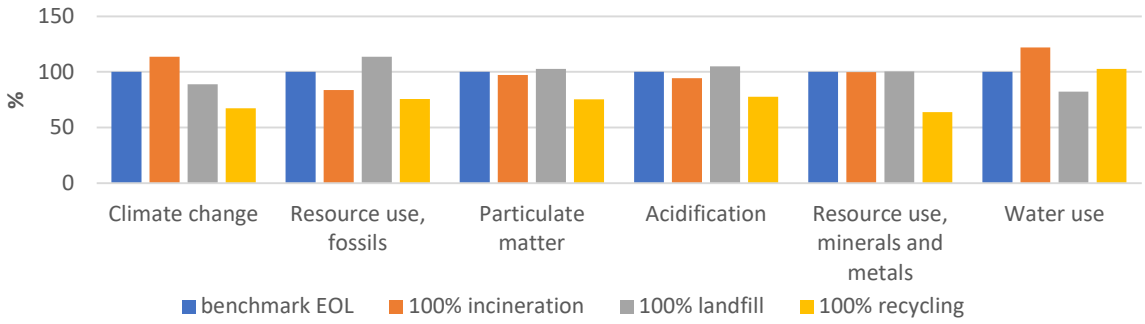


Figure 5: Characterized results of life cycle of 8 m^2a of synthetic turf system with different end of life treatments

Table 19: Characterized results of life cycle of 8 m^2a of synthetic turf system with different end of life treatments

Damage category	Unit	benchmark EOL	100% incineration	100% landfill	100% recycling
Acidification	mol H^+ eq	7.78E-02	7.32E-02	8.15E-02	6.03E-02
Climate change	kg CO_2 eq	1.23E+01	1.39E+01	1.09E+01	8.23E+00
Ecotoxicity, freshwater	CTU_e	1.46E+02	1.39E+02	1.52E+02	9.54E+01
Particulate matter	disease inc.	1.50E-06	1.46E-06	1.54E-06	1.13E-06
Eutrophication, marine	kg N eq	1.98E-02	1.89E-02	2.06E-02	1.55E-02
Eutrophication, freshwater	kg P eq	3.04E-04	2.81E-04	3.23E-04	1.71E-04
Eutrophication, terrestrial	mol N eq	2.10E-01	2.02E-01	2.17E-01	1.64E-01
Human toxicity, cancer	CTU_h	8.29E-09	8.00E-09	8.52E-09	5.38E-09
Human toxicity, non-cancer	CTU_h	7.50E-08	6.67E-08	8.18E-08	5.04E-08
Ionising radiation	kBq ^{235}U eq	4.96E-01	1.35E-01	7.91E-01	8.05E-01
Land use	Pt	2.14E+01	1.97E+01	2.27E+01	1.95E+01
Ozone depletion	Kg CFC-11 eq	1.62E-06	1.62E-06	1.62E-06	1.60E-06
Photochemical ozone formation	kg NMVOC eq	5.60E-02	5.31E-02	5.83E-02	4.31E-02
Resource use, fossils	MJ	2.06E+02	1.72E+02	2.34E+02	1.56E+02
Resource use, minerals and metals	kg Sb eq	6.36E-05	6.35E-05	6.37E-05	4.04E-05
Water use	m^3 depriv.	8.81E-01	1.07E+00	7.23E-01	9.03E-01

40, rue Belliard
1040 Brussels
Belgium