Technical assistance study for the assessment of the feasibility of using "points system" methods in the implementation of Ecodesign Directive (2009/125/EC)

TASK 2

A review of state-of-the art methods

June 2017

EUROPEAN COMMISSION

Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
Directorate Directorate C – Industrial Transformation and Advanced Value Chains
Unit Directorate C1 – Clean Technologies and Products

E-mail: grow-c1@ec.europa.eu

European Commission
B-1049 Brussels

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Prepared by:
This report has been prepared by Paul Waide from Waide Strategic Efficiency, Karolien Peeters from VITO and Clemens Rohdes from Fraunhofer ISI with comments provided by other members of the consortium comprising Waide Strategic Efficiency (technical leader of the study), VITO (contractual lead), Fraunhofer, Viegand Maagøe and VHK.

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Acronyms, units and symbols

Acronyms

AHP	Analytic Hierarchy Process
BREEAM	Building Research Establishment Environmental Assessment Method
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization.
DGNB	Deutsche Gesellschaft für nachhaltiges Bauen
DM	Decision model
EEI	Energy Efficiency Index
ESCCI	End suction close coupled inline water pump
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCM	Life Cycle Management
LEED	Leadership in Energy and Environmental Design
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision Method
MEErP	Methodology for the Ecodesign of Energy-related. Products
MMG	Milieugerelateerde Materiaalprestatie Gebouwen
MSA	Market Surveillance Authorities
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
RoHS	Restriction of the Use of Certain Hazardous Substances Directive
TRV	Thermostatic Radiator Valve
WEEE	Waste Electrical and Electronic Equipment Directive

Executive Summary

The European Commission has instigated this technical assistance project to evaluate and derive a "points-system" methodology that could be applied to the development of Ecodesign requirements for complex products and/ or product systems. This need arises due to the increasingly common investigation of more complex energy-related products and systems for prospective Ecodesign and Energy Labelling implementing measures within the Ecodesign work plan. There are many causes of product complexity including that:

- they may have more than one functional unit (i.e. the quantified performance of a product system for use as a reference unit in a life cycle assessment study), due to the variety of functions the product is capable of performing,
- the functional units may be inherently difficult to assess due to measurement or methodological difficulties.

It is also common for the product groups concerned to have varying degrees of heterogeneity that complicate their assessment against common metrics and measurement methods. However, as savings potentials from the adoption of appropriate Ecodesign technologies can be significant, and these technologies are theoretically capable of being assessed on a modular basis, the European Commission is interested in evaluating whether it is feasible to devise an assessment methodology for product systems comprised of technology/design modules that considers the ensemble of modular technologies deployed.

To inform the assessment to be conducted in later stages (Tasks 3 to 5) of this project it is appropriate to review other methodologies that have been applied to the assessment of the environmental performance of complex and multi-impact criteria systems. This report presents a review of such state-of-the-art methods. In particular it describes and assesses a variety of multi-criteria environmental impact assessment methods and points-systems based decision-making models, to examine their characteristics and assess their potential applicability for adaptation and use in the appraisal of Ecodesign requirements for complex products.

To this end, a broad variety of multi-impact criteria assessment methodologies were compiled and assessed, to examine their inherent characteristics and to explore their potential relevance for potential adaptation or incorporation within a points-based approach for the Ecodesign of complex products. Table ES1 presents a summary of the team's (subjective) evaluation scores of each of the 18 distinct methodologies considered in this review against each of the assessment parameters considered, namely: effectiveness, accuracy, reproducibility, enforceability, transparency, ease and readiness of use, and capacity to be implemented. The details of these methodologies are summarised in the main report.

Most of these methodologies were not been designed with the Ecodesign regulatory process in mind, and thus they are not directly adapted to or applicable to its use; however, they do share many elements that are of value in the conduct of Ecodesign-like assessments. In the case of the methods that address multi-criteria environmental impact analysis, these elements may include derivation of functional units, definition of environmental impact criteria, normalisation and benchmarking, grouping, weighting and aggregation. In other cases, they may share a structured hierarchical modelling framework to facilitate prioritisation and decision-making when judgements are required based on multiple and distinct input criteria.

Most of the methodologies[1] that address environmental impacts are more suited to the setting of specific thresholds i.e. such as would be used in Annex II (Method for setting specific ecodesign requirements) of the Ecodesign Directive.

Some of the methods contain elements that would be suited to setting generic Ecodesign requirements i.e. such as would be used in Annex I (Method for setting generic ecodesign requirements) of the Ecodesign Directive.

With two exceptions (the ISO 14995-1 energy efficient design methodology for machine tools, and the EU Energy Label for space heating systems) the methods do not offer an approach tailored to managing complex functional units where the same component has more than one function.

Table ES1: Summary of the team's evaluation scores of the multi-criteria assessment schemes considered in this review.

Method	Effectiveness	Accuracy	Reproducibility	Enforceability	Transparency	Ease and readiness of use	Capacity to be implemented
LCA ISO 14040 and 14044	5-10	5-10	7-9	2-10	6-10	4-9	7
Product Environmental Footprint	6	6	6	4	9	5	6
French environmental label - field trials	NA	NA	NA	NA	NA	NA	NA
Common framework of core performance indicators for resource efficiency assessment in the building sector	NA	NA	NA	NA	NA	NA	NA
Material based environmental profiles of building elements (MMG)	8	8	7	4	9	7	7
Methodology to integrate cost effectiveness in determining the performance of a technology in the framework of Strategic Ecological Support (STRES)	8	7	5	3	9	5	6
Environmental impact assessment – Hybrid LCA methodology	5-10	5-10	7-9	2-10	6-10	4-9	7
BREEAM	8	6	7	4	4	8	6
LEED	8	6	6	4	4	7	6
DGNB	8	6	6	4	4	7	6
ISO 14955-1: Machine tools	8	7	6	7	8	8	8

[1] Specifically: LCA ISO 14040 and 14044, PEF, MMG, STRES, Hybrid LCA, BREEAM, LEED, DGNB, ISO 14955-1 (partially), Machine Tool Mandatory Point Scheme Proposal, AHP applied to technology portfolio assessments, Points systems for Ecolabelling, Points systems for green public procurement, The "installer energy label" for heating systems, Europump extended product scheme, Ecodesign Lot 37 lighting systems.

Machine Tool Mandatory Point Scheme Proposal	6	3	6	4	3	3	8
AHP	6	6	6	5	6	3	4
Points systems used for Ecolabelling	6	8	7	6	9	7	8
Points systems used for green public procurement	8	8	7	6	9	7	6
The "installer energy label" for heating systems	8	8	7	7	9	8	10
Europump extended product scheme	6.5	8	7	7	9	8	9
Ecodesign Lot 37 lighting systems investigation	8	8	7	7	9	7	8

NA = not applicable

Despite these methods being applied within diverse applications, certain generic similarities and common characteristics are witnessed between many of them (Table ES2).

Table ES2: Summary of the methodological elements included within the multi-criteria assessment schemes considered in this review.

Method	Pure points system (P) or potential component (C) within one?	Classification based on points scored (Y/N)	Hierarchical decision aiding model? (Y/N)	Prioritisation and aggregate score?	Prioritisation method (Panel, Monetisation, Distance to Target)	Multi-criteria assessment decomposed into sub-problem assessments, each of which can be analysed independently?	Application of numerical weightings to sub-problem scores to establish weighted hierarchy?	Pairwise comparison between alternatives?	Potentially applicable to generic process evaluation? (Y/N)
LCA ISO 14040 and 14044	C	N	N	Y	Any	Y	Y	N	N
Product Environmental Footprint	P	N	Y	Y	Any	Y	Y	N	N
French environmental label - field trials	C	N	N	N	NA	Y	N	N	N
Common framework of core performance indicators for resource efficiency assessment in the building sector	C	N	U	Y	Any	Y	U	U	U
Material based environmental	C	N	Y	Y	Monet-	Y	Y	N	N

profiles of building elements (MMG)					isation				
Methodology to integrate cost effectiveness in determining the performance of a technology in the framework of Strategic Ecological Support (STRES)	C	Y	Y	Y	Panel/Monetisation	Y	Y	Y	N
Environmental impact assessment – Hybrid LCA methodology	C	N	N	Y	Any	Y	Y	N	N
BREEAM	P	Y	Y	Y	Panel	Y	Y	Y	N
LEED	P	Y	Y	Y	Panel	Y	Y	Y	N
DGNB	P	Y	Y	Y	Panel	Y	Y	Y	N

Method	Pure points system (P) or potential component (C) within one?	Classification based on points scored (Y/N)	Hierarchical decision aiding model? (Y/N)	Prioritisation and aggregate score?	Prioritisation method (Panel, Monetisation, Distance to Target)	Multi-criteria assessment decomposed into sub-problem assessments, each of which can be analysed independently?	Application of numerical weightings to sub-problem scores to establish weighted hierarchy?	Pairwise comparison between alternatives?	Potentially applicable to generic process evaluation? (Y/N)
ISO 14955-1: Machine tools	C	N	N	N	NA	Y	N	Y	Y
Machine Tool Mandatory Point Scheme Proposal	P	Y	Y	Y	Panel	Y	Y	Y	N
AHP	P or C	Y or N	Y	Y	Usually Panel	Y	Y	Y	Y
Points systems used for Ecolabelling	C	Y	Y	Y	Usually Panel	Y	N	Y	N
Points systems used for green public procurement	P	Y	Y	Y	Usually Panel	Y	Y or N	Y	Y
The “installer energy label” for heating systems	C	N	Y	N	N	Y	Partially	Y	N
Europump extended product scheme	C	N	Y	N	N	Y	N	Y	N
Ecodesign Lot 37 lighting systems investigation	C	N	Y	N	N	Y	N	Y	Y

U =- unknown, NA = not applicable

These similarities may be summarised as follows:

- about half are pure points-systems methodologies and the other half are methodologies that could be adapted for use as a potential component within a points system
- about half the methodologies include a classification system based on the number of points scored
- most employ a hierarchical decision-making model
- the large majority involve prioritisation and aggregate scoring
- most permit the use of a prioritisation method of which the most common in the panel-method, but monetisation is used in one (MMG) and the Distance to Target method could also be used in some cases
- in all cases the process of conducting a multi-criteria assessment involves decomposition into sub-problem assessments, each of which can be analysed independently
- the majority of methods apply numerical weightings to sub-problem scores to establish a weighted hierarchy
- about half the methods entail some kind of pairwise comparison between alternatives
- some of the methods are potentially applicable to generic process evaluation.

Essentially, those methods which address prioritisation, and which make aggregations of scores, could be suitable for adaptation to derive aggregate points system scores across different types of environmental impacts. On the other hand, those methods which do not follow the prioritisation and aggregation steps may be suitable for adaptation, to instead derive the impacts of environmental impact parameters in isolation of one another.

The experience summarised in this report is most pertinent if the intention is to design a points-systems framework that compares across distinct environmental impact criteria; however, the findings of the stakeholder consultations process discussed in Tasks 1 and 3 reveal that this is not supported by the majority of stakeholders, and thus it seems clear that none of these existing methodologies can be directly adapted to apply to the derivation of Ecodesign implementing measures for complex products. Rather, it seems that any suitable points-based methodology would need to be developed afresh in a manner that is informed by the experience with these other multi-criteria assessment methods. This results in the methodological approach that is discussed and set out in Task 3, and which is subsequently applied in the case studies considered in Tasks 4 and 5 of this study.

1. Background

The European Commission has instigated this technical assistance project to evaluate and derive a "points-system" methodology that could be applied to the development of Ecodesign requirements for complex products and/ or product systems. This need arises due to the increasingly common investigation of more complex energy-related products and systems for prospective Ecodesign and Energy Labelling implementing measures within the Ecodesign work plan, most notably since the advent of the 2012-2014 Ecodesign work plan. Some examples of such products are:

- machine tools
- data storage devices
- professional washing machines/ driers,

which are complex in that:

- they may have more than one functional unit (i.e. the quantified performance of a product system for use as a reference unit in a life cycle assessment study), due to the variety of functions the product is capable of performing,
- the functional units may be inherently difficult to assess due to measurement or methodological difficulties.

It is also common for the product groups concerned to have varying degrees of heterogeneity that complicate their assessment against common metrics and measurement methods. However, as savings potentials from the adoption of appropriate Ecodesign technologies can be significant, and these technologies are theoretically capable of being assessed on a modular basis, the European Commission is interested in evaluating whether it is feasible to devise an assessment methodology for product systems comprised of technology/design modules that considers the ensemble of modular technologies deployed.

This notion was first explored within the Ecodesign process in the case of machine tools within a working document put forward by the Commission at the May 2014 Consultation Forum which proposed one potential option based around a points systems approach (European Commission 2014). The resulting discussion highlighted the potential of this notion but also the need to explore options in greater depth and to produce a rationale that would allow the viable approaches to be identified and their strengths and limitations to be assessed. The present technical support services contract, under which the current work is conducted under, aims to elucidate this issue via the conduct of analyses that will clarify the options, identify the most promising method(s) and then demonstrate their viability via some worked case studies.

To be able to fulfil the specific objectives of the project, the study approach and methodology is structured into five tasks as follows:

Task 1 - Stakeholder consultation, including the compilation of a stakeholder list and a stakeholder survey.

Task 2 - Review of state-of-the-art methods, in which relevant existing methodologies will be catalogued and reviewed, followed by a comparative analysis.

Task 3 - Method development, which entails the derivation of a prospective method for establishing Ecodesign requirements for complex products. This is to be derived from consideration of at least: a) the fit with MEErP, b) the fit with the provisions of the Ecodesign Directive, c) suitability for addressing energy-related and resource efficiency aspects, d) modular build on existing Ecodesign implementing measures, e) measurability via standards.

Task 4 - Case studies, where at least two product groups will be evaluated using the method proposed in Task 3. The Task 3 method may be iteratively revised and applied, as appropriate.

Task 5 – Reporting

The study is being carried out by a consortium that spans a broad spectrum of expertise including technological know-how and environmental engineering, economic and environmental assessment, market and consumer analysis. It comprises Waide Strategic Efficiency as the technical leader of the study with the other involved project partners being VITO, Fraunhofer, Viegand Maagøe and VHK.

Why are some products too complex for the use of the conventional Ecodesign methodology?

Typical sources of complexity arise because a product

- may have more than one functional unit (i.e. the quantified performance of a product system for use as a reference unit in a life cycle assessment study), due to the variety of functions the product is capable of performing,
- the functional units may be inherently difficult to assess due to measurement or methodological difficulties

In addition, in cases where the Ecodesign improvement options of a product are highly sensitive to its usage profile whilst still being highly application-dependent and heterogeneous, becomes challenging to identify average or characteristic usage profiles (duty cycles) that can capture the energy savings potential for the plethora of actual applications.

Aim of this report

This report presents a review of state-of-the-art methods. It aims to describe and assess a variety of multi-criteria environmental impact assessment methods and points-systems based decision making models to examine their characteristics and assess their potential applicability for adaptation and use in the appraisal of Ecodesign requirements for complex products.

2. Description of the task

Subtask 2.1 Catalogue and review existing methodologies

In this task an inventory of existing methodologies that could be applied or adapted for the derivation of a points-systems approach for complex products under the Ecodesign Directive is made, based on desk research and stakeholder consultation.

Initially the net is cast wide to collate information about as many types of potential approaches as possible. This first stage entails a systematic searching of sources including: EU regulations and Directives, MS initiatives (e.g. the French trial of environmental labelling[2]) EN/ISO standards, green public procurement procedures, trade and professional bodies guidelines and documents, the academic literature and any other appropriate sources including drawing on the experience of our own professional networks. Based on this exercise a set of specific methods are considered and assessed as set out in Table 1.

Table 1: List of multi-criteria assessment schemes considered in this review

Points system	Assessment area	Short explanation
ISO 14040 and 14044	Life cycle assessment principles, framework and guidelines	International standards on Life cycle assessment, principles and framework (ISO 14040) and requirements and guidelines (ISO 14044)
Product Environmental Footprint (PEF)	Multi-criteria environmental impact life cycle assessment of products	PEF is a Life Cycle Assessment (LCA)-based method to calculate the environmental performance of a product. The method was developed by the European Commission's Joint Research Centre and is currently being tested in a pilot phase.
Field trial of environmental labels in France	Multi-criteria environmental impact life cycle assessment of products	A labelling trial to supply full life cycle environmental impact information using a multi-criteria approach
Common framework of core performance indicators for resource efficiency assessment in the building sector	Multi-criteria environmental impact assessment of buildings	A common framework of indicators to assess the sustainability of buildings being developed by the European Commission
Material based environmental profiles of building elements (MMG)	Multi-criteria environmental impact life cycle assessment of building elements	Methodology and database for life cycle assessment of building elements.

[2] see Centre d’Analyse Stratégique (2013)

Points system	Assessment area	Short explanation
Methodology to integrate cost effectiveness in determining the performance of a technology in the framework of Strategic Ecological Support (STRES)	Multi-criteria environmental impact life cycle assessment of investments	Methodology to determine the cost effectiveness of an environmental or energy-related investment.
Environmental impact assessment - Hybrid LCA methodology	Multi-criteria environmental impact life cycle assessment of goods, processes and services	Hybrid conventional LCA methods and input-output economic modelling for more comprehensive and rapid LCA analysis
BREEAM	Environmental assessment of buildings	System originates in UK, but used all over the world. Designers have to achieve a certain numbers of points related to concepts and efficiency/ design factors, in order to claim certain design levels.
LEED	Environmental assessment of buildings	System originates in US, but used all over the world. Designers have to achieve a certain numbers of points related to concepts and efficiency/ design factors, in order to claim certain design levels.
DGNB	Environmental assessment of buildings	German system for the sustainability evaluation of construction projects.
ISO 14955-1: Machine tools	Energy efficiency of machine tools	A methodology for the design of energy efficient machine tools
Points system Machine Tools	Ecodesign of complex products	Option of ranking machine tool energy in use performance via a points system inspired by the BREEAM system for buildings.
Analytical Hierarchy Process	Multi-criteria evaluation framework applied to technology investment decisions	AHP-type hierarchical decision modelling applied to multi-criteria assessments of technology investment portfolios in businesses
Points systems used for eco-labelling	Multi-criteria environmental impact evaluation framework	Examination of Ecolabelling systems and relation to points systems

Points system	Assessment area	Short explanation
Points systems used for green public procurement	Multi-criteria environmental impact	Examination of Green public procurement systems and the use of points systems in procurement
The EU "installer energy label" for heating systems	Energy labelling of complex products	Applies an extended product approach to develop a heating systems energy label
The Europump Extended Product Approach	Ecodesign for complex products	Applies an extended product approach to develop Ecodesign proposals for various pump systems
Ecodesign Lot 37 lighting systems investigation	Ecodesign of complex products	A methodology which considers the product scope as a holistic system

Subtask 2.2: Comparative analysis (effectiveness, enforceability, transparency, accuracy/reproducibility)

The inventory of methods identified in subtask 2.1 requires consistent comparative analysis to establish their relative suitability for adoption or adaption to form the basis of an Ecodesign points system or related appraisal system for complex products. This sub-task describes how this analysis has been conducted.

The project team have reviewed the inventory of existing approaches for assessing the energy and environmental performance of products and services and analysed them to determine their salient characteristics and to consider their potential suitability for appraising the relative performance of complex products within the Ecodesign framework. The approach used begins by classifying the methods into those that appear on initial inspection to be candidates for being appropriate, applicable and enforceable; those that use methodologies that could be readily adapted for use in an Ecodesign appraisal system; those that contain methodological elements that could be incorporated within an Ecodesign appraisal system and those that have little apparent relevance. This initial sorting and screening process also aims to identify any apparent gaps in the ensemble of current methods.

A standardised template has been developed and used to report the findings on each method in a structured way. As in practice there are too many point systems and related methods in use to perform a thorough assessment of each, the team has attempted to group the methods into sets of basic types and then analyse the most pertinent exemplars of each type for inclusion in the detailed assessment described below. This is to enable classes of methodologies to be scrutinised and evaluated for their suitability. The process for doing this entails: a) characterising and establishing the degree of commonality of methodological elements used within the various points system and related methodologies, b) characterising and establishing the degree of commonality of environmental performance and system factors being appraised.

Comparison matrices are used to facilitate this i.e. for the appraisal of the commonality of methodological elements a methodological comparison matrix is established and populated with the list of methodologies filled in the left column and the list of methodological elements filled across the top row. The same method is used to summarise the commonality of performance and system factors appraised. Note that while it might be natural to focus first on the commonality of factors it is more pertinent for the project to establish the commonality of methodological elements, which allows relevant methods to be identified and introduced from outside the immediate subject field as appropriate. The intention is that this will help to minimise ambiguity and therefore improve the prospects for stakeholder agreement over the rationale used to select the methodological structure which is ultimately to be proposed in the work of Task 3.

The use of a structured assessment template also permits more consistent, comparable and structured reporting of the findings. In particular this makes use of matrices to compare methodologies against key assessment criteria and thereby allows easy visual appraisal of the ensemble of approaches. As there are a plethora of methodologies in use the action of identifying common methodological elements will enable methodologies to be grouped into classes. This will permit the strengths and weaknesses of the broad classes to be characterised, and facilitate a subsequent screening process by basic methodological type.

The intention is that within the work of Task 3 it will be possible to draw conclusions on the suitability of the classes of methodologies such that it might ultimately be possible to propose the adoption of one methodological type over another based on a transparent ranking of the methodological classes. If at some point in the future a stakeholder were to propose consideration of a specific points based methodology that was not captured in the methodological inventory this approach would be most likely to enable the methodology to be categorised within one of the main methodological classes and hence permit its rapid appraisal.

An essential aspect of the evaluation is the focus and process of comparing the methodologies against key performance criteria. This key comparative assessment criteria we propose to include are:

1. Effectiveness
2. Accuracy
3. Reproducibility
4. Enforceability
5. Transparency
6. Ease and readiness of application
7. Capacity to be implemented within the legal, procedural and analytical rubric of the Ecodesign and Energy Labelling Directives

The assessment of **effectiveness** must determine the extent to which the methodology would stimulate the intended ecodesign improvement potential and especially be fair and representative of the actual savings reductions that adoption of a set of ecodesign technology design options would produce. This appraisal requires understanding of how well the methodology treats and values the key ecodesign performance parameters and uses these to generate an overall ranking. In particular it will be essential for any viable system to adequately and appropriately address the energy in use phase. This will require proper accounting for energy efficiency in use impacts by establishing technically appropriate and viable systems boundaries, correctly including and treating the set of low impact technological and design options, applying an appropriate and viable process for identifying typical usage duty cycles, accounting for all relevant energy flows, and establishing an appropriately structured and weighted procedure for grouping and ranking these aspects. Similar processes may be needed for other important environmental impact factors. To assess this parameter the team will derive a set of effectiveness assessment factors and apply these to appraise each of the methodologies considered on a common basis. The same methodological assessment process will be applied to each of the other performance criteria as discussed below.

Other potential effectiveness issues are addressed in the criteria indicated below.

The assessment of the **accuracy** of a methodology entails determining the degree to which the inputs and results are measureable and quantifiable and the likely extent of variance in such measurements, which in turn has a bearing on tolerances. In a test laboratory context the accuracy would be a measure of the repeatability of a test result i.e. the degree to which were the same product to be tested for the same parameter within the same test laboratory that it would produce the same result. It will be beyond scope to produce such an assessment but the project team has attempted to assess the extent to which established methods exist to measure the required inputs and apply their experience on variance in product testing and points quantification to assess the probability that the methodology will be more or less accurate.

Determination of the **reproducibility** of a methodology is an evaluation of the degree to which were the same method to be applied by different actors to assess the same product that they attain the same result. In part this concerns the degree of simplicity and thoroughness/clarity of the methodology and its procedure; however, while simplicity usually aids reproducibility, if a method is too simplistic it will usually not explain how to address complexity found in real world application of the method and hence will reduce reproducibility. For example, this criticism seemed to be implicit in some of the submissions circulated with the Commission's working document on machine tools (European Commission 2014) where there were statements suggesting difficulty in understanding the scope and definitions being applied, which would be liable to cause two different actors to interpret the requirements differently. In a test laboratory context reproducibility is a measure of the variance in results when different test labs test the same product for the same parameter and is usually assessed through round robin testing. Accreditation of test labs is intended to reduce this variance by ensuring standardised metrology, test environments and equipment and procedures are followed; however, in practice many procedural requirements are not fully specified in test procedures. The team's assessment applies its experience to rank the methodologies according to their likely degree of reproducibility.

The extent to which a methodological approach produces results which are **enforceable** is critical for the market surveillance process and hence is a key determinant of the viability of a method. By their nature complex products will be intrinsically more difficult to assess for conformity with Ecodesign and energy labelling implementing measure requirements for simpler products and thus unless efforts are made to ensure methodologies are readily enforceable there is likely to be opposition to their adoption. The team has attempted to apply their experience of the processes used by MSAs to assess conformity and the issues confronted to develop a practicable enforceability assessment method. In part this is informed by the assessments of accuracy and reproducibility which are important elements within enforceability, but equally important (although related) is the extent to which the scope of application is clear, for which proof of use of specified techniques is required (if for example a modular components/features based method is considered) and can be verified (with or without destructive testing), the number and complexity of elements which would require assessment to derive an overall conformity assessment, and the extent to which there is scope to "game" the system. A corollary to this is the extent to which viable methodological standards, especially EN or ISO/IEC/ITU standards, are available and whether certification to these standards is or could be offered by 3rd party bodies. This is an indicator of the extent to which there could be confidence in product certification which is upstream of the market surveillance conformity assessment process.

The assessment of **transparency** aims to determine the degree to which the methodology used within the system is in the public domain, is properly documented, has an open and documented rationale and is readily intellectually accessible. This last point is essentially an evaluation of the systems complexity, noting that the greater the complexity the less the transparency but also noting that there is usually a trade-off between simplicity and accuracy and effectiveness.

The appraisal of **ease and readiness** of application aims to determine the degree of difficulty likely to be encountered by stakeholders, especially product designers and producers, in implementing the methodology. Ideally the methodology would be as simple as possible to implement in order to facilitate engagement, minimise overheads, and minimise misunderstanding about how it is applied and assessed. Points-based assessment schemes have to strike the right balance between trying to be inclusive of all theoretically relevant parameters, while minimising complexity and transparency, and this trade-off has implications for the ease of use. To combat complexity criteria, screening may be appropriate to ensure focus is given to the key parameters which bring the greatest gain. As many complex products are produced by SMEs it is vitally important to minimise the effort required to understand and implement the methodology, and thus the ease of application is a key aspect. The readiness of application assesses the extent to which the methodology can be directly applied versus whether it requires further developmental work.

The **capacity to be implemented** reflects: a) the need to ensure that the methodology would be legally permissible within the relevant Directives through satisfying the appropriate legal constraints within these Directives, b) how well the development and application of the methodology for any specific product group would fit within the Ecodesign and Energy Labelling procedural and decision-making process, c) the extent to which it would work with and complement the MEErP analytical process embedded in the Preparatory Studies, including compatibility with the Ecoreport tool.

The project team has assessed the methodologies against each of these criteria and has applied a transparent ranking for each criterion (on a 0 to 10 scale) to permit a coherent, at a glance, comparison when the findings are presented within the summary matrices. The methodology used is that the project team describes the performance of the method against the assessment parameter (see sections under sub-headings for each method in section 4) and based on this ascribes a score from 0 to 10 for each specific assessment parameter-method pairing. Evidently these rankings simply reflect the project team's assessment and hence are necessarily subjective; however, the intention is to provide easy comparison across methods against specific assessment parameters. While the scores are doubtless contestable they should help furnish a relatively consistent impression of the different methods' characteristics. The findings are presented in Tables 10 and 11 presented in section 5 on the summary of findings.

Note, the current version of the report is an initial draft and does not yet incorporate all elements that will be included in the final report. Furthermore, it is expected that stakeholders will supply suggestions and feedback which will inform amendments made within the final report.

3. Multi-Criteria Decision Analysis

The derivation of Ecodesign implementing measures, which involves the assessment of numerous product environmental impact criteria, is a manifestation of a multi-criteria decision-making process and like all multi-criteria assessment problems faces a challenge of how to determine preferred outcomes given the presence of more than one assessment criterion.

A more general understanding of the theory and principles involved in all such processes can be helpful to contextualise thinking on how methods to address these challenges could be derived and applied in the future.

This section is currently under development and will be expanded in the next iteration of the report. The future version will include text giving background to the theory of multi-criteria decision making (MCDM) and analysis (MCDA) that will be intended to provide useful contextual information to better understand the principles and theory behind the derivation and use of points-systems approaches for multi-criteria assessment.

In general, however, models that support MCDM are concerned with structuring and solving decision and planning problems involving multiple criteria. The rationale for creating such a structured framework is to support decision-makers confronting such problems. Usually there is no unique and unequivocally optimal solution to an MCDM problem that can be derived without incorporating preference information. Thus MCDM models are designed to provide a framework that will allow such preference information to be assessed in conjunction with deterministic or empirical information so that decisions which involve the assessment of multiple criteria can be reached within a structured framework.

MCDM has been an active area of research since the 1970s and draws upon knowledge in many fields including: mathematics, behavioural decision theory, economics, computer technology, software engineering and information systems. There are several MCDM-related organisations including the International Society on Multi-criteria Decision Making, Euro Working Group on MCDA (Euro working Group), and INFORMS Section on MCDM (INFORMS). For a history see: Köksalan, Wallenius and Zionts (2011). Other useful references include: Keeney and Raiffa (1976). A summary of the topic can be found at:

https://en.wikipedia.org/wiki/Multiple-criteria_decision_analysis

MCDM typologies

It should be noted that there are different classifications of MCDM problems and methods. A major distinction between MCDM problems is based on whether the solutions are explicitly or implicitly defined.

- *Multiple-criteria evaluation problems*: These problems consist of a finite, discrete number of alternatives, explicitly known in the beginning of the solution process. Each alternative is represented by its performance in multiple criteria. The problem may be defined as finding the best alternative for a decision-maker (DM), or finding a set of good alternatives. There may also be a need to sort or classify the alternatives. In this context sorting would be undertaken to place the alternatives into a set of preference-ordered classes (such as assigning star ratings to hotels). Classifying refers to assigning alternatives to non-ordered sets (such as diagnosing patients based on their symptoms).

- *Multiple-criteria design problems (multiple objective optimisation problems)*: In these problems, the alternatives are not explicitly known and an alternative (solution) may be found by solving a mathematical model. The number of alternatives may either be infinite (when some variables are continuous) or typically very large if the variables are countable (when all variables are discrete).

Regardless of whether the problem is of the evaluation or design type, preference information is required in order to differentiate between solutions in the decision model.

MCDM methods

The following MCDM methods are available, many of which are implemented by specialised decision-making software (Weistroffe et al 2005), (Mc Ginley 2012):

- Aggregated Indices Randomisation Method (AIRM)
- Analytic hierarchy process (AHP)
- Analytic network process (ANP)
- Best worst method (BWM) (Rezaei, 2015a and 2015b)
- Characteristic Objects METhod (COMET) (Wojciech 2014)
- Choosing By Advantages (CBA)
- Data envelopment analysis
- Decision EXpert (DEX)
- Disaggregation – Aggregation Approaches (UTA*, UTAII, UTADIS)
- Dominance-based rough set approach (DRSA)
- ELECTRE (Outranking)
- Evidential reasoning approach (ER)
- Goal programming (GP)
- Grey relational analysis (GRA)
- Inner product of vectors (IPV)
- Measuring Attractiveness by a categorical Based Evaluation Technique (MACBETH)
- Multi-Attribute Global Inference of Quality (MAGIQ)
- Multi-attribute utility theory (MAUT)
- Multi-attribute value theory (MAVT)
- New Approach to Appraisal (NATA)
- Nonstructural Fuzzy Decision Support System (NSFDSS)
- Potentially all pairwise rankings of all possible alternatives (PAPRIKA)
- PROMETHEE (Outranking)
- Stochastic Multicriteria Acceptability Analysis (SMAA)
- Superiority and inferiority ranking method (SIR method)
- Technique for the Order of Prioritisation by Similarity to Ideal Solution (TOPSIS)
- Value analysis (VA)
- Value engineering (VE)
- VIKOR method (Opricovic & Tzeng 2007)
- Fuzzy VIKOR method (Opricovic 2011)
- Weighted product model (WPM)
- Weighted sum model (WSM)
- Rembrandt method

It is beyond the scope of this exercise to review all of these methods but we focus on the main principles and typologies that have been applied to multi-criteria energy and environmental evaluation exercises as applied to technologies and other energy using or related systems. We do, however, draw the reader's attention to the Analytic Hierarchy Process (AHP). This is a MCDM tool that was first articulated in the 1970s by Thomas Saaty and has the practical value of creating a framework that enables alternative choices across different assessment criteria sets to be compared and ranked against each other. In particular, it permits the assessment of sets of qualitative and quantitative criteria to be assessed within a common analytical structure in order to rank outcomes based on the preferences embedded in the model. The AHP does this by initially decomposing the decision problem into a hierarchy of sub-problems. Then the decision-maker(s) evaluate the relative importance of its various elements by pairwise comparisons. The AHP converts these evaluations to numerical values (weights or priorities), which are used to calculate a score for each alternative (Saaty, 1980).

Decision situations to which the AHP can be applied include (Forman et al 2001):

- Choice – The selection of one alternative from a given set of alternatives, usually where there are multiple decision criteria involved.
- Ranking – Putting a set of alternatives in order from most to least desirable
- Prioritisation – Determining the relative merit of members of a set of alternatives, as opposed to selecting a single one or merely ranking them
- Resource allocation – Apportioning resources among a set of alternatives
- Benchmarking – Comparing the processes in one's own organisation with those of other best-of-breed organisations
- Quality management – Dealing with the multidimensional aspects of quality and quality improvement
- Conflict resolution – Settling disputes between parties with apparently incompatible goals or positions (Saaty et al 2008)

The AHP does not determine a "correct" decision, but rather enables decision-makers to find one that best suits their objective and understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, representing and quantifying its elements, relating those elements to overall goals and for evaluating alternative solutions.

There have been thousands of applications of AHP to complex decision-making situations. These encompass applications in a very diverse set of problems involving planning, resource allocation, priority setting and selection among alternatives, forecasting, total quality management, business process re-engineering, quality function deployment and balanced scorecards (Forman et al 2001), (Bhushan et al 2004), (de Steiguer et al 2003). It has particular application in group decision-making (Saaty et al, 2008) and is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, shipbuilding and education. Commercial software to assist in applying AHP is available.

4. Examination of specific methodologies

4.1 Life cycle analysis - ISO 14040 and 14044

Method description and reference

To assess the environmental impacts of products and services, life cycle assessment (LCA) is most commonly used as the method and tool. In the life cycle impact assessment (LCIA) of LCA, the results of the life cycle inventory analysis (LCI) are linked to specific environmental impact categories (e.g. contribution to climate change, eutrophication, etc.). Various methods are in use to assess the environmental effects of products and systems. Most methods operate on the assumption that a product's entire life cycle should be analysed i.e. they aim for completeness; however, variants exist where it is possible to focus on the impacts deemed to be more important due to their magnitude and/or improvement potential .

The general framework for LCA is described in two ISO standards:

- ISO 14040:2006: Environmental management – Life cycle assessment – Principles and framework;
- ISO 14044:2006: Environmental management – Life cycle assessment – Requirements and guidelines.

The framework proposed by the ISO standards consists of the following elements:

- Selection of impact categories, category indicators and characterisation models;
- Classification: assignment of inventory data to impact categories;
- Characterisation: calculation of category indicator results;
- Normalisation: calculating the magnitude of the category indicator results relative to a chosen reference information dataset;
- Grouping: sorting and possibly ranking of the impact categories;
- Weighting (valuation): converting and possibly aggregating indicator results across impact categories using numerical values based on value-choices.

According to ISO 14040 the first three elements, 1) selection of impact categories, category indicators and characterisation models; 2) classification and 3) characterisation, are mandatory. After completion of the three steps an environmental profile is available which gives the environmental impact of a product for different (selected) impact categories. The environmental profile gives no information on the importance of certain impact categories. All impact categories are treated as being equal. In addition to the three mandatory steps, normalisation, grouping and weighting can take place.

Normalisation

Normalisation is the calculation of the magnitude of the category indicator results relative to some reference information. The aim of the normalisation is to better understand the relative magnitude for each indicator result of the product system under study. A typical product energy efficiency index as derived and applied in energy labelling and Ecodesign regulations will be a classic case of normalisation where the energy consumption of a product will be compared to that of a reference (standard) product providing identical service.

Grouping

Grouping is the assignment of impact categories into one or more sets as predefined in the goal and scope definition, and it may involve sorting and/or ranking. Grouping is an optional element with two different possible procedures:

- to sort the impact categories on a nominal basis, e.g. by characteristics such as inputs and outputs or global, regional and local spatial scales;
- to rank the impact categories in a given hierarchy, e.g. high, medium, and low priority.

Ranking is based on value-choices. Different individuals, organisations, and societies may have different preferences; therefore it is possible that different parties will reach different ranking results based on the same indicator results or normalised indicator results.

Weighting

Weighting is the process of converting indicator results of different impact categories by using numerical factors based on value-choices. It may include aggregation of the weighted indicator results. Weighting is an optional element with two possible procedures:

- to convert the indicator results or normalised results with selected weighting factors;
- to aggregate these converted indicator results or normalised results across impact categories.

The derivation of weighting values is often based on value-choices and hence may not be scientifically based. Different individuals, organisations and societies may have different preferences; therefore it is possible that different parties will reach different weighting results based on the same indicator results or normalised indicator results. In an LCA it may be desirable to use several different weighting factors and weighting methods, and to conduct sensitivity analyses to assess the consequences on the LCIA (life cycle impact assessment) results of different value-choices and weighting methods. Different weighting techniques are discussed in the section below discussing different weighting techniques.

Structure of the points system

ISO 14040 and 14044 are not points systems in any normative sense but are standards that set out a methodological process to assess multi-criteria environmental impacts that could be incorporated within a points system.

The process of: selection of impact categories, category indicators and characterisation models; classification: assignment of inventory data to impact categories; characterisation: calculation of category indicator results; normalisation: calculating the magnitude of the category indicator results relative to a chosen reference information dataset; grouping: sorting and possibly ranking of the impact categories; and weighting (valuation): converting and possibly aggregating indicator results across impact categories using numerical values based on value-choices is akin to the elements found in a standard AHP model. In principle it could also combine numerical scaled values with qualitative values, such as yes/no assessments although the latter do not lend themselves to normalisation.

General remarks

When the LCA method is compared to the AHP there are certain similarities. Both begin with multiple criteria, where the criteria in the LCA method are the various environmental impact categories. In both cases indicator scores are ascribed to each of the assessment criteria (impact categories). Under ISO 14040 it is possible to stop the assessment with this step or to carry on with a process of normalisation, grouping and weighting. The normalisation and grouping steps are directly equivalent to the process within the AHP of ascribing alternatives to each criterion and providing normalised scores. The weighting of the criteria is also directly analogous to the AHP thus the full version of the ISO 14040 method can be said to be an example of the application of the more generic AHP approach to environmental impact assessment.

Method evaluation

Effectiveness

Life cycle assessment is already part of the MEErP methodology (task 5). The methodology is already used to simulate the intended Ecodesign improvement potential. Making use of the EcoReport tool, the methodological steps of classification, characterisation and normalisation (against shares in EU totals) take place. The last step gives an idea of the relative share ('importance') of each impact category in the EU.

The methodology stimulates the intended Ecodesign improvement potential and especially is fair and representative of the actual savings reductions that adoption of a set of Ecodesign technology design options would produce.

Impacts related to the energy in use phase are taken into account. However, the way the total energy use of a product is determined, is not prescribed by the life cycle assessment methodology. In this sense the methodology is incomplete, as proper accountancy for energy efficiency in use impacts is necessary for the Ecodesign appraisal of complex products.

Accuracy

As described in the MEErP methodology report several problems with life cycle assessment might occur:

- there are significant differences in the LCI-data between the available tools/ databases. Possible causes are differences in methodology, lack of data, data bias and use of data that are not up-to-date. Should the LCA in the preparatory studies be based on available LCA tools there would be significant differences depending on the tool/database adopted, which in a legislative context is not desirable;
- there are significant differences in some LCIA multipliers between the available LCA tools/ databases, both in nature/definition of the impacts and in the multiplier values used. And none of the currently available LCIA multipliers exactly meets the requirements established in the Ecodesign Directive, nor are they specifically designed for the realisation of specific policy goals;
- the available LCA-tools/ databases are directed towards LCA-practitioners. Their proper use requires training, experience and background knowledge both in LCA-science and industrial process technologies. Without that, the use of the tools may lead to highly debatable choices and incoherence between the various Ecodesign preparatory studies.

MEErP minimises these problems by

- laying down the ground rules for methodological issues in LCI assessment;
- determining the LCIA impact indicators, based on the EU Ecodesign Directive and other environmental legislation regarding the set of indicators. Its values are directly derived from emission limit values in the legislation (updated for MEErP 2011) and the aggregation level of the data is tuned to the domain of Ecodesign;
- retrieving the available LCI data to build a compact set of unit indicators for the public domain and
- developing a user-friendly, easy-to-use EcoReport 2011 spreadsheet tool for the LCA (see paragraph 6. and separate .xls file).

By implementing the above list, there is a great probability that the results obtained by different practitioners will be more or less the same. The Ecoreport tool is a simplified life cycle assessment instrument, which makes it user friendly but the drawback is that the overall accuracy is lower.

Reproducibility

As explained above, the MEErP methodology describes some methodological aspects of LCA and a user-friendly EcoReport tool is made available. By implementing the prescribed methodological aspects and the EcoReport tool, the reproducibility of the method attains an acceptable level.

Enforceability

In principle any impact parameters that are measureable via existing methodological and test standards can be independently verified and hence are enforceable. Enforceability becomes more challenging the more impact parameters that need to be assessed and the more difficult the parameters are to measure the greater difficulty in enforcement, thus the process set out in ISO 14040 and 14044 covers a broad spectrum of potential enforceability situations. We note that LCA of building products is already enforced by different Member States.

Transparency

The method is transparent in principle but may be less transparent in any specific implementation case.

Ease and readiness

As mentioned above there are numerous cases of the implementation of aspects of the ISO 14040 and 14044 standards including those already applied within the Ecodesign regulatory process. The ease and readiness of implementation varies among these cases.

Capacity to be implemented

A priori the LCA methods within ISO 14040 and 14044 are consistent with the legally enshrined methodological aspects of the Ecodesign regulations and fit within the Ecodesign and Energy Labelling procedural and decision making process. It is broadly compatible with the MEErP and Ecoreport tool approaches, which constitute slightly simplified implementations of a full LCA approach.

4.2 Different weighting techniques

Method description and reference

As described above, weighting is the process of converting indicator results of different environmental impact categories obtained in a life cycle assessment, by using numerical factors based on value-choices. The aim of a weighting procedure is to combine different environmental effect indicators based on their relative importance to derive an overall assessment score. This allows for an easier survey of otherwise complex indicators. Figure 1 illustrates the weighting process. Because weighting steps are based on value-choices and are not determined from empirical data, it is possible that different parties will reach different weighting results based on the same indicator results or normalised indicator results. Weighting has always been a challenging topic in LCA, partly because this element requires the incorporation of social, political and ethical values.

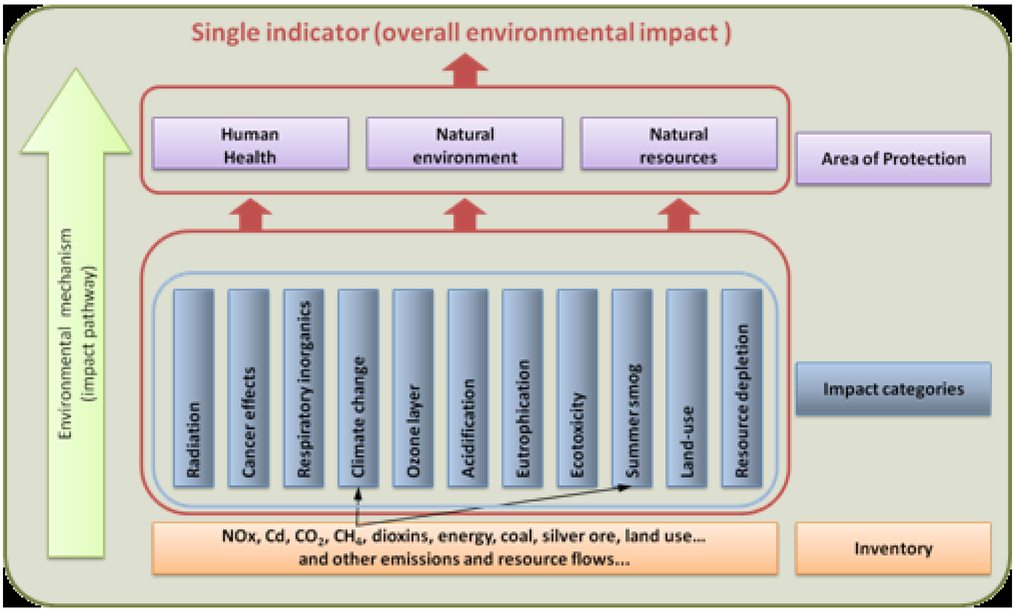

Figure 1: Single score indicators (source: Joint Research Centre JRC)

Despite this controversy, weighting is frequently used in LCA practice and several weighting methods have been developed over the last ten years.

Methods for weighting can be classified in different categories, namely:

1. **Delphi- or panel methods**, where a group of experts representing different stakeholders are asked to provide their weighting factors;
2. **Distance-to-target methods**, where the weighting factors for each environmental impact or theme depend on the difference between the current performance and a target level;
3. **Monetisation or external costing methods**, where the weighting factors are expressed in monetary values (external environmental costs) according to the estimated economic damage incurred in an impact category or to what is necessary to prevent the damage itself.

These three methods of deriving weightings are evaluated in more detail below in order to consider their relative strengths and weaknesses for potential application in an Ecodesign related points scheme.

Method evaluation – Delphi – or panel methods

Panel methods are the most commonly used approach in the derivation of multi-criteria assessment scheme weightings. They bring together and solicit input from the key stakeholders responsible for the development of the scheme within a structured dialogue that enables necessary value judgements to be made in an isolated and focused manner. One reason why this is the most commonly used approach is that it is fast and easy to apply (Debacker et al., 2012). In principle where it is necessary to take input from a broad group of informed and mandated stakeholders within, for example, a regulatory framework, there is an option to formalise the panel weighting process such that a weighted average of stakeholder responses is taken where weightings could be derived based on accepted rules (e.g. the EU’s qualified majority voting system or some equivalent structure that brings in other sets of pertinent stakeholders).

There are, however, several weaknesses in the panel method approach (Goedkoop et al., 2016):

- it is difficult to explain to a panel the meaning of the impact category indicators; they are too abstract ("CO_2 equivalency" or "Sb (Antimony) equivalency"). A panel may be unduly subject to influence and this may introduce undesirable bias and "group think" effects;
- The number of indicators assessed in a life cycle assessment is usually rather large (10 to 15), and this causes cognitive stress making it challenging to get meaningful results;
- panels tend to give a small range of weights (usually between 1 and 3). In social sciences, this is called 'framing';
- it may be unclear what and whom the panel represents and/or the legitimacy or mandate of the panel may not be established;
- panel-based value judgements are necessarily subjective, albeit if the panel is informed by a broad consultation its determinations are likely to become more representative of the values of the stakeholders it seeks to represent.

Effectiveness

Panel methods are effective in that they can enable rapid and relatively consensual decisions to be made but they are perhaps less effective in the degree to which they may lack objectivity. In a political process they can be effective in representing the values of mandated stakeholders.

Accuracy

Once weightings are derived they can be applied very accurately; however, the subjectivity aspect means that the scientific accuracy of the outcomes cannot be assessed against any objective measurement scale. As with other methods the accuracy will also be dependent on the level of uncertainty in the measurement of the impact parameters.

Reproducibility

Reproducibility can be high when the same panel weightings are applied and there is low uncertainty in the measurement of the impact parameters. Reproducibility could be low were different panels to be charged with deriving their own weightings.

Enforceability

Enforceability can be high when the same panel weightings are applied and there is low uncertainty in the measurement of the impact parameters. It can be low were there to be divergence in the weightings applied.

Transparency

The method can be fully transparent providing it is fully documented and made available to users.

Ease and readiness

This could be high or low depending on other aspects of the scheme.

Capacity to be implemented

This could be high or low depending on other aspects of the scheme.

Method evaluation – Distance-to-target methods

A distance-to-target method is more objective than a panel method, but largely depends on the (local/regional) political targets, which are not always in line with the worldwide environmental concern (Debacker et al., 2012). Castellani et al. (2016) used a distance-to-target approach to develop a weighting method for Europe 2020. They explain that weighting factors in distance-to-target (DTT) weighting methods could be based on calculations that are performed on normalization factors. The weighting factor is defined for each environmental impact category as the ratio between the actual impact and the target impact. The target impacts can be the expected level of impact foreseen by policy targets or physical thresholds not to be trespassed as in the case of planetary boundaries.

Goedkoop et al. (2016) mention the following difficulties:

- in the case where multiple policy targets are used, it is not clear if all targets are equally important;
- distance to target methods can be effective at objectively orientating outcomes towards the target objective.

Accuracy

Once weightings are derived they can be applied accurately; especially if the degree to which the target is met is readily measureable. As with other methods the accuracy will also be dependent on the level of uncertainty in the measurement of the impact parameters.

Reproducibility

Reproducibility can be high providing the targets are common and there is low uncertainty in the measurement of the impact parameters.

Enforceability

Enforceability can be high providing the impact parameters are readily measureable via standardised methods.

Transparency

The method can be fully transparent providing it is fully documented and made available to users.

Ease and readiness of use

This could be high or low depending on other aspects of the scheme.

Capacity to be implemented

This could be high or low depending on other aspects of the scheme.

Method evaluation – Monetisation or external costing methods

According to Debacker et al. (2012) this method has the advantage of being the most objective one. The disadvantage is that the process of defining the external costs is difficult and can be done in different ways which lead to different outcomes.

Effectiveness

Monetisation methods are highly effective in leading to comparatively objective decisions and outcomes; however, from a policy making perspective they require acceptance of the methodology applied to determine the monetised weightings and agreement to abide by the outcome.

Accuracy

Once weightings are derived they can be applied accurately; however, the fact that there are different methods for determining the monetised value of the impact criteria and that these also depend on an assessment of value judgements means that the accuracy of their technical underpinning is still somewhat subjective. As with other methods the accuracy will also be dependent on the level of uncertainty in the measurement of the impact parameters.

Reproducibility

Reproducibility can be high when the same weightings are applied and there is low uncertainty in the measurement of the impact parameters.

Enforceability

Enforceability can be high when the same weightings are applied and there is low uncertainty in the measurement of the impact parameters.

Transparency

The method can be very transparent providing it is fully documented and made available to users.

Ease and readiness of use

This could be high or low depending on other aspects of the scheme.

Capacity to be implemented

This could be high or low depending on other aspects of the scheme.

4.3 Product Environmental Footprint

Method description and reference

In April 2013 the European Commission launched a Recommendation on the use of common methods to measure and communicate the life cycle environmental performance of products, also known as Product Environmental Footprint (PEF) as part of their Single Market for Green Product's initiative[3]. The method was developed by the European Commission's Joint Research Centre based on existing, extensively tested and used methods. The Commission also launched a three-year testing period through an open call for organisations to volunteer to participate in a PEF pilot programme[4]. The call was addressed to stakeholders who wanted to propose a product category for which to develop specific Product Environmental Footprint Category Rules (PEFCRs).

The Commission published recommendations on the PEF in the form of guidelines in 2013 (CEC 2013) which set out the process by which specific PEFCR are to be developed. It includes the derivation of 15 default environmental impact categories as shown in Table 2.

[3] http://ec.europa.eu/environment/eussd/smgp/
[4] http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

Table 2: Default EF impact categories (with respective EF impact category indicators) and EF impact assessment models for PEF studies (European Commission, 2013)

EF Impact Category	EF Impact Assessment Model	EF Impact Category Indicators	Source
Climate Change	Bern model - Global Warming Potentials (GWP) over a 100 year time horizon.	kg CO_2 equivalent	Intergovernmental Panel on Climate Change, 2007
Ozone Depletion	EDIP model based on the ODPs of the World Meteorological Organization (WMO) over an infinite time horizon.	kg CFC-11 (*) equivalent	WMO, 1999
Ecotoxicity for aquatic fresh water	USEtox model	CTUe (Comparative Toxic Unit for ecosystems)	Rosenbaum et al., 2008
Human Toxicity - cancer effects	USEtox model	CTUh (Comparative Toxic Unit for humans)	Rosenbaum et al., 2008
Human Toxicity – non-cancer effects	USEtox model	CTUh (Comparative Toxic Unit for humans)	Rosenbaum et al., 2008
Particulate Matter/Respiratory Inorganics	RiskPoll model	kg PM2,5 (**) equivalent	Humbert, 2009
Ionizing Radiation – human health effects	Human Health effect model	kg U^{235} equivalent (to air)	Dreicer et al., 1995
Photochemical Ozone Formation	LOTOS-EUROS model	kg NMVOC (***) equivalent	Van Zelm et al., 2008 as applied in ReCiPe
Acidification	Accumulated Exceedance model	mol H+ eq	Seppälä et al.,2006; Posch et al., 2008
Eutrophication – terrestrial	Accumulated Exceedance model	mol N eq	Seppälä et al.,2006; Posch et al., 2008
Eutrophication – aquatic	EUTREND model	fresh water: kg P equivalent marine: kg N equivalent	Struijs et al., 2009 as implemented in ReCiPe
Resource Depletion – water	Swiss Ecoscarcity model	m^3 water use related to local scarcity of water	Frischknecht et al., 2008
Resource Depletion – mineral, fossil	CML2002 model	kg antimony (Sb) equivalent	van Oers et al., 2002
Land Transformation	Soil Organic Matter (SOM) model	Kg (deficit)	Milà i Canals et al., 2007

(*) CFC-11 = Trichlorofluoromethane, also called freon-11 or R-11, is a chlorofluorocarbon.
(**) PM2,5 = Particulate Matter with a diameter of 2,5 µm or less.
(***) NMVOC = Non-Methane Volatile Organic Compounds

Note, although Table 2 only lists 14 impact categories, Eutrophication aquatic has to be calculated for both a freshwater and a marine environment and thus this makes 15 impact categories in total.

In the framework of the environmental footprint pilot phase the use of normalisation and weighting factors is being tested. Until there is an agreed set of European weighting factors, all impact categories shall receive the same weight (weighting factor = 1). Alternative weighting approaches may also be tested as "additional" compared to the equal weighting approach (the baseline approach). In the event that alternative weighting systems are also tested, a sensitivity analysis will be carried out and the results documented and discussed through a stakeholder consultation process.

For any specific PEFCR, the intention is that a benchmark and performance grades will be established.

The benchmark shall be calculated for all 15 impact categories separately. The final PEFCR shall describe the uncertainties common to the product category and should identify the range in which results could be seen as not being significantly different in comparisons or comparative assertions.

Next to the calculated benchmark, each pilot should define 5 classes of environmental performance (from A to E, with A being the best performing class). The benchmark is the characterised results of the PEF profile of the representative product(s) and always represents class C. The definition of the remaining classes should be based taking into account the estimated spread around the benchmark results, which might differ from one impact category to another and an estimation of the expected environmental performance for the best and worst in class products. All relevant assumptions regarding the identification of the benchmark and the classes of environmental performance shall be documented in the PEFCR, and be part of the virtual consultation process and of the review process.

Structure of the points system

The PEF is essentially aiming towards a points system application of the LCA process as set out in ISO 14040 and 14044.

The process of: selection of impact categories, category indicators and characterisation models; classification: assignment of inventory data to impact categories; characterisation: calculation of category indicator results; normalisation: calculating the magnitude of the category indicator results relative to a chosen reference information dataset; grouping: sorting and possibly ranking of the impact categories; and weighting (valuation): converting and possibly aggregating indicator results across impact categories using numerical values based on value-choices is akin to the elements found in a standard AHP model.

When the PEF method is compared to the AHP there are certain similarities. Both begin with multiple criteria, where the criteria in the PEF method are the various environmental impact categories. In both cases indicator scores are ascribed to each of the assessment criteria (impact categories). The normalisation and grouping steps are directly equivalent to the process within the AHP of ascribing alternatives to each criterion and providing normalised scores. The weighting of the criteria is also directly analogous to the AHP thus the PEF can be said to be an example of the application of the more generic AHP approach to environmental impact assessment.

Method evaluation

Some general observations about the status of the PEF methodology are now given before delivering the team's assessments in accordance with the standard assessment framework applied to all the methodologies.

Robustness of indicators: In total, the PEF methodology requires the assessment of 15 impact indicators. For some of these the PEF guidance document v 5.2 indicates they cannot currently be determined in a sufficiently reliable manner. If it is decided in the pilot to publish the normalised and weighted results, then the following disclaimer shall be added to the screening report: *"Within the Environmental Footprint (EF) pilot phase normalisation and equal weighting were foreseen to be used in the EF screenings to identify the most relevant impact categories. The use of normalisation and weighting for this purpose remains the objective for the EF pilots and beyond. However, currently PEF screening results after the normalisation and equal weighing present some inconsistencies stemming from errors at various levels of the assessment. Therefore, screening results after normalisation and equal weighting are not sufficiently robust to apply for product comparisons in an automatic and mandatory way in the Environmental Footprint (EF) pilots, e.g. to identify the most relevant impact categories. The interpretation of the results reflects these limitations. To avoid potential misinterpretation and misuse of the EF screening results we highlight that the results after normalisation and equal weighting, - without further error checking and possibly corrections, -* ***are likely to overestimate or underestimate especially the relevance of the potential impacts related to the categories Human toxicity - cancer effect, Human toxicity - non-cancer effect, Ecotoxicity for aquatic fresh water, water depletion, resource depletion, ionising radiation and land use****."*

This finding implies that the listed impact parameters cannot yet be adequately evaluated to be used within a regulatory policy instrument.

Application of weighting factors: the JRC is currently developing a weighting method that is intended for use in the derivation of PEFCR. The current approach in the PEF pilot phase is the use of equal weighting factors (all impact categories are considered equally important).

Effectiveness

The method is effective for the indicators which can be reliably measured but not so much for those which are difficult to measure or whose impacts are challenging to quantify. In principle the PEF should be an effective instrument from a technical methodological perspective but faces challenges in the derivation of consensual weightings between the impact categories and in establishing the magnitude of some of the impacts. Furthermore, the large number of impact categories might be considered to be too onerous for implementation in a practical Ecodesign-type regulatory scheme, especially when dealing with complex products for which the derivation of specific functional units may already be demanding, and thus an argument could be made that the number of impact parameters to be considered should be reduced if the scheme is to be considered in this context.

Nonetheless usually the biggest challenge for complex products is the derivation of the functional unit and this is likely to be more important than the number of impact categories provided that good background data is available for each of these.

Accuracy

The accuracy is good for readily measureable impact parameters and less so for those that are less readily measured or established. The current default application of equal weighting between impact categories is arbitrary and hence likely to be inaccurate; however, were suitable weighting processes to be developed this limitation would be overcome.

Reproducibility

Reproducibility should be reasonable when the impact parameters are readily measureable with an acceptable degree of accuracy (however, this is not presently the case for all of the impact parameters) and when PEFCR have been developed. In cases where such a PEFCR is unavailable the reproducibility is likely to be low.

Enforceability

The PEF should be reasonably enforceable from a technical perspective when the impact parameters are readily measureable with an acceptable degree of accuracy; however, this is not presently the case for all of the impact parameters. The large number of impact parameters will make verification of test results and documentation more challenging than for schemes that require less parameters to be assessed.

Transparency

The method is transparent in principle and is being fully documented in a publicly accessible manner.

Ease and readiness

The PEF is methodology is not yet finalised and hence is not fully ready for implementation.

Capacity to be implemented

The PEF method is transparent and in principle should be suitable for implementation once finalised; however, the large number of diverse impact parameters add complexity and will always make it more challenging to implement than standard Ecodesign regulations which are focused on a narrower set of parameters.

A priori the LCA methods embedded within the PEF are consistent with the legally enshrined methodological aspects of the Ecodesign regulations and would fit, in a legal sense, within the Ecodesign and Energy Labelling procedural and decision-making process. They are broadly compatible with the MEErP and Ecoreport tool approaches, which constitute slightly simplified implementations of a full LCA approach. However, the increase in impact parameters requiring assessment would either increase the time and effort needed to undertake a preparatory study and to develop and approve regulatory criteria, or would lead to less analytical and assessment effort being focused on the current criteria of interest within the Ecodesign regulations.

4.4 Field trial of environmental labels in France

Method description and reference

The French government undertook an ambitious environmental labelling field trial involving the voluntary participation of 168 enterprises that displayed an environmental label on products for sale in their shops and/or for sale on-line. Most participating companies were retailers rather than manufacturers. Three of these enterprises are appliance manufacturers.

The ambition, regarding the content, was to supply full life cycle information using a multi-criteria approach covering several environmental impacts. The experiment was undertaken within the context of a legal framework which plans for the mandatory introduction of an environmental label in the near future. Participants were free to choose the products, methodology and shape of their label, etc. but in the future the intention is for the adoption of a single unified approach to inform consumers.

A platform coordinated by the French Agency for the Environment and Energy Management (ADEME) and the French standardisation association (AFNOR) elaborated good practice specifications to evaluate and present data on environmental impacts. Each participating organisation had the freedom to develop their own experimental labelling approach within the auspices of these general guidelines and thus the trial constituted a means of assessing a large range of multi-impact criteria environmental labelling approaches.

The following figures give examples of the labels displayed.

Figure 2. Example of label on the Internet and in shops for appliances implemented by Discounteo (Centre d'Analyse Stratégique, 2013)

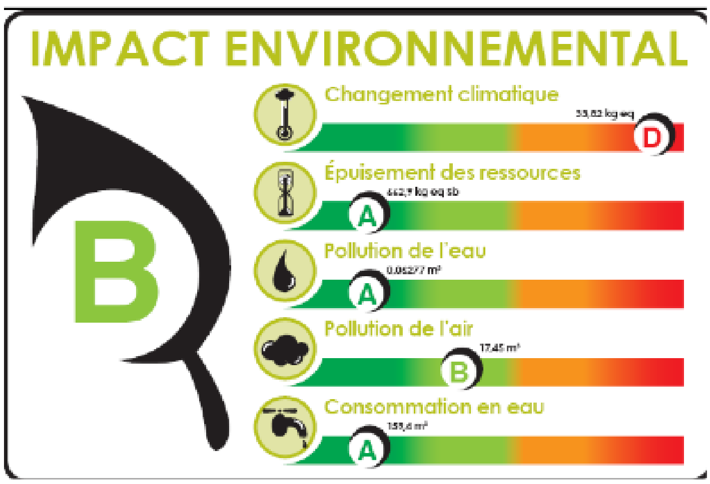

Figure 3. Example of label for paint and glue implemented by Leroy-Merlin (Centre d'Analyse Stratégique, 2013)

The evaluation of this trial found most participating companies were in favour of environmental labelling over the more or less long term, although they identify a number of pre-conditions in terms of the availability of the following elements:

- the need to have established a harmonised methodological framework and technical background information, adapted to the needs of SMEs;
- harmonised specifications per sector;
- complete and updatable databases;
- automated impact calculation tools to avoid start-up costs for enterprises;
- the definition of homogeneous formats to insure consumer understanding and information comparability;
- a system compatible with a (wished for) European or even globally harmonised scheme to optimise French technical investments;
- a standardisation framework to secure long term visibility and support the investments that will need to be made;

- verification procedures to build trust in the system and insure quality information to consumers (the cost of these procedures should not constitute an economic obstacle to companies);
- a reasonable implementation timeframe, acknowledging the need of preparation and adaptation time (small enterprises do not have enough internal resources and large enterprises have large amounts of data to manage);
- supportive accompanying measures from public authorities such as information and communication campaigns.

Given the limited scale of the experiment and the relatively large number of sectors covered, formats tested and participating companies, no generic consumer evaluation could take place regarding possible change in purchasing behaviours or understanding of the various labels.

It seems however that lessons learnt could be gathered through the companies' own evaluations regarding consumers who:

- prefer simple explanatory wording for the impact indicators;
- ask that data be presented as absolute values;
- ask however that this absolute value be positioned on a relative scale in order to compare products;
- are very attached to how the values are presented (with colour codes and ordering with letters);
- in this respect, support the use of the energy label;
- appreciate one general note complementing single impacts per factor.

Structure of the points system

While the environmental label field trial does constitute the implementation of a set of systems for displaying and classifying multi-criteria environmental impacts it is not a points system. The decision was made to structure it such that each impact criteria is displayed separately. In some cases this was done by displaying absolute values but often this was also or exclusively done using a normalised scale and ranking process for each impact parameter, akin to some of the steps in ISO 14040 and 14044. In no cases was a system used to develop an aggregated score or ranking across the impact parameters, even though many consumers reported they would have found this helpful.

Method evaluation

As many different label realisations were tested in this project it is not possible or useful to evaluate them via the same framework applied to the points system methodologies. Rather it can be said that the same remarks as apply to the first stages of ISO 14040 and 14044 will apply here, with the distinction that the label trials did not include aggregate scoring or evaluation across the impact criteria and hence did not apply weightings.

4.5 Common framework of core performance indicators for resource efficiency assessment in the building sector

Method description and reference

In July 2014, as the result of an initiative lead jointly by DG ENV and DG Growth, the EC adopted the Communication on Resource Efficiency Opportunities in the Building

Sector (COM(2014)445)[5]. This communication identified the need for a common European approach to assess the environmental performance of buildings throughout their lifecycle, taking into account the use of resources such as energy, materials and water.

In response to the need identified, a study to identify a common EU framework of indicators to assess the environmental performance of buildings is being carried out by the JRC, during the period of 2015-2017. The overall aim of the study is to develop a common yet flexible framework of indicators that may be integrated into existing and new schemes addressing building environmental impacts, or might be used on its own, although the intention is not to create a new standalone building certification scheme. The intention is that the framework should be rigorous enough to drive improvement in performance and allow for comparison. Moreover, there should be a clear link between the indicators and a set of overarching macro-objectives, thereby ensuring that there is a clear and measurable contribution to strategic policy objectives.

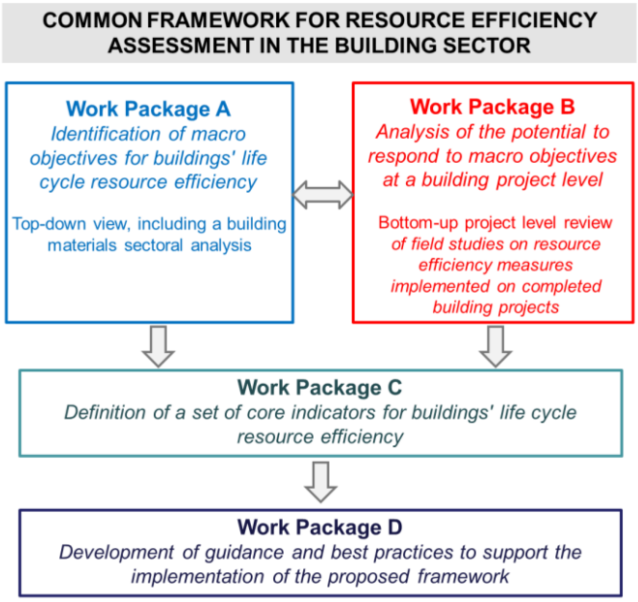

Figure 4. Framework for resource efficiency assessment in the building sector (JRC, 2015)

The macro objectives (work package A in Figure 4) have been defined by JRC and are available in a publication from Dodd et al. (2015). Two types of macro-objectives have been identified – those relating to *'life cycle environmental performance*' and those relating to *'quality, performance and value'*. In the short term, six of these macro-objectives are proposed to be taken forward in order to identify related performance indicators which will make up the framework. These macro-objectives focus on the building level:

'Life cycle environmental performance' macro-objectives for buildings

1. **Greenhouse gas emissions from building life cycle energy use**: Minimise the total GHG emissions along a buildings lifecycle, with a focus on building operational energy use emissions and embodied emissions.

[5] http://susproc.jrc.ec.europa.eu/Efficient_Buildings/index.html

2. **Resource efficient material life cycles**: Optimise building design, engineering and form in order to support lean and circular flows, extend long-term material utility and reduce significant environmental impacts.
3. **Efficient use of water resources**: Make efficient use of water resources, particularly in areas of identified long-term or projected water stress.

'Quality, performance and value' macro-objectives for buildings

4. **Healthy and comfortable spaces**: Design, construction and renovation of buildings that protect human health by minimising the potential for occupier and worker exposure to health risks.
5. **Resilience to climate change**: The futureproofing of building thermal performance to projected changes in the urban microclimate, in order to protect occupier health and comfort.
6. **Optimised life cycle cost and value**: Optimisation of the life cycle cost and value of buildings, inclusive of acquisition, operation, maintenance and disposal.

In order to define the macro-objectives the researchers conducted a prioritisation exercise based on the evidence collated in the study. The prioritisation exercise consisted of five steps:

1. identification of a reference set of 20 priority environmental issues at EU level;
2. association of building life cycle 'hot spots' with these 20 reference environmental issues;
3. association of existing EU strategies and policy instruments with the identified building life cycle 'hot spots';
4. prioritisation and categorisation of the 20 reference environmental issues based on their EU policy and building life cycle significance;
5. clustering of the 20 reference environmental issues so that building-related macro-objectives can then be identified.

The bottom-up exercise (work package B in Figure 4) is currently ongoing. The aim of this work package is to understand the scope and potential in the short to medium term to address the macro-objectives for life cycle resource efficiency at the building project level, taking into account different building uses, forms, as well as potential variation in pertinent geographical and cultural factors. The assessment intends to contribute to ensuring that there is a practical link between top-down macro-objectives and the core indicators that are finally proposed to be implemented at the building project level.

Structure of the points system

This project is ongoing and so far has not led to the derivation of a points system therefore it is premature to assess its structure at this juncture.

Method evaluation

This project is ongoing and so far has not led to the derivation of a system which can be evaluated at this juncture.

4.6 Material based environmental profiles of building elements (MMG)

Method description and reference

MMG (Debacker et al., 2012) is a life cycle assessment based expert evaluation tool. It is used for the assessment of the environmental impacts associated with the choices of building materials at the material element/whole building level. To develop this tool an integrated environmental assessment methodology has also been developed as set out below.

The intention of the assessment of the environmental material performances of building elements is to simplify the identification and selection of environmentally friendly materials and work sections. The list of environmental impact categories considered in the method has been established based on a questionnaire launched amongst Flemish policymakers. The policymakers were asked to select the relevant environmental themes (green list in Figure 5). Those themes were linked to environmental impact categories. To calculate the results of the different environmental impact categories, the recent ReCiPe methods (Goedkoop et al., 2008) were selected. According to the JRC (2011), the compatible ReCiPe methods have a solid scientific basis for all selected impact categories. However, to achieve the goal of decision-making (selecting environmentally-friendly building materials), a multiplicity of individual impact scores is rarely a good basis. For this reason the possibility is offered of presenting the environmental profile of a building element via an aggregated score. Given that current European standards do not propose any specific aggregation method, the MMG derived a weighting system by means of monetary valuation. Under this structure the absolute value of each impact indicator is multiplied by a monetisation factor (e.g. X kg CO_2 equiv. times Y €/kg CO_2 equiv.). These monetised figures express the value of the environmental damage that is not factored into the price of the building materials, but which is passed on to society through, for example, sickness and damage to biodiversity. These environmental costs can then be compared with the respective financial costs. When any impact aggregation approach is applied, it is recommended to use matching impact methods for the different impact categories, so as to avoid gaps and duplication. The MMG project opted – with respect to determining the aggregate score – for the recent ReCiPe methods.

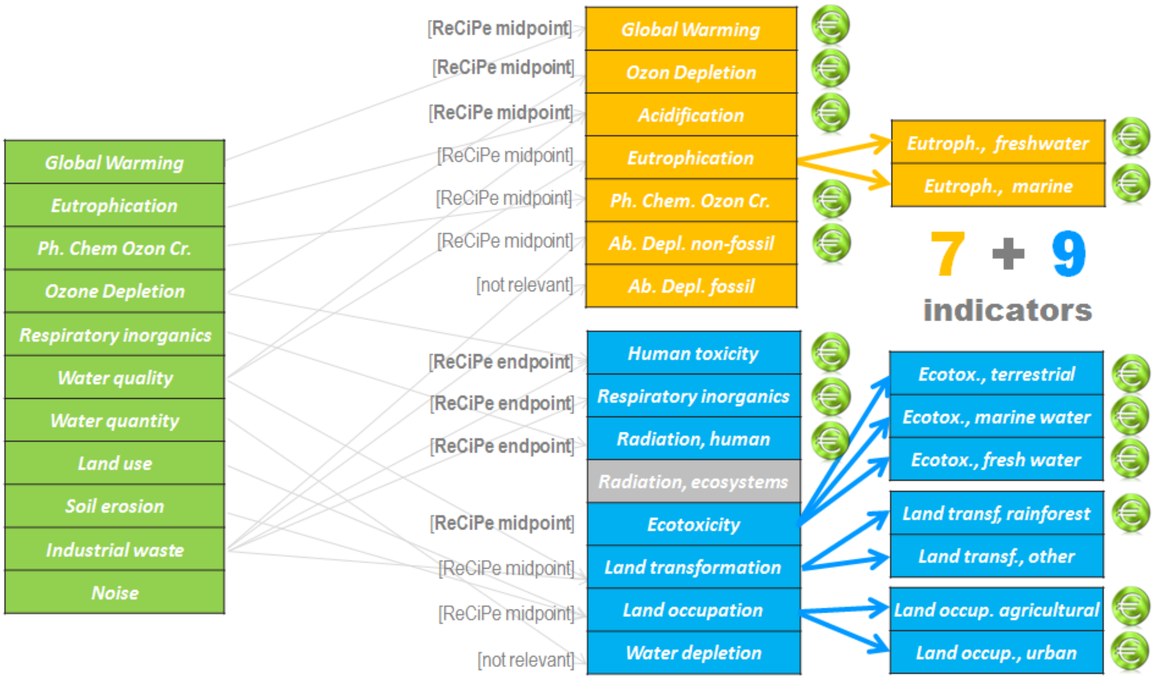

Figure 5: Development of MMG methodology (Debacker et al., 2012)

Structure of the points system

The structure used in the MMG points system is to define environmental impact categories and then to aggregate the points to give an overall total via the application of monetised weightings to the impact category scores. This structure can be said to be akin to a standard AHP model using impact category weightings. It is a fully quantified approach and thus follows an objective logic. The only subjectivity arises due to how the monetised values ascribed to the environmental impacts are determined but this method applies a consistent and detached methodology for assessing these and hence does not carry risk from policy bias more closely related to the specific decision being assessed.

Method evaluation

The part of MMG which is of interest for this research is the developed aggregation or weighting method used to compare the magnitude of impacts across the different environmental impact criteria. The researchers opted for the use of a monetisation or "external costing" methodology to derive the weightings. The developers contend that this method offers significant added value compared with other weighting methods, such as the panel method, the distance-to-target method and damage methods (Allacker 2010, van den Dobbelsteen 2004). As explained in Allacker and De Nocker (2012), the objective of monetary valuation in the research is to express, in monetary terms, how the welfare of current and future generations is affected by the environmental impacts caused by activities in the building sector. This valuation concerns the overall environmental impact, which was defined as the damage imposed on human health, ecosystems, and resources. These environmental costs (also referred to as "external costs" or "shadow costs") arise when the activities of one group of people have an impact on others, and when the first group fails to fully account for these impacts (European Commission 2008). The costs are passed on to society as a whole (e.g., health impacts from air pollution) or to future generations (e.g., global warming).

Effectiveness

The method is effective for the indicators which can be reliably measured but not so much for those which are difficult to measure or whose impacts are challenging to quantify. In principle the MMG is an effective instrument from a technical methodological perspective and creates an internally consistent framework for making assessments across environmental impacts. As with any such method it involves addressing challenges in the derivation of consensual weightings between the impact categories and in establishing the magnitude of some of the impacts; however, the act of using a separate and consistent methodology for doing this is less subject to bias and policy interference than more subjective panel methods. On the other hand the large number of impact categories might be considered to be too onerous for implementation in a practical Ecodesign-type regulatory scheme, especially when dealing with complex products for which the derivation of specific functional units may already be demanding, and thus an argument could be made that the number of impact parameters to be considered should be reduced if the mechanism is to be considered for application in this context.

Accuracy

The accuracy is good for readily measureable impact parameters and less so for those that are less readily measured or established. The relative neutrality of the weighting system applied increases the methods accuracy by comparison with panel-based weighting methods.

Reproducibility

This should be reasonable when the impact parameters are readily measureable with an acceptable degree of accuracy.

Enforceability

The MMG should be reasonably enforceable from a technical perspective when the impact parameters are readily measureable with an acceptable degree of accuracy. The large number of impact parameters will make verification of test results and documentation more challenging than for schemes that require fewer parameters to be assessed.

Transparency

The method is transparent and is fully documented in a publicly accessible manner.

Ease and readiness

MMG appears to be straightforward to apply except for the need to assess a relatively large number of impact parameters. The method is existent and ready to use. It does not require extensive training to be able to use.

Capacity to be implemented

A priori the LCA methods used within the MMG are consistent with the legally enshrined methodological aspects of the Ecodesign regulations and fit within the Ecodesign and Energy Labelling procedural and decision making process. It is broadly compatible with the MEErP and Ecoreport tool approaches, which constitute slightly simplified implementations of a full LCA approach. The application of environmental impact criteria aggregator functions based on monetised weightings is not precluded within the Ecodesign Directive and were such a system to be developed and agreed upon could greatly facilitate a standardised and unambiguous approach to the establishment of priorities and thresholds within Ecodesign; however, this would require agreement at the EU level on the methods to be used to determine monetised impact values and extensive research effort to establish such values. Neither of these are likely to be trivial exercises.

4.7 Methodology to integrate cost effectiveness in determining the performance of a technology in the framework of Strategic Ecological Support (STRES)

Method description and reference

This project has been performed by Vercalsteren et al. (2013) under the authority of Flanders Innovation & Entrepreneurship. The objective of the project was to develop a methodology to calculate the environmental and energy-related benefits of company investments. The intention is to incorporate this newly developed method into a pre-existing framework for the evaluation of requests for subsidies for environmentally friendly investments. Moreover the methodology is intended to assist in defining the extent (magnitude) of the subsidy to be granted. Subsidies will be granted based on the ‘Eco class’ in which a product is classified. There are four different Eco classes ranging from A to D. If a company wants to apply for the subsidies, they have to fill in information on the investment and the process inputs for both a standard technology and the environmentally friendly technology.

The information that a company has to submit regarding the investment is the total investment cost and a breakdown of the cost into the following categories for both the standard technology and the environmentally friendly technology: office machines and computers, motors and mechanical driving gear, electromotors, electric generators and transformers, accumulator, electric batteries and other electric equipment, machines for general use, vehicles, iron and steel, glass, plastic, ceramic products, products from concrete, natural stone and other non-metal products, metal construction, general architectural and civil engineering works, technical advice, architect and engineers, technical tests and analysis.

Based on input output LCA modelling of each of these categories points are awarded for both the standard technology and for the environmentally friendly technology.

The information that a company has to submit regarding the process inputs (for both the standard technology and environmentally friendly technology) are: material inputs, water inputs, energy inputs, emissions, waste and difference in the transportation distance of raw materials.

The environmental impact of both the standard technology and the environmentally friendly technology is calculated, based on the information provided, for the production and in-use life cycle phases. The ReCiPe endpoint method is used in this process, for which the endpoint indicators are Human Health, Ecosystems and Resources (see the discussion below for and explanation of Midpoint and Endpoint indicators). To achieve this points are awarded based on their impacts for each endpoint indicator category and are combined into an overall score using a panel weighting method.

In a successive step the environmental benefit is calculated as the difference in points between the standard technology and the environmentally friendly technology. Subsidies are granted based on the cost effectiveness. The cost effectiveness of an investment is calculated by dividing the achieved environmental benefit by the additional cost (both compared to a standard technology).

Midpoint and endpoint indicators

Environmental indicators exist at two levels, namely at the "midpoint level" and "endpoint level".

A wide range of midpoint indicators exist of which some examples are climate change, radiation, ozone layer depletion, acidification, etc. Midpoint indicators are leading indicators of end-point indicators which concern the final impacts that may be attributed to the mind-point indicators. Endpoint indicators are typically established to facilitate easier interpretation of the importance of midpoint indicators but their values are more uncertain than is the case for midpoint indicators.

For example, endpoint indicators are created in the ReCiPe method from Goedkoop et al. (2008) (Figure 6). ReCiPe uses an "environmental mechanism" as the basis for the modelling, which can be seen as a series of effects that collectively create a certain level of damage to, for instance, human health or ecosystems. For instance, for climate change we know that a number of substances increase radiative forcing, which means heat is prevented from being radiated from the earth to space. As a result, more energy is trapped near the earth's surface, and temperature increases. As a result of this effect we can expect changes in habitats for living organisms, and as a result of this species may become extinct (Figure 7).

From this example it is clear that each successive environmental indicator is dependent on the preceding one and thus as uncertainty and error propagate through the derivation of successive indicators the longer one makes the environmental mechanism the higher the uncertainties become. Radiative forcing is a physical parameter that can be relatively easily measured in a laboratory. The resulting temperature increase is less easy to determine, as there are many parallel positive and negative feedbacks. Our understanding of the expected change in habitat is also incomplete, etc. (http://www.lcia-recipe.net/project-definition)

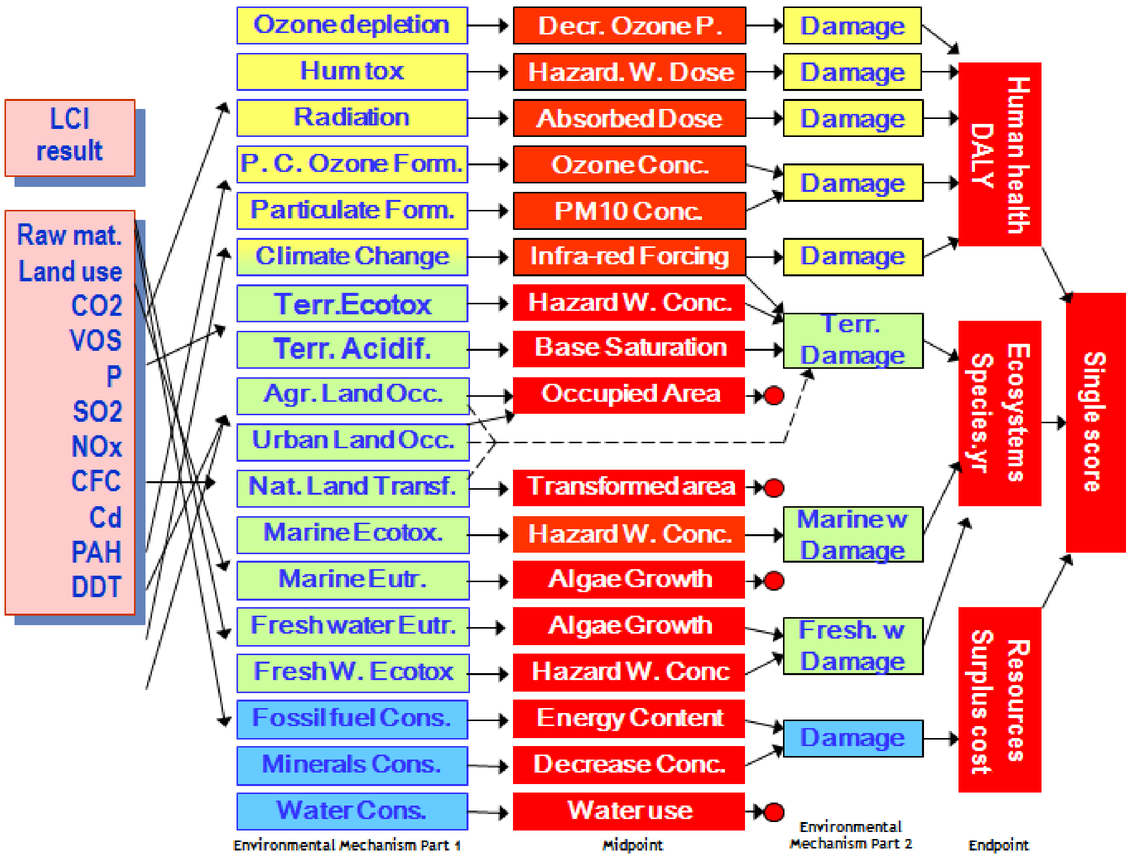

Figure 6: Relationship between LCI parameters (left), midpoint indicator (middle) and endpoint indicator in ReCiPe (Goedkoop et al., 2008).

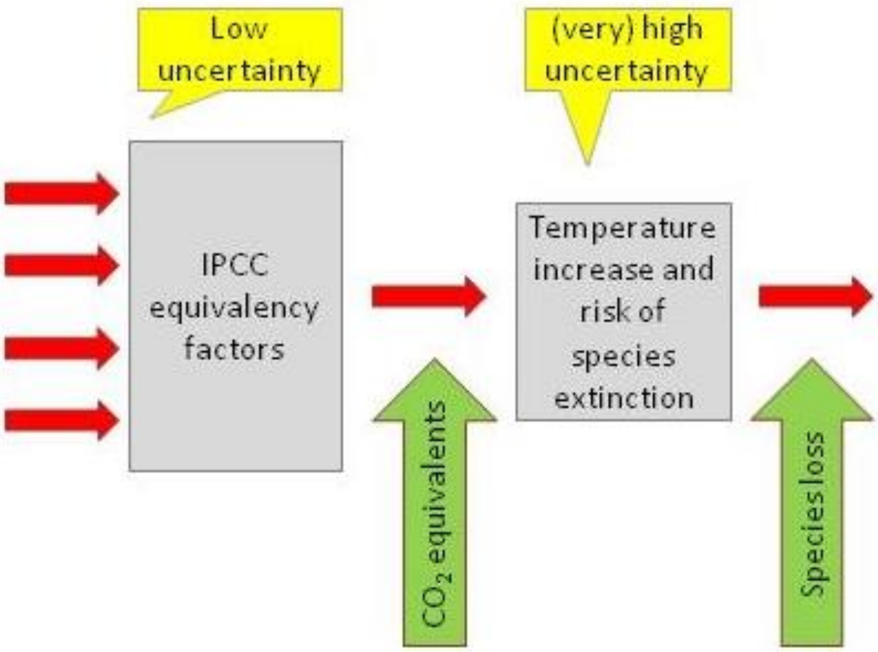

Figure 7: Example of a harmonised midpoint-endpoint model for climate change, linking to human health and ecosystem damage (Goedkoop et al., 2008).

Structure of the points system

The structure used in the STRES points system is to define cost effectiveness from environmental point of view of an investment compared to a standard technology. It is a fully quantified approach and thus follows an objective logic. Subjectivity arises due to how the endpoint indicators are determined in the ReCiPe method and the panel weighting given for aggregated points-scores across the endpoint indicator categories.

In general the value of the points awarded is derived from a calculation that aims to ensure that each ReCiPe point is equivalent to the societal value of avoiding 2 euro worth of damage point. This uses a monetisation methodology similar to that explained for the MMG methodology in section 4.6.

Method evaluation

Effectiveness

The method is based on life cycle assessment and the same problem with effectiveness occurs as in the life cycle assessment methods described previously. The method is effective for the indicators which can be reliably measured but not so much for those which are difficult to measure or whose impacts are challenging to quantify.

Accuracy

The accuracy is good for readily measureable impact parameters and less so for those that are less readily measured or established. The combination of panel-based and monetisation based weighting systems will produce slightly less subjective results by comparison with purely panel-based weighting methods.

Reproducibility

It is very likely that the cost effectiveness will be different when calculated by different companies for the same investment. The reason for this is that a lot of input data need to be gathered. Moreover they have to be assigned to a certain category. Some people will do a lot of effort to figure out which percentage is to be assigned to which category, others will aggregate more or choose a broader, more general category.

Enforceability

STRES should be reasonably enforceable from a technical perspective when the impact parameters are readily measureable with an acceptable degree of accuracy. However, the large number of impact parameters and potential for variability in how accurately companies will attribute costs per component will make verification of test results and documentation more challenging than for schemes that require fewer parameters to be assessed.

Transparency

The method is transparent in principle and is being fully documented in a publicly accessible manner.

Ease and readiness

STRES appears to be less straightforward to apply that some methods due to the need to attribute costs to a large number of sub-components and to assess a relatively large number of impact parameters. The method is existent and ready to use.

Capacity to be implemented

A priori the LCA methods used within STRES are consistent with the legally enshrined methodological aspects of the Ecodesign regulations and fit within the Ecodesign and Energy Labelling procedural and decision making process. It is broadly compatible with the MEErP and Ecoreport tool approaches, which constitute slightly simplified implementations of a full LCA approach. The application of environmental impact criteria aggregator functions based on panel-method or monetised weightings is not precluded within the Ecodesign Directive; however, this would require agreement at the EU level on the methods and weighting to be used and this would not be a trivial exercise.

4.8 Environmental impact assessment via a hybrid IO-LCA methodology

Method description and reference

In a hybrid life cycle assessment of any given economic activity or good, environmental impact data concerning a manufacturing or economic process are combined with Input Output (IO) data on economic and environmental impact flows. Input-output economic activity databases describe the sale and purchase relationships between economic sectors (agriculture, industry, services) within an economy. Within IO environmental impact models these economic value flows are linked to the environmental impact flows resulting from these economic activities. Monetary units such as Euros or dollars are then used to express the environmental flows per economic sector i.e. monetary flows are used as a proxy for environmental impact flows.

Contrary to LCA databases, such IO-databases are developed top-down and give a complete picture of all environmental impacts (all inputs) throughout the complete supply chain at the macro level. The system boundary is defined by the economy which can be a national economy or an economy comprised of several countries together, like the EU. Input Output analysis includes not only the physical production but also the services delivered. Services from, for instance, insurance agencies or consultancies can be easily expressed in monetary units, which makes it less difficult to assess the environmental impact with IO analysis compared to LCA approaches for these sectors. IO methodology does not suffer from "truncation errors" as all previous steps in the chain are automatically included based on monetary relationships. The basic assumption is one of homogeneity meaning that emissions (or other environmental impacts) per monetary unit within one sector are considered to be the same for all actors within the sector.

Nonetheless, the IO methodology is imperfect as it suffers from data quality and limitation issues, such as the fact that detailed IO tables are only assembled typically once every 5 years, and not all the emissions or impact data that are usually included in LCA are available. More critically the IO methodology assumes that environmental impacts within the same sector can be distributed simply on the basis of costs i.e. that they are directly proportional to the value of economic activity by actor within any given sector, which is almost the antithesis of the Ecodesign philosophy.

The IO methodology can be used in combination with LCA in the so-called hybrid approach as now described. In a hybrid LCA-IO methodology, IO data are used to fill data gaps which are present in LCA databases. When emphasis is placed on services and less on actual production, it can be worthwhile to include Input Output databases in the analyses. This is illustrated with an example from Leijting et al. (2013), see Figure . This shows a comparison of 1 m² of a domestic solar panel using data from a LCA database (Ecoinvent v 2.2, left bar) and IO data (US IO database 2002, right bar). The dataset in the LCA database has 1 m² as its units, whereas the dataset in the IO database has 1 dollar as its unit. For the IO dataset, the market price of 1m² of solar panel was estimated in order to make the comparison. The chosen economic sector 'Semiconductor and related device manufacturing' includes the manufacturing of solar cells and devices next to that of other products such as manufacturing of diodes, fuel cells, LEDs etc.

Figure shows that a more generic IO approach can deliver similar results (i.e. the results are of the same order of magnitude) compared to a much more time consuming and data intensive LCA approach.

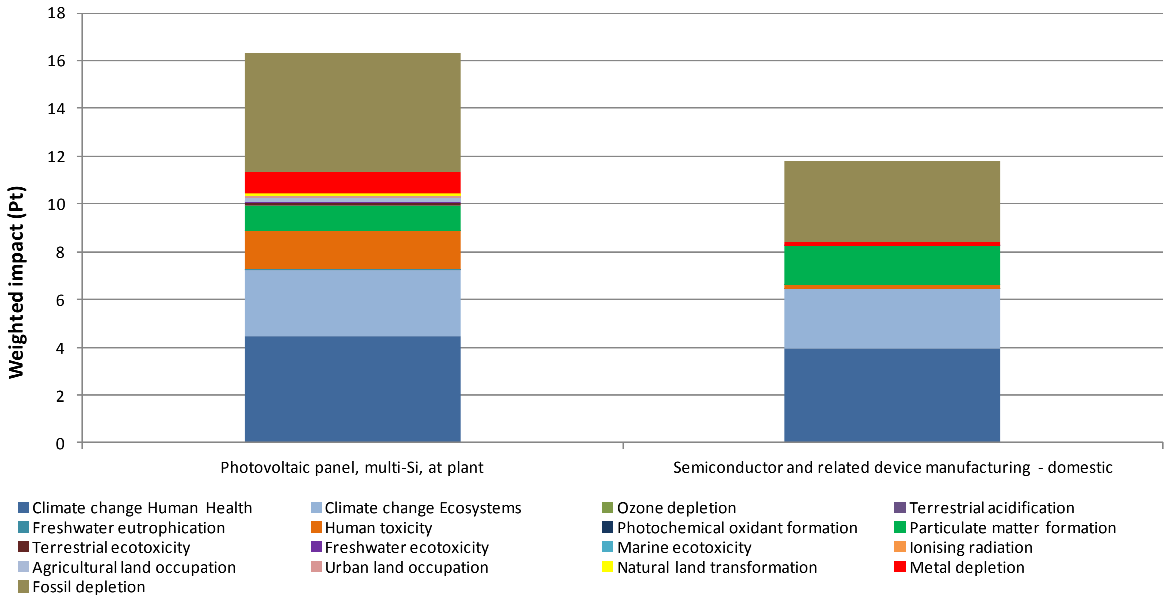

Figure 8: Comparison of 1 m² of solar panel using data from a LCA database (left bar) and an IO database (right bar), Impact Assessment method ReCiPe endpoint H(A).

Structure of the points system

The hybrid LCA-IO methodology of environmental impact assessment is not a points system but otherwise is constructed and behaves in a similar manner to a standard LCA assessment as might be used in accordance with ISO 14040 and ISO 14044. This means that it could be incorporated within a multi-criteria environmental impact points system and used to more rapidly derive impact parameters when full LCA data is either missing or is too time consuming to assess.

Method evaluation

Generally the same remarks apply here as were reported for the ISO 14040 and ISO 14044 standard methodologies.

4.9 BREEAM

Method description and reference

The Building Research Establishment Environmental Assessment Method (BREEAM) was introduced by BRE in 1990 in the UK. The rationale behind the introduction of the methodology was to allow a holistic building sustainability assessment of a broad variety of criteria related to the performance of the building.

Detailed information about the method can be found in the technical manual:

http://www.breeam.com/BREEAMInt2016SchemeDocument/

Table 3 shows the environmental sections that are used to determine the sustainability assessment. For each environmental section, a weighting factor for the different building types is given.

The weighting and ranking exercise is done by an expert panel. The weightings may be adapted to local conditions. This adaptation has to be reviewed and approved by BREEAM.

Table 3: Example of BREEAM section weightings for common project types (BREEAM Technical Manual 2016)

Environmental section (rounded)	Weighting (rounded)						
	Non-residential (rounded)			Single residential dwellings (rounded)		Multiple residential dwellings (rounded)	
	Fully fitted out (rounded)	Shell only (rounded)	Shell and core (rounded)	Partially fitted (rounded)	Fully fitted (rounded)	Partially fitted (rounded)	Fully fitted (rounded)
Management	12.00%	13.50%	13.00%	11.50%	15.00%	12.50%	12.00%
Health and wellbeing	14.00%	8.00%	8.50%	14.50%	15.00%	15.00%	15.00%
Hazards	1.00%	1.50%	1.00%	1.00%	1.00%	1.00%	1.00%
Energy	19.00%	19.50%	19.00%	18.50%	22.00%	18.50%	20.00%
Transport	8.00%	11.00%	8.50%	8.00%	6.50%	8.50%	8.00%
Water	6.00%	3.00%	6.50%	4.50%	6.50%	4.50%	5.50%
Materials	12.50%	16.50%	13.50%	13.50%	9.00%	13.00%	12.50%
Waste	7.50%	8.50%	8.00%	7.00%	6.00%	7.00%	6.50%
Land use and ecology	10.00%	13.00%	11.00%	11.00%	8.50%	10.50%	10.00%
Pollution	6.50%	1.00%	7.00%	5.50%	6.00%	6.00%	6.00%
Total	100.00%	100%	100%	100%	100%	100%	100%
Innovation (additional)	10.00%	10%	10%	10%	10%	10%	10%

Within those sections a range of criteria is defined for which the building in question may be awarded credits. For most criteria, one or two indicators can be achieved. Credits are always discrete numbers; fractions of credits do not exist. Therefore for most criteria, the compliance is a discrete (Yes/No) choice of compliance. This compliance is either the presence of a technology, concept or practice or the quantitative fulfilment of a threshold value.

The energy performance of the building is the most influential single indicator, being awarded up to 15 credits and thus contributing to a maximum of ~5 % of the overall result. The evaluation of the energy use is done by a proprietary metric taking into account a variety of impact factors such as:

a) Building floor area (m^2)
b) Notional building energy demand (MJ/m^2)
c) Actual building energy demand (MJ/m^2)
d) Notional building primary energy consumption (kWh/m^2)
e) Actual building Primary energy consumption (kWh/m^2)
f) Notional building emission rate ($kgCO_2/m^2$)
g) Actual building emission rate ($kgCO_2/m^2$).

These impact factors have to be calculated with accredited building software. The resulting indicator, the "Energy Performance Ratio for International New Constructions (EPRINC)", is then calculated with a proprietary tool. The outcome of this tool is mapped to a discrete credit scale.

Alternatively a checklist approach by which up to 10 credits can be awarded.

Other criteria with a discrete scale are:

- The accessibility index, which is evaluated with a proprietary tool.
- The life cycle impacts

Both criteria are also evaluated with a proprietary tool.

Table 4 shows an example of a BREEAM rating for a specific building. For each section, the credits achieved are related to the credits available resulting in a relative performance within this section. In combination with the weighting factor, the section score can be calculated. The sum of all section scores gives the relative performance of the building.

Table 4: Example of the BREEAM rating overview (BREEAM Technical Manual 2016)

BREEAM section	Credits achieved	Credits available	% of Credits achieved	Section weighting (fully fitted)	Section score
Management	10	20	50.00%	0.12	6.00%
Health and wellbeing	17	21	80.95%	0.14	11.33%
Hazards	1	1	100.00%	0.01	1.00%
Energy	16	34	47.05%	0.19	8.94%
Transport	5	11	45.45%	0.08	3.63%
Water	5	9	55.56%	0.06	3.33%
Materials	10	14	71.43%	0.125	8.92%
Waste	3	13	23.07%	0.075	1.73%
Land use and ecology	5	5	100.00%	0.10	10.00%
Pollution	5	7	71.42%	0.065	4.64%
Surface water run-off	4	5	80.00%	0.035	2.80%
Innovation	2	10	20.00%	0.10	2.00%
Final BREEAM score					64.32%
BREEAM Rating				VERY GOOD	

The overall rating of a building is given on a 6-level rating ranging from "Pass" to "Outstanding" as pass grades and unclassified as fail-grade. This relative performance is mapped to this rating according to the values in Table 5.

Table 5: The six BREEAM building environmental performance classes and associated scoring thresholds (BREEAM Technical Manual 2016)

BREEAM Rating	% score
OUTSTANDING	≥ 85
EXCELLENT	≥ 70
VERY GOOD	≥ 55
GOOD	≥ 45
PASS	≥ 30
UNCLASSIFIED	< 30

For each rating, minimum requirements for individual criteria can be defined. This ensures that a poor performance in crucial criteria cannot be compensated with an excellent performance in other criteria. Therefore it is ensured, that certain minimum criteria are fulfilled, which are regarded as mandatory for a BREEAM certified buildings.

A certain set of criteria is even mandatory for the pass grade, and is therefore mandatory to get certified at all. Those criteria are:

- All national health and safety legislation and regulations for construction sites are considered and implemented
- All fluorescent and compact fluorescent lamps are fitted with high frequency ballasts.
- Materials containing asbestos are prohibited from being specified and used within the building
- All water systems in the building are designed in compliance with the measures outlined in the relevant national health and safety best practice guides or regulations to minimise the risk of microbial contamination, e.g. legionella
- All timber and timber-based products used on the project are legally harvested and traded timber.

An outstanding rating requires at least 10 of the 15 credits available in the energy use criterion.

For each indicator, evidence is required to demonstrate compliance. This evidence may be presented in form of a report, filled checklists etc.

In the example shown in Table 6 all minimum criteria for the “very good” rating are achieved; therefore, this rating can be awarded.

Table 6: Example of check of minimum standards (BREEAM Technical Manual 2016)

Minimum standards for BREEAM 'Very Good' rating	Achieved?
Man 03 Responsible construction practices	Y
Hea 01 Visual comfort	Y
Hea 02 Indoor air quality	Y
Hea 09 Water quality	Y
Ene 01 Reduction of energy use and carbon emissions	Y
Wat 01 Water consumption	Y
Wat 02 Water monitoring	Y
Mat 03 Responsible sourcing of construction products	Y

Structure of the points system

The structure used in the BREEAM points system is to define impact categories, apply scoring up a maximum value within each of these and then to aggregate the points to give an overall total via the application of weightings to the impact category scores. This structure can be said to be akin to a standard AHP model using impact category weightings, although the application of bounded maximum points per category is akin to a second layer to a standard AHP impact category weighting system. Like many AHP models it combines qualitative (yes/no) and quantitative impact categories (where the score is derived on a linear scale and either calculation software based on quantified physical simulation is used or metered data is used and ranked via a normalisation process). The method applied to derive the maximum scores and weightings per impact category is proprietary to the BRE and is not explained to the end users.

Method evaluation

The BREEAM methodology represents an effective and largely transparent methodology to assess the sustainability performance of a building. Through the inclusion of a broad range of sustainability indicators covering the whole lifecycle of the building, a holistic assessment is enabled.

Effectiveness

The methodology uses a very straightforward approach to integrate the broad range of impact criteria into one overall rating. In principle the setting of minimum requirements for crucial indicators ensures a balanced assessment is attained, although expert judgement is clearly been required to determine which indicators are deemed to be crucial and which are not.

Accuracy

For most criteria discrete choices are the basis for credit assignment. Discrete choices lack the ability to represent the potential range of criteria achievement.

Nevertheless, when the broad number of criteria is considered, this issue is of lower importance for the overall result.

Reproducibility

The use of a discrete choice approach for the credit assignment allows an easy reproduction for most of the criteria. Some of the criteria require the use of proprietary tools relying on rather detailed building information. In principle, the reproducibility for those criteria should be high; although the use of detailed input data could lead to differing assumptions for the calculation.

Enforceability

BREEAM ratings are required by some local authorities as well as private sector companies in the UK. In the public sector a variety of institutions require a minimum BREEAM rating for all new buildings. In practice the energy performance rating process used in BREEAM is aligned with that used in mandatory building energy performance requirements such as building codes and energy performance certificates, and thus takes advantage of the same compliance infrastructure and market surveillance mechanism as have been developed for these. From a technical level the enforceability of BREEAM specifications are roughly the same as for building code requirements.

No formal legal requirements for BREEAM ratings appear to be in place although BRE reserves the right to remove licences to BREEAM users that breach their usage guidelines.

Transparency

The method to be applied is very transparent as the guide is publicly available and the assessment can be followed step by step.

Nevertheless for some criteria, the use of proprietary tools is inevitable. Especially for the energy use, a proprietary indicator is used, which is incompatible to common metrics.

The assessment of a broad range of indicators can make an interpretation of the results more difficult than for single indicator based assessments.

The rationale behind the section weightings and the selection of those criteria where it is mandatory to pass are not in the public domain and hence are not transparent.

Ease and readiness

The methodology has been used for more than 20 years, and is commonly used on the market. The wide acceptance and international adoption of the scheme suggests that it is sufficiently straightforward to implement.

Capacity to be implemented

A priori the impact assessment methods used within BREEAM are not inconsistent with the legally enshrined methodological aspects of the Ecodesign regulations and could be adapted to fit within the Ecodesign and Energy Labelling procedural and decision making process. It could be applied in a way that is broadly compatible with the MEErP and Ecoreport tool approaches, which constitute slightly simplified implementations of a full LCA approach. The BREEAM approach entails the application of implicit environmental impact criteria aggregator functions based on panel weightings of which criteria should be assessed and the scoring that they can attain. This approach is not precluded within the Ecodesign Directive and were such a system to be developed and agreed upon could facilitate a standardised and unambiguous approach to the establishment of priorities and thresholds within Ecodesign; however, this would require agreement at the EU level on the weightings to be applied and without the use of a less subjective approach than the panel method agreement on weightings may be very difficult to attain.

4.10 LEED

Method description and reference

The rating system Leadership in Energy and Environmental Design (LEED) has been developed by the US non-profit U.S. Green Building Council in 1994.

The general principles of the system are comparable to the BREEAM system, nevertheless some methodological differences exist.

Whereas the BREEAM system uses points to calculate a relative target achievement, LEED is a "pure" points system. Therefore no weighting factors between the different categories exist, but the weighting is made *implicitly* by the allocation of points to the different criteria.

The LEED system has evolved over time, the most recent update LEED v4 was introduced in 2013. From November 2016, the use of LEED v4 is mandatory.

Within LEED, buildings can qualify for four levels of certification:

- Certified: 40–49 points
- Silver: 50–59 points
- Gold: 60–79 points
- Platinum: 80 points and above.

As is the case for the BREEAM system, LEED has mandatory prerequisites to ensure a balanced fulfilment of the criteria. Those prerequisites are mandatory for all certification levels.

The overlap of the criteria used in both systems is rather large. Differences exist in the concrete implementation of the indicators.

Structure of the points system

The structure used in the LEED points system is to define impact categories, apply scoring up a maximum value within each of these and then to aggregate the points to give an overall total. In general this structure can be said to be akin to a standard AHP model; except the application of bounded maximum points per category is akin to an AHP impact category weighting system. The method used to derive weightings per impact category appears to be proprietary and is not explained to the end users.

Method evaluation

In general the evaluation comments that apply to the BREEAM method also apply to LEED because its features are so similar. Differences arise because to some extent, the methodology is more complex due to its broader scope and the need for a full LCA of the materials used. Also it doesn't use weighting between impact categories and hence might be deemed to be slightly less accurate as a result.

On the other hand, the holistic approach goes beyond the BREEAM and LEED approaches and hence could be considered to be more thorough and accurate.

The flip side of this is that it will be more demanding to implement as more factors are accounted for and require calculation. In consequence the reproducibility and capacity to implement scores given by the team are one point lower than for BREEAM.

Again the system used to derive the weighting factors is not explained and is proprietary.

4.11 DGNB System

Method description and reference

The rating system of the German Society for Sustainable Building (Deutsche Gesellschaft für nachhaltiges Bauen DGNB) is the youngest of the building rating systems described in this report.

The current version of the system is the result of a revision in 2015. The general principle of the methodology is comparable to the BREEAM and LEED approach. Nevertheless, some differences exist.

The DGNB system has been designed as a sustainability assessment system. This is clearly reflected in the indicators and their weighting as shown in the table below.

Compared to the other schemes, energy issues play a minor role in the assessment. Their major impact is on criterion ENV1.1, which considers life cycle impacts of the building with a relative relevance of ~8% and ENV2.1, which considers primary energy use with a relative relevance of 5.6%.

Economic criteria, which are not relevant in BREEAM and LEED, contribute with more that 20% to the overall result. As life cycle costs are considered, energy costs are also relevant in this category.

The system is a point system, where credits are assigned for the individual criteria. The credits are weighted and aggregated to achieve a final score.

Structure of the points system

The structure applied in the DGNB points system (Table 7) is to define impact categories, apply scoring up a maximum value within each of these and then to aggregate the points to give an overall total via the application of weightings to the impact category scores. This structure can be said to be akin to a standard AHP model using impact category weightings, although the application of bounded maximum points per category is akin to a second layer to a standard AHP impact category weighting system. The method applied to derive the maximum scores and weightings per impact category is proprietary to the scheme developers and is not explained to the end users.

Table 7: The impact criteria and weightings applied in the DGNB building environmental rating system

topic	criteria group	criterion no.	criterion	relevance factor	share of total score
Environmental quality (ENV)	Effects on the global and local environment (ENV10)	ENV1.1	Life cycle impact assessment	7	7,9%
		ENV1.2	Local environmental impact	3	3,4%
		ENV1.3	Responsible procurement	1	1,1%
	Resource consumption and waste generation (ENV20)	ENV2.1	Life cycle assessment - primary energy	5	5,6%
		ENV2.2	Drinking water demand and waste water volume	2	2,3%
		ENV2.3	Land use	2	2,3%
Economic quality (ECO)	Life Cycle Cost (ECO10)	ECO1.1	Life Cycle Cost	3	9,6%
	Economic development (ECO20)	ECO2.1	Flexibility and adaptability	3	9,6%
		ECO2.2	Commercial viability	1	3,2%
Sociocultural and functional quality (SOC)	Health, comfort and user satisfaction (SOC10)	SOC1.1	Thermal comfort	5	4,3%
		SOC1.2	Indoor air quality	3	2,6%
		SOC1.3	Acoustic comfort	1	0,9%
		SOC1.4	Visual comfort	3	2,6%
		SOC1.5	User control	2	1,7%
		SOC1.6	Quality of outdoor spaces	1	0,9%
		SOC1.7	Safety and security	1	0,9%
	Functionality (SOC20)	SOC2.1	Design for All	2	1,7%
		SOC2.2	Public access	2	1,7%
		SOC2.3	Cyclist facilities	1	0,9%
	Design quality (SOC30)	SOC3.1	Design and urban quality	3	2,6%
		SOC3.2	Integrated public art	1	0,9%
		SOC3.3	Layout quality	1	0,9%
Technical quality (TEC)	Technical quality (TEC10)	TEC1.1	Fire safety	2	4,1%
		TEC1.2	Sound insulation	2	4,1%
		TEC1.3	Building envelope quality	2	4,1%
		TEC1.4	Adaptability of technical systems	1	2,0%
		TEC1.5	Cleaning and maintenance	2	4,1%
		TEC1.6	Deconstruction and disassembly	2	4,1%
		TEC1.7	Sound emissions	0	0,0%
Process quality (PRO)	Planning quality (PRO10)	PRO1.1	Comprehensive project brief	3	1,4%
		PRO1.2	Integrated design	3	1,4%
		PRO1.3	Design concept	3	1,4%
		PRO1.4	Sustainability Aspects in Tender Phase	2	1,0%
		PRO1.5	Documentation for facility management	2	1,0%
	Construction quality (PRO20)	PRO2.1	Environmental impact of construction	2	1,0%
		PRO2.2	Construction quality assurance	3	1,4%
		PRO2.3	Systematic commissioning	3	1,4%
Site quality (SITE)	Site quality (SITE10)	SITE1.1	Local Environment	2	0,0%
		SITE1.2	Public image and social conditions	2	0,0%
		SITE1.3	Transport access	3	0,0%
		SITE1.4	Access to amenities	2	0,0%

Method evaluation

In general the evaluation comments that apply to the BREEAM method also apply to DGNB because its features are similar. Differences arise because to some extent, the methodology is more complex due to its broader scope and the need for a full LCA of the materials used. However, like BREEAM it does use weighting between impact categories.

On the other hand, the holistic approach goes beyond the BREEAM approach and hence could be considered to be more thorough and accurate. Conversely, it will be more demanding to implement as more factors are accounted for and require calculation. In consequence the reproducibility and capacity to implement scores given by the team are one point lower than for BREEAM.

Again, the system used to derive the weighting factors is not explained in publicly-accessible documents, and is proprietary.

4.12 ISO 14955-1: Machine tools -- Environmental evaluation of machine tools -- Part 1: Design methodology for energy-efficient machine tools

Method description and reference

Although ISO 14955-1 does not define a point system methodology, it provides valuable input for designing such a methodology. It aims to break down the machine tool into individual components for which a functional unit can be defined to perform an environmental assessment. For the defined components, specific improvement options are defined, always keeping in mind their integration into the overall system. Those improvements are compiled to a list of positive environmental features, which can be integrated into the machine tool.

The overall target is to optimise the whole machine tool by an optimisation of the individual components. To figure out which components are relevant for the energy flow of the machine tool, a quantitative mapping of the relevant components to the machine tool functions is performed, for which the energy supply can be measured or simulated. Thereby it is also taken into account that a specific component can fulfil more than one function and therefore the energy supplied to this machine component can be assigned to different generalised machine tool functions. For reasons of comparability and reproducibility, the ISO 14955-2 standard explains in a manner which is complementary to the ISO 14955-1 standard how the measurements of the energy supplied to the machine tools and machine tools components can be conducted, by taking different ambient conditions, operating states and machine tool activities into account. Furthermore it also demonstrates how to include other energy supplies apart from electrical energy such as pneumatic energy, heat exchange or the contaminated air flow and air exchange.

The norm’s focus is purely on the use phase of the product, as most of the environmental impacts of the product occur in this life-cycle-stage of the product.

The methodology for the environmental assessment is divided into 8 steps:

1. General life cycle assessment to decide whether the use-phase is most relevant for the product.
2. Description of the generalised machine tools functions and sub-functions
3. Assignment of machine components to the generalised machine tool functions or sub-functions

4. Identification of machine tool functions relevant for energy consumption during the use phase
5. Mapping of relevant machine tool functions to machine components
6. Comparison of relevant machine components or subsystems, their control and their contribution with a previous generation

The environmental impact assessment ends with step 6. This is then followed by two design implementation steps:

7. Optimisation of relevant machine components or subsystems, their control and their combination
8. Monitoring of the relevant machine components

Structure of the points system

The structure used in the ISO 14995-1 standard is to establish an energy efficiency design procedure for machine tools that makes the energy efficiency design process comprehensive, repeatable and documentable. It is not a points system and hence does not have impact criteria, parameter scoring and weighting. It does, though involve mapping of machine tool functions to components and energy efficiency comparison (although not as far as normalisation) of machine components or subsystems with a set of defined technology approaches at the component or subsystem level.

Method evaluation

Effectiveness

Using an approach covering the different design aspects of the machine tools, the methodology can be very effective in achieving design improvements. An inherent feature of the methodology is the integration into the design process. Product improvements are an integral part of the ISO standard.

Accuracy

The approach described in the ISO standard is rather generic and leaves some room for interpretation.

The impact for the individual technological measures is not predefined, but relies on measurements or own third party values. This approach might lead to very precise results, but may also allow the user to use inappropriate values from literature.

Reproducibility

The methodology is rather vague in some details, especially regarding the savings calculation. Also, engineering estimates are an integral part of the methodology. Both factors lead to a reduced reproducibility.

Enforceability

As an international Standard, the use of the methodology has no mandatory status and as a relatively new standard it is likely there is only limited experience of its implementation. As a result, accreditation and certification experience is likely to be limited at present; however, there is nothing in the standard that is especially difficult to appraise and thus in principle its requirements should be enforceable from a technical perspective. As the standard essentially sets out a design procedure, market surveillance agencies would simply need to check the technical documentation and product characteristics to determine whether a producer had followed that procedure or not.

Transparency

The implementation of the method is very transparent as the assessment can be followed step by step. The methodology is an international standard and therefore accessible via the usual channels. No proprietary parts of the methodology exist.

Ease and readiness

The method is ready for implementation. Still, it leaves some room for interpretation and can therefore not be used as an out-of-the box solution. The fact that it has been adopted as an international standard suggests that it is sufficiently straightforward to implement.

Capacity to be implemented

The ISO 14995-1 approach could be consistent with a generic Ecodesign requirements for the design process and not inconsistent with the legally enshrined methodological aspects of the Ecodesign regulations. It could be readily fitted within the Ecodesign and Energy Labelling procedural and decision making process. It is not concerned with but has no conflict with the MEErP and Ecoreport tool approaches.

4.13 Machine tools points scheme proposed in the Impact Assessment and Ecodesign working document

Method description and reference

In the working document for the Ecodesign Consultation Forum meeting on machine tools and related machinery (ENTR LOT 5), 6 MAY 2014[6], the EC proposed a points system for a specific range of machine tools as policy option 2 (PO2).

The scheme's concept reports to be loosely based on the BREEAM methodology, which is described earlier in this document and was developed for and applied to buildings. Although the points scheme in the working document is inspired by BREEAM there are many specific aspects and differences, as follows:

- under the mandatory Ecodesign proposals of this Policy Option, MT manufacturers would be required to reach a certain level of expected energy savings in order to demonstrate their compliance. The underlying principle is that MT manufacturers are free to use any mix of measures to reach the specified level of energy savings, and that the energy savings percentage achieved is denoted by a certain amount of equivalent points
- the method was proposed exclusively for metal working machine tools (Base cases 1 to 4 in the preparatory study and working document) and Stone and Ceramic cutting machine tools (Base case 10) and was not considered for other types of machine tools such as wood working machine tools
- the focus is solely on the energy-in-use mode and no other environmental impacts or lifecycle stages are considered
- the methodology ascribes points for the inclusion of specific energy savings design options such that 4 points are awarded for each design option which is expected to improve in-use energy efficiency by 1%
- each of these design options are clustered into one of several design option categories and within each category a maximum 20 point cap is imposed on number of points that

[6] WORKING DOCUMENT FOR THE ECODESIGN CONSULTATION FORUM ON MACHINE TOOLS AND RELATED MACHINERY (ENTR LOT 5), 6 MAY 2014, Brussels, 11 April 2014 ENTR/B1/mjb/Lot 5

can be awarded for the category (i.e. no design option category is rewarded for design options that lead to savings beyond a 5% energy efficiency improvement)

- the energy savings design options which may be considered are defined in a table of specific options which is taken from Annex A of the ISO 14955-1 standard and the preparatory study
- the relative savings per category are then mapped to a discrete point scale
- in contrast to the BREEAM methodology (and being closer to the LEED concept) no relative achievement target has to be calculated, but rather the points are simply added up to create an overall score

Structure of the points system

As mentioned above the structure applied to the proposed points system is to group energy savings options into categories that may produce a maximum of 5% of energy savings (e.g. to receive a maximum of 20 points, where each point corresponds to a 0.25% improvement in energy efficiency). In some instances the maximum number of points achievable per category is less. See Table 8 below, and Table 9 for a worked example. In general this structure can be said to be somewhat akin to a standard AHP model; however, where a typical AHP model would have different impact categories for non-related issues in this model all the impact categories pertain to the impact category of the machine tool's energy efficiency in the use mode. The application of bounded maximum points per category is akin to an AHP category weighting system.

Table 8: Description of indicative draft proposed point scheme

Ascribed % of energy savings for measure	Allocated points
'<1%	4
1% - 2%	8
2% - 3%	12
3% - 4%	16
>4%	20

It might occur that a MT has no relevant parts that can be attributed in some category groups, i.e., where the feature/ technology is not applicable, or where it is absent on the product model concerned. In this case, the points allocated to that group of technology/ features is deemed to be the average of all other category groups' points[7] relevant to, and present in the MT under consideration. Please see the worked example below. It must be emphasised that this example is purely illustrative, taking a perhaps "slightly better than average" Machine Tool, and is for explanatory purposes only. It does not purport to represent a real, or average Machine Tool, etc.

▶ Worked illustrative example: application of the points methodology for a hypothetical metal-working MT

Table 9 shows the measures (taken from Annex C of the working document) selected by the MT manufacturer, plus the points allocated to the feature groups (in the far left column). The "Grand Total" gives the overall points gained by the MT in question, e.g.,

[7] This approach is as used in the BREEAM building design scheme.

in the "Electric Systems" section, a converter with power factor correction is fitted, scoring 2 out of a maximum 4 points for this category. An important aspect of the "points" system to note is illustrated by the points allocated to "Pneumatic Systems". As there is no pneumatic system on the particular machine tool being examined, the average score of the relevant categories was allocated to the non-relevant "Pneumatic System". In this way, the phenomenon of being marked down for an irrelevant feature is avoided, and is a design feature taken from the BREEAM certification scheme. The measures applied to the machine have allocated to it 35 points (i.e., 8.75% energy savings indicated) out of a total possible of 90 points. This relatively high score shows that it is a relatively energy-efficient machine (note, the actual energy saving achieved in practice may not exactly attain this figure, but this approach is intended to be indicative, and iterative).

Table 9: Example calculation of points to be allocated to a metal-working MT

Ascribed % energy savings for measure	Maximum possible allocated points by category	Points achieved by example machine	Allocation for those systems not present on the machine (the average of the other scores)
Overall Machine	19	7	
Drive Units	16	4	
Hydraulic System	5	4	
Pneumatic System	20		8 (=27/70 x 20)
Electric Systems	4	2	
Cooling lubricant	7	3	
Cooling	3	1	
Power Electronics	6	2	
Peripheral	2	0	
Control	4	2	
Grand Total	**86**	**33 Points**	

Comments

The rationale put forward for the use of the points system in the working document is to allow an easy evaluation of the energy-related performance of the product.

The intention of the points system is to assess the energy efficiency impacts of design options on a modular basis. By so doing the aspiration is to map energy design options to modules within machine tools which serve specific functions and thereby limit the complexities created by machine tools having multiple possible functional units which might give rise to potentially unmanageable complexity in the definition and derivation of the overall machine tool energy efficiency as a result.

The reason why other life cycle stages or non-energy in use impacts were not considered is not directly stated, but would appear to be because both the preparatory study and the ISO 14995 standard indicate that the potential to improve the energy in use dominates the overall energy-related lifecycle impacts of machine tools.

While the intention of the methodology is laudable its implementation raises certain issues, as follows:

- the decision to cap the maximum efficiency improvement associated with any specific grouping (category) of design options to 4% seems arbitrary and is not substantiated[8]
- this decision does not appear to afford the possibility that an innovative and disruptive technology might occur which could lead to much greater savings
- tying the points allocation to the list of design options within the ISO 14995-1 standard is pragmatic; however, the list of options within the working document does not include all the options mentioned within ISO 14995-1 and again does not automatically engender renewal in the event that innovative new design options might be introduced – thus the system as currently specified would offer no encouragement or reward to innovative design options
- there is a lack of documentation to substantiate the magnitude of energy savings impacts expected from the listed design options
- the method treats the energy savings (efficiency gains) as being additive when in most cases they would be expected to be multiplicative (i.e. if five sets of design options all lead to a 4% efficiency gain their net effect would generally be expected to be and efficiency gain of =100*(1-0.96*0.96*0.96*0.96*0.96) %= 19% and not 20% as a simple summing would imply
- the technical basis behind the grouping (categorisation) of the design options is not reported and thus is unsubstantiated – as a result the degree to which the categorisation is sound and how robust this is for all types of metal working machine tools is unclear

Therefore a catalogue of saving options is defined on the basis of the preparatory study and the ISO 14955 standard. The relative savings per category are then mapped to a discrete point scale.

In contrast to the BREEAM methodology (and being closer to the LEED concept) no relative target achievement is to be calculated, but the points are merely added up to create an overall score.

Method evaluation

Effectiveness

In principle by using a straightforward approach covering the different design aspects of the machine tools, the methodology could be effective in achieving design improvements; however, there is considerable uncertainty about: whether the right design options are being addressed, about the ability to capture future innovations, about the degree to which the method treats functional units effectively and the extent to which higher efficiency design options are awarded appropriately.

Accuracy

The different technological options are assigned deemed saving values based on generic technological criteria. Obviously, they do not reflect the real savings, but are a generic characterisation of the technology. The effects resulting from the combined implementation of measures are not considered at all, nor is there compelling evidence to support the magnitude of projected savings.

[8] The stated aim was to "cap" the points attributed to avoid "over-scoring" any one particular feature, in the belief that over-reliance on, one feature might preclude the full use of other, separate, advanced features

Reproducibility

By using a deemed savings approach on a technical measure basis, the reproducibility should be reasonably high.

Enforceability

If used in the context of Ecodesign implementation, the enforceability should be reasonable in principle; however, the fact that it requires performance declaration and verification of system modules and components will certainly add complexity and difficulty to compliance verification processes. That some of these system elements may have multiple functions and energy flows will further complicate compliance assessment. This implies that some innovative methods may need to be established to support compliance processes for such a system to be practically verifiable.

Transparency

The implementation of the method is very transparent as the assessment can be followed step by step. Nevertheless, in their actual state, the deemed savings allocated are neither transparent nor consistent. The saving estimates have no direct relation to the saving potentials identified in the Ecodesign preparatory study.

Ease and readiness

The method seems to be rather straightforward to implement, however, it's far from being ready for implementation. At the moment only the fragmentary information in the EC working document is available.

Capacity to be implemented

The lack of detail on how to implement the scheme suggests that it is a work in progress and hence currently has a low capacity to be implemented.

The method, to the extent it is described, is not inconsistent with the legally enshrined methodological aspects of the Ecodesign regulations. It could be readily made to fit within the Ecodesign and Energy Labelling procedural and decision-making process. It has no conflict with the MEErP and Ecoreport tool approaches.

4.14 The Analytical Hierarchy Process (AHP)

There are hundreds or sources on AHP. The text below is largely drawn from Wikipedia, the free encyclopaedia (accessed May 2nd 2016).

Method description and reference

The analytic hierarchy process (AHP) is a structured technique for organising and analysing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. It has particular application in group decision making (Saaty et al, 2008) and is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, shipbuilding (Saracoglu 2013) and education.

Rather than prescribing a "correct" decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals and for evaluating alternative solutions.

Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analysed independently.

The elements of the hierarchy can relate to any aspect of the decision problem—tangible or intangible, carefully measured or roughly estimated, well or poorly understood—anything at all that applies to the decision at hand.

Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to each other two at a time (i.e. via a pairwise comparison), with respect to their impact on an element above them in the hierarchy. In making the comparisons, the decision makers can use concrete data about the elements, but they typically use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations (Saaty 2008a).

The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes the AHP from other decision-making techniques.

In the final step of the process, numerical priorities are calculated for each of the decision alternatives. These numbers represent the alternatives' relative ability to achieve the decision goal, so they allow a straightforward consideration of the various courses of action.

Several firms supply computer software to assist in using the process.

Uses and applications

While it can be used by individuals working on straightforward decisions, the Analytic Hierarchy Process (AHP) is most useful where teams of people are working on complex problems, especially those with high stakes, involving human perceptions and judgments, whose resolutions have long-term repercussions (Bhushan et al 2004). It has unique advantages when important elements of the decision are difficult to quantify or compare, or where communication among team members is impeded by their different specialisations, terminologies, or perspectives.

Decision situations to which the AHP can be applied include (Forman et al 2001):

- Choice – The selection of one alternative from a given set of alternatives, usually where there are multiple decision criteria involved.
- Ranking – Putting a set of alternatives in order from most to least desirable
- Prioritisation – Determining the relative merit of members of a set of alternatives, as opposed to selecting a single one or merely ranking them
- Resource allocation – Apportioning resources among a set of alternatives
- Benchmarking – Comparing the processes in one's own organisation with those of other best-of-breed organisations
- Quality management – Dealing with the multidimensional aspects of quality and quality improvement
- Conflict resolution – Settling disputes between parties with apparently incompatible goals or positions (Saaty et al 2008)

The applications of AHP to complex decision situations have numbered in the thousands (de Steiguer et al 2003) and have produced extensive results in problems involving planning, resource allocation, priority setting and selection among alternatives (Bhushan et al 2004). Other areas have included forecasting, total quality management, business process re-engineering, quality function deployment and the balanced scorecard (Forman et al 2001). Many AHP applications are never reported to the world at large, because they take place at high levels of large organisations where security and privacy considerations prohibit their disclosure. But some uses of AHP are discussed in the literature. Some examples include:

- Deciding how best to reduce the impact of global climate change (Fondazione Eni Enrico Mattei)(Berrittella et al 2007)
- Quantifying the overall quality of software systems (Microsoft Corporation) (McCaffrey et al 2005)
- Selecting university faculty (Bloomsburg University of Pennsylvania) (Grandzol 2005)
- Deciding where to locate offshore manufacturing plants (University of Cambridge) (Atthirawong & McCarthy 2002)
- Assessing risk in operating cross-country petroleum pipelines (American Society of Civil Engineers) (Dey 2003)
- Deciding how best to manage U.S. watersheds (U.S. Department of Agriculture) (de Steiguer et al 2003)

AHP is sometimes used in designing highly specific procedures for particular situations, such as the rating of buildings by historic significance (Lippert and Weber 1995). It was recently applied to a project that uses video footage to assess the condition of highways in Virginia. Highway engineers first used it to determine the optimum scope of the project, then to justify its budget to lawmakers (Larson et al 2007).

Though using the analytic hierarchy process requires no specialised academic training, it is considered an important subject in many institutions of higher learning, including schools of engineering (Drake 1998) and graduate schools of business (Bodin et al 2004). It is a particularly important subject in the quality field and is taught in many specialised courses including Six Sigma, Lean Six Sigma and QFD (Hallowell 2005), (QFD 2007), (Quality 2007).

Structure of the points system

AHP is a tool to facilitate group decision-making with regard to multiple criteria. Using the AHP involves the mathematical synthesis of numerous judgments about the decision problem at hand. It is not uncommon for these judgments to number in the dozens or even the hundreds. While the maths can be done by hand or with a calculator, it is far more common to use one of several computerised methods for entering and synthesising the judgments. The simplest of these involve standard spreadsheet software, while the most complex use custom software, often augmented by special devices for acquiring the judgments of decision makers gathered in a meeting room.

The procedure for using the AHP can be summarised as:

1.Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it and the criteria for evaluating the alternatives.

2.Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements. For example, when comparing potential purchases of commercial real estate, the investors might say they prefer location over price and price over timing.

3.Synthesise these judgments to yield a set of overall priorities for the hierarchy. This would combine the investors' judgments about location, price and timing for properties A, B, C and D into overall priorities for each property.

4.Check the consistency of the judgments.

5.Come to a final decision based on the results of this process (Saaty 2008b).

These steps are now described in detail.

Model the problem as a hierarchy

The first step in the analytic hierarchy process is to model the problem as a hierarchy. In doing this, participants explore the aspects of the problem at levels from general to detailed, then express it in the multileveled way that the AHP requires. As they work to build the hierarchy, they increase their understanding of the problem, of its context and of each other's thoughts and feelings about both (Saaty 2008b).

Hierarchies defined

A hierarchy is a stratified system of ranking and organising people, things, ideas, etc., where each element of the system, except for the top one, is subordinate to one or more other elements. Though the concept of hierarchy is easily grasped intuitively, it can also be described mathematically (Saaty 2010). Diagrams of hierarchies are often shaped roughly like pyramids, but other than having a single element at the top, there is nothing necessarily pyramid-shaped about a hierarchy.

Hierarchies in the AHP

An AHP hierarchy is a structured means of modelling the decision at hand. It consists of an overall goal, a group of options or alternatives for reaching the goal and a group of factors or criteria that relate the alternatives to the goal. The criteria can be further broken down into sub criteria, sub-subcriteria and so on, in as many levels as the problem requires. A criterion may not apply uniformly, but may have graded differences like a little sweetness is enjoyable but too much sweetness can be harmful. In that case the criterion is divided into sub criteria indicating different intensities of the criterion, like: little, medium, high and these intensities are prioritised through comparisons under the parent criterion, sweetness. Published descriptions of AHP applications often include diagrams and descriptions of their hierarchies; some simple ones are shown below.

The design of any AHP hierarchy will depend not only on the nature of the problem at hand, but also on the knowledge, judgments, values, opinions, needs, wants, etc. of the participants in the decision-making process. Constructing a hierarchy typically involves significant discussion, research and discovery by those involved. Even after its initial construction, it can be changed to accommodate newly-thought-of criteria or criteria not originally considered to be important; alternatives can also be added, deleted, or changed (Saaty 2008b).

To better understand AHP hierarchies, consider a decision problem with a goal to be reached, three alternative ways of reaching the goal and four criteria against which the alternatives need to be measured.

Such a hierarchy can be visualised as a diagram, Figure 10, with the goal at the top, the three alternatives at the bottom and the four criteria in between. There are useful terms for describing the parts of such diagrams: Each box is called a node. A node that is connected to one or more nodes in a level below it is called a parent node. The nodes to which it is so connected are called its children.

Applying these definitions to the diagram below, the goal is the parent of the four criteria and the four criteria are children of the goal. Each criterion is a parent of the three Alternatives. Note that there are only three Alternatives, but in the diagram, each of them is repeated under each of its parents.

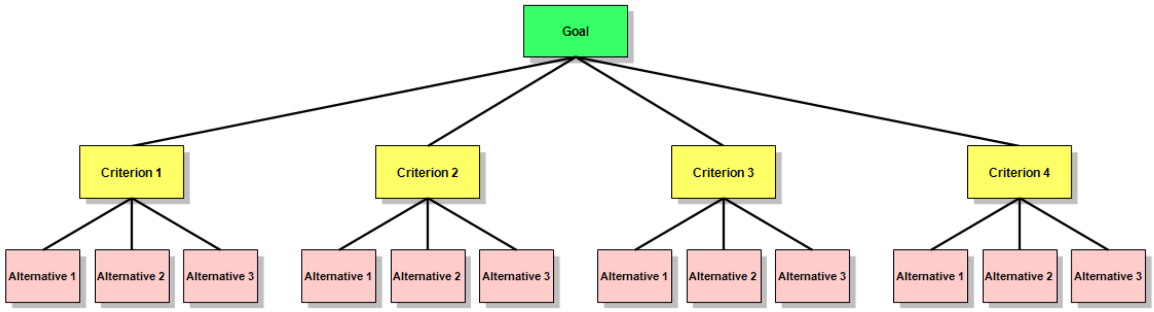

Figure 10. A simple AHP hierarchy. There are three Alternatives for reaching the Goal and four Criteria to be used in deciding among them.

To reduce the size of the drawing required, it is common to represent AHP hierarchies as shown in Figure 11, with only one node for each alternative and with multiple lines connecting the alternatives and the criteria that apply to them. To avoid clutter, these lines are sometimes omitted or reduced in number. Regardless of any such simplifications in the diagram, in the actual hierarchy each criterion is individually connected to the alternatives. The lines may be thought of as being directed downward from the parent in one level to its children in the level below.

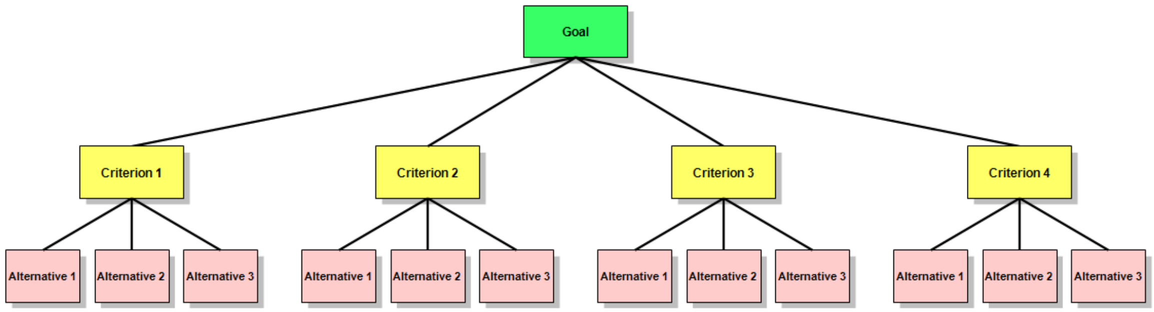

Figure 11. AHP hierarchy for choosing a leader. There is one goal, three candidates and four criteria for choosing among them.

Evaluate the hierarchy

Once the hierarchy has been constructed, the participants analyse it through a series of pairwise comparisons that derive numerical scales of measurement for the nodes. The criteria are pairwise compared against the goal for importance. The alternatives are pairwise compared against each of the criteria for preference. The comparisons are processed mathematically and priorities are derived for each node.

An important task of the decision makers is to determine the weight to be given each criterion in making the choice in question. Another important task is to determine the weight to be given to each candidate option with regard to each of the criteria. The AHP not only allows this, but also puts a meaningful and comparatively objective numerical value on each of the four criteria.

Establish priorities

This section explains priorities, shows how they are established and provides a simple example.

Priorities defined and explained

Priorities are numbers associated with the nodes of an AHP hierarchy. They represent the relative weights of the nodes in any group.

Like probabilities, priorities are absolute numbers between zero and one, without units or dimensions. A node with priority 0.200 has twice the weight in reaching the goal as one with priority 0.100, ten times the weight of one with priority 0.020 and so forth. Depending on the problem at hand, "weight" can refer to importance, or preference, or likelihood, or whatever factor is being considered by the decision makers.

Priorities are distributed over a hierarchy according to its architecture and their values depend on the information entered by users of the process. Priorities of the Goal, the Criteria and the Alternatives are intimately related, but need to be considered separately.

By definition, the priority of the Goal is 1.000. The priorities of the alternatives always add up to 1.000. Things can become complicated with multiple levels of Criteria, but if there is only one level, their priorities also add to 1.000. All this is illustrated by the priorities in the example below.

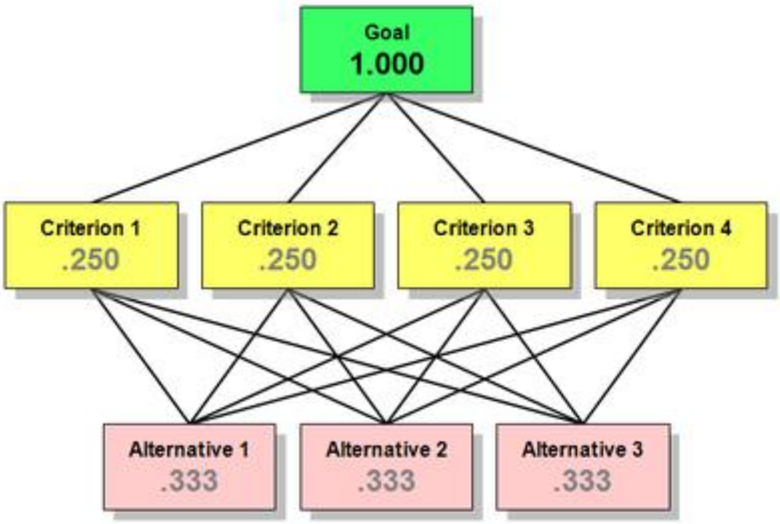

Figure 12. Simple AHP hierarchy with associated default priorities.

It can be observed that the priorities on each level of the example—the goal, the criteria and the alternatives—all add up to 1.000.

The priorities shown are those that exist before any information has been entered about weights of the criteria or alternatives, so the priorities within each level are all equal. They are called the hierarchy's default priorities. If a fifth Criterion were added to this hierarchy, the default priority for each Criterion would be 0.200. If there were only two Alternatives, each would have a default priority of 0.500.

Two additional concepts apply when a hierarchy has more than one level of criteria: local priorities and global priorities. Consider the hierarchy shown below, which has several Sub-criteria under each Criterion.

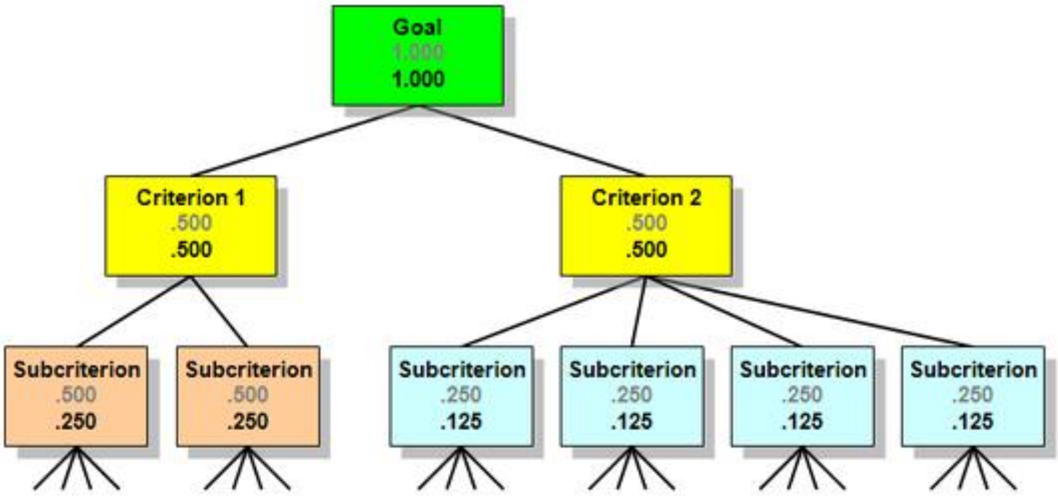

Figure 13. A more complex AHP hierarchy, with local and global default priorities. In the interest of clarity, the decision alternatives do not appear in the diagram.

The local priorities, shown in grey, represent the relative weights of the nodes within a group of siblings with respect to their parent. You can easily see that the local priorities of each group of Criteria and their sibling Sub-criteria add up to 1.000. The global priorities, shown in black, are obtained by multiplying the local priorities of the siblings by their parent's global priority. The global priorities for all the sub-criteria in the level add up to 1.000.

The rule is: within a hierarchy, the global priorities of child nodes always add up to the global priority of their parent. Within a group of children, the local priorities add up to 1.000.

The text above has considers default priorities; however, the weighting to be given when the AHP is applied to support a multi-stakeholder multi-criteria decision making process is amended by inviting the stakeholders to input information (or ascribe importance) to each of the various nodes via a pairwise comparison process. The answers provided are processed numerically and used to develop the final weightings.

Method evaluation

AHP is structured tool that allows information and values to be fairly reflected within multi-criteria, multi-decision maker decision-making processes. While default priorities reflect a neutral perspective the application of stakeholders' inputs/value judgements allows the preferences to be determined in a structured way. In principle, this technique could be used in the Ecodesign regulatory process to enable the relative importance of diverse impact criteria to be determined and to provide the hierarchical basis of the value judgments implicit in any points-system. It could also be used to assist any panel-based decision-making process e.g. to help establish weightings between pertinent parameters within any single impact parameter where these weightings require some degree of judgement. One of the strengths of the AHP is that it allows a mixture of deterministic (measurable and quantifiable) data and subjective data (reflecting stakeholder value judgements) to be combined within the same decision-making tree; this reflects the blend of types of information that decision makers are often confronted with in real life, and such as is found in Ecodesign regulatory processes.

Effectiveness

AHP is an effective multi-criteria decision-making tool as is demonstrated by its application in many hundreds of diverse applications. It can be set up in software to facilitate its use.

Accuracy

The decision tree and associated weightings coming out of any AHP multi-criteria decision-making process are stable once established and are as accurate as the degree of accuracy embedded within the quantifiable/measurable parts of the input information themselves (albeit that errors could propagate through any multi-layered decision tree).

Reproducibility

Once an AHP decision model is established its application should be as reproducible as the reproducibility of the quantifiable criteria measurements used within the AHP scheme permits. Overall it is likely to be similar to that experienced for other EU environmentally-related product regulations such as Ecodesign, RoHS, WEEE etc.

Enforceability

Enforcing an implementing measure established using an AHP decision making tree is in principle no different from enforcing any Ecodesign implementing measure except that a set of calculations could be required related to that decision tree.

Transparency

An AHP decision model can be fully transparent and placed within the public domain, albeit it may take considerable effort to understand.

Ease and readiness

AHP model development can be done with the use of commercially available software and a facilitation process charged with gathering the inputs, including stakeholder views on the importance of the pairwise mode comparisons. However, this is necessarily more involved than current Ecodesign regulatory processes.

Capacity to be implemented

Developing an AHP model for Ecodesign regulatory development purposes would necessitate a rather involved process wherein designated decision-makers would provide inputs into the model development (via the pairwise comparison process). This would doubtless require more effort and thought than the current process for stakeholder and Member States to express their views and could be challenging to implement in practice. Once the model is established it should not pose undue challenges for implementation.

4.15 Points systems used for Ecolabelling

The European Ecolabelling scheme is established through the legal instruments:

Regulation (EC) No 66/2010 of the European Parliament and of the Council of 25 November 2009 on the EU Ecolabel

Commission Regulation (EU) No 782/2013 of 14 August 2013 amending Annex III to Regulation (EU) No 66/2010 of the European Parliament and of the Council on the EU Ecolabel Text with EEA relevance

The EU Ecolabel covers a wide range of product groups, from major areas of manufacturing to tourist accommodation services.

Key experts, in consultation with main stakeholders, develop the criteria for each product group in order to decrease the main environmental impacts over the entire life cycle of the product. Because the life cycle of every product and service is different, the criteria are tailored to address the unique characteristics of each product type.

Every four years on average, the criteria are revised to reflect technical innovation such as evolution of materials, production processes or in emission reduction and changes in the market. The intention is that the EU Ecolabel will represent the highest environmental performance for the product or services it is applied to.

Currently EU Ecolabelling criteria have been established for the following products and services:

- Rinse-off Cosmetic Products
- Absorbent Hygiene Products
- All-purpose cleaners
- All-Purpose Cleaners and Sanitary Cleaners
- Detergents for Dishwashers
- Industrial and Institutional Automatic Dishwasher Detergents
- Hand Dishwashing Detergents
- Laundry Detergents
- Industrial and Institutional Laundry Detergents
- Textiles
- Footwear
- Paints and varnishes
- Imaging Equipment
- Personal Computers
- Notebook Computers
- Televisions
- Wooden Floor Coverings
- Hard Coverings
- Wooden furniture
- Growing media and soil improvers
- Growing Media, Soil Improvers and Mulch
- Heat Pumps
- Water-Based Heaters
- Lubricants
- Bed Mattresses
- Sanitary Tapware
- Flushing Toilets and Urinals

- Converted Paper
- Newsprint Paper
- Printed Paper
- Copying and Graphic Paper
- Tissue Paper
- Holiday Accommodation
- Campsite Services
- Tourist Accommodation Services

Method description and reference

The approach taken to derive the Ecolabel criteria can vary from product to product as the development group determine best fits the needs of the product. In practice the first stages of a standard LCA approach are followed wherein a set of pertinent environmental impact criteria are established and typical impact magnitudes established. These may then subsequently be screened for their potential to be reduced and for the viability of application and potentially limited to a smaller set of impact criteria that will be used within the Ecolabel award system. Once the set of criteria has been established it is common practice to set requirements for each of them. Although aggregation via weighting is not precluded from the EU Ecolabel thus far there has been no example of it being used. Rather in the case of quantifiable criteria the practice is to use normalisation and benchmarking to establish minimum values that have to be met to be eligible to receive the Ecolabel.

The Ecolabel criteria are binary in the sense that a product/service either satisfies them and hence is eligible to apply for the use of the Ecolabel, or it doesn't and hence is ineligible. In all instances of the label as currently implemented all the criteria have to be met for a product or service to be eligible for the label. However, not all the criteria are quantitative. For example, some many concern the presence or absence of a feature or service.

Thus for most products the Ecolabel criteria are similar in structure to Ecodesign criteria but will tend to address more environmental impact parameters. Furthermore, unlike for Ecodesign regulations the energy efficiency requirements set within Ecolabels are not guided by an objective of minimising the life cycle cost.

The EU criteria are developed by an ad hoc working groups established for each product of interest and are subject to approval by the Ecolabel board, which is comprised of a set of notified bodies. In consequence, the criteria are developed using a "panel type" assessment process and thus involve an implicit hierarchical decision making process.

Method evaluation

Effectiveness

The Ecolabel has been awarded to over 30000 products and services across the EU and hence is effective at influencing part of the market. As it is a voluntary scheme it does not have the same scale of impact that is associated with the mandatory energy label or Ecodesign requirements but it applies to a diverse set of products and services that would not be entirely suited to those instruments and furthermore it addresses a broader set of environmental impacts.

Accuracy

In principle the accuracy by which the quantifiable criteria used within the Ecolabelling scheme can be determined is similar to that experienced for other EU environmentally-related product regulations such as Ecodesign, RoHS, WEEE etc.

Reproducibility

In principle, the reproducibility of the quantifiable criteria measurements used within the Ecolabelling scheme is similar to that experienced for other EU environmentally-related product regulations such as Ecodesign, RoHS, WEEE etc.

Enforceability

From a technical perspective, the enforceability of the Ecolabelling scheme is similar to that experienced for other EU environmentally-related product regulations such as Ecodesign, RoHS, WEEE etc. The fact that on average a greater number of assessment criteria need to be evaluated implies that document inspection and verification testing against Ecolabelling criteria is a more involved process than for energy labelling or Ecodesign regulations.

Transparency

The scheme criteria are fully transparent and within the public domain.

Ease and readiness

The scheme is up and running and relatively straightforward to use; however, the fact that on average a greater number of assessment criteria need to be met than for energy labelling or Ecodesign regulations implies that it requires a greater product design and administrative effort to attain the EU Ecolabel requirements.

Capacity to be implemented

The Ecolabel methodology has some similarities with the Ecodesign preparatory study process and need not be inconsistent with the legally enshrined methodological aspects of the Ecodesign regulations. It could be readily made to fit within the Ecodesign and Energy Labelling procedural and decision making process. It has no conflict with the MEErP and Ecoreport tool approaches.

4.16 Points systems used for green public procurement

The 2004 Procurement Directives (2004/17/EC and 2004/18/EC) explicitly allow for the inclusion of environmental considerations in procurement. Case law from the European Court of Justice had already underlined this – with key cases in 2002 (Concordia Bus) and 2003 (EVN Wienstrom) establishing the scope for inclusion of environmental criteria in competitive tenders. Provided that such criteria are applied in a fair and transparent manner, public authorities can pursue high environmental standards in their purchasing.

There are also EU environmental requirements in respect of procurement in certain areas – for example the control of hazardous substances, waste and recycling, purchase of clean vehicles, office IT equipment and the energy performance of buildings (see box).

Many public authorities in Europe have taken the approach of establishing a GPP policy, or including commitments to GPP implementation within other policies. A majority of Member States have adopted a National Action Plan on GPP.

GPP requires effective co-operation between different departments and staff members within an organisation. Moreover, high level support is generally considered to be an important factor in determining the success of GPP implementation.

To be most effective such a policy should:

- set out clear targets, priority sectors and timeframes
- indicate the scope of the purchasing activities covered
- assign overall responsibilities for implementing the policy
- provide for effective communication of the policy and make appropriate guidance and training available
- include a mechanism for monitoring performance

A number of resources for GPP implementation have been developed at EU level and can be accessed from the EU GPP website. The website includes information on the policy and legal framework for GPP, latest developments at EU and Member State level, studies about GPP, training materials, and many other useful resources.

It also contains the EU GPP Criteria and Technical Background Reports in a number of different EU languages. The EU GPP criteria cover a large range of products and service groups commonly purchased by public authorities. The means for verifying compliance with the criteria are clearly set out, in order to ensure that purchased products and services actually deliver the expected environmental performance.

The criteria can be directly inserted into tender documents and are divided into two types, core and comprehensive. The core criteria address the key environmental aspects and are designed to be used with minimum additional verification effort or cost increases. The comprehensive criteria aim at purchasing the best environmental products available on the market.

There are different mechanisms through which environmental impacts can be factored into public procurement, as follows:

Life cycle cost assessments: this means taking into account other costs than the purchase price of the product, but also the costs incurred during its life-time (energy use, maintenance).

Functional specifications: also called: performance-based or outcome based specifications. This means instead of providing detailed technical specifications of a product, it is also possible to ask for a function or outcome instead of a product. This could mean that a purchasing authority would opt for transport instead of a car; or chooses to conclude a service contract for 5000 copies per day instead of a supply contract for a copying machine. This technique also covers all cases where green specifications are not currently included in detailed standards, but are to be defined by way of functional or performance based requirements. When the procurement organisation emphasises the importance of a 'green' outcome, the supplier can be more creative in thinking of a ‘greener’ solution. A substantial number of purchasing organisations in the EU use functional specifications.

Green contract variants: this means that suppliers are asked to submit greener variants for the same product. Whilst doing so, the contracting authority will set minimal technical specifications for all bids to comply with. Then it will invite bidders to submit bids on the basis of these requirements and invite them also to submit (if feasible) bids on the basis of the “basic” requirements plus some environmental requirements. Having received all offers, the contracting authority will compare all offers on the basis of the same set of award criteria (which should include an environmental award criterion). This will allow the contracting authority to choose a green variant if it has accumulated most points at the award stage (this will for example be possible if its price is not extremely higher than that of the “neutral” bids).

GPP criteria been set for many products and services across the EU and are used in different ways to influence the award of procurement contracts. For example implementing GPP in the construction sector may involve the following elements:

- selection criteria for architects and engineers based on experience in sustainable building design, and for contractors in applying appropriate environmental management measures on site
- minimum energy performance standards, with additional points available for performance beyond the minimum
- preference for designs which incorporate renewable energy systems
- restrictions on hazardous substances in building materials and incentives for the use of sustainable timber and materials made of recycled content
- contract clauses related to waste and resource management and transport of construction materials to site which minimise environmental impact

These factors, along with all the traditional elements considered in public procurement can be evaluated and ranked via a hierarchical decision process such as AHP. This typically involves establishing the award criteria and grouping them where appropriate, devising scoring systems per criteria which are either, bounded within groups and simply summed to attain an aggregate score across the groups, or are summed within groups and weighted across groups to produce an aggregate score.

In Malta, for example, specifications for a new school building required it to be energy self-sufficient through the use of on-site renewable energy production. Tenderers were able to present different solutions for achieving this goal. Minimum levels of energy and water efficiency were specified, with additional points available for even better performance during the award stage.

Method description and reference

There are a great many examples of hierarchical points based methods used within procurement – either for green public procurement or other forms. In practice they are all forms of AHP models most commonly using groupings and weightings derived via panel methods. Any specific implementation using such approaches will give greater or lesser importance to specific impact parameters including environmental impacts, economic impact parameters (such as initial cost, and lifecycle cost), and parameters to determine the functional value of the good or service being procured. However, the structural elements will be similar and need not be analysed in greater depth here to understand their value in the context of Ecodesign of complex products.

It should be noted, however, that it is more common for environmental impact parameters to be treated in GPP via the setting of simple environmental performance thresholds than from the use of points-schemes. Points schemes, albeit often very simple ones, are routinely used in the evaluation of competing bids for services around the world and there is nothing inherently innovative in their adaptation to include environmental impact factors.

Method evaluation

Effectiveness

There is considerable and growing evidence of the impact of GPP thus in general it can be said to be an effective policy instrument. When GPP is applied to products, complex or conventional, it tends to operate at a lower level of detail and sophistication than is applied in the development of Ecodesign or energy labelling criteria, however, GPP schemes will typically make use of such criteria to inform the technical underpinning of their own criteria. The same can be true of Ecolabel criteria.

Accuracy

In principle, the accuracy by which the quantifiable criteria used within GPP schemes can be determined is similar to that experienced for EU environmentally-related product regulations such as Ecodesign, RoHS, WEEE etc.

Reproducibility

In principle the reproducibility of the quantifiable criteria measurements used within the GPP schemes is similar to that experienced for EU environmentally-related product regulations such as Ecodesign, RoHS, WEEE etc.

Enforceability

From a technical perspective the enforceability of the GPP schemes is similar to that experienced for EU environmentally-related product regulations such as Ecodesign, RoHS, WEEE etc. to the extent that the GPP scheme is basing its criteria on these existing initiatives.

Transparency

The criteria applied in GPP are usually fully transparent and within the public domain.

Ease and readiness

Numerous GPP schemes have and are being implemented and are relatively straightforward to use. There ease of use will depend in part on the number of impact criteria that they require to be assessed.

Capacity to be implemented

GPP is serving a different purpose to Ecodesign and hence is not directly applicable in that context. Some aspects of GPP points-systems approaches could be incorporated within Ecodesign and Energy Labelling procedural and decision making process. These methodologies have no conflict with the MEErP and Ecoreport tool approaches.

4.17 Extended Product Approaches - The “installer energy label” for heating systems

The EU energy label for spacer heating systems applies to packages of space heater, temperature control and solar device offered for sale, hire or hire-purchase (European Commission 2013b).

Method description and reference

The space heating installer energy label is innovative compared to conventional energy labels in two principal respects:

It is essentially an extended product approach which ranks and displays the energy efficiency of the heating system as a system and not just for each individual component within it.

It is to be implemented by the installer of the system using component ratings supplied by the product component manufacturers.

Ostensibly the method used considers the seasonal heating efficiency of the boiler at the location in isolation; it then adds efficiency credits, depending on the nature of controls used. It should be noted that the controls considered are solely those which concern the direct control of the boiler, and not the control of the heating distribution system (which is often where larger energy savings may be possible). The additional parameters considered include: the impact of using an additional boiler, the impact of using a solar heating device, the impact of using a heat pump, the impact of using a solar heating device and a heat pump, and all the above is then taken through the calculation structure shown in Figure 14 to derive an overall heating system efficiency score.

This approach is a classic example of a modular approach to determining the energy efficiency of a system. It indicates how the energy performance of individual system modules (components) can be assessed in isolation and then their collective performance, as a specific assembly of components within an overall heating system, can be determined via a set of logical calculations (using credits and multiplicative efficiencies). Although each component has a distinct function, and a distinct efficiency in performing that function, this does not prohibit their collective efficiency from being estimated in a sufficiently robust manner to permit an overall energy labelling class to be determined for the heating system.

Although the method is relatively innovative, implementation has only recently begun and hence it is too early to be able to report findings on how it is working in practice.

From a technical perspective, the method makes considerable progress in being able to reveal the efficiency of the heating system. However, it has the following limitations:

- it does not address the heat losses in the distribution system and hence gives no reward to the use of distribution loss reduction measures such as: zoning, TRVs, individually programmable heat emitter controls and actuators linked to a room thermostat, learning the thermal response of rooms and optimum stop/start controllers, weather compensation controls.
- it does not address the impact of heating system sizing on its overall performance.

In practice, these latter two factors (especially the first) can have a very large impact on the overall efficiency of the heating system.

Nonetheless, despite these system boundary analysis limitations the labelling scheme has considerably broadened the extent of the heating system that is taken into account when rating its efficiency and hence has amplified the visibility of the energy savings possibilities. From a technical and policy-making perspective it is a successful example of a workable compromise being struck between technical precision and the overarching policy need to present the public with information on the energy efficiency of the heating systems they are considering procuring.

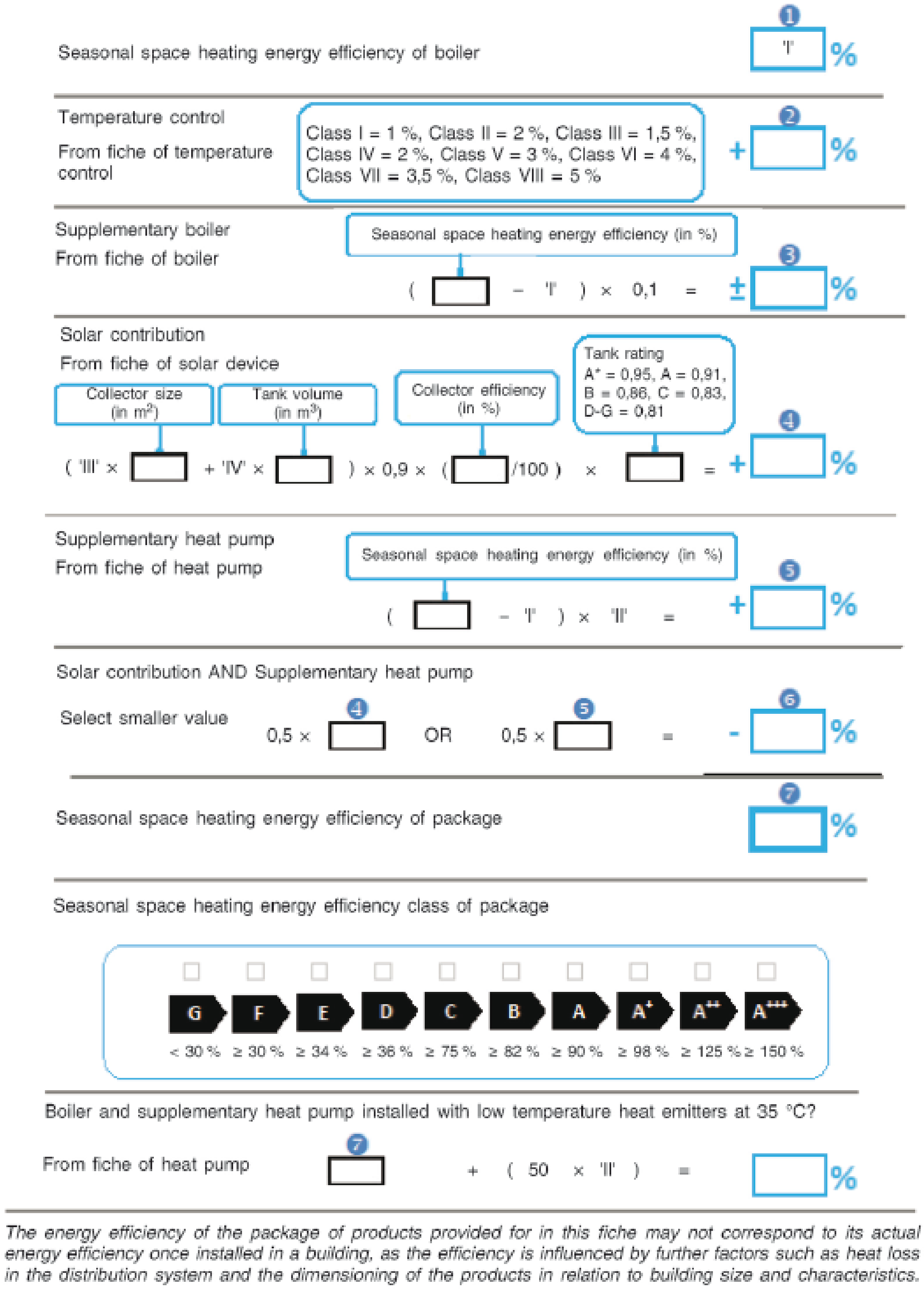

Figure 14. For preferential boiler space heaters and preferential boiler combination heaters, element of the fiche for a package of space heater, temperature control and solar device and a package of combination heater, temperature control and solar device, respectively, indicating the seasonal space heating energy efficiency of the package offered

This example is also interesting from a technical perspective because it addresses one of the key challenges for complex products, namely, how to characterise the performance of modules (components) that have more than one function? In this case the boilers, solar heaters and heat pumps may well serve dual space and water heating functions. The approach taken is to determine their efficiency for doing each function uniquely and then to separately label the system space heating efficiency and the system water heating efficiency. It does not go so far as to integrate a duty cycle for each function in isolation to derive a combined functional duty cycle, although in principle such an approach could be imagined.

Method evaluation

Effectiveness

The scheme has only just entered into force and thus there is currently no evidence of its effectiveness. However, if it has even a modest proportion of the impact of other energy labels it will likely lead to energy savings and as a minimum it allows the energy efficiency of the heating system to be made visible in such a manner than it can readily be completed by other policy instruments such as EPCs, building codes, incentives etc.

Accuracy

In principle, the accuracy by which the quantifiable criteria used within the heating system energy label can be determined is similar to that experienced for other labelled products except that because the overall systems efficiency rating is effectively a multiplicative sum of the efficiencies of its individual components compound errors will be propagated through to the system level. This is unavoidable when dealing with multiple components, however, and is not indicative of any methodological weakness.

Reproducibility

In principle, the reproducibility of the quantifiable criteria measurements used within the space heating energy label is similar to that experienced for other EU environmentally-related product regulations, such as Ecodesign, RoHS, WEEE etc.

Enforceability

From a technical perspective the enforceability of the space heating energy labelling schemes is similar to that experienced for EU environmentally-related product regulations such as Ecodesign, RoHS, WEEE etc.; however, it introduces a different challenge because it requires the actions of system installers, as well as component suppliers to be addressed.

Transparency

The criteria applied and the process of deriving the space heating systems energy label are fully transparent and within the public domain.

Ease and readiness

The system for installers to determine and apply the space heating systems energy label is readily available and relatively straightforward to use. Nonetheless, teething issues can be expected in the early stages of the scheme's deployment, as a large number of heating systems installers need to become familiarised with the scheme.

Capacity to be implemented

The fact that the space heating systems energy label has been adopted within the rubric of the EU energy labelling framework shows it has satisfied all the "capacity to be implemented" criteria being considered in this assessment.

4.18 Extended Product Approaches - The Europump Extended Product Approach

Europump have published a proposal for an extended product approach that could be applied for establishing Ecodesign requirements for pumps (Europump 2013).

Method description

If the product is the pump, the extended product is the pump, plus the power drive system (PDS) and the controls. The broader system would bring into play the aspects of the application that the extended pump product system is being required to perform. In principle, any Ecodesign implementing measures that are based solely on a Product Approach would only take the efficiency of the product into account (i.e. of the pump hydraulics alone in this case), whereas the Extended Product Approach will also take the load profile and control method curve into account. This allows the benefit of measures that allow reductions in the pump head to be taken into account, and hence given proper credit. In the case of water pumps, Europump estimates that this will lead to a ten-fold increase in savings compared to product-only implementing measures.

The methodology characterises combinations of pump types (8 distinct types) and system types (closed loop systems or open loop systems, and constant flow systems or variable flow systems) within a matrix. It proposes characteristic load profiles for closed loop systems or open loop systems, depending on whether they are for constant flow or variable flow applications. Following on from this functional mapping process a system is proposed to calculate the EEI based on each specific case found within the matrix.

A complication arises because with the exception of circulator pumps and ESCCI (End suction close coupled inline water pump) pump types, there is no one-to-one mapping between the pump type and the system type (closed/open loop, constant/variable flow). As a result for pump types which are used in more than one system type, more than one EEI value needs to be calculated.

Method evaluation

Effectiveness

The Europump extended product scheme is an industry proposal which has not currently been incorporated into the EU's Ecodesign or energy labelling regulatory framework and thus there is currently no evidence of its effectiveness. However, as it presents a means of setting Ecodesign criteria for pumps as systems, and as most of the energy savings potential for pumps resides in how they are operated as a system, it clearly has considerable potential to lead to significant energy savings. While the system matches pump types with system types (open or closed loop, constant or variable flow) the challenge is how to do this in a prospective mandatory regulation where the pump application (and hence system type) is not necessarily known. For example, measures that might lead to large energy savings in variable flow applications may, however, lead to some energy consumption increases in fixed flow applications.

Accuracy

In principle, the accuracy to which the quantifiable criteria used within the Europump extended product scheme can be determined is similar to that experienced for other products subject to Ecodesign or energy labelling requirements. However, because the overall systems efficiency rating is effectively a multiplicative sum of the efficiencies of its individual components, compound errors will be propagated through to the system level. This is unavoidable when dealing with multiple components, however, and is not indicative of any methodological weakness.

Reproducibility

In principle, the reproducibility of the quantifiable criteria measurements used within the Europump extended product scheme is similar to that experienced for other EU environmentally-related product regulations such as Ecodesign, RoHS, WEEE etc.

Enforceability

From a technical perspective the enforceability of the Europump extended product scheme proposals is similar to that experienced for EU environmentally-related product regulations such as Ecodesign, RoHS, WEEE etc.; however, it introduces a different challenge because it would appear to require the actions of system specifiers and installers, as well as component suppliers to be addressed.

Transparency

The criteria applied and the process of deriving the Europump extended product scheme are fully transparent and within the public domain.

Ease and readiness

The system to determine and apply the Europump extended product scheme is readily available and relatively straightforward to use in principle. Nonetheless teething issues can be expected in the early stages were the schemes to be implemented as a large number of pump systems installers would need to become familiarised with the scheme.

Capacity to be implemented

There are no inherent legal or administrative process barriers to the adoption of the Europump extended product scheme within the Ecodesign regulatory framework.

Other extended product approaches

It should be noted that this pump methodology is just one among many addressing extended products. CENELEC TC 22X which addresses power electronics, drew the study team's attention to work on extended products including: pumps, fans, compressors, conveyors, lifts or cranes, as well as simple or complex machine tools, etc.

4.19 Ecodesign Lot 37 lighting systems investigation

The on-going Lot 37 lighting study into lighting systems[9] has established how the energy performance of each separate module of a lighting system can be analysed in a compartmentalised manner and fed into a calculation to determine the overall energy efficiency of the lighting system.

Method description

In the case of in-door lighting the study presents a technically viable pathway by which the characteristics of each component within a lighting system are combined to give an overall energy performance indicator.

This compartmentalisation and causative flow is shown in Figure 1 wherein each system level element has its own colour code as follows: electrical efficiency (dark green), installation (dark blue), luminaire (sky blue), lamp (orange), control system (light green), control gear (red), and design process (yellow). This demarcation is

[9] http://ecodesign-lightingsystems.eu/

done to help delineate the various aspects of a lighting system and to enable their contribution to the overall eco-efficiency of the system to be analysed and determined.

In the case of non-residential lighting, the EN 12464 standard series on indoor lighting is used to define minimum recommended lighting service levels for any given lighting service application, and these allow normalised service levels to be established. The energy consumption and efficiency of any given lighting system can then be derived for each required application and normalised against the required lighting service levels. For any given lighting service level requirement the indicator of the energy performance of the lighting system is given by the Lighting Energy Numerical Indicator (LENI) which is expressed in kWh/year per m2 (see far left of Figure 15). The LENI value for any given in-door lighting system is derived by the application of the standards EN 15193 and EN 13201-5 in conjunction with the light levels required for the specific application under EN 12464.

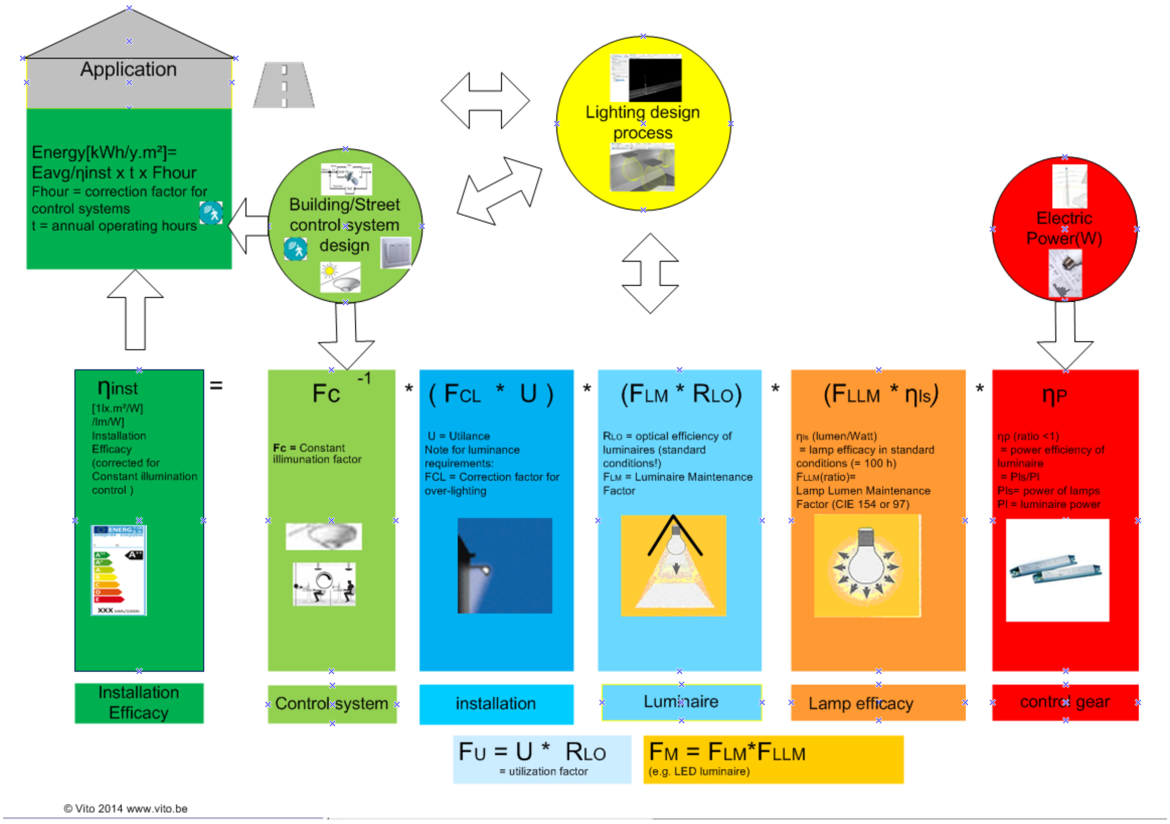

Figure 15. Components of a lighting system and the most relevant performance parameters related to energy efficiency

By comparing the available average and best available technology (BAT) solutions for each application it is possible to determine the range of viable LENI values per application. If life cycle cost optimisation were to be incorporated into this process it becomes technically possible to devise a specific LENI target for each class of typical lighting system, in a manner that could meet the aims of the Ecodesign regulatory process. However, a priori this would be applicable at the application level rather than at the sub-system level, and thus this raises the question of on whom regulatory requirements could be placed. The space heater energy label demonstrates that it is at least legally permissible for system labelling requirements to be imposed on installers, and not solely on component manufacturers.

Method evaluation

Effectiveness

The LENI approach described above is already adopted in European standards, is incorporated in lighting design software and is embedded in some Member State building codes. While it works from a technical perspective it is voluntary to apply in most of the EU and thought to only being applied by a limited proportion of market actors as a consequence.

Accuracy

In principle, the accuracy by which the quantifiable criteria used within the LENI approach can be determined is similar to that experienced for other products subject to Ecodesign or energy labelling requirements except that because the overall systems efficiency rating is effectively a multiplicative sum of the efficiencies of its individual components compound errors will be propagated through to the system level. This is unavoidable when dealing with multiple components, however, and is not indicative of any methodological weakness.

Reproducibility

In principle, the reproducibility of the quantifiable criteria measurements used within the LENI calculation at the component level is similar to that experienced for other EU environmentally-related product regulations such as Ecodesign, RoHS, WEEE etc. There are more calculation steps at the systems level necessary to derive the LENI and hence there is more scope to introduce variance than for simple products.

Enforceability

The enforceability of the LENI approach is similar to that of other technical energy using systems specified with the Energy Performance in Buildings Directive (Article 8), and has been demonstrated through incorporation into building code requirements in countries such as the UK and Switzerland. It introduces a different challenge compared to standard products within Ecodesign because the actions of system specifiers and installers, as well as component suppliers, need to be addressed.

Transparency

The criteria applied and the process of deriving the LENI calculation are fully transparent and within the public domain.

Ease and readiness

The means to apply the LENI calculation method is readily available and relatively straightforward to use in principle. Nonetheless it is more complex than some less sophisticated lighting energy performance calculations such as the lighting power density indicator.

Capacity to be implemented

There are no inherent legal or administrative process barriers to the adoption of the LENI calculation approach within the Ecodesign regulatory framework but there are questions to be resolved concerning on whom measures could be applied.

5. Summary of findings

A broad variety of multi-impact criteria assessment methodologies have been compiled and assessed to examine their inherent characteristics and explore their potential relevance for potential adaptation or incorporation within a points based approach for the Ecodesign of complex products.

Table 10 presents a summary of the team's (subjective) evaluation scores of each of the methodologies considered in this review against each of the assessment parameters.

As many (most) of these methodologies have not been designed with the Ecodesign regulatory process in mind, they are not directly adapted or applicable to its use. However, they do share many elements that are of value in the conduct of Ecodesign-like assessments. In the case of the methods that address multi-criteria environmental impact analysis these elements may include derivation of functional units, definition of environmental impact criteria, normalisation and benchmarking, grouping, weighting and aggregation. In other cases they may share a structured hierarchical modelling framework to facilitate prioritisation and decision-making when judgements are required based on multiple and distinct input criteria.

Most of the methodologies[10] that address environmental impacts are more suited to the setting of specific thresholds i.e. such as would be used in Annex II (Method for setting specific ecodesign requirements).

Some of the methods contain elements that would be suited to setting generic Ecodesign requirements i.e. such as would be used in Annex I (Method for setting generic ecodesign requirements) of the Ecodesign Directive (European Commission 2010)[11].

With two exceptions (the ISO 14995-1 energy efficient design methodology for machine tools, and the EU Energy Label for space heating systems) the methods do not offer an approach tailored to managing complex functional units where the same component has more than one function. The ISO 14995-1 standard facilitates this, however, through its detailed mapping and attribution of functionality to product sub-systems for the specific case of machine tools. The space heating energy label does so similarly for space heating components that may both provide space heating and water heating services.

Despite these methods being applied within diverse applications, certain generic similarities and common characteristics are witnessed between many of them (see Table 11).

[10] Specifically: LCA ISO 14040 and 14044, PEF, MMG, STRES, Hybrid LCA, BREEAM, LEED, DGNB, ISO 14955-1 (partially), Machine Tool Mandatory Point Scheme Proposal, AHP applied to technology portfolio assessments, Points systems for ecolabelling, Points systems for green public procurement, The "installer energy label" for heating systems, Europump extended product scheme, Ecodesign Lot 37 lighting systems.

[11] Specifically: ISO 14955-1 and AHP applied to technology portfolio assessments. Potentially: points systems for ecolabelling, green public procurement, and applied to market surveillance.

Table 10: Summary of the team's evaluation scores of the multi-criteria assessment schemes considered in this review.

Method	Effectiveness	Accuracy	Reproducibility	Enforceability	Transparency	Ease and readiness of use	Capacity to be implemented
LCA ISO 14040 and 14044	5-10	5-10	7-9	2-10	6-10	4-9	7
Product Environmental Footprint	6	6	6	4	9	5	6
French environmental label - field trials	NA	NA	NA	NA	NA	NA	NA
Common framework of core performance indicators for resource efficiency assessment in the building sector	NA	NA	NA	NA	NA	NA	NA
Material based environmental profiles of building elements (MMG)	8	8	7	4	9	7	7
Methodology to integrate cost effectiveness in determining the performance of a technology in the framework of Strategic Ecological Support (STRES)	8	7	5	3	9	5	6
Environmental impact assessment – Hybrid LCA methodology	5-10	5-10	7-9	2-10	6-10	4-9	7
BREEAM	8	6	7	4	4	8	6
LEED	8	6	6	4	4	7	6
DGNB	8	6	6	4	4	7	6
ISO 14955-1: Machine tools	8	7	6	7	8	8	8
Machine Tool Mandatory Point Scheme Proposal	6	3	6	4	3	3	8
AHP	6	6	6	5	6	3	4
Points systems used for Ecolabelling	6	8	7	6	9	7	8
Points systems used for green public procurement	8	8	7	6	9	7	6
The "installer energy label" for heating systems	8	8	7	7	9	8	10
Europump extended product scheme	6.5	8	7	7	9	8	9
Ecodesign Lot 37 lighting systems investigation	8	8	7	7	9	7	8

NA = not applicable

Table 11 presents a summary of the methodological elements within each of the methodologies considered in this assessment.

Table 11: Summary of the methodological elements included within the multi-criteria assessment schemes considered in this review.

Method	Pure points system (P) or potential component (C) within one?	Classification based on points scored (Y/N)	Hierarchical decision aiding model? (Y/N)	Prioritisation and aggregate score?	Prioritisation method (Panel, Monetisation, Distance to Target)	Multi-criteria assessment decomposed into sub-problem assessments, each of which can be analysed independently?	Application of numerical weightings to sub-problem scores to establish weighted hierarchy?	Pairwise comparison between alternatives?	Potentially applicable to generic process evaluation? (Y/N)
LCA ISO 14040 and 14044	C	N	N	Y	Any	Y	Y	N	N
Product Environmental Footprint	P	N	Y	Y	Any	Y	Y	N	N
French environmental label - field trials	C	N	N	N	NA	Y	N	N	N
Common framework of core performance indicators for resource efficiency assessment in the building sector	C	N	U	Y	Any	Y	U	U	U
Material based environmental profiles of building elements (MMG)	C	N	Y	Y	Monet-isation	Y	Y	N	N
Methodology to integrate cost effectiveness in determining the performance of a technology in the framework of Strategic Ecological Support (STRES)	C	Y	Y	Y	Panel/Mo netisation	Y	Y	Y	N
Environmental impact assessment – Hybrid LCA methodology	C	N	N	Y	Any	Y	Y	N	N
BREEAM	P	Y	Y	Y	Panel	Y	Y	Y	N
LEED	P	Y	Y	Y	Panel	Y	Y	Y	N
DGNB	P	Y	Y	Y	Panel	Y	Y	Y	N

Method	Pure points system (P) or potential component (C) within one?	Classification based on points scored (Y/N)	Hierarchical decision aiding model? (Y/N)	Prioritisation and aggregate score?	Prioritisation method (Panel, Monetisation, Distance to Target)	Multi-criteria assessment decomposed into sub-problem assessments, each of which can be analysed independently?	Application of numerical weightings to sub-problem scores to establish weighted hierarchy?	Pairwise comparison between alternatives?	Potentially applicable to generic process evaluation? (Y/N)
ISO 14955-1: Machine tools	C	N	N	N	NA	Y	N	Y	Y
Machine Tool Mandatory Point Scheme Proposal	P	Y	Y	Y	Panel	Y	Y	Y	N
AHP	P or C	Y or N	Y	Y	Usually Panel	Y	Y	Y	Y
Points systems used for Ecolabelling	C	Y	Y	Y	Usually Panel	Y	N	Y	N
Points systems used for green public procurement	P	Y	Y	Y	Usually Panel	Y	Y or N	Y	Y
The "installer energy label" for heating systems	C	N	Y	N	N	Y	Partially	Y	N
Europump extended product scheme	C	N	Y	N	N	Y	N	Y	N
Ecodesign Lot 37 lighting systems investigation	C	N	Y	N	N	Y	N	Y	Y

U =- unknown, NA = not applicable

These similarities may be summarised as follows:

- about half are pure points-systems methodologies and the other half are methodologies that could be adapted for use as a potential component within a points system
- about half the methodologies include a classification system based on the number of points scored
- most employ a hierarchical decision-making model
- the large majority involve prioritisation and aggregate scoring
- most permit the use of a prioritisation method of which the most common in the panel-method, but monetisation is used in one (MMG) and the Distance to Target method could also be used in some cases
- in all cases the process of conducting a multi-criteria assessment involves decomposition into sub-problem assessments, each of which can be analysed independently

- the majority of methods apply numerical weightings to sub-problem scores to establish a weighted hierarchy
- about half the methods entail some kind of pairwise comparison between alternatives
- some of the methods are potentially applicable to generic process evaluation

Essentially, those methods which address prioritisation, and which make aggregations of scores, could be suitable for adaptation to derive aggregate points system scores across different types of environmental impacts. On the other hand, those methods which do not follow the prioritisation and aggregation steps may be suitable for adaptation, to instead derive the impacts of environmental impact parameters in isolation of one another.

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