3 Methodological Bases

3.1 Ecological Scarcity Method

A detailed description of the method with explanations regarding the calculations can be found in (Frischknecht *et al*. 2013) and (Ahbe *et al*. 1990, 2014) as well as in chapter 7.

3.1.1 How does the ESM fit to the Phases of the ISO Standard?

According to ISO standards 14040:2006 and 14044:2006, an environmental impact assessment is divided into four phases:

1) Goal and scope definition
2) Life cycle inventory analysis
3) Impact assessment
4) Interpretation

Using these ISO phases as a basis, the ESM, in accordance with its objectives, involves a method for impact assessment and interpretation once a life cycle inventory analysis has been correctly drawn up. The latter, together with a correct scope definetion, have already been described in detail in the relevant literature (cf. Frischknecht *et al*., 2013, ISO 2006).

3.1.2 What are the Elements of the ESM?

The Ecological Scarcity Method essentially consists of three elements:

1) the assessment and aggregation algorithm as calculation specification (always remains the same),
2) the data set for the target country (in this case the EU), consisting of the selection of environmental impacts to be taken into consideration with the associated current impact values and the quantitative target environmental impacts which are described by the environmental authorities and should, if possible, be outperformed,
3) the life cycle inventories, for instance of the company's site or processes under investigation, which are to be assessed.

3.2 Basic Principle

3.2.1 How can the ESM be applied?

The ESM can be applied anywhere in which different environmental impacts need to be meaningfully assessed and compared with one another. One possible focus in the

S. Ahbe et al., *The Ecological Scarcity Method for the European Union*,
AutoUni – Schriftenreihe 105, https://doi.org/10.1007/978-3-658-19506-9_3

corporate field is the assessment of manufacturing sites or of comparable process steps which need to have their environmental impact reduced. Another widespread application is the analysis of different possible manufacturing scenarios with corresponding derivation of achievable environmental targets.

The internal cohesion between these forms of assessment is that, for instance, a production site may be viewed as an aggregate of the processes that take place on site and the assessment of these processes is conducted within one plant (see Figure 2). Further applications can be found in Frischknecht *et al*. 2013.

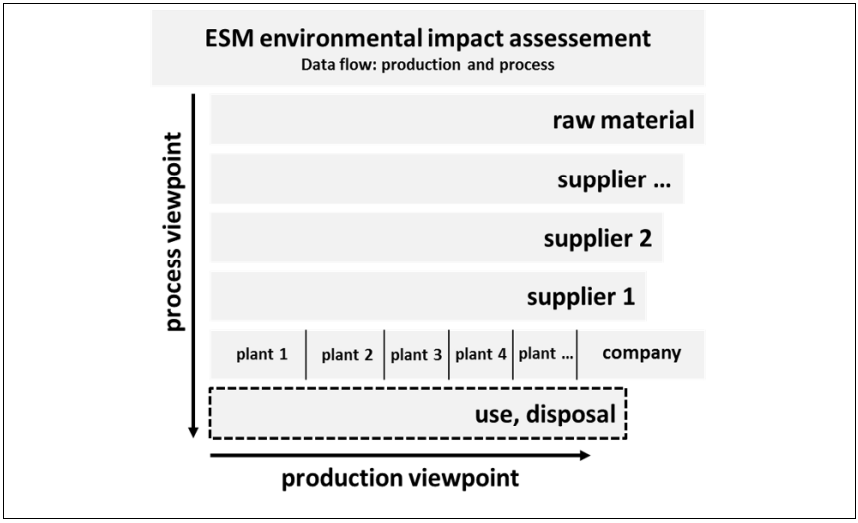

Figure 2: Data flow in ESM environmental impact assessment

3.2.2 Which Requirement apply to the ESM and its underlying Data?

In environmental impact assessments, particularly if carried out for the purpose of corporate presentation, care must be taken to avoid creating any impression of self-interested bias in the results. Years of prior industrial experience with handling environmental impact assessments led, from the initial design stage for the ESM back in 1990, to specification of the following requirements that are indispensable for achieving the desired transparency and that also apply to the treatment of data in the present paper:

Completeness

The assessment must include all substantial environmental impacts of the process or site under consideration.

Public goals

The assessment must be made on the basis of the published environmental goals of the relevant national authority and, for reasons of neutrality and traceability, these must be used as benchmarks for the assessment.

Independence of the author of the assessment

The results of the environmental impact assessment must be independent of the author of the assessment (as in the drawing up of business accounts).

Unambiguous statement

When making comparisons, the statements made in the assessment must be unambiguous and be usable and reproducible in business practice.

Systematic aggregation

Aggregation of the assessment result to form an overall statement must be systematic and must not be left to the discretion of a (subjective) user.

3.2.3 Coordination with Environmental Authorities

One essential principle of the ESM is to coordinate data sets with the relevant highest environmental authorities with responsibility for a particular geographic or policy area. This ensures that both the actual state of the environment and the desirable nominal state concur with any existing determinations made by the regulatory authorities, thereby avoiding any bias in terms of viewpoint or assessment by the author of the environmental impact assessments. Another significant reason for this is that these assessment data should be identical for all parties drawing up environmental impact assessments. Having an identical and uniform basis for assessment is an absolutely necessary prerequisite for communicating the results to third parties.

3.2.4 Requirements for European Eco Factors

The Eco Factors for each environmental impact are calculated in accordance with the method's calculation specification essentially from the two loads or consumption variables that substantially determine the particular environmental situation:

- current annual flow (or consumption), synonymous with current annual load,
- critical annual flow (or consumption), synonymous with a target annual load, exceeding which can no longer be considered acceptable.

Current flow can be determined from previous surveys and statistics compiled to describe the actual state of the environment with regard to the particular impacts under consideration in the country in question.

Critical flow, on the other hand, can only be determined once a prior environmental policy decision has been made defining the 'just about acceptable' state of the environ-

ment. By definition, this is a per impact environmental objective which is articulated at European Union level by the relevant highest authorities and implemented in the respective countries in the context of plans of action. The administrative body with competence for setting environmental targets is the European Commission with the relevant Directorates-General as the executive of the EU, together with their relevant institutes and subordinate authorities, the most important of which are listed below:

European Environment Agency in Copenhagen

In line with its remit, the European Environment Agency (EEA) in Copenhagen, Denmark, plays a prominent role in the present case. The purpose of the EEA is, in its own words (EEA 2009):

> "The task of our agency, which has some 130 staff and an annual budget of €40 million, is to contribute to shaping European and national policy by providing independent information and assessments on environmental issues. Our work focuses on the following areas:
>
> – state of the environment;
> – current developments, including impact of economic and social factors;
> – policy strategies and their effectiveness;
> – possible future trends and problems."

The European Environment Agency is thus a key interface between the environmental authorities of each EU member state, acting as a coordinating body for the individual countries' environment status reports and, in this role, also supplying neutral environmental information to interested parties. The EEA supplied the basic data for the present study.

Institute for Prospective Technological Studies (IPTS) in Sevilla

IPTS in Sevilla, Spain, is part of the Joint Research Center of the European Commission. It concentrates on "best-practise" questions in the field of technology as well as on possible political measures for a target-oriented controlling of corresponding technological developments. With members of IPTS conversations were hold and informations were exchanged in this study.

Institute for Environment and Sustainability (IES) in Ispra

IES in Ispra, Italy, is likewise part of the European Commission Joint Research Centre. Its main mission is to research methods for recording environmental impacts and their consequences. Its activities therefore focus on the possibilities for using environment-related data and assessment methods. IES is mentioned for the sake of completeness, but had no direct influence on the content and course of the present study, since the assessment method itself was not at issue but instead the transposition of the method to other geographic regions.

3.3 Method

3.3.1 Requirements for European Eco Factors

The ESM enables comparing different environmental impacts with one another and to convert them into a single aggregated value. In simple terms, the aggregation mechanism states the “degree of undesirability” of an environmental impact. This is characterised by the ratio of the current state of the environment to the desired mitigation target, i.e. the scarcity situation. A level of undesirability exists for each and every environmental impact in a given region or country, making this a criterion common to all impacts that is sufficiently meaningful for the purpose of aggregation.

3.3.2 What further Options are there for Applying the ESM?

Because the individual environmental impacts are directly comparable, the corresponding eco-points (EP) can serve as a unit of measurement for environmental impacts and be used in various forms for the findings of the assessment (see data section for more details about the calculation formula). Accordingly, such direct comparisons may be used, for example:

1) to rank different investment options,
2) to draw up environmental budgets, for instance per site, per sector or department, or
3) to determine environmental impact, for instance per tonne of manufactured product, per unit or the like, and
4) to define measures to maximise environmental mitigation within a specified period or financial budget and
5) for further *ad hoc* purposes.
6) Financial management accounting can provide a point of reference for the basic structure of possible assessment approaches and the use of eco-points.

3.3.3 How can Traceability be communicated?

The traceability of environmental impact assessments is of vital significance especially when communicating with third parties such as clients, competitors, industry associations, authorities, auditors etc.. Were any doubts arise in this connection, the assessment result would be considerably devalued and its suitability may be as a basis for decision making called into question. To ensure a high level of reliability, the assessment result must be free of subjective considerations on the part of the assessor, since other assessors would otherwise come to different assessment results. It would be counterproductive for business decision making if environmental decisions could be undermined in this respect. The logical comparison is with drawing up a corporate balance sheet: the balance sheet total must be totally independent of the person drawing it up, if banks, creditors and investors are to be able to rely on a disinterested, neutral picture of a company's current financial circumstances.

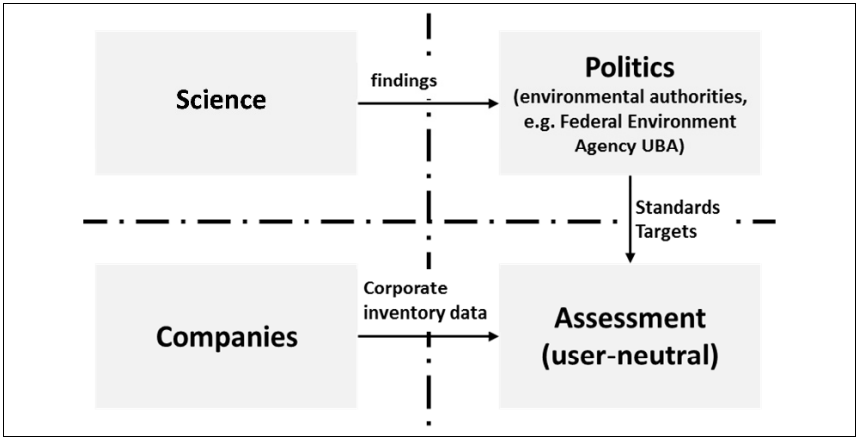

Figure 3: "Separation of powers" in the ESM, taking Germany as an example

Figure 3 shows how bias and arbitrariness are largely eliminated from the assessment result by applying a "separation of powers" in the ESM.

The essential factor is that there is a substantive and personal separation not only between obtaining the scientific findings on the one hand and the setting of standards and targets by the environmental authorities on the other, but also from the company which, while indeed generating and collecting environmentally relevant life cycle inventory data arising from its business activities, has no influence that could affect the assessment on the first two processes and so cannot influence the result by selecting the assessment parameters. Third parties would doubtless suspect bias if the company drawing up the assessment also wished to define the problematic environmental impacts to be assessed and quite possibly the associated environmental targets as well.

3.3.4 What Transparency Rules need to be observed?

One significant characteristic of the ESM is that the assessment result does not depend on the particular assessor, providing that some important rules are observed:

1) Role of the authorities: the data sets used for the environmental impact assessments have a decisive influence on the assessment results. It is therefore crucial for reliable communication both within and outside a company that the basis for assessment is free of any possible self-interest on the part of the company. This is ensured by using the targets officially set by the highest environmental authorities for determining ecological scarcity values. This avoids any impairment of the credibility of the assessment result due to suspected bias on the part of the assessor.

2) Statement of sources: when environmental data are used, it must always be evident which data have been used and where they come from. The data set used (for EU,

Germany, Switzerland etc.) must always be clearly stated in the assessment. The data sets for different geographic regions are not interchangeable, since both the respective national loads and the corresponding environmental targets differ from one country to the next. Within an assessment, the data set used must be clearly stated and always used in any direct comparison.

3) Date of publication of the data set: this must likewise be stated because the update status within a geographic region must be known. The reason for this is obvious: both the scarcity situation of the individual environmental impacts and the extent of environmental impacts under consideration can change over time. For Switzerland, for instance, the fourth updated data set is already available (from 1990, 1998, 2006 and 2013). Another rule is always to use the most recent and thus most up to date data set.

4) Description of the data set: this should be as unambiguous as possible, for instance „ESM-D-2014“ or “ESM-CH-2013” etc.

5) Comparability: if comparative assessments are to be performed, care must be taken to ensure that the investigated variants are actually comparable. Accordingly, one production process can only be compared with another if it leads to the same output. Or a manufacturing site can be compared over two periods (e.g. financial years) in order to determine whether the total environmental impact has perhaps risen or fallen over time. Similar criteria for comparability are also found in management cost accounting.

6) Data accuracy: one inherent aspect of environmental impact assessments is that it is rarely possible to obtain completely accurate data sets and so it is often necessary to work with averaged, interpolated or extrapolated values. The relative assessment error can frequently also be reduced by working with lower accuracy data if the alternative is to omit the corresponding data completely because of concerns about inadequate accuracy. This should always be declared, especially in contact with third parties.

7) Data updating: the data sets used for assessment should be periodically updated. A period of 5 to 7 years has proved to be appropriate, after which the underlying data are checked or adapted to the new circumstances. Obviously, new findings may have been made in the meantime concerning the extent of the environmental impacts under consideration and the respective current and critical impacts. Updating at shorter intervals makes less sense because it results in numerous versions of data sets which differ only slightly from one another and are consequently unsuitable for comparison.

3.3.5 Basis for Assessment

The basis for assessment which underlies the method is of particular significance. In the Ecological Scarcity Method, this basis is provided by the environmental policy defined by the authorities for desirable targets by level and by the time horizon until

these targets are achieved. The environmental policies of the individual countries are essentially in competition with those at EU-28 level, since, from a purely geographic standpoint, both are valid for any location within the European Union.

EU-28 with environmental policy management

European Union environmental policy has become considerably more influential and significant in recent years. This is because the scope and diversity of EU programmes have substantially increased in content terms over recent years. In policy terms, there is a discernible trend for individual countries to hand over more and more responsibilities to the EU. As a consequence, a wide-ranging environmental programme backed by policy targets is now in place at EU-28 level. The European Commission acts autonomously here, making its own determinations regarding the future state of the European environment. The statistical surveys required to describe the current environmental situation are likewise carried out on an extensive scale. Thus the environmental policy of the European Commission can be used as a neutral standard of evaluation specifically for the communication with third parties like authorities, customers, competitors etc.

Individual country data as an interim solution

Within Europe, eco-factor data sets for the ESM assessment method are currently available for Switzerland and Germany. In Switzerland, this data set has been maintained for many years and is constantly being extended. In Germany, Eco Factors were first determined in 2014 and coordinated with German environmental policy targets with the collaboration of the Federal Environment Agency (UBA). The requirements of the ESM are thus met in both cases.

The Eco Factors which were derived by calculation from EU data and used in the present paper for the **27 individual EU countries** other than Germany meet these requirements only in part. One essential fact to be borne in mind is that no coordination with the highest environmental authorities of the individual countries has yet taken place and the countries have thus not formally identified with the content of the underlying targets. However, in line with the strict requirements of the Ecological Scarcity Method, this is an essential prerequisite for the unreserved acceptance of the assessment results by third parties, some of whom have very different basic attitudes towards environmental issues.

For the Eco Factors for the individual countries to be obtained deductively as described here from existing EU data in order to save time and effort can be considered a first major step forwards. For reasons of acceptance, it would be important for coordination with each country's specific environmental policy to be achieved over time. This way, the aim of providing a neutral basis for assessment which is accepted by all parties and takes account of each country's environmental targets will remain in focus.

3.3.6 Rules for Assessment

A number of general rules can be defined for environmental impact assessments:

Assess as directly as possible

In other words, the more specific, regional – i.e. in this case the national governments – Eco Factors should normally be used if they have been properly determined in accordance with the above methodology and have been coordinated with the aims of the respective country's environmental authority.

Taking a wider view

The following circumstances may necessitate assessment on the larger scale of EU-28 environmental policy as an exception to the above rule:

- if different sites or processes in a number of European countries are to be compared or aggregated, as may for example be the case for company-wide investigations across various manufacturing sites, or
- if no or too few Eco Factors are available for an individual country, so that the only Eco Factors available in sufficient quality and quantity are those from the next higher geographic level.

In both cases, it makes sense to carry out an European assessment using EU-28 Eco Factors covering the whole of Europe. It is therefore absolutely essential for the documentation to state precisely which data set has been used for the assessment, since the result is, as described above, numerically dependent on this (cf. Ahbe *et al*. 2014).

3.3.7 What must be borne in Mind when drawing up Assessment?

Drawing up traceable, reliable environmental impact assessments which are suitable as the basis for decision making for major investments or for communication with third parties depends on a number of factors:

1) a carefully drawn up environmental inventory: this includes carrying out appropriate substantive analyses of the processes while taking proper account of issues such as handling of co-products, credit for recycled fractions, use of manufacturing waste, usage data, application of allocation rules and many others.
2) proper declaration of the data sets and sources used and assumptions made etc., thus ensuring transparency of the relevant basis for calculation for the assessment.
3) the name of the author of the assessment and, if applicable, the software and databases used must be stated to ensure traceability.

3.4 Methods

3.4.1 The ESM: Midpoint or Endpoint Method?

The scientific literature contains numerous systems, sets of rules and standards which are intended to be suitable for providing an overview of the various assessment methods and for assisting in informed decision-making. It makes sense in this connection to give proper consideration to all the elements of the assessment system so that traceable conclusions can be drawn.

The literature conventionally divides assessment methods into “midpoint” and “endpoint” methods. The former are those which, during assessment, focus on various impact categories such as ozone depletion, acidification, greenhouse effect etc. (midpoint indicators) while the latter are those guided by harm categories such as “human health”, “biodiversity” etc. (endpoint indicators). The two types of method generally assume different horizons with regard to the range of the assessment, since endpoint methods include a further aggregation step and so are more likely to achieve the actual aim of assessing actual environmental harm.

Closer examination of the true situation reveals that this division and the associated interpretation lose their significance in the ESM. Since the official environmental targets used are unambiguously directed towards environmental harm and the deliberate avoidance of such harm, assessment is provided right up to an “endpoint”, although the literature usually categorises this method in the midpoint category. In this case the answer to the above question depends on the nature and manner of determination of the official targets defined and not on the assessment method itself. In this respect, a clear distinction must be drawn between the assessment method and the data sets, which are independent of the method, stating the environmental targets (cf. Figure 4, see next page).

3.4.2 Does the ESM comply with ISO 14040:2006 and 14044:2006?

DIN EN ISO 14040:2006 describes the basic procedure and broad framework within which an environmental impact assessment (also known as a “life cycle assessment”) is drawn up and provides information about the four phases of a life cycle assessment (goal definition, life cycle inventory, impact assessment, interpretation), reporting and critical review.

A life cycle assessment should in principle preferably be drawn up on the basis of scientific findings. Alternatively, use may be made of both further scientific approaches and international agreements. If none of these approaches is appropriate, decisions may be made on the basis of values which must then be described in detail (cf. Frischknecht *et al*. 2013).

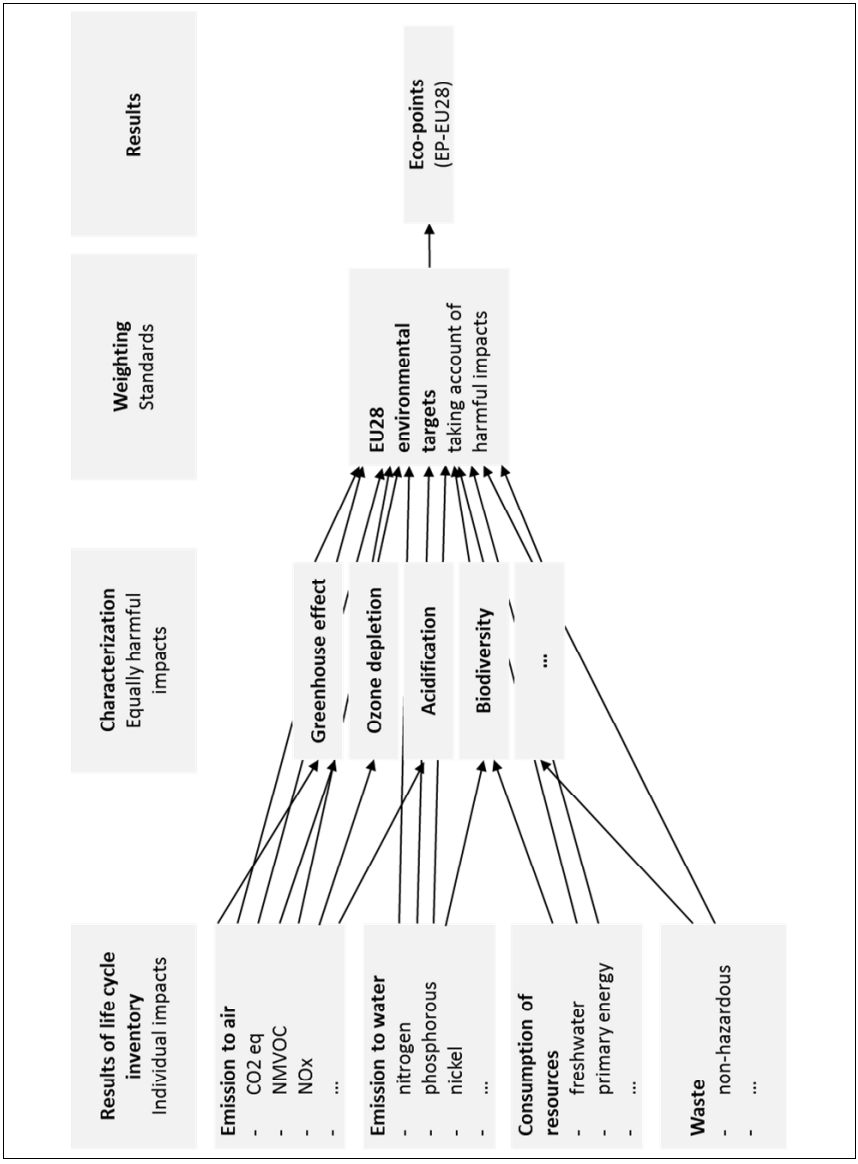

Figure 4: Alignment of environmental targets with harmful impacts (as described by the Swiss Federal Office for the Environment, Berne)

Scientific findings are only capable of revealing environmentally relevant interrelationships. They do not in themselves set any targets. If environmental targets are to be defined, the state deemed "critical" with the associated annual load (or annual consumption) must be defined in the context of a consensus-building process. This process, where societally supported and guided along official pathways, becomes a societal or political declaration of intent, which then defines the critical state. In this way, a country's environmental policy target setting process includes the opinions of numerous stakeholders and is also supported by experts who then add a scientific dimension to the discussions.

As has already been mentioned, the ESM makes reference to environmental policy targets which are derived from scientific findings (cf. figure 3) and defined by the highest environmental authorities.

Because of the method used to obtain the targets and the applied aggregation principle, the ESM conceptually and systematically excludes any “subjective weighting” by the author of the assessment which might result in user-related distortion of the results. The aggregation algorithm used here is solely based on the official determinations regarding the actual and nominal state of the environment. In every assessment, the contribution of each individual environmental impact to the final result is quantitatively visible, countable and thus traceable. Thanks to this mechanism, the ESM meets two requirements: firstly, complete aggregation of all individual statements as required by industry as a system-supported basis for decision making and secondly, fundamental absence of bias on the part of the author of the assessment and thus utter transparency and traceability for third parties. It is precisely these two requirements from business which led to the development of the ESM assessment method (cf. Ahbe *et al*. 1990).

3.5 Responsible Use of Environmental Impact Assessments

If the above rules are consistently observed, the ESM can be used to draw up assessments for both in-house (internal) corporate requirements and for marketing purposes and comparative studies for third parties (external).

Industry associations and authorities also have an interest in assessments having a basis for assessment which is traceable at any time. Many years of experience in Switzerland have demonstrated that credibility is distinctly increased if the basis for assessment originates from publicly controlled sources.

3.6 Use of Data

3.6.1 Types of Impact under Consideration

From a corporate standpoint, the environmental impacts to be recorded with the ESM must be

- known,
- researched,
- permitted and
- planned.

Environmental impacts which are as yet unknown or those which have not yet been sufficiently well researched for it to be possible to derive corresponding environmental targets are accordingly excluded from assessment. Similarly, only permitted impacts are included since prohibitions, such as for example emission prohibitions, cannot be effectively implemented by means of such an assessment method. The method furthermore focusses on planned environmental impacts, i.e. those which are part of the process under consideration, and not for instance merely on existing risks for spills or other losses of process control.

Numerous anthropogenic impacts which influence the state of the environment are currently known. In the present project, Eco Factors were determined for the individual countries of the European Union on the basis of the same environmental impacts as for the preceding determination of Eco Factors for Germany. Selection criteria were:

- the impacts are typical and significant in connection with business processes.
- consultation with the German Federal Environment Agency regarding the impacts officially considered significant in this connection.

The types of impact under consideration are therefore also in the present case (cf. Ahbe *et al*. 2014) as follows:

- air pollution by:
  - greenhouse gases as CO_2eq
  - NMVOC
  - NO_x as NO_2
  - SO_2
  - fine particulate matter (PM2.5)
  - NH_3
- surface water pollution by:
  - nitrogen
  - phosphorus
  - nickel
  - zinc

- COD
- lead
- cadmium
- copper
- EPA-PAH 16

- consumption of resources by:
  - freshwater consumption
  - renewable energy consumption
  - non-renewable primary energy consumption

- waste:
  - waste generation, non-hazardous
  - waste generation, hazardous

The decision initially to use the same types of impacts at an European level as were used for determining the German Eco Factors was made on the basis of the largely identical business processes and very similar weighting by the relevant authorities, some of which are also involved in joint reduction programmes.

From the standpoint of a multinational industrial concern, it is easier to implement environmental protection measures if a uniform scope of impacts is taken into consideration. This continues to apply until more recent findings preclude such a definition.

3.6.2 Comparability of Eco Factors and Eco Points

It follows directly from the rules for determining an individual country's Eco Factors that country A's aggregated assessment results cannot be compared directly and in absolute terms with country B's. This follows directly from the fact that the two countries are generally of different sizes and, not least for this reason, usually have different current annual flows and different quantitative environmental objectives, i.e. critical flows, which define the magnitude of the Eco Factors by calculation.

It is therefore absolutely necessary for the documentation to state precisely which data set has been used for a completed assessment, since the assessment result is, as described above, numerically dependent on it (cf. Ahbe *et al*. 2014).

The question frequently arises as to how an individual eco-factor, i.e. a scarcity state, per type of impact can adequately represent a large geographic region in which there may quite obviously be very different local scarcities. In other words, a production site may be located on a relatively unpolluted river as the receiving stream or alternatively on a river which is already highly polluted. Similarly, a production site emitting large volumes of air pollutants may be located in a relatively unpolluted, rural region or alternatively in a highly industrialized conurbation which is already highly polluted. Similar considerations apply to other types of impact.

For the purposes of scarcity definition, the ESM by definition focuses on the average conditions of a country or region. The emission and consumption data are here based

on pre-existing impact patterns specific to this country which are determined by conurbations, industrial regions, surface water structure etc. and have given rise to the definition of the corresponding official environmental targets[1]. Against this background, if official targets exist which, for the purposes of refinement for instance, make reference to individual sub-regions of a country, these more detailed targets may also be used with the ESM.

A differentiation must be made here with site specific environmental impact assessments (EIA), which are drawn up directly for a specific location and are intended to assess the direct interaction between the emitters in question and their immediate surroundings[2]. If this is the intention, the relevant regulations for investigating and drawing up this site-specific EIA[3] must be observed.

1 Conditions at the point of discharge itself are often not critical, but instead the conditions arising from the total loads at a considerable distance from the point of discharge, for example in the North Sea, Baltic Sea or North Atlantic catchment basins.
2 This differentiation of EIAs also applies, due to their local focus, to other assessment methods.
3 For example the German Law on Environmental Impact Assessments (UVPG).