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Abstract

This deliverable deals with the evaluating of the final degrees of achievement of the project targets regarding material reduction. Further the environmental impacts and costs of the processes and products developed in the individual work packages are considered in relation to the environmental impacts of the manufacturing processes of state-of-the-art PV modules, based in LCI baseline.

Public introduction[1]

The eco-efficiency analysis (EEA) assesses and provides the ecological and economic proof of the success in the R&D in this project. This will be calculated based on *project developments* (recovery and recycling processes, reuse of material, demonstrator module, waste prevention etc.) compared to state of the art at the beginning of the project (*baseline*).

This technical report deals with the evaluating of the final degrees of achievement of the project targets regarding material reduction and with the environmental impacts and the costs of the processes and products developed in the individual work packages within the project.

Compared to the baseline the project developments show large savings potentials of key materials and environmental burdens.

Regarding sc-Si PV-modules four project targets – reduction of demand of argon gas, ceramics, process water and aluminium – can be achieved totally by implementing of all project developments into the production chain. With fulfilment levels of 95 % and 88 % another two project targets - reduction of demand of silver and organics – are well advanced. Only the reduction of the demand of silicon could not be realized close to the target value. Compared to the LCIA result of the baseline environmental advantages exist for all the examined impact categories except of human toxicity. The environmental relief potentials range from 10 % for freshwater eutrophication to a maximum of 78 % for depletion of mineral, fossil and renewable resources. The environmental impact potentials increase by less than 1 % for non-carcinogenic human toxicity and 37 % for carcinogenic human toxicity. The burdens of human toxicity are a result of the production and recycling of the galvanised steel used for NICE module Generation 2 that replaces the aluminium frame of the standard PV-module. The estimated cost savings ranges

[1] All deliverables which are not public will contain an introduction that will be made public through the project WEBsite

from 0.5 % for argon gas recovery to 2.5 % for an advanced metallization scheme. The highest cost saving potential is expected for the cell process.

Regarding mc-Si PV-modules two project targets– reduction of demand of process water and aluminium - can be achieved totally by implementation of all project developments (except the new cell process) into the production chain. With fulfilment levels between 71 % and 99 % the remaining project targets – reduction of demand of argon gas, ceramics and organics, silver and silicon – are also almost achieved and well advanced respectively. Compared to the LCIA result of the baseline environmental advantages exist for all the examined impact categories except of human toxicity. The environmental relief potentials range from 11 % for ionizing radiation on human health to a maximum of 78 % for freshwater ecotoxicity. The environmental impact potentials increase by 3 % for non-carcinogenic human toxicity and 61 % for carcinogenic human toxicity. Both deteriorations are also a result of the galvanised steels used for NICE module instead of the aluminium frame. The estimated cost savings ranges from 0.06 % for argon gas recovery to 3 % for an advanced metallization scheme. The highest cost saving potential is also expected for the cell process.

In general the project developments for both PV module types show a better eco-efficiency with low cost advantages and partly significant environmental relief potentials. The total ecological benefit achieved for sc-Si PV modules is 45 % and for mc-Si PV modules 42 %.

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1 INTRODUCTION

The eco-efficiency analysis (EEA) assesses and provides the ecological and economic proof of the success in the R&D in this project. This will be calculated based on *project developments* (recovery and recycling processes, reuse of material, demonstrator module, waste prevention etc.) compared to state of the art at the beginning of the project (*baseline*).

A strength of the eco-efficiency analysis is the simultaneous consideration of ecological aspects in a life cycle assessment (LCA) and economic aspects in a life cycle costing (LCC) due to identify the most promising project developments.

For the comparison with the new processes and products developed in this project a standard EVA laminated module (60 6-inch solar cells) with front glass and polymer back sheet including aluminium framing was defined as baseline. The research of recently published life cycle inventory (LCI) data is finished and data gaps were filled by using expert assumptions. All project partners provided input for the LCI. The results were reviewed by the project team and the PV experts in the consortium. Based on the LCI a material and energy flow model for *baseline* was created.

For each project development in the individual work packages of this project, the material and energy flow model was modified based on information and LCI data by the project partners.

This deliverable deals with the evaluating of the final degrees of achievement of the project targets regarding material reduction. Further the environmental impacts and costs of the processes and products developed in the individual work packages are considered in relation to the environmental impacts and costs of the manufacturing processes of state-of-the-art PV modules.

2 METHODOLOGICAL PRINCIPLES

The decisive components of the examination are an ecological assessment of the environmental impact, cost considerations and their combination within the context of an eco-efficiency analysis. Figure 2.1 summarizes the steps for determining and considering the joint environmental and economic impact.

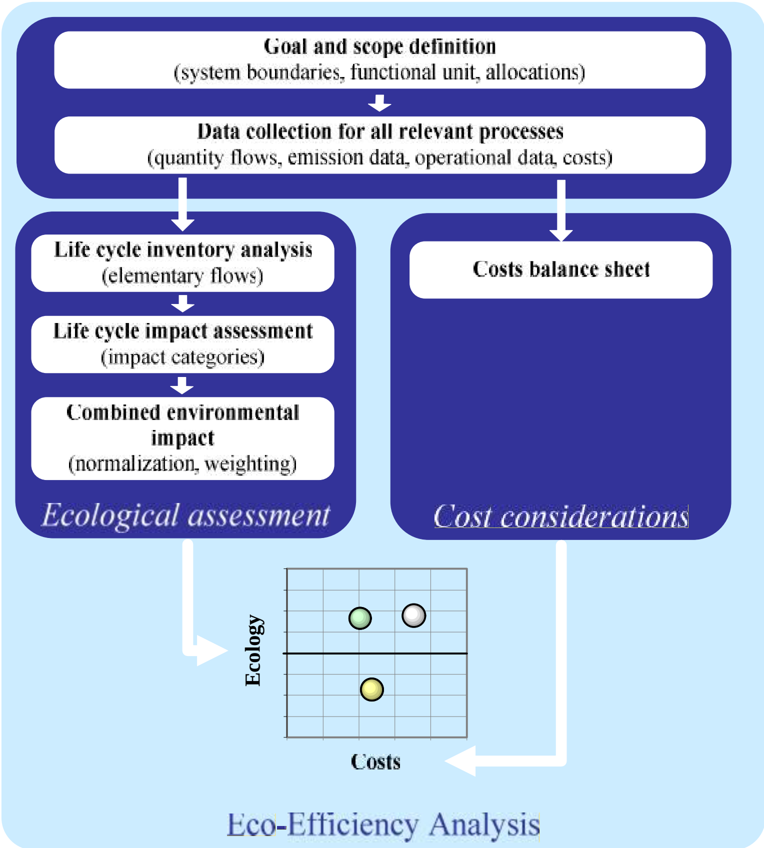


Figure 2.1: Steps for considering the joint environmental and economic impact within the context of the eco-efficiency analysis

The ecological assessment is based on life cycle assessment standards and as a result provides individual values which characterize the environmental impact of the processes. The goal and scope definition include the determination of functional unit and system boundaries. For the cost considerations, the cost savings expected from the project developments are approximated. Finally, the eco-efficiency analysis compares the result of the LCA with the expected cost savings.

2.1 Life cycle assessment examination

Under the LCA we refer to a system analysis method for integrated, media-wide recording and evaluation of environment-related matters in connection with products, processes and services. LCA are characterized by the analyses of environmental influences in association with prior or subsequent life cycle stages. Also considered here are inputs and withdrawals of raw materials and energy to and from environmental media, namely water, air and earth.

Overall, LCA can make a comprehensive statement on the relevance to the environment of the systems investigated and are therefore optimally suited for environment-related comparison of various systems.
This cycle assessment examination carried out under the norm specifications for the execution of eco-balances DIN EN ISO 14040 and DIN EN ISO 14044. Starting with the definition of target under the terms of the life cycle inventory analysis, all relevant parameters were recorded and summarized in the life cycle impact assessment regarding their environmental impact. The results were assessed and interpreted.

2.1.1 Goal and scope definition

The goal and scope definition include the determination of functional unit and system boundaries.

2.1.1.1 Functional unit

The focus of an LCA is the functional unit defined in ISO 14041 as "Quantified use of a product system for the application as comparative unit in an eco-balance study". This is the reference both for the comparison of observed scenarios and the norm for the input and output data given in the study.
The functional unit is specified with one sc-Si PV-module and one mc-Si PV-module, respectively, with a PV-module area of 1.677 m².

2.1.1.2 Scenarios

As already mentioned in chapter 1 a state-of-the art reference PV-module should be compared to the developments made in the project for new products and processes. The various contents will be represented using different scenarios.
The state-of-the art reference PV-module was modelled in the scenario *baseline*. The project developments are modelled in several scenarios named after the new process or product:

- Argon gas recovery
- Reusable crucibles
- New wire sawing process with thinner diamond wire
- New silicon kerf recovery process from sawing machines coolant
- New cell process
- Reuse process water
- Advanced metallization scheme
- Cell doctor
- Usage of an EVA-free glass/glass frameless NICE module Generation 2
- Combination of all project developments

2.1.1.3 System boundaries

In order that scenarios can be compared, the functional unit must also be specified and the boundaries for the study of all comparative scenarios be defined. As set forth in ISO 14041 the system boundary specifies the modules which shall be taken up into the system. In the ideal situation, the system shall be modelled such that inputs and outputs are elementary flows on their system boundaries (c.f. Figure 2.2).
In the case that there are simply not enough data and means available in order to carry out such a comprehensive task then decisions must be made as to which modules shall be

included or which emissions must be considered and at what level of precision the modules shall be examined or emissions recorded [ISO 14041].

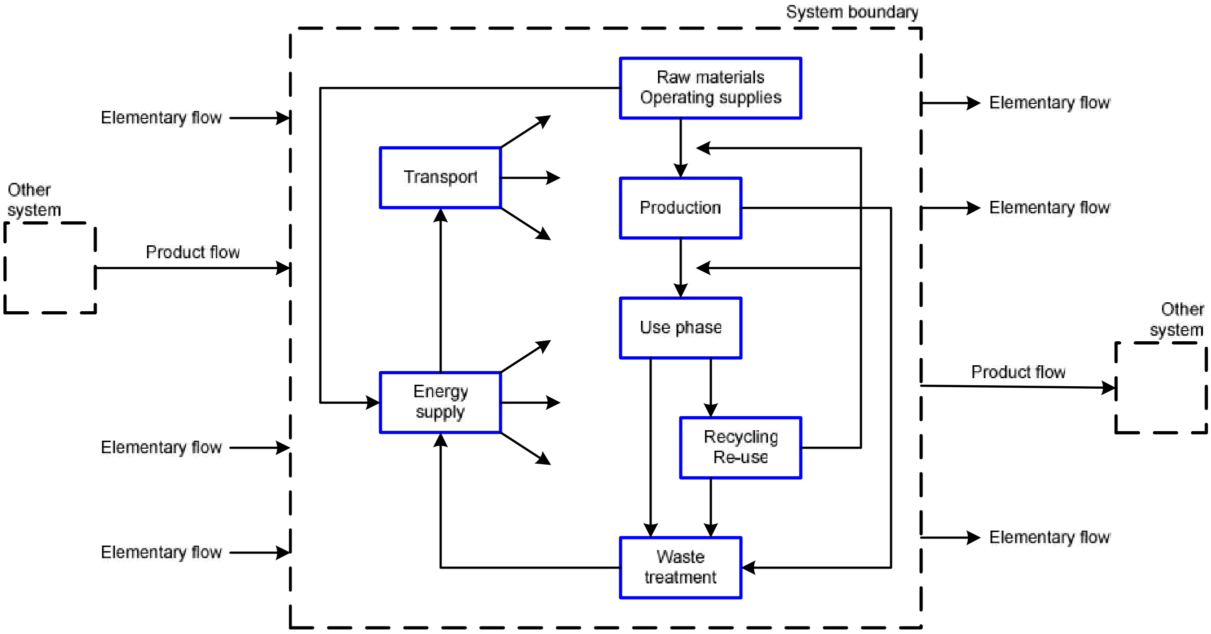


Figure 2.2: Example of a product system [ISO 14041]

The following processes are considered within the system boundaries:

- Manufacture and disposal of PV-modules including any treatment of remaining residues or recyclable materials.
- All transports, from the supply of raw material and pre-products through to disposal.
- All relevant material and energy flows associated with the processes from extraction and treatment of raw materials through supply of the operating materials and starting products and insofar as possible also including the disposal of residues. In ideal circumstances the system boundaries also include the gain of raw materials from natural deposits, making these available for technical processing, and the release of elementary flows to the environmental media of water, air and earth.

Data gaps and assumptions

When setting the limits for the complexity of the model, care must be taken that for the product examined there is a possibility for comparison of the specific scenarios. In this section the criteria described for the determination of the system boundaries are specified.

The specifications of ISO 14041, namely, that the material and energy input (input side) and the emissions and products (output side) shall be elementary flows for the system boundaries, were considered as far as possible in the modelling. For all input materials and fuels within the detailed boundaries described below, prior chains have been modelled beginning with the extraction from natural resources up until these are made available for the respective procedure. If no relevant data were available, then comparable procedures were examined and assumptions made accordingly.

Detail boundaries of upstream processes

The manufacture of raw materials, operating materials and starting materials in upstream processes (processes preceding the respective module) is not considered if the detailed

boundaries defined in this section as criteria are applicable. In such cases in the balance sheet in place of the elementary flow the respective material flow is shown.
The detail boundary for neglecting the modelling of upstream processes of input material was specified at 1 % weight of a reference flow (mostly the output required). The sum of all neglected input materials for a process should be however, not greater than 3 % weight of the reference flow. The exceptions to this are materials with a small mass, when the upstream process could be significant for the overall LCA in respect of toxic or energy aspects.

Detail boundaries of downstream processes
For waste the same criteria apply as for the downstream processes (processes following the respective module), i.e. the disposal was then modelled when the cut-off criteria were not sufficient and when the description of modules or datasets used from libraries or data bases did not indicate that these were considered.

Offset of credits in equivalence systems
As well as the analysed product, which is the main benefit, there could be additional benefits from recycling processes at the end of the life cycle. These include e.g. electricity and heat from waste incineration or secondary raw materials from recycling. As a result, the appropriate energy quantities and products are not to be made conventionally from primary raw materials (assuming that demand remains the same). The effects on the environment associated with conventional production of an individual additional benefit are therefore "saved" or "avoided". To complete the scenarios, the "avoided" environmental impacts are balanced out and "credited" to the environmental impacts of the respective product[2].
For a complete analysis it was necessary to balance the environmental impacts as associated with conventional production of an equivalent material and energy quantity. The "saved" environmental impacts are thus credited to the environmental impacts of the product system. This means that the elementary flows retained by balancing the conventional manufacturing process are attributed to the respective system as a credit i.e. to be offset against the environmental impacts of the product system examined.
The conventional production process for an additional benefit is designated as "equivalence process" or "equivalence system". For each quantifiable additional benefit a model has been created for a specific equivalence system which produces the same or comparable functional equivalent benefit. Due to quality losses or process related reasons the additional benefits do not always substitute primary raw materials with 100 %. This ratio is described by a so-called substitution factor as per case or specific to the material.
The procedure described has the advantage that the net result of the LCA is related only to the system input and output which is directly related to the functional unit. The evaluation of results is therefore made easier and the informative value is thus increased. Figure 2.3 shows the necessary consideration of equivalence processes and credits in simplified form based on the example of waste incineration.

[2] The elementary flows (credits) contained in the balancing of the conventional production of additional benefit are deducted from the environment effects of the respective balance model (gross result) in order to reach a net result. Negative net results can thus also occur.

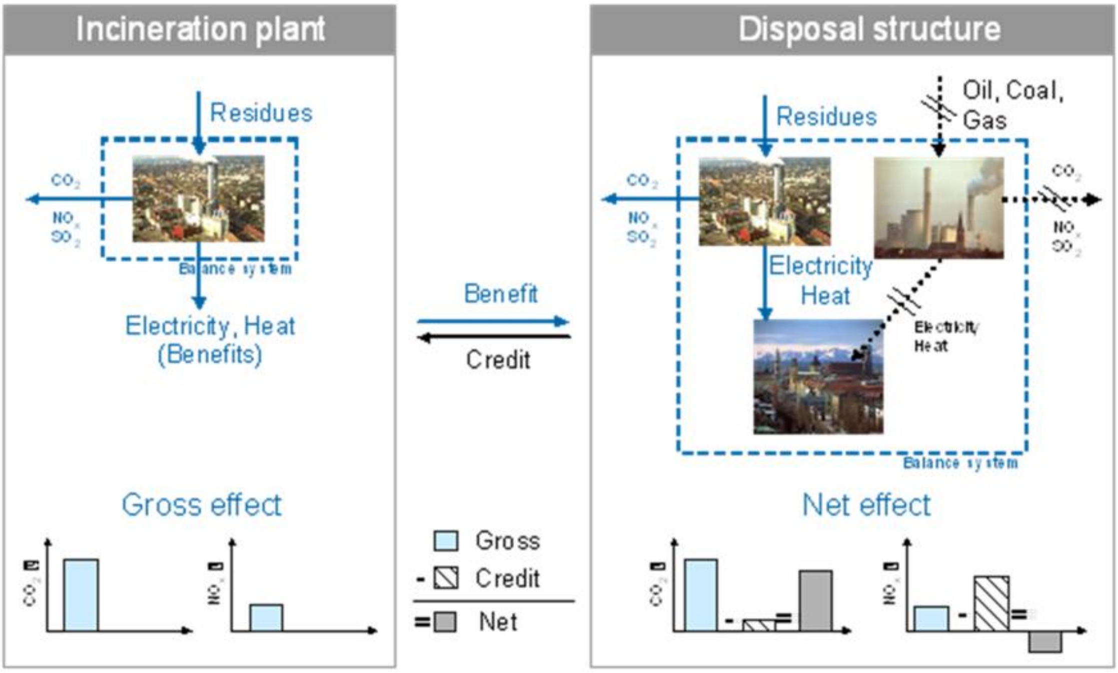


Figure 2.3: Example of a product system [ISO 14041]

The allocation method represented under Figure 2.3 is applied to all further additional and quantifiable benefits. The system boundaries for additional benefit as a rule are selected such that benefits demanded by the market are treated as output from the examined product system. If in the case of secondary or primary raw materials there was no functional or technical equivalence such that both quantities could not be seen as identical, then a substitution factor was considered.

Geographic and time reference

For classifying the LCA results and assessing the data validity or, if applicable, maintaining the comparability with other LCA, a geographic and temporal reference must be defined.

The geographical coverage arises out of the economic context and from the product definition (e.g. production site, supply chains, etc.). The time-period coverage extensively reflects the reference year/ reference period of the data collection [Klöpffer 2009].

The plans and datasets used in general cover the market situation in Western Europe or World respectively. They are taken from bifa and project partners internal or commercial databases (essentially ecoinvent database) in versions mainly with a time reference beginning from 2015 and newer. Data investigations by project partners mainly have been carried out in 2016/17.

2.1.2 Life cycle inventory analysis

Drawing up an LCI includes the collection, deduction and preparation of specific process input and output data, system and process modelling and the calculation of the LCI. The latter quantify input and output flows for the complete balance system or for specified part or equivalence systems. The LCIs are a basis for the LCIA and, also in the form of net results, for evaluations.

The modelling of the investigated product system is an essential basis for data recording and calculating the respective balance. It is necessary therefore to identify the processes relevant

for the respective system model and to determine or deduct the required data. The system model thus forms the basis for data recording, the system calculation and all associated calculation procedures. Modelling and balancing were undertaken with the software program GaBi[3].
To obtain the LCI data, extensive information from the project partners, data bases, specialist literature together with corporate information and publications of related LCA studies were collected, sighted and evaluated. LCI is described in chapter 3.

2.1.3 Life cycle impact assessment

2.1.3.1 Procedures

Together with the definition of goal and scope as well as the LCI the third component of an LCA is the LCIA. Under the framework of LCIA the comprehensive results of the LCI are summarized and prepared for evaluation. The results of the LCI are aligned as far as possible in terms of (potential) environmental impacts and within these impact categories are calculated as accumulated values.
Each of the impact categories is related to a more or less complex impact mechanism, at the end of which there are undesired effects on one or more environmental issues. At the beginning is the release of certain substances from the examined system or an approach into the environment caused by the system. The name of the impact category designates its impact mechanism.

2.1.3.2 Selection of the impact categories and assignment of LCI parameter

Each impact category is determined by one or more appropriate impact indicators. The impact indicator defines the relationship between the examination system characterized by the LCI and the impact category midpoint in terms of environment and should represent the impact category as well as possible. The impact indicator can be selected from the life cycle results or impact points throughout the whole of the environmental impact mechanism. In this way it may be that direct emissions from the LCI are also used as impact indicators.
The selection of impact categories observed within a specific LCA is oriented to the current state of environment-related knowledge and as necessary also to the project-specific cognitive interest. The development of ecological balancing and environment-related discussions during the last years has led to commonly around more than ten impact categories which are considered on the grounds of their relatively high environmental relevancy. In this project the impact categories necessary for the calculation of eco-efficiency according to the method described in [Offermann 2017] were examined. The selected LCIA methods correspond to the methods recommended by the Joint Research Centre (JRC) of the European Commission in the International reference Life Cycle Data System (ILCD) handbook (cf. Table 2.1). The ILCD Handbook embraces a series of guidance documents to facilitate best life cycle assessment practice [JRC 2017].
The evaluation is then based essentially on the indicator results as calculated for the individual impact indicators. If several LCI parameters are combined under one impact indicator then for the conversion of the LCI results a joint unit of the impact indicator is necessary. For this, more or less complex characterization models are used which describe the relationship between the impact indicator and the assigned life cycle assessment parameters.

[3] GaBi = LCA software from thinkstep AG

These models can lead to a common characterization factor, e.g. kg CO_2 equivalent per kg of the emitted greenhouse gas, whereby the LCI results are converted to this joint unit and can then be summed to the impact indicator result.

Table 2.1: Recommended methods and their classification at midpoint [JRC 2011]

Impact category	Recommended default LCIA method	Indicator
Climate change	Baseline model of 100 years of the IPCC	Radiative forcing as Global Warming Potential (GWP100)
Ozone depletion	Steady-state ODPs 1999 as in WMO assessment	Ozone Depletion Potential (ODP)
Human toxicity, cancer effects	USEtox model [Rosenbaum 2008]	Comparative Toxic Unit for humans (CTUh)
Human toxicity, non-cancer effects	USEtox model [Rosenbaum 2008]	Comparative Toxic Unit for humans (CTUh)
Particulate matter/ Respiratory inorganics	RiskPoll model [Rabl and Spadaro, 2004, Greco 2007]	Intake fraction for fine particles (kg PM2.5 eq/kg)
Ionising radiation on human health	Human health effect model as developed by Dreicer et al, 1995 [Frischknecht 2000]	Human exposure efficiency relative to U235
Photochemical ozone formation	LOTOS-EUROS [Van Zelm 2008] as applied in ReCiPe	Tropospheric ozone concentration increase
Acidification	Accumulated Exceedance [Seppälä 2006, Posch 2008]	Accumulated Exceedance (AE)
Terrestrial eutrophication	Accumulated Exceedance [Seppälä 2006, Posch 2008]	Accumulated Exceedance (AE)
Eutrophication of marine ecosystems	EUTREND model [Struijs 2009] as implemented in ReCiPe	Fraction of nutrients reaching marine end compartment (N)
Freshwater eutrophication	EUTREND model [Struijs 2009] as implemented in ReCiPe	Fraction of nutrients reaching fresh water end compartment (P)
Ecotoxicity freshwater	USEtox model [Rosenbaum 2008]	Comparative Toxic Unit for ecosystems (CTUe)
Resource depletion, mineral, fossil and renewable[1)]	CML 2002 [Guinée 2002]	Scarcity

[1)] Depletion of renewable resources is included in the analysis but none of the analysed methods is mature for recommendation

2.1.3.3 Description of the impact categories

Impact categories considered in the Life Cycle Impact Assessment (LCIA) include climate change, ozone depletion, eutrophication, acidification, human toxicity (cancer and non-cancer related), respiratory inorganics, ionizing radiation, ecotoxicity, photochemical ozone formation, land use, and resource depletion. The emissions and resources derived from LCI are assigned to each of these impact categories. They are then converted into indicators using factors calculated by impact assessment models. These factors reflect pressures per unit emission or resource consumed in the context of each impact category. Emissions and resources consumed, as well as different product options, can then be cross-compared in terms of the indicators. [JRC 2010a]

Climate change

Manmade climate change is caused by the emission of greenhouse gases (and by other activities influencing their atmospheric concentration). Greenhouse gases are substances with the ability to absorb infrared radiation from the earth (radiative forcing). When modelling the radiative forcing of an emission, the change in concentration and radiative forcing is determined, taking into account the residence time of the substance. A globally-recognised model (the Bern model) has been developed by the Intergovernmental Panel on Climate Change (IPCC) that calculates the radiative forcing of all greenhouse gases and branded them Global Warming Potentials (GWP). [IRC 2010]

IPCC has three versions of the method, indication three different timeframes. The impact in terms of cumulative radiative forcing of greenhouse gas (GHG) emissions is either cut off after 20, 100 or 500 years. At midpoint level, GWP's from the Intergovernmental Panel on Climate Change is recommended. It is based on the most up-to-date and scientifically-robust consensus-based model available, which produces characterisation factors based on radiative forcing and residence time of the GHG emitted.

On the other hand, it is clear that in almost all policy instruments, like for instance the Kyoto Protocol, the 100 year perspective is used and that this time perspective has the broadest acceptance. Recommendation of the 100-year timeframe is propose das default, but it is also suggested to use the shorter (20-year) and longer (500-year) timeframes as a sensitivity analysis. This check is especially relevant when assessing agricultural systems, as the N_2O often emitted in these systems has a long lifetime, and thus has a significantly higher characterisation factor (factor 2) in the 500 year perspective compared to the 100 year perspective. Methane has almost a factor 4 lower characterisation factor in the 500 years perspective.

EPS converts IPCC damage estimates to estimates that can be related to a kilogram of CO_2-equivalent emission. [IRC 2011a]

Ozone depletion

Ozone depletion occurs if the rate of ozone destruction is increased due to fugitive losses of anthropogenic substances which persist in the atmosphere. Stratospheric ozone, which is 90% of the total ozone in the atmosphere, is vital for life because it hinders harmful solar ultraviolet UV-B radiation from penetrating the lower levels of the atmosphere. If not absorbed, UV-B radiation below 300 nanometres will reach the troposphere and the surface of the earth, where it can increase the human risk of skin cancer and cataract when appropriate precautions are not taken. It may also cause premature aging and suppression of the immune system. In addition to the increased risk to Human Health's the UV-B radiation can also damage terrestrial plant life and aquatic ecosystems. The characterization factor for ozone depletion accounts for the destruction of the stratospheric ozone layer by anthropogenic emissions of ozone depleting substances (ODS). These are persistent chemicals that contain chlorine or bromine atoms. Because of their long atmospheric lifetime Cl and Br can reach the stratosphere. Chlorine atoms in chlorofluorocarbons (CFC) and bromine atoms in halons are effective in degrading ozone due to heterogeneous catalysis, which leads to a slow depletion of stratospheric ozone around the globe. The chlorine and bromine atoms that are released from these reactions have the ability to destroy a large quantity of ozone molecules in the stratosphere because they act as free radical catalysts in a sequence of degradation reactions, in which they react with ozone to split it into molecular and atomic oxygen without being consumed [WMO 2003].

The ODPs are equivalency factors that encompass the atmospheric residence time of ozone depleting substances, the formation of EESC and the resulting stratospheric ozone depletion. As there is a wide consensus about the use of OPD's for characterisation at midpoint, only one representative was selected, in this case the EDIP method, which is based on the 1999 WMO assessment [WMO 1999]. [IRC 2011a]

Human toxicity, cancer effects and non-cancer effects

LCA characterisation models and factors for toxic effects rely on models that account for a chemical's fate in the environment, human exposure, and differences in toxicological response (both likelihood of effects and severity). The scope and methodology of an LCA differs from that of many approaches adopted for toxicological assessments in a regulatory context. Regulatory assessments of chemical emissions usually have the objective of evaluating whether there will be an unacceptable risk of a toxicological effect to an individual or subpopulation.

USEtox is the preferred choice as a default method for the calculation of characterisation factors - straightforward multimedia models are widely used in LCIA for modelling chemical fate and human exposure. USEtox reflects the latest consensus amongst such modellers and their associated models. It also reflects the principles of the earlier OECD consensus model [Klasmeier 2006] that focused on fate and long-range transport of contaminants. Like the other multimedia model based approaches, USEtox includes several vital model elements of toxicological effects assessment [Hauschild 2008]. The model has been set up to model a global default continent, and it has a nested multimedia model in which it is possible to consider global, continental and urban scale differentiation.

In USEtox, a distinction is made between recommended and interim characterization factors, reflecting the level of expected reliability of the calculations in a qualitative way [Rosenbaum 2008].

The calculation of separate midpoint factors for cancer and non-cancer is recommended, as at least this distinction of effects is generally feasible in current practice and likely significant. [JRC 2011a]

Particulate matter/Respiratory inorganics

Ambient concentrations of particulate matter (PM) are elevated by emissions of primary and secondary particulates. The mechanism for the creation of secondary emissions involves emissions of SO_2 and NO_x that create sulphate and nitrate aerosols. Particulate matter is measured in a variety of ways: total suspended particulates (TSP), particulate matter less than 10 microns in diameter (PM10), particulate matter less than 2.5 microns in diameter (PM2.5) or particulate matter less than 0.1 microns in diameter (PM0.1).

The pollutant can be a single chemical (e.g. CO) or group of agents (e.g. PM2.5). The fate factor relates the emission flow to the mass in the air. The exposure factor determines the change in intake rate per change in mass in the environment. The dose-response slope relates the change in intake with the marginal change in morbidity and mortality cases and the severity is the change in damage per morbidity and mortality case. [IRC 2010]

RiskPoll [Rabl and Spadaro, 2004] makes a complete assessment of impacts and damage costs due to primary and secondary PM, including model for creation of secondary PM due to

SO_2 and NO_x emissions. It also parameterizes the dominant factors of influence for generic landscape characteristic.

[Greco 2007] represents an interesting alternative to RiskPoll:

a. it covers both primary and secondary aerosols (apart from NH_3);
b. population densities can be adapted to match any landscape parameters (because of regressions).

   Weaknesses are:

   1. does not evaluate secondary PM from NH_3,
   2. only addresses mobile (i.e., low stack) sources, and
   3. cannot adapt to different wind speeds. [IRC 2011a]

The RiskPoll model [Rabl and Spadaro 2004, Greco 2007] is applied in this study.

Ionising radiation on human health

The same framework for human toxicity and ecotoxicity applies for ionizing radiation: the modelling starts with releases at the point of emission, expressed as Becquerel (Bq), and calculates the radiative fate and exposure, based on detailed nuclear physics knowledge.

For human toxicity, the exposure analysis calculates the dose that a human actually absorbs, given the radiation levels that are calculated in the fate analysis. The measure for the effective dose is the Sievert (Sv), based on human body equivalence factors for the different ionising radiation types (radiation, neutrons: 1 Sv = 1 J/kg body weight). [JRC 2010]

For damage to human health related to the routine releases of radioactive material to the environment, the method described in [Frischknecht 2000] has been considered, since to our knowledge this is the only method that meets the general requirements for a quantitative approach.

[Frischknecht 2000] list the DALYs (disability-adjusted life years) for the same types of cancers which are used for human carcinogens, with 0.05 fatal and 0.12 non-fatal cases per Man-Sv, as reported by [Ron and Muirhead 1998]. Radiation induced cancer cases are assumed to occur at the same age pattern as for other cancer causes. The number of severe hereditary effects is assumed to be 0.01 case per Man-Sv [ICRP-International Commission on Radiological Protection, 1999], resulting in 61 DALYs per case without age weighting.

Since currently only a single method is presently considered relevant for each of the ionizing radiation subcategories, no detailed criteria-based comparison is planned as with the other impact categories. Hence no specific criteria have been developed for this impact category. Instead the evaluation is focused on the level of quality reached by the available methods within each main criterion. [IRC 2011a]

Photochemical ozone formation

The negative impacts from the photochemically generated pollutants are due to their reactive nature which enables them to oxidise organic molecules on the surfaces they expose. Impacts on humans arise when the ozone and other reactive oxygen compounds are inhaled and come into contact with the surface of the respiratory tract, where they damage tissue and cause respiratory diseases. Impacts on vegetation arise when the reactive compounds attack the surfaces of the plants or enter the stomata of the plant leaves and cause oxidative damage on photosynthetic organelles. [IRC 2010]

The impact category appears under several different names in the various LCIA methodologies: (tropospheric) ozone formation, photochemical ozone formation or creation, photo oxidant formation, photo smog, or summer smog. There are minor differences in terms of substances included and atmospheric and meteorological conditions assumed in the

modelling, but in essence they all address the impacts from ozone and other reactive oxygen compounds formed as secondary contaminants in the troposphere by the oxidation of the primary contaminants Volatile Organic Compounds (VOC) or carbon monoxide in the presence of nitrogen oxides, NO_x under the influence of light.
As applied in the ReCiPe method for photochemical ozone formation [Van Zelm 2008], the LOTOS EUROS model consists of a detailed model of the impact on human health.
ReCiPe currently calculates the indicator value by summing impacts from grid cells in which there is a resident human population. This gives the indicator a bias towards human health impacts and makes it inappropriate to represent impacts on the AOP Natural environment. The recommendation is therefore to calculate the area- and time integrated ozone concentration increases by the LOTOS-EUROS model, aggregating over all of Europe without giving priority to inhabited regions, before applying these as characterisation factors at midpoint level for photochemical ozone formation. Factors should be provided for NMVOC, CH_4, CO and NO_x, at present factors for CO and CH_4 are missing (more long-lived than the typical NMVOC and hence dispersed over a larger region). [IRC 2011a]
LOTOS-EUROS [Van Zelm 2008] is applied in this Study.

Acidification
This impact category addresses the impacts from acidification generated by the emission of airborne acidifying chemicals. Acidification refers literally to processes that increase the acidity of water and soil systems by hydrogen ion concentration. It is caused by atmospheric deposition of acidifying substances generated largely from emissions of nitrogen oxides (NO_x), sulphur dioxide (SO_2) and ammonia (NH_3), the latter contributing to acidification after it is nitrified (in the soil). [IRC 2010]
Current LCIA characterization models focus on terrestrial acidification as it tends to precede aquatic acidification when inland water is acidified after the depletion of the acid neutralization capacity of its watershed. The impact indicators of existing methods cover the majority of impact mechanisms and relevant elementary flows for the Area of Protection (AOP) Ecosystem Quality. The method of Accumulated Exceedance (AE) [Seppälä 2006] provides European Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication. The atmospheric transport and deposition model to land area and major lakes\rivers is determined using the EMEP model combined with a European critical load database. The acidification potential is expressed in accumulated Exceedance. The dose-response curve implicitly equals 1. A more recent publication [Posch 2008] updated the factors of the AE method using the newest 2006 version of the EMEP Eulerian atmospheric dispersion model [Tarrason 2006], which provides also depositions onto different land cover categories, and the newest critical load data base [Hettelingh 2007] consisting of about 1.2 million different ecosystem such as forests, surface waters, and semi-natural vegetation. [IRC 2011a]

Eutrophication, terrestrial, marine ecosystems and freshwater
The eutrophication addresses the impacts from the macro-nutrients nitrogen and phosphorus in bio-available forms on aquatic and terrestrial ecosystems.
In natural terrestrial systems, the addition of nutrients may change the species composition of the vegetation by favouring those species which benefit from higher levels of nutrients to grow faster than more nutrient efficient plants. This therefore changes the plant community from nutrient-poor (e.g. heath lands, dunes and raised bogs) to nutrient rich and more commonly, due to the widespread dispersion of nutrients, plant communities. The primary

impact on the plant community leads to secondary impacts on other species in the terrestrial ecosystem. Terrestrial eutrophication is caused by deposition of airborne emissions of nitrogen compounds like nitrogen oxides (NOx = NO and NO_2) from combustion processes and ammonia, NH3 from agriculture. Airborne spreading of phosphorus is not prevalent, and terrestrial eutrophication is therefore mainly associated with nitrogen compounds. [IRC 2010]
As midpoint characterisation method for terrestrial eutrophication it is recommended the use of the Accumulated Exceedance ([Seppälä 2006], and [Posch 2008]), classified as being "recommended with some improvements needed".
In aquatic systems, the addition of nutrients has a similar primary impact by fertilising the plants (algae or macrophytes) with several consequences for the ecosystem:
Species composition of the plant community changes to more nutrient-demanding species;
Algal blooms create shadowing, filtering the light penetrating into the water mass, changing life conditions from the macrophytes, which need the light for photosynthesis, and for predatory fish which need the light to see and catch their prey;
Oxygen depletion near the bottom of the water body where dead algae deposit and degrade.
All these consequences lead to a change in the species composition and of the function of the exposed aquatic ecosystem. [IRC 2010]
The midpoint method recommended for aquatic eutrophication (both fresh water and marine) is the method developed by [Struijs 2009] that uses the EUTREND model for atmospheric emissions and distinguishes freshwater systems (only P-emissions considered) and marine systems (only N considered). It is classified as being "recommended with some improvements needed". [IRC 2011a]

Freshwater ecotoxicity
Models and factors for toxicity effects in LCA must be based on the relative risk and associated consequences of chemicals that are released into the environment. These must build on the principles of comparative risk assessment, while providing indicators linked to the Area of Protection "Natural Environment". LCA characterisation models and factors for toxicity effects must be based on models that account for a chemical‘s fate in the environment, species exposure, and differences in toxicological response (likelihood of effects and severity). The scope and methodology of an LCA differs from that of many approaches adopted for toxicological assessments in a regulatory context. In LCA it is desirable to account for the full extent of the likelihood of an effect (recommended midpoint indicator basis) and differences in severity (recommended endpoint indicator basis). [IRC 2010]
USEtox is preferred as the recommended default method for the midpoint evaluation of freshwater ecotoxicity impacts. This is equally consistent with the model recommended for toxicity impacts for humans. It results from a consensus building effort amongst related modellers and, hence, the underlying principles reflect common and agreed recommendations from these experts. The model accounts for all important parameters in the impact pathway as identified by a systematic model comparison within the consensus process. The model addresses the freshwater part of the environment problem and includes the vital model elements in a scientifically up-to-date way. USEtox has also been set up to model a global default continent. In USEtox, a distinction is made between interim and recommended characterization factors, reflecting the level of expected reliability of the calculations in a qualitative way [Rosenbaum 2008]. Ecotoxicological characterisation factors for 'metals', 'dissociating substances' and 'amphiphilics' (e.g. detergents) are all classified as interim in USEtox. The providers argue that this is due to the relatively high uncertainty of addressing

fate and effects for all chemicals within these substance groups at this time. For the remaining set of chemicals, recommended aquatic ecotoxicological characterisation factors are based on effect data of at least three different species covering at least three different trophic levels (or taxa)
No available method is recommended to address marine and terrestrial ecotoxicity. It should be noted that the use of indicators for freshwater ecosystems is not a proxy for marine and terrestrial ones and, in many cases, only accounts for part of the long-term fate and ecosystem exposure of emissions. Actually, chemicals that doesn't remain long in fresh water and have a high persistence may imply terrestrial or marine effects not yet addressed by USEtox. [IRC 2011a]

Resource depletion, water, mineral, fossil and renewable
Van Oers 2002 describe the depletion of resources as follows: abiotic resource depletion is the decrease of availability of the total reserve of potential functions of resources, due to the use beyond their rate of replacement‖. This impact category considers the effect on both renewable and non-renewable resources. Depletion of minerals and fossil fuels falls within the category non-renewable resources, while extraction of water, wind (abiotic) and wood (biotic) falls within renewable resources.
The depletion of biotic resources is considered in the impact category "Resource Depletion". Water is treated as a separate issue, as it has many unique properties that make the problem of water availability very different from such factors as, for example, mineral resources.
For the impact of renewable resource use, such as wood and fish, two main approaches are used: One based only on the amount of renewable resource used (expressed as weight, volume or exergy), and another based on the amount of renewable resource used, considering the regeneration rate. [IRC 2010]
The methods such as Swiss Ecoscarcity 2007 and CML 2002 are recommended to describe depletion of resource. The Swiss Ecoscarcity method [Frischknecht 2008] covers several resource depletion categories. Fossil depletion is characterised by using the net calorific value of the fuels as the basis of the characterisation. The renewable energy is characterised by the amount produced. Fossil and renewable energy can be combined using the distance-to-target approach, where the difference between the actual use and the desired target use, set by the Swiss government form the basis of the weights adopted. For non-renewable resources, the energy content (net calorific value, in MJ) is multiplied by a factor of 3.3, while the renewable energy resources are multiplied with a factor 1.1. As a consequence, this impact category concerns not only one but two midpoints. For non-renewable resources, MJ (higher heating value) per kg is used as a characterisation factor. For renewable resources, a correction factor is sometimes used for the ratio between primary energy input and produced energy. Wood is only considered to be renewable if there is an appropriate forest-management regime.
CML 2002 method includes non-renewable resources (fossil fuels and minerals). In Guinée et al. [Guinée 2002] only the ultimate stock reserves are included, which refers to the quantity of resources that is ultimately available, estimated by multiplying the average natural concentration of the resources in the earth's crust by the mass of the crust [Guinée 1995]. In Van Oers 2002, additional characterisation factors have been listed based on USGS economic reserve and reserve base figures in addition to the ultimate reserve. The characterisation factors are named 'abiotic depletion potentials' (ADP) and expressed in kg of antimony equivalent, which is the adopted reference element. The abiotic depletion potential is calculated for elements and, in the case of economic reserves and reserve base, several mineral compounds. [IRC 2011a]

2.1.4 Combination of individual results to create the ecology index

The individual results were combined to create the overall ecology index in three steps:

1. Standardization:
   The individual results were converted in the common reference unit of “population equivalents“.
2. Weighting:
   The individual impact categories were weighted based on the method adopted from [Offermann 2017].
3. Combining:
   The weighted results were combined to create the ecology index based on the method adopted from [Offermann 2017].

2.1.4.1 Standardization: Calculation of population equivalents

In DIN EN ISO 14044 standardization is one of the optional components of impact assessment. The starting point for the aggregating of the individual impact indicators/lifecycle inventories is presented by the population equivalent values (PE), which are calculated from the respective impact indicators/lifecycle inventories and the corresponding total emissions in Europe (EU-27[4]). Positive population equivalents represent an environmental impact, while negative population equivalents signify ecological benefits.

The population equivalents calculated within the context of standardization enable a comparison of the various impact indicator results in terms of order of magnitude. The larger the number of population equivalents, the more significant this impact category is for the environmentally-related assessment of the considered procedure or scenarios in terms of their contribution to the environmental impact. The population equivalent as parameter for determining the relevance of an impact indicator result is obtained using the following approach:

$$Population\ Equivalent\ (PE) = \frac{Impact\ indicator\ result}{Reference\ value} \times Population\ of\ Europe$$

The reference values used to standardise the results of this project are shown in Table 2.2.

4 EU-27: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden and United Kingdom [JRC 2018]

Table 2.2: Basis for the standardisation: Recommended Normalisation Factors (NFs) for EU-27 (2010) based on the domestic inventory [JRC 2018]

Impact category	**Unit**	**Domestic**	**Normalisation factor per person (domestic)**	**Overall robustness**
Climate change	kg CO_2 eq	4.6E+12	9.22E+03	Very high
Ecotoxicity, freshwater	CTUe	4.36E+12	8.74E+03	Low
Particulate matter	kg PM2.5 eq	1.09E+09	2.80E+00	Very high
Resource depletion	kg Sb eq	5.03E+07	1.01E-01	Medium
Human toxicity, cancer	CTUh	1.84E+04	3.69E-05	Low
Ionizing radiation	kBq U235 eq	5.64E+11	1.13E+03	Medium
Photochemical ozone formation	kg NMVOC eq	1.58E+10	3.17E+01	Medium
Human toxicity, non-cancer	CTUh	2.66E+05	5.33E-04	Low
Ozone depletion	kg CFC-11 eq	1.08E+07	2.16E-02	Medium
Acidification	mol H+ eq	2.36E+10	4.73E+01	High
Eutrophication, marine	N eq	8.44E+09	1.69E+01	Medium to low
Eutrophication, freshwater	P eq	7.41E+08	1.48E+00	Medium to low
Eutrophication, terrestrial	mol N eq	8.76E+10	1.76E+02	Medium

2.1.4.2 Weighting

In DIN EN ISO 14044 weighting is also one of the optional components of impact assessment. To obtain a single ecological indicator (so-called single score), a cross-category weighting is performed. The standardized indicator values of the impact categories are weighted among each other using a weighting key.

The weighting key allows individual impact categories to have a correspondingly greater or lesser influence on the overall result of the ecological analysis. It is also possible to combine environmental categories with several impact categories, such as eutrophication.

The weighting key[5] used in this project is shown in Table 2.3. [Offermann 2017]

[5] The weighting key is based on the midpoint weighting factors from [JRC 2011a]. These represent average values from three weighting keys.

Table 2.3: Weighting factors for the standardized impact categories [Offermann 2017]

Impact category	Unit	Weighting factor
Climate change	CO_2 eq	27.4 %
Ecotoxicity, freshwater	CTUe	13.1 %
Particulate matter / Respiratory inorganics	PM2.5 eq	8.3 %
Resource depletion	Sb eq	8.3 %
Human toxicity, cancer	CTUh	7.1 %
Ionizing radiation	U235 eq	7.1 %
Photochemical ozone formation	NMVOC eq	6.0 %
Human toxicity, non-cancer	CTUh	4.8 %
Ozone depletion	CFC-11 eq	4.8 %
Acidification	H+ eq	4.8 %
Eutrophication, marine	N eq	2.8 %
Eutrophication, freshwater	P eq	2.8 %
Eutrophication, terrestrial	N eq	2.8 %

2.1.4.3 Combining

To obtain a single ecological index value the weighted indicator values are summed up. This establishes a relation between the different impact categories. The result is a dimensionless single value. [Offermann 2017]

2.2 Cost consideration

The economic part of the eco-efficiency analysis deals with the costs of manufacturing of Si PV modules. Costs are the expenses incurred for the production of all system components.

Because of the discussion of the results focuses on the core topics of the project (material savings and enhanced dismantling), the efficiency differences of the examined standard PV-module and NICE module as well as the differences in the installation (BOS) are neglected and are not considered in the evaluation. The same assumption was made at life cycle analysis (cf. chapter 3.5).

Basis was the current cost consideration of the International Technology Roadmap for Photovoltaic. The aim of IRTPV is to inform suppliers and customers about anticipated technology trends in the field of crystalline silicon photovoltaics and to stimulate discussion on required improvements and standards. The objectives of the roadmap is not to recommend detailed technical solutions for identified areas in need of improvements, but instead to emphasize to the PV community the need for improvement and to encourage the development of comprehensive solutions. The current publication covers the entire c-Si PV value chain from crystallization, wafering and cell manufacturing to module manufacturing and PV systems [ITRPV 2018].

2.3 Eco-efficiency analysis

As a result of the economic and ecological analysis, two indicators are obtained for each of the scenarios considered:

- Ecology index → a standardized and weighted ecological single score indicator
- Cost index → a monetary single value

The two indicator values are compared to a reference system and the relative deviations from the reference system are shown in an eco-efficiency portfolio.

The reference system in this project corresponds to the baseline. According to the method in [Offermann 2017] the ecology index and the cost index are equally weighted into the eco-efficiency analysis.

3 LIFE CYCLE INVENTORY ANALYSIS

The model structure is designed to facilitate a sectoral evaluation of the results of the LCA. On the one hand it will make it possible to identify the contributions of the individual production chain sections crystallization, wafering, cell processing, module design/assembly, installation as well as enhanced disassembly and module recycling (cf. Figure 3.1).

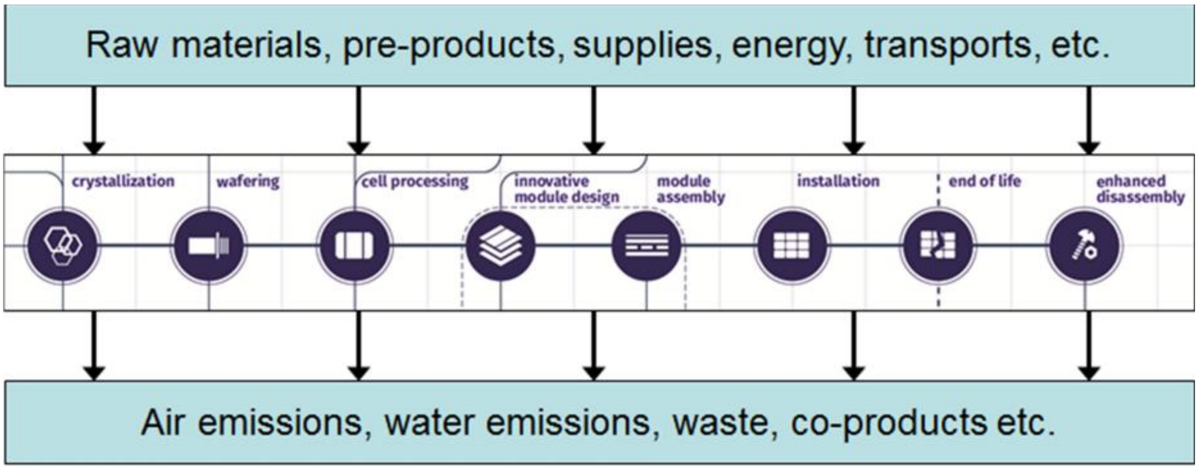


Figure 3.1: Sections of LCA and cost consideration

On the other side the model structure enables to use the results to evaluate direct emissions from sources that are owned or controlled by the reporting entity, indirect emissions from consumption of purchased energy and all other indirect emissions. Table 3.1 gives an overview of the three emission categories.

Table 3.1: Emission categories (Scopes) according to the Greenhouse Gas Protocol

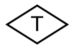
Emission category	**Definition (source: GHG protocol)**	**Content regarding this study**
Scope 1	Direct emissions from sources that are owned or controlled by the reporting entity	Manufacturing processes (including in-house energy supply and in-house transports): - crystallization - wafering - cell processing - module assembly
Scope 2	Indirect emissions from consumption of purchased electricity, heat or steam	External energy supply
Scope 3	Other indirect emissions (production of purchased material and fuels, transport-related activities not owned or controlled by the reporting entity, electricity-related activities not covered in Scope 2, outsourced activities, waste disposal, etc.)	Upstream and downstream processes: - Production of raw materials - Production of pre-products - Fuel supply - External transports - Use phase - Disposal/Recycling

In the following subchapters the subsystems of the balance models

- upstream process chain,
- manufacturing process including external energy supply and
- downstream process chain

are graphically presented and the most important process data summarized. The graphic elements used in the figures are shown in Table 3.2.

Table 3.2: Emission categories (Scopes) according to the Greenhouse Gas Protocol

Element	Description
	Aggregated process module (all upstream and downstream processes are fully integrated into the module)
	Transport model including all upstream processes
	Subsystem border
	Linking modules, models and subsystems
	Material, substance or energy flow

3.1 Crystallization

Upstream process chain

Figure 3.2 and Figure 3.3 show the modules and transports for the production of raw materials, pre-products and supplies for manufacturing of single-crystalline silicone (sc-Si) and multi-crystalline silicon (mc-Si) as well as the links between them.

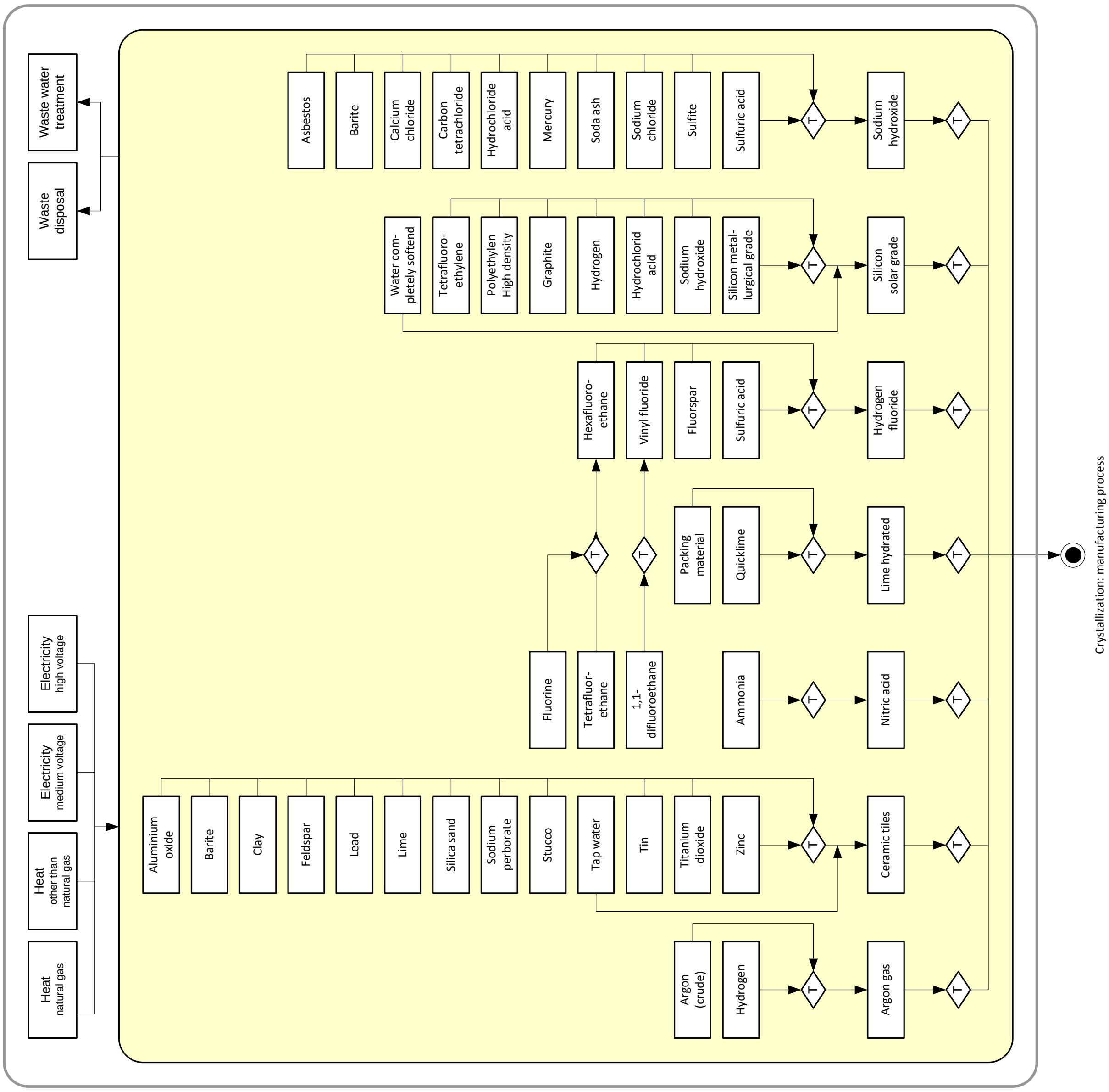


Figure 3.2: Single-crystalline silicon (sc-Si) production: balance model of upstream process chain

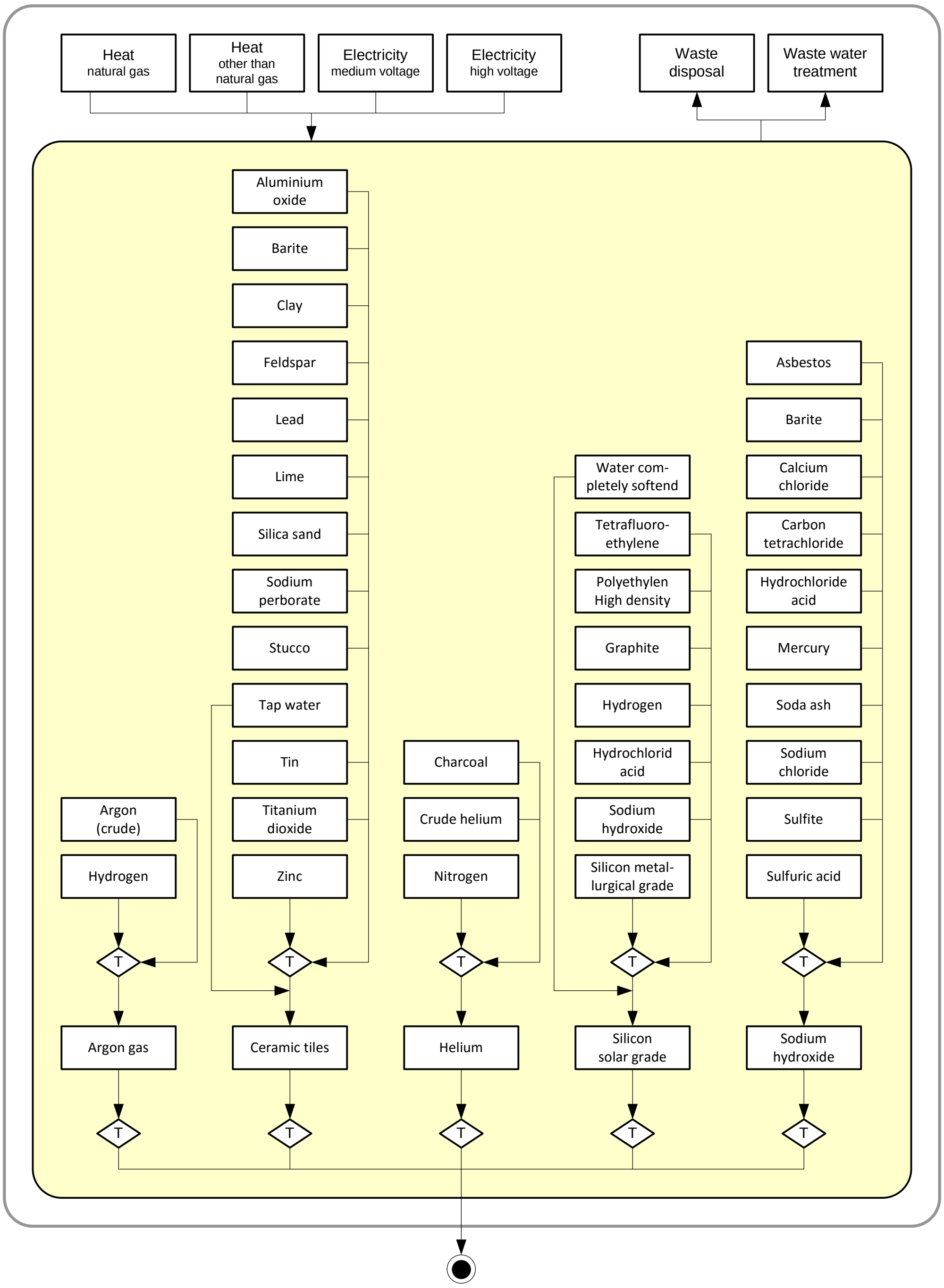


Figure 3.3: Multi-crystalline silicon (mc-Si) production: balance model of upstream process chain

Manufacturing process

Figure 3.4 and Figure 3.5 are schematic illustrations of the balancing models of the two subsystems.

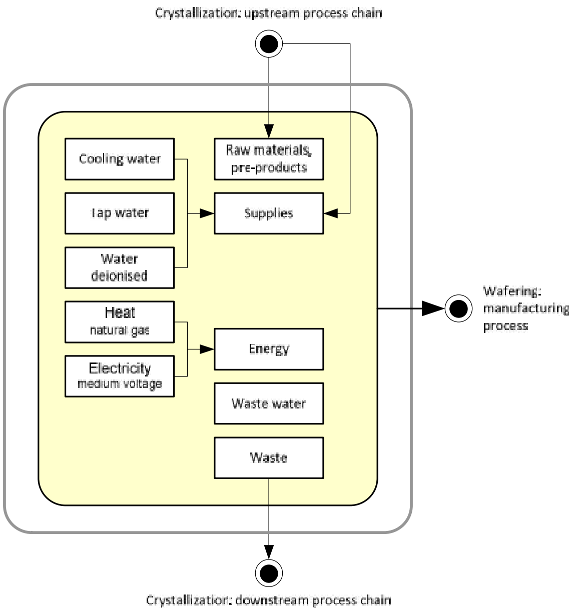


Figure 3.4: Single-crystalline silicon production: balance model of manufacturing process

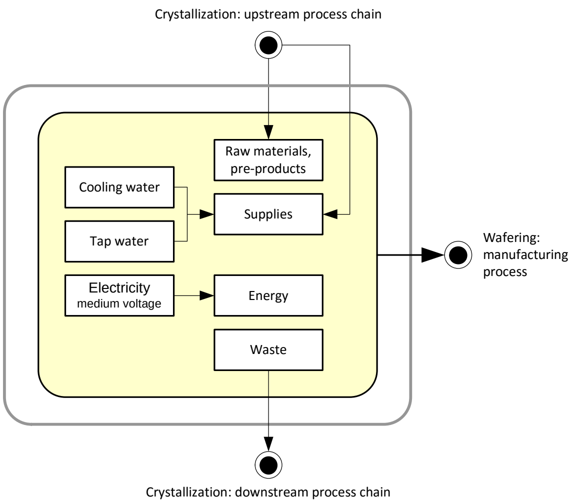


Figure 3.5: Multi-crystalline silicon production: balance model of manufacturing process

Table 3.3 and Table 3.4 show the data for the two production processes with respect to manufacturing of 1,000 kg crystalline silicon.

Table 3.3: In-/Output table with process data for manufacturing of 1,000 kg single-crystalline silicon [bifa 2013, IEA 2015, Ecosolar 2018]

Inputs		**Outputs**	
Material/Energy	**Quantity**	**Emission/Waste**	**Quantity**
Argon gas	1,000 kg	Inorganic production waste	167 kg
Ceramic tiles[1)]	167 kg	Water (to fresh water)	5,090 m³
Lime	22.2 kg	BOD[2)] (to fresh water)	130 kg
Hydrogen fluoride (hydrofluoric acid)	10 kg	COD[2)] (to fresh water)	130 kg
Nitric acid	66.8 kg	DOC[2)] (to fresh water)	40.5 kg
Sodium hydroxide	41.5 kg	Hydroxide (to fresh water)	367 kg
Silicon, solar grade	781 kg	Nitrate (to fresh water)	83.5 kg
Cooling water	5,090 m³	TOC[2)] (to fresh water)	40.5 kg
Water, deionised	4,010 kg	Nitrogen oxides (to fresh water)	33.9 kg
Tap water	94.1 t		
Electricity, medium voltage	68.2 MWh		
Heat, natural gas	68.2 GJ		

[1)] crucibles approximated by ceramic tiles
[2)] BOD = Biological oxygen demand; COD = Chemical oxygen demand; DOC = Dissolved organic carbon; TOC = Total organic bound carbon

Table 3.4: In-/Output table with process data for manufacturing of 1,000 kg multi-crystalline silicon [bifa 2013, IEA 2015, Ecosolar 2018]

Inputs		**Outputs**	
Material/Energy	**Quantity**	**Emission/Waste**	**Quantity**
Argon gas	186 kg	Inorganic production waste	289 kg
Ceramic tiles[1)]	289 kg	Water (to fresh water)	1,060 m³
Sodium hydroxide	5 kg		
Helium	0.08 kg		
Silicon, solar grade	896 kg		
Cooling water	1,060 kg		
Electricity, medium voltage	7.68 GJ		

1) crucibles approximated by ceramic tiles
2) BOD = Biological oxygen demand; COD = Chemical oxygen demand; DOC = Dissolved organic carbon; TOC = Total organic bound carbon

Downstream process chain

Figure 3.6 shows the modules and transports for the treatment of waste from the manufacturing process of single- and multi-crystalline silicon.
The inorganic production waste is collected and disposed in a residual waste landfill. No environmental credits will be awarded for this.

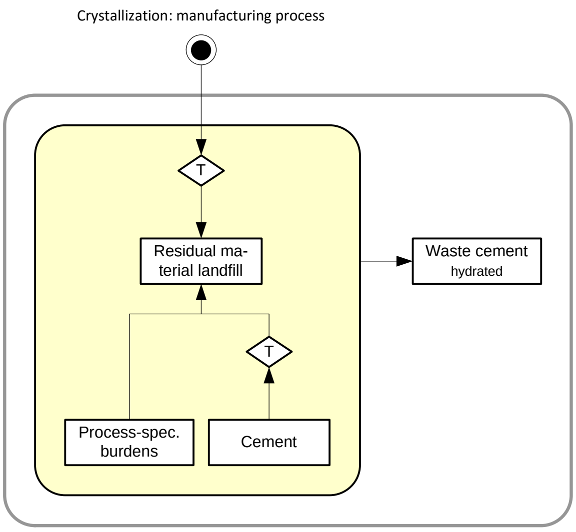


Figure 3.6: Single- and multi-crystalline silicon production: balance model of downstream process chain

3.2 Wafering

Upstream process chain

Figure 3.7 shows the modules and transports for the production of raw materials, pre-products and supplies for manufacturing of sc-Si and mc-Si wafer as well as the links between them.

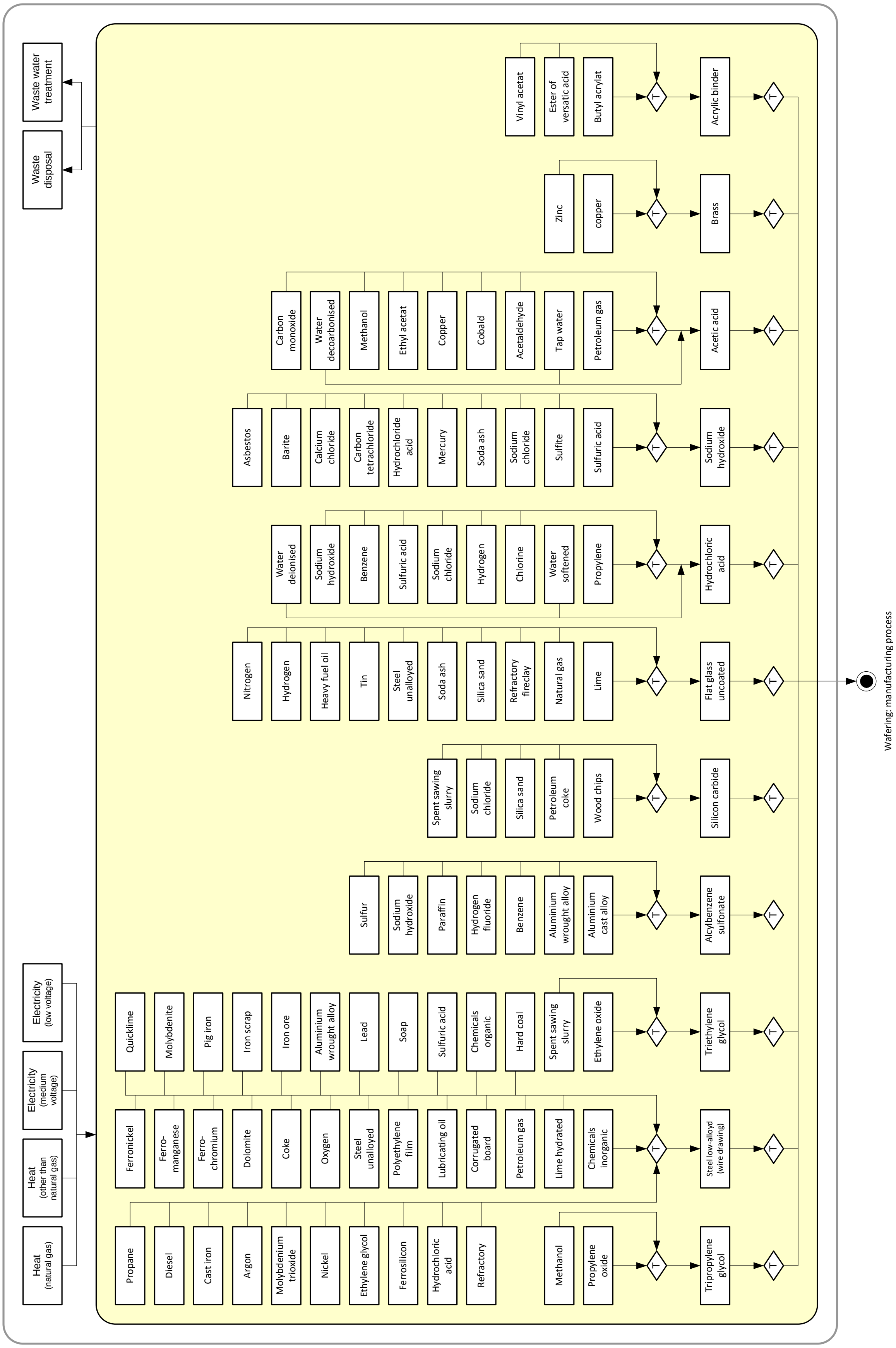


Figure 3.7: sc-Si and mc-Si wafer production: balance model of upstream process chain

Manufacturing process
Figure 3.8 is a schematic illustration of the balancing model of the two subsystems.

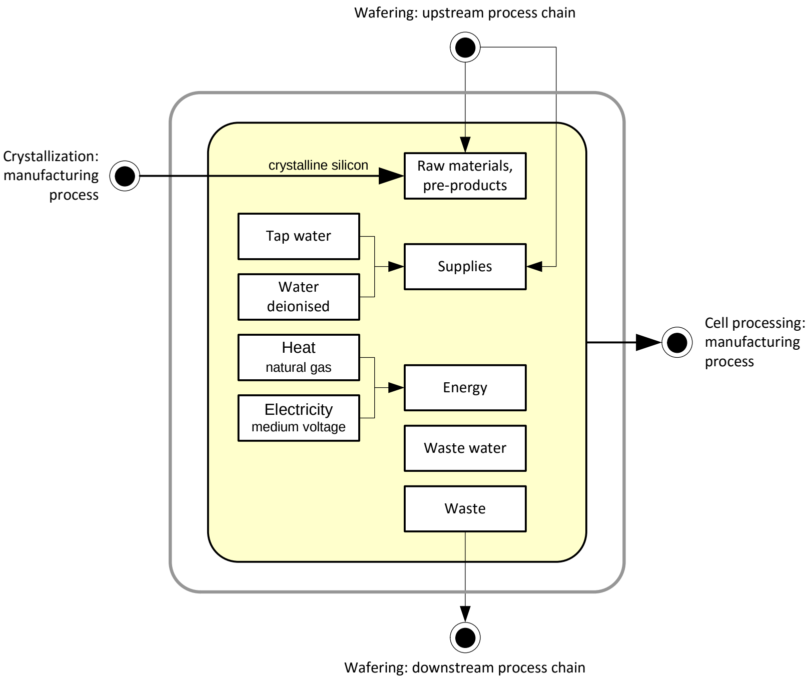


Figure 3.8: sc-Si and mc-Si wafer production: balance model of manufacturing process

Table 3.5 and Table 3.6 show the data for the two production processes with respect to manufacturing of 1,000 m² wafer.

Table 3.5: In-/Output table with process data for manufacturing of 1,000 kg single-crystalline silicon [bifa 2013, IEA 2015, Ecosolar 2018]

Inputs		**Outputs**	
Material/Energy	**Quantity**	**Emission/Waste**	**Quantity**
Single crystalline silicon (sc-Si)	1,580 kg	Waste from silicon wafer production	110 kg
Acrylic binder	2 kg	BOD[1)] (to fresh water)	29.5 kg
Silicon carbide	2,030 kg	COD[1)] (to fresh water)	29.5 kg
Acetic acid	39 kg	DOC[1)] (to fresh water)	11.1 kg
Alkylbenzene sulfonate	240 kg	TOC[1)] (to fresh water)	11.1 kg
Brass	7.4 kg		
Flat glass, uncoated	10 kg		
Hydrochloride acid	2.7 kg		
Sodium hydroxide	15 kg		
Steel, low-alloyed	797 kg		
Triethylene glycol	2,168 kg		
Dipropylene dlycol	300 kg		

Inputs		Outputs	
Material/Energy	**Quantity**	**Emission/Waste**	**Quantity**
Tap water	6 kg		
Water, deionised	18,000 kg		
Electricity, medium voltage	25.7 MWh		
Heat, natural gas	4 GJ		

1) BOD = Biological oxygen demand; COD = Chemical oxygen demand; DOC = Dissolved organic carbon; TOC = Total organic bound carbon

Table 3.6: In-/Output table with process data for manufacturing of 1,000 kg multi-crystalline silicon [bifa 2013, IEA 2015, Ecosolar 2018]

Inputs		Outputs	
Material/Energy	**Quantity**	**Emission/Waste**	**Quantity**
Single crystalline silicon (mc-Si)	1,020 kg	Waste from silicon wafer production	170 kg
Acrylic binder	3.8 kg	BOD[1)] (to fresh water)	29.5 kg
Silicon carbide	2,030 kg	COD[1)] (to fresh water)	29.5 kg
Acetic acid	39 kg	DOC[1)] (to fresh water)	11.1 kg
Alkylbenzene sulfonate	240 kg	TOC[1)] (to fresh water)	11.1 kg
Brass	7.4 kg		
Flat glass, uncoated	40.8 kg		
Hydrochloride acid	2.7 kg		
Sodium hydroxide	15 kg		
Steel, low-alloyed	797 kg		
Triethylene glycol	2,168 kg		
Dipropylene dlycol	300 kg		
Tap water	6 kg		
Water, deionised	18,000 kg		
Electricity, medium voltage	20.8 MWh		
Heat, natural gas	4 GJ		

1) BOD = Biological oxygen demand; COD = Chemical oxygen demand; DOC = Dissolved organic carbon; TOC = Total organic bound carbon

Downstream process chain

Figure 3.9 shows the modules and transports for the treatment of waste from the manufacturing process of sc-Si and mc-Si wafer.

The waste from silicon wafer production is collected and disposed in a residual waste landfill. No environmental credits will be awarded for this.

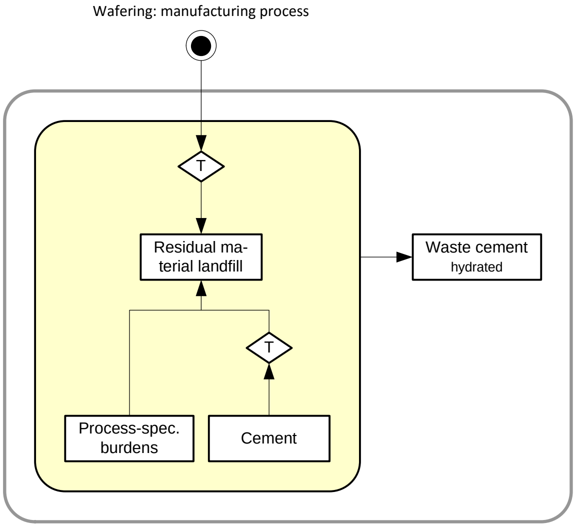


Figure 3.9: sc-Si and mc-Si wafer production: balance model of downstream process chain

3.3 Cell processing

Upstream process chain

Figure 3.10 and Figure 3.11 show the modules and transports for the production of raw materials, pre-products and supplies for manufacturing of sc-Si and mc-Si photovoltaic cells as well as the links between them.

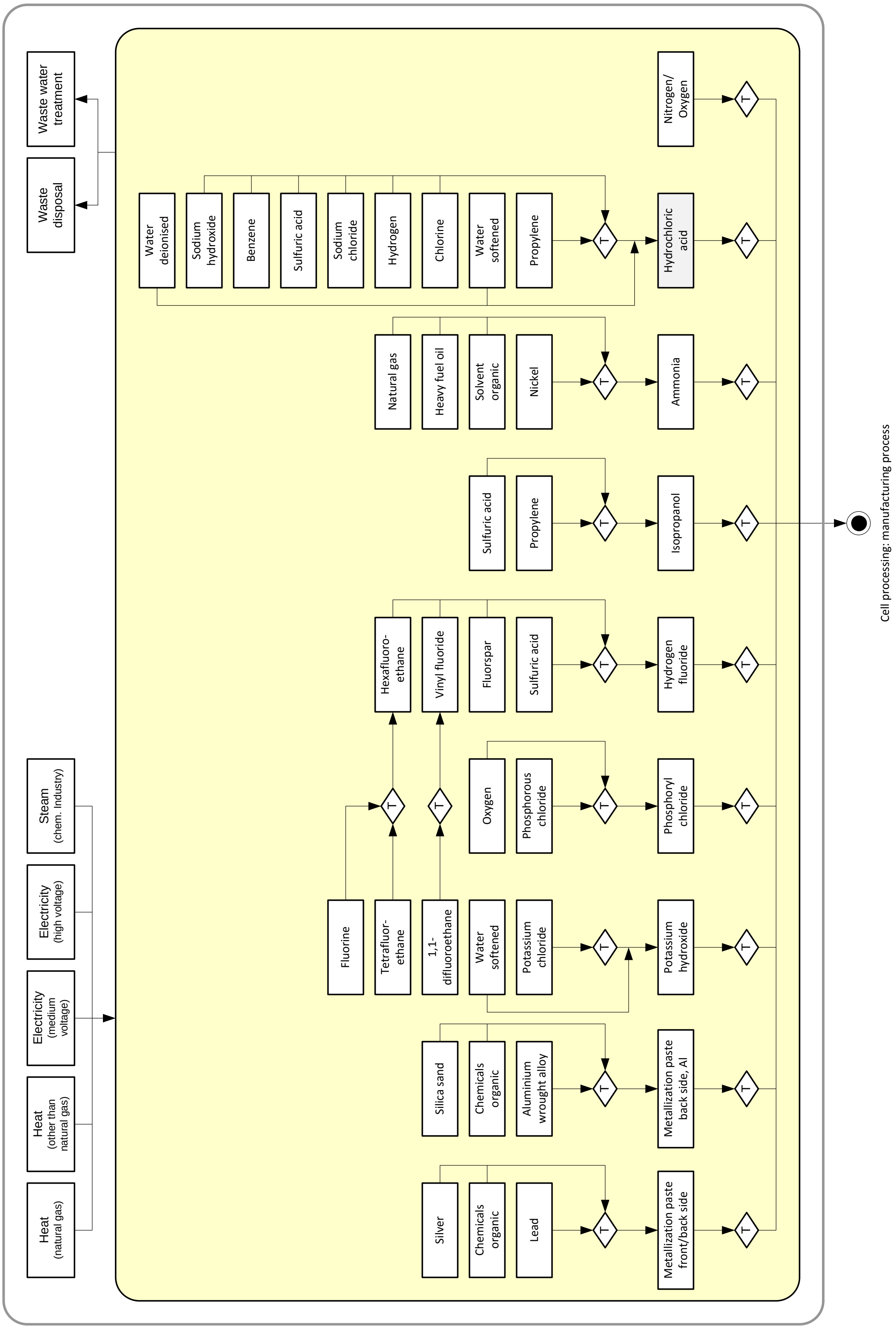


Figure 3.10: sc-Si photovoltaic cell production: balance model of upstream process chain

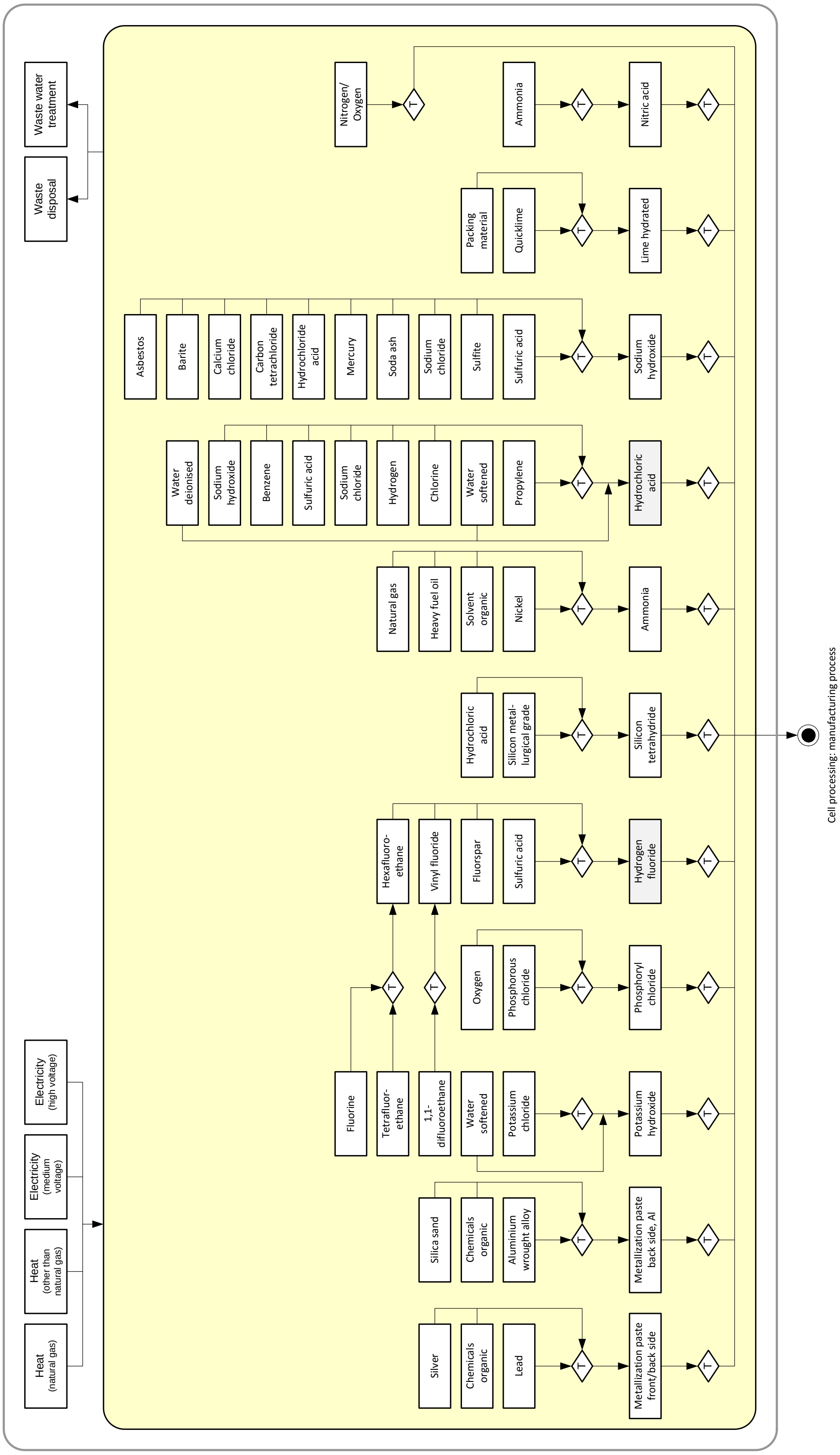


Figure 3.11: mc-Si photovoltaic cell production: balance model of upstream process chain

Manufacturing process

Figure 3.12 and Figure 3.13 are schematic illustrations of the balancing models of the two subsystems.

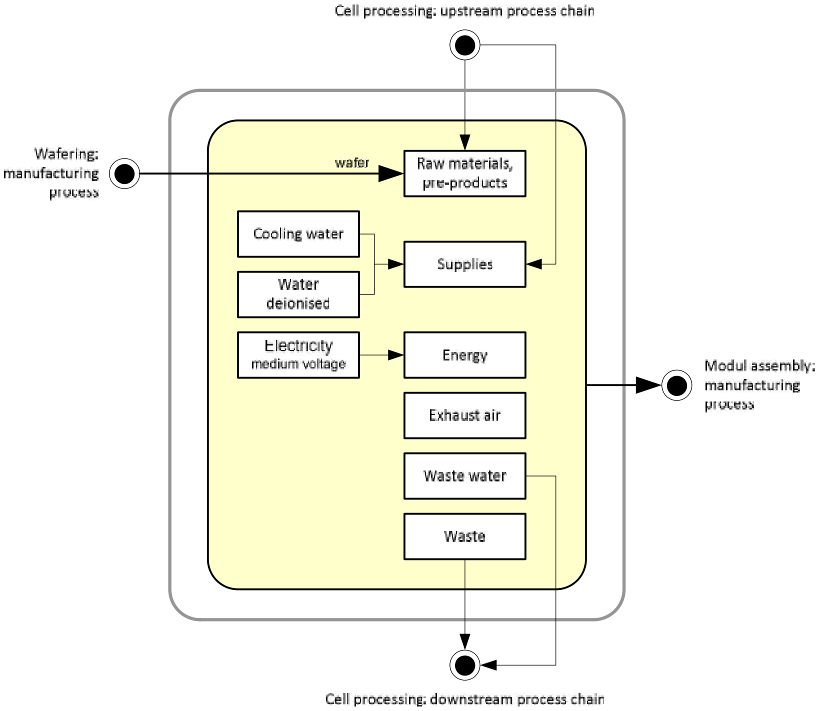


Figure 3.12: si-Si photovoltaic cell production: balance model of manufacturing process

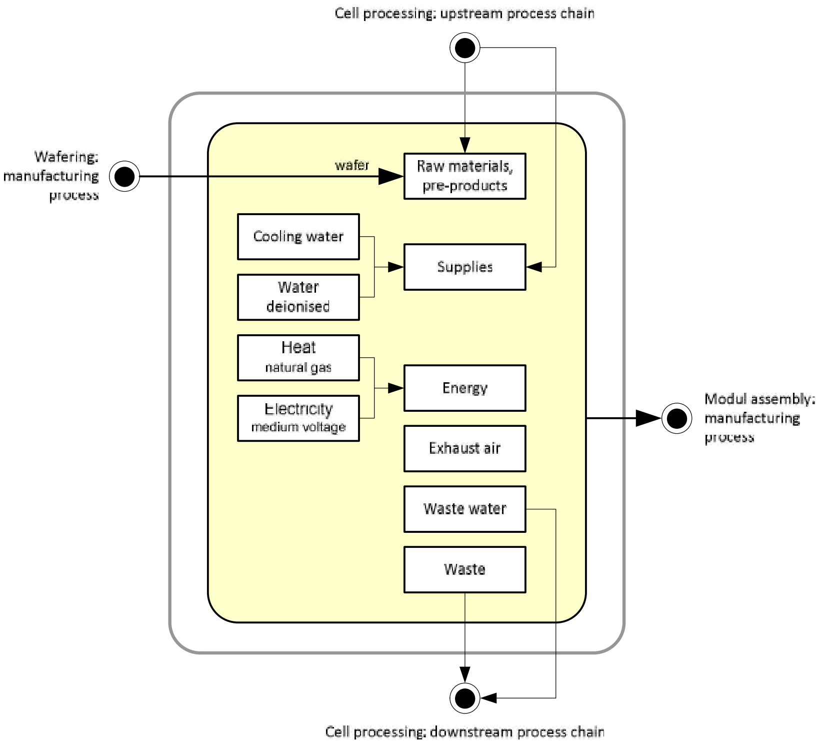


Figure 3.13: mc-Si photovoltaic cell production: balance model of manufacturing process

Table 3.7 and Table 3.8 show the data for the two production processes with respect to manufacturing of 1,000 m² photovoltaic cells.

Table 3.7: In-/Output table with process data for manufacturing of 1,000 m² sc-Si photovoltaic cells [bifa 2013, IEA 2015, Ecosolar 2018]

Inputs		**Outputs**	
Material/Energy	**Quantity**	**Emission/Waste**	**Quantity**
sc-Si wafer	1,030 m²	PV cell production effluent	159 m³
Hydrochloric acid	0.8 kg	Waste water	11.6 m³
Hydrogen fluoride (hydrofluoric acid)	0.3 kg	Water (to fresh water)	307 m³
Isopropanol	41.4 kg	Spent solvent mixture	158 kg
Metallization paste, back side	1.3 kg	Inorganic production waste	2,330 kg
Metallization paste, back side, Al	64 kg	Acetaldehyde (to air)	0.69 kg
Metallization paste, front side	3.9 kg	Aluminium (to air)	0.0077 kg
Phosphoryl chloride	1.7 kg	Ammonia (to air)	0.037 kg
Ammonia	10.9 kg	Carbon dioxide, fossil (to air)	167 kg
Nitrogen	44.7 kg	Chlorine (to air)	0.046 kg
Oxygen	12.2 kg	Hydrogen (to air)	0.14 kg
Potassium hydroxide	3.5 kg	Lead (to air)	0.0077 kg
Cooling water	307 m³	NMVOC[1)] (to air)	12.6 kg
Water, deionised	154 m³	Propanol (to air)	14.7 kg
Electricity, medium voltage	8.5 MWh	Silicon dust (to air)	3 kg
		Silver (to air)	0.0077 kg
		Tin (to air)	0.0077 kg

1) NMVOC = Non-Methane Volatile Organic Compounds

Table 3.8: In-/Output table with process data for manufacturing of 1,000 m² mc-Si photovoltaic cells [bifa 2013, IEA 2015, Ecosolar 2018]

Inputs		**Outputs**	
Material/Energy	**Quantity**	**Emission/Waste**	**Quantity**
mc-Si wafer	1,040 m²	Waste water	575 m³
Hydrochloric acid	81.3 kg	Water (to fresh water)	329 m³
Hydrogen fluoride (hydrofluoric acid)	143 kg	Spent solvent mixture	20.5 kg
Metallization paste, back side	1.4 kg	Inorganic production waste	16.4 kg
Metallization paste, back side, Al	53.4 kg	NMVOC[1)] (to air)	1.6 kg
Metallization paste, front side	4.5 kg	Nitrogen oxides (to air)	0.033 kg
Phosphoryl chloride	0.5 kg		
Silicon tetrahydride (silane)	5 kg		
Ammonia	6.5 kg		
Nitrogen	1,950 kg		
Oxygen	573 kg		

Inputs		Outputs	
Material/Energy	**Quantity**	**Emission/Waste**	**Quantity**
Lime, hydrated	196 kg		
Nitric acid	402 kg		
Sodium hydroxide	46 kg		
Potassium hydroxide	27.9 kg		
Cooling water	29 m^3		
Water, deionised	154 m^3		
Electricity, medium voltage	13.1 MWh		
Heat, natural gas	638 MJ		

1) NMVOC = Non-Methane Volatile Organic Compounds

Downstream process chain

Figure 3.14 shows the modules and transports for the treatment of waste from the manufacturing process of sc-Si and mc-Si photovoltaic cells.

The inorganic production waste is collected and disposed in a residual waste landfill whereas the spent solvent mixture is burned in a hazardous waste incineration. No environmental credits will be awarded for the two disposal processes.

The waste water and the photovoltaic cell production effluent are purified in various waste water treatment plants. Waste paper and plastics extracted from the waste water are thermally recycled in waste incineration plants. The heat and electricity generated during combustion are environmental credits because they replace conventional energy generation processes and avoid the emissions associated with the burning of fossil fuels.

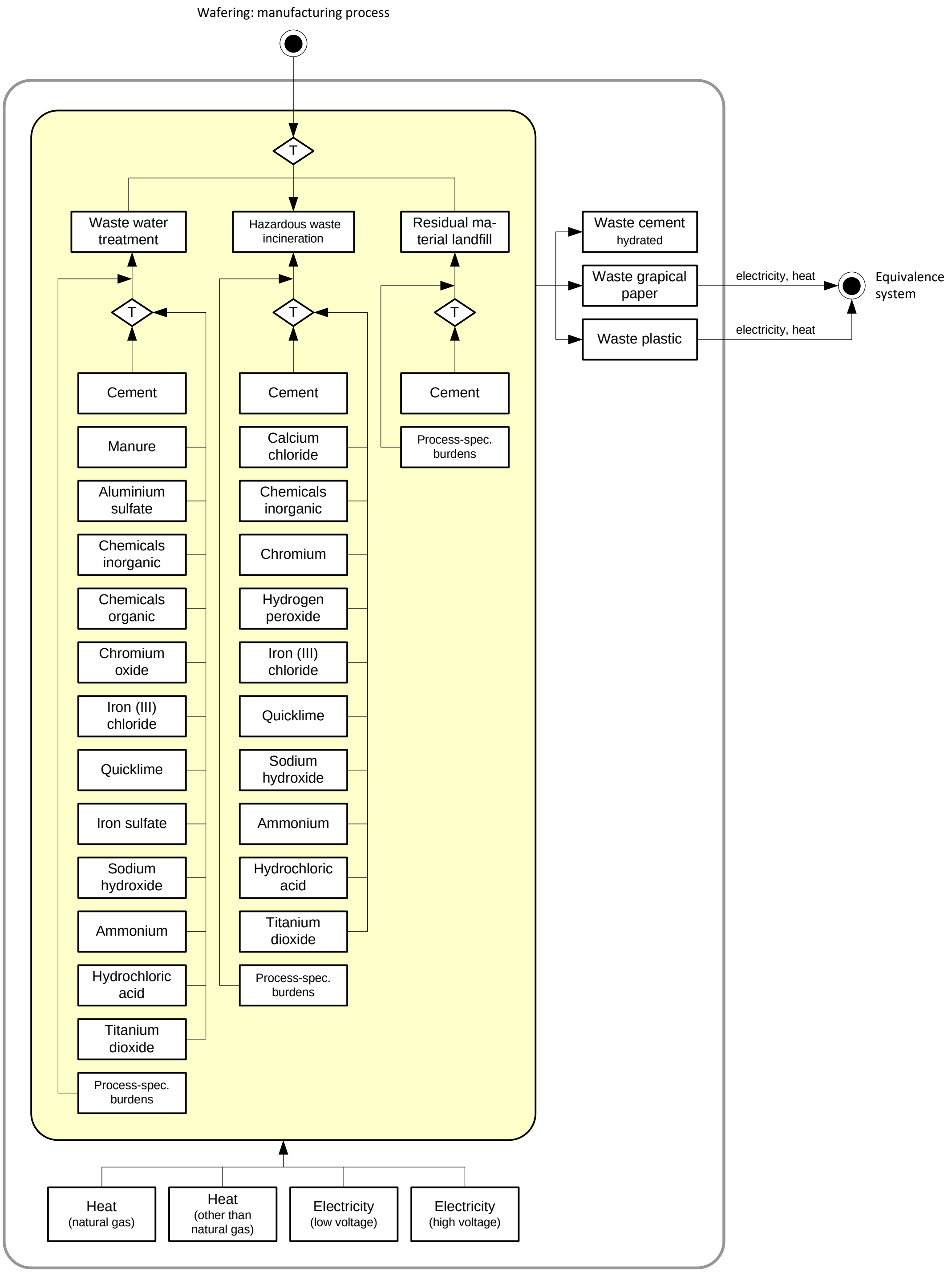


Figure 3.14: sc-Si and mc-Si photovoltaic cell production: balance model of downstream process chain

3.4 Module design/assembly

3.4.1 Standard PV-module

The standard PV-module is an EVA laminated module (60 6-inch solar cells) with front glass and polymer back sheet including aluminium framing.

Upstream process chain

Figure 3.15 and Figure 3.16 show the modules and transports for the production of raw materials, pre-products and supplies for manufacturing of sc-Si and mc-Si photovoltaic modules as well as the links between them.

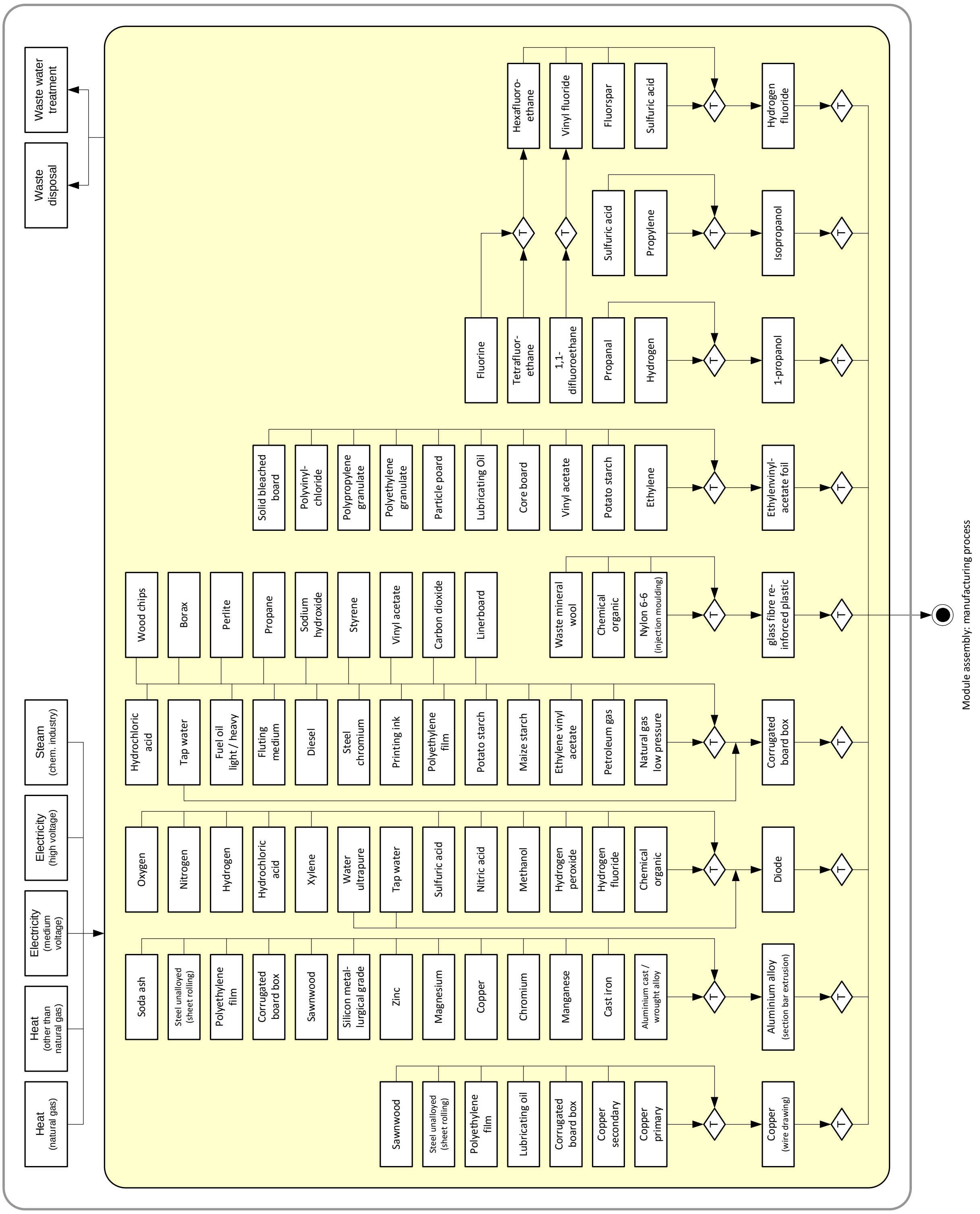


Figure 3.15: sc-Si and mc-Si photovoltaic module production: balance model of upstream process chain PART I

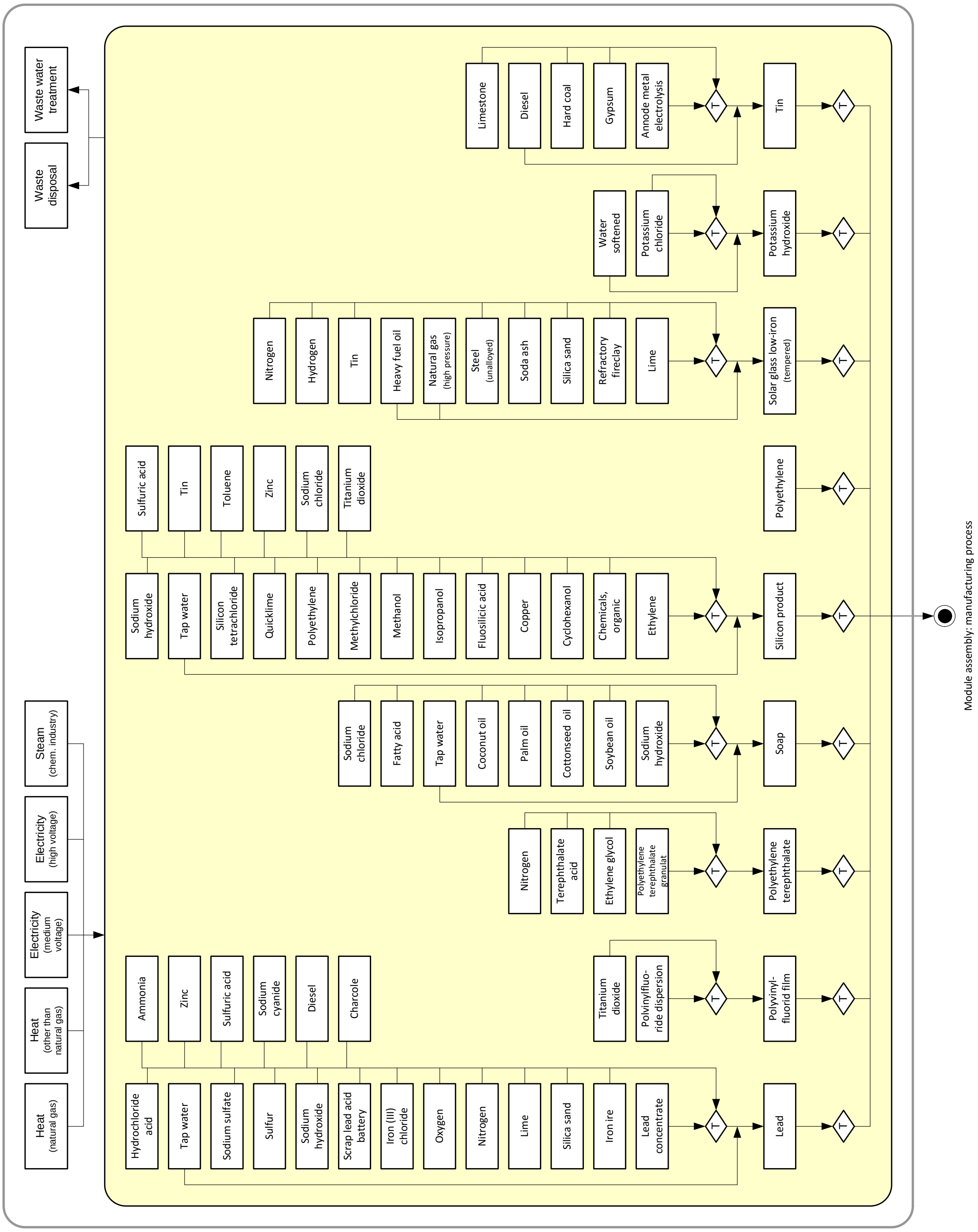


Figure 3.16: sc-Si and mc-Si photovoltaic module production: balance model of upstream process chain PART II

Manufacturing process

Figure 3.17 is a schematic illustration of the balancing model of the two subsystems.

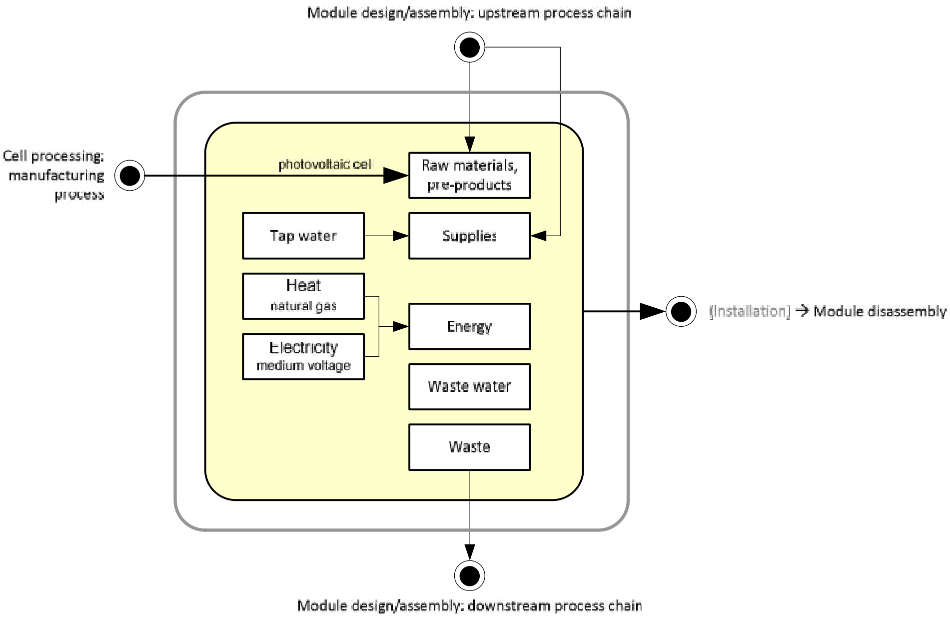


Figure 3.17: sc-Si and mc-Si photovoltaic module production: balance model of manufacturing process

Table 3.9 show the data for the two production processes with respect to manufacturing of 1,000 m² PV-modules.

Table 3.9: In-/Output table with process data for manufacturing of 1,000 m² sc-Si and mc-Si photovoltaic modules, respectively [bifa 2013, IEA 2015, Ecosolar 2018]

Inputs		**Outputs**	
Material/Energy	**Quantity**	**Emission/Waste**	**Quantity**
sc-Si photovoltaic cells	935 m²	Plastic waste	1,640 kg
1-Propanol	15.9 kg	Waste mineral oil	1.61 kg
Aluminium alloy, section bar extrusion	984 kg	Polyvinyl fluoride waste	112 kg
Copper, wire drawed	103 kg	Municipal solid waste	30 kg
Corrugated board box	763 kg	Waste water	5.03 m³
Diode	2.81kg	Carbon dioxide, fossil (to air)	21.8 kg
Ethylvinylacetate, foil	875 kg	NMVOC[1)] (to air)	8.06 kg
Glass fibre reinforced plastic	295 kg		
Hydrogen fluoride (hydrofluoric acid)	62.4 kg		
Isopropanol	0.15 kg		
Lead	0.72 kg		
Polyethylene terephthalate	346 kg		
Polyvinyl fluoride, film	112 kg		
Potassium hydroxide	51.4 kg		

Inputs		Outputs	
Material/Energy	**Quantity**	**Emission/Waste**	**Quantity**
Silicone product	122 kg		
Soap	11.6 kg		
Solar glass, low-iron, tempered	8,810 kg		
Tin	12.9 kg		
Polyethylene, high density	23.8 kg		
Tap water	5.03 m³		
Diesel	8.75 MJ		
Electricity, medium voltage	3.73 MWh		

1) NMVOC = Non-Methane Volatile Organic Compounds

Downstream process chain

Figure 3.18 shows the modules and transports for the treatment of waste from the manufacturing process of sc-Si and mc-Si photovoltaic cells.

Waste mineral oil is mainly burned in a hazardous waste incineration. No environmental credits will be awarded for the disposal processes. Additionally, a smaller part of waste mineral oil is used in the clinker production.

Municipal solid waste, polyvinyl fluoride waste and most of the plastic waste are thermally recycled in waste incineration plants. The heat and electricity generated during combustion are environmental credits because they replace conventional energy generation processes and avoid the emissions associated with the burning of fossil fuels. A smaller part of plastic waste is also used in the clinker production.

The waste water is purified in a waste water treatment plant. Waste paper and plastics extracted from the waste water are also thermally recycled in waste incineration plants and environmental credits generated.

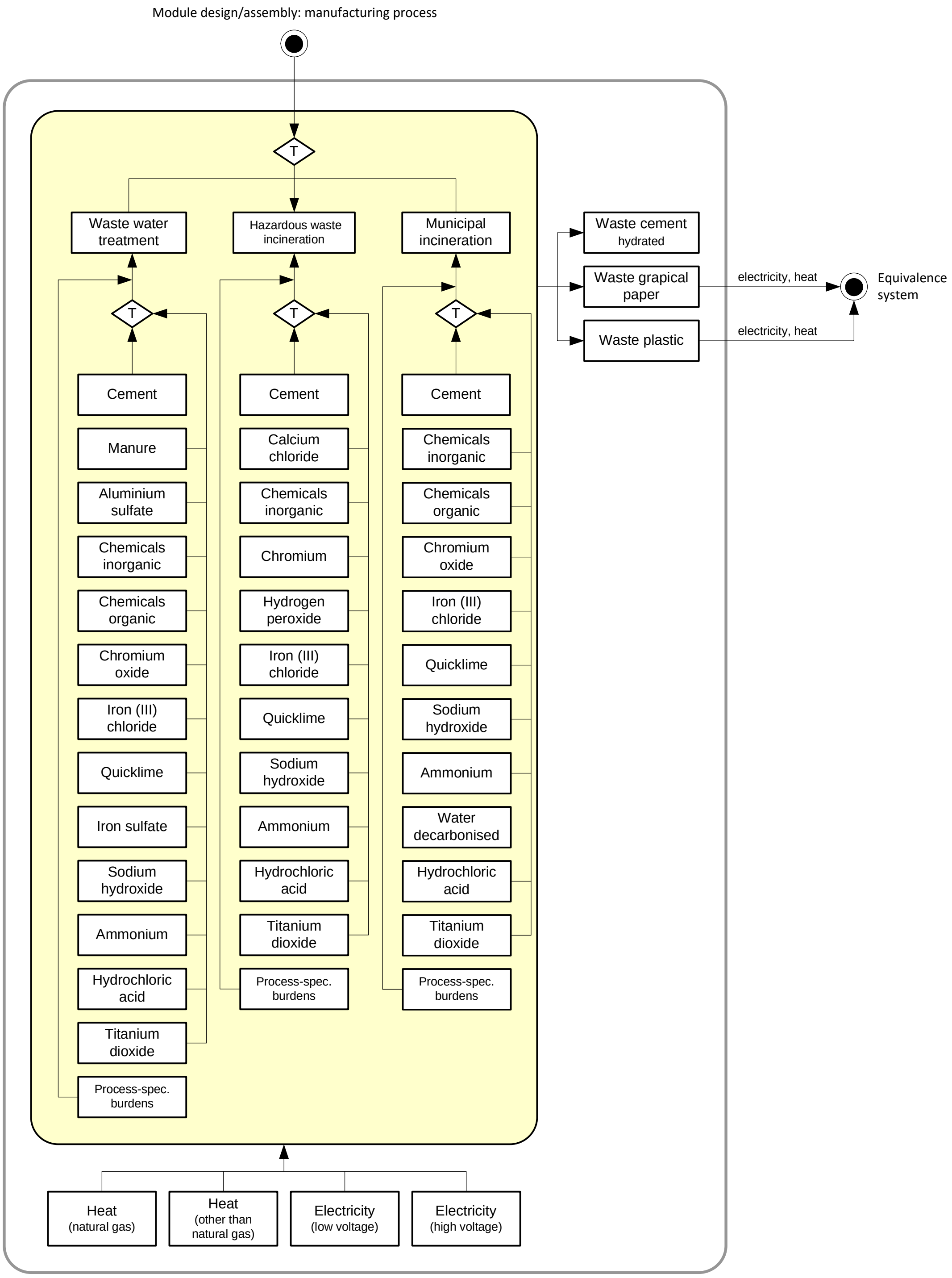


Figure 3.18: sc-Si and mc-Si photovoltaic module production: balance model of downstream process chain

3.4.2 Demonstrator module

The demonstrator module is an EVA-free glass/glass frameless NICE module Generation 2.

Upstream process chain

Figure 3.19 and Figure 3.20 show the modules and transports for the production of raw materials, pre-products and supplies for manufacturing of NICE Gen. 2 photovoltaic modules as well as the links between them.

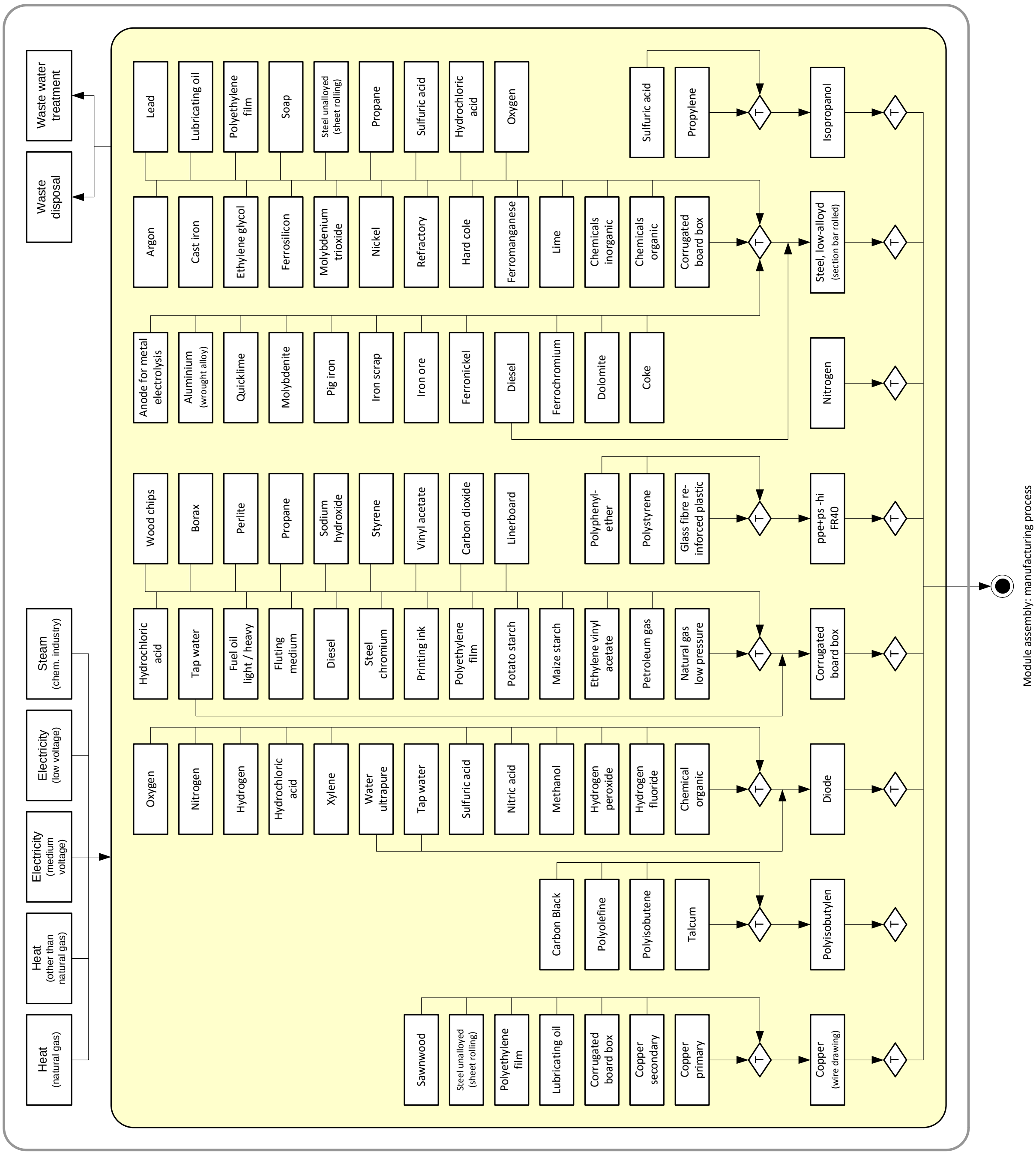


Figure 3.19: NICE module Gen. 2 production: balance model of upstream process chain PART I

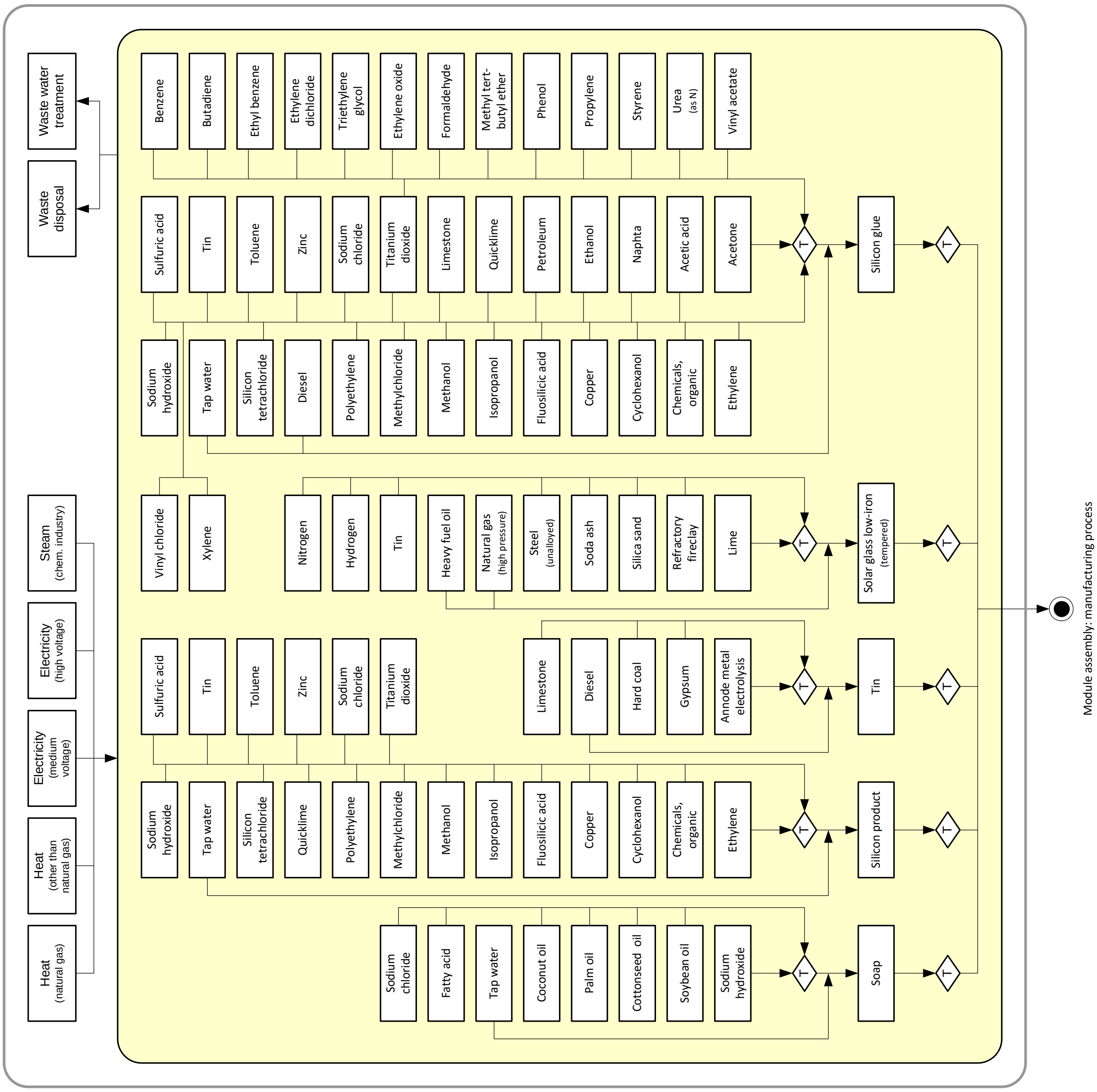


Figure 3.20: NICE module Gen. 2 production: balance model of upstream process chain PART II

Manufacturing process

Figure 3.21 is a schematic illustration of the balancing model of the subsystem.

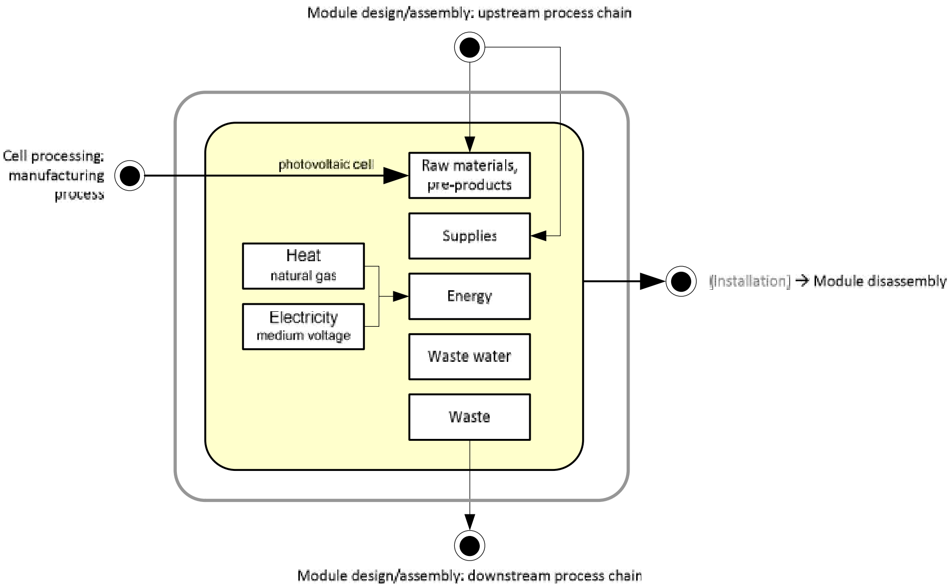


Figure 3.21: NICE module Gen. 2 production: balance model of manufacturing process

For reasons of confidentiality, the process data provided by the project partner are not presented in detail.

Downstream process chain

Figure 3.22 shows the modules and transports for the treatment of waste from the manufacturing process of sc-Si and mc-Si photovoltaic cells.

Waste mineral oil is mainly burned in a hazardous waste incineration. No environmental credits will be awarded for the disposal processes. Additionally, a smaller part of waste mineral oil is used in the clinker production.

Municipal solid waste and most of the plastic waste are thermally recycled in waste incineration plants. The heat and electricity generated during combustion are environmental credits because they replace conventional energy generation processes and avoid the emissions associated with the burning of fossil fuels. A smaller part of plastic waste is also used in the clinker production.

The waste water is purified in a waste water treatment plant. Waste paper and plastics extracted from the waste water are also thermally recycled in waste incineration plants and environmental credits generated.

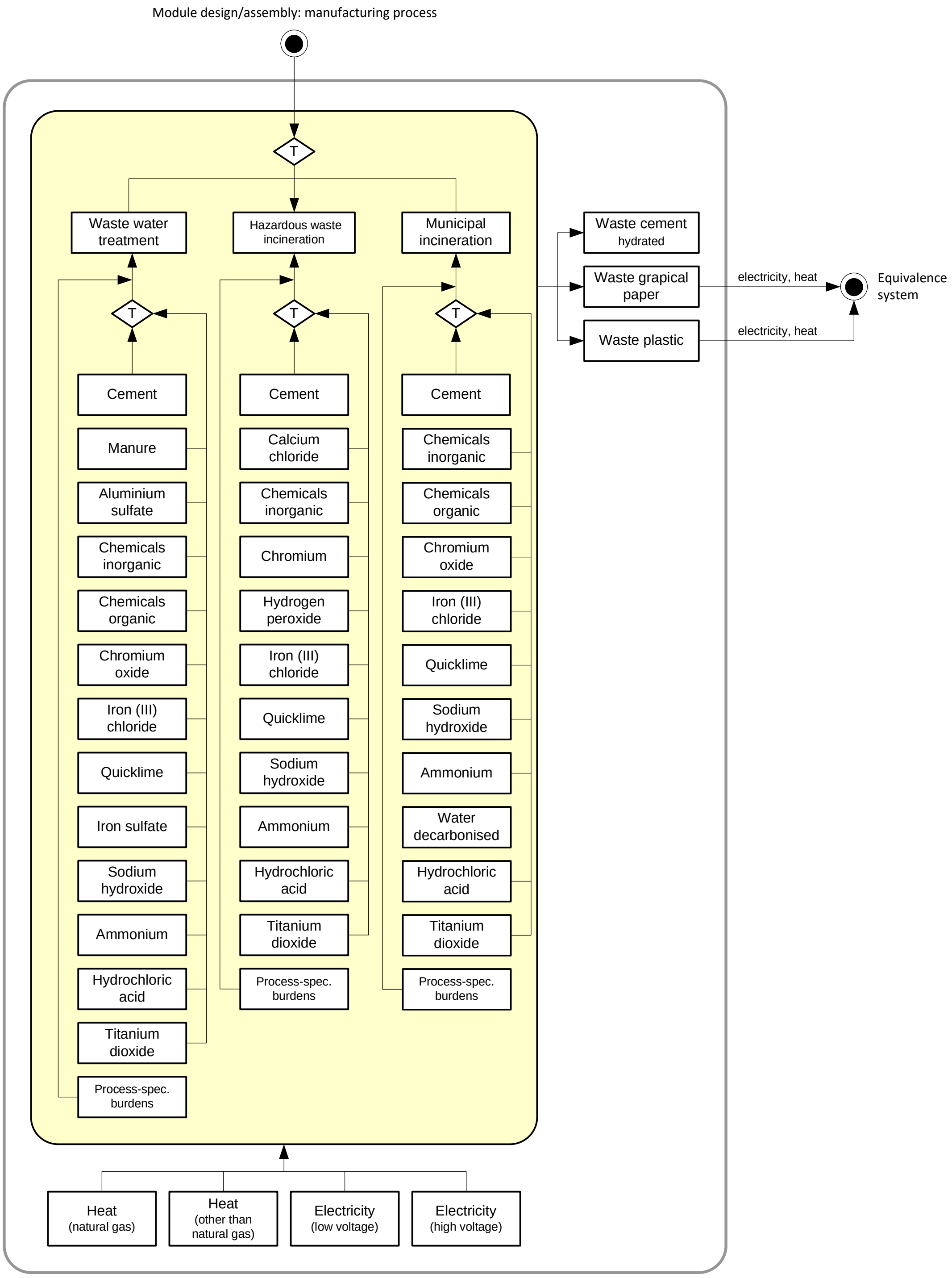


Figure 3.22: NICE module Gen. 2 production: balance model of downstream process chain

3.5 Installation

Because of the discussion of the results focuses on the core topics of the project (material savings and enhanced dismantling), the efficiency differences of the examined standard PV-module and NICE module as well as the differences in the installation (BOS) are neglected and are not considered in the evaluation.

3.6 Module disassembly and recycling

In the following, two recycling processes will be described.

3.6.1 Standard PV-module

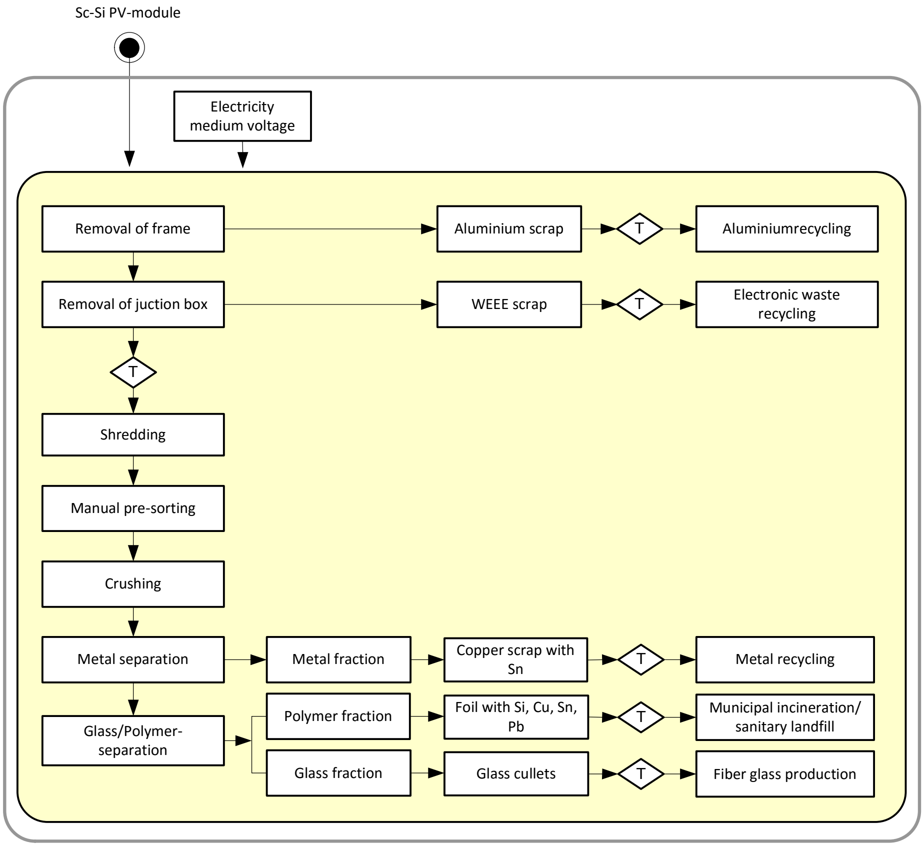


Figure 3.23: sc-Si and mc-Si photovoltaic module production: balance model of module disassembly process

In Figure 3.23 the disassembly and recycling of the sc-Si PV module is shown. The process is a standard flat glass recycling process by Maltha [Held 2013].

This technological process is a mechanical process consisting of shredding, crushing, sieving and metal separation to separate the module materials.

The aluminium frames are removed in a manual process. The aluminium will be sold for re-melting. The material will recycle in an aluminium smelter.

The junction box is manually separated and goes to the electronic-waste recycling. Next are the extraction and separation of metals (copper wire) and the removal of foil with solar cells and glass (glass/polymer separation). This crushed glass is contaminated with polymers, silicon and metals, and can be used with other recycled glass in the glass-fibre industry as thermal insulating material.

The output fractions from sc-Si PV module recycling process are: aluminium scrap, WEEE-scrap (Junction box), copper scrap, foil with silicon and glass.

3.6.2 Demonstrator module

Disassembly and recycling of the NICE PV-module is described in Figure 3.24. The process describes the production line for NICE modules under development by AIMEN.

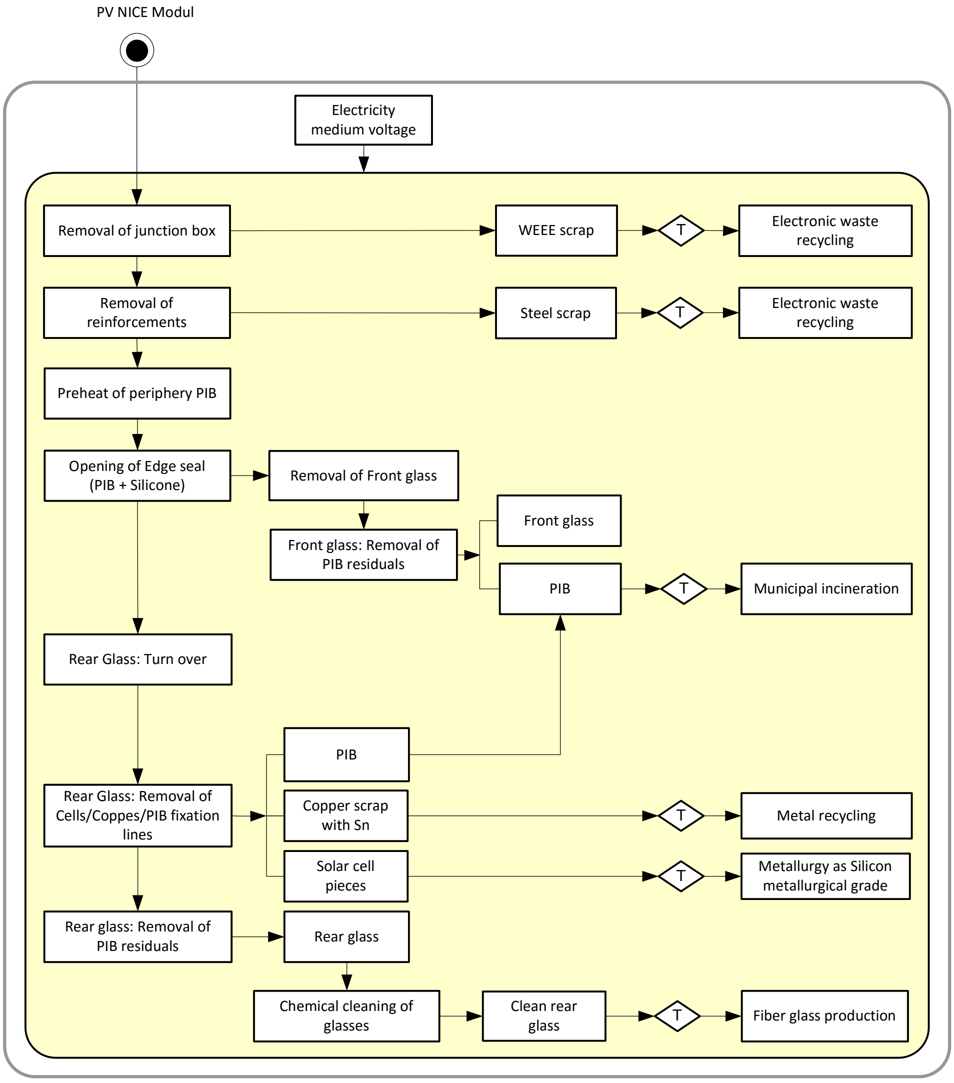


Figure 3.24: NICE PV-module production: balance model of enhanced module disassembly process

At the beginning the junction box is mechanically separated. Next two steel reinforcements are removed. These modules are preheated, the edge seals are opened with a thermal cutter and the PIB residual are removed by a robot with a heated knife. The output of this process is a clean glass sheet. During the next step the rear glass, with the cells and copper connectors, are flipped. The cell/copper/PIB fixation lines are removed by a heated blade after which they are collected. The PIB residuals are removed from the rear glass by a robot with a heated knife which yields another clean glass sheets. Recovered copper scrap goes to metal recycling. The broken solar cell is used in metallurgy. This glass sheet is then chemically cleaned. The PIB will treat in municipal incineration.

The output fractions from the NICE PV module recycling process are: steel scrap, WEEE-scrap (junction box), copper scrap, contaminated glass and clean glass.

3.7 Equivalence system

In Table 3.10 the benefits of the balance model and the substituted materials, products and energies from the primary raw materials are summarised. The credits result exclusively from aluminium, copper and steel - and glass recycling.

Table 3.10 also contains the considered substitution factors in the credit calculation.

Table 3.10: Benefits associated with the balance model

Benefit	Substituted material, product or energy	Substitution factor
Electric power	Electricity from European electricity mix	1.0 [1)]
Thermal energy	Process heat and district heating from European heating mix	1.0[1)]
Secondary steel	Converter steel (steel of basic oxygen furnace)	0.57[2)]
Secondary aluminium	Primary aluminium	0.304[3)]
Secondary copper	Primary copper	0.43[2)]
Contaminated glass	Glass cullets	0.75
Quality glass	Glass sheet	0.50[4)]

1) Assumption
2) The primary part of the generation mix only
3) The part of aluminium from the new scrap of the generation mix only
4) Assumption of scratched glass

3.8 Data validation

3.8.1 Completeness

The mass balances of the datasets/subnets used have been checked and are coherent.

3.8.2 Data symmetry analysis

In all the fields of the balance model it is possible that missing data (gaps in the data) occur. This may affect entire processes on the grounds of non-resilience or missing data and emission data for individual harmful substances or system parameters. In principle the attempt was always made to close such known gaps by means of plausible assumptions.
The detailed data symmetry analysis can be found in the appendix A.

The data symmetry analysis has two major tasks [UBA 2000]:

1. It shall serve to compare the datasets of various processes, based on plausibility and as necessary to trace missing life cycle analysis items.
2. Secondly, the data symmetry analysis for the examination of results of the impact assessment shall be taken into consideration whereby the differences in results shall be attributed to the imbalance of data in the various scenarios.

The data symmetry analyses undertaken in the course of this study showed inconspicuous results.

3.8.3 Documentation of data used

Except datasets based on data from project partners (cf. chapter 3.1 to 3.6) or literature data, almost all other datasets are from ecoinvent database [ecoinvent 2018]. Most of the datasets describe Global or European markets and processes and are valid for the time period 2011 to 2016. Some exceptions are older with a validity period 1997 to 2011.

4 RESOURCE CONSUMPTION: PROJECT TARGETS

Due to the progress made in the PV industry since the writing of the proposal first improvements were already observed. The baseline process used as a benchmark includes recent developments (status 2015). The initial data sets for the individual process chain sections crystallization, wafering, cell processing and module design/assembly therefore were updated and the expected material reductions based on Eco-Solar innovations were adjusted.
Figure 4.1 and Figure 4.2 show the reduction of waste and resource consumption per sc-Si PV-module and mc-Si PV-module, respectively, envisaged in the project. The reduction potentials to be achieved are between approx. 40 % for aluminium and approx. 95% for process water.

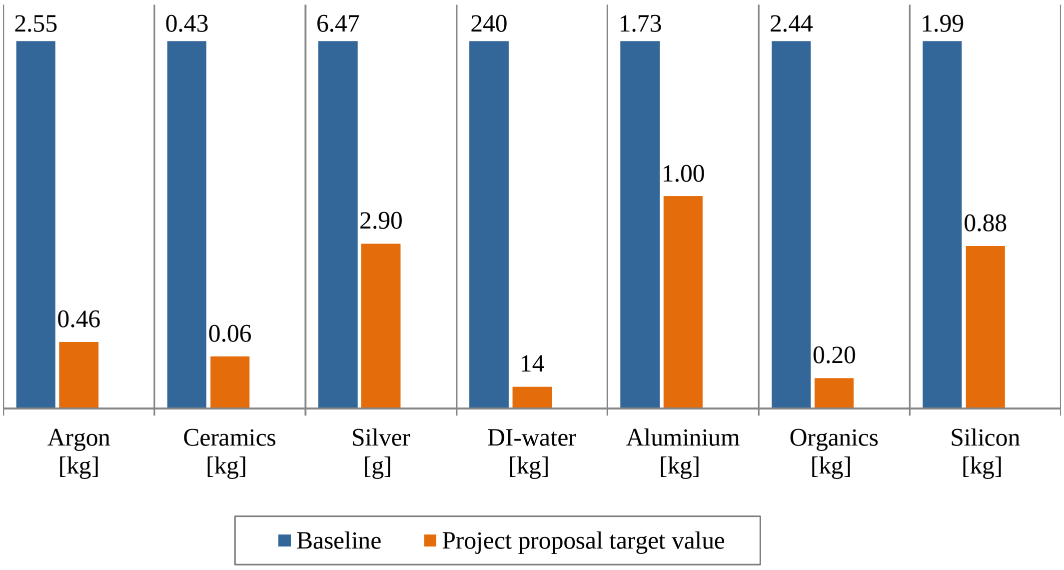


Figure 4.1: Reduction of waste and resource consumption per one sc-Si PV-module (60 6-inch solar cells) envisaged in Eco-Solar

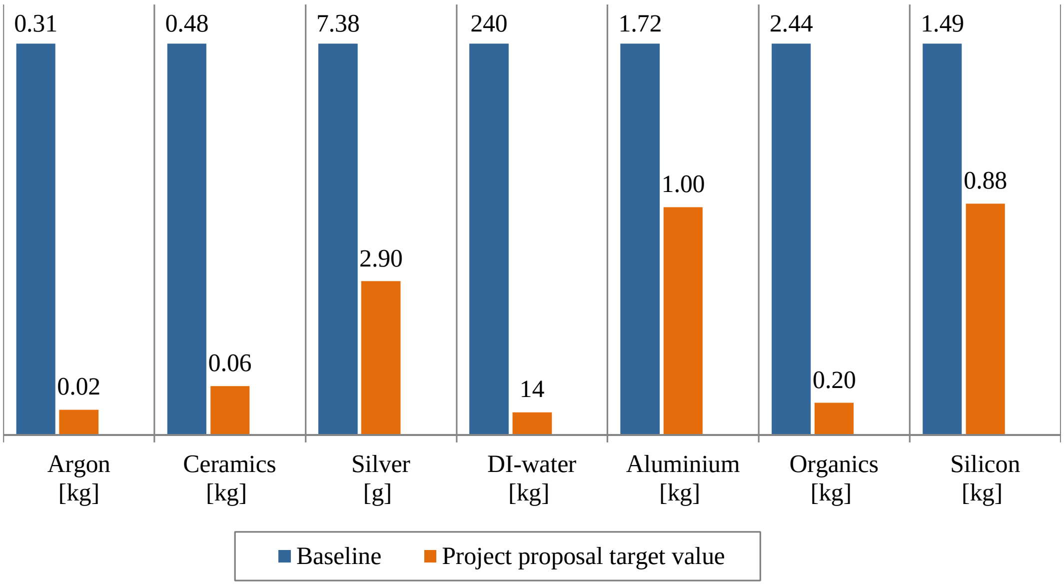


Figure 4.2: Reduction of waste and resource consumption per one mc-Si PV-module (60 6-inch solar cells) envisaged in Eco-Solar

5 LIFE CYCLE IMPACT ASSESSMENT: BASELINE

5.1 Explanation of the presentation of the results

Depictions were employed to evaluate the considered impact categories as explained in Figure 5.1.

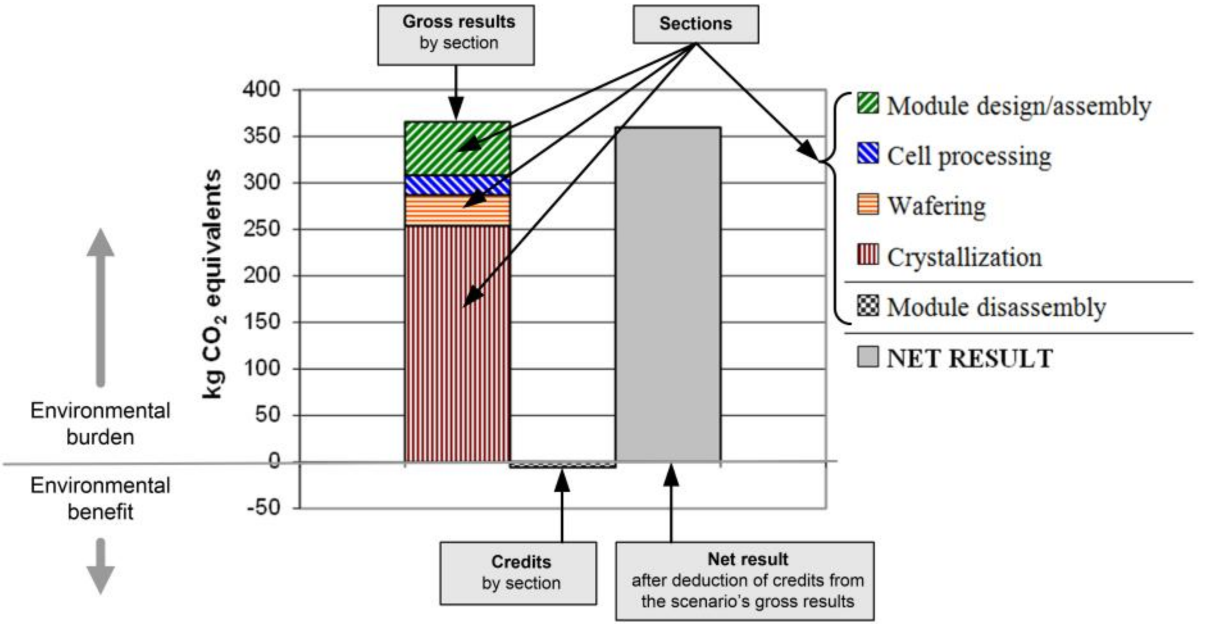


Figure 5.1: Explanation of the chart for sectoral evaluation of the considered impact categories

The life cycle assessment provides three sets of results. The respective bars on the left of Figure 5.1 show the gross expense results (environmental burden – bar upward) on one hand and on the other hand the credits (environmental benefits – bar downward). The sectoral display in color-coded sections makes it possible to identify the sections with relevant contributions to the overall result.

The net result for the considered impact category results from the offsetting of the environmental impact and benefit, which is displayed respectively in the grey bar on the right in Figure 5.2. It shows whether the environment suffers (bar upward) or sustains benefits (bar downward) due to the contribution of the scenario.

5.2 Climate change

Figure 5.2 and Figure 5.3 show the proportions of the production chain sections at the result of global warming potential.

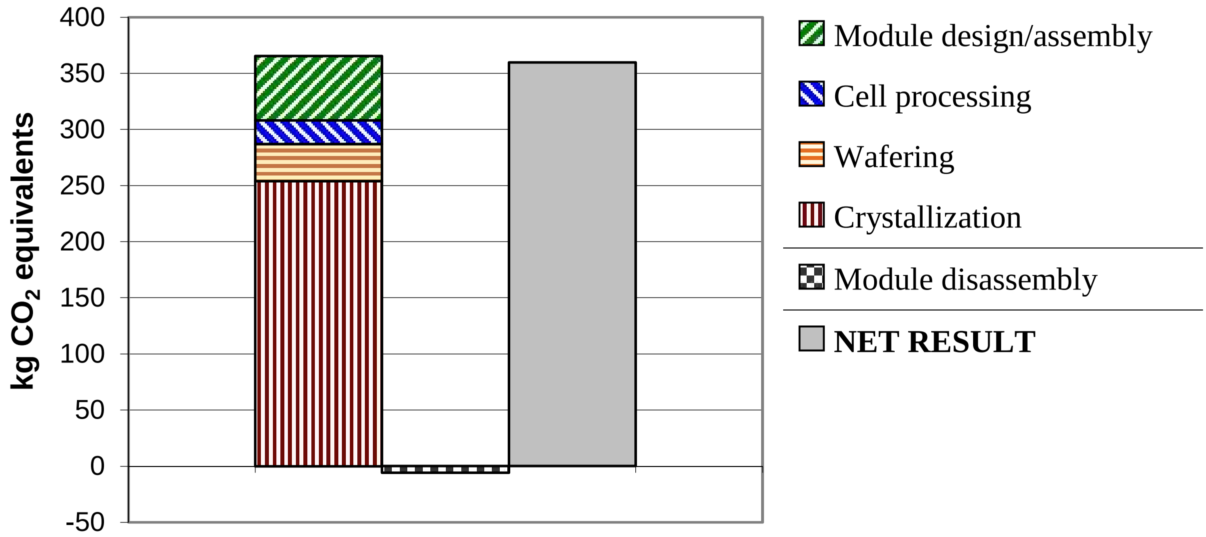


Figure 5.2: Baseline: global warming potential of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **360 kg CO_2 equivalents**[6] is determined by the crystallization process. 69 % of total greenhouse gas emissions (mainly carbon dioxide, methane, nitrous oxide) come from this section. With a share of 16 % emissions of module design/assembly play a minor role and emissions of wafering and cell processing contribute less than 10 % to the net result each. The effect of disassembly credits is small with a reduction of less than 2 %.

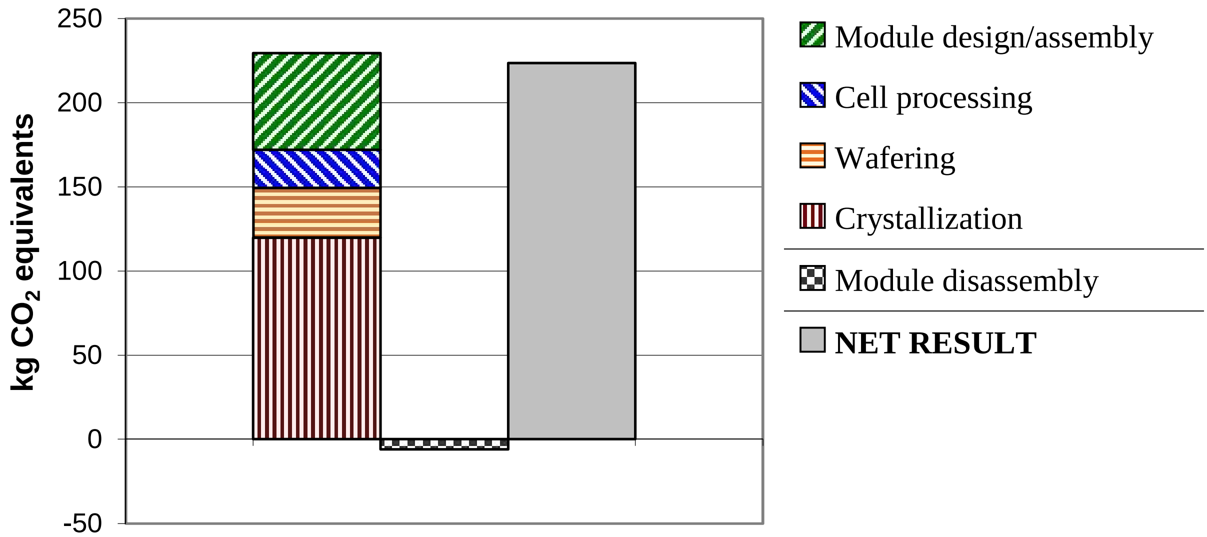


Figure 5.3: Baseline: global warming potential of one mc-Si PV-module (60 6-inch solar cells)

[6] CO_2 = Carbon dioxide (effect mechanism of impact category cf. chapter 2.1.3.3)

The net result of one mc-Si PV-module in the amount of total **224 kg CO_2 equivalents** is determined by the crystallization process as well as module design/assembly on a smaller scale. 54 % and 26 % total greenhouse gas emissions (mainly carbon dioxide, methane, nitrous oxide as well) come from these two sections. With a share of 13 % and 10 % emissions of wafering and cell processing play a minor role. The effect of disassembly credits is small with a reduction of less than 3 %.
The corresponding LCIA data are summarized in annexes B and C. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.1 and Table 5.2.

Table 5.1: Baseline: contributions of the most important processes to the gross result of global warming potential of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	**Key process**	**Emission category**	**Contribution [CO_2 eq]**	**Share of gross result**
Crystallization	Production of silicon, solar grade	Scope 3	150 kg	41 %
Crystallization	Electricity supply, medium voltage	Scope 2	84 kg	23 %
Wafering	Electricity supply, medium voltage	Scope 2	20 kg	6 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	17 kg	5 %
Cell processing	Electricity supply, medium voltage	Scope 2	14 kg	4 %
Crystallization	Heat supply, fuels other than natural gas	Scope 2	11 kg	3 %
TOTAL			**279 kg**	**81 %**

Table 5.2: Baseline: contributions of the most important processes to the gross result of global warming potential of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	**Key process**	**Emission category**	**Contribution [CO_2 eq]**	**Share of gross result**
Crystallization	Production of silicon, solar grade	Scope 3	112 kg	49 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	17 kg	7 %
Wafering	Electricity supply, medium voltage	Scope 2	16 kg	7 %
Module design/ assembly	Production of aluminium alloy	Scope 3	11 kg	5 %
Cell processing	Electricity supply, medium voltage	Scope 2	10 kg	4 %
Crystallization	Electricity supply, medium voltage	Scope 2	6 kg	3 %
TOTAL			**172 kg**	**75 %**

For both module types, 58 % of the credits originate from the recycling of the aluminium frame. The resulting secondary raw material avoids relevant emissions associated with the conventional production of aluminium from primary raw materials. In addition, the recycling of glass fibre reinforced plastic (part of junction box) and the energetic utilization of plastic parts also provide relevant contributions to the credits in the amount of 23 % and 10 %, respectively.

5.3 Freshwater Ecotoxicity

Figure 5.4 and Figure 5.5 show the proportions of the production chain sections at the result of freshwater ecotoxicity potential.

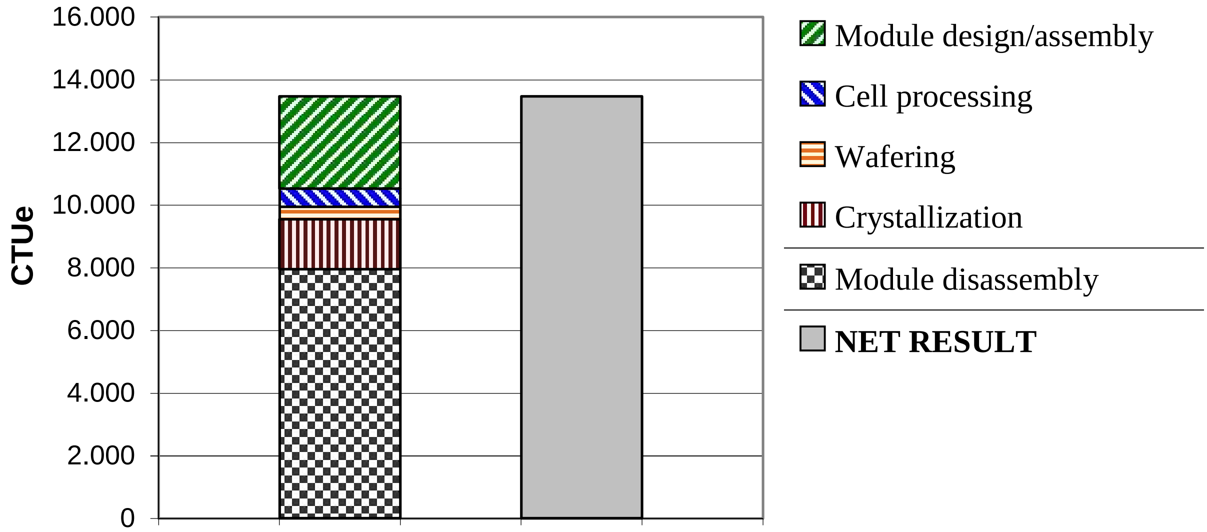


Figure 5.4: Baseline: freshwater ecotoxicity potential of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **13,470 CTUe**[7] is determined by the module disassembly (treatment of waste fractions) as well as module design/assembly on a smaller scale. 59 % and 22 % of total emissions into water (mainly Copper, Zinc ions, Vanadium ions and chromium(VI)) come from these two sections. With a share of 12 % emissions of the crystallization process play a minor role and emissions of wafering and cell processing together contribute less than 10 % to the net result.

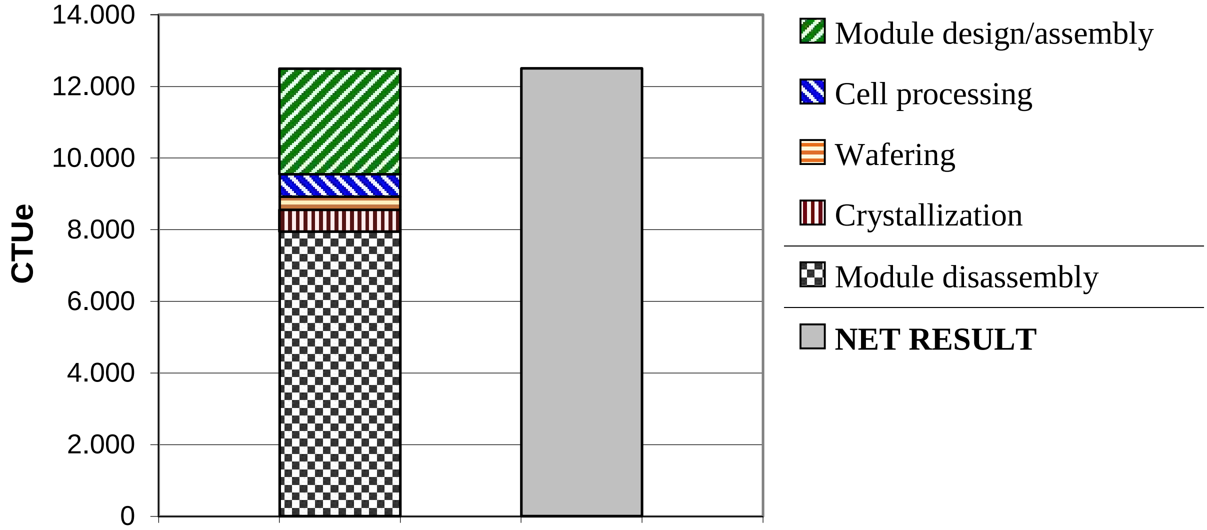


Figure 5.5: Baseline: freshwater ecotoxicity potential of one mc-Si PV-module (60 6-inch solar cells)

[7] CTUh = Comparative toxic unit for aquatic ecotoxicity impacts (effect mechanism cf. chapter 2.1.3.3)

The net result of one mc-Si PV-module in the amount of total **12,500 CTUe** is also determined by module disassembly (treatment of waste fractions) as well as module design/assembly on a smaller scale. 64 % and 24 % of total emissions into water (mainly Copper, Zinc ions, Vanadium ions and chromium(VI) as well) come from these two sections. Emissions of the crystallization pro-cess, wafering and cell processing contribute less than 6 % to the net result each.
The corresponding LCIA data are summarized in annexes B and C. There are no credits resulting of the disassembly of both types of PV-modules because of emissions from treatment of the waste fractions are higher than credits from recycling of these fractions.
The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.3 and Table 5.4.

Table 5.3: Baseline: contributions of the most important processes to the gross result of freshwater ecotoxicity potential of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [CTUe]	Share of gross result
Enhanced disassembly	Treatment of aluminium scrap	Scope 3	7,505	56 %
Module design/ assembly	Production of aluminium alloy	Scope 3	2,055	15 %
Crystallization	Electricity supply, medium voltage	Scope 2	791	6 %
Crystallization	Production of silicon, solar grade	Scope 3	713	5 %
Module design/ assembly	Production of copper	Scope 3	567	4 %
Module disassembly	Treatment of shredder fraction from manual dismantling	Scope 3	342	3 %
TOTAL			**11.974**	**89 %**

Table 5.4: Baseline: contributions of the most important processes to the gross result of freshwater ecotoxicity potential of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [CTUe]	Share of gross result
Module disassembly	Treatment of aluminium scrap	Scope 3	7,505	60 %
Module design/ assembly	Production of aluminium alloy	Scope 3	2,055	16 %
Module design/ assembly	Production of copper	Scope 3	567	5 %
Crystallization	Production of silicon, solar grade	Scope 3	533	4 %
Cell processing	Production of metallization paste, front side	Scope 3	370	3 %
Module disassembly	Treatment of shredder fraction from manual dismantling	Scope 3	342	3 %
TOTAL			**11.373**	**91 %**

5.4 Particulate matter / Respiratory inorganics

Figure 5.6 and Figure 5.7 show the proportions of the production chain sections at the result of the impact category particulate matter / respiratory inorganics.

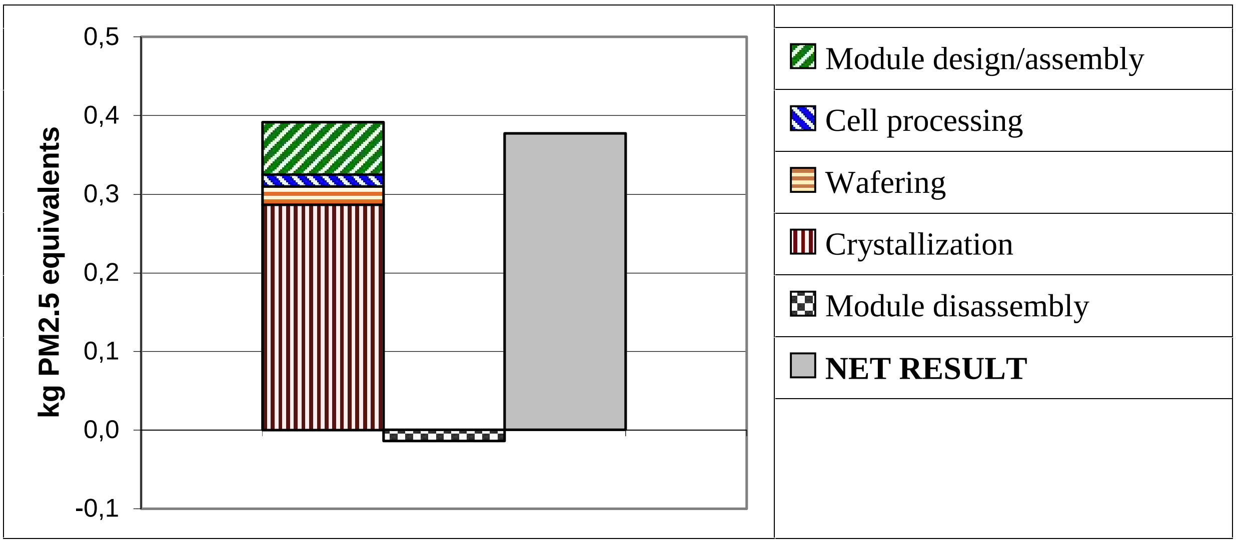


Figure 5.6: Baseline: particulate matter / respiratory inorganics of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **0.38 kg PM2.5 equivalents**[8] is primary determined by the crystallization process as well as module design/assembly on a smaller scale. 76 % and 18 % of total air emissions (mainly pm2.5 dust and sulphur dioxide) come from these two sections. Emissions of wafering and cell processing together contribute less than 10 % to the net result. The effect of disassembly credits is small with a reduction of less than 4 %.

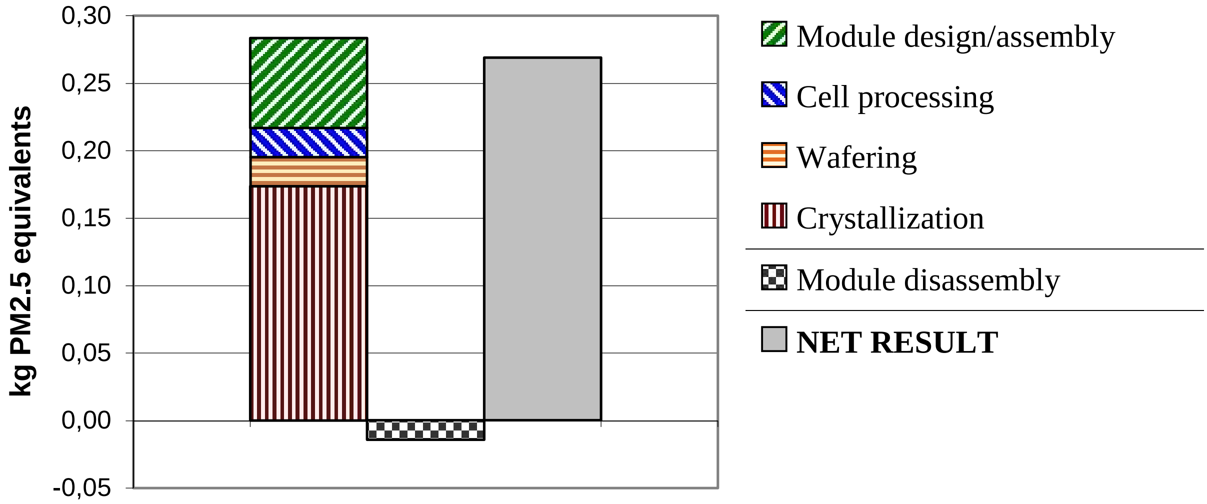


Figure 5.7: Baseline: particulate matter / respiratory inorganics of one mc-Si PV-module (60 6-inch solar cells)

[8] PM2.5 = Particulate matter less than 2.5 microns in diameter (effect mechanism cf. chapter 2.1.3.3)

The net result of one mc-Si PV-module in the amount of total **0.27 kg PM2.5 equivalents** is also determined by the crystallization process as well as module design/assembly on a smaller scale. 65 % and 25 % of total air emissions (mainly pm2.5 dust and sulphur dioxide as well) come from these two sections. Emissions of wafering and cell processing contribute less than 9 % to the net result each. The effect of disassembly credits is small with a reduction of less than 5 %.
The corresponding LCIA data are summarized in annexes B and C. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.5 and Table 5.6.

Table 5.5: Baseline: contributions of the most important processes to the gross result of particulate matter / respiratory inorganics of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	**Key process**	**Emission category**	**Contribution [PM2.5 eq]**	**Share of gross result**
Crystallization	Production of silicon, solar grade	Scope 3	220 g	56 %
Crystallization	Electricity supply, medium voltage	Scope 2	44 g	11 %
Module design/ assembly	Production of aluminium alloy	Scope 3	19 g	5 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	15 g	4 %
Crystallization	Production of argon	Scope 3	13 g	3 %
Wafering	Electricity supply, medium voltage	Scope 2	10 g	3 %
TOTAL			**320 g**	**82 %**

Table 5.6: Baseline: contributions of the most important processes to the gross result of particulate matter / respiratory inorganics of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	**Key process**	**Emission category**	**Contribution [PM2.5 eq]**	**Share of gross result**
Crystallization	Production of silicon, solar grade	Scope 3	164 g	58 %
Module design/ assembly	Production of aluminium alloy	Scope 3	19 g	7 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	15 g	5 %
Wafering	Electricity supply, medium voltage	Scope 2	8.5 g	3 %
Module design/ assembly	Production of copper	Scope 3	6.4 g	2 %
Module design/ assembly	Production of polyvinylchloride film	Scope 3	5.5 g	2 %
TOTAL			**218 g**	**77 %**

For both module types, almost 80 % of the credits originate from the recycling of the aluminium frame. The resulting secondary raw materials avoid relevant emissions associated with conventional production of aluminium from primary raw materials.

5.5 Depletion of mineral, fossil and renewable resources

Figure 5.8 and Figure 5.9 show the proportions of the production chain sections at the result of the impact category depletion of mineral, fossil and renewable resources.

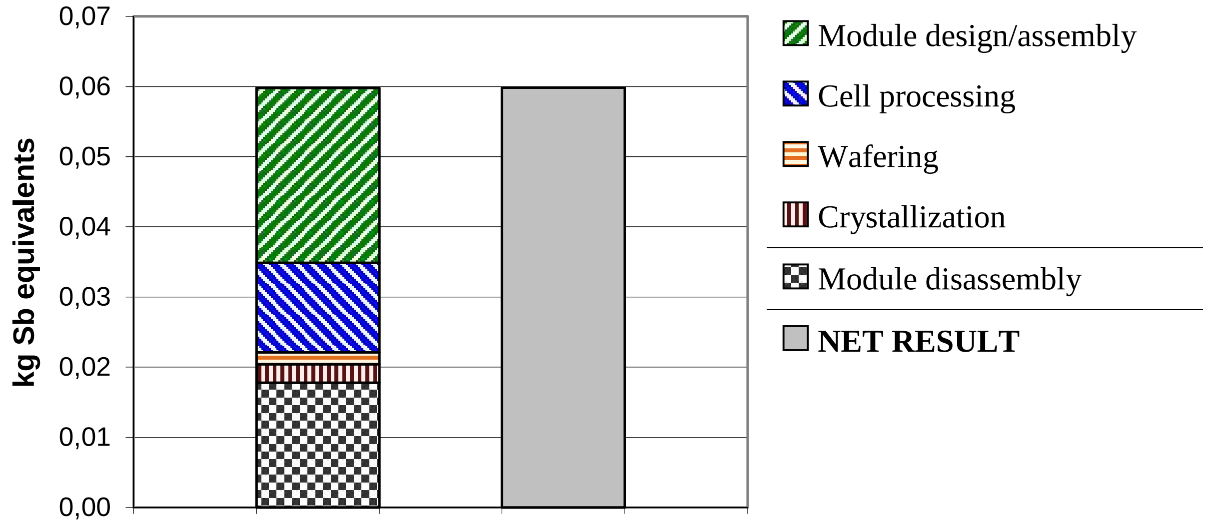


Figure 5.8: Baseline: depletion of mineral, fossil and renewable resources of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of **total 0.06 kg Sb equivalents**[9] is deter-mined by module design/assembly, module disassembly (treatment of waste fractions) and cell processing. 21 % to 42 % of total used resources (mainly indium, silver, cadmium, lead and gold) are consumed in these three sections. Resource consumption in wafering and in the crystallization process together correspond less than 10 % to the net result.

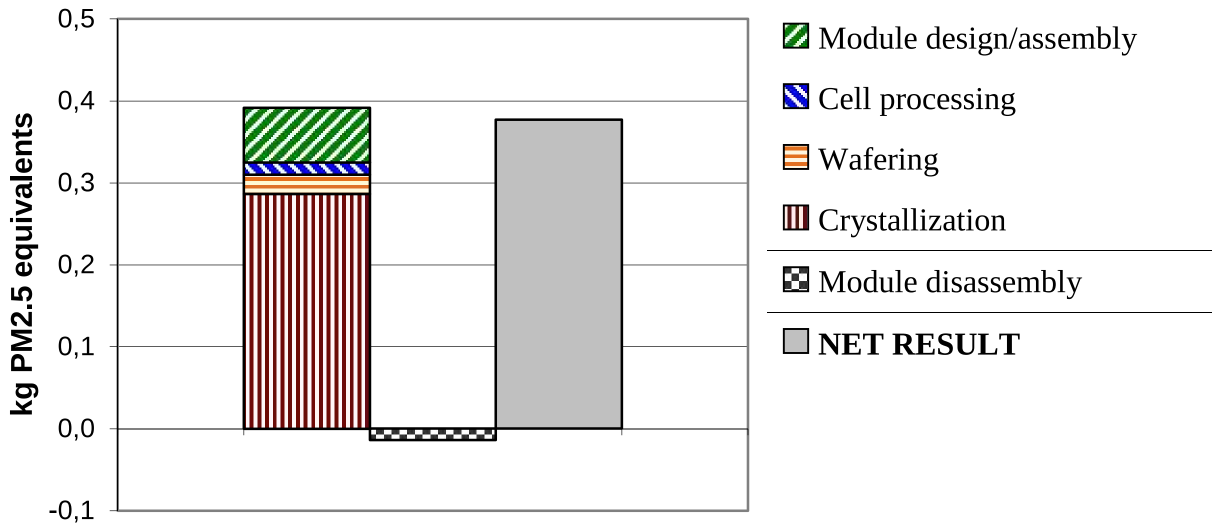


Figure 5.9: Baseline: depletion of mineral, fossil and renewable resources of one mc-Si PV-module (60 6-inch solar cells)

[9] Sb = Antimony (effect mechanism of impact category cf. chapter 2.1.3.3)

The net result of one mc-Si PV-module in the amount of total **0.063 kg Sb equivalents** is also determined by module design/assembly, module disassembly (treatment of waste fractions) and cell processing. 27 % to 40 % of total used resources (mainly indium, silver, cadmium, lead and gold as well) are consumed in these three sections. Resource consumption in wafering and in the crystallization process together correspond less than 6 % to the net result.

There are no credits resulting of the disassembly of both types of PV-modules because of emissions from treatment of the waste fractions are higher than credits from recycling of these fractions.

The corresponding LCIA data are summarized in annexes B and C. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.7 and Table 5.8.

Table 5.7: Baseline: contributions of the most important processes to the gross result of depletion of mineral, fossil and renewable resources of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [Sb eq]	Share of gross result
Module disassembly	Treatment of aluminium scrap	Scope 3	21 g	34 %
Module design/ assembly	Production of aluminium alloy	Scope 3	17 g	28 %
Cell processing	Production of metallization paste, front side	Scope 3	9.9 g	17 %
Module design/ assembly	Production of tin	Scope 3	2.9 g	5 %
Cell processing	Production of metallization paste, back side	Scope 3	2.7 g	4 %
Module design/ assembly	Production of polyvinylchloride film	Scope 3	1.6 g	3 %
TOTAL			**54 g**	**91 %**

Table 5.8: Baseline: contributions of the most important processes to the gross result of depletion of mineral, fossil and renewable resources of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [Sb eq]	Share of gross result
Module disassembly	Treatment of aluminium scrap	Scope 3	21 g	33 %
Module design/ assembly	Production of aluminium alloy	Scope 3	17 g	27 %
Cell processing	Production of metallization paste, front side	Scope 3	11 g	18 %
Module design/ assembly	Production of tin	Scope 3	2.9 g	5 %
Cell processing	Production of metallization paste, back side	Scope 3	2.8 g	4 %
Module design/ assembly	Production of hydrogen fluoride	Scope 3	2.4 g	4 %
TOTAL			**57 g**	**91 %**

5.6 Human toxicity, cancer effects

Figure 5.10 and Figure 5.11 show the proportions of the production chain sections at the result of carcinogenic human toxicity potential.

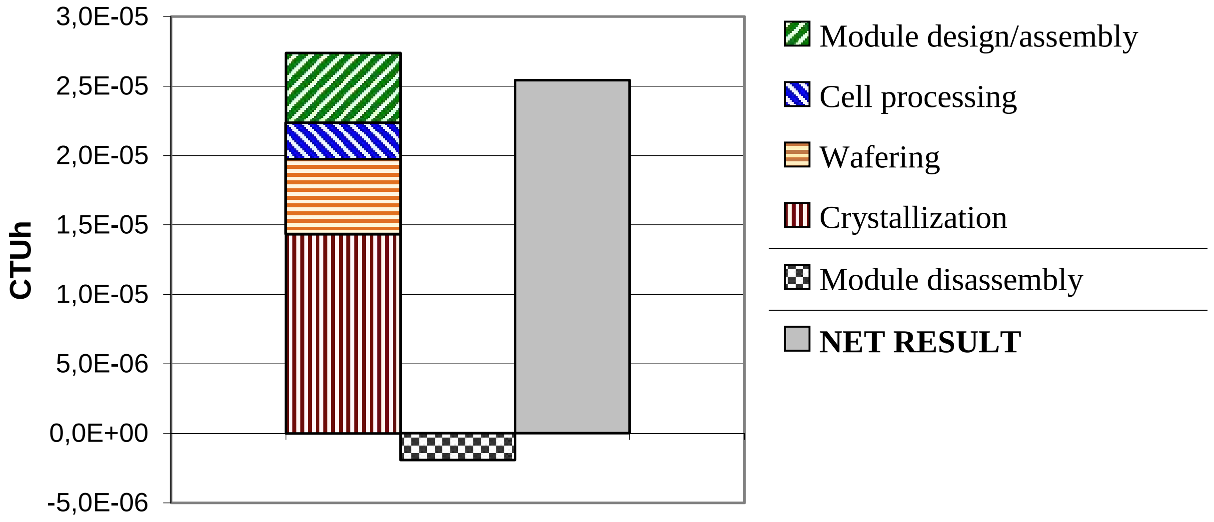


Figure 5.10: Baseline: carcinogenic human toxicity potential of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **2.54E-05 CTUh**[10] is determined by the crystallization process as well as wafering and module design/assembly on a smaller scale. 52 % to 18 % of total emissions to air and water (mainly chromium(VI) into water)

[10] CTUh = Comparative toxic unit for human toxicity impacts (effect mechanism cf. chapter 2.1.3.3)

come from these three sections. Emissions of cell processing contribute less than 10 % to the net result. After allocation of the disassembly credits the net result is reduced by about 8 %.

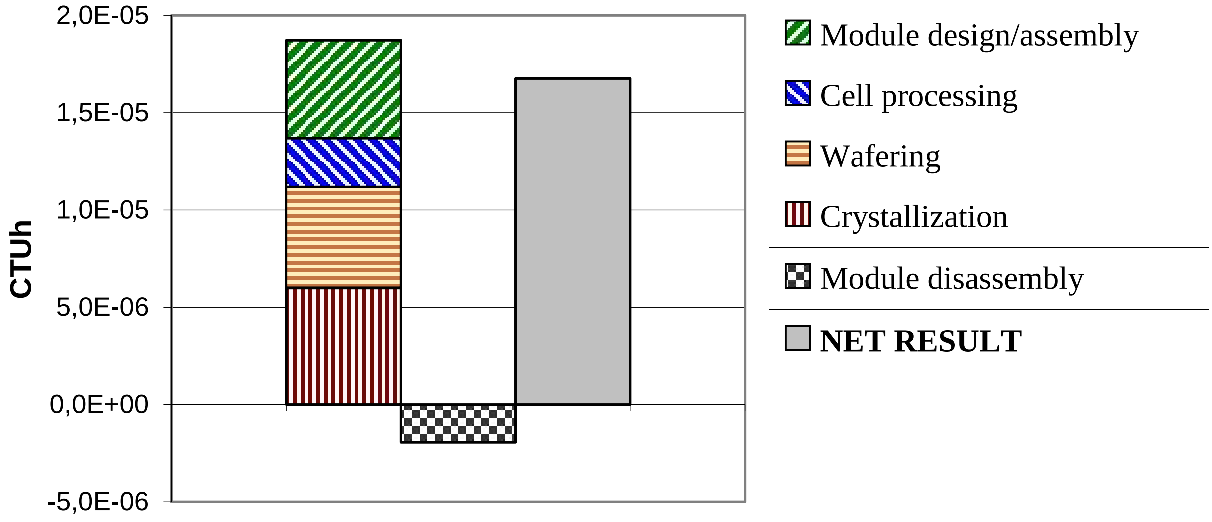


Figure 5.11: Baseline: carcinogenic human toxicity potential of one mc-Si PV-module (60 6-inch solar cells)

The net result of one mc-Si PV-module in the amount of total **1.68E-05 CTUh** is determined by the crystallization process, wafering as well as module design/assembly to about similar pro-portions. Between 30 % and 36 % of total emissions to air and water (mainly chromium(VI) into water as well) come from each of the three sections. With a share of 15 % emissions of cell pro-cessing play a minor role. After allocation of the disassembly credits the net result is reduced by about 12 %.

The corresponding LCIA data are summarized in annexes B and C. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.9 and Table 5.10.

Table 5.9: Baseline: contributions of the most important processes to the gross result of carcinogenic human toxicity potential of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [CTUh]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	7.34E-06	27 %
Crystallization	Electricity supply, medium voltage	Scope 2	6.18E-06	23 %
Wafering	Production of hot rolled low-alloyed steel	Scope 3	2.88E-06	11 %
Module design/ assembly	Production of aluminium alloy	Scope 3	2.24E-06	8 %
Wafering	Electricity supply, medium voltage	Scope 2	1.47E-06	5 %
Cell processing	Electricity supply, medium voltage	Scope 2	1.03E-06	4 %
TOTAL			**2.11E-05**	**77 %**

Table 5.10: Baseline: contributions of the most important processes to the gross result of carcinogenic human toxicity potential of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [CTUh]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	5.49E-06	29 %
Wafering	Production of hot rolled low-alloyed steel	Scope 3	2.90E-06	16 %
Module design/ assembly	Production of aluminium alloy	Scope 3	2.24E-06	12 %
Wafering	Electricity supply, medium voltage	Scope 2	1.20E-06	6 %
Module design/ assembly	Production of copper	Scope 3	9.03E-07	5 %
Cell processing	Electricity supply, medium voltage	Scope 2	7.29E-07	4 %
TOTAL			**1.35E-05**	**72 %**

For both module types, more than 80 % of the credits originate from the recycling of the aluminium frame. The resulting secondary raw materials avoid relevant emissions associated with conventional production of aluminium from primary raw materials.

5.7 Ionizing radiation on human health

Figure 5.12 and Figure 5.13 show the proportions of the production chain sections at the result of the impact category ionizing radiation on human health.

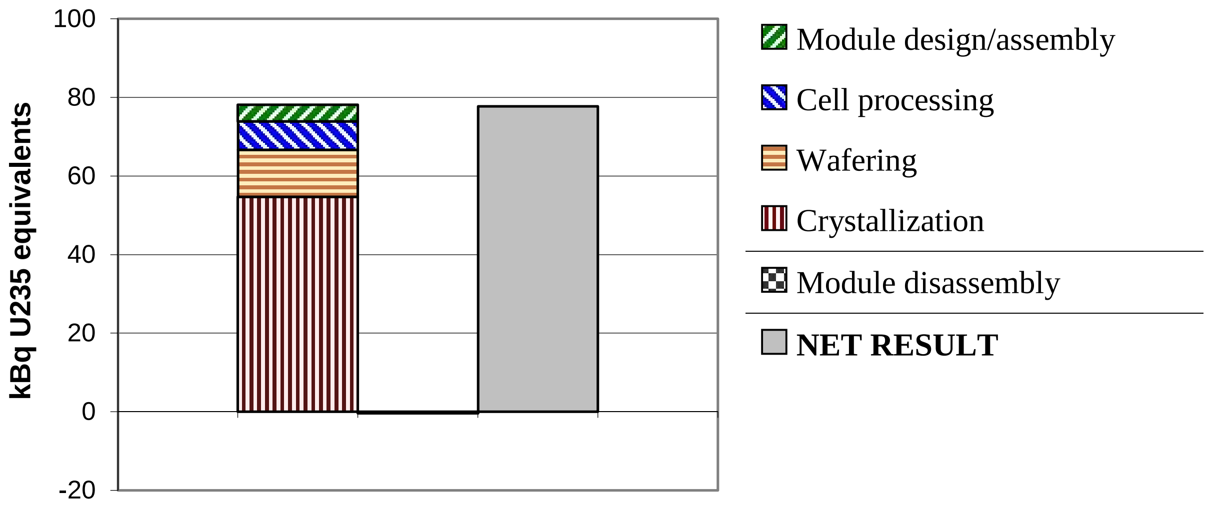


Figure 5.12: Baseline: effect of ionizing radiation on human health of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **78 kBq U235 equivalents**[11] is principally determined by the crystallization process. 70 % of the total air emissions (mainly radon-222 and C-14) come from this section. With a share of 15 % radiation from wafering

[11] U235 = Uranium-235 (effect mechanism of impact category cf. chapter 2.1.3.3)

plays a minor role and radiation from cell processing and module design/assembly contribute less than 10 % to the net result each. The effect of disassembly credits is marginal with a reduction of less than 0.5 %.

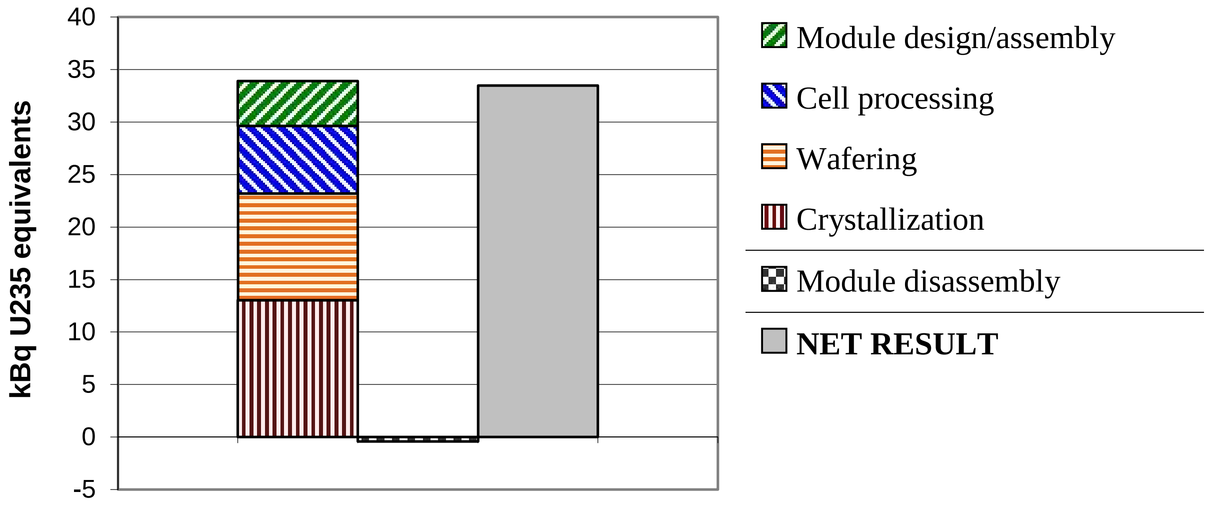


Figure 5.13: Baseline: effect of ionizing radiation on human health of one mc-Si PV-module (60 6-inch solar cells)

The net result of one mc-Si PV-module in the amount of total **33 kBq U235 equivalents** is determined by the crystallization process and Wafering. 39 % and 30 % of total air emissions (mainly radon-222 and C-14 as well) come from these two sections. With proportions of 19 % and 13 % radiation from wafering and module design/assembly plays a minor role. The effect of disassembly credits is small with a reduction of less than 2 %.

The corresponding LCIA data are summarized in annexes B and C. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.11 and Table 5.12.

Table 5.11: Baseline: contributions of the most important processes to the gross result of carcinogenic human toxicity potential of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [U235 eq]	Share of gross result
Crystallization	Electricity supply, medium voltage	Scope 2	40 kBq	51 %
Crystallization	Production of silicon, solar grade	Scope 3	13 kBq	17 %
Wafering	Electricity supply, medium voltage	Scope 2	9.6 kBq	12 %
Cell processing	Electricity supply, medium voltage	Scope 2	6.7 kBq	9 %
Wafering	Production of silicon carbide	Scope 3	1.8 kBq	2 %
Module design/ assembly	Electricity supply, medium voltage	Scope 2	1.4 kBq	2 %
TOTAL			**73 kBq**	**93 %**

Table 5.12: Baseline: contributions of the most important processes to the gross result of carcinogenic human toxicity potential of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [U235 eq]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	9.9 kBq	51 %
Wafering	Electricity supply, medium voltage	Scope 2	7.8 kBq	17 %
Cell processing	Electricity supply, medium voltage	Scope 2	4.7 kBq	12 %
Crystallization	Electricity supply, medium voltage	Scope 2	2.9 kBq	9 %
Wafering	Production of silicon carbide	Scope 3	1.8 kBq	2 %
Module design/ assembly	Electricity supply, medium voltage	Scope 2	1.4 kBq	2 %
TOTAL			**29 kBq**	**85 %**

More than 40 % of the credits for one mc-Si PV-module originate from the energetic utilization of plastic parts. The resulting electrical and thermal energy avoids relevant emissions associated with producing the same amount of electricity and heat from primary fuels. In addition, the recycling of the aluminium frame, of glass fibre reinforced plastic (part of junction box) and of the tin content on the PV module provide relevant contributions to the credits of 27 % to 12 %, respectively.

5.8 Photochemical ozone formation

Figure 5.14 and Figure 5.15 show the proportions of the production chain sections at the result of photochemical ozone formation potential.

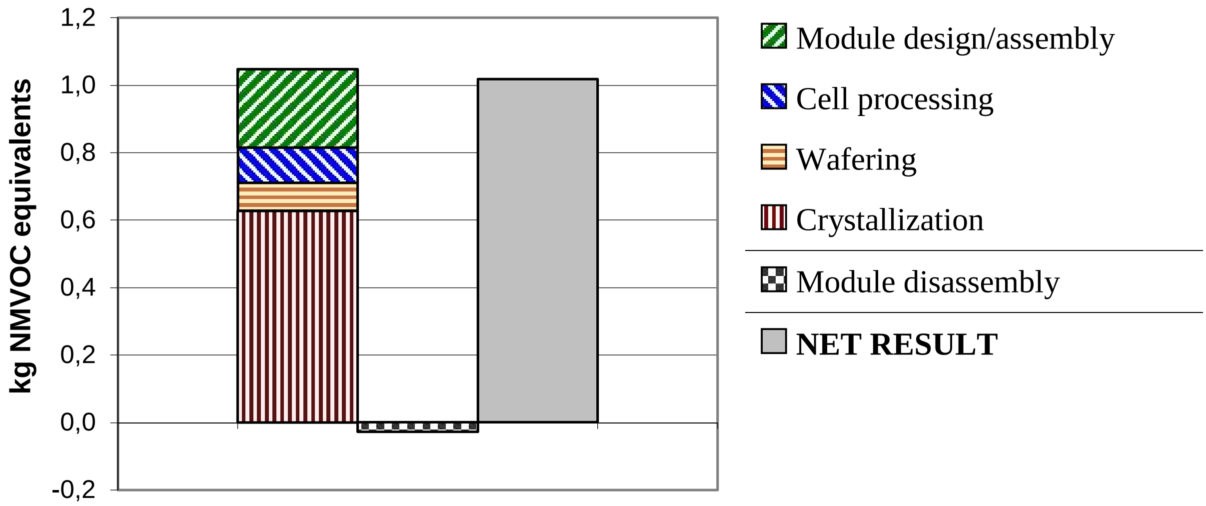


Figure 5.14: Baseline: photochemical ozone formation potential of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **1.02 kg NMVOC equivalents**[12] is determined by the crystallization process as well as module design/assembly on a smaller

[12] NMVOC = Non methane volatile organic compounds (effect mechanism cf. chapter 2.1.3.3)

scale. 60 % and 22 % of total air emissions (mainly nitrogen oxides, sulphur dioxide and unspecific NMVOC) come from these two sections. With a share of 10 % emissions of cell processing play a minor role and emissions of wafering contribute less than 8 % to the net result. The effect of disassembly credits is small with a reduction of less than 3 %.

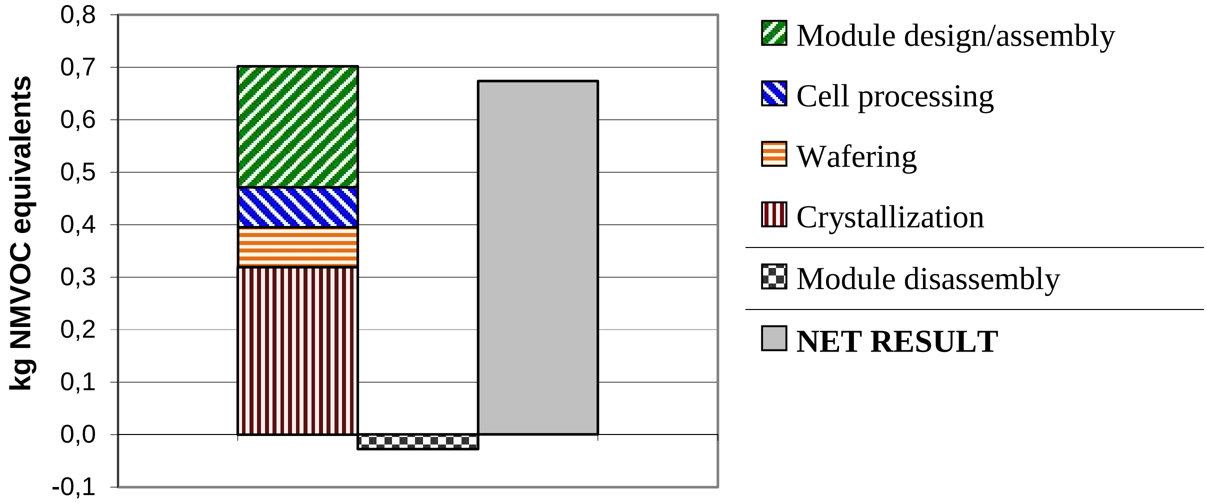


Figure 5.15: Baseline: photochemical ozone formation potential of one mc-Si PV-module (60 6-inch solar cells)

The net result of one mc-Si PV-module in the amount of total **0.67 kg NMVOC** equivalents is determined by the crystallization process and module design/assembly. 47 % and 34 % of total air emissions (mainly nitrogen oxides, sulphur dioxide and unspecific NMVOC as well) come from these two sections. With a share of 11 % each emissions of cell processing and wafering play a minor role. The effect of disassembly credits is small with a reduction of less than 5 %.

The corresponding LCIA data are summarized in annexes B and C. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.13 and Table 5.14.

Table 5.13: Baseline: contributions of the most important processes to the gross result of photochemical ozone formation potential of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [NMVOC eq]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	0.4 kg	39 %
Crystallization	Electricity supply, medium voltage	Scope 2	0.17 kg	16 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	0.083 kg	8 %
Cell processing	Photovoltaic cell production	Scope 1	0.043 kg	4 %
Wafering	Electricity supply, medium voltage	Scope 2	0.042 kg	4 %
Module design/ assembly	Production of aluminium alloy	Scope 3	0.035 kg	3 %
TOTAL			**0.78 kg**	**74 %**

Table 5.14: Baseline: contributions of the most important processes to the gross result of photochemical ozone formation potential of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [NMVOC eq]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	0.3 kg	43 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	0.08 kg	12 %
Module design/ assembly	Production of aluminium alloy	Scope 3	0.035 kg	5 %
Wafering	Electricity supply, medium voltage	Scope 2	0.033 kg	5 %
Cell processing	Production of metallization paste, front side	Scope 3	0.02 kg	3 %
Cell processing	Electricity supply, medium voltage	Scope 2	0.02 kg	3 %
TOTAL			**0.49 kg**	**74 %**

For both module types, 61 % of the credits originate from the recycling of the aluminium frame. The resulting secondary raw material avoids relevant emissions associated with the conventional production of aluminium from primary raw materials. In addition, the recycling of glass fibre reinforced plastic (part of junction box) also provides relevant contributions to the credits in the amount of 20 %.

5.9 Human toxicity, non-cancer effects

Figure 5.16 and Figure 5.17 the proportions of the production chain sections at the result of non-carcinogenic human toxicity potentials.

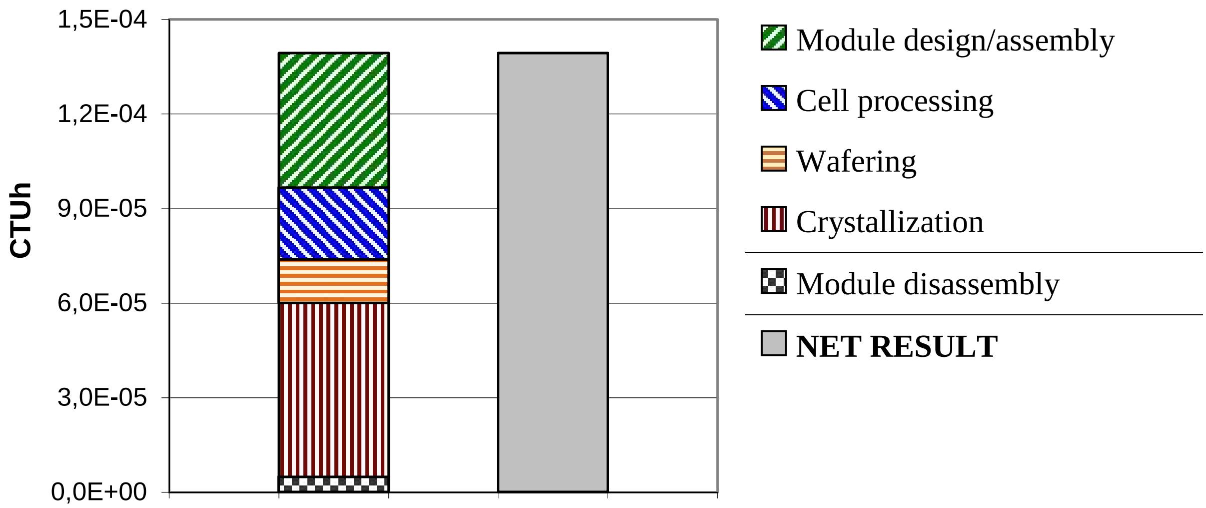


Figure 5.16: Baseline: non-carcinogenic human toxicity potential of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **1.39E-04 CTUh**[13] is determined by the crystallization process as well as module design/assembly. 40 % and 31 % of total emissions into water and air (mainly zinc ions and arsenic ions into water as well as zinc, arsenic and cadmium into air) come from these two sections. With a share of 16 % emissions of cell processing play a minor role. Emissions of wafering and module disassembly contribute less than 10 % to the net result each.

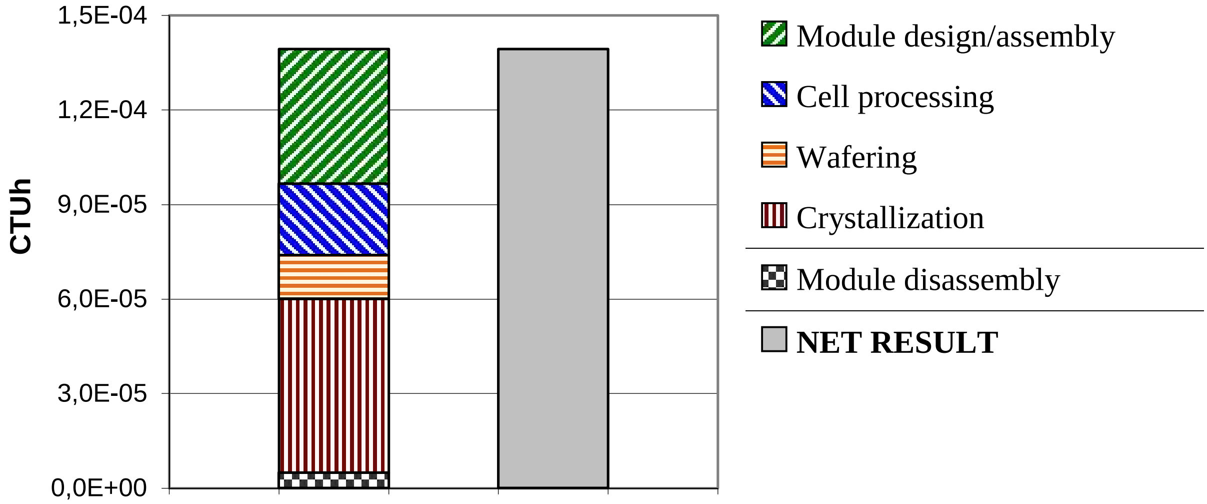


Figure 5.17: Baseline: non-carcinogenic human toxicity potential of one mc-Si PV-module (60 6-inch solar cells)

The net result of one mc-Si PV-module in the amount of total **1.04E-04 CTUh** is determined by module design/assembly as well as cell processing and the crystallization process on a smaller scale. 39 % as well as 23 % and 21 % of total emissions to water and air (mainly also zinc ions and arsenic ions into water as well as zinc, arsenic and cadmium into air) come from these three sections. With a share of 12 % emissions of wafering play a minor role whereas module disassembly contributes less than 5 % to the net result.

There are no credits resulting of the disassembly of both types of PV-modules because of emissions from treatment of the waste fractions are higher than credits from recycling of these fractions.

The corresponding LCIA data are summarized in annexes B and C. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.15 and Table 5.16.

[13] CTUh = Comparative toxic unit for human toxicity impacts (effect mechanism cf. chapter 2.1.3.3)

Table 5.15: Baseline: contributions of the most important processes to the gross result of photochemical ozone formation potential of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [CTUh]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	2.76E-05	20 %
Module design/ assembly	Production of copper	Scope 3	2.69E-05	19 %
Crystallization	Electricity supply, medium voltage	Scope 2	2.36E-05	17 %
Cell processing	Production of metallization paste, front side	Scope 3	1.33E-05	10 %
Module design/ assembly	Production of aluminium alloy	Scope 3	5.65E-06	4 %
Wafering	Electricity supply, medium voltage	Scope 2	5.63E-06	4 %
TOTAL			**1.03E-4**	**74 %**

Table 5.16: Baseline: contributions of the most important processes to the gross result of photochemical ozone formation potential of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [CTUh]	Share of gross result
Module design/ assembly	Production of copper	Scope 3	2.69E-05	25 %
Crystallization	Production of silicon, solar grade	Scope 3	2.06E-05	19 %
Cell processing	Production of metallization paste, front side	Scope 3	1.55E-05	14 %
Module design/ assembly	Production of aluminium alloy	Scope 3	5.65E-06	5 %
Module disassembly	Treatment of aluminium scrap	Scope 3	4.61E-06	4 %
Wafering	Electricity supply, medium voltage	Scope 2	4.60E-06	4 %
TOTAL			**7.79E-5**	**72 %**

5.10 Ozone depletion

Figure 5.18 and Figure 5.19 show the proportions of the production chain sections at the result of ozone depletion potentials.

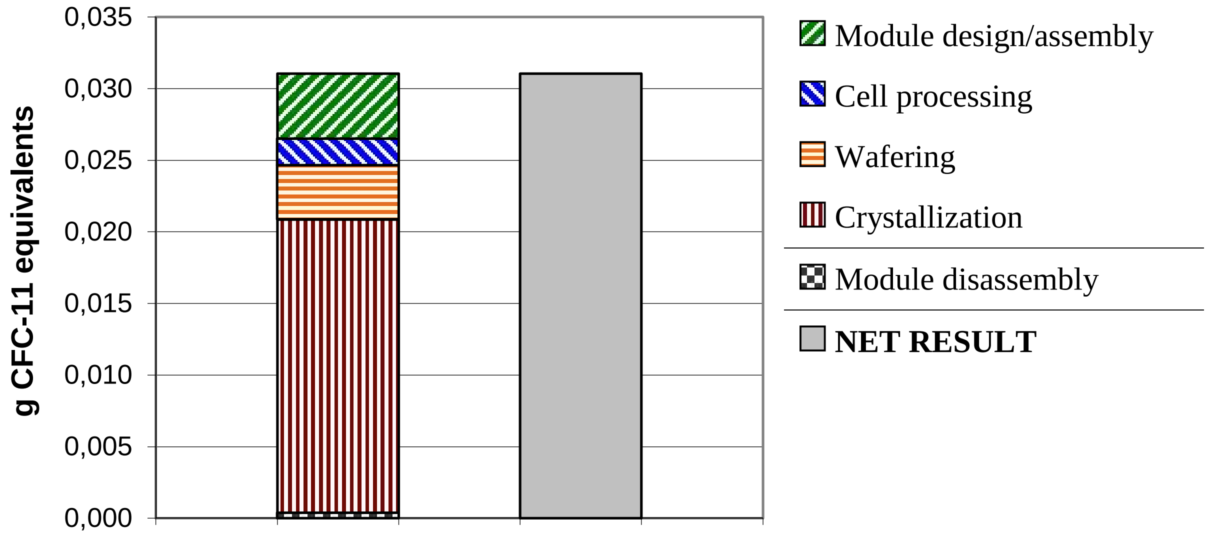


Figure 5.18: Baseline: ozone depletion potential of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **0.031 g CFC-11 equivalents**[14] is determined by the crystallization process. 66 % of total emissions to air and water (mainly zinc ions and arsenic ions into water as well as zinc, arsenic and cadmium into air) come from this section. With a share of 15 % and 12 % emissions of wafering and module design/assembly play a minor role. Emissions of cell processing and module disassembly together contribute less than 10 % to the net result.

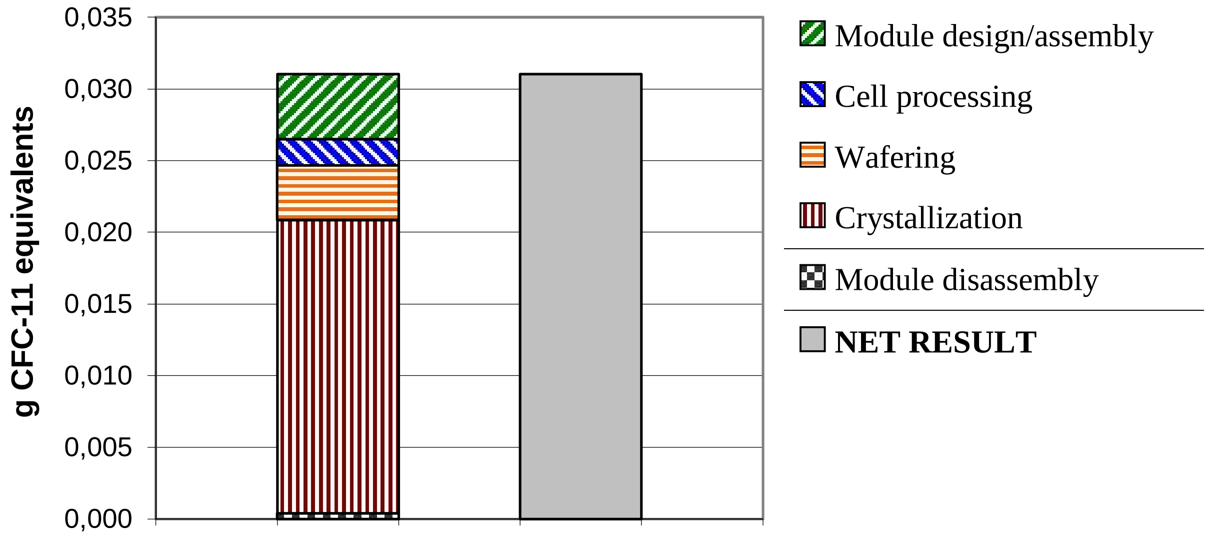


Figure 5.19: Baseline: ozone depletion potential of one mc-Si PV-module (60 6-inch solar cells)

[14] CFC-11 = Trichlorofluoromethane (effect mechanism of impact category cf. chapter 2.1.3.3)

The net result of one mc-Si PV-module in the amount of total **0.019 g CFC-11 equivalents** is determined by the crystallization process as well as module design/assembly on a smaller scale. 46 % and 24 % of total emissions to air and water (mainly also zinc ions and arsenic ions into water as well as zinc, arsenic and cadmium into air) come from these two sections. With a share of 18 % and 11 % emissions of wafering and cell processing play a minor role whereas emissions of module disassembly contribute less than 2 % to the net result.
There are no credits resulting of the disassembly of both types of PV-modules because of emissions from treatment of the waste fractions are higher than credits from recycling of these fractions.
The corresponding LCIA data are summarized in annexes B and C. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.17 and Table 5.18.

Table 5.17: Baseline: contributions of the most important processes to the gross result of ozone depletion potential of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [CFC-11 eq]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	0.011 g	35 %
Crystallization	Electricity supply, medium voltage	Scope 2	0.009 g	28 %
Wafering	Electricity supply, medium voltage	Scope 2	0.002 g	7 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	0.002 g	5 %
Cell processing	Electricity supply, medium voltage	Scope 2	0.001 g	5 %
Wafering	Production of dipropylene glycol monomethyl ether	Scope 3	0.001 g	3 %
TOTAL			**0.025 g**	**82 %**

Table 5.18: Baseline: contributions of the most important processes to the gross result of ozone depletion potential of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [CFC-11 eq]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	0.008 g	42 %
Crystallization	Electricity supply, medium voltage	Scope 2	0.002 g	9 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	0.002 g	8 %
Cell processing	Electricity supply, medium voltage	Scope 2	0.001 g	5 %
Wafering	Production of dipropylene glycol monomethyl ether	Scope 3	0.001 g	4 %
Module design/ assembly	Production of aluminium alloy	Scope 3	0.001 g	4 %
TOTAL			**0.014 g**	**73 %**

5.11 Acidification

Figure 5.20 and Figure 5.21 show the proportions of the production chain sections at the result of acidification potentials.

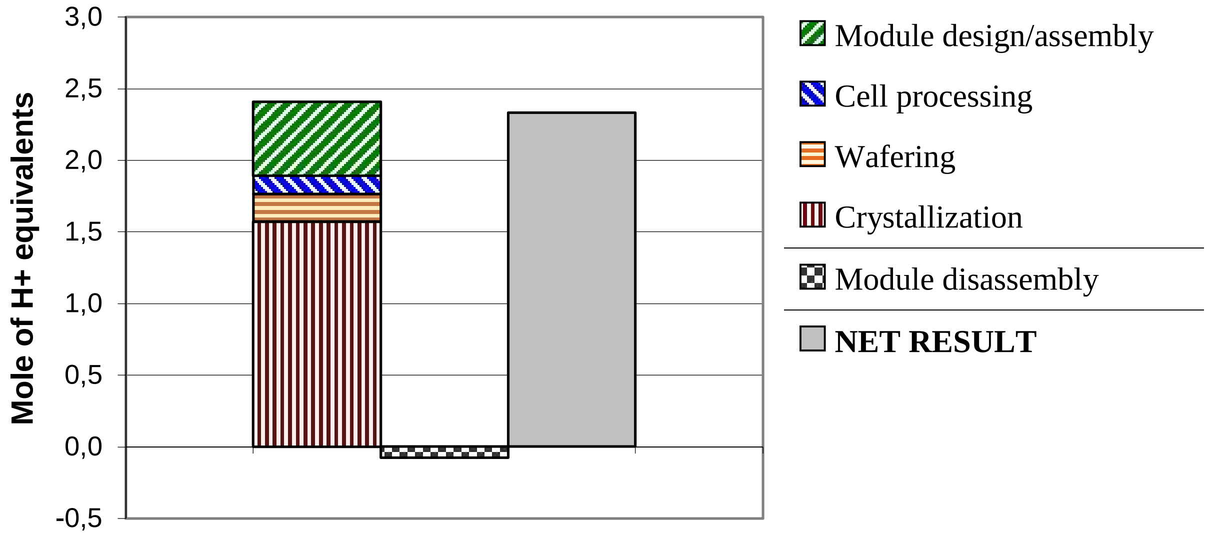


Figure 5.20: Baseline: acidification potential of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **2.3 Mole of H^+ equivalents**[15] is deter-mined by the crystallization process as well as module design/assembly on a smaller scale. 67 % and 22 % of total air emissions (mainly sulphur dioxide and nitrogen oxides) come from these two sections. Emissions of wafering and cell processing contribute less than 9 % to the net result each. The effect of disassembly credits is small with a reduction of less than 3 %.

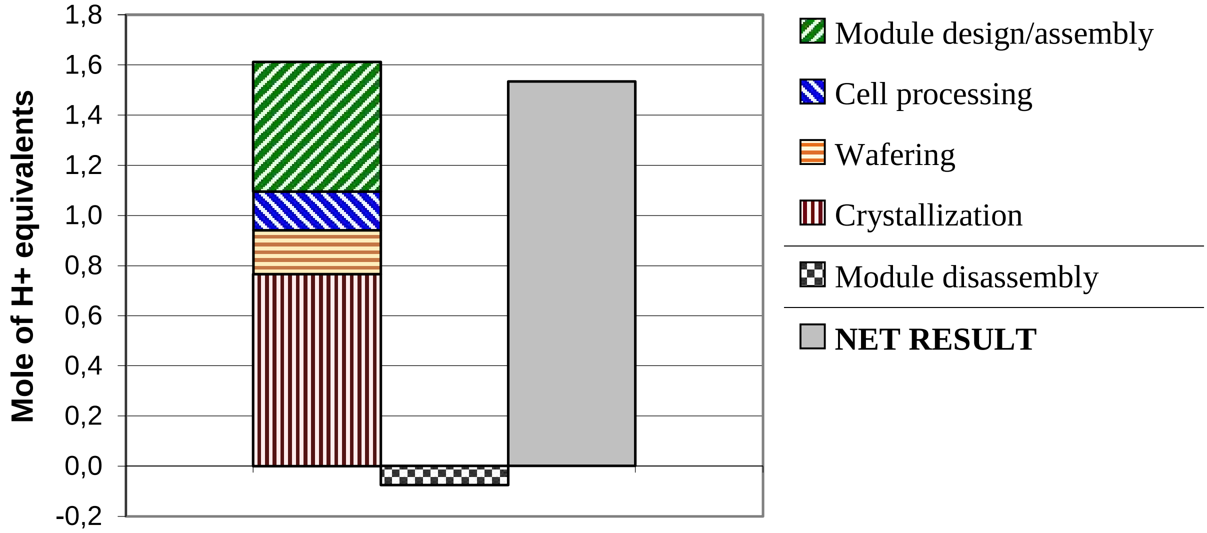


Figure 5.21: Baseline: acidification potential of one mc-Si PV-module (60 6-inch solar cells)

[15] H^+ = Hydrogen ion or proton (effect mechanism of impact category cf. chapter 2.1.3.3)

The net result of one mc-Si PV-module in the amount of total **1.5 Mole of H^+ equivalents** is also determined by the crystallization process as well as module design/assembly on a smaller scale. 50 % and 34 % of total air emissions (mainly sulphur dioxide and nitrogen oxides as well) come from these two sections. With a share of 11 % and 10 % emissions of wafering and cell processing play a minor role. The effect of disassembly credits is small with a reduction of a little more than 5 %.
The corresponding LCIA data are summarized in annexes B and C. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.19 and Table 5.20.

Table 5.19: Baseline: contributions of the most important processes to the gross result of acidification potential of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [H^+ eq]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	0.96 Mole	40 %
Crystallization	Electricity supply, medium voltage	Scope 2	0.47 Mole	19 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	0.18 Mole	8 %
Wafering	Electricity supply, medium voltage	Scope 2	0.11 Mole	5 %
Crystallization	Heat supply, fuels other than natural gas	Scope 2	0.09 Mole	4 %
Cell processing	Electricity supply, medium voltage	Scope 2	0.08 Mole	3 %
TOTAL			**1.9** Mole	**79 %**

Table 5.20: Baseline: contributions of the most important processes to the gross result of acidification potential of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [H^+ eq]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	0.72 Mole	45 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	0.18 Mole	11 %
Wafering	Electricity supply, medium voltage	Scope 2	0.09 Mole	6 %
Module design/ assembly	Production of copper	Scope 3	0.07 Mole	4 %
Module design/ assembly	Production of aluminium alloy	Scope 3	0.07 Mole	4 %
Cell processing	Electricity supply, medium voltage	Scope 2	0.06 Mole	3 %
TOTAL			**1.2** Mole	**74 %**

For both module types, 63 % of the credits originate from the recycling of the aluminium frame. The resulting secondary raw material avoids relevant emissions associated with the conventional production of aluminium from primary raw materials. In addition, the recycling of the glass fibre reinforced plastic (part of junction box) and of the tin content on the PV module also provide relevant contributions to the credits in the amount of 16 % and 10 %, respectively.

5.12 Eutrophication of marine ecosystems

Figure 5.22 and Figure 5.23 show the proportions of the production chain sections at the result of marine eutrophication potential.

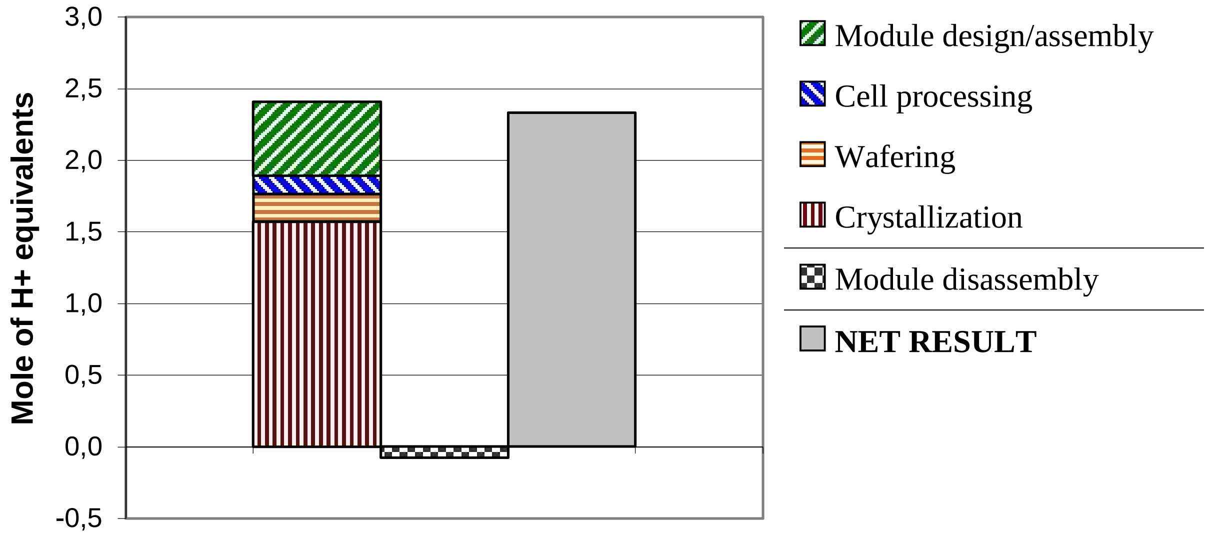


Figure 5.22: Baseline: marine eutrophication potential of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **0.41 kg N equivalents**[16] is determined by the crystallization process. 65 % of total emissions to air and water (mainly nitrogen oxides into air and nitrate into water) come from this section. With a share of 19 % and 13 % emissions of module design/assembly and cell processing play a minor role. Emissions of wafering contribute less than 7 % to the net result. The effect of disassembly credits is small with a reduction of less than 5 %.

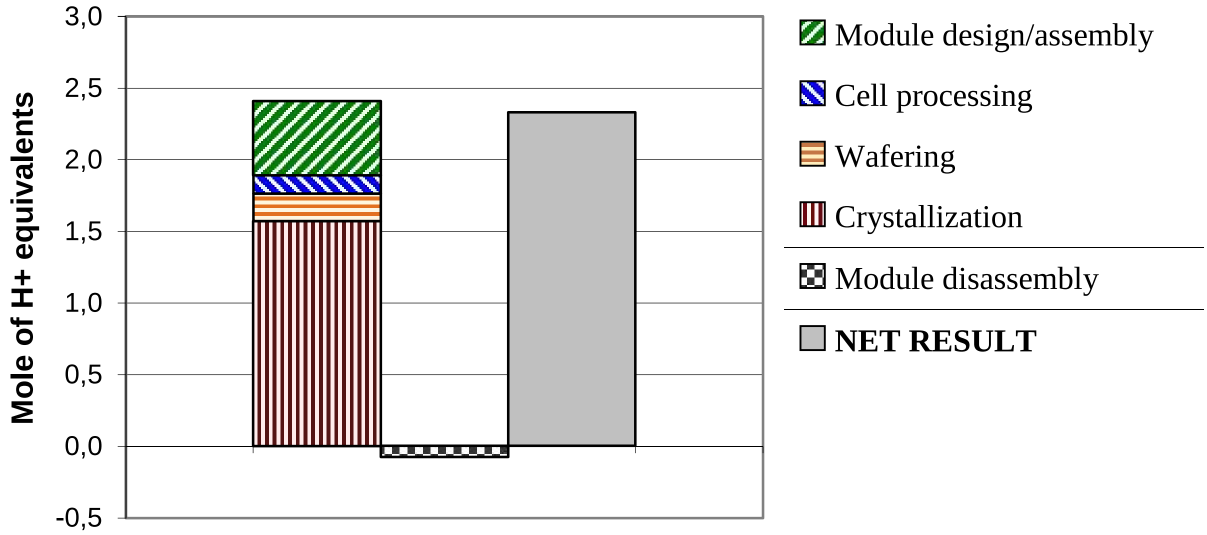


Figure 5.23: Baseline: marine eutrophication potential of one mc-Si PV-module (60 6-inch solar cells)

[16] N = Nitrogen (effect mechanism of impact category cf. chapter 2.1.3.3)

The net result of one mc-Si PV-module in the amount of total **0.22 kg N equivalents** is determined by the crystallization process as well as module design/assembly on a smaller scale. 65 % and 36 % of total emissions to air and water (mainly also nitrogen oxides into air and nitrate into water) come from these two sections. With a share of 12 % each emissions of module wafering and cell processing play a minor role. After allocation of the disassembly credits the net result is reduced by about 9 %.
The corresponding LCIA data are summarized in annexes B and C. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.21 and Table 5.22.

Table 5.21: Baseline: contributions of the most important processes to the gross result of marine eutrophication potential of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [N eq]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	0.13 kg	31 %
Crystallization	Electricity supply, medium voltage	Scope 2	0.07 kg	16 %
Crystallization	Production of ingot, Czochralski process	Scope 1	0.05 kg	11 %
Cell processing	Treatment of waste water from PV cell production	Scope 3	0.03 kg	7 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	0.04 kg	6 %
Wafering	Electricity supply, medium voltage	Scope 2	0.02 kg	4 %
TOTAL			**0.33 kg**	**76 %**

Table 5.22: Baseline: contributions of the most important processes to the gross result of marine eutrophication potential of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [N eq]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	0.1 kg	42 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	0.3 kg	12 %
Wafering	Electricity supply, medium voltage	Scope 2	0.01 kg	6 %
Module design/ assembly	Production of aluminium alloy	Scope 3	0.01 kg	4 %
Cell processing	Electricity supply, medium voltage	Scope 2	0.008 kg	3 %
Cell processing	Production of metallization paste, front side	Scope 3	0.007 kg	3 %
TOTAL			**0.17 kg**	**70 %**

For both module types, 36 % of the credits originate from the recycling of the aluminium frame. The resulting secondary raw material avoids relevant emissions associated with the conventional production of aluminium from primary raw materials. In addition, the recycling of glass fibre reinforced plastic (part of junction box) and copper (mainly in cables) also provide relevant contributions to the credits in the amount of 20 % and 33 %, respectively.

5.13 Freshwater eutrophication

Figure 5.24 and Figure 5.25 show the proportions of the production chain sections at the result of freshwater eutrophication potential.

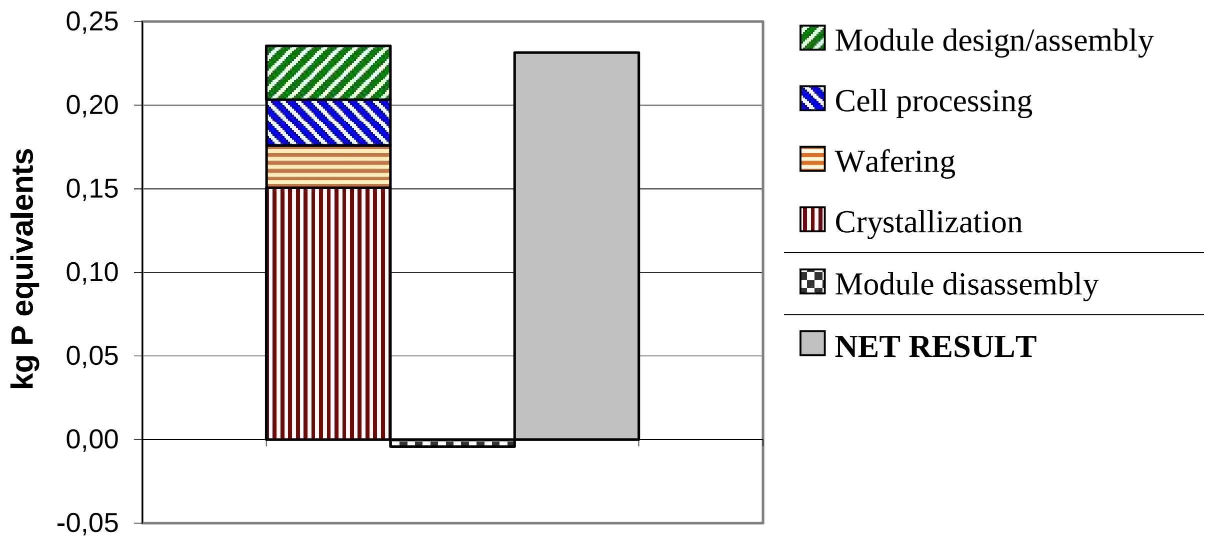


Figure 5.24: Baseline: marine eutrophication potential of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **0.23 kg P equivalents**[17] is determined by the crystallization process. 65 % of total emissions to water (almost exclusively phosphate) come from this section. With a share of 14 % to 11 % emissions of module de-sign/assembly, wafering and cell processing play a minor role. The effect of disassembly credits is small with a reduction of less than 2 %.

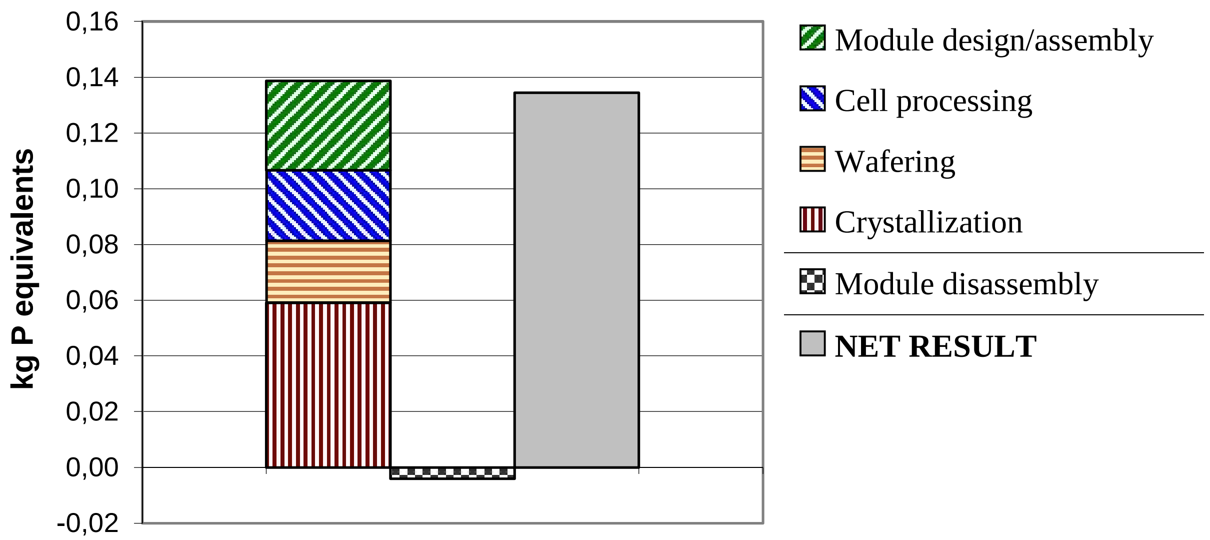


Figure 5.25: Baseline: marine eutrophication potential of one mc-Si PV-module (60 6-inch solar cells)

[17] P = Phosphorus (effect mechanism cf. chapter 2.1.3.3)

The net result of one mc-Si PV-module in the amount of total **0.13 kg P equivalents** is determined by the crystallization process as well as module design/assembly on a smaller scale. 44 % and 24 % of total emissions to water (almost exclusively phosphate as well) come from these two sections. With a share of 19 % and 17 % emissions of wafering and cell processing play a minor role. The effect of disassembly credits is small with a reduction of a little more than 3 %.
The corresponding LCIA data are summarized in annexes B and C. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.23 and Table 5.24.

Table 5.23: Baseline: contributions of the most important processes to the gross result of freshwater eutrophication potential of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	**Key process**	**Emission category**	**Contribution [P eq]**	**Share of gross result**
Crystallization	Electricity supply, medium voltage	Scope 2	73 g	31 %
Crystallization	Production of silicon, solar grade	Scope 3	71 g	30 %
Wafering	Electricity supply, medium voltage	Scope 2	17 g	7 %
Module design/ assembly	Production of copper	Scope 3	14 g	6 %
Cell processing	Electricity supply, medium voltage	Scope 2	12 g	5 %
Cell processing	Production of metallization paste, front side	Scope 3	8 g	4 %
TOTAL			**20 g**	**83 %**

Table 5.24: Baseline contributions of the most important processes to the gross result of freshwater eutrophication potential of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	**Key process**	**Emission category**	**Contribution [P eq]**	**Share of gross result**
Crystallization	Production of silicon, solar grade	Scope 3	53 g	38 %
Module design/ assembly	Production of copper	Scope 3	14 g	10 %
Wafering	Electricity supply, medium voltage	Scope 2	14 g	10 %
Cell processing	Production of metallization paste, front side	Scope 3	10 g	7 %
Cell processing	Electricity supply, medium voltage	Scope 2	9 g	6 %
Crystallization	Electricity supply, medium voltage	Scope 2	5 g	4 %
TOTAL			**11 g**	**76 %**

For both module types, 46 % of the credits originate from the recycling of the aluminium frame. The resulting secondary raw material avoids relevant emissions associated with the conventional production of aluminium from primary raw materials. In addition, the recycling of copper (mainly in cables) and the energetic utilization of plastic parts also provide relevant contributions to the credits in the amount of 28 % and 12 %, respectively.

5.14 Terrestrial eutrophication

Figure 5.26 and Figure 5.27 show the proportions of the production chain sections at the result of terrestrial eutrophication potential.

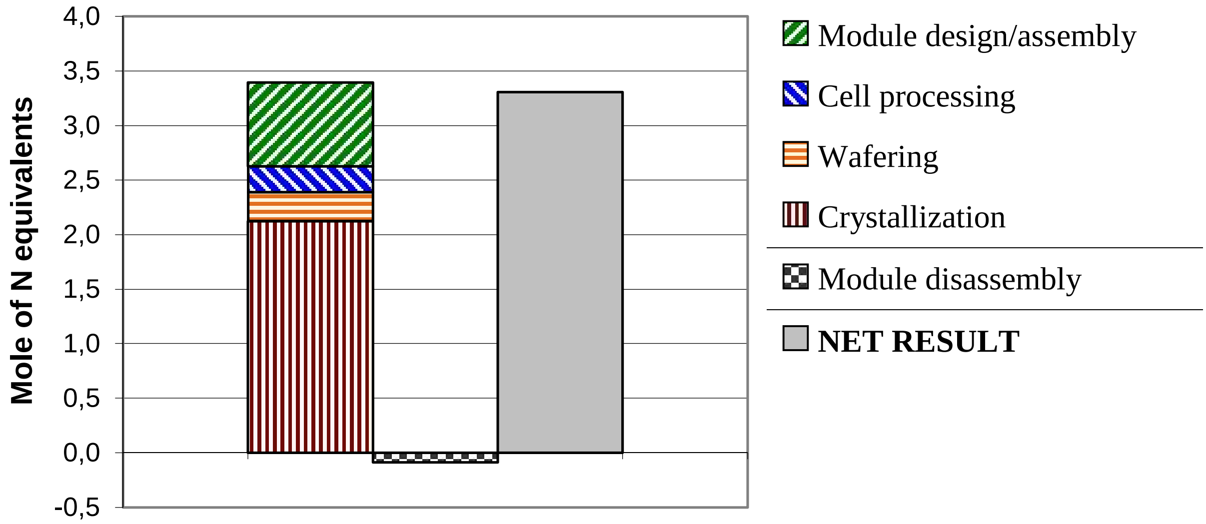


Figure 5.26: Baseline: terrestrial eutrophication potential of one sc-Si PV-module (60 6-inch solar cells)

The net result of one sc-Si PV-module in the amount of total **3.3 Mole of N equivalents**[18] is determined by the crystallization process as well as the module design/assembly on a smaller scale. 65 % and 23 % of total air emissions (mainly nitrogen oxides and ammonia) come from these two sections. Emissions of wafering and cell processing contribute less than 8 % to the net result each. The effect of disassembly credits is small with a reduction of less than 3 %.

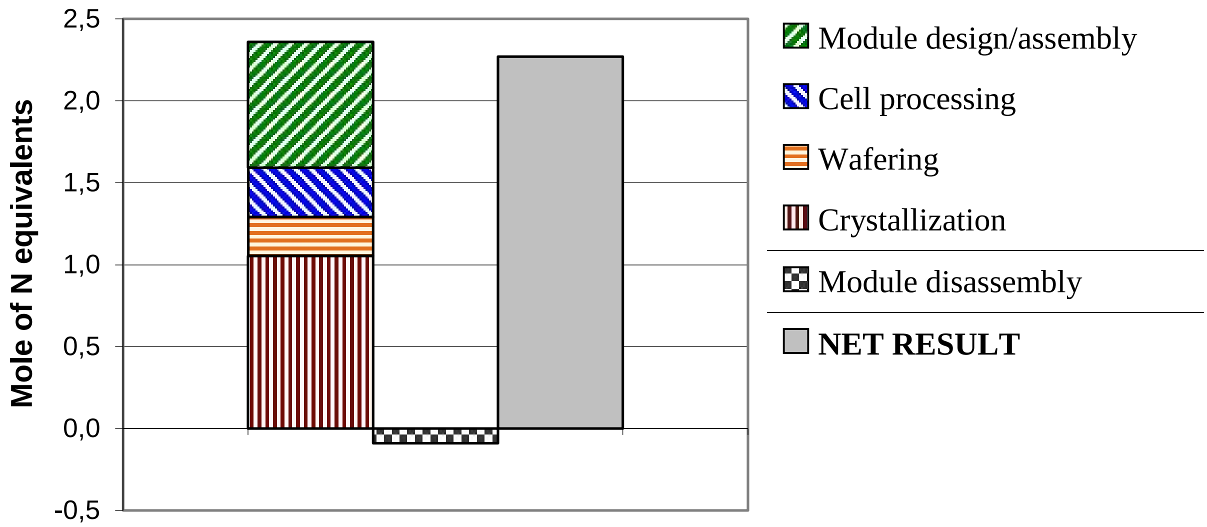


Figure 5.27: Baseline: terrestrial eutrophication potential of one mc-Si PV-module (60 6-inch solar cells)

[18] N = Nitrogen (effect mechanism of impact category cf. chapter 2.1.3.3)

The net result of one mc-Si PV-module in the amount of total **2.3 Mole of N equivalents** is also determined by the crystallization process as well as the module design/assembly on a smaller scale. 46 % and 34 % of total air emissions (mainly nitrogen oxides and ammonia as well) come from these two sections. With a share of 13 % and 11 % emissions of cell processing and wafering play a minor role. The effect of disassembly credits is small with a reduction of a little more than 4 %.
The corresponding LCIA data are summarized in the appendix B. The contributions of the most important processes in the production chain sections to the gross results are shown in Table 5.25 and Table 5.26.

Table 5.25: Baseline: contributions of the most important processes to the gross result of terrestrial eutrophication potential of one sc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [N eq]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	1.3 Mole	39 %
Crystallization	Electricity supply, medium voltage	Scope 2	0.60 Mole	18 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	0.33 Mole	10 %
Wafering	Electricity supply, medium voltage	Scope 2	0.14 Mole	4 %
Crystallization	Heat supply, fuels other than natural gas	Scope 2	0.11 Mole	3 %
Module design/ assembly	Production of aluminium alloy	Scope 3	0.11 Mole	3 %
TOTAL			**2.6 Mole**	**77 %**

Table 5.26: Baseline: contributions of the most important processes to the gross result of terrestrial eutrophication potential of one mc-Si PV- module (60 6-inch solar cells)

Production chain section	Key process	Emission category	Contribution [N eq]	Share of gross result
Crystallization	Production of silicon, solar grade	Scope 3	1.0 Mole	42 %
Module design/ assembly	Production of solar glass, low-iron	Scope 3	0.33 Mole	14 %
Wafering	Electricity supply, medium voltage	Scope 2	0.12 Mole	5 %
Module design/ assembly	Production of aluminium alloy	Scope 3	0.11 Mole	5 %
Cell processing	Production of metallization paste, front side	Scope 3	0.09 Mole	4 %
Cell processing	Electricity supply, medium voltage	Scope 2	0.97 Mole	3 %
TOTAL			**1.7 Mole**	**72 %**

For both module types, 61 % of the credits originate from the recycling of the aluminium frame. The resulting secondary raw material avoids relevant emissions associated with the conventional production of aluminium from primary raw materials. In addition, the recycling of glass fibre reinforced plastic (part of junction box) also provides relevant contributions to the credits in the amount of almost 20 %.

6 RESOURCE CONSUMPTION AND LIFE CYCLE IMPACT ASSESSMENT: PROJECT DEVELOPMENTS

In this chapter, the descriptions of the approaches to the project developments are limited to the essentials. Detailed descriptions and information can be found in the reports of the individual work packages.

6.1 WP1: Recovery & reuse during feedstock crystallisation

6.1.1 Argon gas recovery

Approach

This approach considers that used argon gas will be treated and afterwards meets the requirement of argon gas for up to 90 % weight by weight. The process data for modelling the argon recovery process are provided by project partner NORSUN.

sc-Si PV-module

Figure 6.1 shows that the project target of *reduction of argon gas demand to 0.46 kg per PV module* can be achieved totally by implementation the recovery process into the production chain.

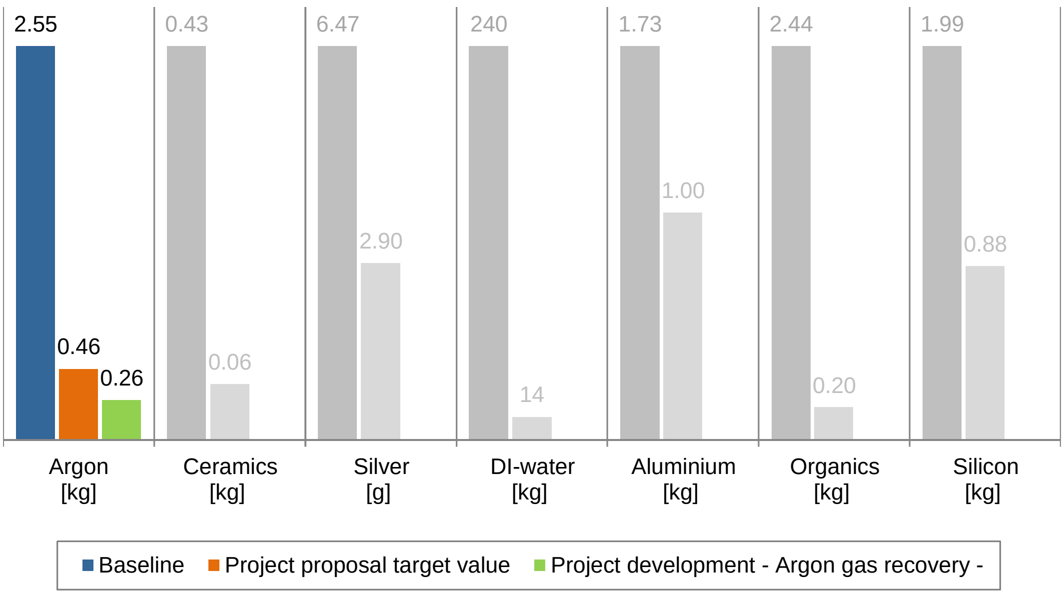


Figure 6.1: Argon gas recovery: reduction of waste and resource consumption for one sc-Si PV-module (60 6-inch solar cells)

Table 6.1 summarizes the environmental effects of argon gas recovery. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the argon gas recovery is implemented into the production chain, even if they are not high. The environmental relief potential ranges from less than 1 % for several impact categories to a maximum of 3 % for particulate matter/respiratory inorganics. All improvements trace back to the crystallization process only.

Table 6.1: Argon gas recovery: comparison of LCIA net results of baseline and project development for one sc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of argon gas recovery compared to baseline**	
Climate change	CO_2 eq	360 kg	Benefit of 5.7 kg	reduction 2 %
Ecotoxicity, freshwater	CTUe	13,470	Benefit of 36	reduction < 1 %
Particulate matter	PM2.5 eq	0.38 kg	Benefit of 11 g	reduction 3 %
Resource depletion	Sb eq	0.06 kg	Benefit of 0.03 g	reduction < 1 %
Human toxicity, cancer	CTUh	2.54E-05	Benefit of 3.08E-07	reduction 1 %
Ionizing radiation	U235 eq	78 kBq	Benefit of 0.76 kBq	reduction 1 %
Photochemical ozone formation	NMVOC eq	1.02 kg	Benefit of 14 g	reduction 1 %
Human toxicity, non-cancer	CTUh	1.39E-04	Benefit of 1.13E-06	reduction < 1 %
Ozone depletion	CFC-11 eq	0.031 g	Benefit of 0.28 mg	reduction < 1 %
Acidification	H+ eq	2.3 Mole	Benefit of 0.038 Mole	reduction 2 %
Eutrophication, marine	N eq	0.41 kg	Benefit of 5.5 g	reduction 1 %
Eutrophication, freshwater	P eq	0.23 kg	Benefit of 3.5 g	reduction 1 %
Eutrophication, terrestrial	N eq	3.3 Mole	Benefit of 0.055 Mole	reduction 2 %

mc-Si PV-module

Figure 6.2 shows that the project target of *reduction of argon gas demand to 0.02 kg per PV module* can be fulfilled to 97 % by implementation the recovery process into the production chain.

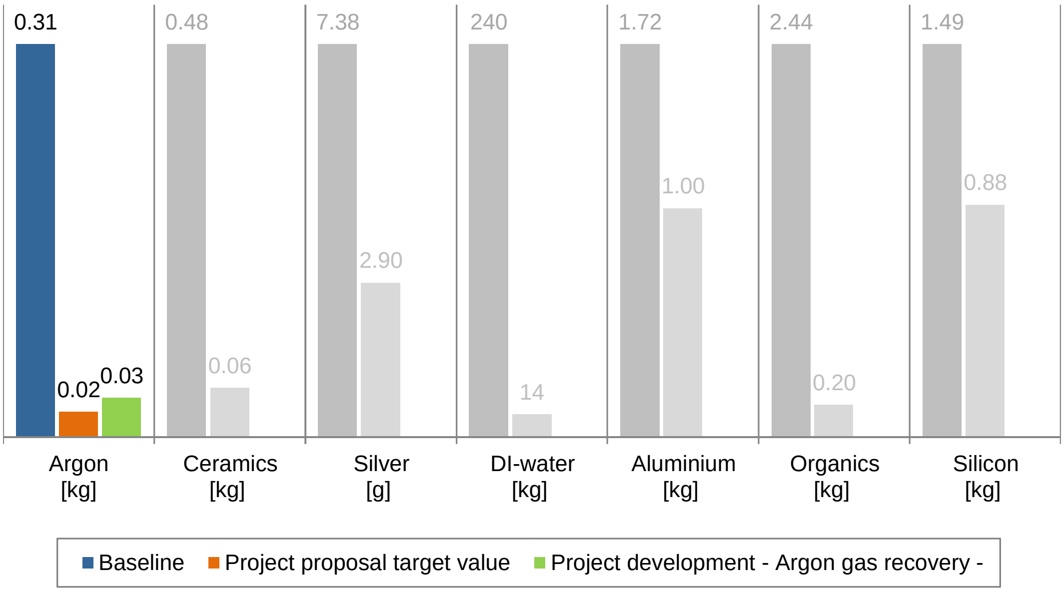


Figure 6.2: Argon gas recovery: reduction of waste and resource consumption for one mc-Si PV-module (60 6-inch solar cells)

Table 6.2 summarizes the environmental effects of argon gas recovery. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the argon gas recovery is implemented into the production chain, even if they are small. The environmental relief potential ranges from < 0.1 % for several impact categories to a maximum of 0.5 % for freshwater eutrophication. All improvements trace back to the crystallization process only.

Table 6.2: Argon gas recovery: comparison of LCIA net results of baseline and project development for one mc-Si PV-module (60 6-inch solar cells)

Impact category	Unit	Baseline	Environmental impact of argon gas recovery compared to baseline	
Climate change	CO_2 eq	224 kg	Benefit of 0.48 kg	reduction 0.2 %
Ecotoxicity, freshwater	CTUe	21,500	Benefit of 2.5	reduction < 0.1 %
Particulate matter	PM2.5 eq	0.27 kg	Benefit of 1.2 g	reduction 0.5 %
Resource depletion	Sb eq	0.063 kg	Benefit of 0.0015 g	reduction < 0.1 %
Human toxicity, cancer	CTUh	1.58E-05	Benefit of 2.22E-08	reduction 0.1 %
Ionizing radiation	U235 eq	33 kBq	Benefit of 0.01 kBq	reduction < 0.1 %
Photochemical ozone formation	NMVOC eq	0.67 kg	Benefit of 1.3 g	reduction 0.2 %
Human toxicity, non-cancer	CTUh	1.08E-04	Benefit of 7.08E-08	reduction 0.1 %
Ozone depletion	CFC-11 eq	0.019 g	Benefit of 0.01 mg	reduction 0.1 %
Acidification	H+ eq	1.53 Mole	Benefit of 0.007 Mole	reduction 0.4 %
Eutrophication, marine	N eq	0.22 kg	Benefit of 0.7 g	reduction 0.3 %
Eutrophication, freshwater	P eq	0.13 kg	Benefit of 0.65 g	reduction 0.5 %
Eutrophication, terrestrial	N eq	2.3 Mole	Benefit of 0.009 Mole	reduction 0.4 %

6.1.2 Reusable crucibles

Approach

Project partners Steuler and SINTEF tested small silicon nitride crucibles for reusability in a laboratory scale. The tests showed that the crucibles are reusable. Based on the laboratory results partners assume, that it seems highly probable that a 10-time use is easily attainable. In consultation with partners a seven-time reuse of large crucibles was agreed as approach.

sc-Si PV-module

Figure 6.3 shows that the project target of *reduction of ceramic demand to 0.06 kg per PV module* can be fulfilled to 97 % by using reusable crucibles into the production chain.

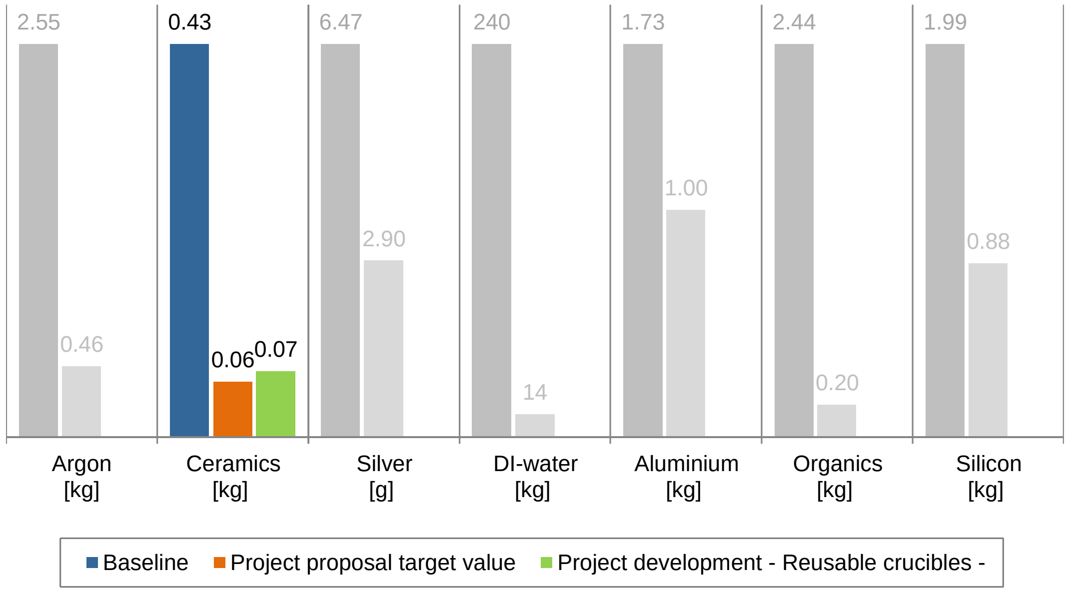


Figure 6.3: Reusable crucibles: reduction of waste and resource consumption for one sc-Si PV-module (60 6-inch solar cells)

Table 6.3 summarizes the environmental effects of reusable crucibles. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if reusable crucibles are used into the production chain, even if they are very small. The environmental relief potential ranges from less than 0.1 % for several impact categories to a maximum of 1.0 % for depletion of mineral, fossil and renewable resources. All improvements trace back to the crystallization process only

Table 6.3: Reusable crucibles: comparison of LCIA net results of baseline and project development for one sc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of reusable crucibles compared to baseline**	
Climate change	CO_2 eq	360 kg	Benefit of 0.31 kg	reduction 0.1 %
Ecotoxicity, freshwater	CTUe	13,470	Benefit of 2.7	reduction < 0.1 %
Particulate matter	PM2.5 eq	0.38 kg	Benefit of 3.5 g	reduction 0.9 %
Resource depletion	Sb eq	0.06 kg	Benefit of 0.59 g	reduction 1.0 %
Human toxicity, cancer	CTUh	2.54E-05	Benefit of 2.37E-09	reduction < 0.1 %
Ionizing radiation	U235 eq	78 kBq	Benefit of 0.02 kBq	reduction < 0.1 %
Photochemical ozone formation	NMVOC eq	1.02 kg	Benefit of 1.1 g	reduction 0.1 %
Human toxicity, non-cancer	CTUh	1.39E-04	Benefit of 1.68E-07	reduction 0.1 %
Ozone depletion	CFC-11 eq	0.031 g	Benefit of 0.02 mg	reduction 0.1 %
Acidification	H+ eq	2.3 Mole	Benefit of 0.007 Mole	reduction 0.3 %
Eutrophication, marine	N eq	0.41 kg	Benefit of 0.62 g	reduction 0.1 %
Eutrophication, freshwater	P eq	0.23 kg	Benefit of 0.62 g	reduction 0.3 %
Eutrophication, terrestrial	N eq	3.3 Mole	Benefit of 0.008 Mole	reduction 0.2 %

mc-Si PV-module

Figure 6.4 shows that the project target of *reduction of ceramic demand to 0.06 kg per PV module* can be fulfilled to 95 % by using reusable crucibles into the production chain.

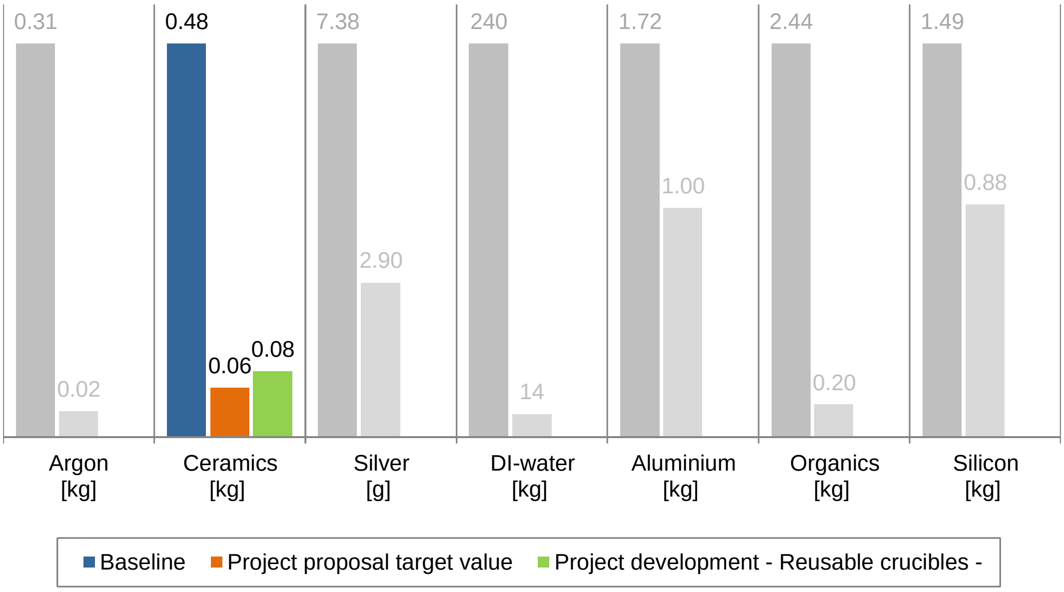


Figure 6.4: Reusable crucibles: reduction of waste and resource consumption for one mc-Si PV-module (60 6-inch solar cells)

Table 6.4 summarizes the environmental effects of reusable crucibles. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if reusable crucibles are used into the production chain, even if they are very small. The environmental relief potential ranges from less than 0.1 % for carcinogenic human toxicity and freshwater ecotoxicity to a maximum of 1.5 % for depletion of mineral, fossil and renewable resources. All improvements trace back to the crystallization process only.

Table 6.4: Reusable crucibles: comparison of LCIA net results of baseline and project development for one mc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of reusable crucibles compared to baseline**	
Climate change	CO_2 eq	224 kg	Benefit of 0.35 kg	reduction 0.2 %
Ecotoxicity, freshwater	CTUe	21,500	Benefit of 3.0	reduction < 0.1 %
Particulate matter	PM2.5 eq	0.27 kg	Benefit of 4.0 g	reduction 1.5 %
Resource depletion	Sb eq	0.063 kg	Benefit of 0.66 g	reduction 1.0 %
Human toxicity, cancer	CTUh	1.58E-05	Benefit of 2.67E-09	reduction < 0.1 %
Ionizing radiation	U235 eq	33 kBq	Benefit of 0.021 kBq	reduction 0.1 %
Photochemical ozone formation	NMVOC eq	0.67 kg	Benefit of 1.3 g	reduction 0.2 %
Human toxicity, non-cancer	CTUh	1.08E-04	Benefit of 1.84E-07	reduction 0.2 %
Ozone depletion	CFC-11 eq	0.019 g	Benefit of 0.02 mg	reduction 0.1 %
Acidification	H+ eq	1.53 Mole	Benefit of 0.007 Mole	reduction 0.5 %
Eutrophication, marine	N eq	0.22 kg	Benefit of 0.65 g	reduction 0.3 %

Impact category	Unit	Baseline	Environmental impact of reusable crucibles compared to baseline	
Eutrophication, freshwater	P eq	0.13 kg	Benefit of 0.63 g	reduction 0.5 %
Eutrophication, terrestrial	N eq	2.3 Mole	Benefit of 0.008 Mole	reduction 0.4 %

6.2 WP2: Recovery & reuse of Si-kerf-loss

6.2.1 New wire sawing process with thinner diamond wire

Approach

This approach considers that a newly wire sawing process developed by the project partner NORSUN makes it possible to use thinner diamond wire (from 80 to 60 µm). This allows more wafers to be sawn out from one silicon ingot. The currently assumed yield plus is 7.92 %. Further the thinner diamond wire leads to a decrease in silicon kerf and wire waste generation.

sc-Si PV-module

Figure 6.5 shows that by implementation the new sawing process into the production chain the project targets of

- *reduction of argon gas demand to 0.46 kg per PV module can be fulfilled to 10 %,*
- *reduction of ceramic demand to 0.06 kg per PV module can be fulfilled to 9 % and*
- *reduction of silicon demand to 0.88 kg per PV module can be fulfilled to 14 %.*

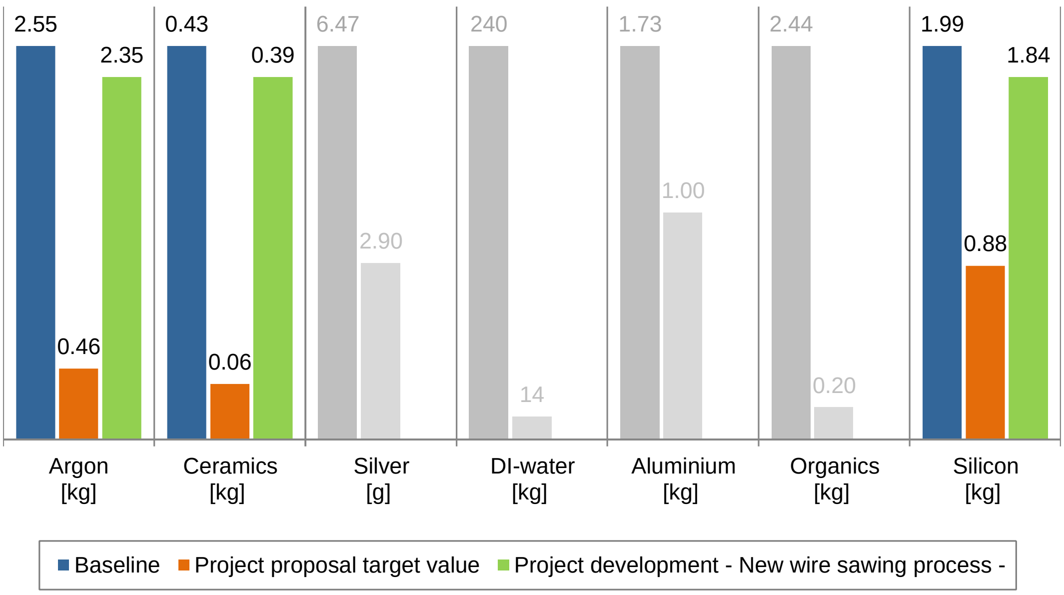


Figure 6.5: New wire sawing process with thinner diamond wire: reduction of waste and resource consumption for one sc-Si PV-module (60 6-inch solar cells)

Table 6.5 summarizes the environmental effects of the new wire sawing process. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the new sawing process is implemented into the production chain. The environmental relief potential ranges from 1 % for depletion of mineral, fossil and renewable resources to a maximum of 10 % for carcinogenic human toxicity. The improvements are mainly due to the crystallization process as well wafering on a smaller scale.

Table 6.5: New wire sawing process with thinner diamond wire: comparison of LCIA net results of baseline and project development for one sc-Si PV-module (60 6-inch solar cells)

Impact category	Unit	Baseline	Environmental impact of new wire sawing process compared to baseline	
Climate change	CO_2 eq	360 kg	Benefit of 21 kg	reduction 6 %
Ecotoxicity, freshwater	CTUe	13,470	Benefit of 173	reduction 1 %
Particulate matter	PM2.5 eq	0.38 kg	Benefit of 25 g	reduction 7 %
Resource depletion	Sb eq	0.06 kg	Benefit of 0.35 g	reduction 1 %
Human toxicity, cancer	CTUh	2.54E-05	Benefit of 2.61E-06	reduction 10 %
Ionizing radiation	U235 eq	78 kBq	Benefit of 4.4 kBq	reduction 6 %
Photochemical ozone formation	NMVOC eq	1.02 kg	Benefit of 56 g	reduction 5 %
Human toxicity, non-cancer	CTUh	1.39E-04	Benefit of 6.16E-06	reduction 4 %
Ozone depletion	CFC-11 eq	0.031 g	Benefit of 1.7 mg	reduction 5 %
Acidification	H+ eq	2.3 Mole	Benefit of 0.14 Mole	reduction 6 %
Eutrophication, marine	N eq	0.41 kg	Benefit of 32 g	reduction 6 %
Eutrophication, freshwater	P eq	0.23 kg	Benefit of 13 g	reduction 6 %
Eutrophication, terrestrial	N eq	3.3 Mole	Benefit of 0.19 Mole	reduction 6 %

mc-Si PV-module

Figure 6.6 shows that by implementation the new sawing process into the production chain the project targets of

- *reduction of argon gas demand to 0.02 kg per PV module can be fulfilled to 8 %,*
- *reduction of ceramic demand to 0.06 kg per PV module can be fulfilled to 9 % and*
- *reduction of silicon demand to 0.88 kg per PV module can be fulfilled to 19 %.*

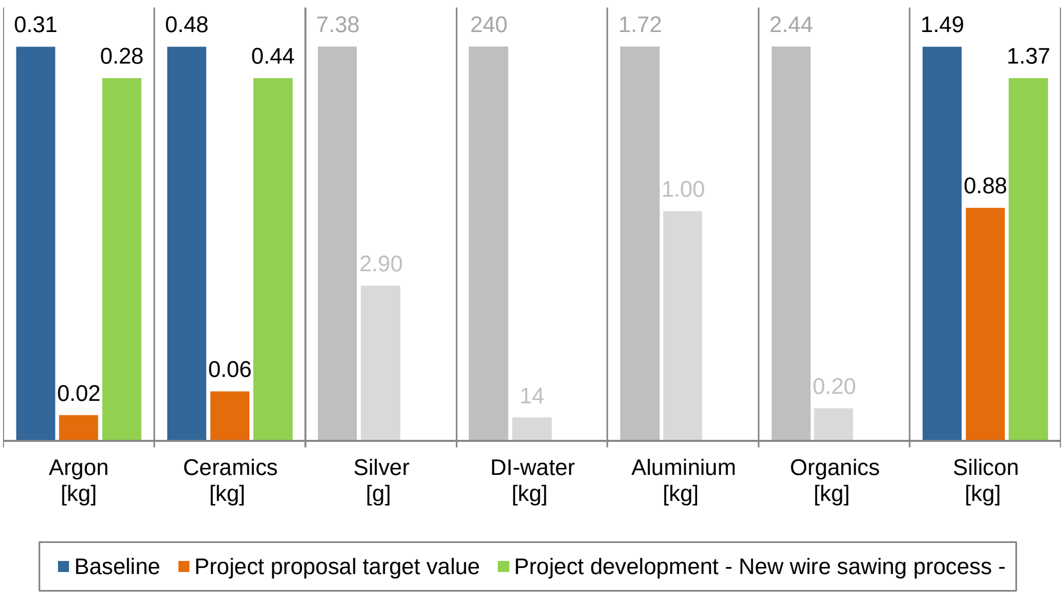


Figure 6.6: New wire sawing process with thinner diamond wire: reduction of waste and resource consumption for one mc-Si PV-module (60 6-inch solar cells)

Table 6.6 summarizes the environmental effects of the new wire sawing process. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the new sawing process is implemented into the production chain. The environmental relief potential ranges from less than 0.5 % for depletion of mineral, fossil and renewable resources as well as fresh water ecotoxicity to a maximum of 12 % for carcinogenic human toxicity. The improvements are mainly due to the crystallization process as well wafering on a smaller scale.

Table 6.6: New wire sawing process with thinner diamond wire: comparison of LCIA net results of baseline and project development for one mc-Si PV-module (60 6-inch solar cells)

Impact category	Unit	Baseline	Environmental impact of new wire sawing process compared to baseline	
Climate change	CO_2 eq	224 kg	Benefit of 11 kg	reduction 5 %
Ecotoxicity, freshwater	CTUe	21,500	Benefit of 95	reduction < 1 %
Particulate matter	PM2.5 eq	0.27 kg	Benefit of 16 g	reduction 6 %
Resource depletion	Sb eq	0.063 kg	Benefit of 0.26 g	reduction < 1 %
Human toxicity, cancer	CTUh	1.58E-05	Benefit of 1.96E-06	reduction 12 %
Ionizing radiation	U235 eq	33 kBq	Benefit of 1.1 kBq	reduction 3 %
Photochemical ozone formation	NMVOC eq	0.67 kg	Benefit of 31 g	reduction 5 %
Human toxicity, non-cancer	CTUh	1.08E-04	Benefit of 3.60E-06	reduction 3 %
Ozone depletion	CFC-11 eq	0.019 g	Benefit of 0.8 mg	reduction 4 %
Acidification	H+ eq	1.53 Mole	Benefit of 0.073 Mole	reduction 5 %
Eutrophication, marine	N eq	0.22 kg	Benefit of 10 g	reduction 5 %
Eutrophication, freshwater	P eq	0.13 kg	Benefit of 6.3 g	reduction 5 %
Eutrophication, terrestrial	N eq	2.3 Mole	Benefit of 0.1 Mole	reduction 4 %

6.2.2 New silicon kerf recovery process from sawing machines coolant

Approach

This approach considers that a newly developed silicon kerf recovery process from sawing machines coolant makes it possible to reuse at least part of the silicon. The current assumption is that for sc-Si wafer 10 %[19] and for mc-Si wafer 20 % of secondary silicon from kerf can be added to the necessary silicon demand for wafer production without the need for additional preparation of the secondary silicon during melting. In addition, 20 % of the silicon content in the crucibles can be substituted as well by the secondary silicon.
The data for modelling the kerf recovery process are provided by project partner GARBO.

[19] The CABRISS project demonstrated that the approach can also be used for sc-Si wafer despite the high oxygen content, but with a lower amount than for mc-Si wafers

sc-Si PV-module

Figure 6.7 shows that by implementation the recovery process into the production chain the project targets of

- *reduction of ceramic demand to 0.06 kg per PV module can be fulfilled by 14 % and*
- *reduction of silicon demand to 0.88 kg per PV module can be fulfilled by 23 %.*

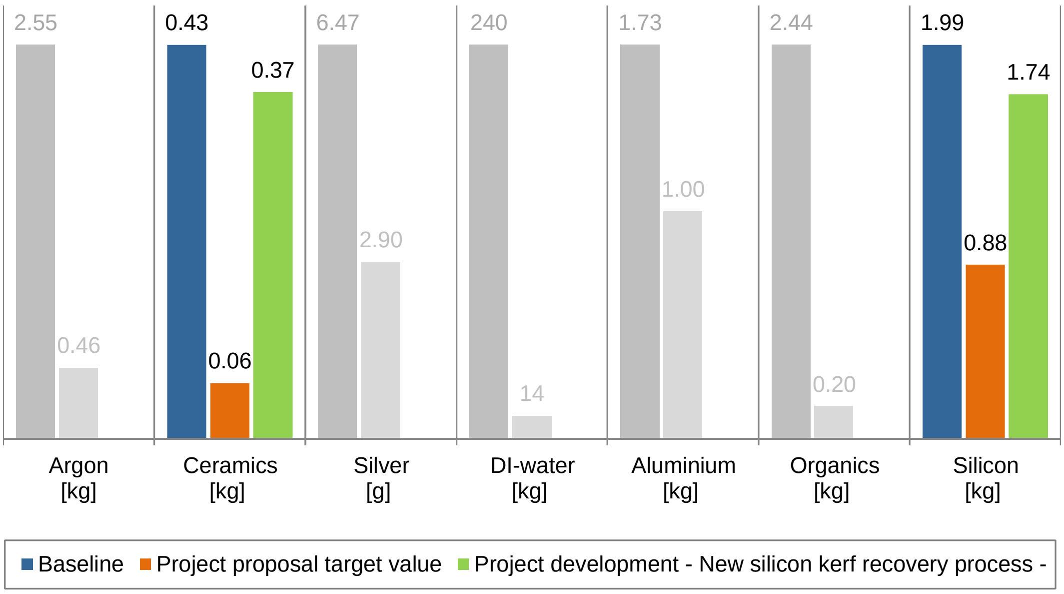


Figure 6.7: New silicon kerf recovery process: reduction of waste and resource consumption for one sc-Si PV-module (60 6-inch solar cells)

Table 6.7 summarizes the environmental effects of the new silicon kerf recovery process. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the new recovery process is implemented into the production chain. The environmental relief potential ranges from less than 0.5 % for depletion of mineral, fossil and renewable resources as well as fresh water ecotoxicity to a maximum of 6 % for particulate matter / respiratory inorganics. All improvements trace back to the crystallization process only.

Table 6.7: New silicon kerf recovery process: comparison of LCIA net results of baseline and project development for one sc-Si PV-module (60 6-inch solar cells)

Impact category	Unit	Baseline	Environmental impact of kerf recovery process compared to baseline	
Climate change	CO_2 eq	360 kg	Benefit of 15 kg	reduction 4 %
Ecotoxicity, freshwater	CTUe	13,470	Benefit of 68	reduction < 1 %
Particulate matter	PM2.5 eq	0.38 kg	Benefit of 22 g	reduction 6 %
Resource depletion	Sb eq	0.06 kg	Benefit of 0.15 g	reduction < 1 %
Human toxicity, cancer	CTUh	2.54E-05	Benefit of 7.11E-07	reduction 3 %
Ionizing radiation	U235 eq	78 kBq	Benefit of 1.2 kBq	reduction 2 %
Photochemical ozone formation	NMVOC eq	1.02 kg	Benefit of 39 g	reduction 4 %
Human toxicity, non-cancer	CTUh	1.39E-04	Benefit of 2.64E-06	reduction 2 %

Impact category	Unit	Baseline	Environmental impact of kerf recovery process compared to baseline	
Ozone depletion	CFC-11 eq	0.031 g	Benefit of 0.98 mg	reduction 3 %
Acidification	H+ eq	2.3 Mole	Benefit of 0.098 Mole	reduction 4 %
Eutrophication, marine	N eq	0.41 kg	Benefit of 13 g	reduction 3 %
Eutrophication, freshwater	P eq	0.23 kg	Benefit of 7.3 g	reduction 3 %
Eutrophication, terrestrial	N eq	3.3 Mole	Benefit of 0.13 Mole	reduction 4 %

mc-Si PV-module

Figure 6.8 shows that by implementation the recovery process into the production chain the project tar-gets of

- *reduction of ceramic demand to 0.06 kg per PV module can be fulfilled by 14 % and*
- *reduction of silicon demand to 0.88 kg per PV module can be fulfilled by 58 %.*

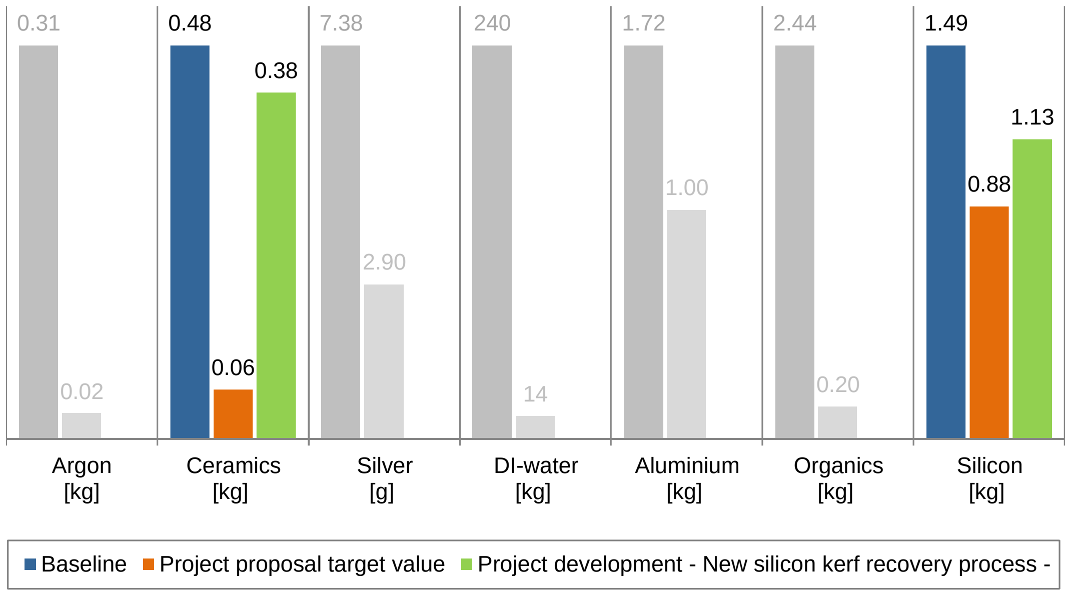


Figure 6.8: New silicon kerf recovery process: reduction of waste and resource consumption for one mc-Si PV-module (60 6-inch solar cells)

Table 6.8 summarizes the environmental effects of the new silicon kerf recovery process. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the new recovery process is implemented into the production chain. The environmental relief potential ranges from less than 0.5 % for depletion of mineral, fossil and renewable resources as well as fresh water ecotoxicity to a maximum of 12 % for particulate matter / respiratory inorganics. All improvements trace back to the crystallization process only.

Table 6.8: New silicon kerf recovery process: comparison of LCIA net results of baseline and project development for one mc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of kerf recovery process compared to baseline**	
Climate change	CO_2 eq	224 kg	Benefit of 22 kg	reduction 10 %
Ecotoxicity, freshwater	CTUe	21,500	Benefit of 102	reduction < 1 %
Particulate matter	PM2.5 eq	0.27 kg	Benefit of 33 g	reduction 12 %
Resource depletion	Sb eq	0.063 kg	Benefit of 0.19 g	reduction < 1 %
Human toxicity, cancer	CTUh	1.58E-05	Benefit of 1.06E-06	reduction 6 %
Ionizing radiation	U235 eq	33 kBq	Benefit of 1.9 kBq	reduction 6 %
Photochemical ozone formation	NMVOC eq	0.67 kg	Benefit of 59 g	reduction 9 %
Human toxicity, non-cancer	CTUh	1.08E-04	Benefit of 3.94E-06	reduction 4 %
Ozone depletion	CFC-11 eq	0.019 g	Benefit of 1.47 mg	reduction 8 %
Acidification	H+ eq	1.53 Mole	Benefit of0.14 Mole	reduction 9 %
Eutrophication, marine	N eq	0.22 kg	Benefit of 20 g	reduction 9 %
Eutrophication, freshwater	P eq	0.13 kg	Benefit of 11 g	reduction 8 %
Eutrophication, terrestrial	N eq	2.3 Mole	Benefit of 0.2 Mole	reduction 9 %

6.3 WP3: Remanufacturing, resource efficiency and reuse in solar cell processing

6.3.1 New cell process

Approach

This approach considers the current cell process at SoliTek. For reasons of confidentiality, the data for modelling the new cell process provided by the project partner and the resulting balance model are not presented in detail. This approach is not recommended for sc-Si wafer.

mc-Si PV-module

Regarding project targets no changes occurred compared to the baseline-scenario yet though better cell efficiencies due to process modifications were obtained.

Table 6.9 summarizes the environmental effects of the new cell process. Compared to the LCIA result of the baseline no environmental advantages exist for one of the examined impact categories if the new cell process is implemented into the production chain. The additional environmental pollution ranges from 2 % for fresh water ecotoxicity to a maximum of 33 % for depletion of mineral, fossil and renewable resources. Reasons are ecological disadvantages of upstream processes for raw materials which differ from the standard cell process. All deteriorations trace back to cell processing only.

Table 6.9: New cell process: comparison of LCIA net results of baseline and project development for one mc-Si PV-module (60 6-inch solar cells)

Impact category	Unit	Baseline	Environmental impact of new cell process compared to baseline	
Climate change	CO_2 eq	224 kg	Burden of 20 kg	Increase 9 %
Ecotoxicity, freshwater	CTUe	21,500	Burden of 397	Increase 2 %
Particulate matter	PM2.5 eq	0.27 kg	Burden of 21 g	Increase 8 %
Resource depletion	Sb eq	0.063 kg	Burden of 21 g	Increase 33 %
Human toxicity, cancer	CTUh	1.58E-05	Burden of 1.42E-06	Increase 8 %
Ionizing radiation	U235 eq	33 kBq	Burden of 7.7 kBq	Increase 23 %
Photochemical ozone formation	NMVOC eq	0.67 kg	Burden of 137 g	Increase 20 %
Human toxicity, non-cancer	CTUh	1.08E-04	Burden of 1.15E-05	Increase 11 %
Ozone depletion	CFC-11 eq	0.019 g	Burden of 2.7 mg	Increase 14 %
Acidification	H+ eq	1.53 Mole	Burden of 0.25 Mole	Increase 16 %
Eutrophication, marine	N eq	0.22 kg	Burden of 51 g	Increase 23 %
Eutrophication, freshwater	P eq	0.13 kg	Burden of 17 g	Increase 13 %
Eutrophication, terrestrial	N eq	2.3 Mole	Burden of 0.52 Mole	Increase 23 %

6.3.2 Reuse process water

Approach

In consultation with project partner ISC Konstanz this approach considers, that waste water from cell processing will be treated and afterwards meets the requirement of process water for up to 97 % weight by weight.

sc-Si PV-module

Figure 6.9 shows that the project target of reduction of *process water demand to 14 kg per PV module* can be achieved totally by the implementation the water treatment process into the production chain.

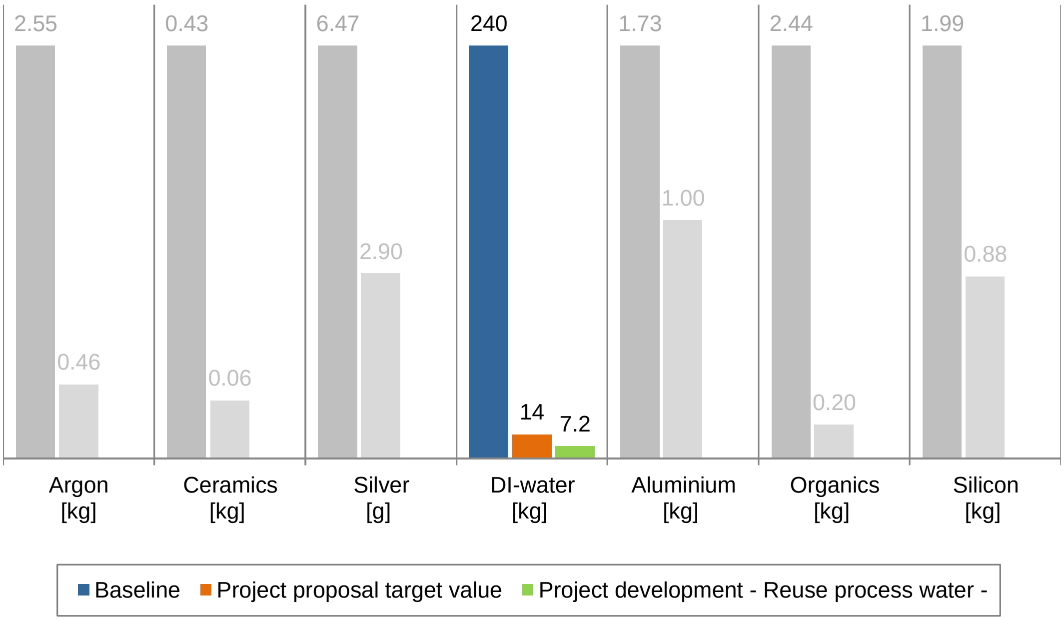


Figure 6.9: Reuse process water: reduction of waste and resource consumption for one sc-Si PV-module (60 6-inch solar cells)

Table 6.10 summarizes the environmental effects of reuse process water. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the treatment process is implemented into the production chain, even if they are marginal. The environmental relief potential ranges from less than 0.01 % for most of the impact categories to a maximum of 0.2 % for acidification and freshwater eutrophication. All improvements trace back to cell processing only.

Table 6.10: Reuse process water: comparison of LCIA net results of baseline and project development for one sc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of reuse process water compared to baseline**	
Climate change	CO_2 eq	360 kg	Benefit of 5.9 g	reduction < 0.01 %
Ecotoxicity, freshwater	CTUe	13,470	Benefit of 0.1	reduction < 0.01 %
Particulate matter	PM2.5 eq	0.38 kg	Benefit of 6.6 mg	reduction < 0.01 %
Resource depletion	Sb eq	0.06 kg	Benefit of 0.28 mg	reduction < 0.01 %
Human toxicity, cancer	CTUh	2.54E-05	Benefit of 1.24E-09	reduction < 0.01 %
Ionizing radiation	U235 eq	78 kBq	Benefit of 0.3 Bq	reduction < 0.01 %
Photochemical ozone formation	NMVOC eq	1.02 kg	Benefit of 21 mg	reduction < 0.01 %
Human toxicity, non-cancer	CTUh	1.39E-04	Benefit of 7.61E-09	reduction < 0.01 %
Ozone depletion	CFC-11 eq	0.031 g	Benefit of 0.55 µg	reduction < 0.01 %
Acidification	H+ eq	2.3 Mole	Benefit of 0.004 Mole	reduction 0.2 %
Eutrophication, marine	N eq	0.41 kg	Benefit of 0.26 g	reduction 0.1 %
Eutrophication, freshwater	P eq	0.23 kg	Benefit of 0.47 g	reduction 0.2 %
Eutrophication, terrestrial	N eq	3.3 Mole	Benefit of 0.004 Mole	reduction 0.1 %

mc-Si PV-module

Figure 6.10 shows that the project target of *reduction of process water demand to 14 kg per PV module* can be achieved totally by the implementation the water treatment process into the production chain.

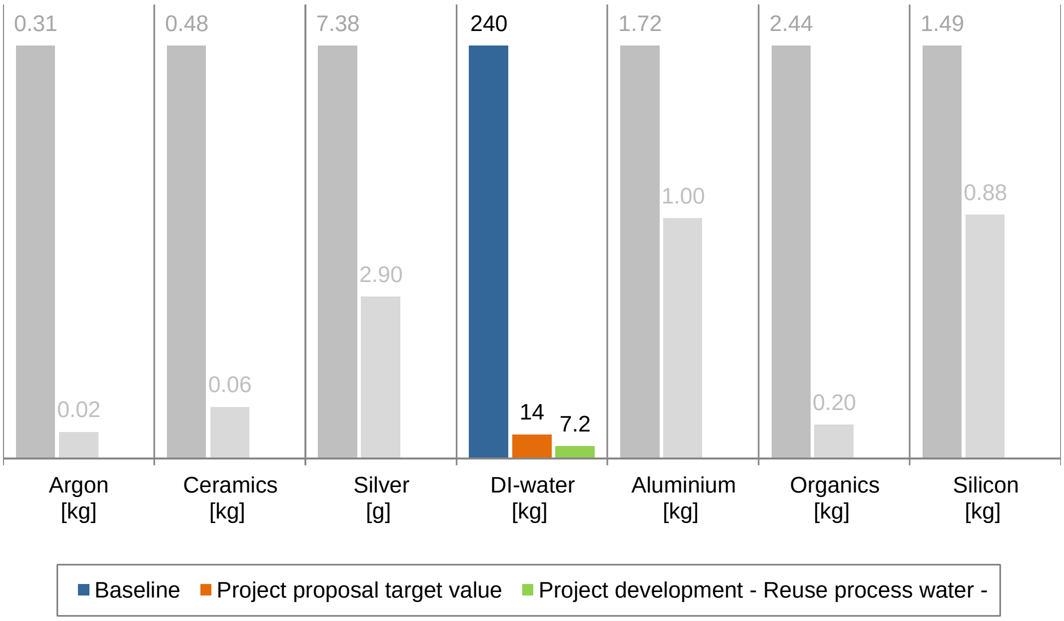


Figure 6.10: Reuse process water: reduction of waste and resource consumption for one mc-Si PV-module (60 6-inch solar cells)

Table 6.11 summarizes the environmental effects of reuse process water. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the treatment process is implemented into the production chain, even if they are marginal. The environmental relief potential ranges from less than 0.1 % for several impact categories to a maximum of 0.5 % for freshwater eutrophication. All improvements trace back to cell processing only.

Table 6.11: Reuse process water: comparison of LCIA net results of baseline and project development for one mc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of reuse process water compared to baseline**	
Climate change	CO_2 eq	224 kg	Benefit of 0.22 kg	reduction 0.1 %
Ecotoxicity, freshwater	CTUe	21,500	Benefit of 2.7	reduction < 0.1 %
Particulate matter	PM2.5 eq	0.27 kg	Benefit of 0.2 g	reduction < 0.1 %
Resource depletion	Sb eq	0.063 kg	Benefit of 0.02 g	reduction < 0.1 %
Human toxicity, cancer	CTUh	1.58E-05	Benefit of 5.28E-08	reduction 0.3 %
Ionizing radiation	U235 eq	33 kBq	Benefit of 0.07 Bq	reduction 0.2 %
Photochemical ozone formation	NMVOC eq	0.67 kg	Benefit of 0.64 g	reduction < 0.1 %
Human toxicity, non-cancer	CTUh	1.08E-04	Benefit of 1.15E-07	reduction 0.1 %
Ozone depletion	CFC-11 eq	0.019 g	Benefit of 0.08 mg	reduction 0.4 %

Impact category	Unit	Baseline	Environmental impact of reuse process water compared to baseline	
Acidification	H+ eq	1.53 Mole	Benefit of 0.005 Mole	reduction 0.3 %
Eutrophication, marine	N eq	0.22 kg	Benefit of 0.46 g	reduction 0.2 %
Eutrophication, freshwater	P eq	0.13 kg	Benefit of 0.62 g	reduction 0.5 %
Eutrophication, terrestrial	N eq	2.3 Mole	Benefit of 0.006 Mole	reduction 0.3 %

6.3.3 Advanced metallization scheme

Approach

According to project partner SoliTek silver metallization paste for the back side (approx. 67 % silver content) can be saved, if the rear side pads are printed with aluminium, so there is a slight increase of aluminium metallization paste consumption. Further experiments regarding the busbars and front side showed, that the amount of silver metallization paste for the front side (approx. 84 % silver content) can be reduce to 50 mg/cell. This corresponds to approx. 33 % of the paste quantity. In coordination with project partner a reduction of the total amount of silver metallization paste for the front and back side by about 50 % with a simultaneous increase of aluminium metallization paste by about 2 % was agreed as approach.

sc-Si PV-module

Figure 6.11 shows that the project target of r*eduction of silver demand to 2.9 g per PV module* can be fulfilled to 86 % by the implementation the advanced metallization scheme into the production chain. The simultaneous increase in aluminium demand is negligible.

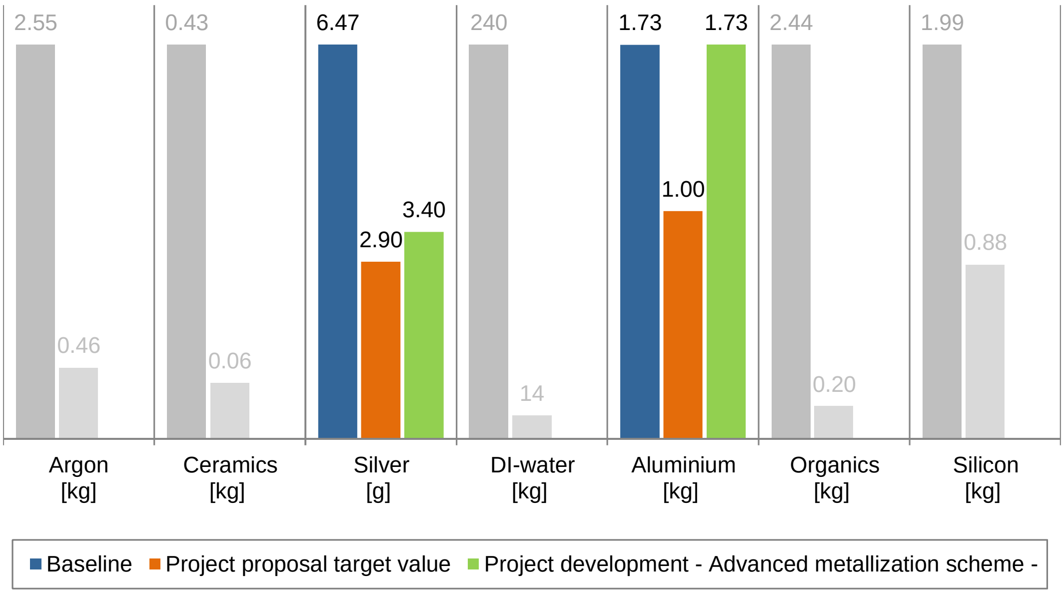


Figure 6.11: Advanced metallization scheme: reduction of waste and resource consumption for one sc-Si PV-module (60 6-inch solar cells)

Table 6.12 summarizes the environmental effects of the advanced metallization scheme. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the new process is implemented into the production chain. The environmental relief potential ranges from less than 1 % for several impact categories to a maximum of 10 % for depletion of mineral, fossil and renewable resources. All improvements trace back to cell processing only.

Table 6.12: Advanced metallization scheme: comparison of LCIA net results of baseline and project development for one sc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of the advanced metallization scheme compared to baseline**	
Climate change	CO_2 eq	360 kg	Benefit of 1.0 kg	reduction < 1 %
Ecotoxicity, freshwater	CTUe	13,470	Benefit of 191	reduction 1 %
Particulate matter	PM2.5 eq	0.38 kg	Benefit of 2.0 g	reduction < 1 %
Resource depletion	Sb eq	0.06 kg	Benefit of 6.0 g	reduction 10 %
Human toxicity, cancer	CTUh	2.54E-05	Benefit of 3.10E-07	reduction 1 %
Ionizing radiation	U235 eq	78 kBq	Benefit of 0.12 kBq	reduction < 1 %
Photochemical ozone formation	NMVOC eq	1.02 kg	Benefit of 10 g	reduction 1 %
Human toxicity, non-cancer	CTUh	1.39E-04	Benefit of 8.02E-06	reduction 6 %
Ozone depletion	CFC-11 eq	0.031 g	Benefit of 0.08 mg	reduction < 1 %
Acidification	H+ eq	2.3 Mole	Benefit of 0.017 Mole	reduction < 1 %
Eutrophication, marine	N eq	0.41 kg	Benefit of 4.0 g	reduction < 1 %
Eutrophication, freshwater	P eq	0.23 kg	Benefit of 5.5 g	reduction 2 %
Eutrophication, terrestrial	N eq	3.3 Mole	Benefit of 0.052 Mole	reduction 2 %

mc-Si PV-module

Figure 6.12 shows that the project target of *reduction of silver demand to 2.9 g per PV module* can be fulfilled to 76 % by the implementation the advanced metallization scheme into the production chain. The simultaneous increase in aluminium demand is also negligible.

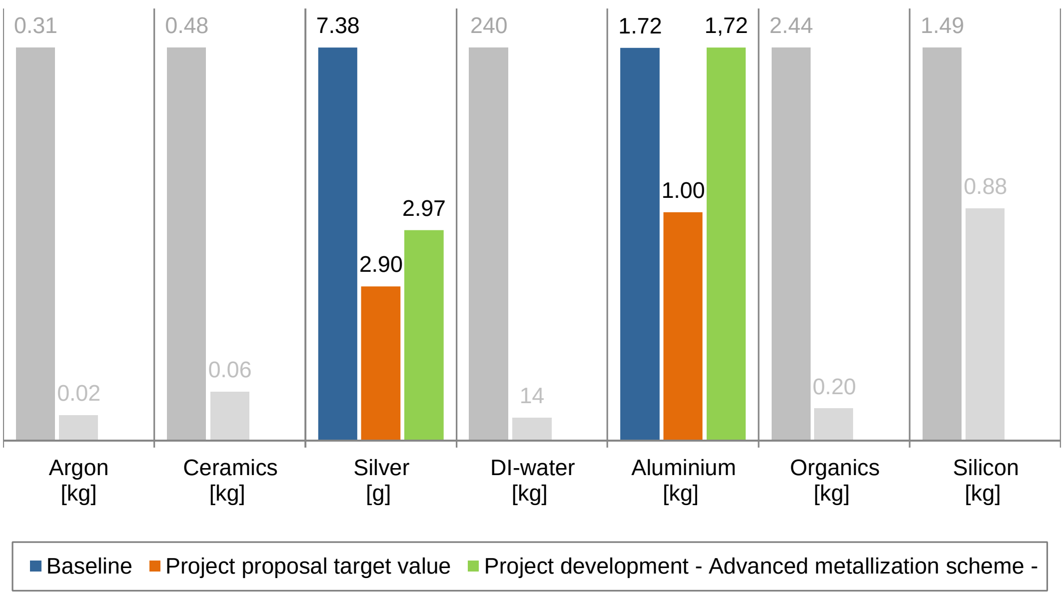


Figure 6.12: Advanced metallization scheme: reduction of waste and resource consumption for one mc-Si PV-module (60 6-inch solar cells)

Table 6.13 summarizes the environmental effects of the advanced metallization scheme. Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the new process is implemented into the production chain. The environmental relief potential ranges from less than 1 % for several impact categories to a maximum of 11 % for depletion of mineral, fossil and renewable resources. All improvements trace back to cell processing only.

Table 6.13: Advanced metallization scheme: comparison of LCIA net results of baseline and project development for one mc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of the advanced metallization scheme compared to baseline**	
Climate change	CO_2 eq	224 kg	Benefit of 1.1 kg	reduction < 1 %
Ecotoxicity, freshwater	CTUe	21,500	Benefit of 213	reduction 2 %
Particulate matter	PM2.5 eq	0.27 kg	Benefit of 2.3 g	reduction < 1 %
Resource depletion	Sb eq	0.063 kg	Benefit of 6.6 g	reduction 11 %
Human toxicity, cancer	CTUh	1.58E-05	Benefit of 3.46E-07	reduction 2 %
Ionizing radiation	U235 eq	33 kBq	Benefit of 0.13 kBq	reduction < 1 %
Photochemical ozone formation	NMVOC eq	0.67 kg	Benefit of 12 g	reduction 2 %
Human toxicity, non-cancer	CTUh	1.08E-04	Benefit of 8.94E-06	reduction 8 %
Ozone depletion	CFC-11 eq	0.019 g	Benefit of 0.09 mg	reduction < 1 %
Acidification	H+ eq	1.53 Mole	Benefit of 0.019 Mole	reduction 1 %
Eutrophication, marine	N eq	0.22 kg	Benefit of 4.5 g	reduction 2 %
Eutrophication, freshwater	P eq	0.13 kg	Benefit of 6.1 g	reduction 5 %
Eutrophication, terrestrial	N eq	2.3 Mole	Benefit of 0.057 Mole	reduction 3 %

6.3.4 Cell Doctor

Approach

This approach considers that a newly cell repair process developed by the project partner AIMEN makes it possible to avoid about 50 % of the cell scrap. This corresponds to approx. 0.015 m² sc-Si wafers and 0.02 m² mc-Si wafer respectively that can be saved.

sc-Si PV-module

Figure 6.13 shows that the project target of *reduction of silicon demand to 0.88 kg per PV module* can be fulfilled to 3 % by using the cell repair process into the production chain.

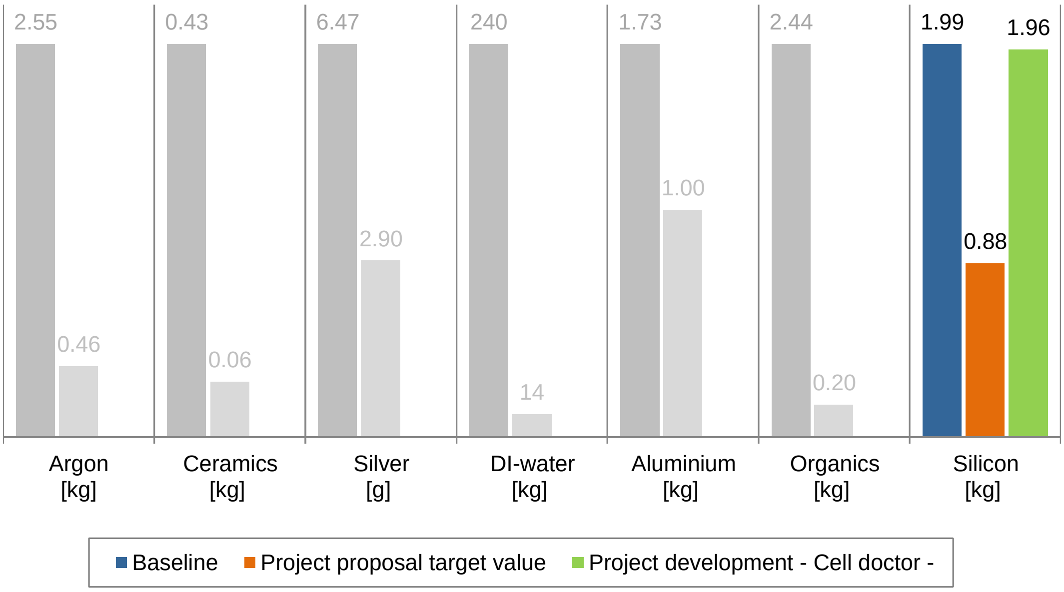


Figure 6.13: Cell doctor: reduction of waste and resource consumption for one sc-Si PV-module (60 6-inch solar cells)

Table 6.14 summarizes the environmental effects of the "Cell Doctor". Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the cell repair process is implemented into the production chain, even if they are very small. The environ-mental relief potential ranges from less than 1 % for several impact categories to a maximum of 2 % for carcinogenic human toxicity. The improvements are mainly due to cell processing as well as the crystallization process and wafering on a smaller scale.

Table 6.14: Cell doctor: comparison of LCIA net results of baseline and project development for one sc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of the cell doctor compared to baseline**	
Climate change	CO_2 eq	360 kg	Benefit of 4.7 kg	reduction 1 %
Ecotoxicity, freshwater	CTUe	13,470	Benefit of 35	reduction < 1 %
Particulate matter	PM2.5 eq	0.38 kg	Benefit of 4.6 g	reduction 1 %
Resource depletion	Sb eq	0.06 kg	Benefit of 0.07 g	reduction < 1 %
Human toxicity, cancer	CTUh	2.54E-05	Benefit of 4.01E-07	reduction 2 %
Ionizing radiation	U235 eq	78 kBq	Benefit of 1 kBq	reduction 1 %
Photochemical ozone formation	NMVOC eq	1.02 kg	Benefit of 11 g	reduction 1 %
Human toxicity, non-cancer	CTUh	1.39E-04	Benefit of 1.22E-06	reduction < 1 %
Ozone depletion	CFC-11 eq	0.031 g	Benefit of 0.38 mg	reduction 1 %
Acidification	H+ eq	2.3 Mole	Benefit of 0.031 Mole	reduction 1 %
Eutrophication, marine	N eq	0.41 kg	Benefit of 5 g	reduction 1 %
Eutrophication, freshwater	P eq	0.23 kg	Benefit of 3.2 g	reduction 1 %
Eutrophication, terrestrial	N eq	3.3 Mole	Benefit of 0.043 Mole	reduction 1 %

mc-Si PV-module

Figure 6.14 shows that the project target of r*eduction of silicon demand to 0.88 kg per PV module* can be fulfilled to 5 % by using the cell repair process into the production chain.

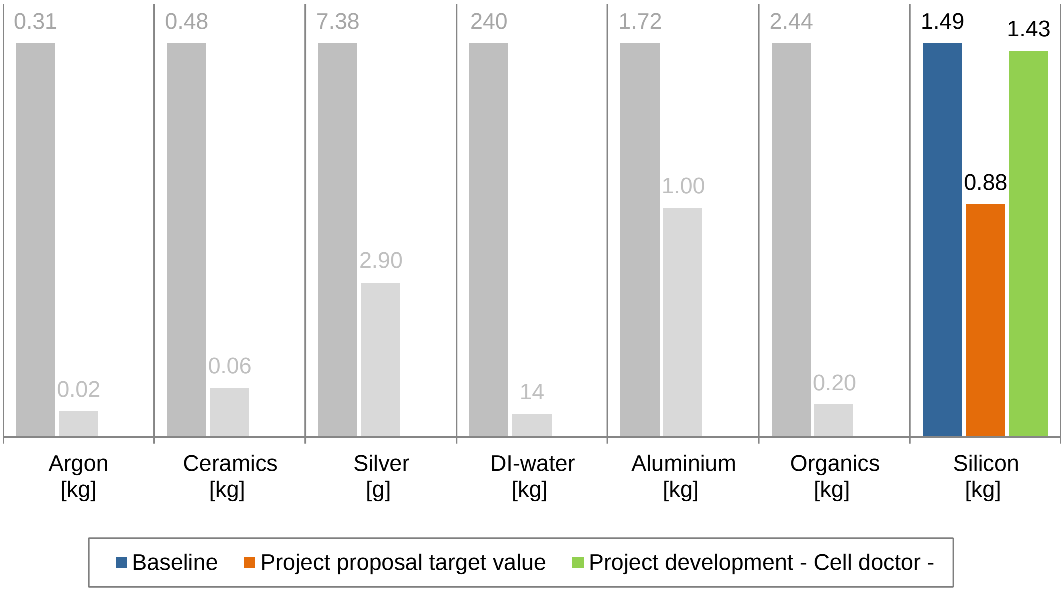


Figure 6.14: Cell doctor: reduction of waste and resource consumption for one mc-Si PV-module (60 6-inch solar cells)

Table 6.15 summarizes the environmental effects of the "Cell Doctor". Compared to the LCIA result of the baseline environmental advantages exist for all examined impact categories if the cell repair process is implemented into the production chain, even if they are very small. The environ-mental relief potential ranges from less than 1 % for several impact categories to a maximum of 2 % for fresh water eutrophication. The improvements are mainly due to cell processing as well as the crystallization process and wafering on a smaller scale.

Table 6.15: Cell doctor: comparison of LCIA net results of baseline and project development for one mc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of the cell doctor compared to baseline**	
Climate change	CO_2 eq	224 kg	Benefit of 2.9 kg	reduction 1 %
Ecotoxicity, freshwater	CTUe	21,500	Benefit of 19	reduction < 1 %
Particulate matter	PM2.5 eq	0.27 kg	Benefit of 3.8 g	reduction 1 %
Resource depletion	Sb eq	0.063 kg	Benefit of 0.06 g	reduction < 1 %
Human toxicity, cancer	CTUh	1.58E-05	Benefit of 2.16E-07	reduction 1 %
Ionizing radiation	U235 eq	33 kBq	Benefit of 0.4 kBq	reduction 1 %
Photochemical ozone formation	NMVOC eq	0.67 kg	Benefit of 7.6 g	reduction 1 %
Human toxicity, non-cancer	CTUh	1.08E-04	Benefit of 6.87E-07	reduction < 1 %
Ozone depletion	CFC-11 eq	0.019 g	Benefit of 0.24 mg	reduction 1 %
Acidification	H+ eq	1.53 Mole	Benefit of 0.022 Mole	reduction 1 %
Eutrophication, marine	N eq	0.22 kg	Benefit of 2.8 g	reduction 1 %

Impact category	Unit	Baseline	Environmental impact of the cell doctor compared to baseline	
Eutrophication, freshwater	P eq	0.13 kg	Benefit of 2 g	reduction 2 %
Eutrophication, terrestrial	N eq	2.3 Mole	Benefit of 0.029 Mole	reduction 1 %

6.4 WP4: Module design for remanufacturing

6.4.1 Usage of an EVA-free glass/glass frameless NICE module Generation 2

Approach

This approach considers that the standard EVA laminated modules with front glass and organic back sheet including an aluminium framing shall be replaced by EVA-free glass/glass frameless NICE modules. The balance model includes both the production and the enhanced disassembly process including treatment and recycling of resulting waste fractions. The regarding material and processing data are provided by project partner APOLLON.

sc-Si PV-module

Figure 6.15 shows that the project target of *reduction of aluminium demand to 1 kg per PV module* can be achieved totally by using the NICE modules. In addition the project target of *reduction of organics demand to 0.2 kg per PV module* can be fulfilled by 95 %. All other project targets also benefit to a small extent, due to the frameless NICE module has a slightly smaller cell area than the standard module (approx. 1.7 %).

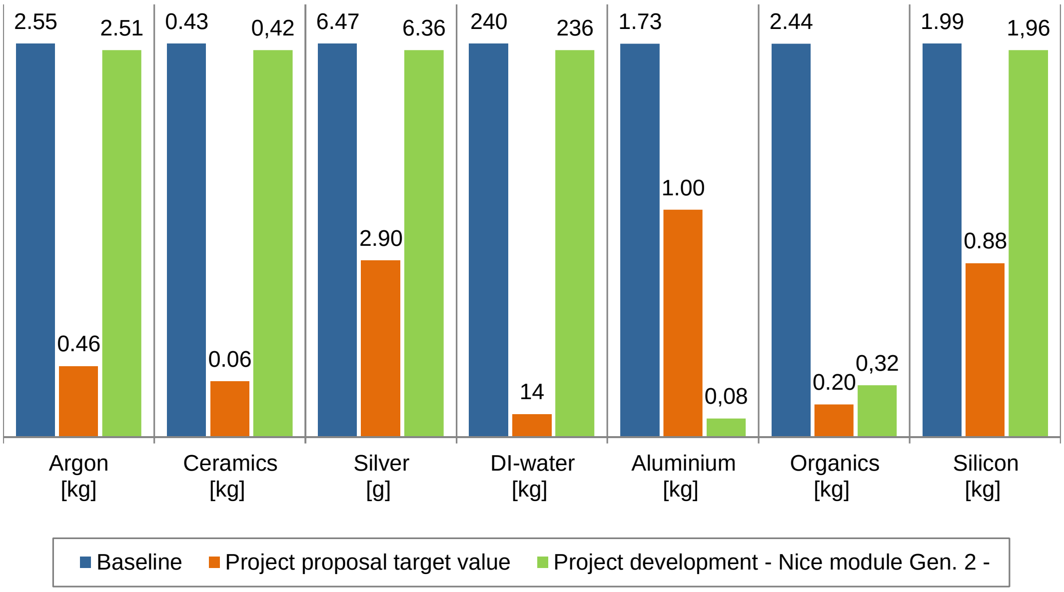


Figure 6.15: Usage of an EVA-free glass/glass frameless NICE module: reduction of waste and resource consumption for one sc-Si PV-module (60 6-inch solar cells)

Table 6.17 summarizes the environmental effects the NICE module. Compared to the LCIA result of the baseline environmental advantages exist for ten of the examined impact categories if the standard PV-module be replaced by the NICE PV-module. The environmental relief potential ranges from less than 1 % for acidification to 69 % for freshwater ecotoxicity. At the other three impact categories, however, the use of the NICE module causes environmental burdens. The additional environmental pollution ranges from

2 % for freshwater eutrophication to a maximum of 53 % for carcinogenic human toxicity. The burdens of carcinogenic human toxicity, for example, are a result of chromium(VI) emissions to water, which arise during the production and recycling of the two galvanised steels that replace the standard aluminium frame.
The improvements and deteriorations are mainly due to module design/assembly of NICE module and the enhanced module dismantling. Because of the slightly smaller area of the NICE module compared to the standard module all other sections into the production chain contribute to the results as well, but on a smaller scale.

Table 6.16: Usage of an EVA-free glass/glass frameless NICE module: comparison of LCIA net results of baseline and project development for one sc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of usage a NICE module compared to baseline**	
Climate change	CO_2 eq	360 kg	Benefit of 16 kg	reduction 5 %
Ecotoxicity, freshwater	CTUe	13,470	Benefit of 9,316	reduction 69 %
Particulate matter	PM2.5 eq	0.38 kg	Benefit of 13 g	reduction 3 %
Resource depletion	Sb eq	0.06 kg	Benefit of 40 g	reduction 66 %
Human toxicity, cancer	CTUh	2.54E-05	Burden of 1.35E-05	increase 53 %
Ionizing radiation	U235 eq	78 kBq	Benefit of 1.1 kBq	reduction 1 %
Photochemical ozone formation	NMVOC eq	1.02 kg	Benefit of 36 g	reduction 4 %
Human toxicity, non-cancer	CTUh	1.39E-04	Burden of 1.98E-05	increase 14 %
Ozone depletion	CFC-11 eq	0.031 g	Benefit of 1.68 mg	reduction 5 %
Acidification	H+ eq	2.3 Mole	Benefit of 0.002 Mole	reduction < 1 %
Eutrophication, marine	N eq	0.41 kg	Benefit of 22 g	reduction 5 %
Eutrophication, freshwater	P eq	0.23 kg	Burden of 5.1 g	increase 2 %
Eutrophication, terrestrial	N eq	3.3 Mole	Benefit of 0.036 Mole	reduction 1 %

mc-Si PV-module
Figure 6.16 shows that the project target of *reduction of aluminium demand to 1 kg per PV module* also can be achieved totally by using the NICE modules. In additional the project target of *reduction of organics demand to 0.2 kg per PV module* can be fulfilled by 95 %. All other project targets also benefit to a small extent, due to the NICE module has a slightly smaller area than the standard module (approx. 1.7 %).

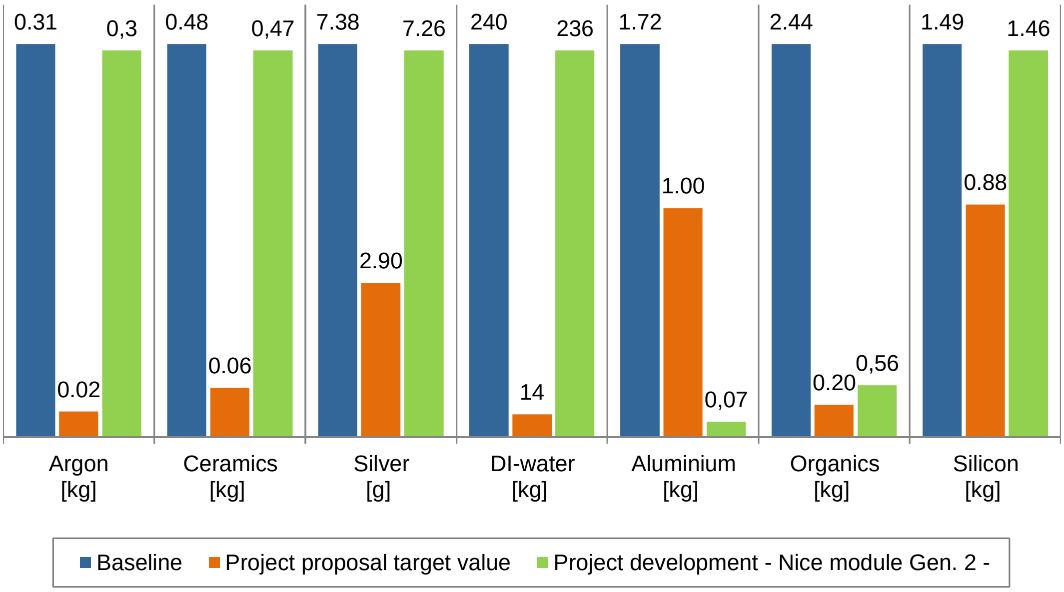


Figure 6.16: Usage of an EVA-free glass/glass frameless NICE module: reduction of waste and resource consumption for one mc-Si PV-module (60 6-inch solar cells)

Table 6.17 summarizes the environmental effects the NICE module. Compared to the LCIA result of the baseline environmental advantages exist for nine of the examined impact categories if the standard PV-module be replaced by the NICE PV module. The environmental relief potential ranges from less than 1 % for terrestrial eutrophication to 74 % for freshwater ecotoxicology. At the other four impact categories, however, the use of the NICE module causes environmental burdens. The additional environmental pollution ranges from less than 1 % for acidification to a maximum of 82 % for carcinogenic human toxicity. As the sc-Si PV-module the burdens of carcinogenic human toxicity are a result of the two galvanised steels that replace the standard aluminium frame.

The improvements and deteriorations are also mainly due to module design/assembly of NICE module and the enhanced module dismantling. Because of the slightly smaller area of the NICE module compared to the standard module all other sections into the production chain contribute to the results as well, but on a smaller scale.

Table 6.17: Usage of an EVA-free glass/glass frameless NICE module: comparison of LCIA net results of baseline and project development for one mc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of usage a NICE module compared to baseline**	
Climate change	CO_2 eq	224 kg	Benefit of 14 kg	reduction 6 %
Ecotoxicity, freshwater	CTUe	21,500	Benefit of 9,300	reduction 74 %
Particulate matter	PM2.5 eq	0.27 kg	Benefit of 11 g	reduction 4 %
Resource depletion	Sb eq	0.063 kg	Burden of 40 g	reduction 63%
Human toxicity, cancer	CTUh	1.58E-05	Benefit of 1.37E-05	increase 82 %
Ionizing radiation	U235 eq	33 kBq	Benefit of 0.36 kBq	reduction 1 %
Photochemical ozone formation	NMVOC eq	0.67 kg	Benefit of 30 g	reduction 4 %

Impact category	Unit	Baseline	Environmental impact of usage a NICE module compared to baseline	
Human toxicity, non-cancer	CTUh	1.08E-04	Burden of 2.04E-05	increase 19 %
Ozone depletion	CFC-11 eq	0.019 g	Benefit of 1.48 mg	reduction 8 %
Acidification	H+ eq	1.53 Mole	Burden of 0.012 Mole	increase < 1 %
Eutrophication, marine	N eq	0.22 kg	Benefit of 19 g	reduction 8 %
Eutrophication, freshwater	P eq	0.13 kg	Burden of 6.7 g	increase 5 %
Eutrophication, terrestrial	N eq	2.3 Mole	Benefit of 0.018 Mole	reduction <1 %

6.5 Combination of all project developments

Approach

The approaches consider that all measured project developments described can be implemented in the production chains, except the new cell process for the mc-Si PV-module. The new cell process does not result in material savings and the new cell process involves further environmental pollution only.

sc-Si PV-module

Figure 6.17 shows that by implementing all project developments into the production chain the project targets of

- *reduction of argon gas demand to 0.46 kg per PV module can be achieved totally,*
- *reduction of ceramic demand to 0.06 kg per PV module can be achieved totally,*
- *reduction of silver demand to 2.9 g per PV module can be fulfilled to 88 %,*
- *reduction of process water demand to 14 kg per PV module can be achieved totally,*
- *reduction of aluminium demand to 1 kg per PV module can be achieved totally,*
- *reduction of organics demand to 0.2 kg per PV module can be fulfilled to 95 % and*
- *reduction of silicon demand to 0.88 kg per PV module can be fulfilled to 35 %.*

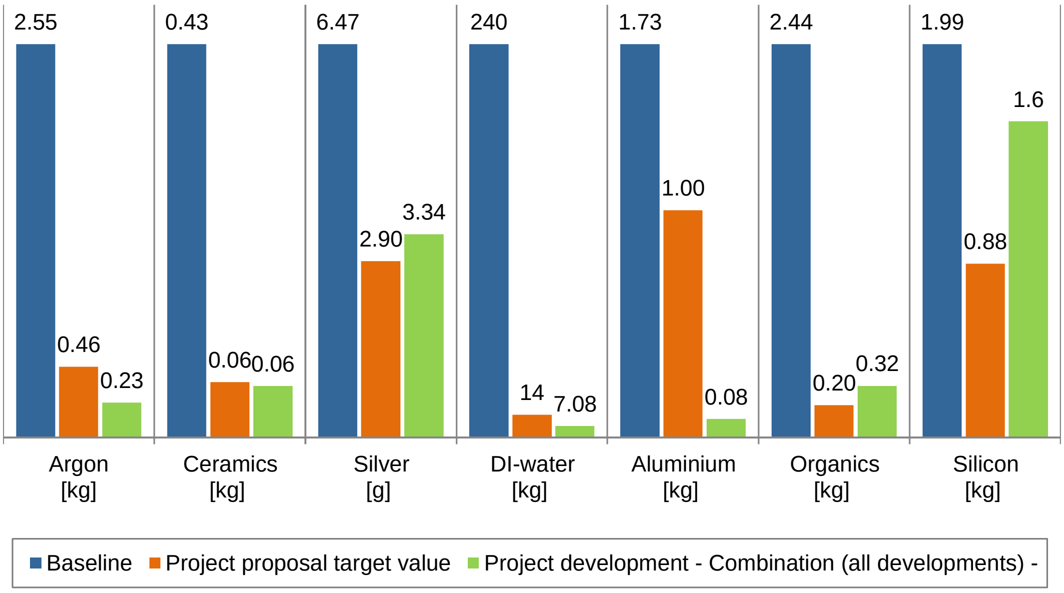


Figure 6.17: Combination of all project developments: reduction of waste and resource consumption for one sc-Si PV-module (60 6-inch solar cells)

Figure 6.18 and Figure 6.19 present the effects of the project developments on climate change and resource depletion exemplary. Compared to the baseline-scenario, a better result was achieved for both impact categories. In the case of climate change, the greenhouse emissions are reduced by more than 17 %. The improvements are mainly due to the crystallization process. The other sections contribute less than 10 % to improvement each. In the case of depletion of mineral, fossil and renewable resources, the resource consumption is reduced by more than 73 %. The improvements are primary determined by the module design/assembly as well as cell processing on a smaller scale. The other production sections contribute less than 4 % to improvement each and the burden of module dismantling has become an emission reduction.

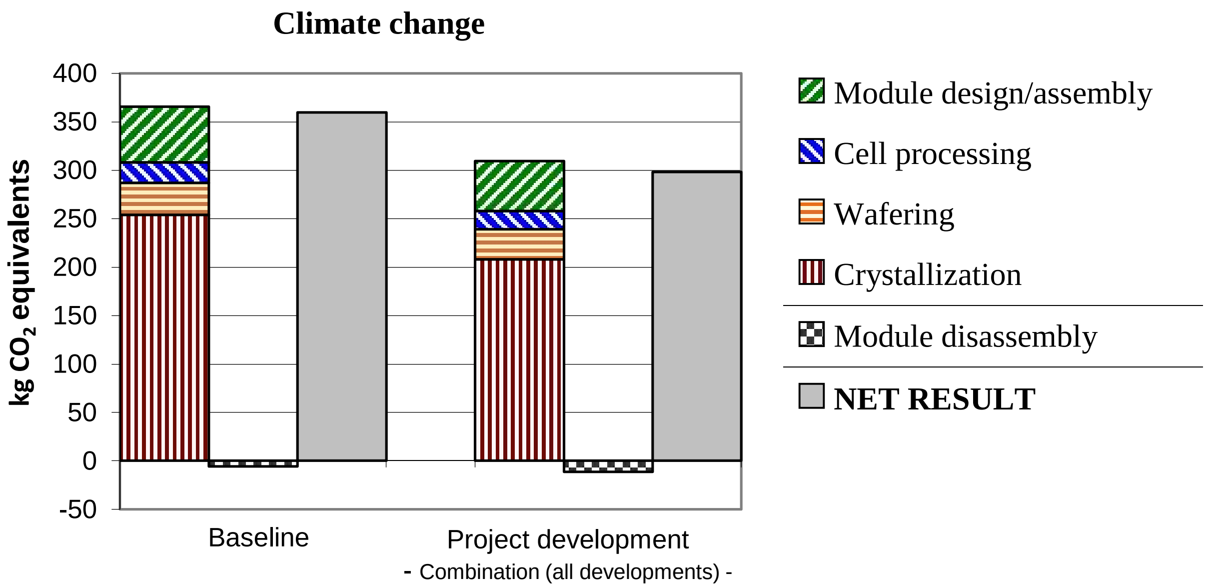


Figure 6.18: Combination of all project developments: comparison of results for global warming potential of one sc-Si PV-module (60 6-inch solar cells)

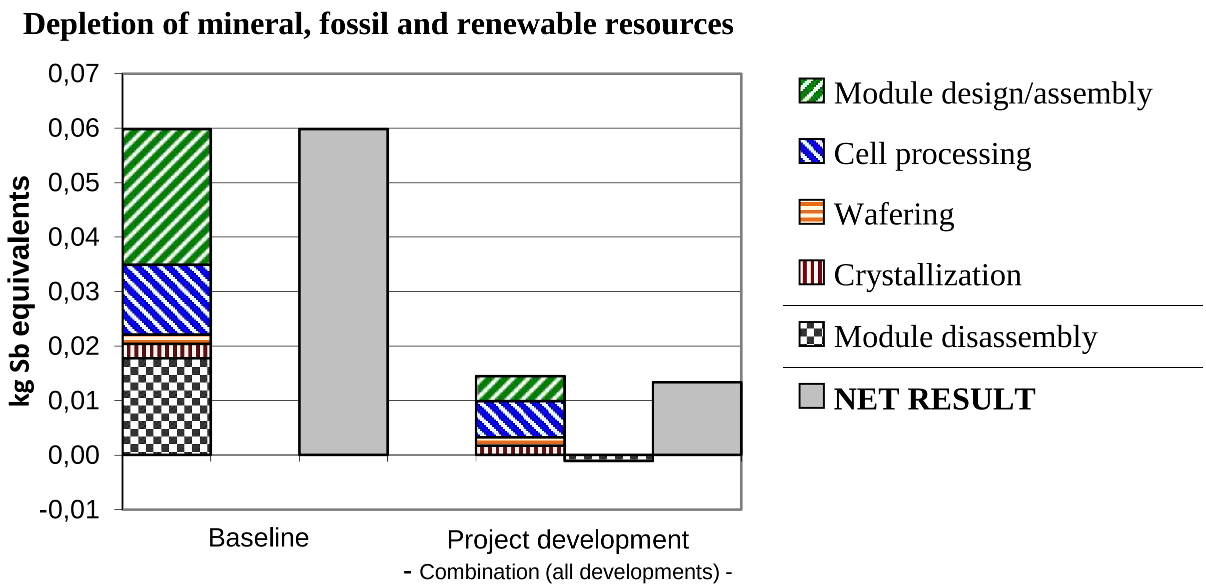


Figure 6.19: Combination of all project developments: comparison of results for depletion of mineral, fossil and renewable resources of one sc-Si PV-module (60 6-inch solar cells)

In Table 6.18 the other results of the combination of all project developments are compared with those of the baseline-scenario. Compared to the LCIA result of the baseline environmental advantages exist for all of the examined impact categories except of carcinogenic and non- carcinogenic human toxicity. The environmental relief potentials range from 10 % for freshwater eutrophication to a maximum of 78 % for depletion of mineral, fossil and renewable resources. The environmental impact potentials increase by less than 1 % and 37 % respectively. Both deteriorations are a result of the galvanised steels used for NICE module instead of the aluminium frame.

Table 6.18: Combination of all project developments: comparison of LCIA results of baseline and project developments for one sc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of combination of all project developments compared to baseline**	
Climate change	CO_2 eq	360 kg	Benefit of 61 kg	reduction 17 %
Ecotoxicity, freshwater	CTUe	13,470	Benefit of 9,802	reduction 73 %
Particulate matter	PM2.5 eq	0.38 kg	Benefit of 0.076 kg	reduction 20 %
Resource depletion	Sb eq	0.06 kg	Benefit of 0.046 kg	reduction 78 %
Human toxicity, cancer	CTUh	2.54E-05	Burden of 9.39E-06	increase 37 %
Ionizing radiation	U235 eq	78 kBq	Benefit of 8.3 kBq	reduction 11 %
Photochemical ozone formation	NMVOC eq	1.02 kg	Benefit of 0.16 kg	reduction 16 %
Human toxicity, non-cancer	CTUh	1.39E-04	Burden of 1.30E-06	increase < 1 %
Ozone depletion	CFC-11 eq	0.031 g	Benefit of 0.005 g	reduction 16 %
Acidification	H+ eq	2.3 Mole	Benefit of 0.29 Mole	reduction 12 %
Eutrophication, marine	N eq	0.41 kg	Benefit of 0.07 kg	reduction 17 %
Eutrophication, freshwater	P eq	0.23 kg	Benefit of 0.024 kg	reduction 10 %
Eutrophication, terrestrial	N eq	3.3 Mole	Benefit of 0.46 Mole	reduction 14 %

mc-Si PV-module

Figure 6.20 shows that by implementing all project developments (except the new cell process) into the production chain the project targets of

- *reduction of argon gas demand to 0.02 kg per PV can be fulfilled to 97 %,*
- *reduction of ceramic demand to 0.06 kg per PV module can be fulfilled to 99 %,*
- *reduction of silver demand to 2.9 g per PV module can be fulfilled to 78 %,*
- *reduction of process water demand to 14 kg per PV module can be achieved totally,*
- *reduction of aluminium demand to 1 kg per PV module can be achieved totally,*
- *reduction of organics demand to 0.2 kg per PV module can be fulfilled to 95 % and*
- *reduction of silicon demand to 0.88 kg per PV module can be fulfilled to 71 %.*

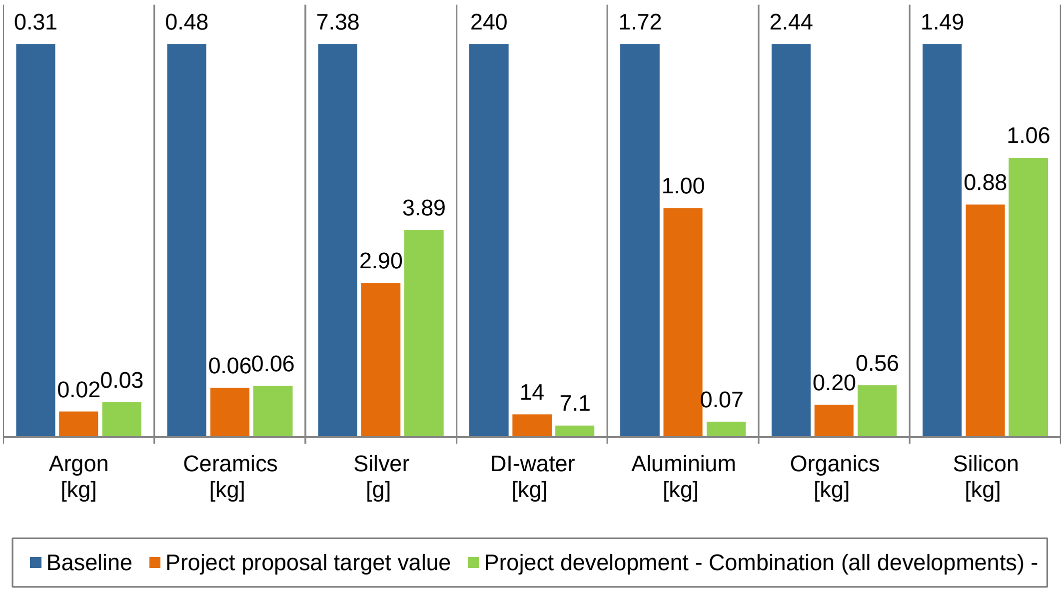


Figure 6.20: Combination of all project developments: reduction of waste and resource consumption for one mc-Si PV-module (60 6-inch solar cells)

Figure 6.21 and Figure 6.22 present the effects of the project developments on climate change and resource depletion exemplary. Compared to the baseline-scenario, a better result was achieved for both impact categories. In the case of climate change, the greenhouse emissions are reduced by almost 22 %. The improvements are mainly due to the crystallization process. The other sections contribute less than 12 % to improvement each. In the case of depletion of mineral, fossil and renewable resources, the resource consumption is reduced by 75 %. The improvements are primary determined by the module design/assembly as well as cell processing on a smaller scale. The other production sections contribute less than 3 % to improvement each and the burden of module dismantling has become an emission reduction.

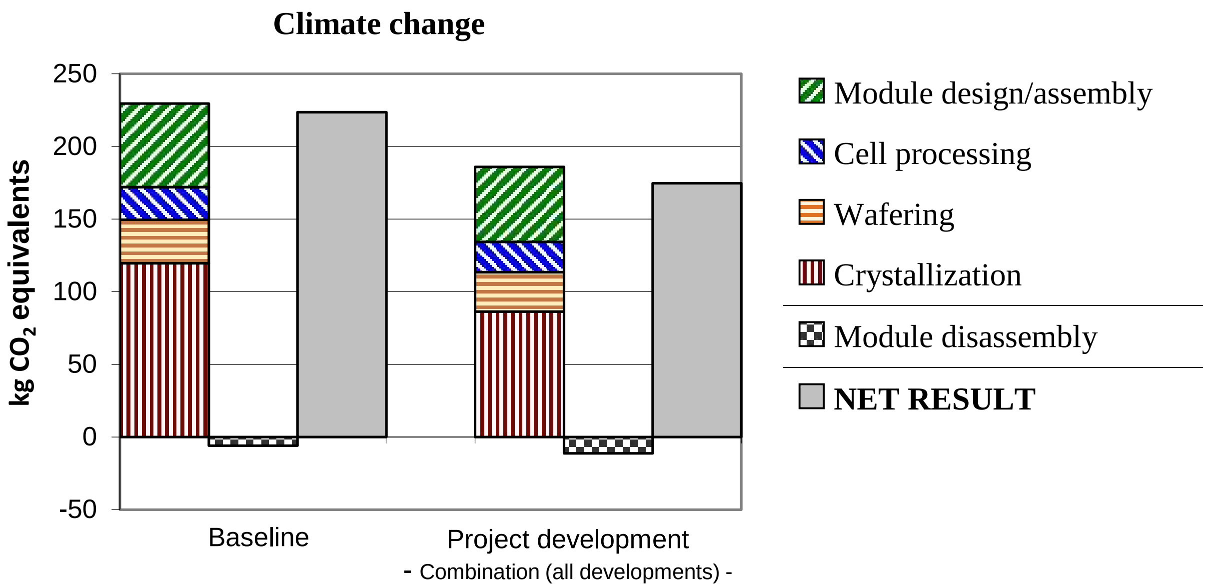


Figure 6.21: Combination of all project developments: reduction of waste and resource consumption for one mc-Si PV-module (60 6-inch solar cells)

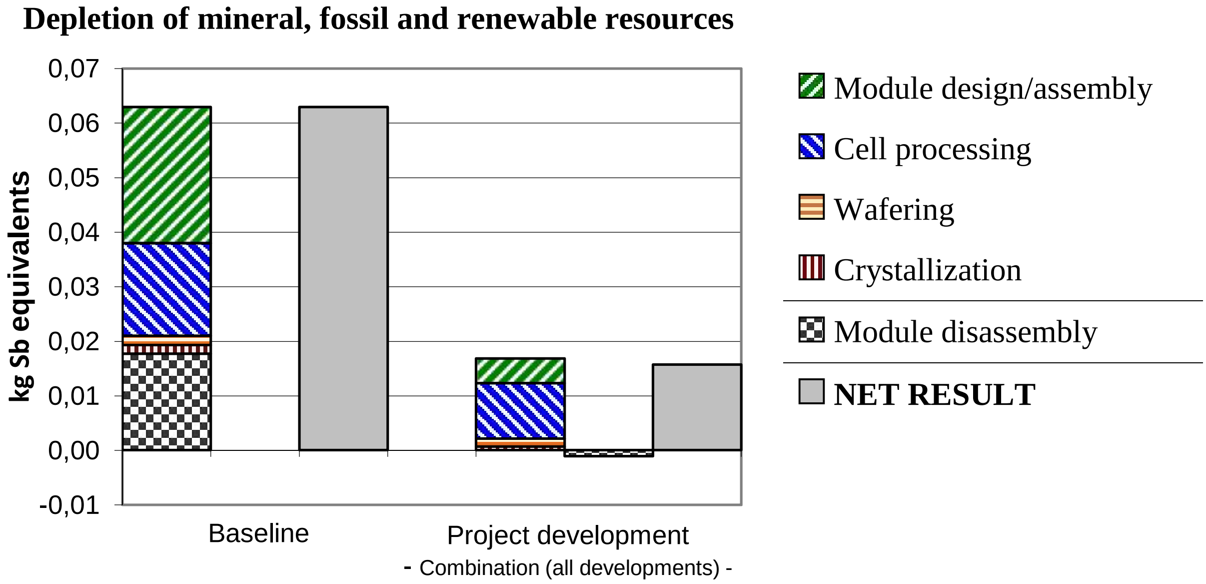


Figure 6.22: Combination of all project developments: comparison of results for global warming potential of one mc-Si PV-module (60 6-inch solar cells)

In Table 6.19 the other results of the combination of all project developments are compared with those of the baseline-scenario. Compared to the LCIA result of the baseline environmental advantages exist for all of the examined impact categories except of carcinogenic and non-carcinogenic human toxicity. The environmental relief potentials range from 11 % for ionizing radiation on human health to a maximum of 78 % for freshwater ecotoxicity. The environmental impact potentials increase by 3 % and 61 % respectively. Both deteriorations are a result of the galvanised steels used for NICE module instead of the aluminium frame.

Table 6.19: Combination of all project developments: comparison of LCIA results of baseline and project developments for one mc-Si PV-module (60 6-inch solar cells)

Impact category	**Unit**	**Baseline**	**Environmental impact of combination of all project developments compared to baseline**	
Climate change	CO_2 eq	224 kg	Benefit of 49 kg	reduction 22 %
Ecotoxicity, freshwater	CTUe	21,500	Benefit of 9,717	reduction 78 %
Particulate matter	PM2.5 eq	0.27 kg	Benefit of 0.066 kg	reduction 24 %
Resource depletion	Sb eq	0.063 kg	Benefit of 0.047 kg	reduction 75 %
Human toxicity, cancer	CTUh	1.58E-05	Burden of 1.02E-05	increase 61 %
Ionizing radiation	U235 eq	33 kBq	Benefit of 3.7 kBq	reduction 11 %
Photoch. ozone formation	NMVOC eq	0.67 kg	Benefit of 0.13 kg	reduction 20 %
Human toxicity, non-cancer	CTUh	1.08E-04	Burden of 3.58E-06	increase 3 %
Ozone depletion	CFC-11 eq	0.019 g	Benefit of 0.004 g	reduction 21 %
Acidification	H+ eq	1.53 Mole	Benefit of 0.22 Mole	reduction 14 %
Eutrophication, marine	N eq	0.22 kg	Benefit of 0.05 kg	reduction 24 %
Eutrophication, freshwater	P eq	0.13 kg	Benefit of 0.016 kg	reduction 12 %
Eutrophication, terrestrial	N eq	2.3 Mole	Benefit of 0.37 Mole	reduction 16 %

6.6 Conclusion

6.6.1 Overall comparison of resource consumption

Regarding sc-Si PV-modules four project targets – reduction of demand of argon gas, ceramics, process water and aluminium – can be achieved totally by implementing of all project developments into the production chain. With fulfilment levels of 95 % and 88 % another two project targets - reduction of demand of silver and organics – are well advanced. Only the reduction of the demand of silicon could not be realized close to the target value.
Regarding mc-Si PV-modules two project targets– reduction of demand of process water and aluminium - can be achieved totally be achieved totally by implementing of all project developments (except the new cell process) into the production chain. With fulfilment levels between 71 % and 99 % the remaining project targets – reduction of demand of argon gas, ceramics and organics, silver and silicon – are also almost achieved and well advanced respectively.

6.6.2 Overall comparison of standardised net results of impact categories for 4,400 PV-modules of a (fictive) 570 kWp open ground photovoltaic power plant

The comparison of LCIA results of baseline – a standard EVA laminated module (60 6-inch solar cells, about 270Wp) with front glass and polymer back sheet including aluminium framing – and the new products and processes developed in this project show environmental relief potentials between 10 % and more than 78 %. However, the amount of these percentage improvement potentials does not say anything about the absolute environmental relief potential of the impact categories.

Therefore, for an overall comparison it is useful to appreciate the relevance of the impact categories regarding the specific project. This is done by the standardisation step. Here in each case the relationship between the net result of the impact indicator and a reference value from the corresponding impact category is calculated. The aggregated annual values of environmental impacts in Europe were used as the reference values (cf. chapter 2.1.4.1

The so-called total numbers of population equivalents (PE) calculated in this way for each impact category allow an order of magnitude-based comparison of the various impact indicator results. The larger the total number of population equivalents, the more significant this impact category is for the ecology-orientated evaluation of the systems considered regarding their relative contribution to the environmental burden.

The overall comparison of the standardised net results is done for a (fictive) 570 kWp open ground photovoltaic power plant with for 4,400 PV-modules as described in [IEA 2015].

In Figure 6.23 it becomes clear that the combination of all project developments for sc-Si PV-modules has the greatest advantages regarding freshwater ecotoxicity as well as depletion of mineral, fossil and renewable resources only. For 4,400 sc-Si PV-modules these both impact categories are expected to achieve savings equivalent to those of more than 4,900 inhabitants per year of emissions generated and more than 2,000 inhabitants per year of consumed resources. Further in a quantity of more than 1,000 population equivalents a greater amount of emissions responsible for ozone depletion are avoided larger magnitude as well. These are the three most important impact categories in the ecology-oriented assessment of the considered sc-Si PV-modules in terms of their relative contributions to the environmental impact. All other impact categories - with partly higher relative percentage environmental relief potentials than those mentioned above - have only light advantages with less than 90 population inhabitants except the human toxicity impact categories. Both are deteriorating by approx. 10 and 1,100 population inhabitant equivalents respectively.

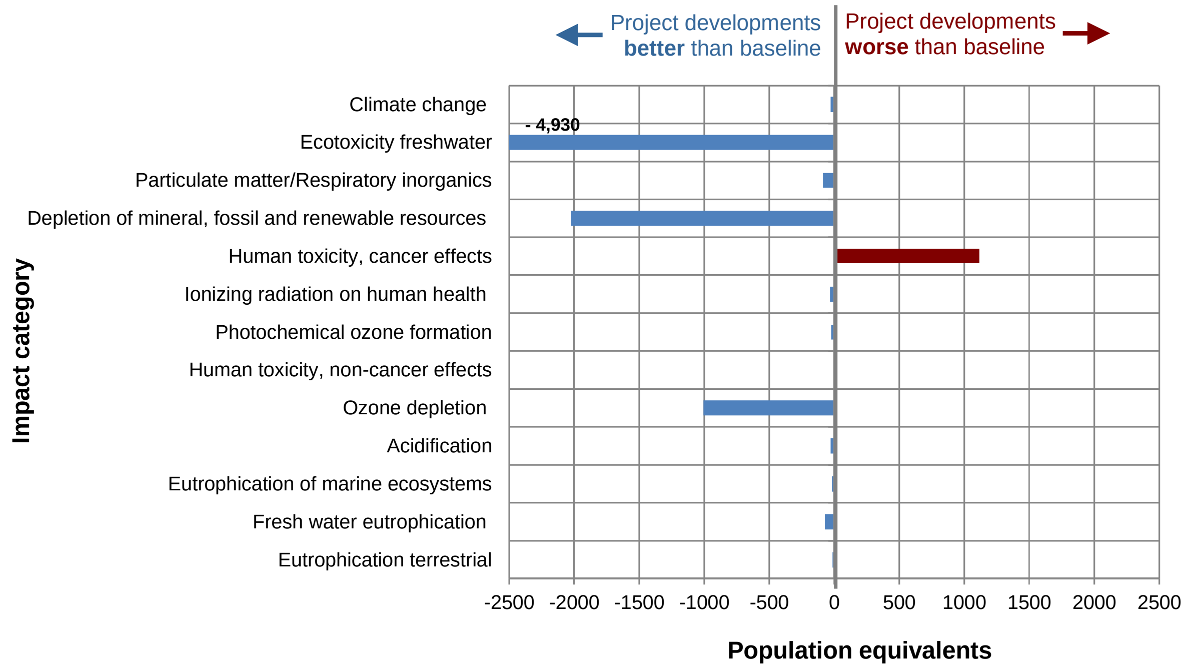


Figure 6.23: Overall comparison (combination of all project developments): Differences in standardised net results of all evaluated impact categories related to 4,400 sc-Si PV-modules (60 6-inch solar cells)

In Figure 6.24 it becomes clear that the combination of all project developments for mc-Si PV-modules shows a very similar result than for sc-Si PV-modules. The greatest advantages are reached for fresh water ecotoxicity as well as depletion of miner-al, fossil and renewable resources only. For 4,400 mc-Si PV-modules these both impact categories are expected to achieve savings equivalent to those of more than 4,900 inhabitants per year of emissions generated and more than 2,000 inhabitants per year of consumed resources. Further in a quantity of more than 800 population equivalents a greater amount of emissions responsible for ozone depletion are avoided larger magnitude as well. These are the three most important impact categories in the ecology-oriented assessment of the considered mc-Si PV-modules in terms of their relative contributions to the environmental impact. All other impact categories - with partly higher relative percentage environmental relief potentials than those mentioned above - have only light advantages with less than 75 population inhabitants except the human toxicity impact categories. Both are deteriorating by approx. 30 and 1,200 population inhabitant equivalents respectively.

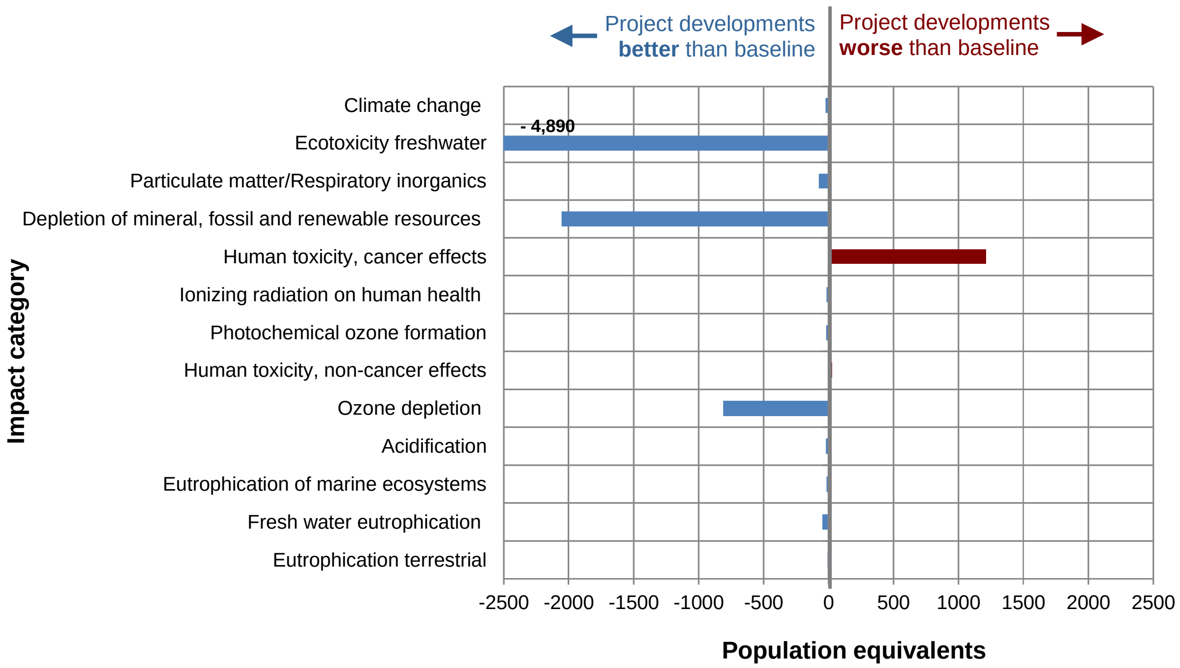


Figure 6.24: Overall comparison (combination of all project developments): Differences in standardised net results of all evaluated impact categories related to 4,400 mc-Si PV-modules (60 6-inch solar cells)

There is an identifiable systematic environmentally-related advantage if all project developments are implemented into the production chain of both types of modules. Advantages in 11 impact categories with partially high population equivalents are counteracted by environmental disadvantages with lower population equivalents in the two human toxicity impact categories only.

Interestingly, both the great benefits of freshwater ecotoxicity and the notable deterioration in carcinogenic human toxicity are due to the replacement of the aluminium frame by the galvanised steels.

On the one hand, the emissions of the aluminium frame leads to the avoidance of copper emissions into the water, which originate from the treatment of the aluminium as a precursor to the reuse in the aluminium smelter. These emissions account for the largest share of burdens in the impact category freshwater ecotoxicity in the baseline.

On the other hand, the production of steel results in additional chromium(VI) emissions into the fresh water which affect adversely the ecological result of the NICE module. The burdens are not only a result of the steel production in the upstream process chain of the module design/assembly but also from the recycling of the steel after module disassembly. In the second case, converter steel made of iron ore is substituted by electrical steel made of scrap. This results in no credit for the two human toxicological impact categories only, because of the production of electrical steel generates a significantly higher amount of chromium(VI) emissions into the water (cancer effect) and mercury emissions to air (non-cancer effect) than the production of converter steel. For all other impact categories, the substitution achieves partly significant environmental benefits.

7 COST CONSIDERATION: BASELINE

As mentioned in chapter 0, baseline for the present cost consideration was the current cost consideration of the International Technology Roadmap for Photovoltaic [ITRPV 2018].

Figure 7.1 shows the price development of mc-Si modules from January 2011 to January 2018 with separate price trends for poly-Si, multi crystalline wafers and cells. After the tremendous price erosion during the second half of 2016 a quite smooth price decline during 2017 can be seen. The inset of Figure 7.1 shows the comparison of the proportion of price attributable to silicon, wafer, cell and module price. The overall price level difference between January 2016 and December 2017 is about 40 % but between January 2017 and December 2017 the decrease was only about 9 % and the share of the different price elements remained nearly constant during 2017. The price fraction of poly-Si is at around 23 %. Wafer and cell conversion process decreased and module conversion remained at 37 % during 2017. [ITRPV 2018]

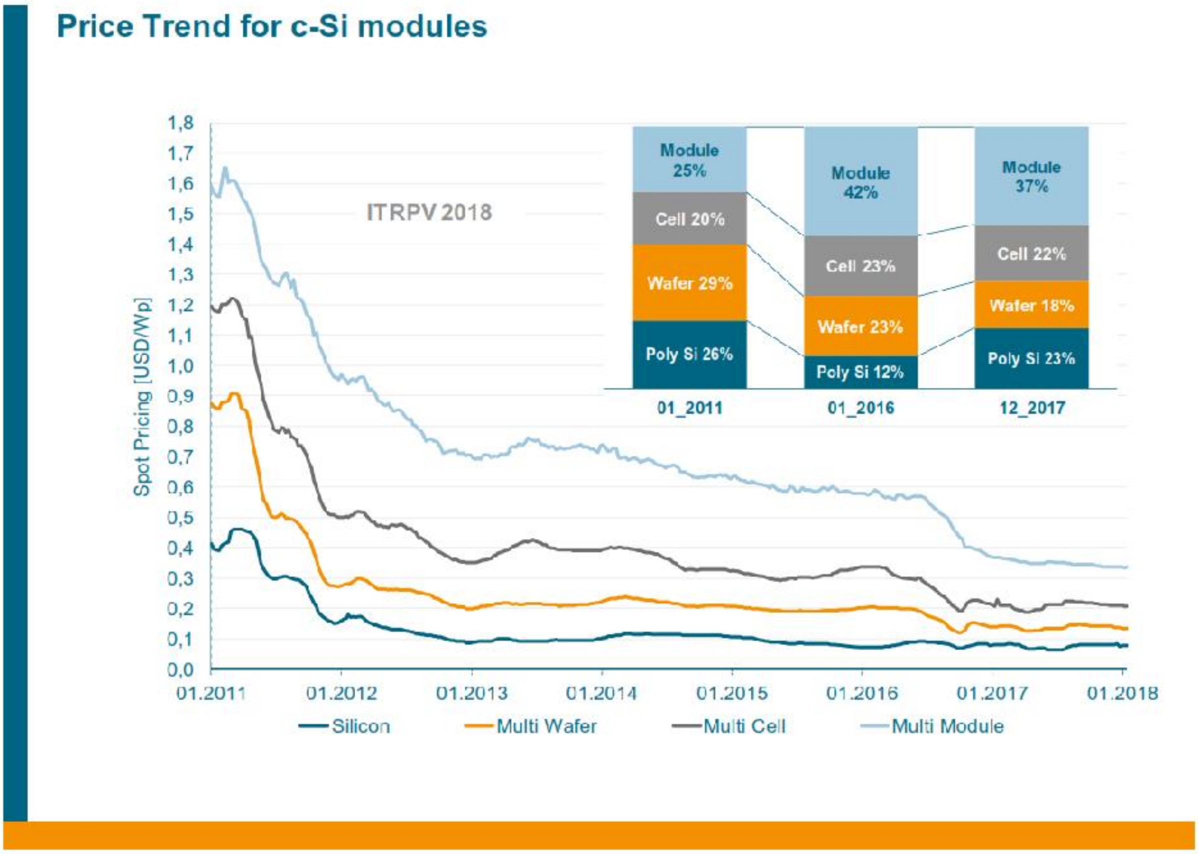


Figure 7.1: Price trends for poly-Si, mc-Si wafers, cells, and c-Si modules (assumption 12/2017: 4.2 g poly-Si per Wp, average mc-Si cell efficiency of 18.85 % {4.59 Wp})
Inset: comparison of the proportion of the price attributable to different module cost elements between 01/2011, 01/2016 and 12/2017 (1.60, 0.57, and 0.34 US $/Wp) [ITRPV 2018]

Figure 7.2 summarizes average module efficiencies at different years. The corresponding module prices at the end of 2016 and 2017 are 0.68 US $/Wp and 0.34 US $/WP respectively.

Year over year learning

Year	1980	2010	2011	2012	2013	2014	2015	2016	2017
avg. Module power p- type (ITRPV-data)	147.6	241.5	248	253	262	267.5	278.5	287.5	290
Module efficency [%], avg. Mod. area: 1.64m²	9 [15]	14.7	15.1	15.4	16	16.3	17	17.5	17.7
Module price [$2017]	35.7	1.66	1.04	0.74	0.76	0.66	0.61	0.38	0.34
Module price (Wp-increase only) [USD(2017)/Wp]		1.63	1.62	1.59	1.53	1.50	1.44	1.40	1.38
Module price (cost reduction per piece only) [USD (2017)/Wp]		1.63	1.08	0.81	0.89	0.82	0.83	0.643	0.62

Figure 7.2: Yearly learning for module efficiency and price per piece on module price data [ITRPV 2018]

The percentages from Figure 7.1 multiplied by module price from Figure 7.2 (0.34 US $/Wp) results in the following specific cost contributions for the standard mc-Si PV module (glass-EVA-Tedlar laminate, nominal power of 270 Wp, 60 cells with an area of 156 x 156 mm each):

- Production polysilicon: 0.0782 US $/Wp → 21.11 US $/mc-Si PV module
- Crystallization and wafering: 0.0612 US $/Wp → 16.52 US $/mc-Si PV module
- Cell processing: 0.0748 US $/Wp → 20.20 US $/mc-Si PV /module
- Module assembly: 0.1258 US $/Wp → 33.97 US $/mc-Si PV module

The total price for the considered baseline mc-Si PV module is approx. 91.8 US $.

In the absence of equivalent data for sc-Si PV modules, bifa estimated the specific cost contributions and the total price based on the mc-Si PV base module. It was assumed that the costs for the production of the polysilicon are identical. In addition, it was believed that the cost of cell processing and module assembly differ only insignificantly from those for the mc-Si modules. The differences are neglected.
Compared to that, it can be assumed that the costs for the crystallization process and wafering would be higher in relation to the mc-Si module. In [PVinsights 2018] the difference in the "Solar PV Wafer Weekly Spot Price" between 156 mm multi solar wafer and 156 mm mono solar wafer is about 30 % (last update 2018-08-22). Even if it is just a "Spot Price", the costs indicate a trend. For this reason the difference in the amount of 30 % is taken over for our project. This leads to following specific cost contributions for the standard sc-Si PV module (glass-EVA-Tedlar laminate, nominal power of 270 Wp, 60 cells with an area of 156 x 156 mm each):

- Production polysilicon: 0.0782 US $/Wp → 21.11 US $/mc-Si PV module
- Crystallization and wafering: 0.0796 US $/Wp → 21.48 US $/mc-Si PV module
- Cell processing: 0.0748 US $/Wp → 20.20 US $/mc-Si PV /module
- Module assembly: 0.1258 US $/Wp → 33.97 US $/mc-Si PV module

The total price for the considered baseline sc-Si PV module is approximated to approx. 96.8 US $.

8 COST CONSIDERATION: PROJECT DEVELOPMENTS

Purchase prices for raw materials and auxiliaries are market prices provided by the project partners. Investment as well as operation and consumption costs estimated by the project partners for the project improvements are not presented in detail for reasons of confidentiality.

In the case, that no cost estimation was provided by the project partners (reusable crucibles and new cell process) bifa has roughly assumed the cost difference between project development and baseline.

8.1 WP1: Recovery & reuse during feedstock crystallisation

8.1.1 Argon gas recovery

Approach

This approach considers that used argon gas will be treated and afterwards meets the requirement of argon gas for up to 90 % weight by weight (cf. 6.1.1).

Basis for the cost estimation are

- a purchasing price for primary argon gas in the amount of approx. 0.389 US $/kg and
- incurred investment as well as operation and consumption costs for the treatment of the argon gas used.

sc-Si PV-module

The estimated cost saving is about 2.1 % for crystallization process and wafering. That corresponds to approx. 0.5 % of the total manufacturing process costs of a sc-Si PV-module.

mc-Si PV-module

The estimated cost saving is about 0.34 % for crystallization process and wafering. That corresponds to approx. 0.06 % of the total manufacturing process costs of a mc-Si PV-module.

8.1.2 Reusable crucibles

Approach

In consultation with partners a seven-time reuse of large crucibles was agreed as approach (cf. 6.1.2). Basis for the cost estimation are

- purchasing prices for nitride crucibles and quartz crucibles
- reduction of red zone in the ingot
- difference in cell efficiency between cells from quartz crucibles and nitride crucibles respectively

sc-Si PV-module

bifa assumed the cost saving potential roughly with 5 % for crystallization process and wafering. That corresponds to approx. 1.1 % of the total manufacturing process costs of a sc-Si PV-module.

mc-Si PV-module
bifa assumed the cost saving potential also roughly with 5 % for crystallization process and wafering. That corresponds to approx. 0.9 % of the total manufacturing process costs of a mc-Si PV-module.

8.2 WP2: Recovery & reuse of Si-kerf-loss

8.2.1 6.2.1 New wire sawing process with thinner diamond wire

Approach
Thinner diamond wire allows more wafers to be sawn out from one silicon ingot. The currently assumed yield plus is 7.92 % (cf. 6.2.1).
As basis for the cost estimation, it is assumed that this amount of silicon ingot can offset approximately directly with the purchase price for the necessary poly silicon.

sc-Si PV-module
The estimated cost saving is about 7.9 % for production polysilicon. That corresponds to approx. 1.7 % of the total manufacturing process costs of a sc-Si PV-module.

mc-Si PV-module
The estimated cost saving is also about 7.9 % for production polysilicon. That corresponds to approx. 1.8 % of the total manufacturing process costs of a mc-Si PV-module.

8.2.2 New silicon kerf recovery process from sawing machines coolant

Approach
10 % of secondary silicon from kerf of sc-Si wafer manufacturing and 20 % of secondary silicon from kerf of mc-Si wafer manufacturing can be added to the necessary silicon demand for wafer production. In addition, 20 % of the silicon content in the crucibles can be substituted as well by the secondary silicon (cf. 6.2.2).
Basis for the cost estimation are

- a purchasing price for primary silicon in the amount of approx. 523 US $/kg and
- incurred investment as well as operation and consumption costs for the treatment of the silicon kerf.

sc-Si PV-module
The estimated cost saving is about 0.6 % for production polysilicon. That corresponds to approx. 0.1 % of the total manufacturing process costs of a sc-Si PV-module.

mc-Si PV-module
The estimated cost saving is about 0.9 % for production polysilicon. That corresponds to approx. 0.2 % of the total manufacturing process costs of a mc-Si PV-module.

8.3 WP3: Remanufacturing, resource efficiency and reuse in solar cell processing

8.3.1 New cell process

Approach
This approach considers the current cell process at SoliTek for sc-Si wafer (cf. 6.3.1).

mc-Si PV-module
bifa assumed the cost saving potential roughly with 5 % for cell processing. That corresponds to approx. 1.1 % of the total manufacturing process costs of a mc-Si PV-module.

8.3.2 Reuse process water

Approach
Waste water from cell processing will be treated and afterwards meets the requirement of process water for up to 97 % weight by weight (cf. 6.3.2).
Basis for the cost estimation are

- a purchasing price for city water in the amount of approx. 4.37 US $/m³,
- costs for purification the city water in the amount of approx. 0.54 US $/m³ and
- incurred investment as well as operation and consumption costs for the treatment of the process water used.

sc-Si PV-module
The estimated cost saving is about 2 % for cell processing. That corresponds to approx. 0.4 % of the total manufacturing process costs of a sc-Si PV-module.

mc-Si PV-module
The estimated cost saving is also about 2 % for cell processing. That corresponds to approx. 0.4 % of the total manufacturing process costs of a mc-Si PV-module.

8.3.3 Advanced metallization scheme

Approach
Reduction of the total amount of silver metallization paste for the front and back side by about 50 % with a simultaneous increase of aluminium metallization paste by about 2 % was agreed as approach (cf. 6.3.3).
Basis for the cost estimation are

- a purchasing price for silver metallization paste for the back side in the amount of approx. 372 US $/kg and
- a purchasing price for silver metallization paste for the front side in the amount of approx. 755 US $/kg and
- a purchasing price for aluminium metallization paste for the back side in the amount of approx. 16.30 US $/kg.

sc-Si PV-module
The estimated cost saving is about 12 % for cell processing. That corresponds to approx. 2.5 % of the total manufacturing process costs of a sc-Si PV-module.

mc-Si PV-module
The estimated cost saving is about 13 % for cell processing. That corresponds to approx. 3 % of the total manufacturing process costs of a mc-Si PV-module.

8.3.4 Cell Doctor

Approach
Silicon wafer scrap will reduce about 50 %. This corresponds to approx. 0.015 m² sc-Si wafers and 0.02 m² mc-Si wafer respectively that can be saved (cf. 6.3.4).
Basis for the cost estimation are

- costs for new cells in the amount of 1.3 US $/cell
- incurred investment as well as operation and consumption costs for repairing cells by cell doctor device

sc-Si PV-module
The estimated cost saving is about 5 % for cell processing. That corresponds to approx. 1 % of the total manufacturing process costs of a sc-Si PV-module.

mc-Si PV-module
The estimated cost saving is about 3.8 % for cell processing. That corresponds to approx. 0.8 % of the total manufacturing process costs of a mc-Si PV-module.

8.4 WP4: Module design for remanufacturing

8.4.1 Usage of an EVA-free glass/glass frameless NICE module Generation 2

Approach
The standard EVA laminated modules with front glass and organic back sheet including an aluminium framing shall be replaced by EVA-free glass/glass frameless NICE modules (cf. 6.4.1).
Basis for the cost estimation are

- the manufacturing costs for a standard laminated PV module (framed) in the amount of approx. 0.1258 US $/Wp and
- the manufacturing costs for a NICE PV module (unframed, Gen. 2).

sc-Si PV-module
The estimated cost saving is about 5.2 % for module assembly. That corresponds to approx. 1.8 % of the total manufacturing process costs of a sc-Si PV-module.

mc-Si PV-module
The estimated cost saving is also about 5.2 % for module assembly. That corresponds to approx. 1.9 % of the total manufacturing process costs of a mc-Si PV-module.

8.5 Combination of all project developments

Approach
All measured project developments described can be implemented in the production chains, except the new cell process for the mc-Si PV-module (cf. 6.5).

sc-Si PV-module
The estimated cost savings are

- about 8.5 % for production polysilicon,
- about 7.1 % for crystallization process and wafering,
- about 18.8 % for cell processing and
- about 5.2 % for module assembly.

That corresponds to approx. 9.2 % of the total manufacturing process costs of a sc-Si PV-module.

mc-Si PV-module
The estimated cost savings are

- about 8.8 % for production polysilicon,
- about 5.3 % for crystallization process and wafering,
- about 19.2 % for cell processing and
- about 5.2 % for module assembly.

That corresponds to approx. 9.1 % of the total manufacturing process costs of a mc-Si PV-module.

8.6 Conclusion

For both module types, all project developments result in cost savings.

Regarding sc-Si PV-modules the cost savings ranges from 0.5 % for argon gas recovery to 2.5 % for an advanced metallization scheme. The highest cost saving potential is expected for the cell process.

The result for the mc-Si PV-modules is very similar. The cost savings ranges from 0.06 % for argon gas recovery to a maximum of 3 % for an advanced metallization scheme. The highest cost saving potential is also expected for the cell process.

9 ECO-EFFICIENCY ANALYSIS

9.1 Explanation of the presentation of the result

The eco-efficiency analysis compares the results of the life cycle impact assessment (ecology index) with the specific results of the costs consideration (cost index). Eco-efficiency portfolios are used to visualize the results.

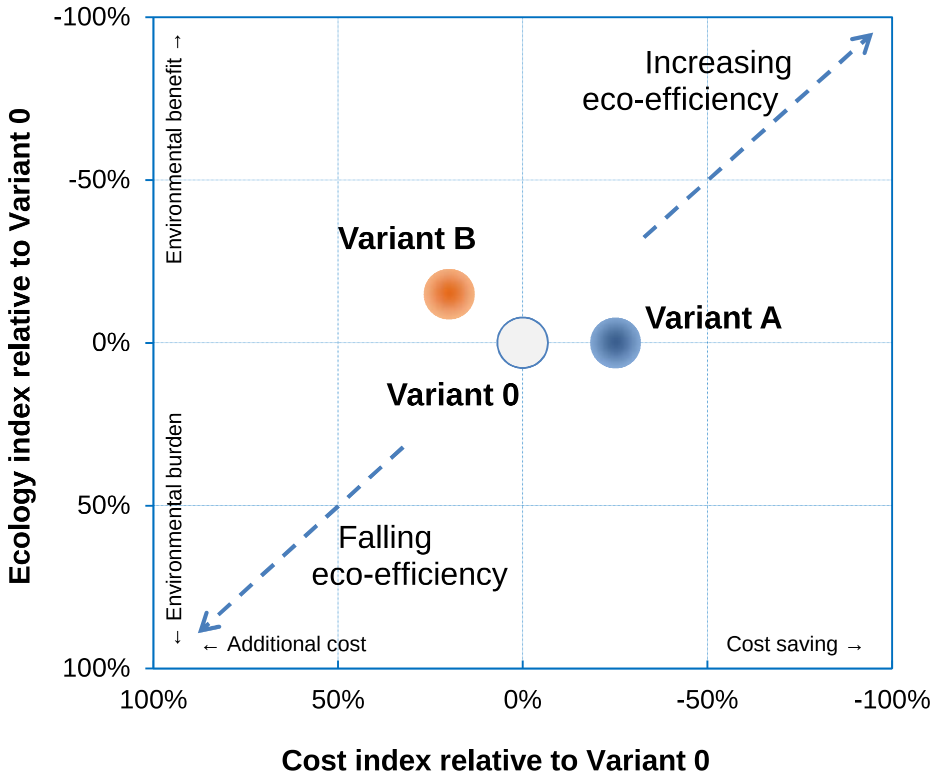


Figure 9.1: Explanation of the eco-efficiency portfolio

Figure 9.1 shows, that an eco-efficiency portfolio is set up such that processes with low eco-efficiency (high costs and positive ecology-indices, i.e. environmental burdens) are found in the bottom left-hand area of the diagram, while processes with high eco-efficiency (low costs and negative ecology-indices, i.e. environmental benefits) are plotted in the top right-hand area of the diagram.

9.2 Result: comparison of the project developments

sc-Si PV-module

The portfolio in Figure 9.2 shows that all project developments achieve a higher eco-efficiency than the baseline. In Table 9.1 the relative deviations from the baseline are summarized.

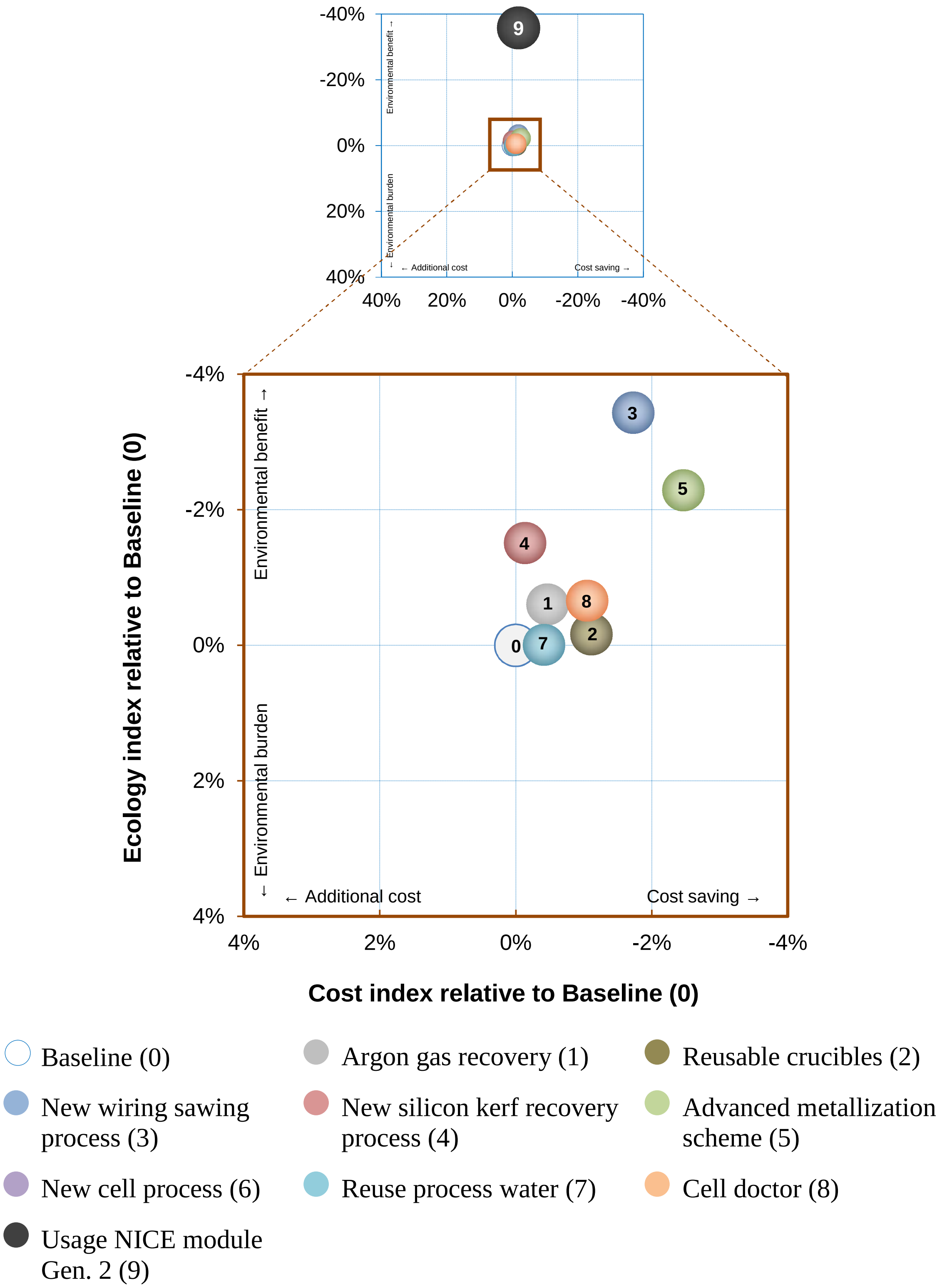


Figure 9.2: Eco-efficiency portfolio for sc-Si PV modules

In addition, Figure 9.2 shows that comparing the project developments with each other the *usage of an EVA-free glass/glass frameless NICE module Generation 2* obtains the highest increasing of eco-efficiency, although this project development does not entail the greatest cost saving. Reason is by far the best ecology index.

Then follow the *new wire sawing process with thinner diamond wire* and the *advanced metallization scheme*, two project developments which perform both a slightly better ecology index and cost index than the remaining project developments.
These (remaining) project developments are positioned much closer to the baseline, but all with better eco-efficiency.

Table 9.1: Relative deviations of the project developments for sc-Si PV-modules (60 6-inch solar cells) from baseline

No.	Project development	Ecology index relative to Baseline	Cost index relative to Baseline
1	Argon gas recovery	- 0.6 %	- 0.5 %
2	Reusable crucibles	- 0.2 %	- 1.1 %
3	New wire sawing process with thinner diamond wire	- 3.4 %	- 1.7 %
4	New silicon kerf recovery process from sawing machines coolant	- 1.5 %	- 0.1 %
5	Advanced metallization scheme	- 2.3 %	- 2.5 %
6	New cell process	-	-
7	Reuse process water	- 0.005 %	- 0.4 %
8	Cell Doctor	- 0.7 %	- 1.0 %
9	Usage of an EVA-free glass/glass frameless NICE module Generation 2	-36 %	- 1.8 %

mc-Si PV-module

The portfolio in Figure 9.3 shows that all project developments achieve a higher eco-efficiency than the baseline with the exception of the *new cell process*. In Table 9.2 the relative deviations from the baseline are summarized.

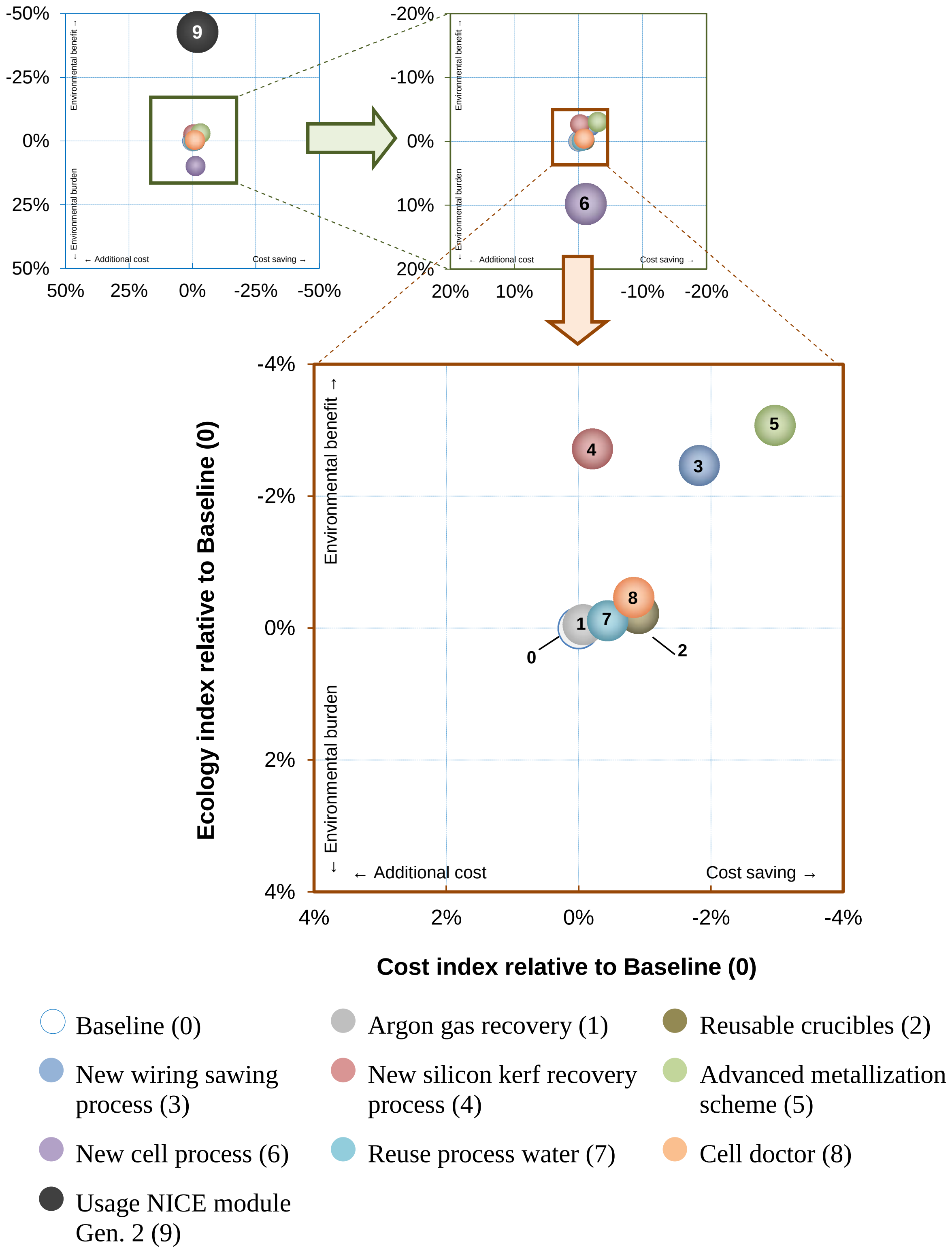


Figure 9.3: Eco-efficiency portfolio for mc-Si PV modules

In addition, Figure 9.2 shows that comparing the project developments with each other the *usage of an EVA-free glass/glass frameless NICE module Generation 2* obtains the highest increasing of eco-efficiency, although this project development does not entail the greatest cost saving. Reason is by far the best ecology index.

Then follow the *advanced metallization scheme* and the *new wire sawing process with thinner diamond wire*, two project developments which perform both a slightly better ecology index and cost index than the remaining project developments. The *new silicon kerf recovery process from sawing machines coolant* generates also a good ecology index but the cost index does not improve in the same order of magnitude.
Due to the additional environmental impact for all examined impact categories (cf. 6.3.1), the *new cell process* has a significantly worse ecology index than the baseline.
The remaining project developments are positioned close to the baseline, but all with better eco-efficiency.

Table 9.2: Relative deviations of the project developments for mc-Si PV-modules (60 6-inch solar cells) from baseline

No.	Project development	Ecology index relative to Baseline	Cost index relative to Baseline
1	Argon gas recovery	- 0.05 %	- 0.06 %
2	Reusable crucibles	- 0.2 %	- 0.9 %
3	New wire sawing process with thinner diamond wire	- 2.5 %	- 1.8 %
4	New silicon kerf recovery process from sawing machines coolant	- 2.7 %	- 0.2 %
5	Advanced metallization scheme	- 3.1 %	- 3.0 %
6	New cell process	+ 9.8 %	- 1.1 %
7	Reuse process water	- 0.1 %	- 0.4 %
8	Cell Doctor	- 0.5 %	- 0.8 %
9	Usage of an EVA-free glass/glass frameless NICE module Generation 2	-43 %	- 1.9 %

10 SUMMARY

The aim of this project was the development of an integrated value chain to manufacture and implement solar panels in the most ecological way. This should be achieved by maximizing resource efficiency, taking into account reuse of materials during production and repurposing solar panel components. The project developments were analyzed with respect to

This report deals with the evaluation of the achievement of the project targets regarding material reduction. In addition the environmental impacts and costs of the processes and products developed in the individual work packages are considered in relation to the environmental impacts and costs of the manufacturing processes of state-of-the-art sc-Si and mc-Si PV modules.

The project developments are

- Argon gas recovery
- Reusable crucibles
- New wire sawing process with thinner diamond wire
- New silicon kerf recovery process from sawing machines coolant
- New cell process
- Reuse process water
- Advanced metallization scheme
- “Cell doctor”
- Usage of an EVA-free glass/glass frameless NICE module Gen. 2

As reference module in baseline a standard EVA laminated module (60 6-inch solar cells, about 270Wp) with front glass and polymer back sheet including aluminium framing was chosen.

10.1 sc-Si PV-modules

By implementing of all project developments into the production chain of sc-Si PV-modules the project targets of

- reduction of argon gas demand to 0.46 kg per PV module can be achieved totally,
- reduction of ceramic demand to 0.06 kg per PV module can be achieved totally,
- reduction of silver demand to 2.9 g per PV module can be fulfilled to 88 %,
- reduction of process water demand to 14 kg per PV module can be achieved totally,
- reduction of aluminium demand to 1 kg per PV module can be achieved totally,
- reduction of organics demand to 0.2 kg per PV module can be fulfilled to 95 % and
- reduction of silicon demand to 0.88 kg per PV module can be fulfilled to 35 %.

Compared to the life cycle impact assessment result of the baseline environmental advantages exist for all of the examined impact categories except human toxicity. The environmental relief potentials range from 10 % for freshwater eutrophication to a maximum of 78 % for depletion of mineral, fossil and renewable resources. The environmental impact potentials increase by less than 1 % for non-carcinogenic human toxicity and 37 % for carcinogenic human toxicity. Both deteriorations are a result of the galvanised steels used for NICE module instead of the aluminium frame.

The estimated cost savings are about

- 8.5 % for production of polysilicon,
- 7.1 % for crystallization process and wafering,
- 18.8 % for cell processing and
- 5.2 % for module assembly.

That corresponds to approx. 9.2 % of the total manufacturing process costs of a sc-Si PV-module.

The eco-efficiency analysis shows that all project developments achieve a higher eco-efficiency than the baseline. Comparing the project developments with each other the usage of an EVA-free glass/glass frameless NICE module Generation 2 obtains the highest increase of eco-efficiency. Then follow the new wire sawing process with thinner diamond wire and the advanced metallization scheme, two project developments which perform both a slightly better ecology index and cost index than the remaining project developments. These remaining project developments are positioned much closer to the baseline, but all with better eco-efficiency.

10.2 mc-Si PV-modules

By implementing of all project developments into the production chain of mc-Si PV-modules the project targets of

- reduction of argon gas demand to 0.02 kg per PV can be fulfilled to 97 %,
- reduction of ceramic demand to 0.06 kg per PV module can be fulfilled to 99 %,
- reduction of silver demand to 2.9 g per PV module can be fulfilled to 78 %,
- reduction of process water demand to 14 kg per PV module can be achieved totally,
- reduction of aluminium demand to 1 kg per PV module can be achieved totally,
- reduction of organics demand to 0.2 kg per PV module can be fulfilled to 95 % and
- reduction of silicon demand to 0.88 kg per PV module can be fulfilled to 71 %.

Compared to the LCIA result of the baseline environmental advantages exist for all of the examined impact categories except human toxicity. The environmental relief potentials range from 11 % for ionizing radiation on human health to a maximum of 78 % for freshwater ecotoxicity. The environmental impact potentials increase by 3 % for non-carcinogenic human toxicity and 61 % for carcinogenic human toxicity. Both deteriorations are also a result of the galvanised steels used for NICE module instead of the aluminium frame.

The estimated cost savings are about

- 8.8 % for production of polysilicon,
- 5.5 % for crystallization process and wafering,
- 19.2 % for cell processing and
- 5.2 % for module assembly.

That corresponds to approx. 9.1 % of the total manufacturing process costs of a mc-Si PV-module.

The eco-efficiency analysis shows that all project developments achieve a higher eco-efficiency than the baseline with the exception of the new cell process. Comparing the project developments with each other the usage of an EVA-free glass/glass frameless NICE module Generation 2 obtains the highest increase of eco-efficiency followed by the advanced metallization scheme and the new wire sawing process with thinner diamond wire. The new silicon kerf recovery process from sawing machines coolant generates also a good ecology index but the cost index does not improve in the same order of magnitude. Due to the additional environmental impact for all examined impact categories, the new cell process has a worse ecology index than the baseline. Reasons are ecological disadvantages of upstream processes for raw materials which differ from the standard cell process. The remaining project developments are positioned close to the baseline, but all with better eco-efficiency.

10.3 Conclusion

Compared to the manufacturing processes of standard PV modules the project developments show large savings potentials of key materials and environmental burdens.

Summarised for sc-Si PV modules and mc-Si PV modules, by implementing all of the project developments in the production chains, ten of the fourteen project targets regarding material saving can be fully achieved or achieved to more than 90 %. With fulfilment levels between 71 % and 88 % further three project targets are well advanced. Only one project target could not be realized close to the target value.

In general the project developments show a better eco-efficiency with low cost advantages and partly significant environmental relief potentials. The total ecological benefit achieved for sc-Si PV modules is 45 % and for mc-Si PV modules 42 %.

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ANNEX A: DATA SYMMETRY ANALYSIS

The data symmetry analysis has two major tasks [UBA 2000]:

1. It shall serve to compare the datasets of various processes, on the basis of plausibility and as necessary to trace missing life cycle analysis items.
2. Secondly, the data symmetry analysis for the examination of results of the impact assessment shall be taken into consideration whereby the differences in results shall be attributed to the imbalance of data in the various scenarios.

The data symmetry analyses undertaken in the course of this study showed inconspicuous results (cf. Table A.1 to Table A.6).

Table A.1: Data symmetry analysis of balance models – Input flows: energy and material resources

Flow	**mc-Si PV module**					**sc-Si PV module**				
	Crystallization	**Wafering**	**Cell processing**	**Module assembly**	**Module disassembly**	**Crystallization**	**Wafering**	**Cell processing**	**Module assembly**	**Module disassembly**
Non-renewable energy resources										
Crude oil (in MJ)	■					■				
Crude oil ecoinvent	■	■	■	■	■	■	■	■	■	■
Oil sand (10% bitumen) (in MJ)	■					■				
Oil sand (100% bitumen) (in MJ)	■					■				
Coal, hard, unspecified, in ground	■	■	■	■	■	■	■	■	■	■
Hard coal (in MJ)	■					■				
Coal, brown, in ground	■	■	■	■	■	■	■	■	■	■
Lignite (in MJ)	■					■				
Coalbed methane (in MJ)	■					■				
Natural gas (in MJ)	■					■				
Pit Methane (in MJ)	■					■				
Shale gas (in MJ)	■					■				
Tight gas (in MJ)	■					■				
Peat (in kg)	■	■	■	■	■	■	■	■	■	■
Peat (in MJ)	■					■				
Uranium natural (in MJ)	■					■				
Uranium, in ground	■	■	■	■	■	■	■	■	■	■
Non-renewable elements										
Aluminium	■	■	■	■	■	■	■	■	■	■
Antimony	■					■				
Cadmium	■	■	■	■	■	■	■	■	■	■
Cerium	■	■	■	■	■	■	■	■	■	■
Chromium	■	■	■	■	■	■	■	■	■	■
Cobalt	■	■	■	■	■	■	■	■	■	■
Copper	■	■	■	■	■	■	■	■	■	■
Dysprosium	■					■				
Erbium	■					■				

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Europium	■	■	■	■	■	■	■	■	■	■
Gadolinium	■	■	■	■	■	■	■	■	■	■
Gallium	■	■	■	■	■	■	■	■	■	■
Gold	■	■	■	■	■	■	■	■	■	■
Holmium	■					■				
Indium	■	■	■	■	■	■	■	■	■	■
Iodine	■	■	■	■	■	■	■	■	■	■
Iridium	■					■				
Iron	■	■	■	■	■	■	■	■	■	■
Lanthanum	■	■	■	■	■	■	■	■	■	■
Lead	■	■	■	■	■	■	■	■	■	■
Lithium	■	■	■	■	■	■	■	■	■	■
Lutetium	■					■				
Magnesium	■					■				
Manganese	■	■	■	■	■	■	■	■	■	■
Mercury	■					■				
Molybdenum	■	■	■	■	■	■	■	■	■	■
Neodymium	■	■	■	■	■	■	■	■	■	■
Nickel	■	■	■	■	■	■	■	■	■	■
Osmium	■					■				
Palladium	■	■	■	■	■	■	■	■	■	■
Phosphorus	■	■	■	■	■	■	■	■	■	■
Platinum	■	■	■	■	■	■	■	■	■	■
Praseodymium	■	■	■	■	■	■	■	■	■	■
Rhenium	■	■	■	■	■	■	■	■	■	■
Rhodium	■	■	■	■	■	■	■	■	■	■
Ruthenium	■					■				
Silicon	■					■				
Silver	■	■	■	■	■	■	■	■	■	■
Strontium	■	■	■	■	■	■	■	■	■	■
Sulphur	■	■	■	■	■	■	■	■	■	■
Tantalum	■	■	■	■	■	■	■	■	■	■
Tellurium	■	■	■	■	■	■	■	■	■	■
Thulium	■					■				
Tin	■	■	■	■	■	■	■	■	■	■
Titanium	■					■				
Vanadium	■					■				
Ytterbium	■					■				
Yttrium	■					■				

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Zinc	■	■	■	■	■	■	■	■	■	■
Zirconium	■	■	■	■	■	■	■	■	■	■
Non-renewable resources										
Anhydrite (Rock)	■	■	■	■	■	■	■	■	■	■
Barite, 15% in crude ore, in ground	■	■	■	■	■	■	■	■	■	■
Barium sulphate	■					■				
Basalt	■	■	■	■	■	■	■	■	■	■
Bauxite	■					■				
Bentonite	■					■				
Borax	■	■	■	■	■	■	■	■	■	■
Calcium chloride	■					■				
Cinnabar	■	■	■	■	■	■	■	■	■	■
Clay	■	■	■	■	■	■	■	■	■	■
Colemanite ore	■	■	■	■	■	■	■	■	■	■
Dolomite	■	■	■	■	■	■	■	■	■	■
Feldspar (aluminium silicates)	■	■	■	■	■	■	■	■	■	■
Ferro manganese	■					■				
Fluorspar (calcium fluoride; fluorite)	■	■	■	■	■	■	■	■	■	■
Granite	■	■	■	■	■	■	■	■	■	■
Graphite	■					■				
Gypsum (natural gypsum)	■	■	■	■	■	■	■	■	■	■
Heavy spar (BaSO4)	■					■				
Ilmenite (titanium ore)	■					■				
Inert rock	■	■	■	■	■	■	■	■	■	■
Kaolin ore	■					■				
Kaolinite (24% in ore as mined)	■	■	■	■	■	■	■	■	■	■
Limestone (calcium carbonate)	■					■				
Magnesit (Magnesium carbonate)	■					■				
Magnesite	■	■	■	■	■	■	■	■	■	■
Magnesium chloride leach (40%)	■					■				
Natural Aggregate	■					■				
Natural pumice	■					■				
Olivine	■	■	■	■	■	■	■	■	■	■
Perlite (Rhyolithe)	■	■	■	■	■	■	■	■	■	■
Phosphate ore	■					■				
Potashsalt, crude (hard salt, 10% K2O)	■					■				
Potassium chloride	■					■				
Pyrite	■					■				
Quartz sand (silica sand; silicon	■					■				

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
dioxide)										
Sand	■	■	■	■	■	■	■	■	■	■
Shale	■	■	■	■	■	■	■	■	■	■
Slate	■					■				
Sodium chloride (rock salt)	■	■	■	■	■	■	■	■	■	■
Sodium nitrate	■	■	■	■	■	■	■	■	■	■
Sodium sulphate	■	■	■	■	■	■	■	■	■	■
Soil	■					■				
Spodumen (LiAlSi2 O6)	■	■	■	■	■	■	■	■	■	■
Stone from mountains	■					■				
Sulphur (bonded)	■					■				
Talc	■	■	■	■	■	■	■	■	■	■
Tin ore (0.01%)	■					■				
Titanium dioxide	■	■	■	■	■	■	■	■	■	■
Titanium ore	■					■				
Ulexite	■	■	■	■	■	■	■	■	■	■
Renewable resources										
Air	■					■				
Carbon dioxide	■	■	■	■	■	■	■	■	■	■
Forest, primary	■					■				
Nitrogen	■	■	■	■	■	■	■	■	■	■
Oxygen	■	■	■	■	■	■	■	■	■	■
Wood, unspecified, standing	■	■	■	■	■	■	■	■	■	■

Table A.2: Data symmetry analysis of balance models – Output flows: emissions to air

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Long-term emissions to air										
Acetaldehyde								■		
Ammonia	■	■	■	■	■	■	■	■	■	■
Antimony	■	■	■	■	■	■	■	■	■	■
Arsenic	■	■	■	■	■	■	■	■	■	■
Barium	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Beryllium	■	■	■	■	■	■	■	■	■	■
Cadmium	■	■	■	■	■	■	■	■	■	■
Carbon dioxide, fossil				■				■	■	
Chromium VI	■	■	■	■	■	■	■	■	■	■
Cobalt	■	■	■	■	■	■	■	■	■	■
Copper	■	■	■	■	■	■	■	■	■	■
Dinitrogen monoxide	■	■	■	■	■	■	■	■	■	■
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	■	■	■	■	■	■	■	■	■	■
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	■	■	■	■	■	■	■	■	■	■
Lead	■	■	■	■	■	■	■	■	■	■
Mercury	■	■	■	■	■	■	■	■	■	■
Molybdenum	■	■	■	■	■	■	■	■	■	■
Nickel	■	■	■	■	■	■	■	■	■	■
Nitrate	■	■	■	■	■	■	■	■	■	■
Nitrogen oxides	■	■	■	■	■	■	■	■	■	■
NMVOC, non-methane volatile organic compounds, unspecified origin				■					■	
Particulates, < 2.5 um	■	■	■	■	■	■	■	■	■	■
Propanol								■		
Selenium	■	■	■	■	■	■	■	■	■	■
Silver	■	■	■	■	■	■	■	■	■	■
Tin	■	■	■	■	■	■	■	■	■	■
Vanadium	■	■	■	■	■	■	■	■	■	■
Zinc	■	■	■	■	■	■	■	■	■	■
Heavy metals to air										
Antimony	■	■	■	■	■	■	■	■	■	■
Arsenic	■	■	■	■	■	■	■	■	■	■
Arsenic (+V)	■					■				
Cadmium	■	■	■	■	■	■	■	■	■	■
Chromium	■	■	■	■	■	■	■	■	■	■
Chromium (+III)	■					■				
Chromium (+VI)	■	■	■	■	■	■	■	■	■	■
Cobalt	■	■	■	■	■	■	■	■	■	■
Copper	■	■	■	■	■	■	■	■	■	■
Lead	■	■	■	■	■	■	■	■	■	■
Mercury	■	■	■	■	■	■	■	■	■	■
Molybdenum	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Nickel	■	■	■	■	■	■	■	■	■	■
Selenium	■	■	■	■	■	■	■	■	■	■
Silver	■	■	■	■	■	■	■	■	■	■
Thallium	■	■	■	■	■	■	■	■	■	■
Tin	■	■	■	■	■	■	■	■	■	■
Vanadium	■	■	■	■	■	■	■	■	■	■
Zinc	■	■	■	■	■	■	■	■	■	■
Inorganic emissions to air										
Ammonia	■	■	■	■	■	■	■	■	■	■
Ammonium	■					■				
Barium	■	■	■	■	■	■	■	■	■	■
Beryllium	■	■	■	■	■	■	■	■	■	■
Carbon dioxide	■	■	■	■	■	■	■	■	■	■
Carbon dioxide (aviation)	■					■				
Carbon dioxide (land use change)	■					■				
Carbon dioxide (peat oxidation)	■					■				
Carbon disulphide	■	■	■	■	■	■	■	■	■	■
Carbon monoxide	■	■	■	■	■	■	■	■	■	■
Carbon monoxide, non-fossil	■	■	■	■	■	■	■	■	■	■
Nitrate	■	■	■	■	■	■	■	■	■	■
Nitrogen dioxide	■					■				
Nitrogen monoxide	■					■				
Nitrogen oxides	■	■	■	■	■	■	■	■	■	■
Nitrogentriflouride	■	■	■	■	■	■	■	■	■	■
Nitrous oxide (laughing gas)	■	■	■	■	■	■	■	■	■	■
Sodium formate	■	■	■	■	■	■	■	■	■	■
Sulphur dioxide	■	■	■	■	■	■	■	■	■	■
Sulphur hexafluoride	■	■	■	■	■	■	■	■	■	■
Sulphur oxides	■	■	■	■	■	■	■	■	■	■
Sulphur trioxide	■	■	■	■	■	■	■	■	■	■
Sulphuric acid	■	■	■	■	■	■	■	■	■	■
Organic emissions to air (group VOC)										
Anthracene	■				■	■				■
Benzo{a}anthracene	■	■	■	■	■	■	■	■	■	■
Benzo{a}pyrene	■	■	■	■	■	■	■	■	■	■
Dibenz(a)anthracene	■	■	■	■	■	■	■	■	■	■
Naphthalene	■	■	■	■	■	■	■	■	■	■
Phenanthrene	■	■	■	■	■	■	■	■	■	■
Pyrene	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
1,1,1-Trichloroethane	■	■	■	■	■	■	■	■	■	■
2,4-Dichlorophenol	■	■	■	■	■	■	■	■	■	■
2-Chlorotoluene	■	■	■	■	■	■	■	■	■	■
Bromoxynil	■	■	■	■	■	■	■	■	■	■
Carbon tetrachloride (tetrachloromethane)	■	■	■	■	■	■	■	■	■	■
Chlorinated hydrocarbons (unspecified)	■	■	■	■	■	■	■	■	■	■
Chloromethane (methyl chloride)	■	■	■	■	■	■	■	■	■	■
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene)	■	■	■	■	■	■	■	■	■	■
Dichloroethane (ethylene dichloride)	■	■	■	■	■	■	■	■	■	■
Dichloromethane (methylene chloride)	■	■	■	■	■	■	■	■	■	■
Halon (1211)	■	■	■	■	■	■	■	■	■	■
Halon (1301)	■	■	■	■	■	■	■	■	■	■
Hexachlorobenzene (Perchlorobenzene)	■	■	■	■	■	■	■	■	■	■
Hydrocarbons, chloro-/fluoro-	■					■				
Hydrocarbons, halogenated	■					■				
Methyl bromide	■	■	■	■	■	■	■	■	■	■
Pentachlorobenzene	■	■	■	■	■	■	■	■	■	■
Pentachlorophenol (PCP)	■	■	■	■	■	■	■	■	■	■
Polychlorinated biphenyls (PCB unspecified)	■	■	■	■	■	■	■	■	■	■
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	■	■	■	■	■	■	■	■	■	■
Polychlorinated dibenzo-p-furans (2,3,7,8 - TCDD)	■					■				
R 11 (trichlorofluoromethane)	■	■	■	■	■	■	■	■	■	■
R 113 (trichlorotrifluoroethane)	■	■	■	■	■	■	■	■	■	■
R 114 (dichlorotetrafluoroethane)	■	■	■	■	■	■	■	■	■	■
R 116 (hexafluoroethane)	■	■	■	■	■	■	■	■	■	■
R 12 (dichlorodifluoromethane)	■	■	■	■	■	■	■	■	■	■
R 124 (chlorotetrafluoroethane)	■	■	■	■	■	■	■	■	■	■
R 125 (pentafluoroethane)	■					■				
R 134a (tetrafluoroethane)	■	■	■	■	■	■	■	■	■	■
R 143 (trifluoroethane)	■					■				
R 152a (difluoroethane)	■	■	■	■	■	■	■	■	■	■
R 21 (Dichlorofluoromethane)	■	■	■	■	■	■	■	■	■	■
R 22 (chlorodifluoromethane)	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	**Wafering**	**Cell processing**	**Module assembly**	**Module disassembly**	**Crystallization**	**Wafering**	**Cell processing**	**Module assembly**	**Module disassembly**
R 23 (trifluoromethane)	■	■	■	■	■	■	■	■	■	■
R 245fa (1,1,1,3,3-Pentafluoropropane)	■					■				
R 32 (difluoromethane)	■					■				
Tetrachloroethene (perchloroethylene)	■	■	■	■	■	■	■	■	■	■
Tetrafluoromethane	■	■	■	■	■	■	■	■	■	■
Trichloroethene (isomers)	■					■				
Trichloromethane (chloroform)	■	■	■	■	■	■	■	■	■	■
Vinyl chloride (VCM; chloroethene)	■	■	■	■	■	■	■	■	■	■
1,3,5-Trimethylbenzene	■					■				
1-Butanol	■	■	■	■	■	■	■	■	■	■
1-Butylene (Vinylacetylene)	■					■				
1-Methoxy-2-propanol	■					■				
1-Pentene	■	■	■	■	■	■	■	■	■	■
1-Propanol	■	■	■	■	■	■	■	■	■	■
1-Undecane	■					■				
2,2-Dimethylbutane	■					■				
2-Methyl-1-butene	■					■				
2-Methyl-2-butene	■	■	■	■	■	■	■	■	■	■
2-Methylpentane	■					■				
3-Methylpentane	■	■	■	■	■	■	■	■	■	■
Acenaphthene	■	■	■	■	■	■	■	■	■	■
Acetaldehyde (Ethanal)	■	■	■	■	■	■	■	■	■	■
Acetic acid	■	■	■	■	■	■	■	■	■	■
Acetone (dimethylcetone)	■	■	■	■	■	■	■	■	■	■
Acetonitrile	■	■	■	■	■	■	■	■	■	■
Acrolein	■	■	■	■	■	■	■	■	■	■
Acrylic acid	■	■	■	■	■	■	■	■	■	■
Acrylonitrile	■					■				
Aldehyde (unspecified)	■	■	■	■	■	■	■	■	■	■
Aniline	■	■	■	■	■	■	■	■	■	■
Benzaldehyde	■	■	■	■	■	■	■	■	■	■
Benzene	■	■	■	■	■	■	■	■	■	■
Biphenyl	■					■				
Butadiene	■	■	■	■	■	■	■	■	■	■
Butane	■	■	■	■	■	■	■	■	■	■
Butanone (methyl ethyl ketone)	■	■	■	■	■	■	■	■	■	■
Butylene glycol (butane diol)	■	■	■	■	■	■	■	■	■	■
Butyrolactone	■	■	■	■	■	■	■	■	■	■
Caprolactam	■					■				

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Chloramine	■	■	■	■	■	■	■	■	■	■
cis-2-Pentene	■					■				
Cumene (isopropylbenzene)	■	■	■	■	■	■	■	■	■	■
Cyclohexane (hexahydro benzene)	■	■	■	■	■	■	■	■	■	■
Cyclopentane	■					■				
Decane	■					■				
Diethyl ether	■	■	■	■	■	■	■	■	■	■
Diethylamine	■	■	■	■	■	■	■	■	■	■
Diethylene glycol	■	■	■	■	■	■	■	■	■	■
Dodecane	■					■				
Ethane	■	■	■	■	■	■	■	■	■	■
Ethanol	■	■	■	■	■	■	■	■	■	■
Ethene (ethylene)	■	■	■	■	■	■	■	■	■	■
Ethine (acetylene)	■	■	■	■	■	■	■	■	■	■
Ethyl benzene	■	■	■	■	■	■	■	■	■	■
Ethylamine	■	■	■	■	■	■	■	■	■	■
Ethylene acetate (ethyl acetate)	■	■	■	■	■	■	■	■	■	■
Ethylene oxide	■	■	■	■	■	■	■	■	■	■
Ethylenediamine	■	■	■	■	■	■	■	■	■	■
Fluoranthene	■	■	■	■	■	■	■	■	■	■
Fluorene	■					■				
Formaldehyde (methanal)	■	■	■	■	■	■	■	■	■	■
Formic acid (methane acid)	■	■	■	■	■	■	■	■	■	■
Furan	■	■	■	■	■	■	■	■	■	■
Heptane (isomers)	■	■	■	■	■	■	■	■	■	■
Hexamethylene diamine (HMDA)	■					■				
Hexane (isomers)	■	■	■	■	■	■	■	■	■	■
Hydrocarbons, aromatic	■	■	■	■	■	■	■	■	■	■
iso-Butane	■					■				
iso-Butanol	■	■	■	■	■	■	■	■	■	■
iso-Pentane	■					■				
Isoprene	■	■	■	■	■	■	■	■	■	■
Isopropanol	■	■	■	■	■	■	■	■	■	■
Mercaptan (unspecified)	■					■				
meta-Cresol	■					■				
Methacrylate	■	■	■	■	■	■	■	■	■	■
Methanol	■	■	■	■	■	■	■	■	■	■
Methyl acetate	■	■	■	■	■	■	■	■	■	■
Methyl amine	■	■	■	■	■	■	■	■	■	■

Flow	**mc-Si PV module**					**sc-Si PV module**				
	Crystallization	**Wafering**	**Cell processing**	**Module assembly**	**Module disassembly**	**Crystallization**	**Wafering**	**Cell processing**	**Module assembly**	**Module disassembly**
Methyl formate	■	■	■	■	■	■	■	■	■	■
Methyl isobutyl ketone	■	■	■	■	■	■	■	■	■	■
Methyl methacrylate (MMA)	■					■				
Methyl tert-butylether	■	■	■	■	■	■	■	■	■	■
Monoethanolamine	■	■	■	■	■	■	■	■	■	■
n-Butyl acetate	■					■				
Nitrobenzene	■	■	■	■	■	■	■	■	■	■
NMVOC (unspecified)	■	■	■	■	■	■	■	■	■	■
Nonane	■					■				
Octane	■					■				
o-Nitrotoluene	■	■	■	■	■	■	■	■	■	■
para-Cresol	■					■				
Pentane (n-pentane)	■	■	■	■	■	■	■	■	■	■
Phenol (hydroxy benzene)	■	■	■	■	■	■	■	■	■	■
Propane	■	■	■	■	■	■	■	■	■	■
Propene (propylene)	■	■	■	■	■	■	■	■	■	■
Propionaldehyde	■	■	■	■	■	■	■	■	■	■
Propionic acid (propane acid)	■	■	■	■	■	■	■	■	■	■
Propylene oxide	■	■	■	■	■	■	■	■	■	■
Styrene	■	■	■	■	■	■	■	■	■	■
Toluene (methyl benzene)	■	■	■	■	■	■	■	■	■	■
trans-2-Butene	■					■				
trans-2-Pentene	■					■				
Trimethylamine	■	■	■	■	■	■	■	■	■	■
Xylene (dimethyl benzene)	■	■	■	■	■	■	■	■	■	■
Xylene (meta-Xylene; 1,3-Dimethylbenzene)	■	■	■	■	■	■	■	■	■	■
Xylene (ortho-Xylene; 1,2-Dimethylbenzene)	■	■	■	■	■	■	■	■	■	■
Methane	■	■	■	■	■	■	■	■	■	■
Methane (biotic)	■	■	■	■	■	■	■	■	■	■
Particles to air										
Dust (PM10)	■					■				
Dust (PM2.5 - PM10)	■	■	■	■	■	■	■	■	■	■
Dust (PM2.5)	■	■	■	■	■	■	■	■	■	■
Pesticides to air										
2,4-Dichlorophenoxyacetic acid (2,4-D)	■	■	■	■	■	■	■	■	■	■
Acephate	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Acetochlor	■					■				
Acifluorfen	■	■	■	■	■	■	■	■	■	■
Alachlor	■	■	■	■	■	■	■	■	■	■
Atrazine	■	■	■	■	■	■	■	■	■	■
Azoxystrobin	■	■	■	■	■	■	■	■	■	■
Benomyl	■					■				
Bentazone	■	■	■	■	■	■	■	■	■	■
Carbaryl	■	■	■	■	■	■	■	■	■	■
Carbofuran	■					■				
Carfentrazone-ethyl	■	■	■	■	■	■	■	■	■	■
Chlormequat-chloride	■					■				
Chlorpyriphos	■	■	■	■	■	■	■	■	■	■
Clethodim	■	■	■	■	■	■	■	■	■	■
Cyfluthrin	■	■	■	■	■	■	■	■	■	■
Cypermethrin	■					■				
Cyprodinil (CGA-219417)	■					■				
Deltamethrin	■					■				
Dicamba	■	■	■	■	■	■	■	■	■	■
Dichlorprop	■	■	■	■	■	■	■	■	■	■
Diflubenzuron	■	■	■	■	■	■	■	■	■	■
Diflufenican	■					■				
Dimethenamid	■	■	■	■	■	■	■	■	■	■
Dimethoate	■					■				
Esfenvalerate	■	■	■	■	■	■	■	■	■	■
Ethephon	■	■	■	■	■	■	■	■	■	■
Fenvalerate	■					■				
Fipronil	■					■				
Fluazifop-p-butyl	■	■	■	■	■	■	■	■	■	■
Flufenacet	■	■	■	■	■	■	■	■	■	■
Flumetsulam	■	■	■	■	■	■	■	■	■	■
Flumiclorac-pentyl	■	■	■	■	■	■	■	■	■	■
Flumioxazin	■	■	■	■	■	■	■	■	■	■
Glyphosate	■	■	■	■	■	■	■	■	■	■
Imazamox	■	■	■	■	■	■	■	■	■	■
Imazethapyr	■	■	■	■	■	■	■	■	■	■
Imidacloprid	■					■				
Ioxynil	■					■				
Isoproturon	■					■				
Lambda-cyhalothrin	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Mancozeb	■					■				
MCPA	■	■	■	■	■	■	■	■	■	■
Mecoprop	■					■				
Methomyl	■	■	■	■	■	■	■	■	■	■
Metolachlor	■	■	■	■	■	■	■	■	■	■
Metribuzin	■	■	■	■	■	■	■	■	■	■
Paraquat	■	■	■	■	■	■	■	■	■	■
Parathion-methyl	■	■	■	■	■	■	■	■	■	■
Pendimethalin	■	■	■	■	■	■	■	■	■	■
Permethrin	■	■	■	■	■	■	■	■	■	■
Propiconazole	■	■	■	■	■	■	■	■	■	■
Quizalofop-ethyl	■	■	■	■	■	■	■	■	■	■
Sethoxydim	■	■	■	■	■	■	■	■	■	■
Sulfentrazone	■	■	■	■	■	■	■	■	■	■
Tebuconazole	■	■	■	■	■	■	■	■	■	■
Terbufos	■					■				
Thiodicarb	■	■	■	■	■	■	■	■	■	■
Thiram	■					■				
Trifluralin	■	■	■	■	■	■	■	■	■	■
Radioactive emissions to air										
Thorium (Th230)	■	■	■	■	■	■	■	■	■	■
Uranium	■	■	■	■	■	■	■	■	■	■
Uranium (total)	■					■				

Table A.3: Data symmetry analysis of balance models – Output flows: emissions to fresh water

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Long-term emissions to fresh water										
Ammonium, ion	■	■	■	■	■	■	■	■	■	■
Antimony	■	■	■	■	■	■	■	■	■	■
Arsenic, ion	■	■	■	■	■	■	■	■	■	■
Barium	■	■	■	■	■	■	■	■	■	■
Beryllium	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Cadmium, ion	■	■	■	■	■	■	■	■	■	■
Chromium (+VI)	■	■	■	■	■	■	■	■	■	■
Cobalt	■	■	■	■	■	■	■	■	■	■
Copper	■	■	■	■	■	■	■	■	■	■
Lead	■	■	■	■	■	■	■	■	■	■
Mercury	■	■	■	■	■	■	■	■	■	■
Molybdenum	■	■	■	■	■	■	■	■	■	■
Nickel, ion	■	■	■	■	■	■	■	■	■	■
Nitrate	■	■	■	■	■	■	■	■	■	■
Nitrite	■	■	■	■	■	■	■	■	■	■
Nitrogen organic bound	■	■	■	■	■	■	■	■	■	■
Phosphate	■	■	■	■	■	■	■	■	■	■
Selenium	■	■	■	■	■	■	■	■	■	■
Silver	■	■	■	■	■	■	■	■	■	■
Thallium	■	■	■	■	■	■	■	■	■	■
Tin, ion	■	■	■	■	■	■	■	■	■	■
Vanadium, ion	■	■	■	■	■	■	■	■	■	■
Zinc, ion	■	■	■	■	■	■	■	■	■	■
Heavy metals to fresh water										
Antimony	■	■	■	■	■	■	■	■	■	■
Arsenic	■					■				
Arsenic (+V)	■	■	■	■	■	■	■	■	■	■
Cadmium	■	■	■	■	■	■	■	■	■	■
Chromium	■					■				
Chromium (+III)	■	■	■	■	■	■	■	■	■	■
Chromium (+VI)	■	■	■	■	■	■	■	■	■	■
Cobalt	■	■	■	■	■	■	■	■	■	■
Copper	■	■	■	■	■	■	■	■	■	■
Lead	■	■	■	■	■	■	■	■	■	■
Mercury	■	■	■	■	■	■	■	■	■	■
Molybdenum	■	■	■	■	■	■	■	■	■	■
Nickel	■	■	■	■	■	■	■	■	■	■
Selenium	■	■	■	■	■	■	■	■	■	■
Silver	■	■	■	■	■	■	■	■	■	■
Thallium	■	■	■	■	■	■	■	■	■	■
Tin	■	■	■	■	■	■	■	■	■	■
Vanadium	■	■	■	■	■	■	■	■	■	■
Zinc	■	■	■	■	■	■	■	■	■	■
Inorganic emissions to fresh water										

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Ammonia	■					■				
Ammonium / ammonia	■	■	■	■	■	■	■	■	■	■
Barium	■	■	■	■	■	■	■	■	■	■
Beryllium	■	■	■	■	■	■	■	■	■	■
Carbon disulphide	■	■	■	■	■	■	■	■	■	■
Cyanide	■	■	■	■	■	■	■	■	■	■
Nitrate	■	■	■	■	■	■	■	■	■	■
Nitrite	■	■	■	■	■	■	■	■	■	■
Nitrogen	■	■	■	■	■	■	■	■	■	■
Nitrogen (as total N)	■					■				
Nitrogen organic bound	■	■	■	■	■	■	■	■	■	■
Phosphate	■	■	■	■	■	■	■	■	■	■
Phosphorus	■	■	■	■	■	■	■	■	■	■
Sulphuric acid	■					■				
Organic emissions to fresh water										
1,1,1-Trichloroethane	■	■	■	■	■	■	■	■	■	■
1,2-Dibromoethane	■					■				
2-Chlorotoluene	■	■	■	■	■	■	■	■	■	■
Bromoxynil	■	■	■	■	■	■	■	■	■	■
Chlorobenzene	■	■	■	■	■	■	■	■	■	■
Chloromethane (methyl chloride)	■					■				
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene)	■	■	■	■	■	■	■	■	■	■
Dichloroethane (ethylene dichloride)	■	■	■	■	■	■	■	■	■	■
Dichloromethane (methylene chloride)	■	■	■	■	■	■	■	■	■	■
Dichloropropane	■					■				
Pentachlorophenol (PCP)	■					■				
Polychlorinated biphenyls (PCB unspecified)	■	■	■	■	■	■	■	■	■	■
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	■					■				
Tetrachloroethene (perchloroethylene)	■					■				
Trichloromethane (chloroform)	■	■	■	■	■	■	■	■	■	■
Vinyl chloride (VCM; chloroethene)	■	■	■	■	■	■	■	■	■	■
4-Methyl-2-pentanol	■	■	■	■	■	■	■	■	■	■
Acenaphthene	■	■	■	■	■	■	■	■	■	■
Acetic acid	■	■	■	■	■	■	■	■	■	■
Acetonitrile	■	■	■	■	■	■	■	■	■	■
Acrylonitrile	■					■				

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Aniline	■	■	■	■	■	■	■	■	■	■
Anthracene	■	■	■	■	■	■	■	■	■	■
Benzene	■	■	■	■	■	■	■	■	■	■
Benzo{a}anthracene	■	■	■	■	■	■	■	■	■	■
Benzo{a}pyrene	■	■	■	■	■	■	■	■	■	■
Butylene glycol (butane diol)	■	■	■	■	■	■	■	■	■	■
Butyrolactone	■	■	■	■	■	■	■	■	■	■
Cresol (methyl phenol)	■					■				
Dibenz(a)anthracene	■	■	■	■	■	■	■	■	■	■
Ethanol	■	■	■	■	■	■	■	■	■	■
Ethyl benzene	■	■	■	■	■	■	■	■	■	■
Ethylene acetate (ethyl acetate)	■	■	■	■	■	■	■	■	■	■
Ethylene oxide	■	■	■	■	■	■	■	■	■	■
Fluoranthene	■	■	■	■	■	■	■	■	■	■
Formaldehyde (methanal)	■	■	■	■	■	■	■	■	■	■
Hexane (isomers)	■					■				
Methanol	■	■	■	■	■	■	■	■	■	■
Methyl tert-butylether	■	■	■	■	■	■	■	■	■	■
Naphthalene	■	■	■	■	■	■	■	■	■	■
Phenanthrene	■	■	■	■	■	■	■	■	■	■
Phenol (hydroxy benzene)	■	■	■	■	■	■	■	■	■	■
Propanol	■	■	■	■	■	■	■	■	■	■
Propanol (iso-propanol; isopropanol)	■	■	■	■	■	■	■	■	■	■
Propene	■	■	■	■	■	■	■	■	■	■
Propylene oxide	■	■	■	■	■	■	■	■	■	■
Pyrene	■	■	■	■	■	■	■	■	■	■
Sodium formate	■	■	■	■	■	■	■	■	■	■
Toluene (methyl benzene)	■	■	■	■	■	■	■	■	■	■
Triethylene glycol	■	■	■	■	■	■	■	■	■	■
Xylene (isomers; dimethyl benzene)	■	■	■	■	■	■	■	■	■	■
Xylene (meta-Xylene; 1,3-Dimethylbenzene)	■	■	■	■	■	■	■	■	■	■
Xylene (ortho-Xylene; 1,2-Dimethylbenzene)	■	■	■	■	■	■	■	■	■	■
1-Butanol	■	■	■	■	■	■	■	■	■	■
Acetaldehyde (Ethanal)	■	■	■	■	■	■	■	■	■	■
Acetone (dimethylcetone)	■	■	■	■	■	■	■	■	■	■
Acrylic acid	■	■	■	■	■	■	■	■	■	■
Allyl chloride	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Biphenyl	■					■				
Chloramine	■	■	■	■	■	■	■	■	■	■
Cumene (isopropylbenzene)	■	■	■	■	■	■	■	■	■	■
Diethylamine	■	■	■	■	■	■	■	■	■	■
Ethylamine	■	■	■	■	■	■	■	■	■	■
Ethylenediamine	■	■	■	■	■	■	■	■	■	■
Formic acid	■	■	■	■	■	■	■	■	■	■
iso-Butanol	■	■	■	■	■	■	■	■	■	■
Methyl acetate	■	■	■	■	■	■	■	■	■	■
Methyl acrylate	■	■	■	■	■	■	■	■	■	■
Methyl amine	■	■	■	■	■	■	■	■	■	■
Methyl formate	■	■	■	■	■	■	■	■	■	■
Methyl isobutyl ketone	■	■	■	■	■	■	■	■	■	■
Monoethanolamine	■	■	■	■	■	■	■	■	■	■
n-Butyl acetate	■	■	■	■	■	■	■	■	■	■
Nitrobenzene	■	■	■	■	■	■	■	■	■	■
Propionaldehyde	■	■	■	■	■	■	■	■	■	■
Propionic acid	■	■	■	■	■	■	■	■	■	■
Trimethylamine	■	■	■	■	■	■	■	■	■	■
Other emissions to fresh water										
Acetochlor	■					■				
Alachlor	■					■				
Atrazine	■	■	■	■	■	■	■	■	■	■
Benomyl	■					■				
Bentazone	■	■	■	■	■	■	■	■	■	■
Carbaryl	■	■	■	■	■	■	■	■	■	■
Carbofuran	■					■				
Chlormequat-chloride	■					■				
Cypermethrin	■					■				
Cyprodinil (CGA-219417)	■					■				
Deltamethrin	■					■				
Dicamba	■	■	■	■	■	■	■	■	■	■
Dichlorprop	■	■	■	■	■	■	■	■	■	■
Diflufenican	■					■				
Dimethenamid	■	■	■	■	■	■	■	■	■	■
Dimethoate	■					■				
Ethephon	■	■	■	■	■	■	■	■	■	■
Fenvalerate	■					■				
Fipronil	■					■				

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Glyphosate	■	■	■	■	■	■	■	■	■	■
Imidacloprid	■					■				
Ioxynil	■					■				
Isoproturon	■					■				
Lambda cyhalothrin	■	■	■	■	■	■	■	■	■	■
Mancozeb	■					■				
MCPA	■	■	■	■	■	■	■	■	■	■
Mecoprop	■					■				
Methomyl	■	■	■	■	■	■	■	■	■	■
Metolachlor	■	■	■	■	■	■	■	■	■	■
Parathion-methyl	■					■				
Pendimethalin	■	■	■	■	■	■	■	■	■	■
Propiconazole	■	■	■	■	■	■	■	■	■	■
Tebuconazole	■	■	■	■	■	■	■	■	■	■
Terbufos	■					■				
Thiram	■					■				
Trifluralin	■					■				
Radioactive emissions to fresh water										
Radium (Ra226)	■	■	■	■	■	■	■	■	■	■

Table A.4: Data symmetry analysis of balance models – Output flows: emissions to sea water

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Long-term emissions to sea water										
Arsenic (+V)	■	■	■	■	■	■	■	■	■	■
Cadmium	■	■	■	■	■	■	■	■	■	■
Chromium	■					■				
Chromium (+III)	■	■	■	■	■	■	■	■	■	■
Cobalt	■	■	■	■	■	■	■	■	■	■
Copper	■	■	■	■	■	■	■	■	■	■
Lead	■	■	■	■	■	■	■	■	■	■
Mercury	■	■	■	■	■	■	■	■	■	■
Molybdenum	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Nickel	■	■	■	■	■	■	■	■	■	■
Selenium	■	■	■	■	■	■	■	■	■	■
Silver	■	■	■	■	■	■	■	■	■	■
Tin	■					■				
Vanadium	■	■	■	■	■	■	■	■	■	■
Zinc	■	■	■	■	■	■	■	■	■	■
Inorganic emissions to sea water										
Ammonia	■					■				
Ammonium / ammonia	■	■	■	■	■	■	■	■	■	■
Barium	■	■	■	■	■	■	■	■	■	■
Beryllium	■					■				
Cyanide	■	■	■	■	■	■	■	■	■	■
Nitrate	■	■	■	■	■	■	■	■	■	■
Nitrate (as total N)	■					■				
Nitrite	■	■	■	■	■	■	■	■	■	■
Nitrogen	■	■	■	■	■	■	■	■	■	■
Nitrogen (as total N)	■					■				
Nitrogen organic bound	■	■	■	■	■	■	■	■	■	■
Phosphorus	■	■	■	■	■	■	■	■	■	■
Organic emissions to sea water										
Tetrachloroethene (perchloroethylene)	■					■				
Acenaphthene	■	■	■	■	■	■	■	■	■	■
Acetic acid	■					■				
Anthracene	■					■				
Benzene	■	■	■	■	■	■	■	■	■	■
Benzo{a}anthracene	■					■				
Cresol (methyl phenol)	■					■				
Ethyl benzene	■	■	■	■	■	■	■	■	■	■
Fluoranthene	■					■				
Glutaraldehyde	■	■	■	■	■	■	■	■	■	■
Hexane (isomers)	■					■				
Methanol	■	■	■	■	■	■	■	■	■	■
Methyl tert-butylether	■	■	■	■	■	■	■	■	■	■
Phenol (hydroxy benzene)	■	■	■	■	■	■	■	■	■	■
Toluene (methyl benzene)	■	■	■	■	■	■	■	■	■	■
Triethylene glycol	■	■	■	■	■	■	■	■	■	■
Xylene (isomers; dimethyl benzene)	■	■	■	■	■	■	■	■	■	■
Ethylene Glycol	■					■				
Naphthalene	■					■				

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Other emissions to sea water										
Tributyltinoxide	■	■	■	■	■	■	■	■	■	■

Table A.5: Data symmetry analysis of balance models – Output flows: emissions to agriculture soil

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Heavy metals to agriculture soil										
Arsenic	■	■	■	■	■	■	■	■	■	■
Arsenic (+V)	■					■				
Cadmium	■	■	■	■	■	■	■	■	■	■
Chromium	■	■	■	■	■	■	■	■	■	■
Chromium (+III)	■					■				
Cobalt	■	■	■	■	■	■	■	■	■	■
Copper	■	■	■	■	■	■	■	■	■	■
Lead	■	■	■	■	■	■	■	■	■	■
Mercury	■	■	■	■	■	■	■	■	■	■
Molybdenum	■	■	■	■	■	■	■	■	■	■
Nickel	■	■	■	■	■	■	■	■	■	■
Silver	■	■	■	■	■	■	■	■	■	■
Tin	■	■	■	■	■	■	■	■	■	■
Vanadium	■	■	■	■	■	■	■	■	■	■
Zinc	■	■	■	■	■	■	■	■	■	■
Inorganic emissions to agriculture soil										
Barium	■	■	■	■	■	■	■	■	■	■
Phosphorus	■	■	■	■	■	■	■	■	■	■
Sulphuric acid	■	■	■	■	■	■	■	■	■	■
Organic emissions to agriculture soil										
Azoxystrobin	■	■	■	■	■	■	■	■	■	■
Bromoxynil	■	■	■	■	■	■	■	■	■	■
Mepiquat chloride	■	■	■	■	■	■	■	■	■	■
Other emissions to agriculture soil										
2,4-Dichlorophenoxyacetic acid (2,4-D)	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Acephate	■	■	■	■	■	■	■	■	■	■
Acetamide	■	■	■	■	■	■	■	■	■	■
Acetochlor	■	■	■	■	■	■	■	■	■	■
Acifluorfen	■	■	■	■	■	■	■	■	■	■
Aclonifen	■	■	■	■	■	■	■	■	■	■
Alachlor	■	■	■	■	■	■	■	■	■	■
Aldicarb	■	■	■	■	■	■	■	■	■	■
Aldrin	■	■	■	■	■	■	■	■	■	■
Anthraquinone	■	■	■	■	■	■	■	■	■	■
Asulam	■	■	■	■	■	■	■	■	■	■
Atrazine	■	■	■	■	■	■	■	■	■	■
Azodrin	■	■	■	■	■	■	■	■	■	■
Benomyl	■	■	■	■	■	■	■	■	■	■
Bensulfuron methyl ester	■	■	■	■	■	■	■	■	■	■
Bentazone	■	■	■	■	■	■	■	■	■	■
Bifenox	■	■	■	■	■	■	■	■	■	■
Bifenthrin	■	■	■	■	■	■	■	■	■	■
Bitertanol	■	■	■	■	■	■	■	■	■	■
Bromuconazole	■	■	■	■	■	■	■	■	■	■
Carbaryl	■	■	■	■	■	■	■	■	■	■
Carbendazim	■	■	■	■	■	■	■	■	■	■
Carbofuran	■	■	■	■	■	■	■	■	■	■
Carfentrazone ethyl ester	■	■	■	■	■	■	■	■	■	■
Carfentrazone-ethyl	■	■	■	■	■	■	■	■	■	■
Chloridazon	■	■	■	■	■	■	■	■	■	■
Chlormequat	■	■	■	■	■	■	■	■	■	■
Chlorothalonil	■	■	■	■	■	■	■	■	■	■
Chlorpyriphos	■	■	■	■	■	■	■	■	■	■
Chlorsulfuron	■	■	■	■	■	■	■	■	■	■
Chlortoluron	■	■	■	■	■	■	■	■	■	■
Choline chloride	■	■	■	■	■	■	■	■	■	■
Clethodim	■	■	■	■	■	■	■	■	■	■
Clodinafop-propargyl	■	■	■	■	■	■	■	■	■	■
Clopyralid	■	■	■	■	■	■	■	■	■	■
Cloquintocet-mexyl	■	■	■	■	■	■	■	■	■	■
Cyfluthrin	■	■	■	■	■	■	■	■	■	■
Cypermethrin	■	■	■	■	■	■	■	■	■	■
Cyproconazole	■	■	■	■	■	■	■	■	■	■
Cyprodinil (CGA-219417)	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Deltamethrin	■	■	■	■	■	■	■	■	■	■
Desmedipham	■	■	■	■	■	■	■	■	■	■
Dicamba	■	■	■	■	■	■	■	■	■	■
Dichlorprop	■	■	■	■	■	■	■	■	■	■
Diclofop-methyl	■	■	■	■	■	■	■	■	■	■
Dicrotophos	■	■	■	■	■	■	■	■	■	■
Difenoconazole	■	■	■	■	■	■	■	■	■	■
Diflubenzuron	■	■	■	■	■	■	■	■	■	■
Diflufenican	■	■	■	■	■	■	■	■	■	■
Dimethachlor	■	■	■	■	■	■	■	■	■	■
Dimethazone	■	■	■	■	■	■	■	■	■	■
Dimethenamid	■	■	■	■	■	■	■	■	■	■
Dimethoate	■	■	■	■	■	■	■	■	■	■
Dithianon	■	■	■	■	■	■	■	■	■	■
Diuron	■	■	■	■	■	■	■	■	■	■
Endosulfan	■	■	■	■	■	■	■	■	■	■
Endothall	■	■	■	■	■	■	■	■	■	■
Epoxiconazole	■	■	■	■	■	■	■	■	■	■
Esfenvalerate	■	■	■	■	■	■	■	■	■	■
Ethalfluralin	■	■	■	■	■	■	■	■	■	■
Ethephon	■	■	■	■	■	■	■	■	■	■
Ethofumesate	■	■	■	■	■	■	■	■	■	■
Fenbuconazole	■	■	■	■	■	■	■	■	■	■
Fenoxaprop ethyl ester	■	■	■	■	■	■	■	■	■	■
Fenoxaprop-p-ethyl	■	■	■	■	■	■	■	■	■	■
Fenpiclonil	■	■	■	■	■	■	■	■	■	■
Fenpropimorph	■	■	■	■	■	■	■	■	■	■
Fipronil	■	■	■	■	■	■	■	■	■	■
Fluazifop-p-butyl	■	■	■	■	■	■	■	■	■	■
Fludioxonil	■	■	■	■	■	■	■	■	■	■
Flufenacet	■	■	■	■	■	■	■	■	■	■
Flumetsulam	■	■	■	■	■	■	■	■	■	■
Flumiclorac-pentyl	■	■	■	■	■	■	■	■	■	■
Flumioxazin	■	■	■	■	■	■	■	■	■	■
Fluroxypyr	■	■	■	■	■	■	■	■	■	■
Fomesafen	■	■	■	■	■	■	■	■	■	■
Glyphosate	■	■	■	■	■	■	■	■	■	■
Halosulfuron-methyl	■	■	■	■	■	■	■	■	■	■
Imazamox	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Imazapyr	■	■	■	■	■	■	■	■	■	■
Imazethapyr	■	■	■	■	■	■	■	■	■	■
Imidacloprid	■	■	■	■	■	■	■	■	■	■
Ioxynil	■	■	■	■	■	■	■	■	■	■
Iprodione	■	■	■	■	■	■	■	■	■	■
Isoproturon	■	■	■	■	■	■	■	■	■	■
Isoxaflutole	■	■	■	■	■	■	■	■	■	■
Kresoxim-methyl	■	■	■	■	■	■	■	■	■	■
Lambda cyhalothrin	■	■	■	■	■	■	■	■	■	■
Lenacil	■	■	■	■	■	■	■	■	■	■
Linuron	■	■	■	■	■	■	■	■	■	■
Malathion	■	■	■	■	■	■	■	■	■	■
Mancozeb	■	■	■	■	■	■	■	■	■	■
MCPA	■	■	■	■	■	■	■	■	■	■
MCPB	■	■	■	■	■	■	■	■	■	■
Mecoprop	■	■	■	■	■	■	■	■	■	■
Mecoprop-P	■	■	■	■	■	■	■	■	■	■
Metalaxyl	■	■	■	■	■	■	■	■	■	■
Metamitron	■	■	■	■	■	■	■	■	■	■
Metam-sodium	■	■	■	■	■	■	■	■	■	■
Metazachlor	■	■	■	■	■	■	■	■	■	■
Methomyl	■	■	■	■	■	■	■	■	■	■
Metolachlor	■	■	■	■	■	■	■	■	■	■
Metribuzin	■	■	■	■	■	■	■	■	■	■
Metsulfuron-methyl	■	■	■	■	■	■	■	■	■	■
Molinate	■	■	■	■	■	■	■	■	■	■
MSMA	■	■	■	■	■	■	■	■	■	■
Napropamide	■	■	■	■	■	■	■	■	■	■
Nicosulfuron	■	■	■	■	■	■	■	■	■	■
Orbencarb	■	■	■	■	■	■	■	■	■	■
Oxydemeton-methyl	■	■	■	■	■	■	■	■	■	■
Paraquat	■	■	■	■	■	■	■	■	■	■
Parathion-ethyl	■	■	■	■	■	■	■	■	■	■
Parathion-methyl	■	■	■	■	■	■	■	■	■	■
Pendimethalin	■	■	■	■	■	■	■	■	■	■
Permethrin	■	■	■	■	■	■	■	■	■	■
Phenmedipham	■	■	■	■	■	■	■	■	■	■
Picloram	■	■	■	■	■	■	■	■	■	■
Pirimicarb	■	■	■	■	■	■	■	■	■	■

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Prochloraz	■	■	■	■	■	■	■	■	■	■
Procymidone	■	■	■	■	■	■	■	■	■	■
Profenofos	■	■	■	■	■	■	■	■	■	■
Prometryne	■	■	■	■	■	■	■	■	■	■
Propanil	■	■	■	■	■	■	■	■	■	■
Propiconazole	■	■	■	■	■	■	■	■	■	■
Prosulfuron	■	■	■	■	■	■	■	■	■	■
Pyrithiobac-sodium salt	■	■	■	■	■	■	■	■	■	■
Quinclorac	■	■	■	■	■	■	■	■	■	■
Quizalofop-ethyl	■	■	■	■	■	■	■	■	■	■
Rimsulfuron	■	■	■	■	■	■	■	■	■	■
Sethoxydim	■	■	■	■	■	■	■	■	■	■
Simazine	■	■	■	■	■	■	■	■	■	■
Sulfosulfuron	■	■	■	■	■	■	■	■	■	■
Tebuconazole	■	■	■	■	■	■	■	■	■	■
Tebupirimphos	■	■	■	■	■	■	■	■	■	■
Teflubenzuron	■	■	■	■	■	■	■	■	■	■
Tefluthrin	■	■	■	■	■	■	■	■	■	■
Terbufos	■	■	■	■	■	■	■	■	■	■
Thidiazuron	■	■	■	■	■	■	■	■	■	■
Thifensulfuron methyl	■	■	■	■	■	■	■	■	■	■
Thiobencarb	■	■	■	■	■	■	■	■	■	■
Thiodicarb	■	■	■	■	■	■	■	■	■	■
Thiram	■	■	■	■	■	■	■	■	■	■
Triadimenol	■	■	■	■	■	■	■	■	■	■
Triallate	■	■	■	■	■	■	■	■	■	■
Triasulfuron	■	■	■	■	■	■	■	■	■	■
Tribenuron methyl	■	■	■	■	■	■	■	■	■	■
Tribufos	■	■	■	■	■	■	■	■	■	■
Triclopyr	■	■	■	■	■	■	■	■	■	■
Trifluralin	■	■	■	■	■	■	■	■	■	■
Trinexapac-ethyl	■	■	■	■	■	■	■	■	■	■
Vinclozolin	■	■	■	■	■	■	■	■	■	■

Table A.6: Data symmetry analysis of balance models – Output flows: emissions to industrial soil

Flow	mc-Si PV module					sc-Si PV module				
	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly	Crystallization	Wafering	Cell processing	Module assembly	Module disassembly
Heavy metals to industrial soil										
Antimony	■	■	■	■	■	■	■	■	■	■
Arsenic	■	■	■	■	■	■	■	■	■	■
Arsenic (+V)	■					■				
Cadmium	■	■	■	■	■	■	■	■	■	■
Chromium	■	■	■	■	■	■	■	■	■	■
Chromium (+III)	■					■				
Chromium (+VI)	■	■	■	■	■	■	■	■	■	■
Cobalt	■	■	■	■	■	■	■	■	■	■
Copper	■	■	■	■	■	■	■	■	■	■
Lead	■	■	■	■	■	■	■	■	■	■
Mercury	■	■	■	■	■	■	■	■	■	■
Molybdenum	■	■	■	■	■	■	■	■	■	■
Nickel	■	■	■	■	■	■	■	■	■	■
Selenium	■	■	■	■	■	■	■	■	■	■
Silver	■	■	■	■	■	■	■	■	■	■
Vanadium	■	■	■	■	■	■	■	■	■	■
Zinc	■	■	■	■	■	■	■	■	■	■
Inorganic emissions to industrial soil										
Barium	■	■	■	■	■	■	■	■	■	■
Beryllium	■					■				
Carbon dioxide, to soil or biomass stock	■	■	■	■	■	■	■	■	■	■
Phosphorus	■	■	■	■	■	■	■	■	■	■
Organic emissions to industrial soil										
Acetic acid	■					■				
Methanol	■					■				
Pentachlorophenol (PCP)	■	■	■	■	■	■	■	■	■	■
Other emissions to industrial soil										
Glyphosate	■	■	■	■	■	■	■	■	■	■

ANNEX B: LIFE CYCLE IMPACT ASSESSMENT DATA FOR RESULTS OF SC-SI PV-MODULES IN CHAPTER 5

Table B.1: Climate change midpoint, excl. biogenic carbon (v1.09) of one sc-Si PV-module (60 6-inch solar cells) in kg CO_2 equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Carbon dioxide, fossil	2,98E-01	-	-	2,62E-01	3,66E-02	-
Dinitrogen monoxide	1,24E-03	7,99E-06	1,23E-06	9,05E-07	1,23E-03	-3,96E-07
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	2,36E-05	1,44E-05	1,67E-06	1,11E-06	7,08E-06	-6,35E-07
Inorganic emissions to air (group VOC)						
Carbon dioxide	3,28E+02	2,31E+02	3,04E+01	1,89E+01	5,16E+01	-4,22E+00
Carbon dioxide (aviation)	4,91E-09	4,91E-09	-	-	-	-
Carbon dioxide (land use change)	3,80E-04	3,80E-04	-	-	-	-
Carbon dioxide (peat oxidation)	1,50E-11	1,50E-11	-	-	-	-
Nitrogentriflouride	3,00E-10	2,55E-10	2,00E-11	1,58E-11	1,39E-11	-4,32E-12
Nitrous oxide (laughing gas)	3,54E+00	2,58E+00	2,89E-01	2,73E-01	4,75E-01	-7,16E-02
Sulphur hexafluoride	8,18E-01	5,57E-01	1,28E-01	8,36E-02	9,59E-02	-4,65E-02
Organic emissions to air (group VOC)						
1,1,1-Trichloroethane	1,72E-05	1,42E-05	7,77E-07	6,61E-07	2,65E-06	-1,11E-06
Carbon tetrachloride (tetrachloromethane)	7,33E-03	5,67E-03	1,48E-03	1,18E-04	1,42E-04	-8,64E-05
Chloromethane (methyl chloride)	4,05E-05	3,35E-05	1,83E-06	1,56E-06	6,24E-06	-2,61E-06
Dichloromethane (methylene chloride)	1,67E-05	1,38E-05	7,41E-07	5,93E-07	2,43E-06	-9,60E-07
Halon (1211)	1,54E-03	1,07E-03	2,08E-04	1,24E-04	1,93E-04	-4,89E-05
Halon (1301)	4,86E-03	2,77E-03	3,80E-04	2,18E-04	1,38E-03	1,03E-04
Methyl bromide	1,21E-11	8,43E-12	5,66E-13	2,62E-13	2,96E-12	-1,17E-13
R 11 (trichlorofluoromethane)	2,99E-05	2,99E-05	1,43E-09	4,68E-10	4,45E-09	1,33E-10
R 113 (trichlorotrifluoroethane)	5,80E-03	4,50E-03	6,65E-04	3,97E-04	2,68E-04	-3,28E-05
R 114 (dichlorotetrafluoroethane)	1,02E-01	7,20E-02	1,62E-02	9,92E-03	4,70E-03	-7,38E-04
R 116 (hexafluoroethane)	-1,63E-03	1,85E-03	6,71E-04	6,26E-03	2,59E-02	-3,63E-02
R 12 (dichlorodifluoromethane)	9,02E-03	5,04E-03	2,27E-05	1,40E-05	4,00E-03	-4,96E-05
R 124 (chlorotetrafluoroethane)	5,76E-04	4,47E-04	6,61E-05	3,95E-05	2,66E-05	-3,26E-06
R 125 (pentafluoroethane)	3,38E-10	3,38E-10	-	-	-	-
R 134a (tetrafluoroethane)	1,39E-02	4,29E-03	3,70E-04	2,26E-04	9,06E-03	-1,80E-05
R 143 (trifluoroethane)	3,05E-11	3,05E-11	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
R 152a (difluoroethane)	6,22E-01	4,70E-04	7,34E-05	1,11E-05	6,21E-01	2,05E-06
R 21 (Dichlorofluoromethane)	5,85E-07	5,85E-07	3,14E-11	1,12E-11	8,99E-11	2,40E-12
R 22 (chlorodifluoromethane)	5,79E-02	5,10E-02	3,03E-03	1,04E-03	2,89E-03	-1,37E-04
R 23 (trifluoromethane)	1,83E-02	1,83E-02	9,78E-07	3,48E-07	2,80E-06	7,47E-08
R 245fa (1,1,1,3,3-Pentafluoropropane)	1,77E-09	1,77E-09	-	-	-	-
R 32 (difluoromethane)	9,78E-12	9,78E-12	-	-	-	-
Tetrafluoromethane	-1,37E-02	1,53E-02	5,53E-03	5,18E-02	2,14E-01	-3,00E-01
Trichloromethane (chloroform)	1,97E-04	1,93E-04	1,17E-06	8,97E-07	3,63E-06	-1,18E-06
Methane	2,46E+01	1,83E+01	2,14E+00	1,25E+00	4,19E+00	-1,26E+00
Methane (biotic)	1,67E+00	1,26E+00	1,68E-01	1,22E-01	1,62E-01	-4,09E-02
Organic emissions to fresh water						
Dichloromethane (methylene chloride)	8,64E-05	5,00E-05	7,59E-06	4,40E-06	2,31E-05	1,27E-06
Inorganic emissions to industrial soil						
Carbon dioxide, to soil or biomass stock	-2,29E-03	-1,37E-03	-1,40E-04	-2,89E-05	-7,61E-04	5,84E-06

Table B.2: Ecotoxicity freshwater midpoint (v1.09) of one sc-Si PV-module (60 6-inch solar cells) in CTUe

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Acetaldehyde	2,90E-04	-	-	2,90E-04	-	-
Antimony	7,95E-03	5,62E-03	1,25E-03	7,64E-04	3,72E-04	-5,69E-05
Arsenic	1,04E-01	7,34E-02	1,63E-02	9,98E-03	4,86E-03	-7,44E-04
Barium	4,07E-03	2,88E-03	6,40E-04	3,91E-04	1,90E-04	-2,91E-05
Beryllium	2,36E-04	1,67E-04	3,71E-05	2,27E-05	1,10E-05	-1,69E-06
Cadmium	6,20E-04	4,38E-04	9,75E-05	5,96E-05	2,90E-05	-4,44E-06
Chromium VI	3,12E-02	2,21E-02	4,90E-03	3,00E-03	1,46E-03	-2,23E-04
Cobalt	1,59E-03	1,12E-03	2,50E-04	1,53E-04	7,42E-05	-1,14E-05
Copper	2,27E-01	1,60E-01	3,56E-02	2,18E-02	1,06E-02	-1,62E-03
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	4,54E-09	2,93E-11	4,52E-12	3,32E-12	4,51E-09	-1,45E-12
Lead	1,81E-03	1,28E-03	2,84E-04	1,74E-04	8,45E-05	-1,29E-05
Mercury	9,67E-04	6,83E-04	1,52E-04	9,29E-05	4,52E-05	-6,92E-06
Molybdenum	2,36E-04	1,67E-04	3,72E-05	2,27E-05	1,11E-05	-1,69E-06
Nickel	1,29E-02	9,14E-03	2,03E-03	1,24E-03	6,05E-04	-9,26E-05
Propanol	2,13E-03	-	-	2,13E-03	-	-
Selenium	1,72E-03	1,21E-03	2,70E-04	1,65E-04	8,02E-05	-1,23E-05

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Silver	1,39E-02	9,81E-03	2,18E-03	1,33E-03	6,49E-04	-9,94E-05
Tin	3,26E-04	2,30E-04	5,12E-05	3,13E-05	1,52E-05	-2,33E-06
Vanadium	3,32E-01	2,35E-01	5,22E-02	3,19E-02	1,55E-02	-2,38E-03
Zinc	1,24E-01	8,78E-02	1,95E-02	1,19E-02	5,81E-03	-8,89E-04
Heavy metals to air						
Antimony	8,82E+00	1,49E+00	8,60E-01	2,72E-01	3,66E+00	2,54E+00
Arsenic	1,88E+00	4,79E-01	1,21E-01	5,26E-02	1,22E+00	8,94E-03
Arsenic (+V)	9,56E-07	9,56E-07	-	-	-	-
Cadmium	1,30E-01	2,04E-02	8,17E-03	3,55E-03	9,53E-02	2,32E-03
Chromium	4,59E+00	1,49E+00	1,94E+00	3,29E-01	8,72E-01	-3,24E-02
Chromium (+III)	2,39E-10	2,39E-10	-	-	-	-
Chromium (+VI)	3,02E-01	1,41E-01	9,73E-02	1,83E-02	4,90E-02	-3,99E-03
Cobalt	3,19E-02	1,90E-02	3,91E-03	1,48E-03	7,71E-03	-1,72E-04
Copper	7,95E+00	1,47E+00	6,28E-01	2,42E-01	5,11E+00	5,03E-01
Lead	6,64E-02	1,68E-02	4,67E-03	6,25E-03	3,53E-02	3,33E-03
Mercury	1,44E-01	8,59E-02	3,08E-02	9,72E-03	1,92E-02	-1,16E-03
Molybdenum	1,91E-03	7,60E-04	1,71E-04	6,67E-05	5,32E-04	3,77E-04
Nickel	1,73E+00	6,32E-01	1,26E-01	5,75E-02	9,34E-01	-1,93E-02
Selenium	1,10E-01	6,90E-02	8,81E-03	5,31E-03	2,96E-02	-2,82E-03
Silver	9,75E-01	1,40E-04	2,23E-05	9,74E-01	9,48E-05	7,02E-06
Thallium	1,04E-02	8,81E-03	2,20E-04	3,57E-04	1,04E-03	-5,42E-05
Tin	2,48E-01	3,84E-03	2,94E-03	1,73E-02	2,21E-01	3,23E-03
Vanadium	1,30E+01	9,57E+00	8,45E-01	5,67E-01	1,53E+00	5,21E-01
Zinc	1,08E+01	2,19E+00	9,47E-01	2,85E-01	3,96E+00	3,41E+00
Inorganic emissions to air						
Barium	9,45E-02	6,13E-02	6,04E-03	3,05E-03	1,75E-02	6,62E-03
Beryllium	1,16E-03	9,82E-04	3,39E-05	1,72E-05	1,49E-04	-2,01E-05
Carbon disulphide	3,83E-03	3,86E-04	4,32E-04	1,11E-04	2,81E-03	8,64E-05
Sodium formate	6,79E-08	2,04E-09	1,09E-09	4,06E-10	5,07E-08	1,36E-08
Sulphuric acid	2,05E-03	5,83E-05	5,59E-05	5,55E-06	9,23E-04	1,00E-03
Organic emissions to air (group VOC)						
Anthracene	1,21E-09	2,55E-10	-	-	-	9,52E-10
Benzo{a}anthracene	2,22E-08	3,98E-09	2,95E-09	9,06E-10	4,88E-09	9,46E-09
Benzo{a}pyrene	2,55E-03	1,80E-03	3,37E-04	9,78E-05	3,48E-04	-3,19E-05
Dibenz(a)anthracene	6,48E-11	1,94E-11	1,44E-11	4,43E-12	2,38E-11	2,65E-12
Naphthalene	6,16E-08	6,11E-10	7,00E-09	5,79E-11	5,15E-08	2,42E-09
Phenanthrene	1,44E-07	1,35E-08	1,10E-08	3,37E-09	1,81E-08	9,78E-08
Pyrene	1,30E-07	2,35E-08	2,14E-08	6,56E-09	3,53E-08	4,34E-08
1,1,1-Trichloroethane	2,41E-08	1,99E-08	1,09E-09	9,27E-10	3,71E-09	-1,56E-09
2,4-Dichlorophenol	2,85E-06	1,33E-06	3,29E-07	1,11E-07	1,11E-06	-2,40E-08
2-Chlorotoluene	8,48E-10	4,36E-10	9,83E-11	4,70E-11	2,79E-10	-1,24E-11
Bromoxynil	3,00E-13	2,61E-13	6,13E-15	1,25E-15	3,10E-14	4,72E-16
Carbon tetrachloride (tetrachloromethane)	5,59E-06	4,32E-06	1,13E-06	8,98E-08	1,08E-07	-6,58E-08

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Chloromethane (methyl chloride)	1,97E-07	1,63E-07	8,90E-09	7,57E-09	3,03E-08	-1,27E-08
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene)	1,11E-08	5,40E-09	8,77E-10	3,69E-10	4,57E-09	-8,08E-11
Dichloroethane (ethylene dichloride)	5,35E-07	2,58E-07	4,57E-08	5,60E-08	2,11E-07	-3,60E-08
Dichloromethane (methylene chloride)	1,86E-07	1,54E-07	8,26E-09	6,61E-09	2,71E-08	-1,07E-08
Hexachlorobenzene (Perchlorobenzene)	1,20E-05	2,42E-06	7,32E-06	1,08E-06	9,86E-07	1,69E-07
Methyl bromide	2,82E-11	1,96E-11	1,32E-12	6,11E-13	6,90E-12	-2,73E-13
Pentachlorobenzene	5,30E-07	1,60E-08	3,14E-09	2,90E-07	5,10E-08	1,70E-07
Pentachlorophenol (PCP)	4,17E-02	2,94E-02	5,48E-03	1,49E-03	5,26E-03	4,46E-05
Polychlorinated biphenyls (PCB unspecified)	7,71E-06	1,82E-06	4,34E-06	6,56E-07	6,91E-07	2,10E-07
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	1,25E-05	6,29E-06	1,70E-06	1,31E-06	2,16E-06	1,04E-06
Polychlorinated dibenzo-p-furans (2,3,7,8 - TCDD)	7,68E-13	7,68E-13	-	-	-	-
Tetrachloroethene (perchloroethylene)	4,64E-07	1,52E-07	8,33E-09	2,87E-07	2,84E-08	-1,18E-08
Trichloroethene (isomers)	1,83E-15	1,83E-15	-	-	-	-
Trichloromethane (chloroform)	1,80E-06	1,75E-06	1,06E-08	8,15E-09	3,31E-08	-1,07E-08
1,3,5-Trimethylbenzene	2,97E-14	2,97E-14	-	-	-	-
1-Methoxy-2-propanol	3,36E-15	3,36E-15	-	-	-	-
1-Propanol	4,76E-05	3,25E-10	5,66E-11	2,49E-11	4,76E-05	-4,21E-12
Acenaphthene	1,90E-07	1,06E-08	2,17E-08	6,50E-10	1,57E-07	4,45E-10
Acetaldehyde (Ethanal)	4,07E-05	1,83E-05	4,26E-06	1,40E-06	1,50E-05	1,63E-06
Acetic acid	2,46E-02	2,44E-03	3,06E-03	2,48E-04	1,90E-02	-1,14E-04
Acetone (dimethylcetone)	4,22E-05	1,05E-05	1,76E-06	5,60E-07	2,94E-05	-2,36E-08
Acetonitrile	1,97E-06	8,05E-07	2,29E-07	6,52E-08	8,84E-07	-1,34E-08
Acrolein	1,17E-03	3,51E-04	1,20E-04	4,13E-05	4,35E-04	2,26E-04
Acrylic acid	6,07E-09	2,20E-09	8,93E-10	1,62E-10	2,69E-09	1,24E-10
Acrylonitrile	6,94E-17	6,94E-17	-	-	-	-
Aniline	1,43E-08	5,19E-09	1,42E-09	5,48E-10	7,29E-09	-1,39E-10
Benzaldehyde	2,90E-05	9,50E-06	3,18E-06	1,16E-06	9,84E-06	5,34E-06
Benzene	2,88E-04	2,05E-04	3,34E-05	1,09E-05	3,94E-05	-1,16E-06
Biphenyl	5,32E-13	5,32E-13	-	-	-	-
Butanone (methyl ethyl ketone)	1,66E-06	6,02E-07	2,44E-07	4,32E-08	7,36E-07	3,38E-08
Butylene glycol (butane diol)	6,80E-09	5,93E-09	2,20E-10	5,51E-11	6,03E-10	-7,72E-12
Butyrolactone	5,54E-09	1,76E-09	1,73E-09	1,69E-10	1,82E-09	7,25E-11
Caprolactam	3,09E-15	3,09E-15	-	-	-	-
Chloramine	9,62E-05	5,19E-05	7,97E-06	4,47E-06	3,27E-05	-8,41E-07

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Cumene (isopropylbenzene)	1,63E-06	2,49E-07	4,73E-08	2,26E-07	1,34E-06	-2,35E-07
Cyclohexane (hexahydro benzene)	6,91E-17	6,67E-17	1,05E-18	8,29E-19	7,29E-19	-2,28E-19
Cyclopentane	5,22E-14	5,22E-14	-	-	-	-
Decane	6,88E-15	6,88E-15	-	-	-	-
Diethyl ether	6,85E-17	4,81E-17	9,02E-18	7,11E-18	6,25E-18	-1,95E-18
Diethylamine	4,30E-10	1,96E-10	4,83E-11	2,20E-11	1,70E-10	-5,81E-12
Diethylene glycol	1,57E-15	1,10E-15	2,06E-16	1,63E-16	1,43E-16	-4,46E-17
Ethanol	1,45E-05	1,14E-05	1,11E-06	6,47E-07	1,44E-06	-1,50E-07
Ethyl benzene	6,60E-07	3,92E-07	6,06E-08	3,34E-08	1,67E-07	7,15E-09
Ethylamine	1,18E-08	5,46E-10	4,06E-11	2,37E-11	1,12E-08	-8,42E-12
Ethylene acetate (ethyl acetate)	3,27E-06	1,18E-06	4,81E-07	8,49E-08	1,45E-06	6,63E-08
Ethylene oxide	8,57E-06	3,90E-08	5,61E-06	4,29E-08	2,90E-06	-1,52E-08
Ethylenediamine	6,87E-07	8,20E-09	1,36E-09	1,92E-09	6,76E-07	-3,54E-10
Fluoranthene	2,82E-07	1,01E-08	8,51E-09	2,61E-09	1,40E-08	2,47E-07
Fluorene	4,72E-11	4,72E-11	-	-	-	-
Formaldehyde (methanal)	1,80E-02	1,20E-02	1,59E-03	8,07E-04	3,48E-03	1,30E-04
Formic acid (methane acid)	1,48E-04	6,04E-05	1,72E-05	4,89E-06	6,63E-05	-9,96E-07
Furan	1,81E-07	7,40E-08	2,10E-08	5,99E-09	8,13E-08	-1,23E-09
Heptane (isomers)	1,60E-09	8,17E-10	1,30E-10	7,86E-11	8,85E-10	-3,11E-10
Hexamethylene diamine (HMDA)	-2,57E-20	-2,57E-20	-	-	-	-
Hexane (isomers)	1,52E-07	9,56E-08	1,64E-08	8,73E-09	3,64E-08	-4,86E-09
iso-Butanol	3,55E-10	9,91E-11	2,17E-11	8,69E-12	2,28E-10	-1,91E-12
Isoprene	1,34E-11	5,49E-12	1,56E-12	4,45E-13	6,03E-12	-9,14E-14
Isopropanol	4,97E-07	1,80E-07	7,28E-08	1,29E-08	2,21E-07	1,01E-08
Mercaptan (unspecified)	2,77E-11	2,77E-11	-	-	-	-
meta-Cresol	1,55E-15	1,55E-15	-	-	-	-
Methacrylate	1,31E-09	4,74E-10	1,92E-10	3,48E-11	5,79E-10	2,66E-11
Methanol	3,04E-04	2,68E-05	9,86E-05	3,02E-06	1,77E-04	-1,26E-06
Methyl acetate	7,50E-11	4,62E-11	7,44E-12	3,28E-12	1,88E-11	-7,72E-13
Methyl amine	3,57E-10	1,41E-10	4,76E-11	1,13E-11	1,59E-10	-1,89E-12
Methyl formate	2,84E-10	7,02E-11	1,69E-11	6,47E-12	1,90E-10	-7,76E-14
Methyl isobutyl ketone	2,82E-13	2,48E-14	3,04E-15	2,76E-15	2,49E-13	1,74E-15
Methyl methacrylate (MMA)	1,46E-16	1,46E-16	-	-	-	-
Methyl tert-butylether	4,58E-08	1,21E-08	5,75E-09	1,18E-09	2,66E-08	2,24E-10
Monoethanolamine	8,65E-05	8,98E-06	2,92E-06	1,65E-06	4,75E-05	2,55E-05
n-Butyl acetate	1,25E-19	1,25E-19	-	-	-	-
Nitrobenzene	9,50E-08	3,54E-08	9,41E-09	3,66E-09	4,74E-08	-9,24E-10
Octane	6,04E-09	6,04E-09	-	-	-	-
o-Nitrotoluene	1,32E-08	8,15E-09	1,31E-09	5,78E-10	3,32E-09	-1,36E-10

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
para-Cresol	2,51E-15	2,51E-15	-	-	-	-
Pentane (n-pentane)	2,18E-05	1,45E-05	2,17E-06	1,29E-06	3,89E-06	-6,07E-08
Phenol (hydroxy benzene)	2,27E-04	4,77E-05	6,52E-06	3,41E-06	1,82E-04	-1,30E-05
Propionaldehyde	1,01E-04	1,90E-07	2,51E-08	1,43E-08	1,01E-04	2,43E-08
Propionic acid (propane acid)	1,39E-04	1,04E-04	1,52E-05	9,07E-06	1,46E-05	-3,35E-06
Propylene oxide	1,04E-03	2,24E-07	1,04E-03	2,60E-08	2,87E-07	1,84E-07
Styrene	5,11E-08	1,21E-08	5,83E-09	1,80E-09	2,09E-08	1,04E-08
Toluene (methyl benzene)	1,37E-05	9,65E-06	1,01E-06	5,44E-07	2,64E-06	-1,31E-07
Trimethylamine	6,30E-12	3,89E-12	6,25E-13	2,76E-13	1,58E-12	-6,49E-14
Xylene (dimethyl benzene)	2,28E-05	1,30E-05	1,81E-06	1,11E-06	7,28E-06	-4,74E-07
Xylene (meta-Xylene; 1,3-Dimethylbenzene)	5,66E-07	3,88E-07	5,83E-08	3,08E-08	6,84E-08	2,05E-08
Xylene (ortho-Xylene; 1,2-Dimethylbenzene)	6,08E-08	1,06E-08	7,10E-09	2,06E-09	2,58E-08	1,52E-08
Pesticides to air						
2,4-Dichlorophenoxyacetic acid (2,4-D)	1,16E-05	5,66E-06	1,63E-06	6,79E-07	3,82E-06	-1,62E-07
Acephate	1,24E-06	6,01E-07	1,74E-07	7,22E-08	4,06E-07	-1,72E-08
Acetochlor	1,78E-18	1,78E-18	-	-	-	-
Alachlor	2,59E-05	1,26E-05	3,64E-06	1,52E-06	8,52E-06	-3,62E-07
Atrazine	3,31E-05	1,61E-05	4,66E-06	1,94E-06	1,09E-05	-4,62E-07
Azoxystrobin	1,47E-05	7,16E-06	2,07E-06	8,60E-07	4,83E-06	-2,05E-07
Benomyl	5,38E-11	5,38E-11	-	-	-	-
Bentazone	3,98E-08	1,94E-08	5,58E-09	2,32E-09	1,31E-08	-5,53E-10
Carbaryl	1,86E-06	9,04E-07	2,61E-07	1,09E-07	6,11E-07	-2,59E-08
Carbofuran	3,60E-11	3,60E-11	-	-	-	-
Carfentrazone-ethyl	1,21E-06	5,87E-07	1,70E-07	7,05E-08	3,96E-07	-1,68E-08
Chlormequat-chloride	7,01E-16	7,01E-16	-	-	-	-
Chlorpyriphos	1,13E-03	5,51E-04	1,59E-04	6,62E-05	3,72E-04	-1,58E-05
Clethodim	2,72E-07	1,32E-07	3,82E-08	1,59E-08	8,92E-08	-3,79E-09
Cyfluthrin	3,13E-03	1,52E-03	4,40E-04	1,83E-04	1,03E-03	-4,37E-05
Cypermethrin	2,32E-13	2,32E-13	-	-	-	-
Cyprodinil (CGA-219417)	1,81E-15	1,81E-15	-	-	-	-
Deltamethrin	3,24E-08	3,24E-08	-	-	-	-
Dicamba	3,08E-07	1,50E-07	4,33E-08	1,80E-08	1,01E-07	-4,30E-09
Dichlorprop	1,62E-15	1,38E-15	3,99E-17	7,99E-18	1,85E-16	3,51E-18
Diflubenzuron	4,14E-05	2,01E-05	5,81E-06	2,42E-06	1,36E-05	-5,77E-07
Diflufenican	6,86E-17	6,86E-17	-	-	-	-
Dimethenamid	9,66E-12	5,87E-12	1,44E-12	6,70E-13	1,76E-12	-8,94E-14
Dimethoate	1,77E-15	1,77E-15	-	-	-	-
Esfenvalerate	6,42E-04	3,12E-04	9,02E-05	3,75E-05	2,11E-04	-8,95E-06
Ethephon	9,50E-15	8,29E-15	1,88E-16	3,85E-17	9,64E-16	1,41E-17
Fenvalerate	1,95E-12	1,95E-12	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Fipronil	1,79E-19	1,79E-19	-	-	-	-
Fluazifop-p-butyl	1,20E-06	5,83E-07	1,68E-07	7,00E-08	3,94E-07	-1,67E-08
Flufenacet	5,64E-06	2,75E-06	7,93E-07	3,30E-07	1,85E-06	-7,87E-08
Flumetsulam	2,39E-06	1,16E-06	3,36E-07	1,40E-07	7,85E-07	-3,33E-08
Flumiclorac-pentyl	7,84E-07	3,82E-07	1,10E-07	4,58E-08	2,58E-07	-1,09E-08
Flumioxazin	1,73E-05	8,43E-06	2,44E-06	1,01E-06	5,69E-06	-2,42E-07
Glyphosate	4,97E-05	2,42E-05	6,99E-06	2,91E-06	1,63E-05	-6,93E-07
Imazamox	6,52E-07	3,17E-07	9,16E-08	3,81E-08	2,14E-07	-9,09E-09
Imazethapyr	4,77E-07	2,32E-07	6,71E-08	2,79E-08	1,57E-07	-6,66E-09
Imidacloprid	2,07E-17	2,07E-17	-	-	-	-
Ioxynil	8,31E-15	8,31E-15	-	-	-	-
Isoproturon	4,41E-14	4,41E-14	-	-	-	-
Lambda-cyhalothrin	2,97E-14	2,59E-14	5,90E-16	1,21E-16	3,03E-15	4,44E-17
Mancozeb	2,92E-09	2,92E-09	-	-	-	-
MCPA	1,31E-14	1,15E-14	2,62E-16	5,30E-17	1,28E-15	2,15E-17
Mecoprop	2,48E-16	2,48E-16	-	-	-	-
Methomyl	5,49E-10	5,49E-10	4,75E-15	9,70E-16	2,43E-14	3,57E-16
Metolachlor	5,66E-05	2,75E-05	7,95E-06	3,30E-06	1,86E-05	-7,88E-07
Metribuzin	1,02E-05	4,95E-06	1,43E-06	5,94E-07	3,34E-06	-1,42E-07
Paraquat	1,99E-05	9,70E-06	2,80E-06	1,16E-06	6,55E-06	-2,78E-07
Parathion-methyl	1,44E-06	7,02E-07	2,02E-07	8,42E-08	4,73E-07	-2,01E-08
Pendimethalin	4,46E-04	2,17E-04	6,26E-05	2,60E-05	1,46E-04	-6,21E-06
Permethrin	1,62E-05	7,90E-06	2,28E-06	9,48E-07	5,33E-06	-2,26E-07
Propiconazole	7,60E-07	3,70E-07	1,07E-07	4,44E-08	2,49E-07	-1,06E-08
Quizalofop-ethyl	9,52E-07	4,63E-07	1,34E-07	5,56E-08	3,13E-07	-1,33E-08
Sethoxydim	1,28E-07	6,24E-08	1,80E-08	7,50E-09	4,21E-08	-1,79E-09
Sulfentrazone	5,13E-05	2,50E-05	7,21E-06	3,00E-06	1,69E-05	-7,16E-07
Tebuconazole	1,10E-14	9,62E-15	2,19E-16	4,48E-17	1,12E-15	1,65E-17
Terbufos	8,57E-20	8,57E-20	-	-	-	-
Thiodicarb	9,11E-07	4,43E-07	1,28E-07	5,32E-08	2,99E-07	-1,27E-08
Thiram	1,76E-08	1,76E-08	-	-	-	-
Trifluralin	3,56E-05	1,73E-05	5,00E-06	2,08E-06	1,17E-05	-4,97E-07
Long-term emissions to fresh water						
Antimony	2,15E+02	2,14E+01	6,44E+00	1,57E+01	3,51E+01	1,37E+02
Arsenic, ion	5,52E+01	2,16E+01	5,23E+00	1,10E+01	1,70E+01	3,77E-01
Barium	1,12E+01	7,80E+00	1,22E+00	8,16E-01	1,27E+00	1,10E-01
Beryllium	1,50E+00	8,12E-01	1,42E-01	1,80E-01	3,68E-01	-3,13E-03
Cadmium, ion	6,33E+00	1,16E+00	4,77E-01	1,50E+00	2,96E+00	2,45E-01
Chromium (+VI)	2,03E+02	1,19E+02	4,04E+01	2,07E+01	3,83E+01	-1,50E+01
Cobalt	2,09E+01	1,17E+01	2,49E+00	2,67E+00	4,04E+00	-2,16E-03
Copper	1,04E+04	3,96E+02	9,90E+01	1,18E+02	2,11E+03	7,70E+03
Lead	8,45E-01	9,99E-02	2,73E-02	5,34E-02	2,92E-01	3,72E-01
Mercury	1,10E+00	7,96E-01	1,36E-01	8,22E-02	1,08E-01	-2,44E-02

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Molybdenum	3,45E-01	1,72E-01	3,47E-02	5,61E-02	8,33E-02	-1,00E-03
Nickel, ion	2,61E+02	1,83E+02	3,55E+01	2,07E+01	2,62E+01	-4,02E+00
Selenium	6,66E+00	3,30E+00	6,56E-01	1,08E+00	1,64E+00	-2,40E-02
Silver	1,73E+01	1,01E+00	5,00E-01	1,64E+00	2,64E+00	1,15E+01
Thallium	2,55E+00	8,64E-01	2,07E-01	5,47E-01	9,05E-01	3,20E-02
Tin, ion	1,81E+00	2,60E-01	1,24E-01	4,18E-01	8,56E-01	1,52E-01
Vanadium, ion	3,36E+02	1,84E+02	3,18E+01	3,61E+01	9,07E+01	-6,24E+00
Zinc, ion	1,68E+03	5,75E+02	1,50E+02	3,44E+02	5,69E+02	4,43E+01
Heavy metals to fresh water						
Antimony	8,74E+01	6,07E+00	1,10E+00	6,51E-01	6,10E+00	7,35E+01
Arsenic	1,72E-11	1,72E-11	-	-	-	-
Arsenic (+V)	1,40E+01	1,00E+01	1,41E+00	1,53E+00	2,29E+00	-1,28E+00
Cadmium	4,51E-02	1,11E-02	8,27E-03	5,85E-03	1,61E-02	3,79E-03
Chromium	1,66E-03	1,66E-03	-	-	-	-
Chromium (+III)	3,62E-02	1,17E-02	5,39E-03	8,44E-04	1,85E-02	-1,56E-04
Chromium (+VI)	2,47E+01	1,05E+01	8,56E+00	2,71E+00	7,00E+00	-3,99E+00
Cobalt	5,53E-02	2,41E-02	5,86E-03	9,60E-03	1,81E-02	-2,39E-03
Copper	3,05E+00	5,40E-01	2,26E-01	4,94E-01	1,80E+00	-7,51E-03
Lead	2,80E-02	8,36E-03	2,14E-03	1,09E-03	1,51E-02	1,30E-03
Mercury	1,34E-02	6,28E-03	3,93E-03	7,17E-04	2,16E-03	3,09E-04
Molybdenum	7,88E-02	5,78E-02	8,51E-03	6,23E-03	8,50E-03	-2,19E-03
Nickel	1,19E+00	6,24E-01	1,61E-01	9,15E-02	4,12E-01	-9,59E-02
Selenium	3,02E-01	2,10E-01	2,80E-02	2,18E-02	4,86E-02	-6,72E-03
Silver	4,53E+00	3,03E+00	2,75E-01	1,37E-01	1,13E+00	-4,64E-02
Thallium	2,37E-02	1,70E-02	1,92E-03	1,86E-03	2,94E-03	-5,62E-05
Tin	9,72E-03	4,92E-03	7,60E-04	1,06E-03	3,06E-03	-8,03E-05
Vanadium	2,80E+00	1,89E+00	3,20E-01	2,40E-01	3,78E-01	-2,82E-02
Zinc	1,05E+01	3,08E+00	9,02E-01	2,62E+00	3,13E+00	7,81E-01
Inorganic emissions to fresh water						
Barium	5,36E+00	3,50E+00	3,37E-01	1,69E-01	1,38E+00	-2,94E-02
Beryllium	4,05E-03	2,29E-03	3,67E-04	4,87E-04	9,43E-04	-3,36E-05
Carbon disulphide	4,46E-05	4,64E-07	7,27E-08	1,05E-07	4,40E-05	-2,80E-08
Sulphuric acid	6,02E-10	6,02E-10	-	-	-	-
Organic emissions to fresh water						
1,1,1-Trichloroethane	1,64E-16	1,15E-16	2,15E-17	1,70E-17	1,49E-17	-4,66E-18
1,2-Dibromoethane	-3,32E-19	-3,32E-19	-	-	-	-
2-Chlorotoluene	1,73E-06	8,91E-07	2,06E-07	1,00E-07	5,58E-07	-2,68E-08
Bromoxynil	1,11E-12	9,15E-13	3,64E-14	7,14E-15	1,51E-13	3,69E-15
Chlorobenzene	3,30E-02	3,17E-02	7,72E-04	1,00E-04	4,41E-04	1,89E-05
Chloromethane (methyl chloride)	-3,08E-14	-3,08E-14	-	-	-	-
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene)	2,07E-02	1,97E-02	5,69E-04	7,25E-05	3,72E-04	1,49E-05
Dichloroethane (ethylene	8,95E-06	2,07E-06	4,69E-07	1,45E-06	4,95E-06	1,88E-08

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
dichloride)						
Dichloromethane (methylene chloride)	1,45E-04	8,40E-05	1,27E-05	7,39E-06	3,88E-05	2,14E-06
Dichloropropane	-2,62E-22	-2,62E-22	-	-	-	-
Pentachlorophenol (PCP)	1,64E-11	1,64E-11	-	-	-	-
Polychlorinated biphenyls (PCB unspecified)	2,30E-05	6,67E-08	6,81E-09	8,07E-09	2,30E-05	-1,70E-08
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	2,99E-17	2,99E-17	-	-	-	-
Tetrachloroethene (perchloroethylene)	1,69E-15	1,69E-15	-	-	-	-
Trichloromethane (chloroform)	2,07E-07	1,77E-07	3,09E-09	1,40E-09	2,55E-08	-2,50E-10
4-Methyl-2-pentanol	2,76E-14	2,43E-15	2,98E-16	2,70E-16	2,44E-14	1,71E-16
Acenaphthene	2,07E-04	9,23E-06	2,41E-05	8,72E-07	1,73E-04	5,20E-07
Acetic acid	9,08E-03	3,82E-05	4,19E-05	3,01E-05	8,99E-03	-1,94E-05
Acetonitrile	6,03E-09	3,56E-09	5,60E-10	2,17E-10	1,74E-09	-4,63E-11
Acrylonitrile	1,43E-15	1,43E-15	-	-	-	-
Aniline	9,44E-06	3,42E-06	9,35E-07	3,62E-07	4,81E-06	-9,16E-08
Anthracene	2,63E-03	3,75E-05	3,10E-04	2,56E-06	2,28E-03	1,51E-06
Benzene	1,18E-02	8,06E-03	4,71E-04	5,92E-04	3,02E-03	-3,64E-04
Benzo{a}anthracene	3,24E-05	2,74E-06	3,55E-06	2,93E-08	2,61E-05	1,73E-08
Benzo{a}pyrene	5,38E-08	4,96E-10	6,36E-09	5,26E-11	4,68E-08	3,10E-11
Butylene glycol (butane diol)	1,33E-07	1,16E-07	4,32E-09	1,08E-09	1,18E-08	-1,52E-10
Butyrolactone	6,88E-08	2,18E-08	2,14E-08	2,10E-09	2,26E-08	8,99E-10
Cresol (methyl phenol)	-1,73E-17	-1,73E-17	-	-	-	-
Dibenz(a)anthracene	1,29E-09	1,19E-11	1,52E-10	1,26E-12	1,12E-09	7,43E-13
Ethanol	2,34E-04	1,31E-06	3,84E-05	1,07E-06	1,94E-04	-7,47E-07
Ethyl benzene	2,41E-03	1,32E-03	2,00E-04	1,17E-04	7,05E-04	6,50E-05
Ethylene acetate (ethyl acetate)	3,10E-07	1,42E-08	4,86E-08	2,68E-09	2,46E-07	-1,25E-09
Ethylene oxide	2,32E-06	4,40E-07	1,06E-07	5,61E-08	1,18E-06	5,42E-07
Fluoranthene	2,60E-02	2,40E-04	3,08E-03	2,54E-05	2,26E-02	1,50E-05
Formaldehyde (methanal)	9,93E-03	3,97E-04	4,12E-03	1,11E-04	5,38E-03	-8,04E-05
Hexane (isomers)	-1,54E-19	-1,54E-19	-	-	-	-
Methanol	1,57E-03	3,08E-06	1,44E-03	1,11E-06	1,27E-04	-6,87E-07
Methyl tert-butylether	1,73E-07	7,30E-08	3,09E-08	4,29E-09	6,59E-08	-1,33E-09
Naphthalene	3,10E-05	3,91E-06	3,24E-06	2,68E-08	2,38E-05	1,58E-08
Phenanthrene	2,71E-03	2,50E-05	3,21E-04	2,65E-06	2,36E-03	1,56E-06
Phenol (hydroxy benzene)	5,87E-02	2,62E-02	5,95E-03	2,31E-03	2,39E-02	3,40E-04
Propanol	9,68E-09	3,01E-09	5,47E-10	2,32E-10	5,94E-09	-4,78E-11
Propanol (iso-propanol; isopropanol)	2,55E-07	1,83E-08	1,13E-09	6,38E-10	2,35E-07	-2,12E-10
Propylene oxide	5,57E-02	1,15E-05	5,57E-02	1,33E-06	1,50E-05	9,87E-06

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Pyrene	1,32E-01	1,22E-03	1,57E-02	1,29E-04	1,15E-01	7,62E-05
Sodium formate	7,10E-07	2,13E-08	1,14E-08	4,25E-09	5,30E-07	1,42E-07
Toluene (methyl benzene)	4,33E-03	2,46E-03	3,43E-04	1,97E-04	1,24E-03	9,06E-05
Triethylene glycol	4,38E-08	2,56E-08	2,73E-09	9,90E-10	1,51E-08	-5,27E-10
Xylene (isomers; dimethyl benzene)	4,56E-03	2,54E-03	3,71E-04	2,14E-04	1,32E-03	1,09E-04
Xylene (meta-Xylene; 1,3-Dimethylbenzene)	9,59E-05	6,39E-05	5,65E-06	2,72E-06	2,46E-05	-1,04E-06
Xylene (ortho-Xylene; 1,2-Dimethylbenzene)	5,20E-05	3,49E-05	3,08E-06	1,48E-06	1,31E-05	-5,69E-07
Acetaldehyde (Ethanal)	5,68E-03	3,80E-05	9,21E-04	2,49E-05	4,67E-03	2,65E-05
Acetone (dimethylcetone)	1,47E-07	9,38E-08	9,25E-09	4,50E-09	4,12E-08	-1,63E-09
Acrylic acid	2,04E-07	7,41E-08	3,00E-08	5,44E-09	9,06E-08	4,16E-09
Allyl chloride	1,65E-06	2,90E-07	6,74E-08	3,88E-08	1,11E-06	1,45E-07
Biphenyl	9,55E-23	9,55E-23	-	-	-	-
Chloramine	4,27E-03	2,31E-03	3,54E-04	1,99E-04	1,45E-03	-3,74E-05
Cumene (isopropylbenzene)	3,15E-02	4,80E-03	9,15E-04	4,37E-03	2,59E-02	-4,55E-03
Diethylamine	5,84E-07	2,66E-07	6,56E-08	2,99E-08	2,30E-07	-7,90E-09
Ethylamine	3,87E-06	1,79E-07	1,33E-08	7,75E-09	3,67E-06	-2,75E-09
Ethylenediamine	4,54E-05	5,42E-07	9,01E-08	1,27E-07	4,47E-05	-2,33E-08
Formic acid	4,09E-08	9,10E-09	1,68E-09	8,97E-10	2,94E-08	-1,92E-10
iso-Butanol	3,64E-08	1,02E-08	2,22E-09	8,90E-10	2,33E-08	-1,95E-10
Methyl acetate	4,79E-09	2,95E-09	4,75E-10	2,10E-10	1,20E-09	-4,93E-11
Methyl acrylate	6,49E-06	2,35E-06	9,54E-07	1,73E-07	2,88E-06	1,32E-07
Methyl amine	8,25E-08	3,25E-08	1,10E-08	2,61E-09	3,68E-08	-4,37E-10
Methyl formate	3,79E-09	9,37E-10	2,26E-10	8,64E-11	2,54E-09	-1,04E-12
Methyl isobutyl ketone	2,70E-07	1,81E-07	1,60E-08	7,69E-09	6,80E-08	-2,95E-09
Monoethanolamine	8,70E-07	5,97E-07	1,26E-07	7,50E-08	9,39E-08	-2,22E-08
n-Butyl acetate	1,19E-03	2,69E-06	1,96E-04	5,23E-06	9,87E-04	-3,93E-06
Nitrobenzene	6,26E-06	2,33E-06	6,20E-07	2,41E-07	3,12E-06	-6,09E-08
Propionaldehyde	2,08E-07	4,50E-08	7,79E-09	4,38E-09	1,51E-07	-9,23E-10
Propionic acid	8,80E-07	5,24E-07	1,15E-07	5,46E-08	2,01E-07	-1,40E-08
Trimethylamine	1,30E-08	8,05E-09	1,29E-09	5,70E-10	3,27E-09	-1,34E-10
Other emissions to fresh water						
Acetochlor	4,45E-18	4,45E-18	-	-	-	-
Alachlor	2,04E-06	2,04E-06	-	-	-	-
Atrazine	8,14E-09	4,95E-09	1,22E-09	5,65E-10	1,49E-09	-7,53E-11
Benomyl	3,03E-10	3,03E-10	-	-	-	-
Bentazone	1,50E-08	5,92E-09	2,01E-09	6,80E-10	6,49E-09	-1,42E-10
Carbaryl	5,23E-13	3,24E-13	7,53E-14	3,48E-14	9,37E-14	-4,60E-15
Carbofuran	3,99E-11	3,99E-11	-	-	-	-
Chlormequat-chloride	3,09E-16	3,09E-16	-	-	-	-
Cypermethrin	1,07E-12	1,07E-12	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Cyprodinil (CGA-219417)	1,33E-14	1,33E-14	-	-	-	-
Deltamethrin	2,75E-07	2,75E-07	-	-	-	-
Dicamba	1,86E-11	1,13E-11	2,78E-12	1,29E-12	3,40E-12	-1,72E-13
Dichlorprop	8,03E-14	6,97E-14	1,68E-15	3,41E-16	8,39E-15	1,31E-16
Diflufenican	1,39E-16	1,39E-16	-	-	-	-
Dimethenamid	1,35E-10	8,20E-11	2,02E-11	9,36E-12	2,46E-11	-1,25E-12
Dimethoate	3,50E-15	3,50E-15	-	-	-	-
Ethephon	1,93E-15	1,69E-15	3,83E-17	7,83E-18	1,96E-16	2,88E-18
Fenvalerate	6,05E-12	6,05E-12	-	-	-	-
Fipronil	9,01E-19	9,01E-19	-	-	-	-
Glyphosate	5,80E-07	2,28E-07	7,84E-08	2,65E-08	2,53E-07	-5,53E-09
Imidacloprid	3,33E-17	3,33E-17	-	-	-	-
Ioxynil	6,80E-15	6,80E-15	-	-	-	-
Isoproturon	5,26E-14	5,26E-14	-	-	-	-
Lambda cyhalothrin	4,73E-14	4,13E-14	9,42E-16	1,92E-16	4,83E-15	7,08E-17
Mancozeb	1,48E-08	1,48E-08	-	-	-	-
MCPA	4,42E-13	3,81E-13	9,85E-15	1,99E-15	4,77E-14	8,12E-16
Mecoprop	1,52E-16	1,52E-16	-	-	-	-
Methomyl	3,03E-10	3,03E-10	6,54E-16	1,34E-16	3,35E-15	4,91E-17
Metolachlor	7,28E-07	2,85E-07	9,84E-08	3,33E-08	3,18E-07	-6,94E-09
Parathion-methyl	1,82E-09	1,82E-09	-	-	-	-
Pendimethalin	5,98E-10	3,64E-10	8,94E-11	4,15E-11	1,09E-10	-5,53E-12
Propiconazole	1,09E-12	9,54E-13	2,18E-14	4,45E-15	1,11E-13	1,64E-15
Tebuconazole	1,05E-13	9,13E-14	2,08E-15	4,25E-16	1,07E-14	1,56E-16
Terbufos	1,09E-17	1,09E-17	-	-	-	-
Thiram	1,83E-07	1,83E-07	-	-	-	-
Trifluralin	1,34E-07	1,34E-07	-	-	-	-
Heavy metals to sea water						
Arsenic (+V)	4,66E-22	3,05E-23	7,96E-24	3,70E-22	5,51E-23	2,17E-24
Cadmium	6,05E-23	4,75E-25	9,51E-26	5,94E-23	4,69E-25	3,50E-26
Chromium	1,79E-24	1,79E-24	-	-	-	-
Chromium (+III)	1,88E-24	9,89E-25	1,68E-25	9,42E-26	5,76E-25	5,27E-26
Cobalt	5,16E-26	3,70E-26	7,68E-27	4,69E-27	2,60E-27	-3,69E-28
Copper	2,69E-20	3,69E-23	1,17E-23	2,68E-20	4,13E-23	4,28E-24
Lead	3,76E-25	1,32E-25	2,43E-26	1,35E-25	7,79E-26	6,35E-27
Mercury	1,66E-24	1,19E-25	4,17E-26	1,13E-24	3,50E-25	1,28E-26
Molybdenum	3,33E-26	1,73E-26	2,96E-27	1,65E-27	1,03E-26	1,08E-27
Nickel	2,81E-21	4,15E-24	1,17E-24	2,80E-21	5,19E-24	5,60E-25
Selenium	1,35E-24	6,98E-25	1,20E-25	6,68E-26	4,18E-25	4,36E-26
Silver	4,44E-24	2,39E-24	3,77E-25	2,22E-25	1,31E-24	1,33E-25
Tin	-8,34E-38	-8,34E-38	-	-	-	-
Vanadium	1,62E-22	8,47E-23	1,42E-23	7,94E-24	5,04E-23	4,79E-24
Zinc	5,99E-18	3,97E-19	8,27E-20	5,42E-18	1,01E-19	-5,50E-21

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Inorganic emissions to sea water						
Barium	6,67E-22	3,60E-22	5,67E-23	3,34E-23	1,97E-22	2,01E-23
Beryllium	-1,39E-34	-1,39E-34	-	-	-	-
Organic emissions to sea water						
Tetrachloroethene (perchloroethylene)	2,08E-22	2,08E-22	-	-	-	-
Acenaphthene	7,26E-11	4,04E-11	5,95E-12	3,50E-12	2,07E-11	2,10E-12
Acetic acid	-2,33E-20	-2,33E-20	-	-	-	-
Anthracene	8,92E-10	8,92E-10	-	-	-	-
Benzene	7,09E-08	3,84E-08	6,05E-09	3,56E-09	2,08E-08	2,10E-09
Benzo{a}anthracene	6,14E-11	6,14E-11	-	-	-	-
Cresol (methyl phenol)	-1,50E-22	-1,50E-22	-	-	-	-
Ethyl benzene	1,83E-09	9,85E-10	1,55E-10	9,14E-11	5,40E-10	5,48E-11
Fluoranthene	1,38E-11	1,38E-11	-	-	-	-
Glutaraldehyde	3,95E-08	2,55E-08	5,30E-09	3,12E-09	6,04E-09	-4,42E-10
Hexane (isomers)	-5,25E-27	-5,25E-27	-	-	-	-
Methanol	1,22E-08	8,45E-09	1,69E-09	1,02E-09	1,41E-09	-4,17E-10
Methyl tert-butylether	1,08E-10	4,51E-11	1,93E-11	2,46E-12	4,16E-11	-8,39E-13
Phenol (hydroxy benzene)	1,01E-07	5,45E-08	8,57E-09	5,02E-09	2,98E-08	2,81E-09
Toluene (methyl benzene)	1,32E-08	7,00E-09	1,14E-09	6,58E-10	3,96E-09	4,05E-10
Triethylene glycol	6,00E-14	4,14E-14	8,18E-15	4,90E-15	7,43E-15	-1,96E-15
Xylene (isomers; dimethyl benzene)	6,20E-09	3,34E-09	5,31E-10	3,12E-10	1,83E-09	1,85E-10
Ethylene Glycol	1,07E-22	1,07E-22	-	-	-	-
Naphthalene	1,41E-10	1,41E-10	-	-	-	-
Other emissions to sea water						
Acetamide	5,18E-15	2,52E-15	7,28E-16	3,03E-16	1,70E-15	-7,23E-17
Tributyltinoxide	2,91E-10	1,42E-10	4,22E-11	2,07E-11	1,14E-10	-2,67E-11
Heavy metals to agricultural soil						
Antimony	1,57E-05	9,03E-06	8,22E-07	2,29E-06	3,39E-06	1,31E-07
Arsenic	1,72E-02	1,42E-02	9,07E-04	5,73E-04	1,49E-03	-6,24E-05
Arsenic (+V)	5,40E-15	5,40E-15	-	-	-	-
Cadmium	3,35E-03	2,45E-03	3,18E-04	1,88E-04	3,99E-04	-1,42E-05
Chromium	2,45E-01	1,83E-01	2,38E-02	1,49E-02	2,43E-02	-1,13E-03
Chromium (+III)	3,48E-06	3,48E-06	-	-	-	-
Cobalt	1,81E-03	1,35E-03	1,76E-04	1,14E-04	1,75E-04	-8,12E-06
Copper	3,14E-01	2,36E-01	2,36E-02	2,01E-02	3,51E-02	-1,43E-03
Lead	7,48E-04	5,30E-04	7,07E-05	5,13E-05	9,98E-05	-3,34E-06
Mercury	3,37E-04	1,20E-04	2,27E-05	2,64E-05	1,70E-04	-2,23E-06
Molybdenum	4,82E-05	1,96E-05	2,62E-06	1,96E-06	2,41E-05	-1,27E-07
Nickel	2,05E-02	1,49E-02	1,89E-03	1,25E-03	2,58E-03	-8,94E-05
Silver	1,53E-11	5,13E-12	9,52E-13	6,87E-12	2,04E-12	3,21E-13
Tin	1,07E-04	3,29E-05	8,86E-06	2,57E-05	4,01E-05	-3,99E-07
Vanadium	1,02E-01	7,94E-02	1,02E-02	5,98E-03	6,88E-03	-4,69E-04

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Zinc	1,72E+00	1,26E+00	1,63E-01	1,08E-01	2,00E-01	-8,18E-03
Inorganic emissions to agricultural soil						
Barium	9,06E-06	5,24E-06	5,47E-07	6,11E-07	2,18E-06	4,87E-07
Sulphuric acid	5,22E-11	1,89E-11	7,67E-12	1,39E-12	2,31E-11	1,06E-12
Organic emissions to agricultural soil						
Azoxystrobin	2,04E-06	3,71E-07	2,47E-07	1,73E-08	1,41E-06	-3,63E-09
Bromoxynil	1,98E-07	1,69E-07	5,78E-09	1,74E-09	2,13E-08	1,34E-10
Mepiquat chloride	4,30E-11	6,94E-12	5,76E-12	4,93E-13	2,98E-11	-3,94E-14
Other emissions to agricultural soil						
2,4-Dichlorophenoxyacetic acid (2,4-D)	1,15E-03	4,81E-04	1,39E-04	4,30E-05	4,99E-04	-8,83E-06
Acephate	1,27E-05	2,04E-06	1,70E-06	1,52E-07	8,79E-06	-1,34E-08
Acetamide	5,58E-09	9,08E-10	7,51E-10	6,81E-11	3,86E-09	-6,13E-12
Acetochlor	1,13E-05	6,94E-06	1,69E-06	7,96E-07	1,99E-06	-1,13E-07
Aclonifen	5,75E-08	2,21E-08	7,76E-09	2,58E-09	2,56E-08	-5,29E-10
Alachlor	3,07E-05	2,55E-05	1,36E-06	7,07E-07	3,29E-06	-1,38E-07
Aldicarb	1,98E-03	3,12E-04	2,67E-04	2,28E-05	1,38E-03	-1,84E-06
Aldrin	4,10E-03	3,59E-03	1,01E-04	6,58E-05	3,54E-04	-1,27E-05
Anthraquinone	2,58E-09	2,25E-09	5,13E-11	1,05E-11	2,63E-10	3,85E-12
Asulam	5,76E-13	2,23E-13	8,27E-14	1,53E-14	2,43E-13	1,09E-14
Atrazine	8,77E-02	3,17E-02	8,94E-04	5,86E-04	5,47E-02	-1,39E-04
Azodrin	4,39E-04	1,69E-04	5,92E-05	1,97E-05	1,95E-04	-4,04E-06
Benomyl	1,41E-06	8,52E-08	1,90E-07	8,16E-09	1,13E-06	-2,04E-09
Bensulfuron methyl ester	1,61E-09	1,40E-09	3,20E-11	6,53E-12	1,64E-10	2,40E-12
Bentazone	1,20E-07	5,26E-08	1,51E-08	5,18E-09	4,78E-08	-1,08E-09
Bifenox	4,16E-08	3,63E-08	8,26E-10	1,69E-10	4,24E-09	6,21E-11
Bifenthrin	3,10E-08	1,90E-08	4,64E-09	2,18E-09	5,46E-09	-3,10E-10
Bitertanol	9,26E-11	8,08E-11	1,84E-12	3,76E-13	9,44E-12	1,38E-13
Bromuconazole	3,59E-09	3,13E-09	7,14E-11	1,46E-11	3,66E-10	5,36E-12
Carbaryl	2,28E-06	1,60E-06	3,13E-07	1,82E-07	2,30E-07	-4,98E-08
Carbendazim	6,07E-03	3,81E-03	8,86E-04	4,76E-04	1,03E-03	-1,32E-04
Carbofuran	4,66E-02	2,84E-03	6,27E-03	2,72E-04	3,73E-02	-6,83E-05
Carfentrazone ethyl ester	4,70E-09	4,10E-09	9,35E-11	1,91E-11	4,79E-10	7,03E-12
Carfentrazone-ethyl	2,56E-08	1,25E-08	3,60E-09	1,50E-09	8,42E-09	-3,58E-10
Chloridazon	3,75E-07	3,27E-07	7,46E-09	1,52E-09	3,82E-08	5,61E-10
Chlorothalonil	6,82E-01	1,03E-02	1,84E-03	6,32E-03	6,64E-01	-8,77E-04
Chlorpyriphos	1,46E-02	2,54E-03	1,96E-03	2,01E-04	9,90E-03	-2,21E-05
Chlorsulfuron	9,03E-09	7,88E-09	1,80E-10	3,67E-11	9,21E-10	1,35E-11
Chlortoluron	1,29E-08	1,12E-08	2,62E-10	5,35E-11	1,33E-09	2,01E-11
Choline chloride	3,41E-09	2,97E-09	6,77E-11	1,38E-11	3,47E-10	5,09E-12
Clethodim	8,88E-08	5,50E-08	1,28E-08	6,80E-09	1,61E-08	-1,81E-09
Clodinafop-propargyl	4,53E-08	3,95E-08	9,01E-10	1,84E-10	4,62E-09	6,77E-11
Clopyralid	3,80E-07	2,72E-07	5,44E-08	3,25E-08	3,09E-08	-9,03E-09
Cloquintocet-mexyl	1,66E-10	1,45E-10	3,30E-12	6,74E-13	1,69E-11	2,48E-13

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Cyfluthrin	2,88E-04	4,85E-05	3,88E-05	3,75E-06	1,98E-04	-3,81E-07
Cypermethrin	1,22E-01	1,45E-02	1,55E-02	1,71E-03	9,10E-02	-3,69E-04
Cyproconazole	5,53E-09	4,80E-09	1,18E-10	2,66E-11	5,69E-10	7,57E-12
Cyprodinil (CGA-219417)	3,23E-06	1,48E-07	3,70E-07	3,88E-09	2,70E-06	1,85E-09
Deltamethrin	3,53E-06	2,50E-06	5,21E-07	3,13E-07	2,84E-07	-8,71E-08
Desmedipham	4,24E-09	2,70E-09	6,36E-10	3,13E-10	6,40E-10	-5,62E-11
Dicamba	1,20E-07	9,42E-08	7,48E-09	3,50E-09	1,58E-08	-5,83E-10
Dichlorprop	5,36E-13	4,65E-13	1,13E-14	2,30E-15	5,63E-14	8,93E-16
Diclofop-methyl	3,68E-08	3,22E-08	7,33E-10	1,50E-10	3,76E-09	5,51E-11
Dicrotophos	1,40E-05	2,21E-06	1,88E-06	1,61E-07	9,76E-06	-1,30E-08
Difenoconazole	1,91E-04	2,31E-05	2,36E-05	2,73E-06	1,42E-04	-5,16E-07
Diflubenzuron	4,81E-01	1,85E-01	6,49E-02	2,15E-02	2,14E-01	-4,43E-03
Diflufenican	9,53E-10	8,31E-10	1,91E-11	3,90E-12	9,75E-11	1,44E-12
Dimethachlor	2,49E-04	1,76E-04	3,67E-05	2,20E-05	2,00E-05	-6,14E-06
Dimethazone	2,83E-05	2,01E-05	4,14E-06	2,48E-06	2,29E-06	-6,90E-07
Dimethenamid	1,80E-05	1,54E-05	7,42E-07	4,11E-07	1,46E-06	-6,60E-08
Dimethoate	4,47E-07	3,89E-07	9,11E-09	1,86E-09	4,62E-08	7,00E-10
Dithianon	4,16E-09	3,62E-09	8,50E-11	1,73E-11	4,30E-10	6,53E-12
Diuron	4,27E-03	3,80E-03	1,05E-04	6,33E-05	3,14E-04	-1,11E-05
Endosulfan	3,90E-03	1,50E-03	5,26E-04	1,75E-04	1,73E-03	-3,59E-05
Endothall	3,50E-08	2,48E-08	5,17E-09	3,10E-09	2,81E-09	-8,64E-10
Epoxiconazole	6,44E-09	5,55E-09	1,65E-10	4,55E-11	6,72E-10	5,68E-12
Esfenvalerate	8,02E-06	3,91E-06	1,12E-06	4,67E-07	2,63E-06	-1,11E-07
Ethalfluralin	2,16E-04	1,53E-04	3,19E-05	1,91E-05	1,74E-05	-5,34E-06
Ethephon	1,09E-05	1,94E-06	1,44E-06	1,24E-07	7,45E-06	-9,41E-09
Ethofumesate	4,73E-07	7,14E-09	5,62E-08	7,74E-10	4,08E-07	2,03E-10
Fenbuconazole	9,11E-11	7,93E-11	1,86E-12	3,79E-13	9,41E-12	1,43E-13
Fenoxaprop ethyl ester	1,62E-09	1,42E-09	3,23E-11	6,60E-12	1,65E-10	2,43E-12
Fenoxaprop-p-ethyl	2,59E-10	1,65E-10	3,89E-11	1,91E-11	3,92E-11	-3,44E-12
Fenpiclonil	1,78E-04	2,70E-06	4,81E-07	1,65E-06	1,74E-04	-2,29E-07
Fenpropimorph	1,53E-09	1,32E-09	3,92E-11	1,07E-11	1,61E-10	1,44E-12
Fipronil	1,76E-03	2,78E-04	2,37E-04	2,03E-05	1,23E-03	-1,64E-06
Fluazifop-p-butyl	5,88E-06	4,13E-06	8,67E-07	5,17E-07	5,10E-07	-1,44E-07
Fludioxonil	2,21E-06	4,11E-08	2,61E-07	2,45E-09	1,91E-06	1,20E-09
Flufenacet	5,17E-07	3,32E-07	4,75E-08	1,89E-08	1,23E-07	-3,99E-09
Flumetsulam	2,06E-07	1,11E-07	2,98E-08	1,31E-08	5,46E-08	-2,54E-09
Flumiclorac-pentyl	1,75E-08	8,50E-09	2,45E-09	1,02E-09	5,74E-09	-2,44E-10
Flumioxazin	1,14E-05	4,61E-06	1,55E-06	5,40E-07	4,84E-06	-1,15E-07
Fluroxypyr	2,50E-07	2,18E-07	4,98E-09	1,02E-09	2,55E-08	3,74E-10
Fomesafen	5,30E-07	2,45E-07	7,38E-08	2,92E-08	1,90E-07	-6,77E-09
Glyphosate	1,84E-03	2,12E-04	1,96E-04	1,34E-05	1,42E-03	-2,31E-06
Halosulfuron-methyl	9,28E-07	8,10E-07	1,84E-08	3,77E-09	9,46E-08	1,39E-09
Imazamox	8,62E-07	3,36E-07	1,16E-07	3,90E-08	3,79E-07	-8,07E-09

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Imazapyr	2,53E-11	1,56E-11	3,79E-12	1,78E-12	4,46E-12	-2,54E-13
Imazethapyr	1,99E-07	7,86E-08	2,70E-08	9,18E-09	8,65E-08	-1,92E-09
Imidacloprid	5,16E-06	8,13E-07	6,94E-07	5,94E-08	3,60E-06	-4,80E-09
Ioxynil	2,96E-07	2,58E-07	5,92E-09	1,21E-09	3,03E-08	4,47E-10
Iprodione	1,03E-03	7,31E-04	1,52E-04	9,15E-05	8,30E-05	-2,55E-05
Isoproturon	8,38E-06	7,30E-06	1,69E-07	3,46E-08	8,61E-07	1,29E-08
Isoxaflutole	4,34E-09	2,65E-09	6,49E-10	3,04E-10	7,76E-10	-4,20E-11
Kresoxim-methyl	2,92E-09	2,49E-09	8,93E-11	2,84E-11	3,11E-10	1,02E-12
Lambda cyhalothrin	8,61E-04	5,80E-04	1,26E-04	7,17E-05	1,03E-04	-1,98E-05
Lenacil	1,36E-08	8,67E-09	2,04E-09	1,00E-09	2,05E-09	-1,80E-10
Linuron	2,11E-02	1,64E-02	9,84E-04	4,58E-04	3,33E-03	-9,06E-05
Malathion	1,32E-04	8,15E-06	1,77E-05	7,85E-07	1,05E-04	-1,97E-07
Mancozeb	2,68E-02	4,06E-04	7,22E-05	2,48E-04	2,61E-02	-3,45E-05
MCPA	3,52E-07	3,07E-07	7,00E-09	1,43E-09	3,59E-08	5,26E-10
MCPB	2,41E-10	9,46E-11	3,44E-11	6,38E-12	1,01E-10	4,54E-12
Mecoprop	2,66E-08	2,32E-08	5,29E-10	1,08E-10	2,71E-09	3,98E-11
Mecoprop-P	1,86E-08	1,62E-08	3,72E-10	7,60E-11	1,90E-09	2,81E-11
Metalaxyl	1,81E-06	1,09E-07	2,43E-07	1,04E-08	1,45E-06	-2,62E-09
Metamitron	2,53E-09	1,62E-09	3,80E-10	1,87E-10	3,83E-10	-3,35E-11
Metam-sodium	1,14E-04	6,90E-06	1,54E-05	6,60E-07	9,15E-05	-1,65E-07
Metazachlor	7,40E-05	5,24E-05	1,09E-05	6,56E-06	5,95E-06	-1,83E-06
Methomyl	1,22E-12	1,06E-12	2,42E-14	4,94E-15	1,24E-13	1,82E-15
Metolachlor	4,08E-02	6,43E-03	2,23E-03	7,46E-04	3,16E-02	-1,67E-04
Metribuzin	1,15E-03	6,21E-05	1,90E-05	1,50E-05	1,06E-03	-2,44E-06
Metsulfuron-methyl	1,87E-04	3,63E-05	2,52E-05	4,08E-06	1,22E-04	-8,68E-07
Molinate	3,32E-06	2,89E-06	6,59E-08	1,35E-08	3,38E-07	4,96E-09
MSMA	8,08E-08	1,27E-08	1,09E-08	9,30E-10	5,64E-08	-7,51E-11
Napropamide	2,67E-04	1,97E-04	4,11E-05	2,47E-05	1,04E-05	-6,88E-06
Nicosulfuron	1,42E-09	8,75E-10	2,13E-10	1,00E-10	2,51E-10	-1,43E-11
Orbencarb	3,77E-04	5,71E-06	1,02E-06	3,49E-06	3,67E-04	-4,85E-07
Oxydemeton-methyl	1,72E-08	1,50E-08	3,51E-10	7,15E-11	1,78E-09	2,70E-11
Paraquat	1,65E-06	1,49E-07	2,22E-07	1,42E-08	1,27E-06	-3,08E-09
Parathion-ethyl	1,73E-04	1,31E-04	1,85E-05	1,10E-05	1,54E-05	-3,21E-06
Parathion-methyl	9,60E-08	4,67E-08	1,35E-08	5,61E-09	3,15E-08	-1,34E-09
Pendimethalin	1,83E-04	6,50E-05	2,45E-05	7,22E-06	8,73E-05	-1,46E-06
Permethrin	5,14E-08	2,53E-08	7,25E-09	3,03E-09	1,66E-08	-7,09E-10
Phenmedipham	3,25E-09	2,08E-09	4,88E-10	2,40E-10	4,93E-10	-4,30E-11
Picloram	7,30E-10	6,37E-10	1,45E-11	2,97E-12	7,44E-11	1,09E-12
Pirimicarb	2,95E-06	3,21E-08	3,50E-07	3,19E-09	2,56E-06	1,58E-09
Prochloraz	1,05E-06	9,13E-07	2,11E-08	4,31E-09	1,08E-07	1,61E-09
Procymidone	9,72E-07	6,88E-07	1,43E-07	8,61E-08	7,81E-08	-2,40E-08
Profenofos	3,28E-03	5,17E-04	4,41E-04	3,77E-05	2,29E-03	-3,05E-06
Prometryne	9,38E-05	1,48E-05	1,26E-05	1,08E-06	6,54E-05	-8,72E-08

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Propanil	6,96E-04	6,07E-04	1,38E-05	2,83E-06	7,09E-05	1,04E-06
Propiconazole	7,95E-08	6,12E-08	4,13E-09	1,47E-09	1,29E-08	-2,07E-10
Prosulfuron	4,96E-08	4,40E-08	1,38E-09	8,31E-10	3,48E-09	-1,39E-10
Pyrithiobac-sodium salt	3,98E-08	6,27E-09	5,35E-09	4,58E-10	2,78E-08	-3,70E-11
Quinclorac	2,80E-08	2,44E-08	5,57E-10	1,14E-10	2,85E-09	4,18E-11
Quizalofop-ethyl	1,35E-06	9,56E-07	2,00E-07	1,20E-07	1,11E-07	-3,33E-08
Rimsulfuron	1,11E-08	6,83E-09	1,66E-09	7,83E-10	1,96E-09	-1,11E-10
Sethoxydim	6,98E-07	4,94E-07	1,03E-07	6,18E-08	5,67E-08	-1,72E-08
Simazine	7,67E-07	4,71E-07	1,15E-07	5,40E-08	1,35E-07	-7,68E-09
Sulfosulfuron	1,24E-08	1,08E-08	2,47E-10	5,04E-11	1,26E-09	1,85E-11
Tebuconazole	1,47E-04	1,04E-04	2,16E-05	1,30E-05	1,18E-05	-3,61E-06
Tebupirimphos	8,54E-08	5,24E-08	1,28E-08	6,01E-09	1,50E-08	-8,55E-10
Teflubenzuron	1,48E-03	2,25E-05	4,00E-06	1,38E-05	1,45E-03	-1,91E-06
Tefluthrin	9,67E-08	6,05E-08	1,39E-08	6,53E-09	1,67E-08	-9,20E-10
Terbufos	1,48E-05	1,23E-05	7,99E-07	4,21E-07	1,36E-06	-6,54E-08
Thidiazuron	3,93E-07	6,20E-08	5,29E-08	4,52E-09	2,74E-07	-3,66E-10
Thifensulfuron methyl	5,14E-07	3,39E-07	4,45E-08	1,75E-08	1,17E-07	-3,62E-09
Thiobencarb	2,53E-06	2,21E-06	5,03E-08	1,03E-08	2,58E-07	3,78E-09
Thiodicarb	1,07E-07	5,19E-08	1,50E-08	6,23E-09	3,50E-08	-1,49E-09
Thiram	7,22E-04	4,36E-05	9,71E-05	4,17E-06	5,78E-04	-1,04E-06
Triadimenol	3,43E-09	2,99E-09	6,92E-11	1,41E-11	3,52E-10	5,27E-12
Triallate	4,18E-09	3,65E-09	8,31E-11	1,70E-11	4,26E-10	6,24E-12
Triasulfuron	3,17E-08	2,76E-08	6,30E-10	1,29E-10	3,23E-09	4,73E-11
Tribenuron methyl	1,74E-09	1,25E-09	1,17E-10	4,41E-11	3,32E-10	-7,92E-12
Tribufos	1,64E-07	2,58E-08	2,20E-08	1,88E-09	1,14E-07	-1,52E-10
Triclopyr	8,43E-05	6,54E-05	9,41E-06	1,64E-06	7,99E-06	-1,75E-07
Trifluralin	8,17E-04	5,79E-04	1,24E-04	7,22E-05	6,26E-05	-2,00E-05
Trinexapac-ethyl	1,43E-08	1,24E-08	2,88E-10	5,88E-11	1,46E-09	2,19E-11
Vinclozolin	8,03E-06	5,68E-06	1,19E-06	7,12E-07	6,45E-07	-1,98E-07
Heavy metals to industrial soil						
Antimony	1,12E-03	1,83E-04	1,14E-04	3,46E-05	4,29E-04	3,62E-04
Arsenic	4,44E-03	2,47E-03	4,20E-04	2,31E-04	1,12E-03	2,01E-04
Arsenic (+V)	8,72E-11	8,72E-11	-	-	-	-
Cadmium	1,55E-04	3,13E-05	1,55E-05	5,45E-06	5,79E-05	4,45E-05
Chromium	6,49E-02	3,75E-02	6,09E-03	3,44E-03	1,59E-02	1,95E-03
Chromium (+III)	8,00E-13	8,00E-13	-	-	-	-
Chromium (+VI)	1,87E+00	1,26E+00	3,04E-01	1,94E-01	1,72E-01	-5,94E-02
Cobalt	1,77E-04	3,41E-05	1,78E-05	6,05E-06	6,63E-05	5,25E-05
Copper	6,82E-01	4,43E-01	1,09E-01	6,90E-02	7,28E-02	-1,15E-02
Lead	2,66E-04	5,57E-05	2,67E-05	9,58E-06	9,92E-05	7,50E-05
Mercury	1,12E-05	5,68E-06	9,98E-07	7,76E-07	3,38E-06	3,60E-07
Molybdenum	2,43E-06	3,95E-07	2,47E-07	7,49E-08	9,26E-07	7,82E-07
Nickel	1,77E-03	4,32E-04	1,76E-04	7,06E-05	6,49E-04	4,47E-04

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Selenium	4,37E-04	7,12E-05	4,46E-05	1,35E-05	1,67E-04	1,41E-04
Silver	5,93E-05	9,66E-06	6,04E-06	1,83E-06	2,26E-05	1,91E-05
Vanadium	3,42E-04	5,57E-05	3,49E-05	1,06E-05	1,31E-04	1,10E-04
Zinc	1,09E+00	2,44E-01	1,09E-01	3,72E-02	3,96E-01	3,00E-01
Inorganic emissions to agricultural soil						
Barium	1,76E-01	1,06E-01	1,64E-02	9,57E-03	4,18E-02	2,33E-03
Beryllium	1,08E-15	1,08E-15	-	-	-	-
Organic emissions to agricultural soil						
Acetic acid	2,37E-12	2,37E-12	-	-	-	-
Methanol	6,85E-15	6,85E-15	-	-	-	-
Pentachlorophenol (PCP)	8,81E-07	5,62E-07	1,41E-07	8,17E-08	1,21E-07	-2,42E-08
Other emissions to agricultural soil						
Glyphosate	3,12E-04	1,87E-04	3,43E-05	1,54E-05	7,93E-05	-4,40E-06

Table B.3: Particulate matter / respiratory inorganics (midpoint, v1.09) of one sc-Si PV-module (60 6-inch solar cells) in kg PM2.5 equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Ammonia	4,28E-06	2,49E-09	3,84E-10	3,90E-06	3,83E-07	-1,23E-10
Particulates, < 2.5 um	9,31E-04	6,57E-04	1,45E-04	8,87E-05	4,68E-05	-6,72E-06
Inorganic emissions to air						
Ammonia	1,11E-03	4,88E-04	9,29E-05	1,63E-04	3,87E-04	-1,88E-05
Carbon monoxide	1,07E-04	6,06E-05	2,14E-05	1,18E-05	3,14E-05	-1,79E-05
Carbon monoxide, non-fossil	4,27E-05	3,72E-05	1,10E-06	2,02E-06	2,29E-06	1,07E-07
Nitrogen dioxide	2,73E-08	2,73E-08	-	-	-	-
Nitrogen monoxide	5,57E-07	5,57E-07	-	-	-	-
Nitrogen oxides	5,21E-03	3,43E-03	4,12E-04	3,51E-04	1,17E-03	-1,48E-04
Sulphur dioxide	8,12E-02	5,59E-02	6,83E-03	3,92E-03	1,75E-02	-2,90E-03
Sulphur oxides	1,34E-05	5,38E-08	9,90E-09	7,27E-09	1,33E-05	-3,09E-09
Sulphur trioxide	4,23E-09	1,85E-09	4,30E-10	1,47E-10	1,80E-09	8,66E-12
Particles to air						
Dust (PM10)	5,62E-11	5,62E-11	-	-	-	-
Dust (PM2.5)	2,89E-01	2,26E-01	1,56E-02	1,09E-02	4,73E-02	-1,13E-02

Table B.4: Resource depletion, mineral, fossils and renewables, midpoint (v1.09) of one sc-Si PV-module (60 6-inch solar cells) in kg Sb equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Non-renewable energy resources						
Crude oil (in MJ)	2,49E-09	2,49E-09	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Crude oil ecoinvent	4,67E-06	2,06E-06	5,81E-07	2,09E-07	1,81E-06	7,56E-09
Oil sand (10% bitumen) (in MJ)	6,97E-12	6,97E-12	-	-	-	-
Oil sand (100% bitumen) (in MJ)	6,08E-12	6,08E-12	-	-	-	-
Coal, hard, unspecified, in ground	1,24E-05	9,82E-06	1,03E-06	6,33E-07	1,39E-06	-4,62E-07
Hard coal (in MJ)	1,12E-11	1,12E-11	-	-	-	-
Coal, brown, in ground	4,33E-06	3,26E-06	5,64E-07	3,45E-07	2,65E-07	-1,10E-07
Lignite (in MJ)	6,21E-12	6,21E-12	-	-	-	-
Coalbed methane (in MJ)	2,98E-13	2,98E-13	-	-	-	-
Gas, mine, off-gas, process, coal mining	2,41E-07	1,91E-07	2,13E-08	1,32E-08	2,48E-08	-8,60E-09
Gas, natural, in ground	7,35E-06	4,65E-06	8,07E-07	4,17E-07	1,79E-06	-3,15E-07
Natural gas (in MJ)	1,91E-10	1,91E-10	-	-	-	-
Pit Methane (in MJ)	1,77E-13	1,77E-13	-	-	-	-
Shale gas (in MJ)	1,80E-12	1,80E-12	-	-	-	-
Tight gas (in MJ)	1,89E-12	1,89E-12	-	-	-	-
Peat (in kg)	1,16E-07	7,86E-08	2,06E-08	1,22E-08	5,19E-09	-1,15E-10
Peat (in MJ)	6,81E-14	6,81E-14	-	-	-	-
Uranium natural (in MJ)	6,65E-10	6,65E-10	-	-	-	-
Uranium, in ground	4,55E-04	3,20E-04	7,16E-05	4,36E-05	2,44E-05	-4,91E-06
Non-renewable elements						
Aluminium	-4,95E-07	8,00E-07	3,07E-07	2,62E-06	1,06E-05	-1,49E-05
Antimony	6,96E-10	6,96E-10	-	-	-	-
Cadmium	4,51E-03	1,81E-04	1,41E-04	1,21E-04	1,98E-03	2,09E-03
Cerium	3,18E-14	1,39E-14	4,61E-15	1,87E-15	1,11E-14	2,25E-16
Chromium	1,22E-06	3,01E-07	5,10E-07	8,48E-08	3,22E-07	-1,38E-09
Cobalt	7,30E-08	1,49E-08	9,00E-09	2,04E-09	4,68E-08	2,77E-10
Copper	6,41E-04	4,55E-05	4,48E-05	2,42E-04	3,51E-04	-4,24E-05
Dysprosium	7,73E-21	7,73E-21	-	-	-	-
Erbium	2,32E-21	2,32E-21	-	-	-	-
Europium	7,96E-17	3,49E-17	1,16E-17	4,69E-18	2,79E-17	5,64E-19
Gadolinium	1,99E-16	8,71E-17	2,89E-17	1,17E-17	6,96E-17	1,41E-18
Gallium	1,04E-13	8,13E-15	1,37E-15	8,65E-14	7,89E-15	2,42E-16
Gold	1,21E-03	1,63E-05	7,48E-06	1,14E-03	4,53E-05	2,80E-06
Holmium	1,55E-20	1,55E-20	-	-	-	-
Indium	3,74E-02	1,51E-03	1,17E-03	1,01E-03	1,64E-02	1,73E-02
Iodine	6,22E-09	2,05E-09	4,62E-10	1,99E-10	3,56E-09	-4,75E-11
Iron	4,10E-06	1,23E-06	1,94E-06	4,36E-07	4,70E-07	2,43E-08
Lanthanum	9,52E-15	4,17E-15	1,38E-15	5,61E-16	3,34E-15	6,75E-17
Lead	1,25E-03	4,76E-05	3,62E-05	1,96E-04	5,03E-04	4,72E-04
Lithium	2,56E-07	4,43E-08	9,92E-09	8,20E-09	1,94E-07	4,02E-11
Lutetium	1,55E-22	1,55E-22	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Magnesium	3,16E-15	3,16E-15	-	-	-	-
Manganese	1,04E-06	1,05E-07	3,93E-07	4,40E-08	4,97E-07	4,53E-09
Mercury	9,91E-17	9,91E-17	-	-	-	-
Molybdenum	1,72E-04	2,34E-05	3,55E-05	6,99E-06	1,49E-04	-4,32E-05
Neodymium	5,24E-15	2,30E-15	7,61E-16	3,09E-16	1,84E-15	3,71E-17
Nickel	1,66E-04	4,37E-05	7,14E-05	1,27E-05	3,83E-05	-3,27E-07
Palladium	3,46E-06	4,97E-07	2,49E-07	1,01E-07	2,59E-06	2,41E-08
Phosphorus	4,16E-07	5,15E-08	1,30E-08	1,70E-07	1,76E-07	5,49E-09
Platinum	1,95E-06	4,59E-07	1,67E-07	7,39E-08	1,24E-06	4,82E-09
Praseodymium	5,56E-16	2,44E-16	8,07E-17	3,28E-17	1,95E-16	3,94E-18
Rhenium	5,03E-08	2,56E-08	6,24E-09	2,07E-09	1,71E-08	-6,18E-10
Silver	1,11E-02	7,81E-05	5,41E-05	9,89E-03	7,13E-04	4,03E-04
Strontium	1,52E-05	4,27E-07	4,14E-07	4,08E-08	6,87E-06	7,47E-06
Sulphur	7,29E-07	3,99E-08	2,08E-08	4,20E-08	3,09E-06	-2,46E-06
Tantalum	5,75E-05	2,09E-05	8,55E-06	1,50E-06	2,55E-05	1,17E-06
Tellurium	6,97E-07	1,43E-10	6,02E-11	6,97E-07	2,38E-10	8,29E-11
Thulium	7,73E-23	7,73E-23	-	-	-	-
Tin	4,32E-04	5,07E-06	1,05E-06	2,85E-07	3,05E-03	-2,63E-03
Titanium	9,38E-14	9,38E-14	-	-	-	-
Vanadium	-4,91E-14	-4,91E-14	-	-	-	-
Ytterbium	1,55E-22	1,55E-22	-	-	-	-
Yttrium	2,98E-17	2,98E-17	-	-	-	-
Zinc	5,22E-04	2,01E-05	1,53E-05	6,51E-05	2,14E-04	2,07E-04
Zirconium	9,38E-05	2,04E-05	1,05E-06	6,21E-07	7,27E-05	-9,66E-07
Non-renewable resources						
Anhydrite (Rock)	1,31E-09	1,67E-10	2,52E-10	2,86E-11	1,00E-09	-1,39E-10
Barite, 15% in crude ore, in ground	1,62E-04	9,89E-05	1,78E-05	8,09E-06	3,60E-05	1,35E-06
Barium sulphate	1,06E-19	1,06E-19	-	-	-	-
Bauxite	9,22E-12	9,22E-12	-	-	-	-
Borax	1,71E-06	1,68E-06	1,10E-08	6,77E-09	1,46E-08	-1,23E-10
Cinnabar	4,95E-06	3,36E-06	1,44E-06	9,19E-08	1,88E-07	-1,23E-07
Colemanite ore	4,90E-07	3,17E-07	3,74E-08	6,66E-08	6,98E-08	-1,56E-09
Ferro manganese	3,93E-25	3,93E-25	-	-	-	-
Fluorspar (calcium fluoride; fluorite)	1,45E-03	1,53E-04	2,41E-05	3,57E-06	1,27E-03	6,37E-07
Graphite	1,00E-16	1,00E-16	-	-	-	-
Heavy spar (BaSO4)	2,50E-14	2,50E-14	-	-	-	-
Ilmenite (titanium ore)	5,17E-13	5,17E-13	-	-	-	-
Kaolin ore	5,89E-15	5,89E-15	-	-	-	-
Kaolinite (24% in ore as mined)	4,07E-08	2,45E-09	5,27E-10	1,35E-09	4,44E-08	-8,01E-09
Magnesit (Magnesium carbonate)	7,06E-12	7,06E-12	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Magnesite	3,06E-08	4,16E-09	1,23E-08	1,92E-09	6,27E-09	5,98E-09
Magnesium chloride leach (40%)	6,64E-14	6,64E-14	-	-	-	-
Olivine	3,83E-12	4,60E-13	6,93E-13	8,55E-14	4,02E-12	-1,43E-12
Perlite (Rhyolithe)	1,22E-09	2,92E-11	1,20E-11	1,49E-12	9,65E-10	2,11E-10
Phosphate ore	1,04E-09	1,04E-09	-	-	-	-
Potashsalt, crude (hard salt, 10% K2O)	2,00E-10	2,00E-10	-	-	-	-
Potassium chloride	-2,98E-19	-2,98E-19	-	-	-	-
Sodium sulphate	1,34E-08	3,09E-09	1,11E-09	4,04E-10	8,08E-09	7,57E-10
Spodumen (LiAlSi2 O6)	2,89E-09	5,21E-10	1,28E-10	9,17E-11	2,13E-09	2,14E-11
Sulphur (bonded)	1,08E-13	1,08E-13	-	-	-	-
Talc	4,43E-07	5,11E-08	8,94E-09	2,96E-08	6,00E-07	-2,46E-07
Tin ore (0.01%)	2,89E-15	2,89E-15	-	-	-	-
Titanium dioxide	4,34E-05	9,30E-06	4,80E-07	2,84E-07	3,38E-05	-4,41E-07
Titanium ore	1,08E-14	1,08E-14	-	-	-	-
Ulexite	1,30E-06	5,04E-08	1,04E-08	6,27E-09	7,14E-06	-5,91E-06

Table B.5: Human toxicity midpoint, cancer effects (v1.09) of one sc-Si PV-module (60 6-inch solar cells) in CTUh

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Acetaldehyde	9,44E-11	-	-	9,44E-11	-	-
Arsenic	2,04E-09	1,44E-09	3,20E-10	1,96E-10	9,52E-11	-1,46E-11
Beryllium	9,24E-12	6,53E-12	1,45E-12	8,88E-13	4,32E-13	-6,62E-14
Cadmium	3,41E-11	2,41E-11	5,37E-12	3,28E-12	1,60E-12	-2,44E-13
Chromium VI	3,31E-09	2,34E-09	5,20E-10	3,18E-10	1,55E-10	-2,37E-11
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	1,06E-12	6,84E-15	1,05E-15	7,74E-16	1,05E-12	-3,39E-16
Lead	2,78E-10	1,97E-10	4,37E-11	2,67E-11	1,30E-11	-1,99E-12
Mercury	5,60E-10	3,96E-10	8,80E-11	5,38E-11	2,62E-11	-4,01E-12
Nickel	1,10E-10	7,74E-11	1,72E-11	1,05E-11	5,12E-12	-7,84E-13
Heavy metals to air						
Arsenic	3,68E-08	9,39E-09	2,38E-09	1,03E-09	2,39E-08	1,75E-10
Arsenic (+V)	1,88E-14	1,88E-14	-	-	-	-
Cadmium	7,15E-09	1,12E-09	4,50E-10	1,96E-10	5,25E-09	1,28E-10
Chromium	4,81E-07	1,56E-07	2,03E-07	3,45E-08	9,14E-08	-3,40E-09
Chromium (+VI)	3,20E-08	1,50E-08	1,03E-08	1,94E-09	5,19E-09	-4,23E-10
Lead	1,02E-08	2,59E-09	7,19E-10	9,63E-10	5,44E-09	5,12E-10
Mercury	8,37E-08	4,98E-08	1,78E-08	5,63E-09	1,11E-08	-6,73E-10
Nickel	1,47E-08	5,36E-09	1,07E-09	4,87E-10	7,91E-09	-1,64E-10

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Inorganic emissions to air						
Beryllium	4,55E-11	3,85E-11	1,33E-12	6,74E-13	5,84E-12	-7,86E-13
Organic emissions to air (group VOC)						
Benzo{a}pyrene	8,33E-10	5,88E-10	1,10E-10	3,19E-11	1,13E-10	-1,04E-11
Dibenz(a)anthracene	2,67E-17	8,01E-18	5,95E-18	1,82E-18	9,83E-18	1,09E-18
Naphthalene	2,42E-14	2,40E-16	2,75E-15	2,28E-17	2,03E-14	9,51E-16
Carbon tetrachloride (tetrachloromethane)	2,44E-10	1,89E-10	4,94E-11	3,93E-12	4,74E-12	-2,88E-12
Dichloroethane (ethylene dichloride)	1,46E-12	7,06E-13	1,25E-13	1,53E-13	5,77E-13	-9,85E-14
Dichloromethane (methylene chloride)	1,28E-13	1,06E-13	5,68E-15	4,55E-15	1,87E-14	-7,36E-15
Hexachlorobenzene (Perchlorobenzene)	1,38E-12	2,78E-13	8,41E-13	1,24E-13	1,13E-13	1,94E-14
Pentachlorophenol (PCP)	4,19E-11	2,95E-11	5,51E-12	1,50E-12	5,29E-12	4,48E-14
Polychlorinated biphenyls (PCB unspecified)	3,11E-12	7,33E-13	1,75E-12	2,65E-13	2,79E-13	8,49E-14
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	2,91E-09	1,47E-09	3,96E-10	3,05E-10	5,04E-10	2,42E-10
Polychlorinated dibenzo-p-furans (2,3,7,8 - TCDD)	1,79E-16	1,79E-16	-	-	-	-
Tetrachloroethene (perchloroethylene)	2,09E-13	6,84E-14	3,75E-15	1,29E-13	1,28E-14	-5,31E-15
Trichloroethene (isomers)	2,21E-21	2,21E-21	-	-	-	-
Trichloromethane (chloroform)	1,47E-12	1,43E-12	8,68E-15	6,67E-15	2,70E-14	-8,75E-15
Vinyl chloride (VCM; chloroethene)	4,68E-12	2,21E-12	4,32E-13	3,62E-13	1,89E-12	-2,15E-13
Acetaldehyde (Ethanal)	1,32E-11	5,97E-12	1,39E-12	4,55E-13	4,89E-12	5,31E-13
Acrylonitrile	3,42E-23	3,42E-23	-	-	-	-
Aniline	1,12E-16	4,08E-17	1,11E-17	4,31E-18	5,73E-17	-1,09E-18
Benzaldehyde	1,67E-13	5,45E-14	1,83E-14	6,65E-15	5,65E-14	3,07E-14
Benzene	1,34E-09	9,53E-10	1,55E-10	5,05E-11	1,83E-10	-5,38E-12
Butadiene	6,48E-15	5,99E-17	1,58E-17	5,48E-18	2,34E-16	6,17E-15
Diethylene glycol	3,76E-22	2,64E-22	4,94E-23	3,90E-23	3,43E-23	-1,07E-23
Ethanol	2,02E-13	1,60E-13	1,55E-14	9,04E-15	2,02E-14	-2,10E-15
Ethyl benzene	7,78E-12	4,62E-12	7,13E-13	3,94E-13	1,96E-12	8,42E-14
Ethylene oxide	7,07E-12	3,21E-14	4,62E-12	3,54E-14	2,39E-12	-1,25E-14
Formaldehyde (methanal)	9,02E-09	6,01E-09	7,94E-10	4,03E-10	1,74E-09	6,48E-11
Furan	2,27E-09	9,29E-10	2,64E-10	7,52E-11	1,02E-09	-1,55E-11
Hexane (isomers)	1,12E-12	7,03E-13	1,21E-13	6,42E-14	2,67E-13	-3,57E-14
Isoprene	1,61E-14	6,57E-15	1,87E-15	5,32E-16	7,22E-15	-1,09E-16
Methyl tert-butylether	1,07E-13	2,83E-14	1,35E-14	2,76E-15	6,24E-14	5,25E-16
Nitrobenzene	9,17E-15	3,42E-15	9,09E-16	3,53E-16	4,58E-15	-8,92E-17
o-Nitrotoluene	2,92E-15	1,80E-15	2,90E-16	1,28E-16	7,34E-16	-3,01E-17
Propylene oxide	2,12E-10	4,56E-14	2,12E-10	5,30E-15	5,85E-14	3,76E-14

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Styrene	1,69E-12	4,00E-13	1,92E-13	5,94E-14	6,90E-13	3,44E-13
Toluene (methyl benzene)	3,41E-15	2,40E-15	2,50E-16	1,35E-16	6,56E-16	-3,25E-17
Xylene (dimethyl benzene)	1,02E-11	5,82E-12	8,10E-13	4,93E-13	3,25E-12	-2,12E-13
Pesticides to air (group VOC)						
Acephate	1,89E-15	9,20E-16	2,66E-16	1,11E-16	6,21E-16	-2,64E-17
Acifluorfen	2,88E-15	1,40E-15	4,04E-16	1,68E-16	9,44E-16	-4,01E-17
Atrazine	1,08E-14	5,24E-15	1,51E-15	6,30E-16	3,54E-15	-1,50E-16
Carbaryl	3,25E-15	1,58E-15	4,57E-16	1,90E-16	1,07E-15	-4,54E-17
Trifluralin	3,82E-14	1,86E-14	5,37E-15	2,23E-15	1,26E-14	-5,33E-16
Long-term emissions to fresh water						
Arsenic, ion	5,04E-07	1,98E-07	4,78E-08	1,00E-07	1,55E-07	3,44E-09
Cadmium, ion	1,04E-09	1,90E-10	7,80E-11	2,45E-10	4,84E-10	4,02E-11
Chromium (+VI)	2,07E-05	1,21E-05	4,11E-06	2,10E-06	3,89E-06	-1,52E-06
Lead	7,70E-10	9,11E-11	2,49E-11	4,87E-11	2,66E-10	3,39E-10
Mercury	5,97E-09	4,33E-09	7,40E-10	4,47E-10	5,89E-10	-1,33E-10
Nickel, ion	6,72E-07	4,70E-07	9,13E-08	5,33E-08	6,73E-08	-1,03E-08
Heavy metals to fresh water						
Arsenic	1,58E-19	1,58E-19	-	-	-	-
Arsenic (+V)	1,28E-07	9,14E-08	1,29E-08	1,40E-08	2,10E-08	-1,17E-08
Cadmium	7,38E-12	1,81E-12	1,35E-12	9,58E-13	2,63E-12	6,20E-13
Chromium	1,67E-10	1,67E-10	-	-	-	-
Chromium (+VI)	2,52E-06	1,06E-06	8,70E-07	2,75E-07	7,12E-07	-4,05E-07
Lead	2,55E-11	7,62E-12	1,95E-12	9,92E-13	1,38E-11	1,18E-12
Mercury	7,28E-11	3,41E-11	2,14E-11	3,90E-12	1,18E-11	1,68E-12
Nickel	3,07E-09	1,61E-09	4,14E-10	2,35E-10	1,06E-09	-2,47E-10
Organic emissions to fresh water						
1,2-Dibromoethane	-2,11E-26	-2,11E-26	-	-	-	-
Chlorobenzene	7,07E-12	6,79E-12	1,65E-13	2,15E-14	9,44E-14	4,06E-15
Dichloroethane (ethylene dichloride)	9,67E-13	2,23E-13	5,07E-14	1,57E-13	5,35E-13	2,04E-15
Dichloromethane (methylene chloride)	6,78E-13	3,93E-13	5,95E-14	3,45E-14	1,81E-13	1,00E-14
Dichloropropane	-9,56E-31	-9,56E-31	-	-	-	-
Pentachlorophenol (PCP)	4,31E-21	4,31E-21	-	-	-	-
Polychlorinated biphenyls (PCB unspecified)	5,08E-12	1,47E-14	1,50E-15	1,78E-15	5,06E-12	-3,75E-15
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	5,04E-22	5,04E-22	-	-	-	-
Tetrachloroethene (perchloroethylene)	1,52E-24	1,52E-24	-	-	-	-
Trichloromethane (chloroform)	1,96E-15	1,68E-15	2,93E-17	1,33E-17	2,42E-16	-2,37E-18
Vinyl chloride (VCM; chloroethene)	5,52E-14	1,78E-14	3,72E-15	2,69E-15	3,16E-14	-5,46E-16
Acrylonitrile	1,37E-23	1,37E-23	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Aniline	1,03E-15	3,75E-16	1,02E-16	3,96E-17	5,27E-16	-1,00E-17
Benzene	4,33E-11	2,96E-11	1,73E-12	2,17E-12	1,11E-11	-1,34E-12
Benzo{a}pyrene	1,57E-16	1,45E-18	1,86E-17	1,53E-19	1,37E-16	9,04E-20
Dibenz(a)anthracene	1,35E-17	1,24E-19	1,59E-18	1,32E-20	1,17E-17	7,77E-21
Ethanol	1,91E-13	1,07E-15	3,13E-14	8,75E-16	1,58E-13	-6,10E-16
Ethyl benzene	6,52E-13	3,57E-13	5,42E-14	3,17E-14	1,91E-13	1,76E-14
Ethylene oxide	1,69E-13	3,21E-14	7,72E-15	4,09E-15	8,61E-14	3,95E-14
Formaldehyde (methanal)	4,14E-12	1,66E-13	1,72E-12	4,63E-14	2,24E-12	-3,35E-14
Hexane (isomers)	-4,60E-30	-4,60E-30	-	-	-	-
Methyl tert-butylether	4,78E-16	2,02E-16	8,55E-17	1,19E-17	1,82E-16	-3,68E-18
Naphthalene	1,72E-14	2,17E-15	1,80E-15	1,49E-17	1,32E-14	8,75E-18
Propylene oxide	7,99E-10	1,64E-13	7,98E-10	1,90E-14	2,15E-13	1,41E-13
Toluene (methyl benzene)	2,55E-13	1,45E-13	2,02E-14	1,16E-14	7,28E-14	5,32E-15
Xylene (isomers; dimethyl benzene)	2,28E-13	1,27E-13	1,86E-14	1,07E-14	6,60E-14	5,48E-15
Acetaldehyde (Ethanal)	1,06E-11	7,10E-14	1,72E-12	4,66E-14	8,74E-12	4,96E-14
Nitrobenzene	3,98E-14	1,49E-14	3,95E-15	1,53E-15	1,99E-14	-3,87E-16
Other emissions to fresh water						
Atrazine	3,46E-19	2,11E-19	5,18E-20	2,40E-20	6,32E-20	-3,21E-21
Carbaryl	8,07E-23	5,00E-23	1,16E-23	5,37E-24	1,45E-23	-7,10E-25
Trifluralin	3,44E-18	3,44E-18	-	-	-	-
Heavy metals to sea water						
Arsenic (+V)	5,54E-11	3,63E-12	9,47E-13	4,40E-11	6,55E-12	2,59E-13
Cadmium	2,81E-12	2,21E-14	4,42E-15	2,76E-12	2,18E-14	1,63E-15
Chromium	2,59E-12	2,59E-12	-	-	-	-
Lead	8,40E-13	2,96E-13	5,43E-14	3,01E-13	1,74E-13	1,42E-14
Mercury	8,88E-12	6,38E-13	2,23E-13	6,07E-12	1,88E-12	6,84E-14
Nickel	2,44E-10	3,61E-13	1,02E-13	2,43E-10	4,51E-13	4,87E-14
Organic emissions to sea water						
Tetrachloroethene (perchloroethylene)	8,83E-29	8,83E-29	-	-	-	-
Benzene	1,36E-13	7,33E-14	1,16E-14	6,81E-15	3,99E-14	4,01E-15
Ethyl benzene	3,81E-15	2,05E-15	3,23E-16	1,91E-16	1,13E-15	1,14E-16
Hexane (isomers)	-1,49E-31	-1,49E-31	-	-	-	-
Methyl tert-butylether	6,94E-17	2,91E-17	1,24E-17	1,59E-18	2,68E-17	-5,42E-19
Toluene (methyl benzene)	2,39E-16	1,27E-16	2,08E-17	1,20E-17	7,20E-17	7,35E-18
Xylene (isomers; dimethyl benzene)	5,41E-16	2,92E-16	4,64E-17	2,72E-17	1,60E-16	1,61E-17
Naphthalene	3,83E-17	3,83E-17	-	-	-	-
Other emissions to sea water						
Acetamide	1,22E-19	5,94E-20	1,71E-20	7,13E-21	4,01E-20	-1,70E-21
Heavy metals to agriculture soil						
Arsenic	3,15E-10	2,61E-10	1,66E-11	1,05E-11	2,74E-11	-1,14E-12
Arsenic (+V)	9,91E-23	9,91E-23	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Cadmium	3,27E-10	2,40E-10	3,10E-11	1,83E-11	3,90E-11	-1,39E-12
Chromium	2,49E-08	1,86E-08	2,42E-09	1,51E-09	2,47E-09	-1,14E-10
Lead	2,55E-10	1,81E-10	2,41E-11	1,75E-11	3,40E-11	-1,14E-12
Mercury	4,32E-10	1,54E-10	2,91E-11	3,38E-11	2,18E-10	-2,86E-12
Nickel	2,83E-10	2,05E-10	2,61E-11	1,73E-11	3,56E-11	-1,23E-12
Other emissions to agriculture soil						
Acephate	6,32E-15	1,02E-15	8,50E-16	7,56E-17	4,38E-15	-6,69E-18
Acetamide	7,83E-16	1,27E-16	1,05E-16	9,56E-18	5,42E-16	-8,60E-19
Acifluorfen	1,64E-17	7,96E-18	2,30E-18	9,56E-19	5,38E-18	-2,28E-19
Aldrin	1,94E-10	1,70E-10	4,80E-12	3,11E-12	1,68E-11	-6,01E-13
Atrazine	7,90E-12	2,86E-12	8,05E-14	5,27E-14	4,92E-12	-1,26E-14
Carbaryl	7,57E-16	5,32E-16	1,04E-16	6,05E-17	7,65E-17	-1,66E-17
Chlorothalonil	1,80E-13	2,73E-15	4,86E-16	1,67E-15	1,76E-13	-2,32E-16
Fomesafen	4,57E-14	2,11E-14	6,35E-15	2,51E-15	1,63E-14	-5,83E-16
Prochloraz	6,21E-16	5,41E-16	1,25E-17	2,55E-18	6,37E-17	9,52E-19
Trifluralin	2,52E-13	1,78E-13	3,81E-14	2,22E-14	1,93E-14	-6,15E-15
Heavy metals to industrial soil						
Arsenic	4,05E-11	2,25E-11	3,84E-12	2,11E-12	1,02E-11	1,83E-12
Arsenic (+V)	7,97E-19	7,97E-19	-	-	-	-
Cadmium	2,53E-14	5,13E-15	2,55E-15	8,93E-16	9,48E-15	7,28E-15
Chromium	6,52E-09	3,77E-09	6,12E-10	3,46E-10	1,60E-09	1,96E-10
Chromium (+VI)	1,90E-07	1,28E-07	3,09E-08	1,98E-08	1,75E-08	-6,04E-09
Lead	2,43E-13	5,08E-14	2,43E-14	8,74E-15	9,04E-14	6,83E-14
Mercury	6,08E-14	3,09E-14	5,43E-15	4,22E-15	1,84E-14	1,96E-15
Nickel	4,56E-12	1,11E-12	4,52E-13	1,82E-13	1,67E-12	1,15E-12
Organic emissions to industrial soil						
Pentachlorophenol (PCP)	2,34E-16	1,49E-16	3,74E-17	2,17E-17	3,22E-17	-6,42E-18

Table B.6: Ionizing radiation midpoint, human health (v1.09) of one cc-Si PV-module (60 6-inch solar cells) in kBq U235 equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Radon-222	5,03E+01	3,55E+01	7,90E+00	4,83E+00	2,35E+00	-3,60E-01
Radioactive emissions to air						
Carbon (C14)	2,57E+01	1,79E+01	3,69E+00	2,27E+00	1,86E+00	-6,62E-02
Cesium (Cs134)	1,85E-07	1,32E-07	2,69E-08	1,70E-08	9,89E-09	-5,73E-10
Cesium (Cs137)	3,78E-06	2,69E-06	5,48E-07	3,46E-07	2,02E-07	-1,18E-08
Cobalt (Co58)	1,78E-08	1,27E-08	2,58E-09	1,60E-09	9,61E-10	-5,96E-11
Cobalt (Co60)	5,26E-06	3,75E-06	7,62E-07	4,76E-07	2,83E-07	-1,71E-08
Hydrogen-3, Tritium	7,30E-03	5,06E-03	1,18E-03	7,16E-04	3,90E-04	-4,20E-05
Iodine (I129)	4,39E-02	3,15E-02	6,53E-03	3,99E-03	2,21E-03	-3,14E-04
Iodine (I131)	5,53E-04	4,29E-04	8,08E-05	4,83E-05	1,84E-05	-2,39E-05

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Iodine (I133)	2,87E-08	2,06E-08	4,15E-09	2,54E-09	1,56E-09	-9,97E-11
Krypton (Kr85)	6,38E-06	4,93E-06	9,30E-07	5,58E-07	2,20E-07	-2,60E-07
Lead (Pb210)	5,65E-03	4,58E-03	3,67E-04	2,53E-04	6,92E-04	-2,44E-04
Plutonium (Pu alpha)	1,22E-09	8,73E-10	1,81E-10	1,11E-10	6,14E-11	-8,71E-12
Plutonium (Pu238)	4,24E-10	3,04E-10	6,32E-11	3,86E-11	2,14E-11	-3,04E-12
Polonium (Po210)	1,01E-02	8,17E-03	6,53E-04	4,49E-04	1,23E-03	-4,34E-04
Radium (Ra226)	1,47E-03	1,13E-03	1,49E-04	9,68E-05	1,38E-04	-4,28E-05
Radon (Rn222)	1,40E+00	9,93E-01	2,21E-01	1,35E-01	6,59E-02	-1,01E-02
Thorium (Th230)	4,41E-03	3,22E-03	4,99E-04	3,76E-04	4,26E-04	-1,19E-04
Uranium	5,30E-04	4,67E-04	9,48E-06	3,35E-06	5,35E-05	-4,01E-06
Uranium (total)	-3,61E-13	-3,61E-13	-	-	-	-
Uranium (U234)	2,58E-02	1,89E-02	3,28E-03	2,19E-03	2,02E-03	-5,56E-04
Uranium (U235)	2,02E-04	1,43E-04	3,17E-05	1,94E-05	9,43E-06	-1,44E-06
Uranium (U238)	1,72E-02	1,29E-02	2,07E-03	1,31E-03	1,34E-03	-3,75E-04
Xenon (Xe133)	1,94E-04	1,39E-04	2,81E-05	1,73E-05	1,03E-05	-1,00E-06
Radioactive emissions to fresh water						
Antimony (Sb124)	2,16E-03	1,69E-03	2,02E-04	1,22E-04	1,63E-04	-1,26E-05
Cesium (Cs134)	5,66E-03	4,12E-03	7,78E-04	4,75E-04	3,22E-04	-2,57E-05
Cesium (Cs137)	8,86E-02	6,32E-02	1,29E-02	8,05E-03	4,73E-03	-2,99E-04
Cobalt (Co58)	8,48E-05	6,06E-05	1,24E-05	7,60E-06	4,53E-06	-2,95E-07
Cobalt (Co60)	6,01E-02	4,29E-02	8,73E-03	5,42E-03	3,22E-03	-2,07E-04
Hydrogen-3, Tritium	9,05E-03	6,84E-03	1,04E-03	6,31E-04	5,97E-04	-5,63E-05
Iodine (I129)	3,83E-08	3,83E-08	-	-	-	-
Iodine (I131)	2,59E-04	2,02E-04	2,42E-05	1,47E-05	1,95E-05	-1,50E-06
Manganese (Mn54)	2,55E-05	1,81E-05	3,75E-06	2,34E-06	1,34E-06	-8,28E-08
Radium (Ra226)	2,00E-02	1,41E-02	3,11E-03	1,90E-03	1,02E-03	-1,35E-04
Silver (Ag110m)	5,03E-04	3,57E-04	7,43E-05	4,67E-05	2,63E-05	-1,59E-06
Uranium	4,55E-09	4,55E-09	-	-	-	-
Uranium (U234)	1,29E-03	9,11E-04	2,03E-04	1,24E-04	6,03E-05	-9,23E-06
Uranium (U235)	1,35E-03	9,54E-04	2,12E-04	1,30E-04	6,31E-05	-9,66E-06
Uranium (U238)	4,40E-02	3,11E-02	6,89E-03	4,21E-03	2,08E-03	-3,36E-04
Radioactive emissions to sea water						
Carbon (C14)	1,50E-07	1,50E-07	-	-	-	-
Cesium (Cs134)	1,20E-10	1,20E-10	-	-	-	-
Cesium (Cs137)	6,84E-04	4,90E-04	1,02E-04	6,22E-05	3,45E-05	-4,89E-06
Cobalt (Co60)	9,61E-10	9,61E-10	-	-	-	-
Hydrogen-3, Tritium	1,26E-03	9,03E-04	1,88E-04	1,15E-04	6,36E-05	-9,01E-06
Ruthenium (Ru106)	9,87E-09	9,87E-09	-	-	-	-
Strontium (Sr90)	3,96E-06	2,84E-06	5,89E-07	3,60E-07	2,00E-07	-2,83E-08
Uranium (U234)	4,60E-12	4,60E-12	-	-	-	-
Uranium (U238)	9,24E-07	1,67E-07	4,24E-08	5,15E-08	6,40E-07	2,22E-08

Table B.7: Photochemical ozone formation midpoint, human health (v1.09) of one sc-Si PV-module (60 6-inch solar cells) in kg NMVOC equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Acetaldehyde	1,07E-03	-	-	1,07E-03	-	-
Nitrogen oxides	8,71E-07	5,63E-09	8,68E-10	6,38E-10	8,65E-07	-2,79E-10
NMVOC, non-methane volatile organic compounds, unspecified origin	1,35E-02	-	-	-	1,35E-02	-
Propanol	2,19E-02	-	-	2,19E-02	-	-
Inorganic emissions to air						
Carbon monoxide	1,38E-02	7,77E-03	2,74E-03	1,52E-03	4,03E-03	-2,30E-03
Carbon monoxide, non-fossil	5,48E-03	4,77E-03	1,41E-04	2,59E-04	2,94E-04	1,37E-05
Nitrogen dioxide	3,78E-06	3,78E-06	-	-	-	-
Nitrogen monoxide	5,03E-05	5,03E-05	-	-	-	-
Nitrogen oxides	7,22E-01	4,75E-01	5,70E-02	4,86E-02	1,62E-01	-2,05E-02
Sulphur dioxide	1,08E-01	7,41E-02	9,06E-03	5,20E-03	2,33E-02	-3,85E-03
Sulphur oxides	1,77E-05	7,14E-08	1,31E-08	9,65E-09	1,76E-05	-4,10E-09
Organic emissions to air (group VOC)						
1,1,1-Trichloroethane	1,79E-09	1,48E-09	8,09E-11	6,88E-11	2,75E-10	-1,15E-10
Chloromethane (methyl chloride)	2,63E-08	2,18E-08	1,19E-09	1,01E-09	4,06E-09	-1,70E-09
Dichloromethane (methylene chloride)	2,20E-07	1,83E-07	9,80E-09	7,84E-09	3,22E-08	-1,27E-08
Hydrocarbons, halogenated	7,69E-18	7,69E-18	-	-	-	-
Tetrachloroethene (perchloroethylene)	3,14E-08	1,03E-08	5,64E-10	1,94E-08	1,92E-09	-7,99E-10
Trichloroethene (isomers)	4,05E-14	4,05E-14	-	-	-	-
Trichloromethane (chloroform)	2,48E-07	2,42E-07	1,46E-09	1,12E-09	4,56E-09	-1,48E-09
1,3,5-Trimethylbenzene	9,04E-12	9,04E-12	-	-	-	-
1-Butanol	1,07E-09	5,94E-10	1,09E-10	3,88E-11	3,39E-10	-8,44E-12
1-Butylene (Vinylacetylene)	4,08E-10	4,08E-10	-	-	-	-
1-Methoxy-2-propanol	1,46E-14	1,46E-14	-	-	-	-
1-Pentene	1,22E-08	2,33E-09	8,53E-09	9,00E-11	1,21E-09	5,21E-11
1-Propanol	4,88E-04	3,33E-09	5,80E-10	2,55E-10	4,88E-04	-4,32E-11
1-Undecane	5,52E-14	5,52E-14	-	-	-	-
2,2-Dimethylbutane	6,23E-11	6,23E-11	-	-	-	-
2-Methyl-1-butene	7,48E-10	7,48E-10	-	-	-	-
2-Methyl-2-butene	8,93E-11	1,54E-11	3,46E-12	2,86E-12	6,75E-11	1,40E-14
2-Methylpentane	7,38E-10	7,38E-10	-	-	-	-
3-Methylpentane	1,11E-07	2,44E-08	6,39E-08	2,95E-09	1,88E-08	6,80E-10
Acetaldehyde (Ethanal)	1,50E-04	6,78E-05	1,57E-05	5,17E-06	5,55E-05	6,03E-06

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Acetic acid	3,89E-04	3,85E-05	4,83E-05	3,92E-06	3,00E-04	-1,79E-06
Acetone (dimethylcetone)	8,48E-05	2,11E-05	3,54E-06	1,12E-06	5,90E-05	-4,73E-08
Aldehyde (unspecified)	7,40E-06	5,53E-06	4,57E-07	4,08E-07	2,48E-06	-1,49E-06
Benzaldehyde	-1,43E-06	-4,68E-07	-1,57E-07	-5,71E-08	-4,85E-07	-2,63E-07
Benzene	1,66E-03	1,18E-03	1,92E-04	6,25E-05	2,27E-04	-6,66E-06
Butadiene	1,63E-08	1,51E-10	3,99E-11	1,38E-11	5,89E-10	1,55E-08
Butane	1,00E-03	6,33E-04	1,04E-04	5,75E-05	2,13E-04	-2,99E-06
Butanone (methyl ethyl ketone)	1,81E-05	6,57E-06	2,66E-06	4,72E-07	8,03E-06	3,69E-07
cis-2-Pentene	1,12E-09	1,12E-09	-	-	-	-
Cumene (isopropylbenzene)	1,67E-05	2,56E-06	4,85E-07	2,31E-06	1,37E-05	-2,41E-06
Cyclohexane (hexahydro benzene)	6,76E-14	6,53E-14	1,03E-15	8,12E-16	7,14E-16	-2,23E-16
Decane	2,29E-12	2,29E-12	-	-	-	-
Diethyl ether	2,83E-14	1,99E-14	3,73E-15	2,94E-15	2,58E-15	-8,06E-16
Dodecane	1,14E-13	1,14E-13	-	-	-	-
Ethane	1,94E-03	1,48E-03	1,44E-04	1,05E-04	2,34E-04	-1,90E-05
Ethanol	6,39E-05	5,04E-05	4,87E-06	2,85E-06	6,37E-06	-6,63E-07
Ethene (ethylene)	4,63E-03	3,54E-03	1,74E-04	1,11E-04	8,19E-04	-1,13E-05
Ethine (acetylene)	1,46E-04	2,84E-05	7,46E-07	2,90E-07	1,17E-04	-2,56E-07
Ethyl benzene	2,86E-05	1,70E-05	2,63E-06	1,45E-06	7,23E-06	3,10E-07
Ethylene acetate (ethyl acetate)	1,02E-05	3,68E-06	1,50E-06	2,65E-07	4,54E-06	2,07E-07
Formaldehyde (methanal)	5,90E-04	3,94E-04	5,20E-05	2,64E-05	1,14E-04	4,24E-06
Formic acid (methane acid)	8,80E-07	3,60E-07	1,02E-07	2,91E-08	3,95E-07	-5,93E-09
Heptane (isomers)	1,32E-04	6,72E-05	1,07E-05	6,47E-06	7,28E-05	-2,56E-05
Hexane (isomers)	9,18E-04	5,76E-04	9,88E-05	5,26E-05	2,19E-04	-2,93E-05
Hydrocarbons, aromatic	5,15E-04	2,55E-04	5,04E-05	1,50E-05	2,03E-04	-8,32E-06
iso-Butane	1,53E-09	1,53E-09	-	-	-	-
iso-Butanol	1,08E-09	3,01E-10	6,60E-11	2,64E-11	6,91E-10	-5,79E-12
iso-Pentane	7,96E-09	7,96E-09	-	-	-	-
Isoprene	4,34E-07	1,78E-07	5,04E-08	1,44E-08	1,95E-07	-2,95E-09
Isopropanol	1,98E-06	7,15E-07	2,90E-07	5,12E-08	8,80E-07	4,02E-08
Methanol	3,21E-04	2,82E-05	1,04E-04	3,18E-06	1,87E-04	-1,32E-06
Methyl acetate	1,30E-11	8,00E-12	1,29E-12	5,67E-13	3,26E-12	-1,33E-13
Methyl formate	2,45E-11	6,05E-12	1,46E-12	5,57E-13	1,64E-11	-6,69E-15
Methyl isobutyl ketone	1,12E-11	9,89E-13	1,21E-13	1,10E-13	9,93E-12	6,95E-14
Methyl tert-butylether	4,97E-07	1,31E-07	6,23E-08	1,28E-08	2,89E-07	2,43E-09
n-Butyl acetate	4,16E-19	4,16E-19	-	-	-	-
NMVOC (unspecified)	1,03E-01	4,71E-02	1,00E-02	2,53E-02	2,22E-02	-1,47E-03
Nonane	6,50E-13	6,50E-13	-	-	-	-
Octane	9,24E-09	9,24E-09	-	-	-	-
Pentane (n-pentane)	1,45E-03	9,65E-04	1,45E-04	8,59E-05	2,59E-04	-4,04E-06

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Propane	8,34E-04	5,73E-04	7,61E-05	4,35E-05	1,49E-04	-7,83E-06
Propene (propylene)	1,91E-03	4,44E-04	1,19E-03	1,94E-04	9,63E-05	-6,86E-06
Propionaldehyde	3,58E-04	6,71E-07	8,86E-08	5,07E-08	3,57E-04	8,60E-08
Propionic acid (propane acid)	3,35E-06	2,50E-06	3,65E-07	2,18E-07	3,50E-07	-8,04E-08
Styrene	7,90E-07	1,88E-07	9,01E-08	2,79E-08	3,24E-07	1,61E-07
Toluene (methyl benzene)	1,16E-03	8,16E-04	8,51E-05	4,60E-05	2,23E-04	-1,11E-05
trans-2-Butene	8,57E-10	8,57E-10	-	-	-	-
trans-2-Pentene	2,10E-09	2,10E-09	-	-	-	-
Xylene (meta-Xylene; 1,3-Dimethylbenzene)	5,73E-05	3,93E-05	5,90E-06	3,12E-06	6,92E-06	2,07E-06
Xylene (ortho-Xylene; 1,2-Dimethylbenzene)	3,57E-06	6,21E-07	4,16E-07	1,21E-07	1,52E-06	8,91E-07
Methane	9,95E-03	7,40E-03	8,66E-04	5,07E-04	1,69E-03	-5,10E-04
Methane (biotic)	7,58E-04	5,71E-04	7,63E-05	5,52E-05	7,35E-05	-1,86E-05

Table B.8: Human toxicity midpoint, non-cancer effects (v1.09) of one sc-Si PV-module (60 6-inch solar cells) in CTUh

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Acetaldehyde	4,84E-10	-	-	4,84E-10	-	-
Antimony	1,77E-11	1,25E-11	2,79E-12	1,70E-12	8,29E-13	-1,27E-13
Arsenic	1,03E-07	7,25E-08	1,61E-08	9,87E-09	4,80E-09	-7,35E-10
Barium	2,80E-10	1,98E-10	4,39E-11	2,69E-11	1,31E-11	-2,00E-12
Beryllium	6,85E-09	4,84E-09	1,08E-09	6,58E-10	3,20E-10	-4,90E-11
Cadmium	7,16E-09	5,06E-09	1,13E-09	6,89E-10	3,35E-10	-5,13E-11
Chromium VI	3,09E-10	2,18E-10	4,86E-11	2,97E-11	1,45E-11	-2,21E-12
Copper	1,31E-10	9,28E-11	2,06E-11	1,26E-11	6,14E-12	-9,40E-13
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	1,58E-15	9,65E-16	1,12E-16	7,41E-17	4,74E-16	-4,25E-17
Lead	9,75E-08	6,90E-08	1,53E-08	9,38E-09	4,56E-09	-6,99E-10
Mercury	6,63E-08	4,68E-08	1,04E-08	6,37E-09	3,10E-09	-4,74E-10
Molybdenum	3,33E-09	2,36E-09	5,24E-10	3,21E-10	1,56E-10	-2,39E-11
Nickel	6,16E-12	4,36E-12	9,69E-13	5,93E-13	2,88E-13	-4,41E-14
Silver	4,46E-09	3,15E-09	7,01E-10	4,29E-10	2,09E-10	-3,19E-11
Vanadium	6,76E-10	4,78E-10	1,06E-10	6,50E-11	3,16E-11	-4,84E-12
Zinc	1,15E-07	8,16E-08	1,81E-08	1,11E-08	5,40E-09	-8,27E-10
Heavy metals to air						
Antimony	1,97E-08	3,31E-09	1,92E-09	6,06E-10	8,16E-09	5,66E-09
Arsenic	1,86E-06	4,73E-07	1,20E-07	5,20E-08	1,20E-06	8,83E-09
Arsenic (+V)	9,45E-13	9,45E-13	-	-	-	-
Cadmium	1,50E-06	2,36E-07	9,44E-08	4,10E-08	1,10E-06	2,68E-08

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Chromium	4,50E-08	1,45E-08	1,90E-08	3,22E-09	8,53E-09	-3,17E-10
Chromium (+III)	1,18E-21	1,18E-21	-	-	-	-
Chromium (+VI)	2,99E-09	1,40E-09	9,64E-10	1,81E-10	4,85E-10	-3,95E-11
Copper	4,60E-09	8,49E-10	3,63E-10	1,40E-10	2,96E-09	2,92E-10
Lead	3,59E-06	9,08E-07	2,52E-07	3,38E-07	1,91E-06	1,80E-07
Mercury	9,90E-06	5,89E-06	2,11E-06	6,66E-07	1,32E-06	-7,97E-08
Molybdenum	2,69E-08	1,07E-08	2,41E-09	9,41E-10	7,50E-09	5,31E-09
Nickel	8,25E-10	3,01E-10	6,02E-11	2,74E-11	4,45E-10	-9,20E-12
Silver	3,13E-07	4,50E-11	7,17E-12	3,13E-07	3,05E-11	2,26E-12
Thallium	5,18E-10	4,40E-10	1,10E-11	1,78E-11	5,17E-11	-2,70E-12
Vanadium	2,66E-08	1,95E-08	1,72E-09	1,15E-09	3,12E-09	1,06E-09
Zinc	1,00E-05	2,04E-06	8,80E-07	2,65E-07	3,68E-06	3,17E-06
Inorganic emissions to air						
Barium	6,49E-09	4,21E-09	4,15E-10	2,09E-10	1,20E-09	4,55E-10
Beryllium	3,37E-08	2,85E-08	9,83E-10	5,00E-10	4,32E-09	-5,83E-10
Carbon disulphide	8,29E-08	8,36E-09	9,35E-09	2,40E-09	6,09E-08	1,87E-09
Organic emissions to air (group VOC)						
Anthracene	1,32E-20	2,79E-21	-	-	-	1,04E-20
Naphthalene	3,33E-14	3,31E-16	3,79E-15	3,13E-17	2,79E-14	1,31E-15
Pyrene	4,52E-18	8,14E-19	7,43E-19	2,28E-19	1,23E-18	1,51E-18
1,1,1-Trichloroethane	2,09E-15	1,73E-15	9,44E-17	8,02E-17	3,21E-16	-1,35E-16
2,4-Dichlorophenol	5,43E-14	2,53E-14	6,27E-15	2,12E-15	2,11E-14	-4,56E-16
2-Chlorotoluene	1,07E-15	5,48E-16	1,24E-16	5,92E-17	3,52E-16	-1,56E-17
Bromoxynil	4,43E-22	3,86E-22	9,07E-24	1,85E-24	4,58E-23	6,98E-25
Carbon tetrachloride (tetrachloromethane)	8,11E-10	6,28E-10	1,64E-10	1,30E-11	1,57E-11	-9,55E-12
Chloromethane (methyl chloride)	1,71E-12	1,41E-12	7,73E-14	6,57E-14	2,63E-13	-1,10E-13
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene)	1,60E-16	7,77E-17	1,26E-17	5,31E-18	6,58E-17	-1,16E-18
Dichloromethane (methylene chloride)	1,49E-12	1,24E-12	6,65E-14	5,32E-14	2,18E-13	-8,61E-14
Hexachlorobenzene (Perchlorobenzene)	4,71E-13	9,50E-14	2,88E-13	4,26E-14	3,88E-14	6,63E-15
Methyl bromide	2,31E-16	1,61E-16	1,08E-17	5,01E-18	5,66E-17	-2,24E-18
Pentachlorobenzene	3,59E-14	1,08E-15	2,13E-16	1,97E-14	3,46E-15	1,15E-14
Pentachlorophenol (PCP)	9,13E-11	6,44E-11	1,20E-11	3,27E-12	1,15E-11	9,77E-14
R 11 (trichlorofluoromethane)	1,13E-14	1,13E-14	5,41E-19	1,76E-19	1,68E-18	5,02E-20
R 12 (dichlorodifluoromethane)	1,91E-11	1,07E-11	4,80E-14	2,97E-14	8,47E-12	-1,05E-13
R 22 (chlorodifluoromethane)	2,94E-13	2,59E-13	1,54E-14	5,27E-15	1,47E-14	-6,97E-16
Tetrachloroethene (perchloroethylene)	7,89E-13	2,59E-13	1,42E-14	4,88E-13	4,83E-14	-2,01E-14

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Trichloromethane (chloroform)	8,41E-12	8,22E-12	4,97E-14	3,82E-14	1,55E-13	-5,01E-14
Vinyl chloride (VCM; chloroethene)	1,62E-12	7,64E-13	1,50E-13	1,26E-13	6,56E-13	-7,45E-14
1-Methoxy-2-propanol	1,77E-22	1,77E-22	-	-	-	-
Acenaphthene	1,76E-15	9,83E-17	2,01E-16	6,01E-18	1,45E-15	4,12E-18
Acetaldehyde (Ethanal)	6,79E-11	3,06E-11	7,12E-12	2,34E-12	2,51E-11	2,73E-12
Acetone (dimethylcetone)	3,33E-12	8,31E-13	1,39E-13	4,42E-14	2,32E-12	-1,86E-15
Acetonitrile	1,68E-13	6,89E-14	1,96E-14	5,58E-15	7,57E-14	-1,15E-15
Acrolein	8,05E-09	2,41E-09	8,22E-10	2,83E-10	2,99E-09	1,55E-09
Acrylic acid	2,24E-14	8,11E-15	3,29E-15	5,96E-16	9,91E-15	4,56E-16
Acrylonitrile	9,28E-23	9,28E-23	-	-	-	-
Aniline	5,55E-15	2,01E-15	5,50E-16	2,13E-16	2,83E-15	-5,39E-17
Benzaldehyde	2,16E-13	7,07E-14	2,37E-14	8,63E-15	7,33E-14	3,98E-14
Benzene	3,38E-10	2,41E-10	3,92E-11	1,28E-11	4,63E-11	-1,36E-12
Biphenyl	6,51E-21	6,51E-21	-	-	-	-
Butadiene	9,70E-15	8,97E-17	2,37E-17	8,20E-18	3,49E-16	9,23E-15
Butanone (methyl ethyl ketone)	2,60E-14	9,42E-15	3,82E-15	6,76E-16	1,15E-14	5,29E-16
Caprolactam	1,54E-22	1,54E-22	-	-	-	-
Chloramine	3,52E-15	1,90E-15	2,92E-16	1,64E-16	1,20E-15	-3,08E-17
Cumene (isopropylbenzene)	2,19E-13	3,37E-14	6,39E-15	3,04E-14	1,81E-13	-3,17E-14
Cyclohexane (hexahydro benzene)	1,60E-21	1,55E-21	2,44E-23	1,92E-23	1,69E-23	-5,28E-24
Diethyl ether	2,48E-22	1,74E-22	3,27E-23	2,57E-23	2,26E-23	-7,06E-24
Ethyl benzene	1,28E-13	7,60E-14	1,17E-14	6,48E-15	3,23E-14	1,39E-15
Ethylene acetate (ethyl acetate)	1,51E-13	5,45E-14	2,22E-14	3,92E-15	6,71E-14	3,06E-15
Fluoranthene	6,77E-17	2,43E-18	2,04E-18	6,26E-19	3,37E-18	5,92E-17
Fluorene	2,44E-19	2,44E-19	-	-	-	-
Formaldehyde (methanal)	1,15E-10	7,68E-11	1,01E-11	5,15E-12	2,22E-11	8,27E-13
Furan	2,53E-10	1,04E-10	2,94E-11	8,39E-12	1,14E-10	-1,72E-12
Hexane (isomers)	1,52E-10	9,57E-11	1,64E-11	8,74E-12	3,64E-11	-4,86E-12
iso-Butanol	2,12E-17	5,91E-18	1,30E-18	5,18E-19	1,36E-17	-1,14E-19
meta-Cresol	1,63E-23	1,63E-23	-	-	-	-
Methanol	1,39E-11	1,22E-12	4,51E-12	1,38E-13	8,10E-12	-5,74E-14
Methyl isobutyl ketone	2,84E-20	2,51E-21	3,07E-22	2,78E-22	2,52E-20	1,76E-22
Methyl methacrylate (MMA)	1,01E-20	1,01E-20	-	-	-	-
Methyl tert-butylether	1,80E-14	4,74E-15	2,26E-15	4,63E-16	1,05E-14	8,81E-17
Nitrobenzene	4,51E-14	1,68E-14	4,47E-15	1,74E-15	2,25E-14	-4,38E-16
Phenol (hydroxy benzene)	5,63E-13	1,18E-13	1,62E-14	8,46E-15	4,52E-13	-3,22E-14
Propylene oxide	3,92E-09	8,41E-13	3,91E-09	9,78E-14	1,08E-12	6,93E-13
Styrene	3,37E-13	8,00E-14	3,84E-14	1,19E-14	1,38E-13	6,87E-14

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Toluene (methyl benzene)	5,69E-11	4,01E-11	4,18E-12	2,26E-12	1,09E-11	-5,43E-13
Xylene (dimethyl benzene)	2,36E-10	1,35E-10	1,88E-11	1,15E-11	7,56E-11	-4,92E-12
Pesticides to air						
2,4-Dichlorophenoxyacetic acid (2,4-D)	3,05E-13	1,48E-13	4,28E-14	1,78E-14	1,00E-13	-4,25E-15
Acephate	5,27E-12	2,56E-12	7,40E-13	3,08E-13	1,73E-12	-7,35E-14
Atrazine	1,25E-14	6,08E-15	1,75E-15	7,30E-16	4,10E-15	-1,74E-16
Benomyl	6,53E-21	6,53E-21	-	-	-	-
Bentazone	1,40E-15	6,84E-16	1,97E-16	8,19E-17	4,61E-16	-1,95E-17
Carbaryl	2,41E-15	1,17E-15	3,39E-16	1,41E-16	7,92E-16	-3,36E-17
Carbofuran	7,93E-20	7,93E-20	-	-	-	-
Chlorpyriphos	4,64E-13	2,26E-13	6,51E-14	2,71E-14	1,52E-13	-6,46E-15
Cyfluthrin	1,71E-15	8,30E-16	2,40E-16	9,97E-17	5,61E-16	-2,38E-17
Cypermethrin	8,92E-25	8,92E-25	-	-	-	-
Deltamethrin	4,31E-18	4,31E-18	-	-	-	-
Dicamba	1,64E-15	7,99E-16	2,31E-16	9,59E-17	5,39E-16	-2,29E-17
Diflubenzuron	2,48E-16	1,21E-16	3,49E-17	1,45E-17	8,15E-17	-3,46E-18
Dimethoate	4,53E-24	4,53E-24	-	-	-	-
Ethephon	1,12E-22	9,75E-23	2,21E-24	4,52E-25	1,13E-23	1,66E-25
Fenvalerate	1,08E-23	1,08E-23	-	-	-	-
Fipronil	1,37E-28	1,37E-28	-	-	-	-
Glyphosate	2,04E-13	9,94E-14	2,87E-14	1,19E-14	6,71E-14	-2,85E-15
Imazethapyr	8,50E-16	4,14E-16	1,19E-16	4,97E-17	2,79E-16	-1,19E-17
Imidacloprid	2,04E-25	2,04E-25	-	-	-	-
Mancozeb	1,32E-18	1,32E-18	-	-	-	-
MCPA	1,12E-21	9,81E-22	2,24E-23	4,52E-24	1,09E-22	1,83E-24
Methomyl	1,74E-18	1,74E-18	1,50E-23	3,07E-24	7,71E-23	1,13E-24
Metolachlor	8,09E-15	3,94E-15	1,14E-15	4,73E-16	2,66E-15	-1,13E-16
Metribuzin	1,06E-14	5,17E-15	1,49E-15	6,22E-16	3,49E-15	-1,48E-16
Paraquat	2,30E-14	1,12E-14	3,23E-15	1,34E-15	7,54E-15	-3,20E-16
Parathion-methyl	1,73E-14	8,44E-15	2,44E-15	1,01E-15	5,69E-15	-2,42E-16
Pendimethalin	1,36E-14	6,61E-15	1,91E-15	7,94E-16	4,46E-15	-1,89E-16
Permethrin	8,68E-16	4,23E-16	1,22E-16	5,08E-17	2,85E-16	-1,21E-17
Propiconazole	2,57E-15	1,25E-15	3,61E-16	1,50E-16	8,44E-16	-3,58E-17
Quizalofop-ethyl	2,68E-15	1,30E-15	3,76E-16	1,56E-16	8,79E-16	-3,73E-17
Sethoxydim	8,77E-17	4,27E-17	1,23E-17	5,13E-18	2,88E-17	-1,22E-18
Tebuconazole	5,33E-24	4,65E-24	1,06E-25	2,17E-26	5,44E-25	7,97E-27
Terbufos	4,88E-27	4,88E-27	-	-	-	-
Thiodicarb	4,03E-16	1,96E-16	5,66E-17	2,35E-17	1,32E-16	-5,62E-18
Thiram	1,67E-18	1,67E-18	-	-	-	-
Trifluralin	3,76E-13	1,83E-13	5,29E-14	2,20E-14	1,24E-13	-5,25E-15
Long-term emissions to fresh water						
Antimony	4,12E-07	4,09E-08	1,23E-08	3,00E-08	6,72E-08	2,62E-07
Arsenic, ion	3,74E-05	1,46E-05	3,54E-06	7,44E-06	1,15E-05	2,55E-07

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Barium	7,21E-07	5,02E-07	7,83E-08	5,25E-08	8,18E-08	7,09E-09
Beryllium	1,79E-09	9,71E-10	1,69E-10	2,16E-10	4,40E-10	-3,74E-12
Cadmium, ion	2,78E-07	5,09E-08	2,09E-08	6,57E-08	1,30E-07	1,08E-08
Chromium (+VI)	4,66E-08	2,72E-08	9,25E-09	4,74E-09	8,76E-09	-3,43E-09
Copper	1,63E-07	6,19E-09	1,55E-09	1,85E-09	3,30E-08	1,20E-07
Lead	2,70E-07	3,20E-08	8,72E-09	1,71E-08	9,34E-08	1,19E-07
Mercury	7,07E-07	5,13E-07	8,76E-08	5,29E-08	6,97E-08	-1,57E-08
Molybdenum	9,01E-08	4,49E-08	9,04E-09	1,46E-08	2,17E-08	-2,62E-10
Nickel, ion	3,78E-08	2,65E-08	5,14E-09	3,00E-09	3,79E-09	-5,81E-10
Silver	3,17E-08	1,84E-09	9,15E-10	2,99E-09	4,84E-09	2,11E-08
Thallium	1,29E-07	4,36E-08	1,04E-08	2,76E-08	4,56E-08	1,61E-09
Vanadium, ion	5,78E-07	3,16E-07	5,47E-08	6,21E-08	1,56E-07	-1,07E-08
Zinc, ion	5,59E-05	1,91E-05	4,98E-06	1,14E-05	1,89E-05	1,47E-06
Heavy metals to fresh water						
Antimony	1,67E-07	1,16E-08	2,10E-09	1,25E-09	1,17E-08	1,41E-07
Arsenic	1,17E-17	1,17E-17	-	-	-	-
Arsenic (+V)	9,45E-06	6,77E-06	9,53E-07	1,04E-06	1,55E-06	-8,68E-07
Cadmium	1,98E-09	4,87E-10	3,63E-10	2,57E-10	7,07E-10	1,66E-10
Chromium	3,75E-13	3,75E-13	-	-	-	-
Chromium (+III)	8,47E-14	2,73E-14	1,26E-14	1,97E-15	4,32E-14	-3,66E-16
Chromium (+VI)	5,66E-09	2,39E-09	1,96E-09	6,19E-10	1,60E-09	-9,13E-10
Copper	4,77E-11	8,44E-12	3,54E-12	7,72E-12	2,81E-11	-1,17E-13
Lead	8,95E-09	2,67E-09	6,84E-10	3,48E-10	4,83E-09	4,14E-10
Mercury	8,62E-09	4,04E-09	2,53E-09	4,61E-10	1,39E-09	1,99E-10
Molybdenum	2,06E-08	1,51E-08	2,22E-09	1,63E-09	2,22E-09	-5,72E-10
Nickel	1,73E-10	9,03E-11	2,33E-11	1,32E-11	5,97E-11	-1,39E-11
Silver	8,29E-09	5,55E-09	5,04E-10	2,51E-10	2,07E-09	-8,48E-11
Thallium	1,19E-09	8,58E-10	9,67E-11	9,38E-11	1,48E-10	-2,84E-12
Vanadium	4,83E-09	3,26E-09	5,51E-10	4,12E-10	6,51E-10	-4,85E-11
Zinc	3,49E-07	1,02E-07	3,00E-08	8,69E-08	1,04E-07	2,59E-08
Inorganic emissions to fresh water						
Barium	3,45E-07	2,25E-07	2,17E-08	1,09E-08	8,89E-08	-1,89E-09
Beryllium	4,84E-12	2,74E-12	4,38E-13	5,82E-13	1,13E-12	-4,02E-14
Carbon disulphide	1,09E-11	1,13E-13	1,78E-14	2,56E-14	1,07E-11	-6,84E-15
Organic emissions to fresh water						
1,1,1-Trichloroethane	1,22E-25	8,58E-26	1,61E-26	1,27E-26	1,12E-26	-3,48E-27
1,2-Dibromoethane	-1,30E-28	-1,30E-28	-	-	-	-
2-Chlorotoluene	2,51E-15	1,30E-15	2,99E-16	1,46E-16	8,11E-16	-3,89E-17
Bromoxynil	2,39E-22	1,97E-22	7,84E-24	1,53E-24	3,24E-23	7,93E-25
Chlorobenzene	7,33E-12	7,03E-12	1,71E-13	2,22E-14	9,78E-14	4,20E-15
Chloromethane (methyl chloride)	-1,44E-21	-1,44E-21	-	-	-	-
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene)	2,53E-12	2,40E-12	6,95E-14	8,86E-15	4,55E-14	1,82E-15

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Dichloromethane (methylene chloride)	6,96E-12	4,03E-12	6,11E-13	3,54E-13	1,86E-12	1,03E-13
Dichloropropane	-1,33E-28	-1,33E-28	-	-	-	-
Pentachlorophenol (PCP)	9,40E-21	9,40E-21	-	-	-	-
Tetrachloroethene (perchloroethylene)	3,55E-24	3,55E-24	-	-	-	-
Trichloromethane (chloroform)	5,91E-15	5,06E-15	8,81E-17	4,01E-17	7,27E-16	-7,13E-18
Vinyl chloride (VCM; chloroethene)	2,26E-13	7,27E-14	1,52E-14	1,10E-14	1,29E-13	-2,23E-15
Acenaphthene	1,30E-14	5,79E-16	1,51E-15	5,47E-17	1,08E-14	3,26E-17
Acetonitrile	3,50E-17	2,07E-17	3,25E-18	1,26E-18	1,01E-17	-2,69E-19
Acrylonitrile	1,72E-23	1,72E-23	-	-	-	-
Aniline	5,10E-14	1,85E-14	5,06E-15	1,96E-15	2,60E-14	-4,96E-16
Anthracene	1,49E-15	2,12E-17	1,76E-16	1,45E-18	1,29E-15	8,55E-19
Benzene	1,10E-11	7,49E-12	4,38E-13	5,50E-13	2,81E-12	-3,38E-13
Ethyl benzene	5,13E-13	2,81E-13	4,27E-14	2,49E-14	1,50E-13	1,39E-14
Ethylene acetate (ethyl acetate)	2,28E-16	1,04E-17	3,57E-17	1,96E-18	1,81E-16	-9,17E-19
Fluoranthene	1,06E-12	9,79E-15	1,26E-13	1,04E-15	9,24E-13	6,11E-16
Formaldehyde (methanal)	1,08E-11	4,32E-13	4,48E-12	1,21E-13	5,85E-12	-8,75E-14
Hexane (isomers)	-6,25E-28	-6,25E-28	-	-	-	-
Methanol	6,23E-12	1,23E-14	5,71E-12	4,42E-15	5,06E-13	-2,74E-15
Methyl tert-butylether	2,08E-16	8,77E-17	3,71E-17	5,15E-18	7,91E-17	-1,60E-18
Naphthalene	5,01E-15	6,31E-16	5,23E-16	4,33E-18	3,85E-15	2,55E-18
Phenol (hydroxy benzene)	9,09E-12	4,05E-12	9,22E-13	3,57E-13	3,70E-12	5,27E-14
Propylene oxide	7,92E-09	1,63E-12	7,91E-09	1,89E-13	2,13E-12	1,40E-12
Pyrene	3,57E-13	3,29E-15	4,23E-14	3,50E-16	3,11E-13	2,06E-16
Toluene (methyl benzene)	1,38E-12	7,86E-13	1,10E-13	6,28E-14	3,95E-13	2,89E-14
Xylene (isomers; dimethyl benzene)	9,21E-13	5,14E-13	7,49E-14	4,33E-14	2,66E-13	2,21E-14
Acetaldehyde (Ethanal)	5,46E-11	3,65E-13	8,84E-12	2,39E-13	4,49E-11	2,55E-13
Acetone (dimethylcetone)	7,11E-16	4,53E-16	4,47E-17	2,18E-17	1,99E-16	-7,87E-18
Acrylic acid	1,52E-16	5,52E-17	2,24E-17	4,05E-18	6,75E-17	3,10E-18
Allyl chloride	9,27E-15	1,63E-15	3,79E-16	2,18E-16	6,23E-15	8,18E-16
Biphenyl	1,17E-32	1,17E-32	-	-	-	-
Chloramine	3,11E-14	1,68E-14	2,57E-15	1,45E-15	1,06E-14	-2,72E-16
Cumene (isopropylbenzene)	1,31E-12	2,00E-13	3,81E-14	1,82E-13	1,08E-12	-1,89E-13
iso-Butanol	8,68E-17	2,42E-17	5,31E-18	2,12E-18	5,56E-17	-4,66E-19
Methyl isobutyl ketone	8,61E-17	5,78E-17	5,10E-18	2,46E-18	2,17E-17	-9,42E-19
Nitrobenzene	1,96E-13	7,30E-14	1,94E-14	7,54E-15	9,77E-14	-1,90E-15
Other emissions to fresh water						
Atrazine	4,02E-19	2,44E-19	6,00E-20	2,78E-20	7,33E-20	-3,72E-21
Benomyl	1,81E-21	1,81E-21	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Bentazone	9,25E-17	3,66E-17	1,24E-17	4,20E-18	4,02E-17	-8,76E-19
Carbaryl	5,98E-23	3,70E-23	8,61E-24	3,98E-24	1,07E-23	-5,26E-25
Carbofuran	1,33E-20	1,33E-20	-	-	-	-
Cypermethrin	9,34E-26	9,34E-26	-	-	-	-
Deltamethrin	6,62E-19	6,62E-19	-	-	-	-
Dicamba	2,07E-20	1,26E-20	3,09E-21	1,43E-21	3,77E-21	-1,91E-22
Dimethoate	8,14E-25	8,14E-25	-	-	-	-
Ethephon	7,35E-24	6,42E-24	1,46E-25	2,98E-26	7,47E-25	1,09E-26
Fenvalerate	5,71E-24	5,71E-24	-	-	-	-
Fipronil	1,47E-28	1,47E-28	-	-	-	-
Glyphosate	2,90E-16	1,14E-16	3,92E-17	1,33E-17	1,27E-16	-2,76E-18
Imidacloprid	2,65E-26	2,65E-26	-	-	-	-
Mancozeb	6,18E-19	6,18E-19	-	-	-	-
MCPA	2,85E-21	2,46E-21	6,35E-23	1,28E-23	3,07E-22	5,23E-24
Methomyl	1,27E-19	1,27E-19	2,75E-25	5,62E-26	1,41E-24	2,07E-26
Metolachlor	1,38E-17	5,39E-18	1,86E-18	6,29E-19	6,01E-18	-1,31E-19
Parathion-methyl	1,98E-18	1,98E-18	-	-	-	-
Pendimethalin	8,00E-22	4,87E-22	1,20E-22	5,55E-23	1,46E-22	-7,40E-24
Propiconazole	8,25E-22	7,20E-22	1,64E-23	3,35E-24	8,41E-23	1,23E-24
Tebuconazole	1,25E-23	1,09E-23	2,49E-25	5,10E-26	1,28E-24	1,87E-26
Terbufos	8,14E-27	8,14E-27	-	-	-	-
Thiram	1,38E-18	1,38E-18	-	-	-	-
Trifluralin	3,38E-17	3,38E-17	-	-	-	-
Heavy metals to sea water						
Arsenic (+V)	4,11E-09	2,69E-10	7,01E-11	3,26E-09	4,85E-10	1,92E-11
Cadmium	7,54E-10	5,93E-12	1,19E-12	7,41E-10	5,85E-12	4,37E-13
Chromium	5,83E-15	5,83E-15	-	-	-	-
Chromium (+III)	1,61E-15	8,49E-16	1,44E-16	8,08E-17	4,94E-16	4,52E-17
Copper	5,78E-11	7,94E-14	2,51E-14	5,76E-11	8,87E-14	9,20E-15
Lead	2,95E-10	1,04E-10	1,90E-11	1,06E-10	6,12E-11	4,99E-12
Mercury	1,05E-09	7,55E-11	2,64E-11	7,19E-10	2,22E-10	8,10E-12
Molybdenum	1,32E-13	6,85E-14	1,18E-14	6,55E-15	4,11E-14	4,28E-15
Nickel	1,37E-11	2,03E-14	5,73E-15	1,37E-11	2,54E-14	2,74E-15
Silver	1,61E-12	8,68E-13	1,37E-13	8,08E-14	4,77E-13	4,85E-14
Vanadium	1,70E-12	8,89E-13	1,49E-13	8,33E-14	5,29E-13	5,02E-14
Zinc	5,54E-07	3,67E-08	7,65E-09	5,01E-07	9,35E-09	-5,09E-10
Inorganic emissions to sea water						
Barium	8,26E-11	4,45E-11	7,02E-12	4,13E-12	2,44E-11	2,48E-12
Beryllium	-1,69E-24	-1,69E-24	-	-	-	-
Organic emissions to sea water						
Tetrachloroethene (perchloroethylene)	2,75E-28	2,75E-28	-	-	-	-
Acenaphthene	5,73E-18	3,19E-18	4,69E-19	2,76E-19	1,63E-18	1,66E-19
Anthracene	2,52E-19	2,52E-19	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Benzene	3,43E-14	1,86E-14	2,93E-15	1,72E-15	1,01E-14	1,01E-15
Ethyl benzene	1,02E-15	5,50E-16	8,67E-17	5,11E-17	3,02E-16	3,06E-17
Fluoranthene	2,98E-19	2,98E-19	-	-	-	-
Hexane (isomers)	-2,03E-29	-2,03E-29	-	-	-	-
Methanol	2,42E-16	1,68E-16	3,37E-17	2,03E-17	2,80E-17	-8,28E-18
Methyl tert-butylether	1,20E-17	5,02E-18	2,14E-18	2,74E-19	4,63E-18	-9,34E-20
Phenol (hydroxy benzene)	4,37E-15	2,37E-15	3,72E-16	2,18E-16	1,29E-15	1,22E-16
Toluene (methyl benzene)	1,12E-14	5,93E-15	9,67E-16	5,57E-16	3,36E-15	3,43E-16
Xylene (isomers; dimethyl benzene)	7,45E-15	4,01E-15	6,38E-16	3,74E-16	2,20E-15	2,22E-16
Ethylene Glycol	2,36E-29	2,36E-29	-	-	-	-
Naphthalene	1,41E-17	1,41E-17	-	-	-	-
Other emissions to sea water						
Tributyltinoxide	2,33E-14	1,13E-14	3,38E-15	1,65E-15	9,10E-15	-2,14E-15
Heavy metals to agricultural soil						
Antimony	3,43E-14	1,98E-14	1,80E-15	5,01E-15	7,40E-15	2,87E-16
Arsenic	2,33E-08	1,94E-08	1,23E-09	7,79E-10	2,03E-09	-8,48E-11
Arsenic (+V)	7,34E-21	7,34E-21	-	-	-	-
Cadmium	8,76E-08	6,43E-08	8,33E-09	4,91E-09	1,05E-08	-3,72E-10
Chromium	5,60E-11	4,19E-11	5,44E-12	3,41E-12	5,56E-12	-2,58E-13
Chromium (+III)	9,55E-18	9,55E-18	-	-	-	-
Copper	4,02E-10	3,03E-10	3,03E-11	2,57E-11	4,51E-11	-1,84E-12
Lead	8,95E-08	6,34E-08	8,46E-09	6,14E-09	1,19E-08	-3,99E-10
Mercury	5,11E-08	1,82E-08	3,44E-09	4,00E-09	2,58E-08	-3,38E-10
Molybdenum	1,52E-09	6,20E-10	8,28E-11	6,19E-11	7,62E-10	-4,00E-12
Nickel	1,59E-11	1,16E-11	1,47E-12	9,74E-13	2,00E-12	-6,94E-14
Silver	1,11E-17	3,71E-18	6,90E-19	4,98E-18	1,48E-18	2,32E-19
Vanadium	2,44E-10	1,90E-10	2,44E-11	1,43E-11	1,65E-11	-1,12E-12
Zinc	3,54E-06	2,59E-06	3,36E-07	2,22E-07	4,11E-07	-1,68E-08
Inorganic emissions to agricultural soil						
Barium	5,83E-13	3,37E-13	3,52E-14	3,93E-14	1,40E-13	3,14E-14
Organic emissions to agricultural soil						
Bromoxynil	1,38E-16	1,18E-16	4,00E-18	1,21E-18	1,47E-17	9,31E-20
Mepiquat chloride	2,02E-21	3,25E-22	2,70E-22	2,31E-23	1,40E-21	-1,85E-24
Other emissions to agricultural soil						
2,4-Dichlorophenoxyacetic acid (2,4-D)	1,41E-11	5,88E-12	1,70E-12	5,26E-13	6,09E-12	-1,08E-13
Acephate	1,76E-11	2,83E-12	2,37E-12	2,11E-13	1,22E-11	-1,86E-14
Aldicarb	7,43E-12	1,17E-12	9,99E-13	8,54E-14	5,18E-12	-6,90E-15
Aldrin	6,14E-10	5,38E-10	1,52E-11	9,84E-12	5,30E-11	-1,90E-12
Asulam	2,93E-21	1,14E-21	4,22E-22	7,82E-23	1,24E-21	5,57E-23
Atrazine	9,16E-12	3,31E-12	9,33E-14	6,11E-14	5,71E-12	-1,46E-14
Azodrin	2,17E-11	8,36E-12	2,93E-12	9,73E-13	9,65E-12	-2,00E-13
Benomyl	2,23E-17	1,35E-18	3,01E-18	1,29E-19	1,79E-17	-3,23E-20

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Bensulfuron methyl ester	1,49E-17	1,30E-17	2,96E-19	6,04E-20	1,51E-18	2,22E-20
Bentazone	1,49E-15	6,58E-16	1,88E-16	6,48E-17	5,97E-16	-1,34E-17
Bifenthrin	1,92E-18	1,18E-18	2,87E-19	1,35E-19	3,38E-19	-1,92E-20
Bitertanol	5,13E-19	4,47E-19	1,02E-20	2,08E-21	5,23E-20	7,66E-22
Carbaryl	5,61E-16	3,94E-16	7,71E-17	4,48E-17	5,67E-17	-1,23E-17
Carbendazim	2,30E-14	1,44E-14	3,36E-15	1,80E-15	3,89E-15	-5,02E-16
Carbofuran	3,24E-11	1,97E-12	4,37E-12	1,89E-13	2,60E-11	-4,75E-14
Chlormequat	4,96E-15	3,55E-15	7,02E-16	4,20E-16	4,03E-16	-1,16E-16
Chlorothalonil	5,44E-12	8,23E-14	1,47E-14	5,04E-14	5,29E-12	-6,99E-15
Chlorpyriphos	4,42E-12	7,69E-13	5,94E-13	6,09E-14	3,00E-12	-6,69E-15
Chlorsulfuron	4,04E-18	3,53E-18	8,04E-20	1,64E-20	4,12E-19	6,04E-21
Cyfluthrin	1,67E-16	2,81E-17	2,25E-17	2,17E-18	1,15E-16	-2,21E-19
Cypermethrin	4,53E-13	5,38E-14	5,73E-14	6,34E-15	3,37E-13	-1,37E-15
Deltamethrin	3,54E-16	2,50E-16	5,22E-17	3,13E-17	2,84E-17	-8,72E-18
Dicamba	2,83E-16	2,21E-16	1,76E-17	8,22E-18	3,71E-17	-1,37E-18
Dicrotophos	8,52E-14	1,34E-14	1,15E-14	9,80E-16	5,94E-14	-7,92E-17
Diflubenzuron	9,91E-13	3,82E-13	1,34E-13	4,44E-14	4,41E-13	-9,12E-15
Dimethoate	1,97E-16	1,71E-16	4,01E-18	8,17E-19	2,03E-17	3,08E-19
Dithianon	1,22E-18	1,06E-18	2,49E-20	5,08E-21	1,26E-19	1,92E-21
Diuron	1,14E-12	1,01E-12	2,80E-14	1,69E-14	8,36E-14	-2,95E-15
Endosulfan	1,18E-12	4,54E-13	1,59E-13	5,28E-14	5,24E-13	-1,08E-14
Endothall	1,14E-16	8,07E-17	1,68E-17	1,01E-17	9,15E-18	-2,81E-18
Ethephon	5,52E-14	9,81E-15	7,25E-15	6,24E-16	3,76E-14	-4,75E-17
Fenbuconazole	2,43E-20	2,12E-20	4,96E-22	1,01E-22	2,51E-21	3,81E-23
Fipronil	7,70E-13	1,21E-13	1,04E-13	8,86E-15	5,37E-13	-7,17E-16
Glyphosate	1,35E-12	1,55E-13	1,44E-13	9,84E-15	1,04E-12	-1,69E-15
Imazethapyr	7,69E-17	3,03E-17	1,04E-17	3,54E-18	3,34E-17	-7,41E-19
Imidacloprid	6,07E-15	9,57E-16	8,16E-16	6,98E-17	4,23E-15	-5,65E-18
Iprodione	2,22E-13	1,57E-13	3,28E-14	1,97E-14	1,78E-14	-5,49E-15
Kresoxim-methyl	3,42E-20	2,91E-20	1,05E-21	3,32E-22	3,64E-21	1,20E-23
Linuron	1,15E-11	8,92E-12	5,34E-13	2,49E-13	1,81E-12	-4,92E-14
Malathion	1,22E-15	7,53E-17	1,64E-16	7,25E-18	9,72E-16	-1,82E-18
Mancozeb	1,74E-12	2,64E-14	4,69E-15	1,61E-14	1,70E-12	-2,24E-15
MCPA	1,61E-14	1,40E-14	3,20E-16	6,53E-17	1,64E-15	2,40E-17
MCPB	4,23E-19	1,66E-19	6,03E-20	1,12E-20	1,77E-19	7,96E-21
Metalaxyl	2,15E-15	1,30E-16	2,89E-16	1,24E-17	1,72E-15	-3,11E-18
Methomyl	9,32E-22	8,13E-22	1,85E-23	3,79E-24	9,50E-23	1,39E-24
Metolachlor	1,91E-12	3,00E-13	1,04E-13	3,49E-14	1,48E-12	-7,79E-15
Metribuzin	3,57E-13	1,92E-14	5,88E-15	4,63E-15	3,28E-13	-7,56E-16
Metsulfuron-methyl	9,87E-15	1,92E-15	1,33E-15	2,16E-16	6,45E-15	-4,58E-17
Molinate	1,06E-13	9,23E-14	2,10E-15	4,30E-16	1,08E-14	1,58E-16
Napropamide	1,36E-13	1,01E-13	2,10E-14	1,26E-14	5,30E-15	-3,51E-15
Paraquat	9,00E-17	8,14E-18	1,21E-17	7,76E-19	6,91E-17	-1,68E-19

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Parathion-ethyl	6,09E-15	4,63E-15	6,51E-16	3,88E-16	5,42E-16	-1,13E-16
Parathion-methyl	2,18E-16	1,06E-16	3,06E-17	1,27E-17	7,16E-17	-3,04E-18
Pendimethalin	6,64E-15	2,37E-15	8,92E-16	2,63E-16	3,18E-15	-5,30E-17
Permethrin	2,66E-18	1,31E-18	3,74E-19	1,57E-19	8,56E-19	-3,66E-20
Phenmedipham	2,01E-19	1,28E-19	3,02E-20	1,49E-20	3,05E-20	-2,66E-21
Picloram	3,17E-19	2,76E-19	6,30E-21	1,29E-21	3,23E-20	4,73E-22
Pirimicarb	8,35E-15	9,10E-17	9,90E-16	9,03E-18	7,25E-15	4,46E-18
Prochloraz	1,16E-15	1,01E-15	2,33E-17	4,76E-18	1,19E-16	1,77E-18
Procymidone	3,61E-15	2,56E-15	5,33E-16	3,20E-16	2,90E-16	-8,91E-17
Profenofos	8,38E-14	1,32E-14	1,13E-14	9,64E-16	5,84E-14	-7,79E-17
Prometryne	1,05E-15	1,65E-16	1,41E-16	1,21E-17	7,31E-16	-9,75E-19
Propanil	1,65E-14	1,44E-14	3,28E-16	6,70E-17	1,68E-15	2,46E-17
Propiconazole	1,19E-16	9,16E-17	6,19E-18	2,21E-18	1,93E-17	-3,10E-19
Quizalofop-ethyl	2,57E-15	1,82E-15	3,80E-16	2,27E-16	2,12E-16	-6,33E-17
Sethoxydim	6,46E-16	4,57E-16	9,54E-17	5,72E-17	5,25E-17	-1,59E-17
Simazine	5,33E-16	3,27E-16	7,97E-17	3,75E-17	9,37E-17	-5,33E-18
Tebuconazole	3,41E-14	2,42E-14	5,03E-15	3,02E-15	2,74E-15	-8,41E-16
Teflubenzuron	1,79E-12	2,71E-14	4,82E-15	1,66E-14	1,74E-12	-2,30E-15
Terbufos	1,13E-13	9,41E-14	6,13E-15	3,23E-15	1,05E-14	-5,01E-16
Thifensulfuron methyl	8,15E-17	5,37E-17	7,06E-18	2,78E-18	1,85E-17	-5,75E-19
Thiobencarb	1,71E-15	1,49E-15	3,40E-17	6,95E-18	1,74E-16	2,56E-18
Thiodicarb	5,95E-18	2,89E-18	8,36E-19	3,48E-19	1,95E-18	-8,29E-20
Thiram	8,61E-15	5,20E-16	1,16E-15	4,98E-17	6,90E-15	-1,25E-17
Triadimenol	6,03E-18	5,26E-18	1,22E-19	2,49E-20	6,20E-19	9,27E-21
Triallate	4,30E-17	3,76E-17	8,56E-19	1,75E-19	4,39E-18	6,43E-20
Triasulfuron	1,10E-16	9,62E-17	2,19E-18	4,48E-19	1,12E-17	1,65E-19
Tribenuron methyl	3,60E-17	2,59E-17	2,41E-18	9,12E-19	6,85E-18	-1,64E-19
Tribufos	2,86E-14	4,51E-15	3,85E-15	3,29E-16	2,00E-14	-2,66E-17
Trifluralin	2,48E-12	1,75E-12	3,75E-13	2,19E-13	1,90E-13	-6,06E-14
Vinclozolin	1,64E-14	1,16E-14	2,42E-15	1,45E-15	1,32E-15	-4,05E-16
Heavy metals to industrial soil						
Antimony	2,15E-12	3,50E-13	2,19E-13	6,63E-14	8,20E-13	6,92E-13
Arsenic	3,00E-09	1,67E-09	2,84E-10	1,57E-10	7,56E-10	1,36E-10
Arsenic (+V)	5,90E-17	5,90E-17	-	-	-	-
Cadmium	6,80E-12	1,38E-12	6,83E-13	2,39E-13	2,54E-12	1,95E-12
Chromium	1,47E-11	8,48E-12	1,38E-12	7,79E-13	3,60E-12	4,40E-13
Chromium (+III)	1,87E-24	1,87E-24	-	-	-	-
Chromium (+VI)	4,29E-10	2,89E-10	6,95E-11	4,45E-11	3,94E-11	-1,36E-11
Copper	1,06E-11	6,92E-12	1,70E-12	1,08E-12	1,14E-12	-1,79E-13
Lead	8,51E-11	1,78E-11	8,53E-12	3,06E-12	3,17E-11	2,40E-11
Mercury	7,20E-12	3,65E-12	6,43E-13	4,99E-13	2,17E-12	2,32E-13
Molybdenum	6,33E-13	1,03E-13	6,45E-14	1,95E-14	2,42E-13	2,04E-13
Nickel	2,57E-13	6,26E-14	2,54E-14	1,02E-14	9,40E-14	6,47E-14

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Silver	1,08E-13	1,77E-14	1,11E-14	3,35E-15	4,14E-14	3,50E-14
Vanadium	5,89E-13	9,60E-14	6,01E-14	1,82E-14	2,25E-13	1,90E-13
Zinc	3,61E-08	8,10E-09	3,63E-09	1,23E-09	1,31E-08	9,95E-09
Inorganic emissions to industrial soil						
Barium	1,13E-08	6,81E-09	1,06E-09	6,15E-10	2,69E-09	1,50E-10
Beryllium	1,29E-24	1,29E-24	-	-	-	-
Organic emissions to industrial soil						
Methanol	3,92E-23	3,92E-23	-	-	-	-
Pentachlorophenol (PCP)	5,11E-16	3,26E-16	8,16E-17	4,73E-17	7,01E-17	-1,40E-17
Other emissions to industrial soil						
Glyphosate	1,56E-13	9,37E-14	1,71E-14	7,70E-15	3,96E-14	-2,20E-15

Table B.9: Ozone depletion midpoint (v1.09) of one sc-Si PV-module (60 6-inch solar cells) in kg CFC-11 equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	3,86E-09	2,35E-09	2,72E-10	1,81E-10	1,16E-09	-1,04E-10
Organic emissions to air						
1,1,1-Trichloroethane	1,41E-08	1,17E-08	6,39E-10	5,43E-10	2,17E-09	-9,11E-10
Carbon tetrachloride (tetrachloromethane)	3,82E-06	2,96E-06	7,73E-07	6,15E-08	7,41E-08	-4,50E-08
Chlorinated hydrocarbons (unspecified)	1,08E-06	1,55E-08	2,32E-09	1,59E-09	5,66E-07	4,94E-07
Chloromethane (methyl chloride)	6,23E-08	5,16E-08	2,82E-09	2,40E-09	9,60E-09	-4,02E-09
Halon (1211)	4,89E-06	3,38E-06	6,59E-07	3,93E-07	6,13E-07	-1,55E-07
Halon (1301)	8,17E-06	4,66E-06	6,39E-07	3,66E-07	2,33E-06	1,74E-07
Hydrocarbons, chloro-/fluoro-	3,67E-18	3,67E-18	-	-	-	-
Hydrocarbons, halogenated	3,80E-19	3,80E-19	-	-	-	-
Methyl bromide	9,20E-13	6,41E-13	4,30E-14	1,99E-14	2,25E-13	-8,90E-15
R 11 (trichlorofluoromethane)	6,29E-09	6,29E-09	3,02E-13	9,85E-14	9,36E-13	2,80E-14
R 113 (trichlorotrifluoroethane)	9,46E-07	7,34E-07	1,08E-07	6,48E-08	4,37E-08	-5,35E-09
R 114 (dichlorotetrafluoroethane)	9,60E-06	6,77E-06	1,52E-06	9,32E-07	4,42E-07	-6,93E-08
R 12 (dichlorodifluoromethane)	8,28E-07	4,62E-07	2,08E-09	1,29E-09	3,67E-07	-4,55E-09
R 124 (chlorotetrafluoroethane)	1,89E-08	1,47E-08	2,17E-09	1,30E-09	8,73E-10	-1,07E-10
R 22 (chlorodifluoromethane)	1,60E-06	1,41E-06	8,37E-08	2,87E-08	7,98E-08	-3,79E-09

Table B.10: Acidification midpoint (v1.09) of one sc-Si PV-module (60 6-inch solar cells) in mole of H+ equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Ammonia	1,94E-04	1,13E-07	1,74E-08	1,77E-04	1,73E-05	-5,59E-09
Nitrogen oxides	6,45E-07	4,17E-09	6,42E-10	4,72E-10	6,40E-07	-2,06E-10
Inorganic emissions to air						
Ammonia	5,04E-02	2,21E-02	4,21E-03	7,37E-03	1,75E-02	-8,50E-04
Nitrogen dioxide	2,80E-06	2,80E-06	-	-	-	-
Nitrogen monoxide	5,68E-05	5,68E-05	-	-	-	-
Nitrogen oxides	5,34E-01	3,51E-01	4,22E-02	3,59E-02	1,20E-01	-1,51E-02
Sulphur dioxide	1,74E+00	1,20E+00	1,46E-01	8,40E-02	3,76E-01	-6,22E-02
Sulphur oxides	2,86E-04	1,15E-06	2,12E-07	1,56E-07	2,85E-04	-6,63E-08
Sulphur trioxide	9,09E-08	3,97E-08	9,24E-09	3,16E-09	3,86E-08	1,86E-10

Table B.11: Eutrophication marine midpoint (v1.09) of one sc-Si PV-module (60 6-inch solar cells) in kg N equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Ammonia	5,91E-06	3,44E-09	5,30E-10	5,38E-06	5,28E-07	-1,70E-10
Nitrate	2,77E-07	1,96E-07	4,35E-08	2,66E-08	1,29E-08	-1,98E-09
Nitrogen oxides	3,39E-07	2,19E-09	3,38E-10	2,48E-10	3,36E-07	-1,08E-10
Inorganic emissions to air						
Ammonia	1,53E-03	6,73E-04	1,28E-04	2,25E-04	5,34E-04	-2,59E-05
Ammonium	8,80E-14	8,80E-14	-	-	-	-
Nitrate	2,21E-07	8,78E-08	2,78E-08	1,30E-08	5,25E-08	3,99E-08
Nitrogen dioxide	1,47E-06	1,47E-06	-	-	-	-
Nitrogen monoxide	3,00E-05	3,00E-05	-	-	-	-
Nitrogen oxides	2,81E-01	1,85E-01	2,22E-02	1,89E-02	6,29E-02	-7,96E-03
Long-term emissions to fresh water						
Ammonium, ion	1,35E-03	1,96E-05	4,04E-06	2,99E-06	1,35E-03	-1,73E-05
Nitrate	3,94E-02	3,21E-02	5,25E-03	3,55E-03	5,74E-03	-7,16E-03
Nitrite	2,88E-05	4,18E-07	8,60E-08	6,36E-08	2,86E-05	-3,69E-07
Nitrogen organic bound	2,84E-03	4,12E-05	8,47E-06	6,27E-06	2,83E-03	-3,64E-05
Inorganic emissions to fresh water						
Ammonia	1,26E-09	1,26E-09	-	-	-	-
Ammonium / ammonia	3,74E-03	3,87E-04	8,30E-05	2,74E-03	1,13E-03	-5,99E-04
Nitrate	8,17E-02	5,02E-02	4,91E-04	2,97E-02	4,75E-03	-3,39E-03
Nitrite	1,04E-04	2,83E-06	7,82E-07	3,73E-06	9,71E-05	-7,23E-08
Nitrogen	2,50E-03	1,41E-03	1,08E-04	4,01E-04	5,90E-04	-1,39E-05
Nitrogen (as total N)	8,62E-12	8,62E-12	-	-	-	-
Nitrogen organic bound	5,39E-04	6,26E-05	5,88E-05	1,62E-05	3,58E-04	4,34E-05

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Inorganic emissions to sea water						
Ammonia	-1,42E-18	-1,42E-18	-	-	-	-
Ammonium / ammonia	1,53E-05	7,35E-06	1,48E-06	8,49E-07	4,71E-06	8,86E-07
Nitrate	3,55E-05	2,38E-05	4,79E-06	2,88E-06	3,96E-06	7,59E-08
Nitrate (as total N)	6,52E-19	6,52E-19	-	-	-	-
Nitrite	7,60E-07	5,45E-07	1,13E-07	6,91E-08	3,83E-08	-5,43E-09
Nitrogen	9,00E-07	5,82E-07	1,39E-07	8,21E-08	1,04E-07	-6,36E-09
Nitrogen (as total N)	1,00E-19	1,00E-19	-	-	-	-
Nitrogen organic bound	3,59E-05	1,63E-05	3,70E-06	2,15E-06	1,10E-05	2,75E-06

Table B.12: Eutrophication freshwater midpoint (v1.09) of one sc-Si PV-module (60 6-inch solar cells) in kg P equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to fresh water						
Phosphate	1,93E-01	1,33E-01	2,19E-02	1,88E-02	2,33E-02	-4,05E-03
Inorganic emissions to fresh water						
Phosphate	3,72E-02	1,70E-02	3,40E-03	8,70E-03	8,20E-03	-1,31E-04
Phosphorus	1,54E-04	1,14E-05	4,98E-06	3,21E-05	1,18E-04	-1,17E-05
Inorganic emissions to sea water						
Phosphorus	1,79E-206	9,36E-207	1,62E-207	9,06E-208	5,43E-207	5,60E-208
Inorganic emissions to agriculture soil						
Phosphorus	4,34E-04	3,38E-04	4,34E-05	2,55E-05	2,93E-05	-2,00E-06
Inorganic emissions to industrial soil						
Phosphorus	2,32E-05	1,40E-05	2,16E-06	1,26E-06	5,50E-06	2,87E-07

Table B.13: Eutrophication terrestrial midpoint (v1.09) of one sc-Si PV-module (60 6-inch solar cells) in mole of N equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Ammonia	8,66E-04	5,03E-07	7,76E-08	7,88E-04	7,73E-05	-2,49E-08
Nitrate	3,13E-05	2,21E-05	4,91E-06	3,00E-06	1,46E-06	-2,24E-07
Nitrogen oxides	3,71E-06	2,40E-08	3,70E-09	2,72E-09	3,68E-06	-1,19E-09
Inorganic emissions to air						
Ammonia	2,25E-01	9,86E-02	1,88E-02	3,29E-02	7,82E-02	-3,79E-03
Ammonium	1,29E-11	1,29E-11	-	-	-	-
Nitrate	2,50E-05	9,91E-06	3,14E-06	1,47E-06	5,93E-06	4,51E-06
Nitrogen dioxide	1,61E-05	1,61E-05	-	-	-	-
Nitrogen monoxide	3,29E-04	3,29E-04	-	-	-	-
Nitrogen oxides	3,07E+00	2,02E+00	2,43E-01	2,07E-01	6,89E-01	-8,72E-02

ANNEX C: LIFE CYCLE IMPACT ASSESSMENT DATA FOR RESULTS OF MC-SI PV-MODULES IN CHAPTER 5

Table C.1: Climate change midpoint, excl. biogenic carbon (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in kg CO_2 equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Carbon dioxide, fossil	3,66E-02	-	-	-	3,66E-02	-
Dinitrogen monoxide	1,23E-03	4,57E-06	1,29E-06	1,94E-06	1,23E-03	-3,96E-07
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	1,76E-05	8,48E-06	1,55E-06	1,14E-06	7,08E-06	-6,35E-07
Inorganic emissions to air						
Carbon dioxide	2,02E+02	1,09E+02	2,73E+01	1,91E+01	5,16E+01	-4,22E+00
Carbon dioxide (aviation)	5,95E-10	5,95E-10	-	-	-	-
Carbon dioxide (land use change)	4,60E-05	4,60E-05	-	-	-	-
Carbon dioxide (peat oxidation)	1,82E-12	1,82E-12	-	-	-	-
Nitrogentriflouride	9,16E-11	5,28E-11	1,72E-11	1,21E-11	1,39E-11	-4,32E-12
Nitrous oxide (laughing gas)	3,44E+00	9,47E-01	2,54E-01	1,84E+00	4,75E-01	-7,16E-02
Sulphur hexafluoride	3,56E-01	1,20E-01	1,11E-01	7,55E-02	9,59E-02	-4,65E-02
Organic emissions to air (group VOC)						
1,1,1-Trichloroethane	1,24E-05	9,10E-06	7,21E-07	1,03E-06	2,65E-06	-1,11E-06
Carbon tetrachloride (tetrachloromethane)	6,07E-03	4,12E-03	1,51E-03	3,75E-04	1,42E-04	-8,64E-05
Chloromethane (methyl chloride)	2,92E-05	2,15E-05	1,70E-06	2,42E-06	6,24E-06	-2,61E-06
Dichloromethane (methylene chloride)	1,22E-05	8,97E-06	7,06E-07	1,04E-06	2,43E-06	-9,60E-07
Halon (1211)	7,78E-04	3,32E-04	1,79E-04	1,22E-04	1,93E-04	-4,89E-05
Halon (1301)	3,73E-03	1,54E-03	3,65E-04	3,34E-04	1,38E-03	1,03E-04
Methyl bromide	9,62E-12	5,61E-12	5,52E-13	6,14E-13	2,96E-12	-1,17E-13
R 11 (trichlorofluoromethane)	2,23E-05	2,23E-05	1,58E-09	2,47E-09	4,45E-09	1,33E-10
R 113 (trichlorotrifluoroethane)	2,16E-03	9,93E-04	5,70E-04	3,63E-04	2,68E-04	-3,28E-05
R 114 (dichlorotetrafluoroethane)	4,18E-02	1,54E-02	1,38E-02	8,58E-03	4,70E-03	-7,38E-04
R 116 (hexafluoroethane)	-3,50E-03	8,55E-04	6,48E-04	5,41E-03	2,59E-02	-3,63E-02
R 12 (dichlorodifluoromethane)	7,67E-03	3,69E-03	1,95E-05	1,76E-05	4,00E-03	-4,96E-05
R 124 (chlorotetrafluoroethane)	2,15E-04	9,86E-05	5,66E-05	3,60E-05	2,66E-05	-3,26E-06
R 125 (pentafluoroethane)	4,10E-11	4,10E-11	-	-	-	-
R 134a (tetrafluoroethane)	1,15E-02	1,97E-03	3,17E-04	2,07E-04	9,06E-03	-1,80E-05
R 143 (trifluoroethane)	3,69E-12	3,69E-12	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
R 152a (difluoroethane)	6,25E-01	1,19E-05	7,38E-05	3,84E-03	6,21E-01	2,05E-06
R 21 (Dichlorofluoromethane)	4,37E-07	4,37E-07	3,38E-11	5,08E-11	8,99E-11	2,40E-12
R 22 (chlorodifluoromethane)	4,21E-02	3,52E-02	2,92E-03	1,18E-03	2,89E-03	-1,37E-04
R 23 (trifluoromethane)	1,36E-02	1,36E-02	1,05E-06	1,58E-06	2,80E-06	7,47E-08
R 245fa (1,1,1,3,3-Pentafluoropropane)	2,14E-10	2,14E-10	-	-	-	-
R 32 (difluoromethane)	1,18E-12	1,18E-12	-	-	-	-
Tetrafluoromethane	-2,91E-02	7,03E-03	5,34E-03	4,47E-02	2,14E-01	-3,00E-01
Trichloromethane (chloroform)	1,63E-04	1,42E-04	2,84E-06	1,58E-05	3,63E-06	-1,18E-06
Methane	1,56E+01	9,39E+00	1,94E+00	1,37E+00	4,19E+00	-1,26E+00
Methane (biotic)	9,35E-01	5,48E-01	1,44E-01	1,21E-01	1,62E-01	-4,09E-02
Organic emissions to fresh water						
Dichloromethane (methylene chloride)	6,31E-05	2,54E-05	7,13E-06	6,17E-06	2,31E-05	1,27E-06
Inorganic emissions to industrial soil						
Carbon dioxide, to soil or biomass stock	-1,91E-03	-9,44E-04	-1,41E-04	-7,24E-05	-7,61E-04	5,84E-06

Table C.2: Ecotoxicity freshwater midpoint (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in CTUe

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Antimony	3,29E-03	1,24E-03	1,07E-03	6,65E-04	3,72E-04	-5,69E-05
Arsenic	4,30E-02	1,62E-02	1,39E-02	8,68E-03	4,86E-03	-7,44E-04
Barium	1,68E-03	6,36E-04	5,46E-04	3,40E-04	1,90E-04	-2,91E-05
Beryllium	9,76E-05	3,69E-05	3,17E-05	1,97E-05	1,10E-05	-1,69E-06
Cadmium	2,57E-04	9,70E-05	8,32E-05	5,18E-05	2,90E-05	-4,44E-06
Chromium VI	1,29E-02	4,88E-03	4,19E-03	2,61E-03	1,46E-03	-2,23E-04
Cobalt	6,57E-04	2,48E-04	2,13E-04	1,33E-04	7,42E-05	-1,14E-05
Copper	9,37E-02	3,54E-02	3,04E-02	1,89E-02	1,06E-02	-1,62E-03
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	4,53E-09	1,68E-11	4,73E-12	7,11E-12	4,51E-09	-1,45E-12
Lead	7,47E-04	2,82E-04	2,42E-04	1,51E-04	8,45E-05	-1,29E-05
Mercury	4,00E-04	1,51E-04	1,30E-04	8,08E-05	4,52E-05	-6,92E-06
Molybdenum	9,78E-05	3,70E-05	3,17E-05	1,98E-05	1,11E-05	-1,69E-06
Nickel	5,35E-03	2,02E-03	1,74E-03	1,08E-03	6,05E-04	-9,26E-05
Selenium	7,10E-04	2,68E-04	2,30E-04	1,43E-04	8,02E-05	-1,23E-05
Silver	5,74E-03	2,17E-03	1,86E-03	1,16E-03	6,49E-04	-9,94E-05
Tin	1,35E-04	5,09E-05	4,37E-05	2,72E-05	1,52E-05	-2,33E-06

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Vanadium	1,37E-01	5,19E-02	4,46E-02	2,78E-02	1,55E-02	-2,38E-03
Zinc	5,14E-02	1,94E-02	1,67E-02	1,04E-02	5,81E-03	-8,89E-04
Heavy metals to air						
Antimony	8,27E+00	8,24E-01	8,79E-01	3,67E-01	3,66E+00	2,54E+00
Arsenic	1,65E+00	2,39E-01	1,17E-01	6,58E-02	1,22E+00	8,94E-03
Arsenic (+V)	1,16E-07	1,16E-07	-	-	-	-
Cadmium	1,20E-01	9,24E-03	7,94E-03	4,81E-03	9,53E-02	2,32E-03
Chromium	3,88E+00	7,35E-01	1,94E+00	3,68E-01	8,72E-01	-3,24E-02
Chromium (+III)	2,89E-11	2,89E-11	-	-	-	-
Chromium (+VI)	2,38E-01	7,56E-02	9,70E-02	2,08E-02	4,90E-02	-3,99E-03
Cobalt	2,30E-02	9,52E-03	3,74E-03	2,16E-03	7,71E-03	-1,72E-04
Copper	7,21E+00	6,77E-01	6,18E-01	3,07E-01	5,11E+00	5,03E-01
Lead	5,70E-02	8,71E-03	4,58E-03	5,06E-03	3,53E-02	3,33E-03
Mercury	9,64E-02	3,80E-02	2,97E-02	1,07E-02	1,92E-02	-1,16E-03
Molybdenum	1,56E-03	3,93E-04	1,68E-04	8,76E-05	5,32E-04	3,77E-04
Nickel	1,43E+00	3,13E-01	1,20E-01	8,21E-02	9,34E-01	-1,93E-02
Selenium	7,35E-02	3,27E-02	7,89E-03	6,07E-03	2,96E-02	-2,82E-03
Silver	2,21E-04	8,61E-05	2,19E-05	1,17E-05	9,48E-05	7,02E-06
Thallium	6,50E-03	5,18E-03	2,17E-04	1,23E-04	1,04E-03	-5,42E-05
Tin	2,30E-01	1,95E-03	3,57E-03	1,04E-03	2,21E-01	3,23E-03
Vanadium	8,54E+00	4,79E+00	7,52E-01	9,48E-01	1,53E+00	5,21E-01
Zinc	9,65E+00	9,21E-01	9,25E-01	4,31E-01	3,96E+00	3,41E+00
Inorganic emissions to air						
Barium	6,74E-02	3,38E-02	5,74E-03	3,70E-03	1,75E-02	6,62E-03
Beryllium	7,69E-04	5,85E-04	3,29E-05	2,22E-05	1,49E-04	-2,01E-05
Carbon disulphide	3,65E-03	1,69E-04	4,29E-04	1,49E-04	2,81E-03	8,64E-05
Sodium formate	6,92E-08	1,25E-09	1,21E-09	2,40E-09	5,07E-08	1,36E-08
Sulphuric acid	2,07E-03	4,22E-05	5,64E-05	4,78E-05	9,23E-04	1,00E-03
Organic emissions to air (group VOC)						
Anthracene	9,83E-10	3,09E-11	-	-	-	9,52E-10
Benzo{a}anthracene	1,82E-08	-1,13E-10	2,90E-09	1,03E-09	4,88E-09	9,46E-09
Benzo{a}pyrene	1,91E-03	1,14E-03	3,34E-04	1,17E-04	3,48E-04	-3,19E-05
Dibenz(a)anthracene	4,52E-11	-5,53E-13	1,42E-11	5,05E-12	2,38E-11	2,65E-12
Naphthalene	6,13E-08	2,76E-10	7,06E-09	7,68E-11	5,15E-08	2,42E-09
Phenanthrene	1,30E-07	-5,82E-10	1,08E-08	3,84E-09	1,81E-08	9,78E-08
Pyrene	1,06E-07	-1,47E-09	2,10E-08	7,47E-09	3,53E-08	4,34E-08
1,1,1-Trichloroethane	1,74E-08	1,28E-08	1,01E-09	1,44E-09	3,71E-09	-1,56E-09
2,4-Dichlorophenol	2,07E-06	5,59E-07	3,12E-07	1,13E-07	1,11E-06	-2,40E-08
2-Chlorotoluene	5,42E-10	1,44E-10	8,79E-11	4,31E-11	2,79E-10	-1,24E-11
Bromoxynil	2,34E-13	1,94E-13	6,17E-15	2,02E-15	3,10E-14	4,72E-16
Carbon tetrachloride (tetrachloromethane)	4,62E-06	3,14E-06	1,15E-06	2,86E-07	1,08E-07	-6,58E-08
Chloromethane (methyl chloride)	1,42E-07	1,04E-07	8,26E-09	1,18E-08	3,03E-08	-1,27E-08

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene)	8,44E-09	2,70E-09	8,22E-10	4,27E-10	4,57E-09	-8,08E-11
Dichloroethane (ethylene dichloride)	3,68E-07	8,26E-08	4,13E-08	6,97E-08	2,11E-07	-3,60E-08
Dichloromethane (methylene chloride)	1,36E-07	9,99E-08	7,87E-09	1,15E-08	2,71E-08	-1,07E-08
Hexachlorobenzene (Perchlorobenzene)	1,07E-05	1,11E-06	7,38E-06	1,07E-06	9,86E-07	1,69E-07
Methyl bromide	2,24E-11	1,31E-11	1,29E-12	1,43E-12	6,90E-12	-2,73E-13
Pentachlorobenzene	2,33E-07	6,33E-09	2,89E-09	2,39E-09	5,10E-08	1,70E-07
Pentachlorophenol (PCP)	3,12E-02	1,87E-02	5,43E-03	1,82E-03	5,26E-03	4,46E-05
Polychlorinated biphenyls (PCB unspecified)	6,90E-06	8,47E-07	4,40E-06	7,56E-07	6,91E-07	2,10E-07
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	9,38E-06	3,42E-06	1,68E-06	1,08E-06	2,16E-06	1,04E-06
Polychlorinated dibenzo-p-furans (2,3,7,8 - TCDD)	9,30E-14	9,30E-14	-	-	-	-
Tetrachloroethene (perchloroethylene)	4,12E-07	9,72E-08	7,72E-09	2,91E-07	2,84E-08	-1,18E-08
Trichloroethene (isomers)	2,22E-16	2,22E-16	-	-	-	-
Trichloromethane (chloroform)	1,48E-06	1,29E-06	2,58E-08	1,44E-07	3,31E-08	-1,07E-08
1,3,5-Trimethylbenzene	3,60E-15	3,60E-15	-	-	-	-
1-Methoxy-2-propanol	4,07E-16	4,07E-16	-	-	-	-
1-Propanol	4,76E-05	1,63E-10	5,35E-11	2,74E-11	4,76E-05	-4,21E-12
Acenaphthene	1,86E-07	6,26E-09	2,18E-08	9,13E-10	1,57E-07	4,45E-10
Acetaldehyde (Ethanal)	3,15E-05	8,96E-06	4,12E-06	1,79E-06	1,50E-05	1,63E-06
Acetic acid	2,34E-02	1,18E-03	3,09E-03	2,85E-04	1,90E-02	-1,14E-04
Acetone (dimethylcetone)	3,81E-05	6,29E-06	1,72E-06	7,61E-07	2,94E-05	-2,36E-08
Acetonitrile	1,51E-06	3,47E-07	2,20E-07	6,76E-08	8,84E-07	-1,34E-08
Acrolein	1,05E-03	2,09E-04	1,22E-04	5,73E-05	4,35E-04	2,26E-04
Acrylic acid	5,85E-09	1,45E-09	9,03E-10	6,86E-10	2,69E-09	1,24E-10
Acrylonitrile	8,41E-18	8,41E-18	-	-	-	-
Aniline	1,08E-08	1,83E-09	1,31E-09	5,19E-10	7,29E-09	-1,39E-10
Benzaldehyde	2,40E-05	4,21E-06	3,16E-06	1,42E-06	9,84E-06	5,34E-06
Benzene	2,07E-04	1,23E-04	3,26E-05	1,35E-05	3,94E-05	-1,16E-06
Biphenyl	6,45E-14	6,45E-14	-	-	-	-
Butanone (methyl ethyl ketone)	1,60E-06	3,95E-07	2,47E-07	1,86E-07	7,36E-07	3,38E-08
Butylene glycol (butane diol)	5,14E-09	4,24E-09	2,14E-10	9,04E-11	6,03E-10	-7,72E-12
Butyrolactone	5,14E-09	1,03E-09	1,74E-09	4,83E-10	1,82E-09	7,25E-11
Caprolactam	3,75E-16	3,75E-16	-	-	-	-
Chloramine	6,60E-05	2,24E-05	7,06E-06	4,74E-06	3,27E-05	-8,41E-07
Cumene (isopropylbenzene)	1,50E-06	1,50E-07	4,68E-08	2,03E-07	1,34E-06	-2,35E-07

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Cyclohexane (hexahydro benzene)	1,13E-17	9,23E-18	9,07E-19	6,36E-19	7,29E-19	-2,28E-19
Cyclopentane	6,32E-15	6,32E-15	-	-	-	-
Decane	8,34E-16	8,34E-16	-	-	-	-
Diethyl ether	3,32E-17	1,57E-17	7,78E-18	5,45E-18	6,25E-18	-1,95E-18
Diethylamine	2,89E-10	6,18E-11	4,34E-11	2,00E-11	1,70E-10	-5,81E-12
Diethylene glycol	7,60E-16	3,59E-16	1,78E-16	1,25E-16	1,43E-16	-4,46E-17
Ethanol	9,18E-06	5,90E-06	9,94E-07	9,92E-07	1,44E-06	-1,50E-07
Ethyl benzene	4,50E-07	1,77E-07	5,66E-08	4,28E-08	1,67E-07	7,15E-09
Ethylamine	1,16E-08	3,46E-10	3,90E-11	3,87E-11	1,12E-08	-8,42E-12
Ethylene acetate (ethyl acetate)	3,15E-06	7,75E-07	4,87E-07	3,66E-07	1,45E-06	6,63E-08
Ethylene oxide	8,60E-06	1,79E-08	5,66E-06	3,61E-08	2,90E-06	-1,52E-08
Ethylenediamine	6,85E-07	4,34E-09	1,32E-09	3,71E-09	6,76E-07	-3,54E-10
Fluoranthene	2,71E-07	-4,87E-10	8,35E-09	2,97E-09	1,40E-08	2,47E-07
Fluorene	5,72E-12	5,72E-12	-	-	-	-
Formaldehyde (methanal)	1,15E-02	5,52E-03	1,45E-03	9,25E-04	3,48E-03	1,30E-04
Formic acid (methane acid)	1,13E-04	2,60E-05	1,65E-05	5,10E-06	6,63E-05	-9,96E-07
Furan	1,38E-07	3,19E-08	2,02E-08	6,22E-09	8,13E-08	-1,23E-09
Heptane (isomers)	1,24E-09	4,30E-10	1,25E-10	1,13E-10	8,85E-10	-3,11E-10
Hexamethylene diamine (HMDA)	-3,11E-21	-3,11E-21	-	-	-	-
Hexane (isomers)	9,82E-08	4,18E-08	1,49E-08	1,01E-08	3,64E-08	-4,86E-09
iso-Butanol	3,01E-10	4,57E-11	2,04E-11	9,49E-12	2,28E-10	-1,91E-12
Isoprene	1,03E-11	2,37E-12	1,50E-12	4,61E-13	6,03E-12	-9,14E-14
Isopropanol	4,79E-07	1,18E-07	7,37E-08	5,57E-08	2,21E-07	1,01E-08
Mercaptan (unspecified)	3,35E-12	3,35E-12	-	-	-	-
meta-Cresol	1,88E-16	1,88E-16	-	-	-	-
Methacrylate	1,26E-09	3,11E-10	1,94E-10	1,48E-10	5,79E-10	2,66E-11
Methanol	2,95E-04	1,39E-05	9,96E-05	5,74E-06	1,77E-04	-1,26E-06
Methyl acetate	5,06E-11	2,20E-11	6,86E-12	3,63E-12	1,88E-11	-7,72E-13
Methyl amine	2,80E-10	6,33E-11	4,61E-11	1,35E-11	1,59E-10	-1,89E-12
Methyl formate	2,54E-10	3,56E-11	1,63E-11	1,13E-11	1,90E-10	-7,76E-14
Methyl isobutyl ketone	2,83E-13	1,54E-14	2,98E-15	1,32E-14	2,49E-13	1,74E-15
Methyl methacrylate (MMA)	1,77E-17	1,77E-17	-	-	-	-
Methyl tert-butylether	4,07E-08	6,66E-09	5,73E-09	1,47E-09	2,66E-08	2,24E-10
Monoethanolamine	8,31E-05	4,29E-06	2,80E-06	3,10E-06	4,75E-05	2,55E-05
n-Butyl acetate	1,51E-20	1,51E-20	-	-	-	-
Nitrobenzene	7,15E-08	1,28E-08	8,68E-09	3,49E-09	4,74E-08	-9,24E-10
Octane	7,32E-10	7,32E-10	-	-	-	-
o-Nitrotoluene	8,92E-09	3,89E-09	1,21E-09	6,40E-10	3,32E-09	-1,36E-10
para-Cresol	3,04E-16	3,04E-16	-	-	-	-
Pentane (n-pentane)	1,39E-05	6,52E-06	1,96E-06	1,58E-06	3,89E-06	-6,07E-08

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Phenol (hydroxy benzene)	2,11E-04	3,03E-05	6,38E-06	5,13E-06	1,82E-04	-1,30E-05
Propionaldehyde	1,01E-04	6,80E-08	2,21E-08	1,37E-08	1,01E-04	2,43E-08
Propionic acid (propane acid)	7,99E-05	4,47E-05	1,33E-05	1,07E-05	1,46E-05	-3,35E-06
Propylene oxide	1,05E-03	1,27E-07	1,05E-03	5,19E-08	2,87E-07	1,84E-07
Styrene	4,73E-08	7,32E-09	5,98E-09	2,67E-09	2,09E-08	1,04E-08
Toluene (methyl benzene)	9,30E-06	5,10E-06	9,26E-07	7,63E-07	2,64E-06	-1,31E-07
Trimethylamine	4,25E-12	1,86E-12	5,77E-13	3,06E-13	1,58E-12	-6,49E-14
Xylene (dimethyl benzene)	1,53E-05	5,66E-06	1,59E-06	1,20E-06	7,28E-06	-4,74E-07
Xylene (meta-Xylene; 1,3-Dimethylbenzene)	2,95E-07	1,24E-07	5,20E-08	2,99E-08	6,84E-08	2,05E-08
Xylene (ortho-Xylene; 1,2-Dimethylbenzene)	5,73E-08	6,10E-09	7,29E-09	2,83E-09	2,58E-08	1,52E-08
Pesticides to air						
2,4-Dichlorophenoxyacetic acid (2,4-D)	7,25E-06	1,51E-06	1,50E-06	5,89E-07	3,82E-06	-1,62E-07
Acephate	7,71E-07	1,60E-07	1,59E-07	6,27E-08	4,06E-07	-1,72E-08
Acetochlor	2,16E-19	2,16E-19	-	-	-	-
Alachlor	1,62E-05	3,36E-06	3,35E-06	1,31E-06	8,52E-06	-3,62E-07
Atrazine	2,07E-05	4,29E-06	4,28E-06	1,68E-06	1,09E-05	-4,62E-07
Azoxystrobin	9,18E-06	1,91E-06	1,90E-06	7,46E-07	4,83E-06	-2,05E-07
Benomyl	6,52E-12	6,52E-12	-	-	-	-
Bentazone	2,48E-08	5,15E-09	5,13E-09	2,01E-09	1,31E-08	-5,53E-10
Carbaryl	1,16E-06	2,41E-07	2,40E-07	9,42E-08	6,11E-07	-2,59E-08
Carbofuran	4,36E-12	4,36E-12	-	-	-	-
Carfentrazone-ethyl	7,53E-07	1,56E-07	1,56E-07	6,12E-08	3,96E-07	-1,68E-08
Chlormequat-chloride	8,50E-17	8,50E-17	-	-	-	-
Chlorpyriphos	7,07E-04	1,47E-04	1,46E-04	5,75E-05	3,72E-04	-1,58E-05
Clethodim	1,69E-07	3,52E-08	3,50E-08	1,38E-08	8,92E-08	-3,79E-09
Cyfluthrin	1,95E-03	4,06E-04	4,04E-04	1,59E-04	1,03E-03	-4,37E-05
Cypermethrin	2,81E-14	2,81E-14	-	-	-	-
Cyprodinil (CGA-219417)	2,19E-16	2,19E-16	-	-	-	-
Deltamethrin	3,92E-09	3,92E-09	-	-	-	-
Dicamba	1,92E-07	3,99E-08	3,98E-08	1,56E-08	1,01E-07	-4,30E-09
Dichlorprop	1,27E-15	1,03E-15	4,04E-17	1,83E-17	1,85E-16	3,51E-18
Diflubenzuron	2,58E-05	5,36E-06	5,34E-06	2,10E-06	1,36E-05	-5,77E-07
Diflufenican	8,31E-18	8,31E-18	-	-	-	-
Dimethenamid	5,94E-12	1,96E-12	1,32E-12	9,82E-13	1,76E-12	-8,94E-14
Dimethoate	2,14E-16	2,14E-16	-	-	-	-
Esfenvalerate	4,00E-04	8,31E-05	8,28E-05	3,25E-05	2,11E-04	-8,95E-06
Ethephon	7,38E-15	6,15E-15	1,89E-16	5,77E-17	9,64E-16	1,41E-17
Fenvalerate	2,36E-13	2,36E-13	-	-	-	-
Fipronil	2,16E-20	2,16E-20	-	-	-	-
Fluazifop-p-butyl	7,48E-07	1,55E-07	1,55E-07	6,08E-08	3,94E-07	-1,67E-08

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Flufenacet	3,52E-06	7,31E-07	7,28E-07	2,86E-07	1,85E-06	-7,87E-08
Flumetsulam	1,49E-06	3,10E-07	3,09E-07	1,21E-07	7,85E-07	-3,33E-08
Flumiclorac-pentyl	4,89E-07	1,02E-07	1,01E-07	3,98E-08	2,58E-07	-1,09E-08
Flumioxazin	1,08E-05	2,25E-06	2,24E-06	8,79E-07	5,69E-06	-2,42E-07
Glyphosate	3,10E-05	6,44E-06	6,42E-06	2,52E-06	1,63E-05	-6,93E-07
Imazamox	4,07E-07	8,45E-08	8,42E-08	3,31E-08	2,14E-07	-9,09E-09
Imazethapyr	2,98E-07	6,18E-08	6,16E-08	2,42E-08	1,57E-07	-6,66E-09
Imidacloprid	2,51E-18	2,51E-18	-	-	-	-
Ioxynil	1,01E-15	1,01E-15	-	-	-	-
Isoproturon	5,34E-15	5,34E-15	-	-	-	-
Lambda-cyhalothrin	2,31E-14	1,93E-14	5,93E-16	1,81E-16	3,03E-15	4,44E-17
Mancozeb	3,53E-10	3,53E-10	-	-	-	-
MCPA	9,41E-15	7,75E-15	2,64E-16	1,02E-16	1,28E-15	2,15E-17
Mecoprop	3,01E-17	3,01E-17	-	-	-	-
Methomyl	6,66E-11	6,66E-11	4,77E-15	1,46E-15	2,43E-14	3,57E-16
Metolachlor	3,53E-05	7,32E-06	7,30E-06	2,87E-06	1,86E-05	-7,88E-07
Metribuzin	6,34E-06	1,32E-06	1,31E-06	5,15E-07	3,34E-06	-1,42E-07
Paraquat	1,24E-05	2,58E-06	2,57E-06	1,01E-06	6,55E-06	-2,78E-07
Parathion-methyl	8,99E-07	1,87E-07	1,86E-07	7,31E-08	4,73E-07	-2,01E-08
Pendimethalin	2,78E-04	5,77E-05	5,75E-05	2,26E-05	1,46E-04	-6,21E-06
Permethrin	1,01E-05	2,10E-06	2,09E-06	8,23E-07	5,33E-06	-2,26E-07
Propiconazole	4,74E-07	9,84E-08	9,80E-08	3,85E-08	2,49E-07	-1,06E-08
Quizalofop-ethyl	5,94E-07	1,23E-07	1,23E-07	4,83E-08	3,13E-07	-1,33E-08
Sethoxydim	8,00E-08	1,66E-08	1,66E-08	6,51E-09	4,21E-08	-1,79E-09
Sulfentrazone	3,20E-05	6,65E-06	6,63E-06	2,60E-06	1,69E-05	-7,16E-07
Tebuconazole	8,59E-15	7,16E-15	2,20E-16	6,72E-17	1,12E-15	1,65E-17
Terbufos	1,04E-20	1,04E-20	-	-	-	-
Thiodicarb	5,68E-07	1,18E-07	1,18E-07	4,62E-08	2,99E-07	-1,27E-08
Thiram	2,13E-09	2,13E-09	-	-	-	-
Trifluralin	2,22E-05	4,61E-06	4,60E-06	1,81E-06	1,17E-05	-4,97E-07
Long-term emissions to fresh water						
Antimony	2,05E+02	9,04E+00	6,10E+00	1,80E+01	3,51E+01	1,37E+02
Arsenic, ion	4,32E+01	8,54E+00	4,82E+00	1,25E+01	1,70E+01	3,77E-01
Barium	6,25E+00	3,00E+00	1,06E+00	8,12E-01	1,27E+00	1,10E-01
Beryllium	1,02E+00	3,34E-01	1,27E-01	1,99E-01	3,68E-01	-3,13E-03
Cadmium, ion	5,87E+00	4,75E-01	4,58E-01	1,73E+00	2,96E+00	2,45E-01
Chromium (+VI)	1,32E+02	4,98E+01	3,86E+01	2,00E+01	3,83E+01	-1,50E+01
Cobalt	1,38E+01	4,60E+00	2,26E+00	2,91E+00	4,04E+00	-2,16E-03
Copper	1,01E+04	1,05E+02	8,79E+01	1,23E+02	2,11E+03	7,70E+03
Lead	7,85E-01	3,61E-02	2,55E-02	5,95E-02	2,92E-01	3,72E-01
Mercury	5,95E-01	3,10E-01	1,20E-01	8,13E-02	1,08E-01	-2,44E-02
Molybdenum	2,45E-01	6,85E-02	3,13E-02	6,26E-02	8,33E-02	-1,00E-03
Nickel, ion	1,47E+02	7,23E+01	3,19E+01	2,06E+01	2,62E+01	-4,02E+00

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Selenium	4,75E+00	1,33E+00	5,94E-01	1,21E+00	1,64E+00	-2,40E-02
Silver	1,69E+01	3,77E-01	4,82E-01	1,89E+00	2,64E+00	1,15E+01
Thallium	2,16E+00	4,02E-01	1,95E-01	6,22E-01	9,05E-01	3,20E-02
Tin, ion	1,72E+00	1,05E-01	1,20E-01	4,82E-01	8,56E-01	1,52E-01
Vanadium, ion	2,26E+02	8,32E+01	2,90E+01	2,98E+01	9,07E+01	-6,24E+00
Zinc, ion	1,38E+03	2,33E+02	1,40E+02	3,92E+02	5,69E+02	4,43E+01
Heavy metals to fresh water						
Antimony	8,39E+01	2,60E+00	9,94E-01	6,87E-01	6,10E+00	7,35E+01
Arsenic	2,09E-12	2,09E-12	-	-	-	-
Arsenic (+V)	8,03E+00	4,64E+00	1,27E+00	1,11E+00	2,29E+00	-1,28E+00
Cadmium	4,02E-02	5,30E-03	8,22E-03	6,81E-03	1,61E-02	3,79E-03
Chromium	2,01E-04	2,01E-04	-	-	-	-
Chromium (+III)	3,19E-02	7,12E-03	5,35E-03	1,06E-03	1,85E-02	-1,56E-04
Chromium (+VI)	1,84E+01	4,63E+00	8,49E+00	2,26E+00	7,00E+00	-3,99E+00
Cobalt	3,77E-02	1,01E-02	5,47E-03	6,43E-03	1,81E-02	-2,39E-03
Copper	2,88E+00	3,06E-01	2,24E-01	5,55E-01	1,80E+00	-7,51E-03
Lead	2,27E-02	3,16E-03	1,99E-03	1,14E-03	1,51E-02	1,30E-03
Mercury	1,04E-02	3,12E-03	3,89E-03	8,75E-04	2,16E-03	3,09E-04
Molybdenum	4,35E-02	2,33E-02	7,40E-03	6,43E-03	8,50E-03	-2,19E-03
Nickel	8,48E-01	2,86E-01	1,52E-01	9,37E-02	4,12E-01	-9,59E-02
Selenium	1,81E-01	9,19E-02	2,45E-02	2,27E-02	4,86E-02	-6,72E-03
Silver	3,46E+00	1,86E+00	2,61E-01	2,52E-01	1,13E+00	-4,64E-02
Thallium	1,53E-02	8,52E-03	1,71E-03	2,22E-03	2,94E-03	-5,62E-05
Tin	7,35E-03	2,47E-03	7,00E-04	1,19E-03	3,06E-03	-8,03E-05
Vanadium	1,56E+00	7,19E-01	2,80E-01	2,14E-01	3,78E-01	-2,82E-02
Zinc	9,36E+00	1,56E+00	8,80E-01	3,01E+00	3,13E+00	7,81E-01
Inorganic emissions to fresh water						
Barium	4,11E+00	2,13E+00	3,20E-01	3,05E-01	1,38E+00	-2,94E-02
Beryllium	2,82E-03	1,03E-03	3,31E-04	5,50E-04	9,43E-04	-3,36E-05
Carbon disulphide	4,44E-05	2,52E-07	7,07E-08	1,27E-07	4,40E-05	-2,80E-08
Sulphuric acid	7,29E-11	7,29E-11	-	-	-	-
Organic emissions to fresh water						
1,1,1-Trichloroethane	7,93E-17	3,75E-17	1,86E-17	1,30E-17	1,49E-17	-4,66E-18
1,2-Dibromoethane	-4,02E-20	-4,02E-20	-	-	-	-
2-Chlorotoluene	1,08E-06	2,78E-07	1,83E-07	9,05E-08	5,58E-07	-2,68E-08
Bromoxynil	8,89E-13	6,75E-13	3,72E-14	2,25E-14	1,51E-13	3,69E-15
Chlorobenzene	2,99E-02	2,36E-02	9,52E-04	4,91E-03	4,41E-04	1,89E-05
Chloromethane (methyl chloride)	-3,73E-15	-3,73E-15	-	-	-	-
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene)	1,87E-02	1,46E-02	6,80E-04	3,06E-03	3,72E-04	1,49E-05
Dichloroethane (ethylene dichloride)	6,68E-06	6,07E-07	4,17E-07	6,88E-07	4,95E-06	1,88E-08
Dichloromethane	1,06E-04	4,27E-05	1,20E-05	1,04E-05	3,88E-05	2,14E-06

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
(methylene chloride)						
Dichloropropane	-3,17E-23	-3,17E-23	-	-	-	-
Pentachlorophenol (PCP)	1,99E-12	1,99E-12	-	-	-	-
Polychlorinated biphenyls (PCB unspecified)	2,30E-05	3,88E-08	6,79E-09	1,03E-08	2,30E-05	-1,70E-08
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	3,62E-18	3,62E-18	-	-	-	-
Tetrachloroethene (perchloroethylene)	2,04E-16	2,04E-16	-	-	-	-
Trichloromethane (chloroform)	1,58E-07	1,28E-07	2,89E-09	1,78E-09	2,55E-08	-2,50E-10
4-Methyl-2-pentanol	2,77E-14	1,51E-15	2,91E-16	1,29E-15	2,44E-14	1,71E-16
Acenaphthene	2,03E-04	4,74E-06	2,42E-05	1,25E-06	1,73E-04	5,20E-07
Acetic acid	9,09E-03	1,98E-05	6,68E-05	2,92E-05	8,99E-03	-1,94E-05
Acetonitrile	4,32E-09	1,84E-09	5,29E-10	2,60E-10	1,74E-09	-4,63E-11
Acrylonitrile	1,73E-16	1,73E-16	-	-	-	-
Aniline	7,13E-06	1,21E-06	8,62E-07	3,42E-07	4,81E-06	-9,16E-08
Anthracene	2,61E-03	1,35E-05	3,13E-04	3,40E-06	2,28E-03	1,51E-06
Benzene	1,02E-02	5,58E-03	4,92E-04	1,49E-03	3,02E-03	-3,64E-04
Benzo{a}anthracene	3,02E-05	4,35E-07	3,58E-06	3,89E-08	2,61E-05	1,73E-08
Benzo{a}pyrene	5,36E-08	2,44E-10	6,42E-09	6,98E-11	4,68E-08	3,10E-11
Butylene glycol (butane diol)	1,01E-07	8,32E-08	4,19E-09	1,77E-09	1,18E-08	-1,52E-10
Butyrolactone	6,38E-08	1,27E-08	2,16E-08	5,99E-09	2,26E-08	8,99E-10
Cresol (methyl phenol)	-2,10E-18	-2,10E-18	-	-	-	-
Dibenz(a)anthracene	1,28E-09	5,84E-12	1,54E-10	1,67E-12	1,12E-09	7,43E-13
Ethanol	2,34E-04	7,23E-07	3,91E-05	1,05E-06	1,94E-04	-7,47E-07
Ethyl benzene	1,84E-03	7,05E-04	1,92E-04	1,73E-04	7,05E-04	6,50E-05
Ethylene acetate (ethyl acetate)	3,01E-07	4,90E-09	4,91E-08	2,43E-09	2,46E-07	-1,25E-09
Ethylene oxide	2,11E-06	1,99E-07	9,90E-08	8,71E-08	1,18E-06	5,42E-07
Fluoranthene	2,59E-02	1,18E-04	3,10E-03	3,38E-05	2,26E-02	1,50E-05
Formaldehyde (methanal)	9,83E-03	2,42E-04	4,17E-03	1,23E-04	5,38E-03	-8,04E-05
Hexane (isomers)	-1,87E-20	-1,87E-20	-	-	-	-
Methanol	1,58E-03	1,22E-06	1,45E-03	1,81E-06	1,27E-04	-6,87E-07
Methyl tert-butylether	1,55E-07	4,40E-08	3,08E-08	1,60E-08	6,59E-08	-1,33E-09
Naphthalene	2,77E-05	5,67E-07	3,27E-06	3,55E-08	2,38E-05	1,58E-08
Phenanthrene	2,70E-03	1,23E-05	3,24E-04	3,52E-06	2,36E-03	1,56E-06
Phenol (hydroxy benzene)	4,76E-02	1,42E-02	5,83E-03	3,34E-03	2,39E-02	3,40E-04
Propanol	8,17E-09	1,49E-09	5,16E-10	2,68E-10	5,94E-09	-4,78E-11
Propanol (iso-propanol; isopropanol)	2,49E-07	1,19E-08	1,09E-09	1,15E-09	2,35E-07	-2,12E-10
Propylene oxide	5,62E-02	6,57E-06	5,62E-02	2,66E-06	1,50E-05	9,87E-06
Pyrene	1,32E-01	5,99E-04	1,58E-02	1,72E-04	1,15E-01	7,62E-05
Sodium formate	7,23E-07	1,31E-08	1,26E-08	2,51E-08	5,30E-07	1,42E-07

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Toluene (methyl benzene)	3,31E-03	1,35E-03	3,29E-04	2,99E-04	1,24E-03	9,06E-05
Triethylene glycol	3,80E-08	1,67E-08	2,67E-09	4,12E-09	1,51E-08	-5,27E-10
Xylene (isomers; dimethyl benzene)	3,48E-03	1,38E-03	3,55E-04	3,21E-04	1,32E-03	1,09E-04
Xylene (meta-Xylene; 1,3-Dimethylbenzene)	7,37E-05	3,96E-05	5,35E-06	5,18E-06	2,46E-05	-1,04E-06
Xylene (ortho-Xylene; 1,2-Dimethylbenzene)	3,99E-05	2,16E-05	2,92E-06	2,83E-06	1,31E-05	-5,69E-07
Acetaldehyde (Ethanal)	5,68E-03	2,12E-05	9,38E-04	2,44E-05	4,67E-03	2,65E-05
Acetone (dimethylcetone)	1,12E-07	5,58E-08	8,67E-09	7,76E-09	4,12E-08	-1,63E-09
Acrylic acid	1,97E-07	4,87E-08	3,04E-08	2,31E-08	9,06E-08	4,16E-09
Allyl chloride	1,85E-06	1,67E-07	6,86E-08	3,61E-07	1,11E-06	1,45E-07
Biphenyl	1,16E-23	1,16E-23	-	-	-	-
Chloramine	2,93E-03	9,95E-04	3,14E-04	2,11E-04	1,45E-03	-3,74E-05
Cumene (isopropylbenzene)	2,91E-02	2,88E-03	9,05E-04	3,94E-03	2,59E-02	-4,55E-03
Diethylamine	3,93E-07	8,41E-08	5,90E-08	2,72E-08	2,30E-07	-7,90E-09
Ethylamine	3,81E-06	1,13E-07	1,28E-08	1,26E-08	3,67E-06	-2,75E-09
Ethylenediamine	4,52E-05	2,87E-07	8,75E-08	2,46E-07	4,47E-05	-2,33E-08
Formic acid	3,59E-08	4,15E-09	1,55E-09	9,81E-10	2,94E-08	-1,92E-10
iso-Butanol	3,08E-08	4,67E-09	2,09E-09	9,72E-10	2,33E-08	-1,95E-10
Methyl acetate	3,23E-09	1,41E-09	4,39E-10	2,32E-10	1,20E-09	-4,93E-11
Methyl acrylate	6,25E-06	1,54E-06	9,65E-07	7,33E-07	2,88E-06	1,32E-07
Methyl amine	6,48E-08	1,46E-08	1,06E-08	3,12E-09	3,68E-08	-4,37E-10
Methyl formate	3,39E-09	4,76E-10	2,18E-10	1,50E-10	2,54E-09	-1,04E-12
Methyl isobutyl ketone	2,07E-07	1,12E-07	1,51E-08	1,47E-08	6,80E-08	-2,95E-09
Monoethanolamine	4,21E-07	1,70E-07	1,10E-07	6,96E-08	9,39E-08	-2,22E-08
n-Butyl acetate	1,19E-03	1,30E-06	1,99E-04	4,59E-06	9,87E-04	-3,93E-06
Nitrobenzene	4,71E-06	8,43E-07	5,72E-07	2,30E-07	3,12E-06	-6,09E-08
Propionaldehyde	1,84E-07	2,10E-08	7,21E-09	4,87E-09	1,51E-07	-9,23E-10
Propionic acid	5,16E-07	1,77E-07	1,03E-07	5,02E-08	2,01E-07	-1,40E-08
Trimethylamine	8,80E-09	3,84E-09	1,19E-09	6,32E-10	3,27E-09	-1,34E-10
Other emissions to fresh water						
Acetochlor	5,39E-19	5,39E-19	-	-	-	-
Alachlor	2,47E-07	2,47E-07	-	-	-	-
Atrazine	5,01E-09	1,65E-09	1,12E-09	8,28E-10	1,49E-09	-7,53E-11
Benomyl	3,67E-11	3,67E-11	-	-	-	-
Bentazone	1,05E-08	1,62E-09	1,90E-09	5,97E-10	6,49E-09	-1,42E-10
Carbaryl	3,25E-13	1,16E-13	6,91E-14	5,10E-14	9,37E-14	-4,60E-15
Carbofuran	4,83E-12	4,83E-12	-	-	-	-
Chlormequat-chloride	3,74E-17	3,74E-17	-	-	-	-
Cypermethrin	1,29E-13	1,29E-13	-	-	-	-
Cyprodinil (CGA-219417)	1,61E-15	1,61E-15	-	-	-	-
Deltamethrin	3,33E-08	3,33E-08	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Dicamba	1,14E-11	3,78E-12	2,55E-12	1,89E-12	3,40E-12	-1,72E-13
Dichlorprop	6,27E-14	5,19E-14	1,69E-15	5,76E-16	8,39E-15	1,31E-16
Diflufenican	1,68E-17	1,68E-17	-	-	-	-
Dimethenamid	8,30E-11	2,74E-11	1,85E-11	1,37E-11	2,46E-11	-1,25E-12
Dimethoate	4,24E-16	4,24E-16	-	-	-	-
Ethephon	1,50E-15	1,25E-15	3,85E-17	1,17E-17	1,96E-16	2,88E-18
Fenvalerate	7,33E-13	7,33E-13	-	-	-	-
Fipronil	1,09E-19	1,09E-19	-	-	-	-
Glyphosate	4,08E-07	6,27E-08	7,42E-08	2,33E-08	2,53E-07	-5,53E-09
Imidacloprid	4,03E-18	4,03E-18	-	-	-	-
Ioxynil	8,24E-16	8,24E-16	-	-	-	-
Isoproturon	6,37E-15	6,37E-15	-	-	-	-
Lambda cyhalothrin	3,69E-14	3,08E-14	9,46E-16	2,89E-16	4,83E-15	7,08E-17
Mancozeb	1,79E-09	1,79E-09	-	-	-	-
MCPA	3,45E-13	2,82E-13	9,93E-15	3,88E-15	4,77E-14	8,12E-16
Mecoprop	1,84E-17	1,84E-17	-	-	-	-
Methomyl	3,67E-11	3,67E-11	6,57E-16	2,00E-16	3,35E-15	4,91E-17
Metolachlor	5,12E-07	7,87E-08	9,32E-08	2,92E-08	3,18E-07	-6,94E-09
Parathion-methyl	2,21E-10	2,21E-10	-	-	-	-
Pendimethalin	3,68E-10	1,21E-10	8,20E-11	6,08E-11	1,09E-10	-5,53E-12
Propiconazole	8,52E-13	7,10E-13	2,19E-14	6,68E-15	1,11E-13	1,64E-15
Tebuconazole	8,15E-14	6,79E-14	2,09E-15	6,38E-16	1,07E-14	1,56E-16
Terbufos	1,32E-18	1,32E-18	-	-	-	-
Thiram	2,21E-08	2,21E-08	-	-	-	-
Trifluralin	1,62E-08	1,62E-08	-	-	-	-
Heavy metals to sea water						
Arsenic (+V)	4,99E-22	1,16E-23	7,46E-24	4,23E-22	5,51E-23	2,17E-24
Cadmium	6,86E-23	2,22E-25	9,15E-26	6,78E-23	4,69E-25	3,50E-26
Chromium	2,16E-25	2,16E-25	-	-	-	-
Chromium (+III)	1,42E-24	4,90E-25	1,60E-25	1,40E-25	5,76E-25	5,27E-26
Cobalt	2,25E-26	9,54E-27	6,57E-27	4,19E-27	2,60E-27	-3,69E-28
Copper	3,06E-20	1,81E-23	1,13E-23	3,05E-20	4,13E-23	4,28E-24
Lead	3,25E-25	6,11E-26	2,28E-26	1,57E-25	7,79E-26	6,35E-27
Mercury	1,74E-24	4,15E-26	3,92E-26	1,29E-24	3,50E-25	1,28E-26
Molybdenum	2,55E-26	8,73E-27	2,84E-27	2,51E-27	1,03E-26	1,08E-27
Nickel	3,20E-21	2,19E-24	1,15E-24	3,19E-21	5,19E-24	5,60E-25
Selenium	1,03E-24	3,53E-25	1,15E-25	1,01E-25	4,18E-25	4,36E-26
Silver	3,39E-24	1,26E-24	3,63E-25	3,25E-25	1,31E-24	1,33E-25
Tin	-1,01E-38	-1,01E-38	-	-	-	-
Vanadium	1,24E-22	4,28E-23	1,36E-23	1,20E-23	5,04E-23	4,79E-24
Zinc	6,47E-18	1,23E-19	7,27E-20	6,18E-18	1,01E-19	-5,50E-21
Inorganic emissions to sea water						
Barium	5,09E-22	1,88E-22	5,45E-23	4,88E-23	1,97E-22	2,01E-23

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Beryllium	-1,68E-35	-1,68E-35	-	-	-	-
Organic emissions to sea water						
Tetrachloroethene (perchloroethylene)	2,52E-23	2,52E-23	-	-	-	-
Acenaphthene	5,37E-11	2,01E-11	5,71E-12	5,12E-12	2,07E-11	2,10E-12
Acetic acid	-2,82E-21	-2,82E-21	-	-	-	-
Anthracene	1,08E-10	1,08E-10	-	-	-	-
Benzene	5,39E-08	2,00E-08	5,81E-09	5,18E-09	2,08E-08	2,10E-09
Benzo{a}anthracene	7,43E-12	7,43E-12	-	-	-	-
Cresol (methyl phenol)	-1,82E-23	-1,82E-23	-	-	-	-
Ethyl benzene	1,39E-09	5,16E-10	1,49E-10	1,33E-10	5,40E-10	5,48E-11
Fluoranthene	1,67E-12	1,67E-12	-	-	-	-
Glutaraldehyde	2,11E-08	7,68E-09	4,63E-09	3,18E-09	6,04E-09	-4,42E-10
Hexane (isomers)	-6,36E-28	-6,36E-28	-	-	-	-
Methanol	5,91E-09	2,48E-09	1,46E-09	9,82E-10	1,41E-09	-4,17E-10
Methyl tert-butylether	9,77E-11	2,77E-11	1,93E-11	1,00E-11	4,16E-11	-8,39E-13
Phenol (hydroxy benzene)	7,64E-08	2,83E-08	8,21E-09	7,33E-09	2,98E-08	2,81E-09
Toluene (methyl benzene)	1,01E-08	3,61E-09	1,10E-09	9,74E-10	3,96E-09	4,05E-10
Triethylene glycol	2,99E-14	1,26E-14	7,07E-15	4,78E-15	7,43E-15	-1,96E-15
Xylene (isomers; dimethyl benzene)	4,72E-09	1,74E-09	5,09E-10	4,54E-10	1,83E-09	1,85E-10
Ethylene Glycol	1,30E-23	1,30E-23	-	-	-	-
Naphthalene	1,71E-11	1,71E-11	-	-	-	-
Other emissions to sea water						
Acetamide	3,23E-15	6,72E-16	6,69E-16	2,63E-16	1,70E-15	-7,23E-17
Tributyltinoxide	2,34E-10	7,32E-11	4,17E-11	3,26E-11	1,14E-10	-2,67E-11
Heavy metals to agricultural soil						
Antimony	1,44E-05	1,65E-06	1,66E-06	7,59E-06	3,39E-06	1,31E-07
Arsenic	1,11E-02	8,03E-03	8,19E-04	8,25E-04	1,49E-03	-6,24E-05
Arsenic (+V)	6,54E-16	6,54E-16	-	-	-	-
Cadmium	1,59E-03	7,61E-04	2,75E-04	1,71E-04	3,99E-04	-1,42E-05
Chromium	1,13E-01	5,65E-02	2,06E-02	1,29E-02	2,43E-02	-1,13E-03
Chromium (+III)	4,22E-07	4,22E-07	-	-	-	-
Cobalt	8,33E-04	4,17E-04	1,53E-04	9,54E-05	1,75E-04	-8,12E-06
Copper	1,68E-01	9,83E-02	2,05E-02	1,59E-02	3,51E-02	-1,43E-03
Lead	3,66E-04	1,70E-04	6,18E-05	3,80E-05	9,98E-05	-3,34E-06
Mercury	2,41E-04	4,12E-05	2,04E-05	1,16E-05	1,70E-04	-2,23E-06
Molybdenum	3,40E-05	6,25E-06	2,29E-06	1,43E-06	2,41E-05	-1,27E-07
Nickel	9,81E-03	4,63E-03	1,63E-03	1,05E-03	2,58E-03	-8,94E-05
Silver	6,21E-12	1,96E-12	8,52E-13	1,04E-12	2,04E-12	3,21E-13
Tin	7,49E-05	2,18E-05	8,98E-06	4,44E-06	4,01E-05	-3,99E-07
Vanadium	4,48E-02	2,41E-02	8,79E-03	5,53E-03	6,88E-03	-4,69E-04
Zinc	8,11E-01	3,89E-01	1,41E-01	8,96E-02	2,00E-01	-8,18E-03
Inorganic emissions to agricultural soil						

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Barium	7,92E-06	3,09E-06	6,60E-07	1,50E-06	2,18E-06	4,87E-07
Sulphuric acid	5,03E-11	1,24E-11	7,76E-12	5,90E-12	2,31E-11	1,06E-12
Organic emissions to agricultural soil						
Azoxystrobin	1,88E-06	2,13E-07	2,47E-07	1,63E-08	1,41E-06	-3,63E-09
Bromoxynil	1,52E-07	1,23E-07	5,61E-09	2,54E-09	2,13E-08	1,34E-10
Mepiquat chloride	3,87E-11	2,66E-12	5,71E-12	4,97E-13	2,98E-11	-3,94E-14
Other emissions to agricultural soil						
2,4-Dichlorophenoxyacetic acid (2,4-D)	8,55E-04	1,89E-04	1,33E-04	4,24E-05	4,99E-04	-8,83E-06
Acephate	1,14E-05	7,51E-07	1,69E-06	1,52E-07	8,79E-06	-1,34E-08
Acetamide	5,00E-09	3,34E-10	7,44E-10	6,87E-11	3,86E-09	-6,13E-12
Acetochlor	6,84E-06	2,28E-06	1,55E-06	1,14E-06	1,99E-06	-1,13E-07
Aclonifen	4,08E-08	6,13E-09	7,36E-09	2,27E-09	2,56E-08	-5,29E-10
Alachlor	2,27E-05	1,68E-05	1,29E-06	1,43E-06	3,29E-06	-1,38E-07
Aldicarb	1,78E-03	1,16E-04	2,64E-04	2,29E-05	1,38E-03	-1,84E-06
Aldrin	3,15E-03	2,52E-03	1,01E-04	1,84E-04	3,54E-04	-1,27E-05
Anthraquinone	2,01E-09	1,67E-09	5,15E-11	1,57E-11	2,63E-10	3,85E-12
Asulam	5,55E-13	1,33E-13	8,60E-14	8,17E-14	2,43E-13	1,09E-14
Atrazine	7,93E-02	2,23E-02	8,87E-04	1,62E-03	5,47E-02	-1,39E-04
Azodrin	3,11E-04	4,68E-05	5,62E-05	1,73E-05	1,95E-04	-4,04E-06
Benomyl	1,36E-06	3,23E-08	1,90E-07	7,64E-09	1,13E-06	-2,04E-09
Bensulfuron methyl ester	1,25E-09	1,04E-09	3,21E-11	9,79E-12	1,64E-10	2,40E-12
Bentazone	8,41E-08	1,85E-08	1,42E-08	4,57E-09	4,78E-08	-1,08E-09
Bifenox	3,24E-08	2,70E-08	8,30E-10	2,53E-10	4,24E-09	6,21E-11
Bifenthrin	1,88E-08	6,27E-09	4,25E-09	3,12E-09	5,46E-09	-3,10E-10
Bitertanol	7,21E-11	6,01E-11	1,85E-12	5,64E-13	9,44E-12	1,38E-13
Bromuconazole	2,80E-09	2,33E-09	7,17E-11	2,19E-11	3,66E-10	5,36E-12
Carbaryl	1,08E-06	4,78E-07	2,69E-07	1,56E-07	2,30E-07	-4,98E-08
Carbendazim	3,04E-03	9,68E-04	7,70E-04	4,06E-04	1,03E-03	-1,32E-04
Carbofuran	4,48E-02	1,07E-03	6,29E-03	2,55E-04	3,73E-02	-6,83E-05
Carfentrazone ethyl ester	3,66E-09	3,06E-09	9,40E-11	2,87E-11	4,79E-10	7,03E-12
Carfentrazone-ethyl	1,60E-08	3,32E-09	3,31E-09	1,30E-09	8,42E-09	-3,58E-10
Chloridazon	2,92E-07	2,44E-07	7,49E-09	2,29E-09	3,82E-08	5,61E-10
Chlorothalonil	6,78E-01	5,56E-03	1,77E-03	7,45E-03	6,64E-01	-8,77E-04
Chlorpyriphos	1,29E-02	9,13E-04	1,94E-03	1,97E-04	9,90E-03	-2,21E-05
Chlorsulfuron	7,04E-09	5,87E-09	1,80E-10	5,50E-11	9,21E-10	1,35E-11
Chlortoluron	1,01E-08	8,36E-09	2,64E-10	8,50E-11	1,33E-09	2,01E-11
Choline chloride	2,65E-09	2,21E-09	6,80E-11	2,08E-11	3,47E-10	5,09E-12
Clethodim	4,54E-08	1,41E-08	1,12E-08	5,83E-09	1,61E-08	-1,81E-09
Clodinafop-propargyl	3,53E-08	2,94E-08	9,05E-10	2,76E-10	4,62E-09	6,77E-11
Clopyralid	1,71E-07	7,45E-08	4,64E-08	2,78E-08	3,09E-08	-9,03E-09
Cloquintocet-mexyl	1,29E-10	1,08E-10	3,31E-12	1,01E-12	1,69E-11	2,48E-13
Cyfluthrin	2,57E-04	1,76E-05	3,84E-05	3,73E-06	1,98E-04	-3,81E-07
Cypermethrin	1,12E-01	4,16E-03	1,52E-02	1,52E-03	9,10E-02	-3,69E-04

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Cyproconazole	4,29E-09	3,56E-09	1,18E-10	3,99E-11	5,69E-10	7,57E-12
Cyprodinil (CGA-219417)	3,19E-06	1,02E-07	3,73E-07	5,10E-09	2,70E-06	1,85E-09
Deltamethrin	1,54E-06	6,33E-07	4,44E-07	2,67E-07	2,84E-07	-8,71E-08
Desmedipham	2,40E-09	8,39E-10	5,73E-10	4,07E-10	6,40E-10	-5,62E-11
Dicamba	8,64E-08	5,85E-08	7,00E-09	5,74E-09	1,58E-08	-5,83E-10
Dichlorprop	4,18E-13	3,46E-13	1,14E-14	3,98E-15	5,63E-14	8,93E-16
Diclofop-methyl	2,87E-08	2,39E-08	7,36E-10	2,25E-10	3,76E-09	5,51E-11
Dicrotophos	1,26E-05	8,20E-07	1,87E-06	1,62E-07	9,76E-06	-1,30E-08
Difenoconazole	1,74E-04	6,52E-06	2,32E-05	2,44E-06	1,42E-04	-5,16E-07
Diflubenzuron	3,41E-01	5,13E-02	6,16E-02	1,89E-02	2,14E-01	-4,43E-03
Diflufenican	7,42E-10	6,18E-10	1,92E-11	5,96E-12	9,75E-11	1,44E-12
Dimethachlor	1,08E-04	4,45E-05	3,13E-05	1,88E-05	2,00E-05	-6,14E-06
Dimethazone	1,25E-05	5,25E-06	3,52E-06	2,12E-06	2,29E-06	-6,90E-07
Dimethenamid	1,33E-05	1,03E-05	7,05E-07	9,35E-07	1,46E-06	-6,60E-08
Dimethoate	3,49E-07	2,90E-07	9,16E-09	2,97E-09	4,62E-08	7,00E-10
Dithianon	3,25E-09	2,70E-09	8,54E-11	2,78E-11	4,30E-10	6,53E-12
Diuron	3,27E-03	2,68E-03	1,04E-04	1,85E-04	3,14E-04	-1,11E-05
Endosulfan	2,76E-03	4,15E-04	4,99E-04	1,54E-04	1,73E-03	-3,59E-05
Endothall	1,53E-08	6,26E-09	4,40E-09	2,65E-09	2,81E-09	-8,64E-10
Epoxiconazole	4,96E-09	4,05E-09	1,61E-10	6,49E-11	6,72E-10	5,68E-12
Esfenvalerate	5,01E-06	1,05E-06	1,03E-06	4,06E-07	2,63E-06	-1,11E-07
Ethalfluralin	9,41E-05	3,86E-05	2,72E-05	1,63E-05	1,74E-05	-5,34E-06
Ethephon	9,81E-06	8,22E-07	1,42E-06	1,25E-07	7,45E-06	-9,41E-09
Ethofumesate	4,69E-07	3,02E-09	5,66E-08	9,98E-10	4,08E-07	2,03E-10
Fenbuconazole	7,10E-11	5,90E-11	1,87E-12	6,07E-13	9,41E-12	1,43E-13
Fenoxaprop ethyl ester	1,26E-09	1,05E-09	3,24E-11	9,89E-12	1,65E-10	2,43E-12
Fenoxaprop-p-ethyl	1,47E-10	5,14E-11	3,50E-11	2,49E-11	3,92E-11	-3,44E-12
Fenpiclonil	1,77E-04	1,45E-06	4,64E-07	1,95E-06	1,74E-04	-2,29E-07
Fenpropimorph	1,18E-09	9,67E-10	3,84E-11	1,55E-11	1,61E-10	1,44E-12
Fipronil	1,59E-03	1,03E-04	2,35E-04	2,04E-05	1,23E-03	-1,64E-06
Fluazifop-p-butyl	2,59E-06	1,04E-06	7,40E-07	4,41E-07	5,10E-07	-1,44E-07
Fludioxonil	2,20E-06	2,46E-08	2,63E-07	3,17E-09	1,91E-06	1,20E-09
Flufenacet	3,55E-07	1,75E-07	4,40E-08	1,69E-08	1,23E-07	-3,99E-09
Flumetsulam	1,27E-07	3,30E-08	2,73E-08	1,48E-08	5,46E-08	-2,54E-09
Flumiclorac-pentyl	1,09E-08	2,26E-09	2,25E-09	8,86E-10	5,74E-09	-2,44E-10
Flumioxazin	7,93E-06	1,26E-06	1,46E-06	4,73E-07	4,84E-06	-1,15E-07
Fluroxypyr	1,95E-07	1,63E-07	5,00E-09	1,53E-09	2,55E-08	3,74E-10
Fomesafen	3,42E-07	6,57E-08	6,83E-08	2,54E-08	1,90E-07	-6,77E-09
Glyphosate	1,74E-03	1,09E-04	1,96E-04	1,60E-05	1,42E-03	-2,31E-06
Halosulfuron-methyl	7,23E-07	6,03E-07	1,85E-08	5,65E-09	9,46E-08	1,39E-09
Imazamox	6,09E-07	9,38E-08	1,10E-07	3,43E-08	3,79E-07	-8,07E-09
Imazapyr	1,53E-11	5,12E-12	3,47E-12	2,55E-12	4,46E-12	-2,54E-13
Imazethapyr	1,40E-07	2,17E-08	2,55E-08	8,06E-09	8,65E-08	-1,92E-09

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Imidacloprid	4,64E-06	3,03E-07	6,88E-07	5,98E-08	3,60E-06	-4,80E-09
Ioxynil	2,31E-07	1,92E-07	5,95E-09	1,84E-09	3,03E-08	4,47E-10
Iprodione	4,50E-04	1,85E-04	1,30E-04	7,81E-05	8,30E-05	-2,55E-05
Isoproturon	6,53E-06	5,43E-06	1,70E-07	5,42E-08	8,61E-07	1,29E-08
Isoxaflutole	2,65E-09	8,79E-10	5,95E-10	4,39E-10	7,76E-10	-4,20E-11
Kresoxim-methyl	2,22E-09	1,79E-09	8,61E-11	3,97E-11	3,11E-10	1,02E-12
Lambda cyhalothrin	4,03E-04	1,49E-04	1,08E-04	6,13E-05	1,03E-04	-1,98E-05
Lenacil	7,71E-09	2,69E-09	1,84E-09	1,30E-09	2,05E-09	-1,80E-10
Linuron	1,60E-02	1,08E-02	9,54E-04	9,23E-04	3,33E-03	-9,06E-05
Malathion	1,27E-04	3,07E-06	1,78E-05	7,34E-07	1,05E-04	-1,97E-07
Mancozeb	2,66E-02	2,18E-04	6,97E-05	2,93E-04	2,61E-02	-3,45E-05
MCPA	2,74E-07	2,29E-07	7,04E-09	2,15E-09	3,59E-08	5,26E-10
MCPB	2,32E-10	5,67E-11	3,57E-11	3,39E-11	1,01E-10	4,54E-12
Mecoprop	2,07E-08	1,73E-08	5,31E-10	1,62E-10	2,71E-09	3,98E-11
Mecoprop-P	1,45E-08	1,21E-08	3,74E-10	1,15E-10	1,90E-09	2,81E-11
Metalaxyl	1,74E-06	4,14E-08	2,44E-07	9,78E-09	1,45E-06	-2,62E-09
Metamitron	1,44E-09	5,02E-10	3,43E-10	2,43E-10	3,83E-10	-3,35E-11
Metam-sodium	1,10E-04	2,62E-06	1,54E-05	6,19E-07	9,15E-05	-1,65E-07
Metazachlor	3,23E-05	1,32E-05	9,31E-06	5,60E-06	5,95E-06	-1,83E-06
Methomyl	9,48E-13	7,90E-13	2,43E-14	7,41E-15	1,24E-13	1,82E-15
Metolachlor	3,60E-02	1,82E-03	2,12E-03	6,61E-04	3,16E-02	-1,67E-04
Metribuzin	1,11E-03	2,13E-05	1,81E-05	1,60E-05	1,06E-03	-2,44E-06
Metsulfuron-methyl	1,60E-04	1,08E-05	2,47E-05	3,63E-06	1,22E-04	-8,68E-07
Molinate	2,58E-06	2,15E-06	6,62E-08	2,02E-08	3,38E-07	4,96E-09
MSMA	7,27E-08	4,74E-09	1,08E-08	9,36E-10	5,64E-08	-7,51E-11
Napropamide	1,09E-04	4,98E-05	3,50E-05	2,10E-05	1,04E-05	-6,88E-06
Nicosulfuron	8,63E-10	2,88E-10	1,95E-10	1,43E-10	2,51E-10	-1,43E-11
Orbencarb	3,75E-04	3,07E-06	9,81E-07	4,12E-06	3,67E-04	-4,85E-07
Oxydemeton-methyl	1,34E-08	1,11E-08	3,53E-10	1,15E-10	1,78E-09	2,70E-11
Paraquat	1,55E-06	5,31E-08	2,22E-07	1,33E-08	1,27E-06	-3,08E-09
Parathion-ethyl	9,54E-05	5,74E-05	1,60E-05	9,80E-06	1,54E-05	-3,21E-06
Parathion-methyl	5,99E-08	1,24E-08	1,24E-08	4,87E-09	3,15E-08	-1,34E-09
Pendimethalin	1,35E-04	1,90E-05	2,34E-05	6,40E-06	8,73E-05	-1,46E-06
Permethrin	3,20E-08	6,82E-09	6,65E-09	2,71E-09	1,66E-08	-7,09E-10
Phenmedipham	1,85E-09	6,45E-10	4,40E-10	3,13E-10	4,93E-10	-4,30E-11
Picloram	5,69E-10	4,74E-10	1,46E-11	4,45E-12	7,44E-11	1,09E-12
Pirimicarb	2,94E-06	1,58E-08	3,53E-07	4,10E-09	2,56E-06	1,58E-09
Prochloraz	8,17E-07	6,80E-07	2,12E-08	6,69E-09	1,08E-07	1,61E-09
Procymidone	4,24E-07	1,74E-07	1,22E-07	7,35E-08	7,81E-08	-2,40E-08
Profenofos	2,95E-03	1,92E-04	4,37E-04	3,80E-05	2,29E-03	-3,05E-06
Prometryne	8,44E-05	5,49E-06	1,25E-05	1,09E-06	6,54E-05	-8,72E-08
Propanil	5,42E-04	4,52E-04	1,39E-05	4,24E-06	7,09E-05	1,04E-06
Propiconazole	5,87E-08	4,06E-08	3,90E-09	1,43E-09	1,29E-08	-2,07E-10

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Prosulfuron	3,76E-08	3,06E-08	1,35E-09	2,24E-09	3,48E-09	-1,39E-10
Pyrithiobac-sodium salt	3,58E-08	2,33E-09	5,31E-09	4,61E-10	2,78E-08	-3,70E-11
Quinclorac	2,18E-08	1,82E-08	5,59E-10	1,71E-10	2,85E-09	4,18E-11
Quizalofop-ethyl	5,92E-07	2,42E-07	1,70E-07	1,02E-07	1,11E-07	-3,33E-08
Rimsulfuron	6,74E-09	2,25E-09	1,52E-09	1,12E-09	1,96E-09	-1,11E-10
Sethoxydim	3,05E-07	1,25E-07	8,78E-08	5,28E-08	5,67E-08	-1,72E-08
Simazine	4,64E-07	1,55E-07	1,05E-07	7,72E-08	1,35E-07	-7,68E-09
Sulfosulfuron	9,66E-09	8,06E-09	2,48E-10	7,56E-11	1,26E-09	1,85E-11
Tebuconazole	6,40E-05	2,63E-05	1,84E-05	1,11E-05	1,18E-05	-3,61E-06
Tebupirimphos	5,17E-08	1,73E-08	1,17E-08	8,60E-09	1,50E-08	-8,55E-10
Teflubenzuron	1,48E-03	1,21E-05	3,86E-06	1,62E-05	1,45E-03	-1,91E-06
Tefluthrin	5,93E-08	2,14E-08	1,27E-08	9,34E-09	1,67E-08	-9,20E-10
Terbufos	1,07E-05	7,81E-06	7,51E-07	8,54E-07	1,36E-06	-6,54E-08
Thidiazuron	3,54E-07	2,30E-08	5,24E-08	4,55E-09	2,74E-07	-3,66E-10
Thifensulfuron methyl	3,56E-07	1,86E-07	4,13E-08	1,58E-08	1,17E-07	-3,62E-09
Thiobencarb	1,97E-06	1,64E-06	5,05E-08	1,54E-08	2,58E-07	3,78E-09
Thiodicarb	6,65E-08	1,38E-08	1,38E-08	5,41E-09	3,50E-08	-1,49E-09
Thiram	6,95E-04	1,65E-05	9,74E-05	3,91E-06	5,78E-04	-1,04E-06
Triadimenol	2,67E-09	2,22E-09	6,95E-11	2,20E-11	3,52E-10	5,27E-12
Triallate	3,26E-09	2,71E-09	8,35E-11	2,55E-11	4,26E-10	6,24E-12
Triasulfuron	2,47E-08	2,06E-08	6,32E-10	1,93E-10	3,23E-09	4,73E-11
Tribenuron methyl	1,25E-09	7,76E-10	1,09E-10	4,10E-11	3,32E-10	-7,92E-12
Tribufos	1,47E-07	9,60E-09	2,18E-08	1,90E-09	1,14E-07	-1,52E-10
Triclopyr	6,76E-05	4,64E-05	9,48E-06	3,90E-06	7,99E-06	-1,75E-07
Trifluralin	3,57E-04	1,47E-04	1,06E-04	6,16E-05	6,26E-05	-2,00E-05
Trinexapac-ethyl	1,11E-08	9,25E-09	2,89E-10	9,18E-11	1,46E-09	2,19E-11
Vinclozolin	3,50E-06	1,43E-06	1,01E-06	6,07E-07	6,45E-07	-1,98E-07
Heavy metals to industrial soil						
Antimony	1,06E-03	1,04E-04	1,17E-04	4,73E-05	4,29E-04	3,62E-04
Arsenic	3,20E-03	1,19E-03	3,93E-04	3,05E-04	1,12E-03	2,01E-04
Arsenic (+V)	1,06E-11	1,06E-11	-	-	-	-
Cadmium	1,43E-04	1,71E-05	1,58E-05	7,48E-06	5,79E-05	4,45E-05
Chromium	4,62E-02	1,81E-02	5,67E-03	4,55E-03	1,59E-02	1,95E-03
Chromium (+III)	9,69E-14	9,69E-14	-	-	-	-
Chromium (+VI)	7,77E-01	2,36E-01	2,61E-01	1,67E-01	1,72E-01	-5,94E-02
Cobalt	1,64E-04	1,88E-05	1,82E-05	8,29E-06	6,63E-05	5,25E-05
Copper	3,00E-01	8,49E-02	9,39E-02	6,00E-02	7,28E-02	-1,15E-02
Lead	2,45E-04	3,02E-05	2,72E-05	1,31E-05	9,92E-05	7,50E-05
Mercury	8,51E-06	2,75E-06	9,54E-07	1,08E-06	3,38E-06	3,60E-07
Molybdenum	2,29E-06	2,25E-07	2,54E-07	1,02E-07	9,26E-07	7,82E-07
Nickel	1,60E-03	2,29E-04	1,78E-04	9,70E-05	6,49E-04	4,47E-04
Selenium	4,13E-04	4,06E-05	4,57E-05	1,84E-05	1,67E-04	1,41E-04
Silver	5,60E-05	5,50E-06	6,20E-06	2,50E-06	2,26E-05	1,91E-05

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Vanadium	3,23E-04	3,18E-05	3,58E-05	1,44E-05	1,31E-04	1,10E-04
Zinc	9,88E-01	1,31E-01	1,11E-01	5,04E-02	3,96E-01	3,00E-01
Inorganic emissions to agricultural soil						
Barium	1,23E-01	5,09E-02	1,52E-02	1,26E-02	4,18E-02	2,33E-03
Beryllium	1,31E-16	1,31E-16	-	-	-	-
Organic emissions to agricultural soil						
Acetic acid	2,87E-13	2,87E-13	-	-	-	-
Methanol	8,30E-16	8,30E-16	-	-	-	-
Pentachlorophenol (PCP)	4,18E-07	1,24E-07	1,23E-07	7,34E-08	1,21E-07	-2,42E-08
Other emissions to agricultural soil						
Glyphosate	2,19E-04	9,00E-05	3,26E-05	2,17E-05	7,93E-05	-4,40E-06

Table C.3: Particulate matter / respiratory inorganics (midpoint, v1.09) of one mc-Si PV-module (60 6-inch solar cells) in kg PM2.5 equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Ammonia	3,85E-07	1,43E-09	4,02E-10	6,04E-10	3,83E-07	-1,23E-10
Particulates, < 2.5 um	3,90E-04	1,48E-04	1,24E-04	7,79E-05	4,68E-05	-6,72E-06
Inorganic emissions to air						
Ammonia	9,00E-04	1,73E-04	8,56E-05	2,73E-04	3,87E-04	-1,88E-05
Carbon monoxide	7,74E-05	3,14E-05	2,12E-05	1,13E-05	3,14E-05	-1,79E-05
Carbon monoxide, non-fossil	3,07E-05	2,47E-05	9,72E-07	2,67E-06	2,29E-06	1,07E-07
Nitrogen dioxide	3,31E-09	3,31E-09	-	-	-	-
Nitrogen monoxide	6,75E-08	6,75E-08	-	-	-	-
Nitrogen oxides	3,53E-03	1,72E-03	3,75E-04	4,15E-04	1,17E-03	-1,48E-04
Sulphur dioxide	5,25E-02	2,70E-02	6,15E-03	4,69E-03	1,75E-02	-2,90E-03
Sulphur oxides	1,33E-05	3,21E-08	9,89E-09	8,61E-09	1,33E-05	-3,09E-09
Sulphur trioxide	3,25E-09	8,92E-10	4,07E-10	1,50E-10	1,80E-09	8,66E-12
Particles to air						
Dust (PM10)	6,81E-12	6,81E-12	-	-	-	-
Dust (PM2.5)	2,12E-01	1,44E-01	1,48E-02	1,64E-02	4,73E-02	-1,13E-02

Table C.4: Resource depletion, mineral, fossils and renewables, midpoint (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in kg Sb equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Non-renewable energy resources						
Crude oil (in MJ)	3,02E-10	3,02E-10	-	-	-	-
Crude oil ecoinvent	3,77E-06	1,09E-06	5,71E-07	2,81E-07	1,81E-06	7,56E-09
Oil sand (10% bitumen) (in	8,44E-13	8,44E-13	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
MJ)						
Oil sand (100% bitumen) (in MJ)	7,37E-13	7,37E-13	-	-	-	-
Coal, hard, unspecified, in ground	7,39E-06	4,86E-06	9,24E-07	6,82E-07	1,39E-06	-4,62E-07
Hard coal (in MJ)	1,35E-12	1,35E-12	-	-	-	-
Coal, brown, in ground	2,06E-06	1,09E-06	4,84E-07	3,24E-07	2,65E-07	-1,10E-07
Lignite (in MJ)	7,52E-13	7,52E-13	-	-	-	-
Coalbed methane (in MJ)	3,60E-14	3,60E-14	-	-	-	-
Gas, mine, off-gas, process, coal mining	1,39E-07	9,02E-08	1,89E-08	1,37E-08	2,48E-08	-8,60E-09
Gas, natural, in ground	4,72E-06	2,03E-06	7,28E-07	4,85E-07	1,79E-06	-3,15E-07
Natural gas (in MJ)	2,31E-11	2,31E-11	-	-	-	-
Pit Methane (in MJ)	2,15E-14	2,15E-14	-	-	-	-
Shale gas (in MJ)	2,19E-13	2,19E-13	-	-	-	-
Tight gas (in MJ)	2,29E-13	2,29E-13	-	-	-	-
Peat (in kg)	4,27E-08	9,67E-09	1,75E-08	1,04E-08	5,19E-09	-1,15E-10
Peat (in MJ)	8,25E-15	8,25E-15	-	-	-	-
Uranium natural (in MJ)	8,05E-11	8,05E-11	-	-	-	-
Uranium, in ground	1,90E-04	7,09E-05	6,12E-05	3,79E-05	2,44E-05	-4,91E-06
Non-renewable elements						
Aluminium	-1,32E-06	3,67E-07	2,99E-07	2,24E-06	1,06E-05	-1,49E-05
Antimony	8,44E-11	8,44E-11	-	-	-	-
Cadmium	4,59E-03	1,28E-04	1,42E-04	2,58E-04	1,98E-03	2,09E-03
Cerium	2,53E-14	6,60E-15	4,56E-15	2,80E-15	1,11E-14	2,25E-16
Chromium	1,07E-06	1,43E-07	5,11E-07	9,41E-08	3,22E-07	-1,38E-09
Cobalt	6,84E-08	5,73E-09	8,85E-09	6,73E-09	4,68E-08	2,77E-10
Copper	6,52E-04	1,92E-05	4,45E-05	2,80E-04	3,51E-04	-4,24E-05
Dysprosium	9,36E-22	9,36E-22	-	-	-	-
Erbium	2,81E-22	2,81E-22	-	-	-	-
Europium	6,34E-17	1,65E-17	1,14E-17	7,02E-18	2,79E-17	5,64E-19
Gadolinium	1,58E-16	4,12E-17	2,85E-17	1,75E-17	6,96E-17	1,41E-18
Gallium	1,48E-14	4,40E-15	1,28E-15	9,71E-16	7,89E-15	2,42E-16
Gold	1,37E-03	9,95E-06	7,50E-06	1,31E-03	4,53E-05	2,80E-06
Holmium	1,87E-21	1,87E-21	-	-	-	-
Indium	3,81E-02	1,06E-03	1,18E-03	2,15E-03	1,64E-02	1,73E-02
Iodine	4,97E-09	8,37E-10	4,26E-10	2,01E-10	3,56E-09	-4,75E-11
Iron	3,52E-06	5,79E-07	1,98E-06	4,65E-07	4,70E-07	2,43E-08
Lanthanum	7,59E-15	1,98E-15	1,37E-15	8,40E-16	3,34E-15	6,75E-17
Lead	1,29E-03	3,17E-05	3,62E-05	2,51E-04	5,03E-04	4,72E-04
Lithium	2,27E-07	1,93E-08	9,77E-09	4,40E-09	1,94E-07	4,02E-11
Lutetium	1,87E-23	1,87E-23	-	-	-	-
Magnesium	3,83E-16	3,83E-16	-	-	-	-
Manganese	9,96E-07	5,24E-08	3,95E-07	4,60E-08	4,97E-07	4,53E-09

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Mercury	1,20E-17	1,20E-17	-	-	-	-
Molybdenum	1,60E-04	1,02E-05	3,55E-05	8,39E-06	1,49E-04	-4,32E-05
Neodymium	4,17E-15	1,09E-15	7,51E-16	4,62E-16	1,84E-15	3,71E-17
Nickel	1,45E-04	2,07E-05	7,16E-05	1,48E-05	3,83E-05	-3,27E-07
Palladium	3,20E-06	1,91E-07	2,41E-07	1,57E-07	2,59E-06	2,41E-08
Phosphorus	2,84E-07	2,55E-08	1,28E-08	6,37E-08	1,76E-07	5,49E-09
Platinum	1,67E-06	1,59E-07	1,57E-07	1,03E-07	1,24E-06	4,82E-09
Praseodymium	4,43E-16	1,15E-16	7,97E-17	4,90E-17	1,95E-16	3,94E-18
Rhenium	4,11E-08	1,40E-08	6,13E-09	4,55E-09	1,71E-08	-6,18E-10
Silver	1,25E-02	4,38E-05	5,38E-05	1,13E-02	7,13E-04	4,03E-04
Strontium	1,54E-05	3,10E-07	4,17E-07	3,53E-07	6,87E-06	7,47E-06
Sulphur	7,09E-07	1,46E-08	2,04E-08	4,71E-08	3,09E-06	-2,46E-06
Tantalum	5,54E-05	1,37E-05	8,65E-06	6,45E-06	2,55E-05	1,17E-06
Tellurium	7,96E-07	9,38E-11	6,09E-11	7,95E-07	2,38E-10	8,29E-11
Thulium	9,36E-24	9,36E-24	-	-	-	-
Tin	4,32E-04	4,60E-06	1,45E-06	7,02E-07	3,05E-03	-2,63E-03
Titanium	1,14E-14	1,14E-14	-	-	-	-
Vanadium	-5,95E-15	-5,95E-15	-	-	-	-
Ytterbium	1,87E-23	1,87E-23	-	-	-	-
Yttrium	3,61E-18	3,61E-18	-	-	-	-
Zinc	5,36E-04	1,36E-05	1,54E-05	8,62E-05	2,14E-04	2,07E-04
Zirconium	9,20E-05	1,84E-05	1,15E-06	7,37E-07	7,27E-05	-9,66E-07
Non-renewable resources						
Anhydrite (Rock)	1,25E-09	1,16E-10	2,55E-10	1,47E-11	1,00E-09	-1,39E-10
Barite, 15% in crude ore, in ground	1,17E-04	5,13E-05	1,69E-05	1,12E-05	3,60E-05	1,35E-06
Barium sulphate	1,28E-20	1,28E-20	-	-	-	-
Bauxite	1,12E-12	1,12E-12	-	-	-	-
Borax	1,87E-06	1,84E-06	9,49E-09	6,48E-09	1,46E-08	-1,23E-10
Cinnabar	4,30E-06	2,40E-06	1,46E-06	3,73E-07	1,88E-07	-1,23E-07
Colemanite ore	3,72E-07	6,13E-08	5,39E-08	1,89E-07	6,98E-08	-1,56E-09
Ferro manganese	4,76E-26	4,76E-26	-	-	-	-
Fluorspar (calcium fluoride; fluorite)	2,57E-03	3,52E-06	2,41E-05	1,26E-03	1,27E-03	6,37E-07
Graphite	1,21E-17	1,21E-17	-	-	-	-
Heavy spar (BaSO4)	3,02E-15	3,02E-15	-	-	-	-
Ilmenite (titanium ore)	6,26E-14	6,26E-14	-	-	-	-
Kaolin ore	7,14E-16	7,14E-16	-	-	-	-
Kaolinite (24% in ore as mined)	3,96E-08	1,17E-09	4,98E-10	1,53E-09	4,44E-08	-8,01E-09
Magnesit (Magnesium carbonate)	8,55E-13	8,55E-13	-	-	-	-
Magnesite	2,85E-08	1,91E-09	1,24E-08	1,90E-09	6,27E-09	5,98E-09
Magnesium chloride leach	8,04E-15	8,04E-15	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
(40%)						
Olivine	3,65E-12	3,08E-13	6,99E-13	4,81E-14	4,02E-12	-1,43E-12
Perlite (Rhyolithe)	1,23E-09	1,03E-11	1,40E-11	2,62E-11	9,65E-10	2,11E-10
Phosphate ore	1,25E-10	1,25E-10	-	-	-	-
Potashsalt, crude (hard salt, 10% K2O)	2,43E-11	2,43E-11	-	-	-	-
Potassium chloride	-3,61E-20	-3,61E-20	-	-	-	-
Sodium sulphate	1,22E-08	1,56E-09	1,08E-09	7,47E-10	8,08E-09	7,57E-10
Spodumen (LiAlSi2 O6)	2,57E-09	2,32E-10	1,26E-10	6,38E-11	2,13E-09	2,14E-11
Sulphur (bonded)	1,30E-14	1,30E-14	-	-	-	-
Talc	4,34E-07	2,43E-08	9,61E-09	4,64E-08	6,00E-07	-2,46E-07
Tin ore (0.01%)	3,50E-16	3,50E-16	-	-	-	-
Titanium dioxide	4,26E-05	8,38E-06	5,24E-07	3,37E-07	3,38E-05	-4,41E-07
Titanium ore	1,31E-15	1,31E-15	-	-	-	-
Ulexite	1,26E-06	1,32E-08	8,89E-09	5,65E-09	7,14E-06	-5,91E-06

Table C.5: Human toxicity midpoint, cancer effects (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in CTUh

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Arsenic	8,42E-10	3,18E-10	2,73E-10	1,70E-10	9,52E-11	-1,46E-11
Beryllium	3,82E-12	1,44E-12	1,24E-12	7,72E-13	4,32E-13	-6,62E-14
Cadmium	1,41E-11	5,34E-12	4,58E-12	2,85E-12	1,60E-12	-2,44E-13
Chromium VI	1,37E-09	5,17E-10	4,44E-10	2,77E-10	1,55E-10	-2,37E-11
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	1,06E-12	3,91E-15	1,10E-15	1,66E-15	1,05E-12	-3,39E-16
Lead	1,15E-10	4,35E-11	3,73E-11	2,32E-11	1,30E-11	-1,99E-12
Mercury	2,32E-10	8,75E-11	7,51E-11	4,68E-11	2,62E-11	-4,01E-12
Nickel	4,53E-11	1,71E-11	1,47E-11	9,16E-12	5,12E-12	-7,84E-13
Heavy metals to air						
Arsenic	3,23E-08	4,68E-09	2,30E-09	1,29E-09	2,39E-08	1,75E-10
Arsenic (+V)	2,27E-15	2,27E-15	-	-	-	-
Cadmium	6,59E-09	5,09E-10	4,37E-10	2,65E-10	5,25E-09	1,28E-10
Chromium	4,07E-07	7,70E-08	2,03E-07	3,85E-08	9,14E-08	-3,40E-09
Chromium (+VI)	2,53E-08	8,01E-09	1,03E-08	2,20E-09	5,19E-09	-4,23E-10
Lead	8,78E-09	1,34E-09	7,05E-10	7,79E-10	5,44E-09	5,12E-10
Mercury	5,58E-08	2,20E-08	1,72E-08	6,18E-09	1,11E-08	-6,73E-10
Nickel	1,21E-08	2,65E-09	1,02E-09	6,96E-10	7,91E-09	-1,64E-10
Inorganic emissions to air						
Beryllium	3,01E-11	2,29E-11	1,29E-12	8,69E-13	5,84E-12	-7,86E-13
Organic emissions to air (group VOC)						

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Benzo{a}pyrene	6,22E-10	3,73E-10	1,09E-10	3,81E-11	1,13E-10	-1,04E-11
Dibenz(a)anthracene	1,86E-17	-2,28E-19	5,84E-18	2,08E-18	9,83E-18	1,09E-18
Naphthalene	2,41E-14	1,09E-16	2,78E-15	3,02E-17	2,03E-14	9,51E-16
Carbon tetrachloride (tetrachloromethane)	2,02E-10	1,37E-10	5,04E-11	1,25E-11	4,74E-12	-2,88E-12
Dichloroethane (ethylene dichloride)	1,01E-12	2,26E-13	1,13E-13	1,90E-13	5,77E-13	-9,85E-14
Dichloromethane (methylene chloride)	9,33E-14	6,87E-14	5,41E-15	7,94E-15	1,87E-14	-7,36E-15
Hexachlorobenzene (Perchlorobenzene)	1,23E-12	1,28E-13	8,48E-13	1,23E-13	1,13E-13	1,94E-14
Pentachlorophenol (PCP)	3,14E-11	1,88E-11	5,46E-12	1,83E-12	5,29E-12	4,48E-14
Polychlorinated biphenyls (PCB unspecified)	2,78E-12	3,42E-13	1,77E-12	3,05E-13	2,79E-13	8,49E-14
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	2,19E-09	7,96E-10	3,92E-10	2,53E-10	5,04E-10	2,42E-10
Polychlorinated dibenzo-p-furans (2,3,7,8 - TCDD)	2,17E-17	2,17E-17	-	-	-	-
Tetrachloroethene (perchloroethylene)	1,86E-13	4,38E-14	3,48E-15	1,31E-13	1,28E-14	-5,31E-15
Trichloroethene (isomers)	2,68E-22	2,68E-22	-	-	-	-
Trichloromethane (chloroform)	1,21E-12	1,05E-12	2,11E-14	1,18E-13	2,70E-14	-8,75E-15
Vinyl chloride (VCM; chloroethene)	3,24E-12	6,34E-13	3,91E-13	5,36E-13	1,89E-12	-2,15E-13
Acetaldehyde (Ethanal)	1,03E-11	2,91E-12	1,34E-12	5,83E-13	4,89E-12	5,31E-13
Acrylonitrile	4,14E-24	4,14E-24	-	-	-	-
Aniline	8,49E-17	1,44E-17	1,03E-17	4,08E-18	5,73E-17	-1,09E-18
Benzaldehyde	1,38E-13	2,42E-14	1,82E-14	8,12E-15	5,65E-14	3,07E-14
Benzene	9,63E-10	5,71E-10	1,51E-10	6,28E-11	1,83E-10	-5,38E-12
Butadiene	6,45E-15	2,87E-17	1,53E-17	7,03E-18	2,34E-16	6,17E-15
Diethylene glycol	1,82E-22	8,60E-23	4,26E-23	2,99E-23	3,43E-23	-1,07E-23
Ethanol	1,28E-13	8,25E-14	1,39E-14	1,39E-14	2,02E-14	-2,10E-15
Ethyl benzene	5,30E-12	2,08E-12	6,67E-13	5,05E-13	1,96E-12	8,42E-14
Ethylene oxide	7,09E-12	1,47E-14	4,67E-12	2,98E-14	2,39E-12	-1,25E-14
Formaldehyde (methanal)	5,75E-09	2,76E-09	7,25E-10	4,62E-10	1,74E-09	6,48E-11
Furan	1,74E-09	4,00E-10	2,54E-10	7,80E-11	1,02E-09	-1,55E-11
Hexane (isomers)	7,22E-13	3,07E-13	1,09E-13	7,41E-14	2,67E-13	-3,57E-14
Isoprene	1,23E-14	2,83E-15	1,80E-15	5,52E-16	7,22E-15	-1,09E-16
Methyl tert-butylether	9,54E-14	1,56E-14	1,34E-14	3,45E-15	6,24E-14	5,25E-16
Nitrobenzene	6,90E-15	1,24E-15	8,38E-16	3,37E-16	4,58E-15	-8,92E-17
o-Nitrotoluene	1,97E-15	8,60E-16	2,68E-16	1,42E-16	7,34E-16	-3,01E-17
Propylene oxide	2,14E-10	2,60E-14	2,14E-10	1,06E-14	5,85E-14	3,76E-14
Styrene	1,56E-12	2,41E-13	1,97E-13	8,81E-14	6,90E-13	3,44E-13
Toluene (methyl benzene)	2,31E-15	1,27E-15	2,30E-16	1,90E-16	6,56E-16	-3,25E-17
Xylene (dimethyl benzene)	6,81E-12	2,52E-12	7,10E-13	5,37E-13	3,25E-12	-2,12E-13

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Pesticides to air (group VOC)						
Acephate	1,18E-15	2,45E-16	2,44E-16	9,59E-17	6,21E-16	-2,64E-17
Acifluorfen	1,79E-15	3,72E-16	3,71E-16	1,46E-16	9,44E-16	-4,01E-17
Atrazine	6,72E-15	1,40E-15	1,39E-15	5,46E-16	3,54E-15	-1,50E-16
Carbaryl	2,03E-15	4,22E-16	4,20E-16	1,65E-16	1,07E-15	-4,54E-17
Trifluralin	2,38E-14	4,95E-15	4,93E-15	1,94E-15	1,26E-14	-5,33E-16
Long-term emissions to fresh water						
Arsenic, ion	3,95E-07	7,80E-08	4,40E-08	1,14E-07	1,55E-07	3,44E-09
Cadmium, ion	9,60E-10	7,77E-11	7,50E-11	2,83E-10	4,84E-10	4,02E-11
Chromium (+VI)	1,34E-05	5,06E-06	3,92E-06	2,03E-06	3,89E-06	-1,52E-06
Lead	7,16E-10	3,29E-11	2,33E-11	5,42E-11	2,66E-10	3,39E-10
Mercury	3,24E-09	1,69E-09	6,52E-10	4,42E-10	5,89E-10	-1,33E-10
Nickel, ion	3,78E-07	1,86E-07	8,21E-08	5,30E-08	6,73E-08	-1,03E-08
Heavy metals to fresh water						
Arsenic	1,91E-20	1,91E-20	-	-	-	-
Arsenic (+V)	7,33E-08	4,24E-08	1,16E-08	1,01E-08	2,10E-08	-1,17E-08
Cadmium	6,58E-12	8,68E-13	1,35E-12	1,12E-12	2,63E-12	6,20E-13
Chromium	2,02E-11	2,02E-11	-	-	-	-
Chromium (+VI)	1,87E-06	4,70E-07	8,64E-07	2,29E-07	7,12E-07	-4,05E-07
Lead	2,07E-11	2,88E-12	1,81E-12	1,04E-12	1,38E-11	1,18E-12
Mercury	5,63E-11	1,70E-11	2,11E-11	4,75E-12	1,18E-11	1,68E-12
Nickel	2,18E-09	7,36E-10	3,91E-10	2,41E-10	1,06E-09	-2,47E-10
Organic emissions to fresh water						
1,2-Dibromoethane	-2,56E-27	-2,56E-27	-	-	-	-
Chlorobenzene	6,40E-12	5,05E-12	2,04E-13	1,05E-12	9,44E-14	4,06E-15
Dichloroethane (ethylene dichloride)	7,22E-13	6,56E-14	4,51E-14	7,44E-14	5,35E-13	2,04E-15
Dichloromethane (methylene chloride)	4,95E-13	1,99E-13	5,59E-14	4,84E-14	1,81E-13	1,00E-14
Dichloropropane	-1,16E-31	-1,16E-31	-	-	-	-
Pentachlorophenol (PCP)	5,22E-22	5,22E-22	-	-	-	-
Polychlorinated biphenyls (PCB unspecified)	5,07E-12	8,55E-15	1,50E-15	2,27E-15	5,06E-12	-3,75E-15
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	6,11E-23	6,11E-23	-	-	-	-
Tetrachloroethene (perchloroethylene)	1,84E-25	1,84E-25	-	-	-	-
Trichloromethane (chloroform)	1,50E-15	1,21E-15	2,74E-17	1,68E-17	2,42E-16	-2,37E-18
Vinyl chloride (VCM; chloroethene)	4,42E-14	7,15E-15	3,39E-15	2,62E-15	3,16E-14	-5,46E-16
Acrylonitrile	1,66E-24	1,66E-24	-	-	-	-
Aniline	7,81E-16	1,32E-16	9,44E-17	3,75E-17	5,27E-16	-1,00E-17
Benzene	3,76E-11	2,05E-11	1,81E-12	5,49E-12	1,11E-11	-1,34E-12
Benzo{a}pyrene	1,56E-16	7,11E-19	1,87E-17	2,04E-19	1,37E-16	9,04E-20

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Dibenz(a)anthracene	1,34E-17	6,11E-20	1,61E-18	1,75E-20	1,17E-17	7,77E-21
Ethanol	1,91E-13	5,90E-16	3,19E-14	8,60E-16	1,58E-13	-6,10E-16
Ethyl benzene	4,98E-13	1,91E-13	5,21E-14	4,68E-14	1,91E-13	1,76E-14
Ethylene oxide	1,54E-13	1,45E-14	7,21E-15	6,35E-15	8,61E-14	3,95E-14
Formaldehyde (methanal)	4,10E-12	1,01E-13	1,74E-12	5,11E-14	2,24E-12	-3,35E-14
Hexane (isomers)	-5,57E-31	-5,57E-31	-	-	-	-
Methyl tert-butylether	4,30E-16	1,22E-16	8,54E-17	4,44E-17	1,82E-16	-3,68E-18
Naphthalene	1,54E-14	3,14E-16	1,81E-15	1,97E-17	1,32E-14	8,75E-18
Propylene oxide	8,06E-10	9,42E-14	8,06E-10	3,81E-14	2,15E-13	1,41E-13
Toluene (methyl benzene)	1,95E-13	7,96E-14	1,94E-14	1,76E-14	7,28E-14	5,32E-15
Xylene (isomers; dimethyl benzene)	1,74E-13	6,90E-14	1,78E-14	1,61E-14	6,60E-14	5,48E-15
Acetaldehyde (Ethanal)	1,06E-11	3,96E-14	1,75E-12	4,56E-14	8,74E-12	4,96E-14
Nitrobenzene	3,00E-14	5,37E-15	3,64E-15	1,46E-15	1,99E-14	-3,87E-16
Other emissions to fresh water						
Atrazine	2,13E-19	7,03E-20	4,75E-20	3,52E-20	6,32E-20	-3,21E-21
Carbaryl	5,02E-23	1,79E-23	1,07E-23	7,88E-24	1,45E-23	-7,10E-25
Trifluralin	4,16E-19	4,16E-19	-	-	-	-
Heavy metals to sea water						
Arsenic (+V)	5,94E-11	1,38E-12	8,88E-13	5,03E-11	6,55E-12	2,59E-13
Cadmium	3,19E-12	1,03E-14	4,25E-15	3,15E-12	2,18E-14	1,63E-15
Chromium	3,13E-13	3,13E-13	-	-	-	-
Lead	7,28E-13	1,37E-13	5,10E-14	3,51E-13	1,74E-13	1,42E-14
Mercury	9,31E-12	2,22E-13	2,10E-13	6,93E-12	1,88E-12	6,84E-14
Nickel	2,78E-10	1,91E-13	1,00E-13	2,77E-10	4,51E-13	4,87E-14
Organic emissions to sea water						
Tetrachloroethene (perchloroethylene)	1,07E-29	1,07E-29	-	-	-	-
Benzene	1,03E-13	3,82E-14	1,11E-14	9,90E-15	3,99E-14	4,01E-15
Ethyl benzene	2,91E-15	1,08E-15	3,11E-16	2,78E-16	1,13E-15	1,14E-16
Hexane (isomers)	-1,81E-32	-1,81E-32	-	-	-	-
Methyl tert-butylether	6,31E-17	1,79E-17	1,24E-17	6,46E-18	2,68E-17	-5,42E-19
Toluene (methyl benzene)	1,83E-16	6,56E-17	1,99E-17	1,77E-17	7,20E-17	7,35E-18
Xylene (isomers; dimethyl benzene)	4,13E-16	1,52E-16	4,45E-17	3,97E-17	1,60E-16	1,61E-17
Naphthalene	4,64E-18	4,64E-18	-	-	-	-
Other emissions to sea water						
Acetamide	7,61E-20	1,58E-20	1,57E-20	6,19E-21	4,01E-20	-1,70E-21
Heavy metals to agriculture soil						
Arsenic	2,04E-10	1,47E-10	1,50E-11	1,51E-11	2,74E-11	-1,14E-12
Arsenic (+V)	1,20E-23	1,20E-23	-	-	-	-
Cadmium	1,55E-10	7,43E-11	2,69E-11	1,67E-11	3,90E-11	-1,39E-12
Chromium	1,15E-08	5,75E-09	2,09E-09	1,31E-09	2,47E-09	-1,14E-10
Lead	1,25E-10	5,79E-11	2,11E-11	1,30E-11	3,40E-11	-1,14E-12

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Mercury	3,09E-10	5,29E-11	2,62E-11	1,49E-11	2,18E-10	-2,86E-12
Nickel	1,35E-10	6,39E-11	2,25E-11	1,45E-11	3,56E-11	-1,23E-12
Other emissions to agriculture soil						
Acephate	5,67E-15	3,75E-16	8,42E-16	7,56E-17	4,38E-15	-6,69E-18
Acetamide	7,01E-16	4,69E-17	1,04E-16	9,64E-18	5,42E-16	-8,60E-19
Acifluorfen	1,02E-17	2,12E-18	2,11E-18	8,30E-19	5,38E-18	-2,28E-19
Aldrin	1,49E-10	1,19E-10	4,79E-12	8,70E-12	1,68E-11	-6,01E-13
Atrazine	7,14E-12	2,01E-12	7,99E-14	1,46E-13	4,92E-12	-1,26E-14
Carbaryl	3,60E-16	1,59E-16	8,93E-17	5,18E-17	7,65E-17	-1,66E-17
Chlorothalonil	1,79E-13	1,47E-15	4,69E-16	1,97E-15	1,76E-13	-2,32E-16
Fomesafen	2,95E-14	5,65E-15	5,88E-15	2,19E-15	1,63E-14	-5,83E-16
Prochloraz	4,84E-16	4,03E-16	1,26E-17	3,97E-18	6,37E-17	9,52E-19
Trifluralin	1,10E-13	4,52E-14	3,27E-14	1,90E-14	1,93E-14	-6,15E-15
Heavy metals to industrial soil						
Arsenic	2,93E-11	1,08E-11	3,59E-12	2,79E-12	1,02E-11	1,83E-12
Arsenic (+V)	9,65E-20	9,65E-20	-	-	-	-
Cadmium	2,34E-14	2,80E-15	2,59E-15	1,22E-15	9,48E-15	7,28E-15
Chromium	4,64E-09	1,82E-09	5,69E-10	4,57E-10	1,60E-09	1,96E-10
Chromium (+VI)	7,91E-08	2,40E-08	2,66E-08	1,70E-08	1,75E-08	-6,04E-09
Lead	2,23E-13	2,76E-14	2,48E-14	1,20E-14	9,04E-14	6,83E-14
Mercury	4,63E-14	1,49E-14	5,18E-15	5,85E-15	1,84E-14	1,96E-15
Nickel	4,11E-12	5,88E-13	4,57E-13	2,50E-13	1,67E-12	1,15E-12
Organic emissions to industrial soil						
Pentachlorophenol (PCP)	1,11E-16	3,29E-17	3,28E-17	1,95E-17	3,22E-17	-6,42E-18

Table C. 6: Ionizing radiation midpoint, human health (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in kBq U235 equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Radon-222	2,08E+01	7,86E+00	6,75E+00	4,20E+00	2,35E+00	-3,60E-01
Radioactive emissions to air						
Carbon (C14)	1,19E+01	4,89E+00	3,18E+00	2,08E+00	1,86E+00	-6,62E-02
Cesium (Cs134)	8,27E-08	3,53E-08	2,30E-08	1,50E-08	9,89E-09	-5,73E-10
Cesium (Cs137)	1,69E-06	7,22E-07	4,70E-07	3,06E-07	2,02E-07	-1,18E-08
Cobalt (Co58)	8,00E-09	3,46E-09	2,21E-09	1,44E-09	9,61E-10	-5,96E-11
Cobalt (Co60)	2,36E-06	1,01E-06	6,53E-07	4,25E-07	2,83E-07	-1,71E-08
Hydrogen-3, Tritium	2,99E-03	1,01E-03	1,01E-03	6,22E-04	3,90E-04	-4,20E-05
Iodine (I129)	1,92E-02	8,11E-03	5,59E-03	3,56E-03	2,21E-03	-3,14E-04
Iodine (I131)	2,32E-04	1,28E-04	6,87E-05	4,10E-05	1,84E-05	-2,39E-05
Iodine (I133)	1,29E-08	5,61E-09	3,55E-09	2,31E-09	1,56E-09	-9,97E-11
Krypton (Kr85)	2,69E-06	1,46E-06	7,92E-07	4,75E-07	2,20E-07	-2,60E-07
Lead (Pb210)	3,54E-03	2,47E-03	3,27E-04	2,99E-04	6,92E-04	-2,44E-04

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Plutonium (Pu alpha)	5,32E-10	2,25E-10	1,55E-10	9,89E-11	6,14E-11	-8,71E-12
Plutonium (Pu238)	1,85E-10	7,84E-11	5,40E-11	3,45E-11	2,14E-11	-3,04E-12
Polonium (Po210)	6,30E-03	4,39E-03	5,82E-04	5,29E-04	1,23E-03	-4,34E-04
Radium (Ra226)	8,00E-04	4,80E-04	1,30E-04	9,61E-05	1,38E-04	-4,28E-05
Radon (Rn222)	5,81E-01	2,20E-01	1,88E-01	1,17E-01	6,59E-02	-1,01E-02
Thorium (Th230)	2,34E-03	1,26E-03	4,32E-04	3,40E-04	4,26E-04	-1,19E-04
Uranium	3,38E-04	2,76E-04	9,43E-06	3,88E-06	5,35E-05	-4,01E-06
Uranium (total)	-4,38E-14	-4,38E-14	-	-	-	-
Uranium (U234)	1,28E-02	6,46E-03	2,82E-03	2,02E-03	2,02E-03	-5,56E-04
Uranium (U235)	8,35E-05	3,15E-05	2,71E-05	1,69E-05	9,43E-06	-1,44E-06
Uranium (U238)	8,61E-03	4,63E-03	1,78E-03	1,23E-03	1,34E-03	-3,75E-04
Xenon (Xe133)	8,71E-05	3,81E-05	2,41E-05	1,56E-05	1,03E-05	-1,00E-06
Radioactive emissions to fresh water						
Antimony (Sb124)	1,28E-03	8,06E-04	1,76E-04	1,42E-04	1,63E-04	-1,26E-05
Cesium (Cs134)	2,66E-03	1,25E-03	6,68E-04	4,44E-04	3,22E-04	-2,57E-05
Cesium (Cs137)	3,96E-02	1,69E-02	1,11E-02	7,18E-03	4,73E-03	-2,99E-04
Cobalt (Co58)	3,78E-05	1,61E-05	1,06E-05	6,87E-06	4,53E-06	-2,95E-07
Cobalt (Co60)	2,69E-02	1,15E-02	7,48E-03	4,86E-03	3,22E-03	-2,07E-04
Hydrogen-3, Tritium	4,80E-03	2,72E-03	8,98E-04	6,49E-04	5,97E-04	-5,63E-05
Iodine (I129)	4,64E-09	4,64E-09	-	-	-	-
Iodine (I131)	1,52E-04	9,63E-05	2,11E-05	1,70E-05	1,95E-05	-1,50E-06
Manganese (Mn54)	1,12E-05	4,70E-06	3,21E-06	2,08E-06	1,34E-06	-8,28E-08
Radium (Ra226)	8,39E-03	3,18E-03	2,66E-03	1,66E-03	1,02E-03	-1,35E-04
Silver (Ag110m)	2,21E-04	9,17E-05	6,36E-05	4,11E-05	2,63E-05	-1,59E-06
Uranium	5,51E-10	5,51E-10	-	-	-	-
Uranium (U234)	5,33E-04	2,01E-04	1,73E-04	1,08E-04	6,03E-05	-9,23E-06
Uranium (U235)	5,58E-04	2,11E-04	1,81E-04	1,13E-04	6,31E-05	-9,66E-06
Uranium (U238)	1,83E-02	6,98E-03	5,88E-03	3,67E-03	2,08E-03	-3,36E-04
Radioactive emissions to sea water						
Carbon (C14)	1,81E-08	1,81E-08	-	-	-	-
Cesium (Cs134)	1,45E-11	1,45E-11	-	-	-	-
Cesium (Cs137)	2,99E-04	1,26E-04	8,71E-05	5,56E-05	3,45E-05	-4,89E-06
Cobalt (Co60)	1,16E-10	1,16E-10	-	-	-	-
Hydrogen-3, Tritium	5,50E-04	2,33E-04	1,60E-04	1,02E-04	6,36E-05	-9,01E-06
Ruthenium (Ru106)	1,20E-09	1,20E-09	-	-	-	-
Strontium (Sr90)	1,73E-06	7,31E-07	5,04E-07	3,21E-07	2,00E-07	-2,83E-08
Uranium (U234)	5,57E-13	5,57E-13	-	-	-	-
Uranium (U238)	8,56E-07	8,55E-08	4,21E-08	6,62E-08	6,40E-07	2,22E-08

Table C.7: Photochemical ozone formation midpoint, human health (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in kg NMVOC equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Nitrogen oxides	8,70E-07	3,22E-09	9,08E-10	1,36E-09	8,65E-07	-2,79E-10
NMVOC, non-methane volatile organic compounds, unspecified origin	1,35E-02	-	-	-	1,35E-02	-
Inorganic emissions to air						
Carbon monoxide	9,92E-03	4,03E-03	2,72E-03	1,45E-03	4,03E-03	-2,30E-03
Carbon monoxide, non-fossil	3,94E-03	3,16E-03	1,25E-04	3,43E-04	2,94E-04	1,37E-05
Nitrogen dioxide	4,58E-07	4,58E-07	-	-	-	-
Nitrogen monoxide	6,09E-06	6,09E-06	-	-	-	-
Nitrogen oxides	4,89E-01	2,39E-01	5,20E-02	5,75E-02	1,62E-01	-2,05E-02
Sulphur dioxide	6,97E-02	3,59E-02	8,16E-03	6,23E-03	2,33E-02	-3,85E-03
Sulphur oxides	1,77E-05	4,26E-08	1,31E-08	1,14E-08	1,76E-05	-4,10E-09
Organic emissions to air (group VOC)						
1,1,1-Trichloroethane	1,29E-09	9,48E-10	7,50E-11	1,07E-10	2,75E-10	-1,15E-10
Chloromethane (methyl chloride)	1,90E-08	1,40E-08	1,10E-09	1,58E-09	4,06E-09	-1,70E-09
Dichloromethane (methylene chloride)	1,61E-07	1,19E-07	9,33E-09	1,37E-08	3,22E-08	-1,27E-08
Hydrocarbons, halogenated	9,32E-19	9,32E-19	-	-	-	-
Tetrachloroethene (perchloroethylene)	2,79E-08	6,59E-09	5,23E-10	1,97E-08	1,92E-09	-7,99E-10
Trichloroethene (isomers)	4,90E-15	4,90E-15	-	-	-	-
Trichloromethane (chloroform)	2,04E-07	1,78E-07	3,56E-09	1,98E-08	4,56E-09	-1,48E-09
1,3,5-Trimethylbenzene	1,10E-12	1,10E-12	-	-	-	-
1-Butanol	7,69E-10	2,94E-10	1,03E-10	4,14E-11	3,39E-10	-8,44E-12
1-Butylene (Vinylacetylene)	4,95E-11	4,95E-11	-	-	-	-
1-Methoxy-2-propanol	1,77E-15	1,77E-15	-	-	-	-
1-Pentene	1,07E-08	7,19E-10	8,61E-09	1,35E-10	1,21E-09	5,21E-11
1-Propanol	4,88E-04	1,67E-09	5,48E-10	2,81E-10	4,88E-04	-4,32E-11
1-Undecane	6,68E-15	6,68E-15	-	-	-	-
2,2-Dimethylbutane	7,55E-12	7,55E-12	-	-	-	-
2-Methyl-1-butene	9,06E-11	9,06E-11	-	-	-	-
2-Methyl-2-butene	7,92E-11	6,71E-12	3,41E-12	1,53E-12	6,75E-11	1,40E-14
2-Methylpentane	8,94E-11	8,94E-11	-	-	-	-
3-Methylpentane	1,00E-07	1,20E-08	6,44E-08	4,49E-09	1,88E-08	6,80E-10
Acetaldehyde (Ethanal)	1,16E-04	3,31E-05	1,52E-05	6,62E-06	5,55E-05	6,03E-06
Acetic acid	3,70E-04	1,87E-05	4,89E-05	4,50E-06	3,00E-04	-1,79E-06
Acetone (dimethylcetone)	7,66E-05	1,26E-05	3,45E-06	1,53E-06	5,90E-05	-4,73E-08

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Aldehyde (unspecified)	5,13E-06	3,21E-06	4,13E-07	5,13E-07	2,48E-06	-1,49E-06
Benzaldehyde	-1,18E-06	-2,08E-07	-1,56E-07	-6,97E-08	-4,85E-07	-2,63E-07
Benzene	1,19E-03	7,07E-04	1,87E-04	7,78E-05	2,27E-04	-6,66E-06
Butadiene	1,63E-08	7,23E-11	3,85E-11	1,77E-11	5,89E-10	1,55E-08
Butane	6,63E-04	2,87E-04	9,47E-05	7,08E-05	2,13E-04	-2,99E-06
Butanone (methyl ethyl ketone)	1,74E-05	4,31E-06	2,70E-06	2,04E-06	8,03E-06	3,69E-07
cis-2-Pentene	1,36E-10	1,36E-10	-	-	-	-
Cumene (isopropylbenzene)	1,54E-05	1,54E-06	4,80E-07	2,08E-06	1,37E-05	-2,41E-06
Cyclohexane (hexahydro benzene)	1,10E-14	9,03E-15	8,88E-16	6,23E-16	7,14E-16	-2,23E-16
Decane	2,77E-13	2,77E-13	-	-	-	-
Diethyl ether	1,37E-14	6,49E-15	3,21E-15	2,25E-15	2,58E-15	-8,06E-16
Dodecane	1,39E-14	1,39E-14	-	-	-	-
Ethane	1,30E-03	8,26E-04	1,30E-04	1,27E-04	2,34E-04	-1,90E-05
Ethanol	4,05E-05	2,60E-05	4,38E-06	4,37E-06	6,37E-06	-6,63E-07
Ethene (ethylene)	3,44E-03	2,31E-03	1,75E-04	1,48E-04	8,19E-04	-1,13E-05
Ethine (acetylene)	1,35E-04	1,66E-05	8,10E-07	9,86E-07	1,17E-04	-2,56E-07
Ethyl benzene	1,95E-05	7,66E-06	2,45E-06	1,86E-06	7,23E-06	3,10E-07
Ethylene acetate (ethyl acetate)	9,82E-06	2,42E-06	1,52E-06	1,14E-06	4,54E-06	2,07E-07
Formaldehyde (methanal)	3,76E-04	1,80E-04	4,74E-05	3,03E-05	1,14E-04	4,24E-06
Formic acid (methane acid)	6,73E-07	1,55E-07	9,83E-08	3,04E-08	3,95E-07	-5,93E-09
Heptane (isomers)	1,02E-04	3,54E-05	1,03E-05	9,29E-06	7,28E-05	-2,56E-05
Hexane (isomers)	5,92E-04	2,52E-04	8,96E-05	6,08E-05	2,19E-04	-2,93E-05
Hydrocarbons, aromatic	4,19E-04	1,52E-04	4,92E-05	2,37E-05	2,03E-04	-8,32E-06
iso-Butane	1,86E-10	1,86E-10	-	-	-	-
iso-Butanol	9,15E-10	1,39E-10	6,21E-11	2,88E-11	6,91E-10	-5,79E-12
iso-Pentane	9,64E-10	9,64E-10	-	-	-	-
Isoprene	3,32E-07	7,65E-08	4,85E-08	1,49E-08	1,95E-07	-2,95E-09
Isopropanol	1,90E-06	4,70E-07	2,93E-07	2,21E-07	8,80E-07	4,02E-08
Methanol	3,11E-04	1,46E-05	1,05E-04	6,05E-06	1,87E-04	-1,32E-06
Methyl acetate	8,76E-12	3,81E-12	1,19E-12	6,28E-13	3,26E-12	-1,33E-13
Methyl formate	2,19E-11	3,07E-12	1,41E-12	9,71E-13	1,64E-11	-6,69E-15
Methyl isobutyl ketone	1,13E-11	6,16E-13	1,19E-13	5,27E-13	9,93E-12	6,95E-14
Methyl tert-butylether	4,41E-07	7,22E-08	6,21E-08	1,59E-08	2,89E-07	2,43E-09
n-Butyl acetate	5,03E-20	5,03E-20	-	-	-	-
NMVOC (unspecified)	6,62E-02	2,68E-02	9,75E-03	8,88E-03	2,22E-02	-1,47E-03
Nonane	7,87E-14	7,87E-14	-	-	-	-
Octane	1,12E-09	1,12E-09	-	-	-	-
Pentane (n-pentane)	9,25E-04	4,34E-04	1,31E-04	1,05E-04	2,59E-04	-4,04E-06
Propane	5,28E-04	2,66E-04	6,85E-05	5,18E-05	1,49E-04	-7,83E-06
Propene (propylene)	1,55E-03	2,51E-04	1,20E-03	1,38E-05	9,63E-05	-6,86E-06

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Propionaldehyde	3,58E-04	2,40E-07	7,83E-08	4,85E-08	3,57E-04	8,60E-08
Propionic acid (propane acid)	1,92E-06	1,07E-06	3,19E-07	2,56E-07	3,50E-07	-8,04E-08
Styrene	7,32E-07	1,13E-07	9,25E-08	4,13E-08	3,24E-07	1,61E-07
Toluene (methyl benzene)	7,86E-04	4,32E-04	7,83E-05	6,46E-05	2,23E-04	-1,11E-05
trans-2-Butene	1,04E-10	1,04E-10	-	-	-	-
trans-2-Pentene	2,55E-10	2,55E-10	-	-	-	-
Xylene (meta-Xylene; 1,3-Dimethylbenzene)	2,98E-05	1,25E-05	5,27E-06	3,02E-06	6,92E-06	2,07E-06
Xylene (ortho-Xylene; 1,2-Dimethylbenzene)	3,36E-06	3,58E-07	4,27E-07	1,66E-07	1,52E-06	8,91E-07
Methane	6,31E-03	3,79E-03	7,84E-04	5,55E-04	1,69E-03	-5,10E-04
Methane (biotic)	4,24E-04	2,49E-04	6,55E-05	5,51E-05	7,35E-05	-1,86E-05

Table C.8: Human toxicity midpoint, non-cancer effects (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in CTUh

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Acetaldehyde	4,84E-10	-	-	4,84E-10	-	-
Antimony	1,77E-11	1,25E-11	2,79E-12	1,70E-12	8,29E-13	-1,27E-13
Arsenic	1,03E-07	7,25E-08	1,61E-08	9,87E-09	4,80E-09	-7,35E-10
Barium	2,80E-10	1,98E-10	4,39E-11	2,69E-11	1,31E-11	-2,00E-12
Beryllium	6,85E-09	4,84E-09	1,08E-09	6,58E-10	3,20E-10	-4,90E-11
Cadmium	7,16E-09	5,06E-09	1,13E-09	6,89E-10	3,35E-10	-5,13E-11
Chromium VI	3,09E-10	2,18E-10	4,86E-11	2,97E-11	1,45E-11	-2,21E-12
Copper	1,31E-10	9,28E-11	2,06E-11	1,26E-11	6,14E-12	-9,40E-13
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	1,58E-15	9,65E-16	1,12E-16	7,41E-17	4,74E-16	-4,25E-17
Lead	9,75E-08	6,90E-08	1,53E-08	9,38E-09	4,56E-09	-6,99E-10
Mercury	6,63E-08	4,68E-08	1,04E-08	6,37E-09	3,10E-09	-4,74E-10
Molybdenum	3,33E-09	2,36E-09	5,24E-10	3,21E-10	1,56E-10	-2,39E-11
Nickel	6,16E-12	4,36E-12	9,69E-13	5,93E-13	2,88E-13	-4,41E-14
Silver	4,46E-09	3,15E-09	7,01E-10	4,29E-10	2,09E-10	-3,19E-11
Vanadium	6,76E-10	4,78E-10	1,06E-10	6,50E-11	3,16E-11	-4,84E-12
Zinc	1,15E-07	8,16E-08	1,81E-08	1,11E-08	5,40E-09	-8,27E-10
Heavy metals to air						
Antimony	1,97E-08	3,31E-09	1,92E-09	6,06E-10	8,16E-09	5,66E-09
Arsenic	1,86E-06	4,73E-07	1,20E-07	5,20E-08	1,20E-06	8,83E-09
Arsenic (+V)	9,45E-13	9,45E-13	-	-	-	-
Cadmium	1,50E-06	2,36E-07	9,44E-08	4,10E-08	1,10E-06	2,68E-08
Chromium	4,50E-08	1,45E-08	1,90E-08	3,22E-09	8,53E-09	-3,17E-10
Chromium (+III)	1,18E-21	1,18E-21	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Chromium (+VI)	2,99E-09	1,40E-09	9,64E-10	1,81E-10	4,85E-10	-3,95E-11
Copper	4,60E-09	8,49E-10	3,63E-10	1,40E-10	2,96E-09	2,92E-10
Lead	3,59E-06	9,08E-07	2,52E-07	3,38E-07	1,91E-06	1,80E-07
Mercury	9,90E-06	5,89E-06	2,11E-06	6,66E-07	1,32E-06	-7,97E-08
Molybdenum	2,69E-08	1,07E-08	2,41E-09	9,41E-10	7,50E-09	5,31E-09
Nickel	8,25E-10	3,01E-10	6,02E-11	2,74E-11	4,45E-10	-9,20E-12
Silver	3,13E-07	4,50E-11	7,17E-12	3,13E-07	3,05E-11	2,26E-12
Thallium	5,18E-10	4,40E-10	1,10E-11	1,78E-11	5,17E-11	-2,70E-12
Vanadium	2,66E-08	1,95E-08	1,72E-09	1,15E-09	3,12E-09	1,06E-09
Inorganic emissions to air						
Barium	6,49E-09	4,21E-09	4,15E-10	2,09E-10	1,20E-09	4,55E-10
Beryllium	3,37E-08	2,85E-08	9,83E-10	5,00E-10	4,32E-09	-5,83E-10
Carbon disulphide	8,29E-08	8,36E-09	9,35E-09	2,40E-09	6,09E-08	1,87E-09
Organic emissions to air (group VOC)						
Anthracene	1,32E-20	2,79E-21	-	-	-	1,04E-20
Naphthalene	3,33E-14	3,31E-16	3,79E-15	3,13E-17	2,79E-14	1,31E-15
Pyrene	4,52E-18	8,14E-19	7,43E-19	2,28E-19	1,23E-18	1,51E-18
1,1,1-Trichloroethane	2,09E-15	1,73E-15	9,44E-17	8,02E-17	3,21E-16	-1,35E-16
2,4-Dichlorophenol	5,43E-14	2,53E-14	6,27E-15	2,12E-15	2,11E-14	-4,56E-16
2-Chlorotoluene	1,07E-15	5,48E-16	1,24E-16	5,92E-17	3,52E-16	-1,56E-17
Bromoxynil	4,43E-22	3,86E-22	9,07E-24	1,85E-24	4,58E-23	6,98E-25
Carbon tetrachloride (tetrachloromethane)	8,11E-10	6,28E-10	1,64E-10	1,30E-11	1,57E-11	-9,55E-12
Chloromethane (methyl chloride)	1,71E-12	1,41E-12	7,73E-14	6,57E-14	2,63E-13	-1,10E-13
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene)	1,60E-16	7,77E-17	1,26E-17	5,31E-18	6,58E-17	-1,16E-18
Dichloromethane (methylene chloride)	1,49E-12	1,24E-12	6,65E-14	5,32E-14	2,18E-13	-8,61E-14
Hexachlorobenzene (Perchlorobenzene)	4,71E-13	9,50E-14	2,88E-13	4,26E-14	3,88E-14	6,63E-15
Methyl bromide	2,31E-16	1,61E-16	1,08E-17	5,01E-18	5,66E-17	-2,24E-18
Pentachlorobenzene	3,59E-14	1,08E-15	2,13E-16	1,97E-14	3,46E-15	1,15E-14
Pentachlorophenol (PCP)	9,13E-11	6,44E-11	1,20E-11	3,27E-12	1,15E-11	9,77E-14
R 11 (trichlorofluoromethane)	1,13E-14	1,13E-14	5,41E-19	1,76E-19	1,68E-18	5,02E-20
R 12 (dichlorodifluoromethane)	1,91E-11	1,07E-11	4,80E-14	2,97E-14	8,47E-12	-1,05E-13
R 22 (chlorodifluoromethane)	2,94E-13	2,59E-13	1,54E-14	5,27E-15	1,47E-14	-6,97E-16
Tetrachloroethene (perchloroethylene)	7,89E-13	2,59E-13	1,42E-14	4,88E-13	4,83E-14	-2,01E-14
Trichloromethane (chloroform)	8,41E-12	8,22E-12	4,97E-14	3,82E-14	1,55E-13	-5,01E-14
Vinyl chloride (VCM; chloroethene)	1,62E-12	7,64E-13	1,50E-13	1,26E-13	6,56E-13	-7,45E-14

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
1-Methoxy-2-propanol	1,77E-22	1,77E-22	-	-	-	-
Acenaphthene	1,76E-15	9,83E-17	2,01E-16	6,01E-18	1,45E-15	4,12E-18
Acetaldehyde (Ethanal)	6,79E-11	3,06E-11	7,12E-12	2,34E-12	2,51E-11	2,73E-12
Acetone (dimethylcetone)	3,33E-12	8,31E-13	1,39E-13	4,42E-14	2,32E-12	-1,86E-15
Acetonitrile	1,68E-13	6,89E-14	1,96E-14	5,58E-15	7,57E-14	-1,15E-15
Acrolein	8,05E-09	2,41E-09	8,22E-10	2,83E-10	2,99E-09	1,55E-09
Acrylic acid	2,24E-14	8,11E-15	3,29E-15	5,96E-16	9,91E-15	4,56E-16
Acrylonitrile	9,28E-23	9,28E-23	-	-	-	-
Aniline	5,55E-15	2,01E-15	5,50E-16	2,13E-16	2,83E-15	-5,39E-17
Benzaldehyde	2,16E-13	7,07E-14	2,37E-14	8,63E-15	7,33E-14	3,98E-14
Benzene	3,38E-10	2,41E-10	3,92E-11	1,28E-11	4,63E-11	-1,36E-12
Biphenyl	6,51E-21	6,51E-21	-	-	-	-
Butadiene	9,70E-15	8,97E-17	2,37E-17	8,20E-18	3,49E-16	9,23E-15
Butanone (methyl ethyl ketone)	2,60E-14	9,42E-15	3,82E-15	6,76E-16	1,15E-14	5,29E-16
Caprolactam	1,54E-22	1,54E-22	-	-	-	-
Chloramine	3,52E-15	1,90E-15	2,92E-16	1,64E-16	1,20E-15	-3,08E-17
Cumene (isopropylbenzene)	2,19E-13	3,37E-14	6,39E-15	3,04E-14	1,81E-13	-3,17E-14
Cyclohexane (hexahydro benzene)	1,60E-21	1,55E-21	2,44E-23	1,92E-23	1,69E-23	-5,28E-24
Diethyl ether	2,48E-22	1,74E-22	3,27E-23	2,57E-23	2,26E-23	-7,06E-24
Ethyl benzene	1,28E-13	7,60E-14	1,17E-14	6,48E-15	3,23E-14	1,39E-15
Ethylene acetate (ethyl acetate)	1,51E-13	5,45E-14	2,22E-14	3,92E-15	6,71E-14	3,06E-15
Fluoranthene	6,77E-17	2,43E-18	2,04E-18	6,26E-19	3,37E-18	5,92E-17
Fluorene	2,44E-19	2,44E-19	-	-	-	-
Formaldehyde (methanal)	1,15E-10	7,68E-11	1,01E-11	5,15E-12	2,22E-11	8,27E-13
Furan	2,53E-10	1,04E-10	2,94E-11	8,39E-12	1,14E-10	-1,72E-12
Hexane (isomers)	1,52E-10	9,57E-11	1,64E-11	8,74E-12	3,64E-11	-4,86E-12
iso-Butanol	2,12E-17	5,91E-18	1,30E-18	5,18E-19	1,36E-17	-1,14E-19
meta-Cresol	1,63E-23	1,63E-23	-	-	-	-
Methanol	1,39E-11	1,22E-12	4,51E-12	1,38E-13	8,10E-12	-5,74E-14
Methyl isobutyl ketone	2,84E-20	2,51E-21	3,07E-22	2,78E-22	2,52E-20	1,76E-22
Methyl methacrylate (MMA)	1,01E-20	1,01E-20	-	-	-	-
Methyl tert-butylether	1,80E-14	4,74E-15	2,26E-15	4,63E-16	1,05E-14	8,81E-17
Nitrobenzene	4,51E-14	1,68E-14	4,47E-15	1,74E-15	2,25E-14	-4,38E-16
Phenol (hydroxy benzene)	5,63E-13	1,18E-13	1,62E-14	8,46E-15	4,52E-13	-3,22E-14
Propylene oxide	3,92E-09	8,41E-13	3,91E-09	9,78E-14	1,08E-12	6,93E-13
Styrene	3,37E-13	8,00E-14	3,84E-14	1,19E-14	1,38E-13	6,87E-14
Toluene (methyl benzene)	5,69E-11	4,01E-11	4,18E-12	2,26E-12	1,09E-11	-5,43E-13
Xylene (dimethyl benzene)	2,36E-10	1,35E-10	1,88E-11	1,15E-11	7,56E-11	-4,92E-12
Pesticides to air						

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
2,4-Dichlorophenoxyacetic acid (2,4-D)	3,05E-13	1,48E-13	4,28E-14	1,78E-14	1,00E-13	-4,25E-15
Acephate	5,27E-12	2,56E-12	7,40E-13	3,08E-13	1,73E-12	-7,35E-14
Atrazine	1,25E-14	6,08E-15	1,75E-15	7,30E-16	4,10E-15	-1,74E-16
Benomyl	6,53E-21	6,53E-21	-	-	-	-
Bentazone	1,40E-15	6,84E-16	1,97E-16	8,19E-17	4,61E-16	-1,95E-17
Carbaryl	2,41E-15	1,17E-15	3,39E-16	1,41E-16	7,92E-16	-3,36E-17
Carbofuran	7,93E-20	7,93E-20	-	-	-	-
Chlorpyriphos	4,64E-13	2,26E-13	6,51E-14	2,71E-14	1,52E-13	-6,46E-15
Cyfluthrin	1,71E-15	8,30E-16	2,40E-16	9,97E-17	5,61E-16	-2,38E-17
Cypermethrin	8,92E-25	8,92E-25	-	-	-	-
Deltamethrin	4,31E-18	4,31E-18	-	-	-	-
Dicamba	1,64E-15	7,99E-16	2,31E-16	9,59E-17	5,39E-16	-2,29E-17
Diflubenzuron	2,48E-16	1,21E-16	3,49E-17	1,45E-17	8,15E-17	-3,46E-18
Dimethoate	4,53E-24	4,53E-24	-	-	-	-
Ethephon	1,12E-22	9,75E-23	2,21E-24	4,52E-25	1,13E-23	1,66E-25
Fenvalerate	1,08E-23	1,08E-23	-	-	-	-
Fipronil	1,37E-28	1,37E-28	-	-	-	-
Glyphosate	2,04E-13	9,94E-14	2,87E-14	1,19E-14	6,71E-14	-2,85E-15
Imazethapyr	8,50E-16	4,14E-16	1,19E-16	4,97E-17	2,79E-16	-1,19E-17
Imidacloprid	2,04E-25	2,04E-25	-	-	-	-
Mancozeb	1,32E-18	1,32E-18	-	-	-	-
MCPA	1,12E-21	9,81E-22	2,24E-23	4,52E-24	1,09E-22	1,83E-24
Methomyl	1,74E-18	1,74E-18	1,50E-23	3,07E-24	7,71E-23	1,13E-24
Metolachlor	8,09E-15	3,94E-15	1,14E-15	4,73E-16	2,66E-15	-1,13E-16
Metribuzin	1,06E-14	5,17E-15	1,49E-15	6,22E-16	3,49E-15	-1,48E-16
Paraquat	2,30E-14	1,12E-14	3,23E-15	1,34E-15	7,54E-15	-3,20E-16
Parathion-methyl	1,73E-14	8,44E-15	2,44E-15	1,01E-15	5,69E-15	-2,42E-16
Pendimethalin	1,36E-14	6,61E-15	1,91E-15	7,94E-16	4,46E-15	-1,89E-16
Permethrin	8,68E-16	4,23E-16	1,22E-16	5,08E-17	2,85E-16	-1,21E-17
Propiconazole	2,57E-15	1,25E-15	3,61E-16	1,50E-16	8,44E-16	-3,58E-17
Quizalofop-ethyl	2,68E-15	1,30E-15	3,76E-16	1,56E-16	8,79E-16	-3,73E-17
Sethoxydim	8,77E-17	4,27E-17	1,23E-17	5,13E-18	2,88E-17	-1,22E-18
Tebuconazole	5,33E-24	4,65E-24	1,06E-25	2,17E-26	5,44E-25	7,97E-27
Terbufos	4,88E-27	4,88E-27	-	-	-	-
Thiodicarb	4,03E-16	1,96E-16	5,66E-17	2,35E-17	1,32E-16	-5,62E-18
Thiram	1,67E-18	1,67E-18	-	-	-	-
Trifluralin	3,76E-13	1,83E-13	5,29E-14	2,20E-14	1,24E-13	-5,25E-15
Long-term emissions to fresh water						
Antimony	4,12E-07	4,09E-08	1,23E-08	3,00E-08	6,72E-08	2,62E-07
Arsenic, ion	3,74E-05	1,46E-05	3,54E-06	7,44E-06	1,15E-05	2,55E-07
Barium	7,21E-07	5,02E-07	7,83E-08	5,25E-08	8,18E-08	7,09E-09
Beryllium	1,79E-09	9,71E-10	1,69E-10	2,16E-10	4,40E-10	-3,74E-12
Cadmium, ion	2,78E-07	5,09E-08	2,09E-08	6,57E-08	1,30E-07	1,08E-08

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Chromium (+VI)	4,66E-08	2,72E-08	9,25E-09	4,74E-09	8,76E-09	-3,43E-09
Copper	1,63E-07	6,19E-09	1,55E-09	1,85E-09	3,30E-08	1,20E-07
Lead	2,70E-07	3,20E-08	8,72E-09	1,71E-08	9,34E-08	1,19E-07
Mercury	7,07E-07	5,13E-07	8,76E-08	5,29E-08	6,97E-08	-1,57E-08
Molybdenum	9,01E-08	4,49E-08	9,04E-09	1,46E-08	2,17E-08	-2,62E-10
Nickel, ion	3,78E-08	2,65E-08	5,14E-09	3,00E-09	3,79E-09	-5,81E-10
Silver	3,17E-08	1,84E-09	9,15E-10	2,99E-09	4,84E-09	2,11E-08
Thallium	1,29E-07	4,36E-08	1,04E-08	2,76E-08	4,56E-08	1,61E-09
Vanadium, ion	5,78E-07	3,16E-07	5,47E-08	6,21E-08	1,56E-07	-1,07E-08
Zinc, ion	5,59E-05	1,91E-05	4,98E-06	1,14E-05	1,89E-05	1,47E-06
Heavy metals to fresh water						
Antimony	1,67E-07	1,16E-08	2,10E-09	1,25E-09	1,17E-08	1,41E-07
Arsenic	1,17E-17	1,17E-17	-	-	-	-
Arsenic (+V)	9,45E-06	6,77E-06	9,53E-07	1,04E-06	1,55E-06	-8,68E-07
Cadmium	1,98E-09	4,87E-10	3,63E-10	2,57E-10	7,07E-10	1,66E-10
Chromium	3,75E-13	3,75E-13	-	-	-	-
Chromium (+III)	8,47E-14	2,73E-14	1,26E-14	1,97E-15	4,32E-14	-3,66E-16
Chromium (+VI)	5,66E-09	2,39E-09	1,96E-09	6,19E-10	1,60E-09	-9,13E-10
Copper	4,77E-11	8,44E-12	3,54E-12	7,72E-12	2,81E-11	-1,17E-13
Lead	8,95E-09	2,67E-09	6,84E-10	3,48E-10	4,83E-09	4,14E-10
Mercury	8,62E-09	4,04E-09	2,53E-09	4,61E-10	1,39E-09	1,99E-10
Molybdenum	2,06E-08	1,51E-08	2,22E-09	1,63E-09	2,22E-09	-5,72E-10
Nickel	1,73E-10	9,03E-11	2,33E-11	1,32E-11	5,97E-11	-1,39E-11
Silver	8,29E-09	5,55E-09	5,04E-10	2,51E-10	2,07E-09	-8,48E-11
Thallium	1,19E-09	8,58E-10	9,67E-11	9,38E-11	1,48E-10	-2,84E-12
Vanadium	4,83E-09	3,26E-09	5,51E-10	4,12E-10	6,51E-10	-4,85E-11
Zinc	3,49E-07	1,02E-07	3,00E-08	8,69E-08	1,04E-07	2,59E-08
Inorganic emissions to fresh water						
Barium	3,45E-07	2,25E-07	2,17E-08	1,09E-08	8,89E-08	-1,89E-09
Beryllium	4,84E-12	2,74E-12	4,38E-13	5,82E-13	1,13E-12	-4,02E-14
Carbon disulphide	1,09E-11	1,13E-13	1,78E-14	2,56E-14	1,07E-11	-6,84E-15
Organic emissions to fresh water						
1,1,1-Trichloroethane	1,22E-25	8,58E-26	1,61E-26	1,27E-26	1,12E-26	-3,48E-27
1,2-Dibromoethane	-1,30E-28	-1,30E-28	-	-	-	-
2-Chlorotoluene	2,51E-15	1,30E-15	2,99E-16	1,46E-16	8,11E-16	-3,89E-17
Bromoxynil	2,39E-22	1,97E-22	7,84E-24	1,53E-24	3,24E-23	7,93E-25
Chlorobenzene	7,33E-12	7,03E-12	1,71E-13	2,22E-14	9,78E-14	4,20E-15
Chloromethane (methyl chloride)	-1,44E-21	-1,44E-21	-	-	-	-
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene)	2,53E-12	2,40E-12	6,95E-14	8,86E-15	4,55E-14	1,82E-15
Dichloromethane (methylene chloride)	6,96E-12	4,03E-12	6,11E-13	3,54E-13	1,86E-12	1,03E-13
Dichloropropane	-1,33E-28	-1,33E-28	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Pentachlorophenol (PCP)	9,40E-21	9,40E-21	-	-	-	-
Tetrachloroethene (perchloroethylene)	3,55E-24	3,55E-24	-	-	-	-
Trichloromethane (chloroform)	5,91E-15	5,06E-15	8,81E-17	4,01E-17	7,27E-16	-7,13E-18
Vinyl chloride (VCM; chloroethene)	2,26E-13	7,27E-14	1,52E-14	1,10E-14	1,29E-13	-2,23E-15
Acenaphthene	1,30E-14	5,79E-16	1,51E-15	5,47E-17	1,08E-14	3,26E-17
Acetonitrile	3,50E-17	2,07E-17	3,25E-18	1,26E-18	1,01E-17	-2,69E-19
Acrylonitrile	1,72E-23	1,72E-23	-	-	-	-
Aniline	5,10E-14	1,85E-14	5,06E-15	1,96E-15	2,60E-14	-4,96E-16
Anthracene	1,49E-15	2,12E-17	1,76E-16	1,45E-18	1,29E-15	8,55E-19
Benzene	1,10E-11	7,49E-12	4,38E-13	5,50E-13	2,81E-12	-3,38E-13
Ethyl benzene	5,13E-13	2,81E-13	4,27E-14	2,49E-14	1,50E-13	1,39E-14
Ethylene acetate (ethyl acetate)	2,28E-16	1,04E-17	3,57E-17	1,96E-18	1,81E-16	-9,17E-19
Fluoranthene	1,06E-12	9,79E-15	1,26E-13	1,04E-15	9,24E-13	6,11E-16
Formaldehyde (methanal)	1,08E-11	4,32E-13	4,48E-12	1,21E-13	5,85E-12	-8,75E-14
Hexane (isomers)	-6,25E-28	-6,25E-28	-	-	-	-
Methanol	6,23E-12	1,23E-14	5,71E-12	4,42E-15	5,06E-13	-2,74E-15
Methyl tert-butylether	2,08E-16	8,77E-17	3,71E-17	5,15E-18	7,91E-17	-1,60E-18
Naphthalene	5,01E-15	6,31E-16	5,23E-16	4,33E-18	3,85E-15	2,55E-18
Phenol (hydroxy benzene)	9,09E-12	4,05E-12	9,22E-13	3,57E-13	3,70E-12	5,27E-14
Propylene oxide	7,92E-09	1,63E-12	7,91E-09	1,89E-13	2,13E-12	1,40E-12
Pyrene	3,57E-13	3,29E-15	4,23E-14	3,50E-16	3,11E-13	2,06E-16
Toluene (methyl benzene)	1,38E-12	7,86E-13	1,10E-13	6,28E-14	3,95E-13	2,89E-14
Xylene (isomers; dimethyl benzene)	9,21E-13	5,14E-13	7,49E-14	4,33E-14	2,66E-13	2,21E-14
Acetaldehyde (Ethanal)	5,46E-11	3,65E-13	8,84E-12	2,39E-13	4,49E-11	2,55E-13
Acetone (dimethylcetone)	7,11E-16	4,53E-16	4,47E-17	2,18E-17	1,99E-16	-7,87E-18
Acrylic acid	1,52E-16	5,52E-17	2,24E-17	4,05E-18	6,75E-17	3,10E-18
Allyl chloride	9,27E-15	1,63E-15	3,79E-16	2,18E-16	6,23E-15	8,18E-16
Biphenyl	1,17E-32	1,17E-32	-	-	-	-
Chloramine	3,11E-14	1,68E-14	2,57E-15	1,45E-15	1,06E-14	-2,72E-16
Cumene (isopropylbenzene)	1,31E-12	2,00E-13	3,81E-14	1,82E-13	1,08E-12	-1,89E-13
iso-Butanol	8,68E-17	2,42E-17	5,31E-18	2,12E-18	5,56E-17	-4,66E-19
Methyl isobutyl ketone	8,61E-17	5,78E-17	5,10E-18	2,46E-18	2,17E-17	-9,42E-19
Nitrobenzene	1,96E-13	7,30E-14	1,94E-14	7,54E-15	9,77E-14	-1,90E-15
Other emissions to fresh water						
Atrazine	4,02E-19	2,44E-19	6,00E-20	2,78E-20	7,33E-20	-3,72E-21
Benomyl	1,81E-21	1,81E-21	-	-	-	-
Bentazone	9,25E-17	3,66E-17	1,24E-17	4,20E-18	4,02E-17	-8,76E-19
Carbaryl	5,98E-23	3,70E-23	8,61E-24	3,98E-24	1,07E-23	-5,26E-25
Carbofuran	1,33E-20	1,33E-20	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Cypermethrin	9,34E-26	9,34E-26	-	-	-	-
Deltamethrin	6,62E-19	6,62E-19	-	-	-	-
Dicamba	2,07E-20	1,26E-20	3,09E-21	1,43E-21	3,77E-21	-1,91E-22
Dimethoate	8,14E-25	8,14E-25	-	-	-	-
Ethephon	7,35E-24	6,42E-24	1,46E-25	2,98E-26	7,47E-25	1,09E-26
Fenvalerate	5,71E-24	5,71E-24	-	-	-	-
Fipronil	1,47E-28	1,47E-28	-	-	-	-
Glyphosate	2,90E-16	1,14E-16	3,92E-17	1,33E-17	1,27E-16	-2,76E-18
Imidacloprid	2,65E-26	2,65E-26	-	-	-	-
Mancozeb	6,18E-19	6,18E-19	-	-	-	-
MCPA	2,85E-21	2,46E-21	6,35E-23	1,28E-23	3,07E-22	5,23E-24
Methomyl	1,27E-19	1,27E-19	2,75E-25	5,62E-26	1,41E-24	2,07E-26
Metolachlor	1,38E-17	5,39E-18	1,86E-18	6,29E-19	6,01E-18	-1,31E-19
Parathion-methyl	1,98E-18	1,98E-18	-	-	-	-
Pendimethalin	8,00E-22	4,87E-22	1,20E-22	5,55E-23	1,46E-22	-7,40E-24
Propiconazole	8,25E-22	7,20E-22	1,64E-23	3,35E-24	8,41E-23	1,23E-24
Tebuconazole	1,25E-23	1,09E-23	2,49E-25	5,10E-26	1,28E-24	1,87E-26
Terbufos	8,14E-27	8,14E-27	-	-	-	-
Thiram	1,38E-18	1,38E-18	-	-	-	-
Trifluralin	3,38E-17	3,38E-17	-	-	-	-
Heavy metals to sea water						
Arsenic (+V)	4,11E-09	2,69E-10	7,01E-11	3,26E-09	4,85E-10	1,92E-11
Cadmium	7,54E-10	5,93E-12	1,19E-12	7,41E-10	5,85E-12	4,37E-13
Chromium	5,83E-15	5,83E-15	-	-	-	-
Chromium (+III)	1,61E-15	8,49E-16	1,44E-16	8,08E-17	4,94E-16	4,52E-17
Copper	5,78E-11	7,94E-14	2,51E-14	5,76E-11	8,87E-14	9,20E-15
Lead	2,95E-10	1,04E-10	1,90E-11	1,06E-10	6,12E-11	4,99E-12
Mercury	1,05E-09	7,55E-11	2,64E-11	7,19E-10	2,22E-10	8,10E-12
Molybdenum	1,32E-13	6,85E-14	1,18E-14	6,55E-15	4,11E-14	4,28E-15
Nickel	1,37E-11	2,03E-14	5,73E-15	1,37E-11	2,54E-14	2,74E-15
Silver	1,61E-12	8,68E-13	1,37E-13	8,08E-14	4,77E-13	4,85E-14
Vanadium	1,70E-12	8,89E-13	1,49E-13	8,33E-14	5,29E-13	5,02E-14
Zinc	5,54E-07	3,67E-08	7,65E-09	5,01E-07	9,35E-09	-5,09E-10
Inorganic emissions to sea water						
Barium	8,26E-11	4,45E-11	7,02E-12	4,13E-12	2,44E-11	2,48E-12
Beryllium	-1,69E-24	-1,69E-24	-	-	-	-
Organic emissions to sea water						
Tetrachloroethene (perchloroethylene)	2,75E-28	2,75E-28	-	-	-	-
Acenaphthene	5,73E-18	3,19E-18	4,69E-19	2,76E-19	1,63E-18	1,66E-19
Anthracene	2,52E-19	2,52E-19	-	-	-	-
Benzene	3,43E-14	1,86E-14	2,93E-15	1,72E-15	1,01E-14	1,01E-15
Ethyl benzene	1,02E-15	5,50E-16	8,67E-17	5,11E-17	3,02E-16	3,06E-17
Fluoranthene	2,98E-19	2,98E-19	-	-	-	-

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Hexane (isomers)	-2,03E-29	-2,03E-29	-	-	-	-
Methanol	2,42E-16	1,68E-16	3,37E-17	2,03E-17	2,80E-17	-8,28E-18
Methyl tert-butylether	1,20E-17	5,02E-18	2,14E-18	2,74E-19	4,63E-18	-9,34E-20
Phenol (hydroxy benzene)	4,37E-15	2,37E-15	3,72E-16	2,18E-16	1,29E-15	1,22E-16
Toluene (methyl benzene)	1,12E-14	5,93E-15	9,67E-16	5,57E-16	3,36E-15	3,43E-16
Xylene (isomers; dimethyl benzene)	7,45E-15	4,01E-15	6,38E-16	3,74E-16	2,20E-15	2,22E-16
Ethylene Glycol	2,36E-29	2,36E-29	-	-	-	-
Naphthalene	1,41E-17	1,41E-17	-	-	-	-
Other emissions to sea water						
Tributyltinoxide	2,33E-14	1,13E-14	3,38E-15	1,65E-15	9,10E-15	-2,14E-15
Heavy metals to agricultural soil						
Antimony	3,43E-14	1,98E-14	1,80E-15	5,01E-15	7,40E-15	2,87E-16
Arsenic	2,33E-08	1,94E-08	1,23E-09	7,79E-10	2,03E-09	-8,48E-11
Arsenic (+V)	7,34E-21	7,34E-21	-	-	-	-
Cadmium	8,76E-08	6,43E-08	8,33E-09	4,91E-09	1,05E-08	-3,72E-10
Chromium	5,60E-11	4,19E-11	5,44E-12	3,41E-12	5,56E-12	-2,58E-13
Chromium (+III)	9,55E-18	9,55E-18	-	-	-	-
Copper	4,02E-10	3,03E-10	3,03E-11	2,57E-11	4,51E-11	-1,84E-12
Lead	8,95E-08	6,34E-08	8,46E-09	6,14E-09	1,19E-08	-3,99E-10
Mercury	5,11E-08	1,82E-08	3,44E-09	4,00E-09	2,58E-08	-3,38E-10
Molybdenum	1,52E-09	6,20E-10	8,28E-11	6,19E-11	7,62E-10	-4,00E-12
Nickel	1,59E-11	1,16E-11	1,47E-12	9,74E-13	2,00E-12	-6,94E-14
Silver	1,11E-17	3,71E-18	6,90E-19	4,98E-18	1,48E-18	2,32E-19
Vanadium	2,44E-10	1,90E-10	2,44E-11	1,43E-11	1,65E-11	-1,12E-12
Zinc	3,54E-06	2,59E-06	3,36E-07	2,22E-07	4,11E-07	-1,68E-08
Inorganic emissions to agricultural soil						
Barium	5,83E-13	3,37E-13	3,52E-14	3,93E-14	1,40E-13	3,14E-14
Organic emissions to agricultural soil						
Bromoxynil	1,38E-16	1,18E-16	4,00E-18	1,21E-18	1,47E-17	9,31E-20
Mepiquat chloride	2,02E-21	3,25E-22	2,70E-22	2,31E-23	1,40E-21	-1,85E-24
Other emissions to agricultural soil						
2,4-Dichlorophenoxyacetic acid (2,4-D)	1,41E-11	5,88E-12	1,70E-12	5,26E-13	6,09E-12	-1,08E-13
Acephate	1,76E-11	2,83E-12	2,37E-12	2,11E-13	1,22E-11	-1,86E-14
Aldicarb	7,43E-12	1,17E-12	9,99E-13	8,54E-14	5,18E-12	-6,90E-15
Aldrin	6,14E-10	5,38E-10	1,52E-11	9,84E-12	5,30E-11	-1,90E-12
Asulam	2,93E-21	1,14E-21	4,22E-22	7,82E-23	1,24E-21	5,57E-23
Atrazine	9,16E-12	3,31E-12	9,33E-14	6,11E-14	5,71E-12	-1,46E-14
Azodrin	2,17E-11	8,36E-12	2,93E-12	9,73E-13	9,65E-12	-2,00E-13
Benomyl	2,23E-17	1,35E-18	3,01E-18	1,29E-19	1,79E-17	-3,23E-20
Bensulfuron methyl ester	1,49E-17	1,30E-17	2,96E-19	6,04E-20	1,51E-18	2,22E-20
Bentazone	1,49E-15	6,58E-16	1,88E-16	6,48E-17	5,97E-16	-1,34E-17
Bifenthrin	1,92E-18	1,18E-18	2,87E-19	1,35E-19	3,38E-19	-1,92E-20

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Bitertanol	5,13E-19	4,47E-19	1,02E-20	2,08E-21	5,23E-20	7,66E-22
Carbaryl	5,61E-16	3,94E-16	7,71E-17	4,48E-17	5,67E-17	-1,23E-17
Carbendazim	2,30E-14	1,44E-14	3,36E-15	1,80E-15	3,89E-15	-5,02E-16
Carbofuran	3,24E-11	1,97E-12	4,37E-12	1,89E-13	2,60E-11	-4,75E-14
Chlormequat	4,96E-15	3,55E-15	7,02E-16	4,20E-16	4,03E-16	-1,16E-16
Chlorothalonil	5,44E-12	8,23E-14	1,47E-14	5,04E-14	5,29E-12	-6,99E-15
Chlorpyriphos	4,42E-12	7,69E-13	5,94E-13	6,09E-14	3,00E-12	-6,69E-15
Chlorsulfuron	4,04E-18	3,53E-18	8,04E-20	1,64E-20	4,12E-19	6,04E-21
Cyfluthrin	1,67E-16	2,81E-17	2,25E-17	2,17E-18	1,15E-16	-2,21E-19
Cypermethrin	4,53E-13	5,38E-14	5,73E-14	6,34E-15	3,37E-13	-1,37E-15
Deltamethrin	3,54E-16	2,50E-16	5,22E-17	3,13E-17	2,84E-17	-8,72E-18
Dicamba	2,83E-16	2,21E-16	1,76E-17	8,22E-18	3,71E-17	-1,37E-18
Dicrotophos	8,52E-14	1,34E-14	1,15E-14	9,80E-16	5,94E-14	-7,92E-17
Diflubenzuron	9,91E-13	3,82E-13	1,34E-13	4,44E-14	4,41E-13	-9,12E-15
Dimethoate	1,97E-16	1,71E-16	4,01E-18	8,17E-19	2,03E-17	3,08E-19
Dithianon	1,22E-18	1,06E-18	2,49E-20	5,08E-21	1,26E-19	1,92E-21
Diuron	1,14E-12	1,01E-12	2,80E-14	1,69E-14	8,36E-14	-2,95E-15
Endosulfan	1,18E-12	4,54E-13	1,59E-13	5,28E-14	5,24E-13	-1,08E-14
Endothall	1,14E-16	8,07E-17	1,68E-17	1,01E-17	9,15E-18	-2,81E-18
Ethephon	5,52E-14	9,81E-15	7,25E-15	6,24E-16	3,76E-14	-4,75E-17
Fenbuconazole	2,43E-20	2,12E-20	4,96E-22	1,01E-22	2,51E-21	3,81E-23
Fipronil	7,70E-13	1,21E-13	1,04E-13	8,86E-15	5,37E-13	-7,17E-16
Glyphosate	1,35E-12	1,55E-13	1,44E-13	9,84E-15	1,04E-12	-1,69E-15
Imazethapyr	7,69E-17	3,03E-17	1,04E-17	3,54E-18	3,34E-17	-7,41E-19
Imidacloprid	6,07E-15	9,57E-16	8,16E-16	6,98E-17	4,23E-15	-5,65E-18
Iprodione	2,22E-13	1,57E-13	3,28E-14	1,97E-14	1,78E-14	-5,49E-15
Kresoxim-methyl	3,42E-20	2,91E-20	1,05E-21	3,32E-22	3,64E-21	1,20E-23
Linuron	1,15E-11	8,92E-12	5,34E-13	2,49E-13	1,81E-12	-4,92E-14
Malathion	1,22E-15	7,53E-17	1,64E-16	7,25E-18	9,72E-16	-1,82E-18
Mancozeb	1,74E-12	2,64E-14	4,69E-15	1,61E-14	1,70E-12	-2,24E-15
MCPA	1,61E-14	1,40E-14	3,20E-16	6,53E-17	1,64E-15	2,40E-17
MCPB	4,23E-19	1,66E-19	6,03E-20	1,12E-20	1,77E-19	7,96E-21
Metalaxyl	2,15E-15	1,30E-16	2,89E-16	1,24E-17	1,72E-15	-3,11E-18
Methomyl	9,32E-22	8,13E-22	1,85E-23	3,79E-24	9,50E-23	1,39E-24
Metolachlor	1,91E-12	3,00E-13	1,04E-13	3,49E-14	1,48E-12	-7,79E-15
Metribuzin	3,57E-13	1,92E-14	5,88E-15	4,63E-15	3,28E-13	-7,56E-16
Metsulfuron-methyl	9,87E-15	1,92E-15	1,33E-15	2,16E-16	6,45E-15	-4,58E-17
Molinate	1,06E-13	9,23E-14	2,10E-15	4,30E-16	1,08E-14	1,58E-16
Napropamide	1,36E-13	1,01E-13	2,10E-14	1,26E-14	5,30E-15	-3,51E-15
Paraquat	9,00E-17	8,14E-18	1,21E-17	7,76E-19	6,91E-17	-1,68E-19
Parathion-ethyl	6,09E-15	4,63E-15	6,51E-16	3,88E-16	5,42E-16	-1,13E-16
Parathion-methyl	2,18E-16	1,06E-16	3,06E-17	1,27E-17	7,16E-17	-3,04E-18
Pendimethalin	6,64E-15	2,37E-15	8,92E-16	2,63E-16	3,18E-15	-5,30E-17

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Permethrin	2,66E-18	1,31E-18	3,74E-19	1,57E-19	8,56E-19	-3,66E-20
Phenmedipham	2,01E-19	1,28E-19	3,02E-20	1,49E-20	3,05E-20	-2,66E-21
Picloram	3,17E-19	2,76E-19	6,30E-21	1,29E-21	3,23E-20	4,73E-22
Pirimicarb	8,35E-15	9,10E-17	9,90E-16	9,03E-18	7,25E-15	4,46E-18
Prochloraz	1,16E-15	1,01E-15	2,33E-17	4,76E-18	1,19E-16	1,77E-18
Procymidone	3,61E-15	2,56E-15	5,33E-16	3,20E-16	2,90E-16	-8,91E-17
Profenofos	8,38E-14	1,32E-14	1,13E-14	9,64E-16	5,84E-14	-7,79E-17
Prometryne	1,05E-15	1,65E-16	1,41E-16	1,21E-17	7,31E-16	-9,75E-19
Propanil	1,65E-14	1,44E-14	3,28E-16	6,70E-17	1,68E-15	2,46E-17
Propiconazole	1,19E-16	9,16E-17	6,19E-18	2,21E-18	1,93E-17	-3,10E-19
Quizalofop-ethyl	2,57E-15	1,82E-15	3,80E-16	2,27E-16	2,12E-16	-6,33E-17
Sethoxydim	6,46E-16	4,57E-16	9,54E-17	5,72E-17	5,25E-17	-1,59E-17
Simazine	5,33E-16	3,27E-16	7,97E-17	3,75E-17	9,37E-17	-5,33E-18
Tebuconazole	3,41E-14	2,42E-14	5,03E-15	3,02E-15	2,74E-15	-8,41E-16
Teflubenzuron	1,79E-12	2,71E-14	4,82E-15	1,66E-14	1,74E-12	-2,30E-15
Terbufos	1,13E-13	9,41E-14	6,13E-15	3,23E-15	1,05E-14	-5,01E-16
Thifensulfuron methyl	8,15E-17	5,37E-17	7,06E-18	2,78E-18	1,85E-17	-5,75E-19
Thiobencarb	1,71E-15	1,49E-15	3,40E-17	6,95E-18	1,74E-16	2,56E-18
Thiodicarb	5,95E-18	2,89E-18	8,36E-19	3,48E-19	1,95E-18	-8,29E-20
Thiram	8,61E-15	5,20E-16	1,16E-15	4,98E-17	6,90E-15	-1,25E-17
Triadimenol	6,03E-18	5,26E-18	1,22E-19	2,49E-20	6,20E-19	9,27E-21
Triallate	4,30E-17	3,76E-17	8,56E-19	1,75E-19	4,39E-18	6,43E-20
Triasulfuron	1,10E-16	9,62E-17	2,19E-18	4,48E-19	1,12E-17	1,65E-19
Tribenuron methyl	3,60E-17	2,59E-17	2,41E-18	9,12E-19	6,85E-18	-1,64E-19
Tribufos	2,86E-14	4,51E-15	3,85E-15	3,29E-16	2,00E-14	-2,66E-17
Trifluralin	2,48E-12	1,75E-12	3,75E-13	2,19E-13	1,90E-13	-6,06E-14
Vinclozolin	1,64E-14	1,16E-14	2,42E-15	1,45E-15	1,32E-15	-4,05E-16
Heavy metals to industrial soil						
Antimony	2,15E-12	3,50E-13	2,19E-13	6,63E-14	8,20E-13	6,92E-13
Arsenic	3,00E-09	1,67E-09	2,84E-10	1,57E-10	7,56E-10	1,36E-10
Arsenic (+V)	5,90E-17	5,90E-17	-	-	-	-
Cadmium	6,80E-12	1,38E-12	6,83E-13	2,39E-13	2,54E-12	1,95E-12
Chromium	1,47E-11	8,48E-12	1,38E-12	7,79E-13	3,60E-12	4,40E-13
Chromium (+III)	1,87E-24	1,87E-24	-	-	-	-
Chromium (+VI)	4,29E-10	2,89E-10	6,95E-11	4,45E-11	3,94E-11	-1,36E-11
Copper	1,06E-11	6,92E-12	1,70E-12	1,08E-12	1,14E-12	-1,79E-13
Lead	8,51E-11	1,78E-11	8,53E-12	3,06E-12	3,17E-11	2,40E-11
Mercury	7,20E-12	3,65E-12	6,43E-13	4,99E-13	2,17E-12	2,32E-13
Molybdenum	6,33E-13	1,03E-13	6,45E-14	1,95E-14	2,42E-13	2,04E-13
Nickel	2,57E-13	6,26E-14	2,54E-14	1,02E-14	9,40E-14	6,47E-14
Silver	1,08E-13	1,77E-14	1,11E-14	3,35E-15	4,14E-14	3,50E-14
Vanadium	5,89E-13	9,60E-14	6,01E-14	1,82E-14	2,25E-13	1,90E-13
Zinc	3,61E-08	8,10E-09	3,63E-09	1,23E-09	1,31E-08	9,95E-09

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Inorganic emissions to industrial soil						
Barium	1,13E-08	6,81E-09	1,06E-09	6,15E-10	2,69E-09	1,50E-10
Beryllium	1,29E-24	1,29E-24	-	-	-	-
Organic emissions to industrial soil						
Methanol	3,92E-23	3,92E-23	-	-	-	-
Pentachlorophenol (PCP)	5,11E-16	3,26E-16	8,16E-17	4,73E-17	7,01E-17	-1,40E-17
Other emissions to industrial soil						
Glyphosate	1,56E-13	9,37E-14	1,71E-14	7,70E-15	3,96E-14	-2,20E-15

Table C.9: Ozone depletion midpoint (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in kg CFC-11 equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Other emissions to industrial soil	2,87E-09	1,38E-09	2,53E-10	1,87E-10	1,16E-09	-1,04E-10
Organic emissions to air						
1,1,1-Trichloroethane	1,02E-08	7,48E-09	5,92E-10	8,45E-10	2,17E-09	-9,11E-10
Carbon tetrachloride (tetrachloromethane)	3,16E-06	2,15E-06	7,88E-07	1,96E-07	7,41E-08	-4,50E-08
Chlorinated hydrocarbons (unspecified)	1,07E-06	7,67E-09	2,14E-09	2,05E-09	5,66E-07	4,94E-07
Chloromethane (methyl chloride)	4,49E-08	3,30E-08	2,61E-09	3,73E-09	9,60E-09	-4,02E-09
Halon (1211)	2,47E-06	1,06E-06	5,70E-07	3,86E-07	6,13E-07	-1,55E-07
Halon (1301)	6,26E-06	2,59E-06	6,14E-07	5,61E-07	2,33E-06	1,74E-07
Hydrocarbons, chloro-/fluoro-	4,45E-19	4,45E-19	-	-	-	-
Hydrocarbons, halogenated	4,60E-20	4,60E-20	-	-	-	-
Methyl bromide	7,31E-13	4,26E-13	4,20E-14	4,66E-14	2,25E-13	-8,90E-15
R 11 (trichlorofluoromethane)	4,70E-09	4,70E-09	3,32E-13	5,21E-13	9,36E-13	2,80E-14
R 113 (trichlorotrifluoroethane)	3,52E-07	1,62E-07	9,29E-08	5,92E-08	4,37E-08	-5,35E-09
R 114 (dichlorotetrafluoroethane)	3,93E-06	1,45E-06	1,30E-06	8,07E-07	4,42E-07	-6,93E-08
R 12 (dichlorodifluoromethane)	7,04E-07	3,38E-07	1,79E-09	1,61E-09	3,67E-07	-4,55E-09
R 124 (chlorotetrafluoroethane)	7,05E-09	3,24E-09	1,86E-09	1,18E-09	8,73E-10	-1,07E-10
R 22 (chlorodifluoromethane)	1,16E-06	9,74E-07	8,06E-08	3,25E-08	7,98E-08	-3,79E-09

Table C.10: Acidification midpoint (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in mole of H+ equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Ammonia	1,74E-05	6,46E-08	1,82E-08	2,74E-08	1,73E-05	-5,59E-09
Nitrogen oxides	6,44E-07	2,38E-09	6,72E-10	1,01E-09	6,40E-07	-2,06E-10
Inorganic emissions to air						
Ammonia	4,08E-02	7,85E-03	3,88E-03	1,24E-02	1,75E-02	-8,50E-04
Nitrogen dioxide	3,39E-07	3,39E-07	-	-	-	-
Nitrogen monoxide	6,88E-06	6,88E-06	-	-	-	-
Nitrogen oxides	3,62E-01	1,77E-01	3,85E-02	4,25E-02	1,20E-01	-1,51E-02
Sulphur dioxide	1,13E+00	5,80E-01	1,32E-01	1,01E-01	3,76E-01	-6,22E-02
Sulphur oxides	2,86E-04	6,88E-07	2,12E-07	1,85E-07	2,85E-04	-6,63E-08
Sulphur trioxide	6,99E-08	1,91E-08	8,73E-09	3,21E-09	3,86E-08	1,86E-10

Table C.11: Eutrophication marine midpoint (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in kg N equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Ammonia	5,31E-07	1,97E-09	5,54E-10	8,33E-10	5,28E-07	-1,70E-10
Nitrate	1,15E-07	4,33E-08	3,72E-08	2,31E-08	1,29E-08	-1,98E-09
Nitrogen oxides	3,38E-07	1,25E-09	3,53E-10	5,31E-10	3,36E-07	-1,08E-10
Inorganic emissions to air						
Ammonia	1,24E-03	2,39E-04	1,18E-04	3,77E-04	5,34E-04	-2,59E-05
Ammonium	1,07E-14	1,07E-14	-	-	-	-
Nitrate	1,58E-07	2,66E-08	2,60E-08	1,33E-08	5,25E-08	3,99E-08
Nitrogen dioxide	1,78E-07	1,78E-07	-	-	-	-
Nitrogen monoxide	3,63E-06	3,63E-06	-	-	-	-
Nitrogen oxides	1,90E-01	9,28E-02	2,02E-02	2,23E-02	6,29E-02	-7,96E-03
Long-term emissions to fresh water						
Ammonium, ion	1,35E-03	9,03E-06	3,88E-06	4,46E-06	1,35E-03	-1,73E-05
Nitrate	1,88E-02	1,22E-02	4,57E-03	3,50E-03	5,74E-03	-7,16E-03
Nitrite	2,86E-05	1,92E-07	8,26E-08	9,51E-08	2,86E-05	-3,69E-07
Nitrogen organic bound	2,83E-03	1,90E-05	8,14E-06	9,37E-06	2,83E-03	-3,64E-05
Inorganic emissions to fresh water						
Ammonia	1,53E-10	1,53E-10	-	-	-	-
Ammonium / ammonia	9,43E-04	1,98E-04	7,93E-05	1,33E-04	1,13E-03	-5,99E-04
Nitrate	2,83E-03	7,22E-04	4,48E-04	3,07E-04	4,75E-03	-3,39E-03
Nitrite	1,00E-04	1,85E-06	7,90E-07	4,65E-07	9,71E-05	-7,23E-08
Nitrogen	1,65E-03	7,89E-04	9,71E-05	1,91E-04	5,90E-04	-1,39E-05
Nitrogen (as total N)	1,04E-12	1,04E-12	-	-	-	-
Nitrogen organic bound	5,11E-04	2,83E-05	5,85E-05	2,25E-05	3,58E-04	4,34E-05

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Inorganic emissions to sea water						
Ammonia	-1,72E-19	-1,72E-19	-	-	-	-
Ammonium / ammonia	1,21E-05	3,77E-06	1,44E-06	1,26E-06	4,71E-06	8,86E-07
Nitrate	1,83E-05	7,21E-06	4,17E-06	2,83E-06	3,96E-06	7,59E-08
Nitrate (as total N)	7,90E-20	7,90E-20	-	-	-	-
Nitrite	3,32E-07	1,40E-07	9,67E-08	6,17E-08	3,83E-08	-5,43E-09
Nitrogen	4,15E-07	1,20E-07	1,20E-07	7,75E-08	1,04E-07	-6,36E-09
Nitrogen (as total N)	1,21E-20	1,21E-20	-	-	-	-
Nitrogen organic bound	2,90E-05	8,45E-06	3,62E-06	3,15E-06	1,10E-05	2,75E-06

Table C.12: Eutrophication freshwater midpoint (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in kg P equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to fresh water						
Phosphate	1,10E-01	5,20E-02	1,92E-02	1,92E-02	2,33E-02	-4,05E-03
Inorganic emissions to fresh water						
Phosphate	2,41E-02	6,83E-03	3,08E-03	6,12E-03	8,20E-03	-1,31E-04
Phosphorus	1,28E-04	5,50E-06	5,14E-06	1,17E-05	1,18E-04	-1,17E-05
Inorganic emissions to sea water						
Phosphorus	1,35E-206	4,65E-207	1,55E-207	1,35E-207	5,43E-207	5,60E-208
Inorganic emissions to agriculture soil						
Phosphorus	1,91E-04	1,03E-04	3,74E-05	2,36E-05	2,93E-05	-2,00E-06
Inorganic emissions to industrial soil						
Phosphorus	1,62E-05	6,70E-06	2,00E-06	1,67E-06	5,50E-06	2,87E-07

Table C.13: Eutrophication terrestrial midpoint (v1.09) of one mc-Si PV-module (60 6-inch solar cells) in mole of N equivalents

Flow	NET RESULT	Crystal-lization	Wafering	Cell pro-cessing	Module assembly	Module disassembly
Long-term emissions to air						
Ammonia	7,78E-05	2,88E-07	8,12E-08	1,22E-07	7,73E-05	-2,49E-08
Nitrate	1,29E-05	4,89E-06	4,19E-06	2,61E-06	1,46E-06	-2,24E-07
Nitrogen oxides	3,71E-06	1,37E-08	3,87E-09	5,81E-09	3,68E-06	-1,19E-09
Inorganic emissions to air						
Ammonia	1,82E-01	3,50E-02	1,73E-02	5,52E-02	7,82E-02	-3,79E-03
Ammonium	1,56E-12	1,56E-12	-	-	-	-
Nitrate	1,79E-05	3,00E-06	2,93E-06	1,50E-06	5,93E-06	4,51E-06
Nitrogen dioxide	1,95E-06	1,95E-06	-	-	-	-
Nitrogen monoxide	3,98E-05	3,98E-05	-	-	-	-
Nitrogen oxides	2,08E+00	1,02E+00	2,21E-01	2,45E-01	6,89E-01	-8,72E-02