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Normative ethics and methodology for life cycle assessment

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Abstract

Prospective life cycle assessment (LCA) provides information on the environmental consequences of individual actions. Retrospective LCA provides information about the environmental properties of the life cycle investigated and of its subsystems. In this paper we analyse the links between the choice of methodology and different theories of normative moral philosophy. The choice of electricity data in an LCA of a conference site with local hydropower production is discussed as an illustration. The two types of LCA can be related to different theories on the characteristics of a good action. Each type of LCA, as well as each of the moral theories, can be criticised from the alternative point of departure. Decisions based on retrospective LCA can have environmentally undesirable consequences. On the other hand, prospective LCA can appear unfair and result in environmentally sub-optimised systems. Both types of LCA also have methodological limitations. We cannot conclude that one type is superior to the other, but the choice of methodology should be consistent with the information sought in the LCA.

Keywords: Life cycle assessment; Moral philosophy; Methodology; Marginal data; Allocation

1. Introduction

Environmental life cycle assessment (LCA) was developed based on the idea of comprehensive environmental assessments of products, which was conceived in Europe and in the United States in the late 1960s and early 1970s [1,2]. Many initiatives have been taken to harmonise [3–5] and standardise [6–9] LCA methodology. Early in the harmonisation process, it was acknowledged that the appropriate LCA methodology depends on the purpose of the individual study [3]. Many attempts have also been made to describe when different types of LCA are appropriate. In this paper, we distinguish between two types of methodology for LCA: retrospective and prospective. Retrospective LCA is defined by its focus on describing the environmentally relevant physical flows to and from a life cycle and its subsystems. Prospective LCA is defined by its aim to describe how environmentally relevant flows will change in response to possible decisions [18,19,21]. Similar distinctions have been made in several other publications [10–20], but often using other terms to denote the two types of LCA and sometimes including further distinctions of subcategories within the two main types of LCA.

We apply the terms prospective and retrospective LCA without the connection to directions in time that is indicated by these words. A prospective LCA in our typology is not necessarily a future-oriented LCA. It can also be an LCA that is carried out to assess the consequences of decisions in the past. Likewise, what we call a retrospective LCA can be carried out to describe the environmentally relevant physical flows of a past, current, or potential future product system.

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The different focuses of prospective and retrospective LCA are reflected in the approach to two areas of methodological problems in the life cycle inventory (LCI) analysis; this is the phase of an LCA in which the material and energy flows are compiled and quantified [7]. One problem area is the choice of average or marginal data in the modelling of subsystems of the life cycle. Average data for a system are those representing the average environmental burdens for producing a unit of the product and/or service in the system. Marginal data represent the effects of a small change in the output of products and/or services from a system on the environmental burdens of the system.

The other problem area concerns allocation and related system boundaries. Allocation is the partitioning of the environmental burdens of a technological activity among the life cycles in which the activity fulfils a function. The partitioning becomes a methodological problem when, for example, the activity results in several products that are used in different life cycles, or when a material, through recycling, is utilised in more than one life cycle. Problems associated with allocation caused the most debate during the development of the international standard for LCI [7]. The allocation problems have also been the topic of many scientific papers and several PhD theses [21–26].

Retrospective LCA excludes the use of marginal data. The system investigated typically includes, and is limited to, the whole life cycle from cradle to grave. Allocation problems are typically solved through partitioning of environmental burdens in proportion to some property of the products: the economic value, mass, volume, etc. [18].

The system boundaries in a prospective LCA are defined to include the activities contributing to the environmental consequences of a change, regardless of whether these are within or outside the cradle-to-grave system of the product investigated. Marginal data are used when applicable to the purpose of assessing the consequences, and allocation problems are avoided by expanding the system boundaries to include affected processes outside the cradle-to-grave system [18].

In some publications it is proposed that the choice between the types of LCA depends on the type of application: retrospective LCA should be used for learning purposes and possibly marketing, and prospective LCA for actual decision-making [10,17,18]. In other publications it is argued that the same type of LCA can, at least in principle, be used independently of the application [21,24], and that the most relevant information is generated through a prospective LCA [19,27,28].

The aim of this paper is to contribute to the understanding of the link between the purpose of an LCA and the choice between retrospective and prospective methodology. We concentrate mainly on the individuals or organisations that the study is intended to inform. Results from an LCA will only be useful if its audience perceives the results as relevant [11,29]. It has been established that retrospective and prospective LCA reflect different study foci: to generate environmental information on the life cycle investigated or on the consequences of changes, respectively [18,19]. Our main task is to improve the understanding of the ethical meaning implied when one or the other of these options is perceived as relevant. We elucidate the philosophical underpinnings of such a perception through the use of a typology of theories within normative ethics.

In addition to the ethical aspects, the perception of what methodology is the most appropriate can be affected by practical limitations in the methodologies. Such limitations are also discussed in this paper. The ethical aspects as well as the practical limitations are illustrated with an example from the electricity sector.

This paper is directed towards LCA researchers and practitioners; however, we believe that an understanding of the ethical meaning of the LCA methodology is useful also to the audience of LCAs. Parts of our results have been presented in previous conference papers [30,31].

2. Ethical relevance of information

We suggest that information from a retrospective LCA is useful for making decisions that aim at avoiding life cycles and subsystems that have an undesirable environmental impact. In other words, the retrospective LCA is valid to an (hypothetical) audience that wants to avoid such product systems and subsystems. Likewise, the prospective LCA is valid if the audience considers changes of a product system "good" if consequences for the total environment are good. Apparently, one reason why different people do not agree on what type of LCA is the most relevant can be differences in the view on what constitutes an environmentally good action. To illuminate these differences and investigate whether a correct view in this matter can be identified, we turn to normative moral philosophy, or normative ethics. This is the area within moral philosophy that deals with the question of what kinds of actions are good or right in general [32].

2.1. Theories within normative ethics

Several theories within normative ethics have been presented. They have been divided into categories as illustrated in Table 1, which is based on Lübcke [33]. According to *teleological ethics*, actions should be judged according to a valuation of their consequences. This requires a value theory, stating what consequences are more or less valuable or desirable. *Deontological ethics*, in contrast, is based on the perception that

Table 1
Typology of theories within normative ethics

	Situation ethics	Rule ethics
Teleological ethics	Consequences of individual action (e.g., Bentham)	Adherence to rule with good consequences (e.g., Mill, Moore)
Deontological ethics	Situation dependent principles (e.g., Adam Smith, Løgstrup)	Adherence to rule that is right in itself (e.g., Kant)

The table presents the basis for evaluating an action according to the four theory categories. It also presents important representatives for the each category, as given by Lübcke [33].

a principle can be good or bad in itself, apart from the values connected with the consequences of applying the principle. Instead, the principles in deontological ethics can be linked to concepts of right and wrong, of rights and duties, and of obligations. As an example of deontological ethics, Kant states, "act only on that maxim whereby you can at the same time will that it should become a universal law". This should not be interpreted as referring to the consequences of the maxim. Instead, the formulation concerns whether it is logically consistent to want the maxim to become a universal law [32].

Another basis for the categorisation of the theories deals with the contrast between considering a specific situation (*situation ethics*) or relying on generally applicable rules (*rule ethics*). According to situation ethics, each individual action should be assessed in relation to the specific situation in which the action is taken. In rule ethics, however, each action should be assessed in relation to a rule or a set of rules. This set of rules can vary in detail and the degree to which it is founded on theory. The assessment of an action in the context of rule ethics has two elements: the action must be judged in the context of the rules, and the rules themselves must be evaluated in the context of overarching normative principles.

Lübcke [33] combines the distinctions and obtains four categories of theories within normative moral philosophy, as illustrated in Table 1. According to teleological situation ethics, an action is good if that individual action has good consequences [32]. Deontological situation ethics also implies that each action is assessed according to the specific situation in which it takes place, but without referring to whether its consequences are good or bad; this reflects situation dependent principles. According to teleological rule ethics, actions are good to the extent that they obey rules that have good consequences. In deontological rule ethics, the rules are based on inherently good principles, and not on their consequences.

2.2. Link between normative ethics and LCA types

The typology presented in Table 1 does not enable us to decide whether an environmentally good action is an action that reduces the environmental burdens of the total life cycle or an action with good consequences for the total environment. On the contrary, the sheer diversity of ethical theories strongly indicates that it is not possible to identify a single, correct view in this matter. However, it is possible to identify links between certain categories of ethical theories and the types of LCA (Fig. 1).

A *retrospective* LCA provides an environmental assessment of the life cycle and subsystems investigated. Such information can be used, among other things, to decide whether or not to become associated with the system, for example by buying the product investigated. It is relevant to base this decision on information from a retrospective LCA if the ethical rule is to avoid being associated with systems that have undesirable environmental impacts. When such a rule is adopted without reference to its consequences, this is a special case of deontological rule ethics. However, the rule can be expected to have good consequences, since it is reasonable to assume that it will give rise to systems with preferable environmental impacts. In other words, the rule can also be a special case of teleological rule ethics.

If an individual action should be assessed according to its particular consequences, it is appropriate to base decisions on information from a *prospective* LCA, since such a study is designed to describe the environmental consequences of a change. In other words, the choice of a prospective LCA methodology is valid from the perspective of teleological situation ethics.

A special case of prospective LCA is when the change that is investigated is the introduction (or abrogation) of a regulation. An example is the LCA on beverage containers that was made to evaluate the Danish ban on one-way containers for beer and carbonised soft drinks [34]. In this instance, the prospective LCA generated information on the consequences of abrogating the regulation. Such information is relevant, from the perspective of teleological situation ethics, to assess the abrogation of the regulation.

A prospective LCA can generate information not only on the consequences of a formal regulation; in principle, it can yield information on the consequences of any type of rule. This means that a prospective LCA can, in principle, generate a part of the information that is relevant in the context of teleological rule ethics, since this requires an assessment of the consequences of ethical rules. In practice, however, the causal relations and the combined systems that would be affected by an

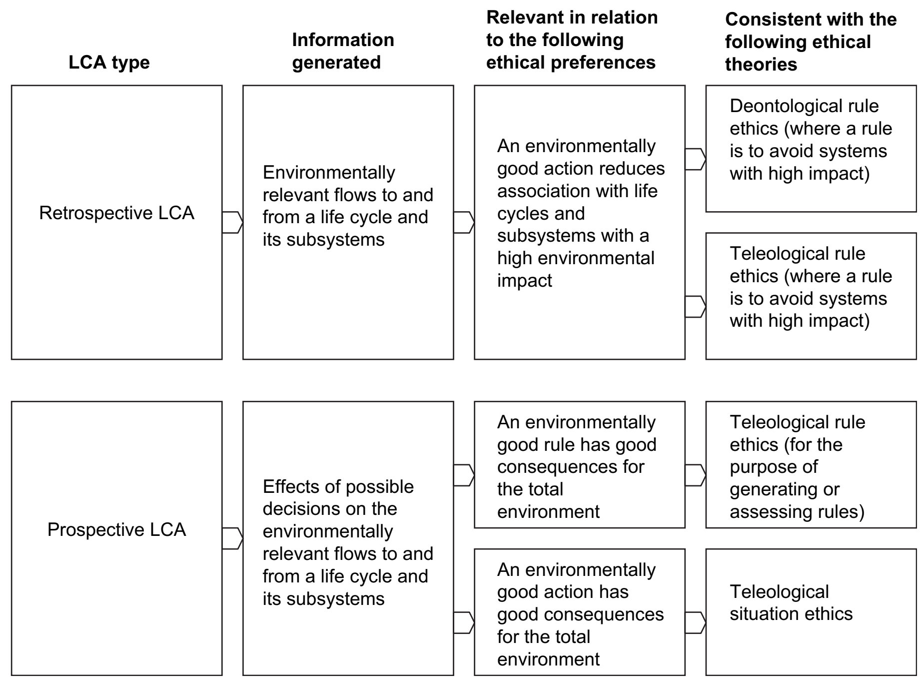

Fig. 1. Illustration of the links between the information generated through different types of LCA, the ethical preferences of the audience, and theories of normative ethics.

ethical rule might well be too complex to model in an LCA.

Finally, prospective LCAs can be used not only for the assessment of actions or rules, but also for generating teleological decision rules, i.e. rules with good consequences. As an example, a series of prospective LCAs that are carried out on several car components can show that the component weight is a critical factor. Such LCA results may form a basis for a rule that the weight should be minimised, or at least taken into account, in the design of all car components.

3. Retrospective LCA and rule ethics

In this section, we discuss the limitations of the retrospective methodology with a focus on system boundaries and allocation problems. We also present a critique of retrospective LCA from the perspective of teleological situation ethics.

3.1. Technical limitations of retrospective LCA methodology

A retrospective LCA focuses on assessing the environmentally relevant physical flows of a life cycle and its subsystems. As stated above, this can be used, e.g., to decide whether or not we want to become associated with the system. One problem in this context is that it is often unclear to what system or subsystems we become associated through our actions. For example, it can be difficult to identify the system from which a customer buys electricity. Kåberger and Karlsson [35] indicate that customers buy electricity from a system that consists of a specific electricity production technology, if they buy electricity on a contract that specifies the electricity production plant or technology. By performing company specific LCIs the major electricity companies in Sweden (Vattenfall [36] and Sydkraft) seems to express the view that customers buy electricity from a system consisting of a specific company's electricity production. Traditionally, LCIs that are conducted in Sweden use data on average Swedish electricity production for electricity that is used within the country. This is consistent with the view that the electricity is bought from the national electricity system. However, the electricity in Norway, Sweden, Denmark, and Finland is freely traded on a common Nordic market, which is connected to the electricity grid of other European countries. This suggests that a Nordic consumer buys electricity from the Nordic electricity system or one that is even larger than that [37]. Gaines [38] suggests that a system is what is distinguished as a system. According to this statement, the electricity system is what an informed observer perceives it to be. Hence, there is no objective answer to the question concerning from what system the customer buys electricity. A Vattenfall customer in Sweden can, for example, defend the view that the electricity is bought from the Vattenfall production system, the Swedish electricity system, or the Nordic electricity system.

If we do not know from which system the electricity is bought, then we do not know what average data to use in the retrospective LCA: technology averages, company averages, national averages, or regional averages. The difference between these averages can be very large. In Norway, more than 99% of the electricity production during 1998 was hydropower. In Denmark, nearly 60% was based on coal. In the Nordic electricity system, 54% was hydropower, 24% nuclear and 10% coal-based [39]. In terms of the kind of emissions normally accounted for in an LCI, there is a very large difference between hydropower and nuclear power, on one hand, and electricity produced from coal and oil on the other. While, for example, CO_2 emissions are less than 1 g/kWh for Vattenfall hydropower (including plant construction) [36], they can be nearly 1 kg/kWh for coal-based electricity production. As a result, the average emissions from electricity production vary greatly between different Nordic countries. This accentuates the problem of identifying the electricity system from which a Nordic consumer buys electricity. The problem is, however, significant also outside the Nordic region [40].

Another methodological problem of retrospective LCA concerns the choice of allocation methods. Many diverse approaches to the allocation problems have been suggested [41]. If the retrospective LCA has the specific aim to describe the causes of the environmental burdens of the life cycle, it is reasonable to partition the environmental burdens of a process with multiple products in proportion to the economic value of these products [42]. Otherwise, it is difficult to find an objective basis for the choice of allocation method.

3.2. Ethical limitations of retrospective LCA methodology

In addition to the technical drawbacks, the retrospective methodology can be criticised from the normative perspective of teleological situation ethics. Such criticism is really a critique of the special case of rule ethics that makes retrospective LCA relevant: the case where one rule is to avoid environmentally poor systems. We illustrate the limitations of this ethical rule with an example from the Nordic electricity sector.

Let us consider a university department that is looking for an environmentally good site for a conference. If the aim is to avoid environmentally poor systems, a retrospective LCA of conference sites will produce information that is relevant as a basis for this decision. Thorskog Castle is a conference hotel near the West Coast of Sweden. Across the hotel site runs a brook. A small hydropower station at this brook makes the hotel self-sufficient with electricity. The hotel is connected to the national electricity grid, which makes it possible for the owners of the hotel to sell excess electricity from the brook. It is reasonable to perceive the hotel and the hydropower station as the relevant electricity system to analyse, which implies that the retrospective LCA is based on average data for this small system. In other words, it is reasonable to use environmental data from the local hydropower production in the retrospective study. The quantities of CO_2, SO_2, NO_X, particulates etc. per kWh produced at the hydropower station will be nearly zero. In terms of the kind of emissions normally accounted for in an LCI, the hotel and the hydropower station is a quite good, although very small, part of the Swedish electricity system.

The consequence of using the facilities at Thorskog Castle for the conference is likely to be that more electricity will be used at the site and, hence, that less excess electricity will be sold to the grid. This means that the consequences of electricity use at Thorskog Castle are similar to the consequences of using electricity anywhere else in the Nordic countries: the production will increase on the margin of the Nordic electricity system. The production affected is likely to include coal power, wind power and natural gas [43], and the increase in emissions of CO_2, SO_2, NO_X, particulates etc. will be much larger than indicated by the retrospective data.

An LCA based on average data clearly does not reflect any marginal effects, i.e., effects of small changes in the production volume. In contrast, most actions can be expected to cause changes that are small enough to be approximated as marginal effects on the production of bulk materials (e.g., steel, aluminium, polyethylene), energy carriers (e.g., electricity, heavy fuel oil, petrol), and services (e.g., waste management) where the total production volume is very high. Since the retrospective LCA results do not reflect the consequences of individual actions, there is a risk that the environment can be harmed by actions that are recommended on the basis of a retrospective LCA.

On a general level, there is a risk that undesirable effects follow from individual actions that are based on rule ethics, because rule ethics by definition does not take into account the consequences of the individual action. A person who embraces teleological situation ethics is likely to consider this to be a serious limitation in rule ethics.

4. Prospective LCA and situational ethics

This section includes a discussion on problems of prospective LCI methodology concerning completeness, uncertainty, complexity, etc. We also present an ethical critique of prospective LCA based on the concept of fairness and on the risk that a widespread use of prospective LCA results in sub-optimisations.

4.1. Technical limitations of prospective LCA methodology

Prospective LCA aims at describing consequences of possible decisions. Perhaps the most important limitation of prospective LCI methodology is that it is generally impossible to model the full consequences of an action in an LCA. The full consequences depend on various types of causal relationships, while a conventional, prospective LCA accounts mainly for very simple causal relationships. For example, the purchase of a product is usually simply assumed to result in the production of the same quantity of that type of product. In principle, the prospective LCI methodology can be refined by introducing multiple simple market models [21,44]. The resulting, ''radically effect-oriented'', LCI takes into account the fact that our purchase of a product may result in a reduced use by other customers. For instance, if the electricity demand is increased in the life cycle investigated, this may contribute to an increased electricity price that, in turn, results in lower electricity use in other life cycles. Hence, the increase in the total production of the product can be smaller than the increase in the quantity that is used in the life cycle investigated.

The consequences of our actions may also depend on psychological, causal relationships that are not accounted for in the simple market models. If a customer buys electricity on a contract that specifies the electricity production technology, he could influence other consumers to do the same. This way, the increase in the total production of a product can be larger than the increase in the quantity that is used in the life cycle investigated. An action on the micro-level might even have a significant impact on the macro-level. If the market is near the point where buying electricity from a specific technology is regarded as the normal thing to do, the influence of a single electricity purchase might spread widely and, indirectly, affect a large share of the consumers. Such, potentially huge, consequences of an individual change are not included in a prospective LCA.

As long as the significance of the excluded causal relationships is unknown, we generally do not even know if the consequences modelled in the prospective LCA are close to, or very far from, the full, real consequences. In the face of this apparently severe limitation, it is still possible to model some of the causal relationships in a prospective LCA. It is not reasonable to assume that teleological situation ethics requires complete knowledge on the consequences of actions. Instead, it must be assumed that decisions should be based on the information that is available or possible to acquire. From the perspective of teleological situation ethics, this is an argument for modelling as much as possible of the causal relationships in an LCA, even when the full consequences cannot be modelled.

The completeness of the prospective LCA model depends, for example, on the resources available for the study. There is no objective resolution to this trade-off between completeness and the quantity of resources spent. Hence, there is an element of subjectivity not only in retrospective but also in prospective LCA.

Another limitation of prospective LCA is related to the fact that the LCA is often carried out for learning purposes, without a specific action in mind [10]. It is not reasonable to describe the consequences of every possible action in a prospective LCA. When no action has been specified, the prospective LCA practitioner can only model the sphere of influence of the decision-makers. This is the parts of the technical system that can be influenced by the decision-makers, either directly or indirectly. In such a study, the system investigated should ideally include the activities where the most important changes can be induced by the decision-makers. Activities which they can only marginally affect should be modelled using marginal data, whereas activities for which the decision-makers can make complete changes (i.e., the foreground system) should be modelled using average data.

The use of marginal data is typical for prospective LCI, since most decisions have marginal effects on large production systems. A problem in this context is that it can be difficult to identify the technologies where marginal effects occur. Economists distinguish between short-term and long-term margins. The former is identified by using an economic model that assumes the production capacity to be fixed, i.e. only the utilisation of the capacity varies. The latter is identified with a model that allows the production capacity to vary. A procedure for identifying a long-term margin in LCAs was presented by Weidema et al. [45]. However, modelling these effects on, e.g., the electricity system based on a single short-term or long-term-margin is a simplification. A single action can often be expected to have short-term as well as multiple long-term effects on the dynamic electricity system. If an accurate identification of such complex marginal effects is possible, it requires fairly advanced, dynamic models of the systems affected [43].

Even excluding the possible macro-effects of changes on the micro-level, the uncertainties involved in a prospective LCI are likely to be large. As indicated above, the uncertainty in complex marginal effects can be quite large [43]. We expect the uncertainties to be even more problematic in a radically effect-oriented LCI, because of the large uncertainties in the economic causal relationships. Furthermore, the prospective LCA results in a model that can be perceived as more complex than the life cycle model obtained in a retrospective LCA. This increases the risk of both calculation errors and misinterpretation of the results.

It would be difficult to establish consensus on a detailed prospective LCI methodology, at least in the near future. This makes it impossible, at present, to apply prospective methodology when a detailed standardisation of the methodology is required, such as for environmental product declarations (EPD). If the prospective methodology were to be preferred for this application, a long-term solution would be to develop a theoretical foundation for detailed prospective LCAs and then try to establish a standard based on this foundation. This article can be regarded as one contribution, among others, to such a solution [21,22, 45,46].

4.2. Ethical limitations of prospective LCA methodology

In addition to the technical limitations, the prospective LCA methodology can be criticised with arguments concerning fairness and sub-optimised systems. Such criticism is really a critique of teleological situation ethics as a basis for LCA methodology. This limitation of teleological situation ethics can also be illustrated with the example of Thorskog Castle. According to these ethics, the choice of conference site should be based on a prospective study. As stated above, the consequences of using electricity at Thorskog Castle are approximately the same as using electricity at any other hotel in the Nordic countries. The effects occur on the margin of the Nordic electricity production system in both the cases. This means that the owners of Thorskog Castle do not benefit, in a prospective LCA, from operating an environmentally good part of the electricity system. This may well appear to be unfair, in particular if the hydropower station and the connection to the electricity grid is deliberately maintained for environmental reasons.

It is reasonable to expect that conferences are more important to the economy of Thorskog Castle than the revenue from excess electricity. If the owners of the hotel decide to shut down the connection to the national electricity grid, the site would become an isolated electricity system. The consequence of choosing Thorskog Castle for the conference would then be that a larger share of the power from the brook is utilised for electricity production. This would have little or no effect on the emissions from the site, which would give Thorskog Castle an advantage in prospective LCAs. Hence, a widespread use of prospective studies would give the owners of the hotel an incentive to cut the connection to the national electricity grid. This would mean that the excess electricity from the hydropower station is no longer utilised and, hence, that the national electricity system is sub-optimised. Accordingly, there is a risk that environmentally poor consequences, in terms of sub-optimised systems, result from a widespread use of prospective LCAs.

5. Conclusions and recommendations

The connections between LCA methodology and the purpose of the study concerns more than the previously observed links between methodology and applications of the study. In LCA typologies where the distinction is based on the application, retrospective LCA is used for learning purposes, while prospective LCA is used for

Table 2
Summary of properties of retrospective and prospective LCA as described in this paper

	Retrospective LCA	Prospective LCA
Information sought	Environmentally relevant physical flows to and from the cradle-to-grave system	Changes in environmentally relevant flows caused by possible decisions
Methodological characteristics	Allocation by partitioning; average or supplier-specific data	Allocation avoided through system expansion; marginal data
Methodology in Thorskog case	Electricity data on Thorskog site	Electricity data on Nordic marginal production
Technical limitations	Subjective choice of system boundary for the average data; subjective choice of partitioning method	Inherent uncertainty; subjective completeness; conceptual complexity; lack of consensus
Ethical validity	Teleological and deontological ethics (for assessing actions when the rule is to avoid bad systems)	Teleological situation ethics; teleological rule ethics (for assessing or generating rules)
Ethical limitations, general	Risk for unaccounted, undesirable consequences	Risk for unfair LCA results; risk for sub-optimised systems
Ethical limitations in the Thorskog case	LCA results do not reflect the environmental consequences of using electricity	LCA results do not reflect the nature of the Thorskog electricity system; risk for loss of excess hydropower electricity

generating information that is relevant for decisions [10,17,18]. In contrast, we claim that both prospective and retrospective LCAs can be used for decision-making. Furthermore, both kinds of LCA can also be used for learning purposes although the prospective LCA, in this case, probably describes the sphere of influence of the decision-makers rather than consequences of specific changes.

There is no doubt that retrospective and prospective LCAs result in different type of information (see Table 2). This paper illustrates that these two types of information are related to different views – connected to different theories of normative moral philosophy – on the characteristics of a good action (Fig. 1). A prospective LCA methodology is valid from the perspective of teleological situation ethics. It is also effective for assessing or generating rules in teleological rule ethics. On the other hand, retrospective LCA methodology is valid for special cases of teleological and deontological rule ethics, where the rule is to avoid being associated with systems with an undesirable environmental impact.

Both retrospective and prospective LCAs have methodological limitations. In a retrospective LCA, for example, there seems to be no general, objective basis for the definition of subsystems or the choice of allocation methods. In these respects, retrospective LCA methodology relies on the establishment of conventions when a detailed standardisation of the methodology is required. An example of such a convention for this type of LCA is the product-specific rules (PSR) in the Swedish system for EPD [47,48]. The need for conventions is emphasised by the fact that the PSR for different types of products do not have the same conventions for calculating the average data for electricity production.

The methodological limitations of prospective LCA include the requirements for specifying what consequences should be modelled. They also include practical modelling problems. The full consequences of an action cannot usually be modelled in an LCA. It is, in general, not even possible to know whether the consequences modelled in a prospective LCA are close to, or very far from, the actual consequences of the action. We have found no general, objective basis for deciding what types of consequences should be included in a prospective LCA. Hence, prospective LCA methodologies probably also rely on the establishment of conventions when a detailed standardisation of the methodology is required.

Both retrospective and prospective LCAs also have ethical limitations. Decisions based on retrospective LCA can have environmentally undesirable consequences. On the other hand, a widespread use of prospective LCA can also have unwanted environmental consequences in terms of sub-optimised systems. Furthermore, actions based on teleological situation ethics may well appear unfair because producers that initiate or maintain good production systems might not get any benefit from this in a prospective LCA.

It is not possible, based on our discussions above, to state that one type of LCA methodology is superior to the other. Hence, the choice between retrospective and prospective LCA methodologies remains; different choices can be appropriate depending on the normative point of departure of the audience. However, the fact that retrospective and prospective LCAs result in complementary information indicates that, on some occasions, it can be relevant to carry out both types of LCA.

It is relevant to state clearly in the goal and scope definition of an LCA, whether the purpose of the study is to describe the environmental burdens of a system or to describe the consequences on the environmental burdens of changes that can be made in the system. It may also be relevant to state what normative point of departure the chosen purpose reflects. Such statements enable the readers of the LCA report to consider whether they share the normative views on which the LCI methodology is based. It also allows for reviewers of the study to consider whether the methodological choices in the LCI are consistent with the purpose and with the normative point of departure on which the study is based.

The discussion and recommendations in this paper focus on the LCI, particularly on the choice between average and marginal data. Similar arguments may well be relevant for the discussion of other methodological problems in LCA and for other types of environmental systems analysis. As an example, teleological situation ethics, with its focus on consequences of actions, is consistent with the view [49,50] that the life cycle impact assessment should consider only environmental burdens above the threshold for actual environmental impacts. The view that all environmental burdens should be accounted for because less environmental burdens are better, regardless of the threshold, can be regarded as a case of rule ethics. This indicates that the '*only-above-threshold*,' approach is the appropriate choice in prospective LCAs and that the '*less-is-better*,' approach is applicable in retrospective LCAs.

References

[1] Hunt RG, Franklin WE. LCA – how it came about – personal reflections on the origin and the development of LCA in the USA. Int J LCA 1996;1(1):4–7.

[2] Baumann H, Tillman A-M. The Hitch Hiker's guide to LCA. Lund, Sweden: Studentlitteratur; 2004. p. 44–51.

[3] Consoli F, Allen D, Boustead I, Fava J, Franklin W, Jensen AA, de Oude N, Parrish R, Perriman R, Postlethwaite D, Quay B,

Séguin J, Vigon B, editors. Guidelines for life-cycle assessment: a 'code of practice' – edition 1. Pensacola, USA: Society of Environmental Toxicology and Chemistry; 1993.
[4] Lindfors L-G, Christiansen K, Hoffman L, Virtanen Y, Juntilla V, Hanssen O-J, et al. Nordic guidelines on life-cycle assessment. Nord 1995:20. Stockholm, Sweden: CE Fritzes AB; 1995.
[5] Guinée J, editor. Handbook on life cycle assessment – operational guide to the ISO standards. Dordrecht, The Netherlands: Kluwer Academic Publishers; 2002.
[6] Environmental management – life cycle assessment – principles and framework. EN ISO 14040:1997. Brussels, Belgium: European Committee for Standardization; 1997.
[7] Environmental management – life cycle assessment – goal and scope definition and inventory analysis. ISO 14041:1998(E). Geneva, Switzerland: International Organization for Standardization; 1998.
[8] Environmental management – life cycle assessment – life cycle impact assessment. ISO 14042:2000. Brussels, Belgium: European Committee for Standardization; 2000.
[9] Environmental management – life cycle assessment – life cycle interpretation. ISO 14043:2000. Brussels, Belgium: European Committee for Standardization; 2000.
[10] Baumann H. LCA use in Swedish industry. Int J LCA 1996;1(3): 122–6.
[11] Cowell SJ. Environmental life cycle assessment of agricultural systems: integration into decision-making. Ph.D. thesis. Guilford, UK: University of Surrey; 1998.
[12] Heintz B, Baisnée P-F. System boundaries. In: Life cycle assessment. Workshop report, Leiden, The Netherlands, 2–3 December 1991. Brussels, Belgium: SETAC; 1992. p. 35–52.
[13] Weidema BP. Development of a method for product life cycle assessment with special references to food products (summary). Ph.D. thesis. Lyngby, Denmark: Technical University of Denmark; 1993.
[14] Weidema B. Application typologies for life cycle assessment – a review. Int J LCA 1998;3(4):237–40.
[15] Frischknecht R. Goal and scope definition and inventory analysis. In: Udo de Haes HA, Wrisberg N, editors, Life cycle assessment: state-of-the-art and research priorities, vol. 1. Bayreuth, Germany: Eco-Informa Press; 1997. LCA documents.
[16] Baumann H. Life cycle assessment and decision making – theories and practices. Ph.D. thesis. Gothenburg, Sweden: Chalmers University of Technology; 1998.
[17] Hofstetter P. Perspectives in life cycle impact assessment – a structured approach to combine models of the technosphere, ecosphere and valuesphere. Ph.D. thesis, Swiss Federal Institute of Technology, Zürich. Dordrecht, The Netherlands: Kluwer Academic Publishers; 1998.
[18] Tillman A-M. Significance of decision-making for LCA methodology. Environ Impact Assess Rev 2000;20:113–23.
[19] Curran MA, Mann M, Norris G. The international workshop on electricity data for life cycle inventories. J Cleaner Prod 2005;13(8):853–62.
[20] Guinée J, editor. Danish–Dutch workshop on LCA methods. held on 16–17 September 1999 at CML, Leiden [Final report, 26-10-99].
[21] Ekvall T. System expansion and allocation in life cycle assessment. Ph.D. thesis. Gothenburg, Sweden: Chalmers University of Technology; 1999.
[22] Azapagic A. Environmental system analysis: the application of linear programming to life cycle assessment – vol. 1. Ph.D. thesis. Guilford, UK: University of Surrey; 1996.
[23] Schneider F. Analyse des Reemplois, Recyclages, Valorisations de Dechets par l'Etude de Systems Cascade. Ph.D. thesis. Lyon, France: l'Institut National des Sciences Appliquees de Lyon; 1996 [in French].
[24] Frischknecht R. Life cycle inventory analysis for decision-making. Ph.D. thesis. Zürich, Switzerland: Swiss Federal Institute of Technology; 1998.
[25] Karlsson R. Life cycle considerations in sustainable business development. Ph.D. thesis. Gothenburg, Sweden: Chalmers University of Technology; 1998.
[26] Trinius W. Environmental assessment in building and construction. Ph.D. thesis. Stockholm, Sweden: Royal University of Technology; 1999.
[27] Wenzel H. Application dependency of LCA methodology: key variables and their mode of influencing the method. Int J LCA 1998;3(5):281–8.
[28] Weidema B. New developments in the methodology for life cycle assessment. In: Proceedings of the third international conference on ecobalance, 25–27 November 1998, Tsukuba, Japan. p. 47–50.
[29] Ekvall T, Tillman A-M. Open-loop recycling: criteria for allocation procedures. Int J LCA 1997;2(3):155–62.
[30] Ekvall T. Moral philosophy, economics, and life cycle inventory analysis. In: Proceedings of total life cycle conference and exposition – land sea & air mobility. Detroit, USA: Society of Automotive Engineers; April 2000. p. 103–10.
[31] Ekvall T, Molander S, Tillman A-M. Marginal or average data – ethical implications. In: Abstract book of first international conference on life cycle management. Copenhagen, August; 2001. p. 91–3.
[32] Norman R. The moral philosophers – an introduction to ethics. New York: Oxford University Press; 1998.
[33] Lübcke P, editor. Filosofilexikonet. Stockholm, Sweden: Bokförlaget Forum AB; 1988. p. 143–4 [in Swedish].
[34] Ekvall T, Frees N, Nielsen PH, Person L, Ryberg A, Weidema B. et al. Life cycle assessment on packaging systems for beer and soft drinks – main report. Environmental project No. 399. Copenhagen, Denmark: Danish Environmental Protection Agency; 1998.
[35] Kåberger T, Karlsson R. Electricity from a competitive market in life-cycle analysis. J Cleaner Prod 1998;6(2):103–9.
[36] Brännström-Norberg B-M, Dethlefsen U, Johansson R, Setterwall C, Tunbrant S. Life-cycle assessment for vattenfall's electricity generation – summary report. Stockholm, Sweden: Vattenfall AB; 1996.
[37] Frees N, Weidema B. Life cycle assessment of packaging systems for beer and soft drinks – energy and transport scenarios. Environmental project no. 406. Copenhagen, Denmark: Danish Environmental Protection Agency; 1998.
[38] Gaines B. General systems research: quo vadis? In: General systems yearbook, vol. 14. 1979. p. 1–9.
[39] Energifakta. Stockholm, Sweden: AB Svensk Energiförsörjning; 2001 [in Swedish].
[40] Dones R, Ménard M, Gantner U. Choice of electricity-mix for different LCA applications. In: Proceedings of the sixth LCA case studies symposium. Brussels, Belgium; 1998.
[41] Huppes G, Schneider F, editors. Proceedings of the European workshop on allocation in LCA. Leiden, Brussels, Belgium: SETAC-Europe; 1994.
[42] Huppes G. Macro-environmental policy: principles and design. Ph.D. thesis, Leiden University. Amsterdam, The Netherlands: Elsevier; 1993.
[43] Mattsson N, Unger T, Ekvall T. Effects of perturbations in a dynamic system – the case of Nordic power production. J Ind Ecol, submitted for publication.
[44] Ekvall T. Cleaner production tools – LCA and beyond. J Cleaner Prod 2002;10(5):403–6.
[45] Weidema BP, Frees N, Nielsen P. Marginal production technologies for life cycle inventories. Int J LCA 1999;4(1):48–56.
[46] Azapagic A, Clift R. Allocation of environmental burdens in multiple-function systems. J Cleaner Prod 1999;7(2):101–19.
[47] Product specific rules for household refrigeration appliances. PSR 2000:1. <http://www.environdec.com/psr/e_psr0001.pdf>.

[48] Product-specific requirements for rotating electrical machines. PSR 2000:2. <http://www.environdec.com/psr/e_psr0002.pdf>.

[49] White PR, de Smet B, Owens JW, Hindle P. LCA back on track – but is it one track of two? SETAC-Europe LCA News 1995;5(4):2–4. Referred to by Cowell SJ. Environmental life cycle assessment of agricultural systems: integration into decision-making. Ph.D. thesis. Guilford, UK: University of Surrey; 1998.

[50] Hauschild M, Pennington D. Indicators for ecotoxicity in life cycle impact assessment. In: Udo de Haes H, Finnveden G, Goedkoop M, Hauschild M, Hertwich E, Hofstetter P, Jolliet O, Klöpffer W, Krewitt W, Lindeijer E, Mueller-Wenk R, Olson S, Pennington D, Potting J, Steen B, editors. Life-cycle impact assessment: striving towards best practice. Brussels Belgium: SETAC Press; 2002.