Chapter 2
The Life Cycle Thinking Approach and the Method of Life Cycle Assessment (LCA)

Abstract This chapter introduces the concepts of life cycle thinking and LCA. It discusses history of LCA development and explains its assessment framework. The evidence of LCA application for impact appraisal of tourism products and services is identified and reviewed. The chapter concludes with a critical evaluation of the advantages and disadvantages of LCA use as compared against the alternative methods for environmental impact appraisal of tourism products and services. Discussion is held on how the shortcomings of the LCA method could potentially be addressed to enhance its applicability in tourism.

2.1 Evolution of Life Cycle Thinking and the LCA Method

While LCA is considered to be a relatively recent method for appraising environmental impacts from products and services (Klöpffer and Grahl 2014), the first attempts to adopt life cycle thinking when describing product and service systems date back to the 1960s (Hunt and Franklin 1996). In the 1970s, a number of studies were carried out in USA on the basis of Resource and Environmental Profile Analysis (REPA) which can be considered as the first evidence of the practical LCA application in the sense of how its concept is understood nowadays (Klöpffer 2006). While making an important contribution to the development of the LCA and life cycle thinking framework, these proto-LCA studies cannot be considered proper, full-scale LCA projects as they were primarily concerned with the analysis of the magnitude of natural resource consumption and identification of the associated releases to the environment, rather than with the critical evaluation of the environmental impacts associated with specific product or service systems (Jensen et al. 1997). Today, this is

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known as Life Cycle Inventory Analysis (LCIA) which constitutes an integral part of LCA (see, for example, International Organisation for Standardisation—ISO 2015a).

In subsequent years, the concept of assessing life cycle-related environmental impacts from products and services had undergone further rapid development, both in North America and Europe. In Europe, it had soon gained broad scientific acceptance and became known as ‘eco-balancing’ (Jensen et al. 1997; Klöpffer 2006). Due to the issue of energy consumption being high on political agenda at the time, the concept of LCA had become particularly well developed in the field of energy use. Life cycle thinking was utilised, for example, with the purpose of identifying areas within manufacturing processes where reduction of energy consumption could be achieved (Jensen et al. 1997). The renowned ability of LCA to coherently assess the diversity and the magnitude of energy impacts alongside associated carbon footprint has found reflection in its popularity to-date as a tool for comprehensive appraisal of energy use patterns (Klöpffer 2006). It has also contributed to the development of specialist, life cycle thinking-based energy assessment tools and simplified variants of LCA, such as Life Cycle Energy Analysis (LCEA), which are broadly utilised today (see, for example, Filimonau et al. 2011b).

In the 1980s, interest in life cycle thinking grew. Due to the continued ‘green’ movement across the world, the concept was further refined (Klöpffer and Grahl 2014). Most notably, it had started paying increasingly more attention to non-energy related environmental impacts, such as those associated with the end-of-life stage of products’ and services’ life frame (Jensen et al. 1997). This is when the concept of LCA had gained broad scientific recognition and been embraced by the Society of Environmental Toxicology and Chemistry (SETAC), a non-for-profit, worldwide professional organisation that strives to support the development of sustainability principles and practice and recognises the crucial role played by LCA in this process (Hertwich et al. 1997). Specialist software (GaBi) was developed and released by PE INTERNATIONAL in 1989 which had become one of the first commercially developed tools and databases designed to conduct life cycle assessments of products and services (PE INTERNATIONAL 2015a). The refined version of this software is still in use today (see Sect. 2.3).

In the 1990s, the range of LCA applications in industry rapidly extended. Two workshops were held by SETAC in USA and Europe with the purpose of developing technical guidelines for conducting LCA and harmonising its methodological framework. This is when the terms ‘life cycle analysis’ and ‘life cycle assessment’ became official (Klöpffer and Grahl 2014). The key principles of LCA were established and its assessment framework was documented and agreed upon. In recognition of the growing global importance of LCA as a tool to provide a holistic outlook on environmental impacts from product or service systems, in 1993 the International Organization for Standardization (ISO) commissioned SETAC LCA experts to develop guidelines on the international standardisation of the LCA methodology (PE INTERNATIONAL 2015a). The first set of standards came into being in 1997; these were subsequently reviewed in 2006 and published as the ISO 14040 series of standards, most notably ISO 14040:2006 Environmental management—Life cycle assessment—Principles and framework and ISO 14044:2006

Environmental management—Life cycle assessment—Requirements and guidelines (ISO 2015a).

Since then, the popularity of LCA has been steadily growing, both in terms of the geographical scope and the functional scale of its application. A number of further, specialised LCA-based guidelines and standards have been developed, such as, for example:

- The Publicly Available Specification (PAS) 2050:2011 'Specification for the assessment of the life cycle greenhouse gas emissions of goods and services' guidelines jointly produced by the UK's Department for Environment, Food and Rural Affairs (DEFRA), British Standards Institution (BSI) and the Carbon Trust (Such 2011);
- The International Reference Life Cycle Data System Handbook released by the European Commission Joint Research Centre's Institute for Environment and Sustainability in cooperation with the European industry, United Nations Environment Programme (UNEP) and Food and Agriculture Organisation (FAO) (Wolf et al. 2012).

These standards were designed with an ultimate aim to explain the value and facilitate the application of LCA and life cycle thinking by organisations when appraising the environmental impacts attributed to their operations, i.e. at the corporate level; they have been developed to provide assessment guidelines to business ventures, rather than to advance the LCA appraisal framework when applied to individual products and services.[1] In recognition of the growing demand for LCA from organisations, ISO has recently updated its family of standards by introducing a new, 14070 series which have been specifically developed for companies and those entities which review organisational environmental performance, most notably ISO 14071:2014 Environmental management—Life cycle assessment—Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006 and ISO 14072:2014 Environmental management—Life cycle assessment—Requirements and guidelines for organizational life cycle assessment (ISO 2015a).

The record of recent research publications demonstrates a rapidly expanding interest in assessments utilising LCA and in the development of the method itself. McManus and Taylor (2015) report that the number of annually published LCA-based studies as registered on Scopus has grown from 10 in 1992 to over 1700 in 2013. The number of product and service systems which have undergone LCA-based analysis has also substantially increased (Finkbeiner 2014). This evidence shows the international acceptance and the academic recognition of LCA as a powerful tool for impact assessment, corporate decision-making and policy design.

[1]A brief overview of some specialised, LCA-related standards designed to appraise organisational environmental performance is provided in Chap. 3.

2.2 LCA as a Tool for Accurate and Holistic Assessment of Environmental Impacts

As per definition adopted in the 1990s, LCA is a tool which undertakes a holistic review of a whole product or service system in order to identify and quantify the energy and material inputs, evaluate the related environmental outputs, and further appraise the corresponding impacts on the environment (Junnila and Horvath 2003; Koroneos et al. 2005). LCA has been broadly recognised by the international scientific community as a means to improve environmental performance of products and services and reveal opportunities for prevention and mitigation of negative environmental effects (Ortiz et al. 2009). It is considered to be the most suitable method for assessing and comparing materials, products and services from an environmental point of view (Arena and de Rosa 2003). LCA is seen as a reliable, scientifically-grounded support tool for environmental management and decision-making across different sectors of the global economy (Koroneos et al. 2005; Paulsen and Borg 2003).

The method of LCA has proven its analytical rigour and scientific soundness in many disciplines (Frischknecht and Rebitzer 2005). Importantly, it has been considered as a method for more thorough and comprehensive assessment of environmental impacts from service sector companies (Junnila 2006a). Despite this, to-date, there has been limited evidence of the LCA application in the service sector in general, and in the tourism industry as part of this sector, in particular (Junnila 2006a; Schianetz et al. 2007), see Sect. 2.5.

There are a number of factors which may help explain the yet limited evidence of application of LCA to services. It may be attributed to the poorly understood evaluation potential of the method (De Camillis et al. 2010) and the assumed linearity of the natural processes that it operates (Junnila and Horvath 2003). Essential cost implications of performing LCA for corporate and institutional budgets may also play a role (Filimonau et al. 2013). The key barrier is deemed to be represented by the time-consuming and laborious procedure of data collection, interpretation and analysis required (Bala et al. 2010; Schianetz et al. 2007), see Sect. 2.6 for details. To some, these factors may outweigh the advantages of LCA which are: transparent evaluation procedure, rigorous analysis, 'prospective' assessment of alternatives, and minimisation of risks of overlooking important environmental aspects of the appraised product and service systems (Patterson and McDonald 2004; Schianetz et al. 2007). At the same time, it is recognised that the lack of application of LCA in the service sector hinders the effective environmental management of service companies as the quantitative impact indicators which have so far been produced by existing methods for environmental assessment of services have limited empirical value and restricted scope of application (Junnila 2006a). Exclusion of the life cycle perspective from appraisal of environmental impacts from products and services may ultimately lead to inaccurate conclusions about their true environmental significance which, in turn, can trigger erroneous policy-making and managerial decisions (Hertwich et al. 1997).

A distinctive feature of LCA is the flexibility of design that allows future scenario and sensitivity analyses to examine different product and service alternatives (Ally and Pryor 2007; Paulsen and Borg 2003). This is vital as all environmental assessment tools are influenced by the hypotheses and assumptions made when defining the research goal, scoping the research framework as well as when performing the data collection and analysis. A sensitivity analysis helps identify factors and input parameters which affect the final results to the greatest extent (Blengini 2009). This implies that the LCA-based environmental assessments can not only highlight both the existing and potential environmental issues within the product or service system under review, but can also help explore how available product or service alternatives, policy options and management frameworks should be refined to encourage impact reduction (Thollier and Jansen 2008).

The key benefit of LCA is that it provides a sound basis for assessing the hidden 'indirect' or embodied, life cycle-related, environmental impacts from products and services (Berners-Lee et al. 2011; Frischknecht et al. 2007) which are significant but rarely addressed in the literature (Chwieduk 2003; Patterson and McDonald 2004). The life cycle environmental burdens are estimated by specialised research groups for a broad range of products and services which represent different geographies and get summarised in the form of extensive life cycle inventories (Koroneos et al. 2005), such as the Ecoinvent database (Frischknecht and Rebitzer 2005), see Sect. 2.3 for details. The content of these databases gives an option to include or exclude the 'indirect' environmental impacts of various components associated, for example, with the infrastructure and capital goods or the 'end-of-life' stages of a product or service's life cycle (Frischknecht et al. 2007). As LCA appraises the environmental impacts from product and service systems starting with the 'birth' (manufacturing) stage and up to the 'death' (final disposal) phase, the assessment principle it relies upon is referred to as the 'cradle-to-grave' concept (Vogtländer 2010), see Sect. 2.4 for details.

LCA can help estimate the 'indirect' environmental contribution from the 'upstream' supply chain industries. Although some authors argue that a traditional LCA can capture less than 50 % of the total 'indirect' environmental impacts, predominantly related to the first-, second-, and third-orders of suppliers (see, for example, Berners-Lee et al. 2011; Foran et al. 2005), the alternative environmental assessment tools are either not capable of addressing the 'indirect' environmental impacts at all, or are limited to the evaluation of the first-order suppliers (Lundie et al. 2007). This is fraught with significant underestimates of the overall environmental impact. Moreover, the hybrid economic-environmental IOA method, which is able to fully expand the extent of analysis to account for all the 'indirect' environmental impacts from suppliers can only be utilised at large scales, such as national economies and their specific industries or sectors (Hendrickson et al. 1998). In contrast, LCA is suitable for smaller scales of evaluation, i.e. it is best applied on the level of individual products and services (Foran et al. 2005). While accounting for only few levels of suppliers may result in (up to 50 %) underestimation of the total environmental impacts (the phenomenon known as the 'truncation' error in LCA) (DEFRA 2008), the LCA-based appraisals are more accurate and offer a more holistic analysis than the assessments provided by any other existing environmental appraisal tools which have been applied so far in the service sector at the level of individual products and services. This implies that LCA is a promising solution to tackle the large diversity and the broad magnitude of the 'indirect' environmental impacts associated with the supply chain, given the limited quality of existing environmental assessment methods. Furthermore, LCA is also capable of appraising the environmental significance of the 'downstream', end-of-life related processes (Hunkeler and Rebitzer 2005), thus providing a truly comprehensive outlook on the product or service system under review. With these advantages, there is a need for broader application of LCA for the appraisal of environmental impacts from the service sector industries, including tourism.

Another important feature of LCA is its ability to appraise a broad range of environmental impacts associated with a product and service, such as, for example, energy use, climate change, resource depletion, human toxicity, ozone layer depletion, eutrophication, acidification, aquatic eco-toxicity, ionizing radiation, photochemical smog formation, land use and water use (Frischknecht et al. 2007; Wolf et al. 2012). This implies that LCA has the capacity to assess a broader diversity of tourism's detrimental environmental effects which represents a unique advantage of this impact appraisal technique over existing alternative approaches. More importantly, LCA enables a *comparative analysis* of the environmental impacts identified. This is performed via a procedure known as normalisation when the environmental effects are brought to a certain, single reference value with further weighting of their relative importance (Cerutti et al. 2014), see Sect. 2.3 for details. This enables determination of the impacts with the largest damaging potential which should further become a priority when developing impact mitigation measures.

Lastly, in terms of the scope of application, LCA is a flexible technique. It can be applied to environmental assessment of products and services in different localities as it handles a number of impact factors representative of countries in the European Union (EU) and North America. Recently, the scope of its application has been extended to a number of countries with developing economies and economies in transition (Wolf et al. 2012) which shows a truly international coverage of the LCA methodology.

2.3 The LCA Assessment Framework

The methodology for conducting LCA for individual products and services has been internationally recognised and documented by the ISO 14040 series of standards (ISO 2015a). According to ISO, LCA consists of the four distinctive stages (Fig. 2.1):

1. **Goal and scope definition** which explains the study purpose, introduces a functional unit for analysis, sets up system boundaries, outlines the impact

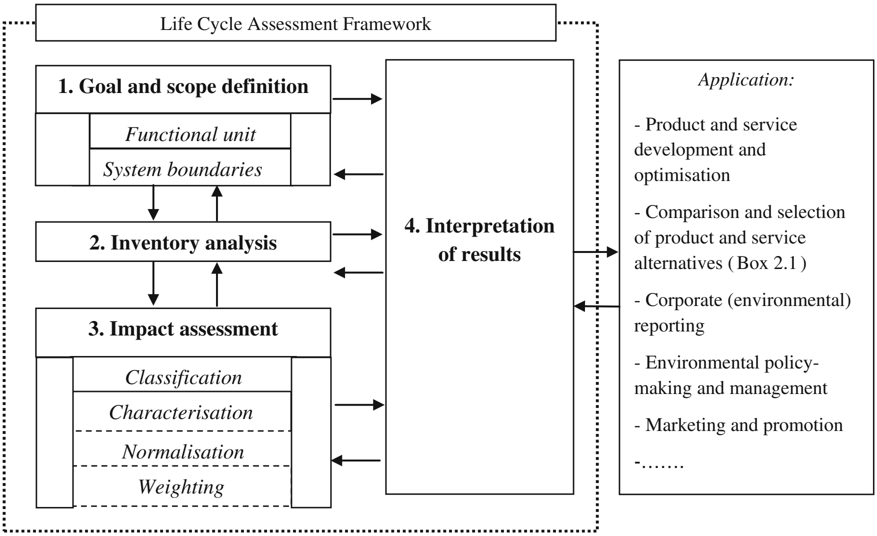

Fig. 2.1 An overview of the key stages and possible applications of LCA. *Source* Adopted from ISO 14040 (2015a)

categories chosen for analysis, justifies the assessment method used and explains the assumptions applied when performing the appraisal.

Box 2.1—LCA as a Tool to Compare Environmental Significance of Product or Service Alternatives

Reading has been one of many people's passions. With the advent of technology, the reading experience has been enhanced as e-reading devices, tablets and smartphones can now offer more choice and flexibility. They can be taken along on holidays and an increasingly larger number of tourists consider reading to be an essential part of their holidaying experience (Wilson 2014).

Forests need to be cut down to produce a traditional, paper book; to print it off and deliver to consumer, energy is required. Likewise, to power electronic devices which can be used to read e-books, large amounts of energy are necessary. Furthermore, electronic equipment is material-intense and there is also energy demand associated with its manufacture and distribution. Lastly, e-reading devices need to be dismantled at the end of their lifespan which has embodied energy and carbon requirements. The question is then, given the available alternatives, what reading method is more environmentally friendly?

LCA can help find answers to this question. A study by Kozak (2003) compares the environmental impacts of a paper book against an e-reader system. It finds that, within the five-year timeframe of the e-reading device, it has potential to generate less pressure on the environment from a number of impact categories, including energy use, associated GHG emissions, water use and acidification. This finding is only true however when a paper book is owned by a single person throughout its all life frame and gets never re-used. If a paper book is re-used, its environmental impacts can be substantially reduced. A similar LCA-based study by Williams (2009a) conducted on a more modern, and consequently more energy-efficient e-reading device, Amazon Kindle, reports that, assuming a life frame of four years and an average use time of two hours per day, it generates the amount of GHG emissions which would be sufficient to manufacture and dispose of 115 paper books. While neither study aimed to discourage use of paper books or e-readers, they do however demonstrate the power of LCA to reveal the true environmental impacts attributed to different product alternatives. This, in turn, may affect consumer choice.

It is worth noting that the ‘paper book versus e-book reader’ environmental debate is on-going and Eco-Libris (2013) provides a good compilation of studies, news and industry reports which have been made available to-date on this matter.

All data in LCA are related to a basis for comparison, the functional unit (FU) (Paulsen and Borg 2003). FU is a vital element of LCA analysis which is defined as the quantified performance of a product or service (Jonsson 2000). For example, when carrying out LCA of a washing machine, ‘1000 washing cycles with full load’ represents a suitable FU for analysis. For an electric kettle, a FU may stand for ‘production of 1 cup of boiled water’. In tourism context, ‘1 guest night of hotel stay’ with associated environmental impacts can serve as a FU for tourist accommodation facilities. For leisure transport, ‘1 passenger km driven by passenger car’ is another example of a FU. Failure to precisely define the product or service’s function can lead to inaccurate assessment outcome and should therefore be avoided at all costs (PE INTERNATIONAL 2015b).

Accurate setup of system boundaries, i.e. processes included and excluded from analysis alongside the rationale behind the boundary cut-off decisions made, is another distinctive feature of the LCA method and part of this stage of LCA analysis (Kellenberger and Althaus 2009; Peuportier 2001). The definition of system boundaries affects the outcome of impact appraisal (see Box 2.2) and should therefore be scrutinized and well justified. This process usually involves a subjective element (Berners-Lee et al. 2011); however, this issue is attributed to all impact assessment techniques and LCA is no exception. To better understand the possible implications of system boundary setup, uncertainty and sensitivity analyses can be undertaken in the final phase of LCA, i.e. interpretation.

2. **Life cycle inventory or inventory analysis (LCIA)** that involves data collection and systematisation.

Here, all environmental inputs and outputs into the system associated with a product or service under review throughout its life cycle are established and then assembled and presented in the form of an inventory. This LCA stage is often referred to as the most labour intense because large sets of data which must be characterised by best quality are required and should therefore be procured to facilitate subsequent impact analysis (PE INTERNATIONAL 2015b).

Box 2.2—System Boundary Setup in LCA and Its Effect on the Assessment Outcome

LCA employs a system approach when conducting impact appraisal of a product or service. Within a product or service system, it strives to accurately document all input and output processes and subsequently evaluate them with regard to the contribution they make to the total environmental impact. Due to the complexity of many product or service systems, it may not be feasible to integrate *all* input and output processes into analysis; if there are some processes whose contribution is known to be of marginal importance to the overall environmental effect, then it is fair to suggest that these can be excluded for the sake of effective resource utilisation.

The choice of including and excluding certain processes from LCA is determined by the so-called cut-off criteria. For instance, it is a common practice among LCA practitioners to ignore all input processes that contribute less than 5 % to the product or service's overall weight assuming these to make a small environmental effect (GaBi 2015). In most cases this assumption proves to be correct. In a small number of cases, however, this may not work. For example, some processes may generate small, but very toxic amounts of strong pollutants, like, for example, in the case of electric car battery or nuclear fuel disposal. In this case, additional cut-off criteria can be applied; these can be based, for instance, on the level of toxicity attached to specific input and output processes attributed to a product or service under review.

Exclusion of capital goods from analysis is another example of the application of cut-off criteria in LCA. Some LCA practitioners choose to ignore the impacts associated with capital goods due to data availability issues assuming their contribution to the overall environmental burden of a product or service system under review to be small. It is important to note, however, that there is growing evidence indicating that exclusion of capital goods may lead to significant underestimates of the total environmental impact (Chester and Horvath 2009; Frischknecht et al. 2007; Morais and Delerue-Matos 2010) and this cut-off criterion should therefore be applied with caution. Chester and Horvath (2009) find, for example, that capital goods contribute an additional 63 % of environmental load for road-based, 155 % for rail, and 31 % for air transport systems over vehicles' life cycle. Similar conclusions have been drawn for tourist accommodation services in the study by Hsu et al. (2014) which signifies the importance of inclusion of capital goods and infrastructure in LCA-based environmental impact appraisals.

Lastly, exclusion decisions can be grounded on such pragmatic factors as data quality and availability. If data are absent or their quality is insufficient to accurately characterise a specific process within a product or service system under review, and there are no viable ways to procure, refine or substitute these data, then a decision can be made that it should be excluded from analysis. In any case, the rationale behind applying specific cut-off criteria for system boundary setup should be properly justified while the decisions made on the grounds of utilising these criteria alongside the potential effect of these decisions on study results should be diligently documented and presented to the LCA project stakeholders (McManus and Taylor 2015).

Allocation is another feature attributed to LCA analysis at the stage of system boundary setup. It is employed in the case when a process within the system under review contributes to the production of more than one product or service. For example, raw milk is used in a number of dairy products, such as cream, liquid milk, dried milk, cheese and cottage cheese which are often manufactured by the same factory but get distributed to different consumers. Allocation deals with the partitioning of the system and relating of inputs and outputs of such multi-function processes to the relevant products and by-products (Frischknecht 2000). It is based on different rules, such as allocation by mass of the final products and by-products, allocation by the market value of the final products and by-products and others (Ekvall and Finnveden 2001). Similar to the definition of cut-off criteria, the choice of the allocation method is rather subjective. Given that it can have a large impact on the LCA outcome, the ISO 14040 series of standards suggest that allocation should be avoided if possible (GaBi 2015). If this is not feasible, the allocation method should be accurately described and the sensitivity of the LCA results for different allocation methods should be tested. The ISO 14040 series of standards also suggests that allocation should be made on the grounds of physical (such as product mass) rather than non-physical (such as market value) relationships between the products or services under review given the frequent fluctuations in market values (GaBi 2015).

The example of rechargeable batteries can be used to show the importance of system boundary setup for the outcome of LCA. Here, a decision is to be made on whether or not the environmental impacts associated with a battery charger should be included in analysis. Chanoine (2011) and Parsons (2007) demonstrate that if it had been excluded from the system, it would have disregarded significant shares of negative environmental effects in certain impact categories, such as human toxicity potential in short-term perspective (where a battery charger generates circa 45 % of the overall impact associated with rechargeable batteries over their life frame), freshwater aquatic ecotoxicity potential in short-term perspective (where it accounts for about 40 % of the total impact) and climate change (where the contribution of a battery charger can be as high as 10 % of the overall impact).

3. **Impact assessment** which diligently evaluates the magnitude of environmental burdens attributed to a product or service system under review.

The general framework of impact assessment adapted by LCA consists of four structural elements: *classification, characterisation, normalisation and weighting* (ISO 2015a). The ISO 14040 series of standards prescribe that the classification and characterisation steps that convert the impact assessment outcome into an easy-to-understand, quantitative indicator for specific impact categories (for example, kg of CO_2-eq. or SO_2-eq. produced) (Box 2.3) should be mandatory elements of assessment, while normalisation and weighting that lead to a unique indicator across all impact categories, showing the *relative* significance of each specific impact, thus enabling allocation of mitigation priorities across various impact categories, are discretionary. This is because normalisation and weighting can be characterised by high levels of uncertainty which is partially due to the insufficient robustness of scientific evidence available to justify some of the normalisation and weighting decisions to be made, and partially because the choice behind these decisions is often subjective (Blengini 2009; ISO 2015a). The normalisation and weighting elements of impact assessment in LCA are however considered to be useful tools which may aid interpretation of the assessment outcome and enhance its understanding by non-professionals (Brady et al. 2011).

Box 2.3—Midpoint Versus Endpoint Assessment of Environmental Impacts in LCA

It is important to note that environmental impacts can be assessed by LCA at either the midpoint, or endpoint level. During the classification step, environmental burdens associated with a specific product or service are assigned to the so-called ‘midpoint’ impact categories, such as climate change, water use, ozone depletion and acidification (UNEP/SETAC Life Cycle Initiative 2011). These impacts are defined as ‘midpoint’ because they are considered to serve as intermediate problems or links in the cause-effect chain of environmental pressures imposed (hence, the ‘midpoint’ approach is often referred to as the ‘problem-oriented’ approach); this is in contrast with the so-called ‘endpoints’ which reflect the ultimate damage inflicted by *all* impacts on the three principle recipients or issues of concern, namely human health, resource depletion and ecosystem quality (hence, reference to it as the ‘damage-oriented approach’) (Bare et al. 2000) (see Fig. A below).

The choice of the impact level used in LCA depends on the goal, scope and objectives of a particular study; it should also take into account the target audience and the level of LCA expertise and scientific knowledge they possess. This is because the 'endpoint' results are easier to understand for non-scientists; hence, they may be more suitable for policy design and managerial decision-making. This notwithstanding, they have a higher level of uncertainty compared to the outcome of 'midpoint' assessments because the science behind establishing reliable links between some impact categories and the ultimate damage they inflict is yet uncertain (PE INTERNATIONAL 2015b). For example, exposure to chemicals may have long-term detrimental effect on human and animal health; the magnitude and the severity of this effect is however cumbersome to quantify, hence, these values can be uncertain (Krewitt et al. 2002).

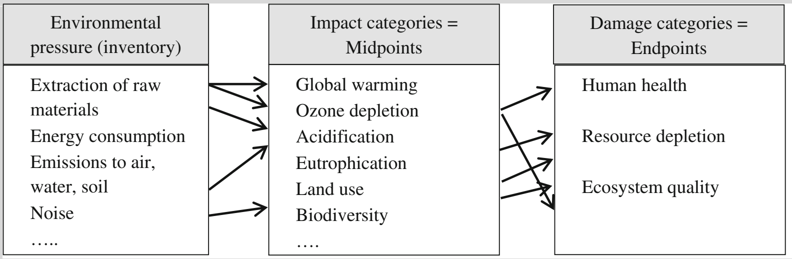

Fig. A Midpoint versus endpoint assessment approaches in life cycle impact assessment. *Source* Adapted from UNEP/SETAC Life Cycle Initiative (2011)

4. **Interpretation of results** which draws conclusions and provides recommendations for environmental improvements.

The ISO 14040 series of standards suggest that a number of checks should be performed at this stage of LCA to ensure the conclusions drawn upon the assessment outcome are feasible. To this end, uncertainty and sensitivity analyses should be carried out with a view to test how changes in appraisal parameters may affect the study results (Blengini 2009; PE INTERNATIONAL 2015b). Contribution analysis is another analytical element which can be undertaken at this LCA stage; it determines the relative environmental contribution of the individual stages within a product or service's life cycle (for instance, manufacturing, use or disposal) compared to the total result (Williams 2009b).

LCA data are collected and stored in the form of extensive databases where the Ecoinvent database (http://www.ecoinvent.org/) is recognised as one the most established and reputable databanks in the field (Frischknecht and Rebitzer 2005). The life cycle databases enable users to construct life cycle inventories of specific products and services. It is important to note that the product or service under assessment can be so unique that existing life cycle inventory databases may have no datasets to characterise its impacts. The product or service can also come from the geography which is not represented in existing life cycle datasets. In this case, the data should be sought from the client who the assessment is performed for. Data obtained directly from the client are more accurate and should therefore be preferred whenever economically viable and practically feasible (PE INTERNATIONAL 2015b). These can be calibrated against the datasets extracted from the life cycle data inventories to enhance generalisability and improve representativeness of the study outcome.

To simplify the process of data inventory building, enable subsequent, detailed impact analysis and facilitate management of complex computations, a number of dedicated LCA software packages have been developed, such as SimaPro (http://www.pre-sustainability.com/simapro-lca-software), GaBi (http://www.gabi-software.com) and Umberto (http://www.umberto.de), to mention a few. There is no consensus in the research community on which LCA software represents the best package in the field as all have their own pluses and minuses. The choice of one or another software platform is largely determined by the available budget, familiarity with software interface and personal user preferences. A number of online resources exist to help novice users make the right choice by comparing the pros and cons of available packages (see, for example, Building Ecology 2015; LinkCycle 2013).

Given that significant resources are invested into the construction and maintenance of life cycle databases, most of them operate on a commercial basis and can therefore be expensive to procure. Table 2.1 provides an overview of the three major software packages alongside their costs. Among all LCA software, OpenLCA (http://www.openlca.org/) is a notable exception as it is free to use. This package is however best applied as part of input-output LCA (see Sect. 2.4 for details) as it is based on aggregate data which are representative of the larger assessment scales, such as sectors of the national economy and/or nation-specific industries (Hendrickson et al. 2006). For conventional, product- or service-specific LCA, the significant costs associated with the procurement of life cycle databases and software packages are acknowledged as the key shortcoming of the method which hampers its broader utilisation, especially by smaller enterprises with limited budgets (Filimonau et al. 2011a). There have been attempts to tackle this issue to ensure life cycle databases on the key industrial processes, materials, products and services become available to a larger number of business ventures. The European reference Life Cycle Database (ELCD) (http://eplca.jrc.ec.europa.eu/) represents the most notable initiative in this respect. It was launched in 2006 with an aim to promote life cycle thinking in business circles and compile a comprehensive, free-to-access and regularly updated life cycle database supplied by leading European business associations and other relevant corporate sources in EU for key materials, energy carriers, means of transport and waste management practices

Table 2.1 Main LCA software packages and the Ecoinvent database: an overview of the key versions and costs

Name	License type		License cost (per year)	License annual maintenance cost	Remarks
Ecoinvent database (version 3)	*Commercial*	*Single*	€2500 + VAT	€500 + VAT	http://www.ecoinvent.org
		Multiple user	€1250 + VAT for all subsequent licences	€500 + VAT	Compatible with most LCA software
	Educational	*Single*	–	–	
		Multiple user	€2500 + VAT	€500 + VAT	Maintenance is free for first year of service
GaBi (various versions)	Varying		Pricing structures vary and depend on the nature of applicant's business and field of operation There is a free version for students and teachers, subject to registration and approval of the registration by the developer		www.gabi-software.com The Ecoinvent database is included as an option
SimaPro (version 8)	*Commercial*	*Single*	£7500 + VAT	£1300 + VAT	http://www.simapro.co.uk/
		Multiple user	£13000 + VAT	£2000 + VAT	The Ecoinvent database comes integrated
	Educational	*Single*	£2500 + VAT	–	
		Multiple user	£2500 + VAT	£1000 + VAT	
Umberto (various versions)	Varying		Pricing structures vary and depend on the nature of applicant's business and field of operation. The cheapest version costs €1862 + VAT		http://www.umberto.de/en/ Some versions include the Ecoinvent and GaBi life cycle databases, some do not

Data are correct as of August 2015 and apply to prospective users from the UK. Pricing structures may be different for prospective users from other countries

(European reference Life Cycle Database—ELCD 2015). To-date, as part of this project, a significant number of datasets have been made available to prospective users; they have also been integrated in the majority of commercial life cycle databases outlined in Table 2.1. While the ELCD initiative has good projections, the use of data it provides has however been restricted so far. This is partially because many EU businesses remain unaware about this initiative; this is also because the processing of free-to-use datasets with subsequent interpretation of the analysis results yet requires specialist knowledge while it represents a scarce type of resource for many enterprises.

2.4 Types and Categories of LCA

To-date, LCA has become a reputable tool for assessing the environmental performance of products and services which has proven its merit in a number of industries. It is often referred to as the most appropriate, well-established and developed method for holistic environmental appraisal where the structured and comprehensive approach to analysis denotes its key advantage over available alternatives (Ness et al. 2007). LCA is cited as a true representation of human-nature interactions due to its capability to account for *all*, or a very large share, of environmental effects associated with products and services (Heiskanen 2002).

LCA has a number of variants which signify the scope and scale of analysis conducted. In terms of the scope of analysis and system boundary setup, there is a traditional, 'cradle-to-grave' LCA assessment approach (Vogtländer 2010) which strives to account for all processes and associated environmental impacts attributed to a product or service's life cycle starting with its 'cradle' (i.e. extraction of raw materials), throughout its manufacture, assembly, distribution and consumer use and finishing with its 'grave' (i.e. the end-of-life disposal process, such as incineration, landfilling, recycling or re-use), see Fig. 2.2. The 'well-to-wheel' (or the 'well-to-propeller' in the case of marine vessels, see Bengtsson et al. 2011) LCA variant represents a similar concept but it is most commonly utilised to assess the environmental performance of fuels, most notably their total energy consumption and associated GHG emissions (Nanaki and Koroneos 2012). Likewise, in the case of LCA studies on agriculture and food production systems, the 'farm (or field)-to-fork' variant is applied which is based on the identical underpinning principle (Wong and Hallsworth 2012).

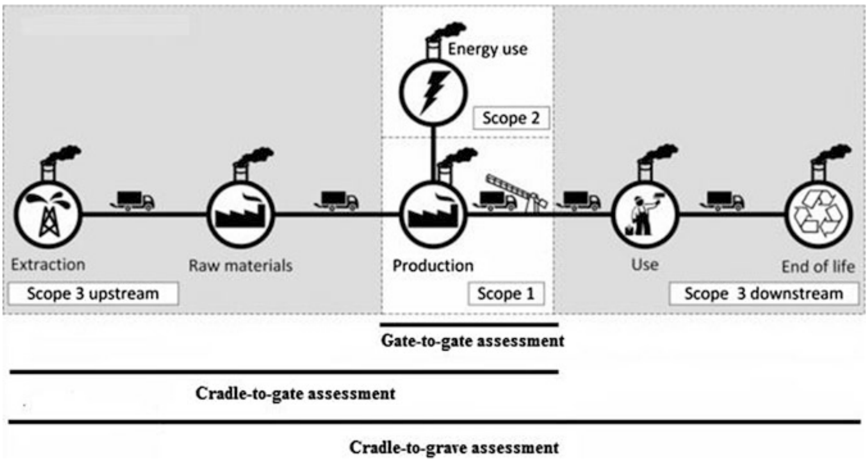

Fig. 2.2 Correlation between the different scopes of environmental impacts from organisational activities as defined by DEFRA, GHG Protocol and ISO 14040 series of standards and the key LCA variants. *Source* Modified from AkzoNobel (2015)

Unlike conventional 'total' or 'cradle-to-grave' LCA, there are 'partial' LCA variants which exclude certain environmental impacts from analysis (Fusi et al. 2014). The 'cradle-to-gate' LCA concept is concerned with appraising the environmental effects attributed to the 'upstream' industrial processes only, i.e. up to the point when a product leaves the factory gate where it gets manufactured and assembled (Kara et al. 2010). The 'cradle-to-gate' thinking is incomplete as it does not capture the totality of environmental pressures associated with a product or service system due to the 'downstream' (use and end-of-life disposal) stages of its lifecycle being left aside. These can be substantial and should not be ignored (Box 2.4). However, it is considered to be a reliable approach to quantifying the environmental significance of those products and services where information on the product use and its final disposal is unavailable (Thorn et al. 2011) or where the impacts associated with these stages of a product or service's lifecycle are known to be negligible. Examples include biodegradable plant pots whose primary environmental burdens occur in pre-use phases (DEFRA 2010).

Another LCA variant based on partial analysis is called 'gate-to-gate'; this concept is concerned with the environmental effects attributed to operations of a specific company. It excludes all 'upstream' as well as all 'downstream' environmental burdens, thus focusing on the on-site environmental impacts only (Fig. 2.2). Similar to the 'cradle-to-gate' LCA variant, the 'gate-to-gate' concept has been an object of criticism; its use is however justified when the data required to characterise the environmental significance of the 'upstream' and 'downstream' processes within a product or service's life cycle are absent or of poor quality (Rugani et al. 2013).

Box 2.4—LCA of Consumer Electronics

In 2010 the UK's Waste and Resources Action Programme (WRAP) set out to review the findings of LCA studies on 15 popular items of individual consumer electronics products with an ultimate goal of comparing the contributions made by the use, manufacturing and end-of-life stages of the products' life cycle to their total environmental pressures. The findings of this project show the important role played by the frequency of product use and product size in determining the relative magnitude of environmental impacts. For instance, in terms of energy consumption and associated GHG emissions, bulkier products and products which operate on a frequent basis (such as kettles, hair driers, fridges, television sets and washing machines) require most energy and generate the largest portion of carbon footprint in the use phase (e.g. up to 94 % in the case of kettles). In contrast, smaller products and products with occasional use (for example, digital cameras, electric drills, blenders and mobile phones) have the largest energy and carbon intensity in the manufacturing and end-of-life phases of their lifecycle (e.g. 91 % in the case of electric drills), see Fig. A below.

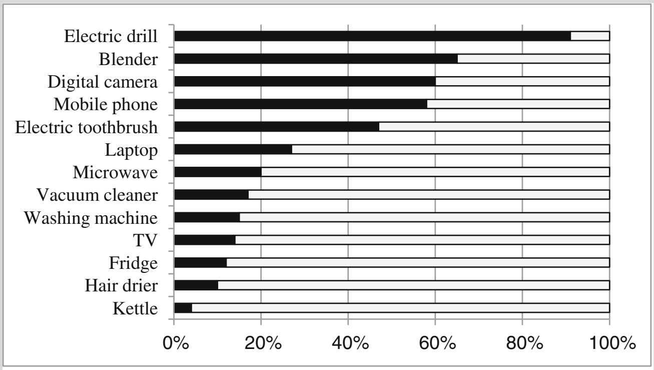

Fig. A Consumer electronics products by energy intensity, comparison of the use phase (*no fill*) against the manufacturing phase (*black fill*) of a product. *Source* Modified from WRAP (2010)

Recently, due to the rise in the 'circular economy' model thinking, the 'cradle-to-cradle' approach has been gaining interest in LCA studies (Vogtländer 2010). This concept is concerned with minimising the amount of waste generated at the end of a product or service's life cycle and maintaining its status as a resource which could subsequently be re-used to manufacture products or services of equal or even superior value (van Dijk et al. 2014), i.e. the process known as 'upcycling' (Braungart et al. 2007). The feasibility of the 'cradle-to-cradle' concept as applied in LCA context has been an object of scientific debate (see, for example, Bjørn and Hauschild 2013); hence, the traditional, 'cradle-to-grave' or 'cradle-to-gate' approach to conducting LCA studies of products and services prevails although the situation may change in the future.

There are LCA variants which integrate environmental assessment with economic analysis. There are the so-called Ecologically-based LCAs or Eco-LCAs which utilise the same evaluation approaches and strategies as conventional LCA but offer a broader scope of analysis due to their focus on ecosystem services and the role these play in sustaining national economies (Baral et al. 2012). In a somewhat similar vein, Economic Input-Output LCA applies an aggregate assessment of sector-level data to denote the environmental impacts attributed to each sector of the national economy. The advantage of these variants is in their capability to account for environmental effects associated with supply chain industries as the data for analysis get retrieved from national statistics and are therefore accurate and detailed (Matthews and Small 2001). However, this also represents a shortcoming as extensive datasets dictate best suitability of these LCA approaches for analysis of economic sectors and entire industries while their potential to evaluate the environmental performance of products and services is limited due to the issues with data disaggregation.

In terms of scale of analysis, there are two major LCA categories, namely, the process-based LCA and the input-output LCA (Hendrickson et al. 1997;

Lenzen 2000). The principles of input-output life cycle analysis have been discussed earlier (see Chap. 1 for details); it represents a derivative of the large-scale, hybrid economic-environmental input-output assessment (IOA) which is generally applied at a 'macro' level, such as national economies, specific industries within national economies and particular industrial sectors (Junnila 2006b; Reynolds et al. 2015). The process-based LCA is a conventional form of environmental life cycle analysis which is carried out on a 'micro' level of specific products and services.

There is no consensus in literature regarding the category of LCA which provides more accurate assessments and the necessity to better analyse the discrepancies in appraisals produced by different categories of LCA is recognised as a knowledge gap (Fthenakis and Kim 2007). There is however evidence to suggest that, compared to the process-based LCA, the input-output LCA generates higher estimates of environmental impacts (Fthenakis and Kim 2007; Hendrickson et al. 1997; Junnila 2006b; Lenzen 2000; Lenzen and Dey 2000). The lower estimates of environmental impacts made by the process-based LCA are often explained by the so-called truncation errors which are attributed to this category of LCA (Lenzen 2000; Lenzen and Dey 2000). The process-based LCA fails to account for *all* environmental contributions on the higher (upstream) orders of a product or service system as these can be of infinite order. Hence, there will always be a bias as there are additional or yet unknown processes that will be overlooked (Berners-Lee et al. 2011). The omission of some upstream processes is deemed to be the primary reason for occurrence of truncation errors in the process-based LCA (Berners-Lee et al. 2011; Nässen et al. 2007). Nonetheless, the input-output LCA is also not perfect as it is unable to account for the negative environmental effects arisen from the use phase of a product or service's life cycle. The limited capability of the input-output LCA to disaggregate data for smaller scales of analysis, such as sub-sectors, is also acknowledged. For instance, while it can appraise the environmental impacts associated with fertilizer use in the 'farming sector' of the national economy, it cannot reduce the analysis to specific sub-sectors, such as 'apple farming' or 'strawberry farming' although these will have different fertilizer requirements and, consequently, different environmental impacts (Loijos 2012). To address the shortcomings of the two methodologies, a 'merged' or 'hybrid' LCA, i.e. a combination of the process-based LCA and the economic environmental input-output LCA, has been proposed (Lenzen 2000; Rodríguez-Alloza et al. 2015). While being more holistic and, arguably, more accurate in nature of analysis, this composite method is currently under development (Cadarso et al. 2015) and there is an ongoing need to test its feasibility for the assessment of specific products and services, especially in the service sector (Berners-Lee et al. 2011).

2.4.1 Simplified LCA

Aside from the different variants of LCA established on the basis of scope and scale of its application, there are other types of LCA which relate to the complexity of analysis it offers. Despite the accuracy and rigour of the original, conventional LCA method, direct application of this technique can be laborious and not always economically viable. Detailed LCA requires extensive analysis as it operates a broad range of impact categories (Frischknecht et al. 2007). This can divert attention from the key environmental issues. Employment of a simplified LCA method which focuses on the most environmentally significant effects often represents a more realistic alternative. Consequently, due to the complexities of LCA and the issues in data collection, a number of simplified LCA-based methods have been developed, aiming to provide quick, but cost-effective analysis, and support decision-making (Hur et al. 2005). The simplified LCA methods are a good solution when, for example, the resources are limited while the quality of the data made available to LCA practitioners are not sufficient for a rigorous LCA (Arena and de Rosa 2003).

The simplified LCA methods employ the 'screening' and 'streamlining' approach by using a reduced inventory of the system under review and identifying only the most critical processes or 'hot spots' (Svensson and Ekvall 1995, cited in Menzies et al. 2007). These 'hot spots' are subsequently analysed in more depth while the processes which are known to make minor contributions to the total environmental impact are excluded from analysis or substituted with reliable estimates (Hur et al. 2005; Menzies et al. 2007). The exclusion decisions are usually made on the basis of the same rules and criteria as the ones applied to allocation and system boundary cut-off, see Box 2.2 for details.

Application of the simplified LCA method has a number of benefits. Most notably, it enables researchers to draw reliable conclusions which are characterised by acceptable levels of uncertainty but concurrently offer significant savings in terms of research budgets and time (Arena and de Rosa 2003; Hertwich et al. 1997). For example, Fleischer et al. (2007) report that the application of a simplified LCA has potential to save up to 80 % of research time while Loijos (2012) suggests that it can cost up to 50 times less than a conventional, full-scale LCA. The quantity and quality of data provided by organisations which commission LCA studies are often insufficient for holistic assessment of environmental impacts of products and services; furthermore, collating detailed life cycle inventory datasets can prove to be a resource-consuming exercise (see, for example, Hu et al. 2015). Hence, the simplified 'screening' or 'modular' LCA method has been employed increasingly more often instead of a full-scale original LCA (Jungbluth et al. 2000), also in the context of tourism (see, for example, Filimonau et al. 2011a, 2014), see Box 2.5.

Box 2.5—Life Cycle Energy Analysis (LCEA) as a Simplified LCA Technique Specialising in the Assessment of Energy and Carbon Impacts

The primary goal of LCA is to evaluate the *overall* impact of a product or service; the assessment is truly holistic as it handles a range of different environmental impact categories, such as climate change, resource depletion, human toxicity, ozone layer depletion, eutrophication, acidification, aquatic eco-toxicity, ionizing radiation, photochemical smog formation (Frischknecht et al. 2007; Menzies et al. 2007). However, a number of tourism related products and services (for example, air and car travel; hotel stay) make a profound contribution to climate change via energy consumption. If there is a need to appraise *only* energy and associated carbon impacts of products and services, then the application of a full-scale, multi-impact, conventional LCA may not be rational due to the cost of collecting and maintaining complex life cycle datasets. In such cases, a simplified derivative of LCA, Life Cycle Energy Analysis (LCEA), can be considered as a suitable alternative.

LCEA employs the original, four-step LCA methodology as prescribed by the ISO standards but it focuses on energy and associated GHG emissions as the only measure of environmental impacts of a specific product or service system (Fay et al. 2000; Huberman and Pearlmutter 2008). Similar to the conventional LCA, LCEA is based upon the lifecycle inventory, where major energy flows within the system under review are identified and their magnitude is accurately quantified (Cabeza et al. 2014). The impact of these energy flows is further assessed by converting the energy use data into GHG emissions (Huberman and Pearlmutter 2008; Menzies et al. 2007). It is important to note that LCEA has not been developed to replace traditional LCA (Fay et al. 2000); instead, it has been designed as a tool capable of presenting a more detailed analysis of energy and related GHG emissions for those products and services whose principal environmental impacts are known to stem from energy consumption (Menzies et al. 2007). Although the employment of such a single impact indicator can be criticised as it ignores other environmental pressures from products and services (such as, for example, acidification and eutrophication, to mention a few), it is nevertheless considered to be a valid substitute. It is simple, cheaper, focuses on energy and carbon impacts and is easy-to-understand for non-professionals.

Filimonau et al. (2011b) applied a simplified variant of LCA, LCEA, to energy and carbon impact appraisal of tourist accommodation facilities. A distinctive feature of analysis was in that, while all operational energy uses and associated GHG emissions were identified and diligently assessed, the non-operational energy and carbon pressures attributed to the hotels under study were only estimated due to the data availability issue. The estimates were drawn upon the analysis of a large number of reliable academic literature sources and personal communication with hotel management. The analysis enabled researchers to conclude that the non-operational energy use and GHG emissions from tourist accommodation facilities, while being cumbersome to accurately appraise, can be described as being equal to circa 15 % of the operational carbon impacts. This number was therefore utilised for analysis. Importantly, in a recent study on tourist accommodation facilities by Hu et al. (2015) a very detailed life cycle inventory of the carbon impacts attributed to a hotel (including both operational and non-operational phases of its life cycle) was constructed. The process of collating the data was lengthy (circa 2 years) and laborious (Hu et al. 2015). The subsequent life cycle based assessment shown that the non-operational carbon effects of the hotel under review constituted only 12 % of its total carbon impact. This confirms the feasibility of a simplified LCA approach, LCEA, as utilised by Filimonau et al. (2011b) and shows its potential to achieve reliable scientific outcomes with less significant time and labour investments.

2.5 LCA Application in Tourism

The concept of '*life cycle*' is not new in tourism research. It has been well-established in the context of studies which examine the evolution of a tourism area or destination where it has been defined as Tourist Area Life Cycle (TALC) or the Butler model (Butler 1980). While the terms are similar and the TALC concept can be used for more effective management of destination resources and to determine the negative economic, socio-cultural and environmental effects of tourism development at a destination (see, for example, Tooman 1997), it has very little to do with a holistic, quantitative assessment of tourism impacts.

The evidence of the application of the principles of life cycle thinking and the method of LCA in the context of environmental impact appraisal in tourism has been limited to-date (De Camillis et al. 2010; Raggi et al. 2008; Schianetz et al. 2007). Table 2.2 presents an overview of the key studies in the field. It shows that the focus of existing research efforts has been on the carbon impacts of tourism. This is primarily because climate change has recently become a key issue on the international political tourism agenda (Gössling 2011). This has triggered development of a dedicated research stream aiming to facilitate knowledge exchange and examine this topic in detail (Becken 2013) which has brought about a substantial number of specialist studies produced on the topic of interest (for a recent overview, see, for example, Moutinho et al. 2015). Some of these research efforts have integrated the method of LCA and life cycle thinking into the analytical frameworks developed.

A handful of LCA studies which have looked into other categories of tourism impacts suggest that while the tourism industry contributes significantly to climate change, the industry also imposes substantial pressures on the environment in a number of other respects (Box 2.6). It is important to note that, in many cases, the LCA-based research projects looking at non-climate change related impacts of tourism were developed by non-tourism academics; furthermore, these impacts were often treated as 'residual' while the focus was on the issue of climate change. This status-quo in tourism impact appraisal calls for a change as holistic analysis is often necessary to identify the primary impact categories upon which abatement should subsequently concentrate. Given the methodological advantages of the concept of LCA that include a multi-impact appraisal approach and a more comprehensive analysis of a single impact category, there is a clear need for more research on tourism impact assessment which would be grounded on life cycle considerations.

Table 2.2 Application of LCA in tourism impact assessment: an overview of the field

Study	Object of analysis	Primary environmental impacts assessed	Geographical scope
Process-based LCA			
Castellani and Sala (2012)	Holiday travel, including accommodation	A range of impacts	Italy
Filimonau et al. (2011a)		Climate change	UK
Filimonau et al. (2014)			UK and France
El Hanandeh (2013)	Religious travel, including accommodation		Saudi Arabia
Pereira et al. (2015)	Holiday travel, excluding accommodation		Brazil
Filimonau et al. (2013)	Holiday package		UK and Portugal
Kuo et al. (2005)	Tourist catering	A range of impacts	Taiwan
Michailidou et al. (2015)	Tourist accommodation		Greece
König et al. (2007)			Portugal
Sára et al. (2004)			Italy
De Camillis et al. (2008)			
Cerutti et al. (2014)			
Filimonau et al. (2011b)		Climate change	UK
Rosselló-Batle et al. (2010)			Spain
Li et al. (2010)			China
Input-output LCA			
Scheepens et al. (2015)	Sector of regional tourism	Climate change	The Netherlands
Berners-Lee et al. (2011)	Large tourism business		UK
Patterson and McDonald (2004)	National tourism industry		New Zealand
Cadarso et al. (2015)			Spain
Zhong et al. (2015)			China
Qin et al. (2015)	Tourist destination		
Rosenblum et al. (2000)	National hotel industry	A range of impacts	USA

Data are correct as of August 2015

Box 2.6—LCA and a Multi-impact Appraisal of Tourism Products and Services

The study by Cerutti et al. (2014) developed as part of activities within the Working Group on Tourist Services in the Italian LCA Network has set out to comprehensively assess the environmental impacts associated with agri-tourism by looking into the effects of tourist stay at holiday farms in Northern Italy. Process-based LCA has been applied to achieve the study objectives. Both upstream and downstream processes related to holiday farm's operations have been accounted for when appraising the magnitude and the diversity of environmental impacts. Among others, the impacts associated with a farm itself, its toilet facilities and furniture, breakfast service provision and on-site orchards maintenance have been considered. The impacts attributed to tourist travel have been excluded from analysis due to data availability.

The outcome of this research shows that most of the impacts attributed to Italian agritourism arise from the *upstream or non-operational* processes, especially those concerned with procurement and preparation of cooking ingredients for breakfast. It also demonstrates that, when normalised and compared against each other, significant environmental impacts are generated by holiday farms not only in terms of climate change, but also from the standpoint of acidification and release of nutrients in the environment (which, in turn, has direct effect on the problem of eutrophication) (see Fig. A below). The study concludes that these impacts should not therefore be ignored when reporting on the holiday farms' environmental performance and establishing mitigation targets.

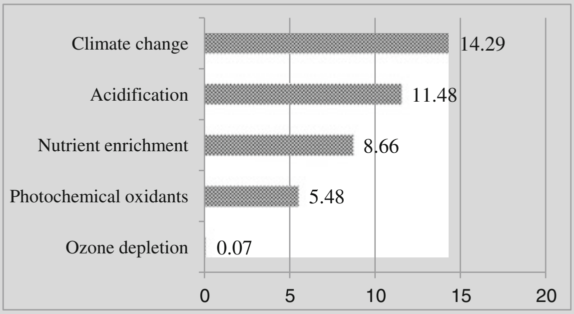

Fig. A Weighted environmental impacts of a holiday farm. *Source* Modified from Cerutti et al. (2014)

Importantly, some research has underlined the necessity for the broader application of life cycle analysis in tourism impact assessment but did not directly employ the traditional, i.e. as defined in the ISO standards and stipulated by the SETAC guidelines, LCA method. World Wild Fund–UK (2002) and Chambers

(2004) utilised, for example, the life cycle thinking approach but not the original LCA methodology to conduct an ecological footprint analysis of holiday packages. The environmental assessments conducted by the UK CEED (1994, 1998) are also based on the life cycle perspective rather than on a full-scale LCA analysis; in addition, they are qualitative in nature; incomplete as they exclude certain phases of a tourism product and service's life cycle from analysis; not widely available and lacking in detail (Chambers 2004).

Michailidou et al. (2015) made an attempt to examine the potential for integration between environmental indicators theory and the method of LCA by appraising the environmental significance of the tourist accommodation sector in Greece; although some LCA-based estimates of hotel performance were derived in this study, application of a full-scale, original LCA was not the primary aim of the project. Kuo and Chen (2008, 2009) applied a life cycle approach to quantify the environmental loads from island tourism in Taiwan. This study assessed the environmental impacts associated with travel to/from the destination along with tourist accommodation and activities at the destination which have been defined as the life cycle elements of tourist trips. However, the original LCA method was not applied and the 'indirect' GHG emissions arising from tourism in the island, such as those related to the capital goods and infrastructure of specific holiday travel elements, were excluded from analysis.

Hu et al. (2015) assessed the carbon footprint generation within the life cycle of a hotel in Taiwan; while the study was carried out in accordance with the PAS 2050:2011 guidelines (see Sect. 3.1.5 for details) which are based on life cycle considerations, it did not utilise any of the two traditional, process-based or input-output, LCA approaches in its analysis. Likewise, the studies by Lai (2015) and Xuchao et al. (2010) adopted various, life cycle thinking-based international standards for carbon accounting and reporting (see Sect. 3.1 for details) but not the conventional LCA methodology when carrying out carbon impact appraisals of tourist accommodation facilities in Hong Kong and Singapore, respectively.

Lastly, the value of revealing the total, direct and indirect inclusive, GHG emissions from tourist activities within specific tourist destinations has been recognised and addressed in a number of studies (see, for instance, Björnsson 2014; Kelly and Williams 2007; Liu et al. 2011a; Sesartic and Stucki 2007). While this research stream represents a considerable step forward in enhancing public comprehension of the carbon significance of the tourism industry in general and its specific destinations in particular, it provides yet limited evidence of LCA utilisation in tourism context which is best applied at the level of specific products and services.

The name of LCA has appeared in some research but the original methodology has never been applied for analysis. Martins-Swan (2001), for example, developed an interactive tool for the qualitative description and self-evaluation of impacts generated by sustainable tourism projects throughout their life frame and called it the 'life-cycle assessment'. In reality, this approach has limited connection to the original LCA as an established method for environmental assessment of products and services.

The need to apply LCA in tourism research has been recognised and the efforts have been undertaken by LCA and tourism practitioners and academia to advance the field (De Camillis et al. 2010). For instance, the Italian LCA Network established a separate Working Group on Tourist Services that has been active since late 2007 and whose primary focus has been on LCA in the tourist accommodation sector (Raggi et al. 2008). The group became a Scientific Association in 2012 and its achievements comprise to-date a number of case studies which have been carried out for tourist accommodation establishments in Italy with further plans to extend the scope of LCA application to cover other significant types and components of Italian tourism (Castellani and Sala 2009; De Camillis et al. 2010; Notarnicola et al. 2015). One of the most noticeable outcomes of the group has been the development and testing of the LCA methodology for application in the agri-food sector which is a vital supply side industry in tourism (Notarnicola et al. 2015), particularly for its tourist accommodation and tourist activities sectors (see Sects. 4.2 and 4.3 for details). The main shortcoming of this project is that a number of studies which have been produced under its aegis are only available in Italian which hampers the recognition of these research efforts by the international academic community. Despite all this recent progress made, the evidence of LCA implementation in tourism remains to be fragmented and rather sporadic and there is a need to enhance the field with more consolidated knowledge and a systematic approach.

2.6 Limitations of LCA

Despite the recent progress made in applying the principles of life cycle thinking and the method of LCA in tourism, the adoption of these concepts by the industry has yet been slow. Given the advantages of LCA, there is a clear need for broader employment of this method to assess the environmental impacts of the industry. This will enable better understanding of the diversity and the magnitude of the detrimental environmental effects associated with tourism products and services which, in turn, should contribute to the development of more effective mitigation strategies.

There are a few possible explanations to the yet limited uptake of LCA by the tourism industry (Box 2.7):

Box 2.7—Key Opportunities and Barriers to the Broader Adoption of LCA by the Industry Professionals

Frankl and Rubrik (2000a, b) looked into the key opportunities and barriers attributed to the implementation of LCA by industry professionals in Germany, Italy, Sweden and Switzerland. In total, 382 business representatives were surveyed.

Results indicate that the industry envisages a number of substantial benefits in the use of LCA for appraisal of environmental impacts from products and services. LCA is seen as a powerful tool to identify the key environmental bottlenecks, educate consumers and company shareholders about the environmental implications of organisation's operations and conduct a critical, comparative analysis of existing products and services against prospective alternatives. While the capability of LCA to achieve short-term environmental improvements is recognised, the primary advantage of applying this method is assigned by industry professionals to the generation of *long-term*, financial and reputational benefits due to the improved environmental performance of the business itself and the products and services it has on offer. The majority of respondents agree that LCA will be more broadly utilised by the industry in the future, especially if combined with other, more country-specific and sector-related impact appraisal tools.

In terms of barriers for LCA implementation, most survey participants (circa 60 %) refer to the problem related to (good quality) data availability and the organisational restrictions attributed to their collection as a primary constraint. The issue of subjectivity in system boundary setup with subsequent possible differences in the generated assessment outcomes is recognised by about 50 % respondents. The lack of expert knowledge required to run LCA and interpret its results is ranked as the number three most important limiting factor, mentioned by almost 50 %. Lastly, poor understanding of the LCA methodology and high costs of LCA analysis are the other problems which have been brought to light by circa 35 and 30 % of participants, respectively.

1. *Poorly understood evaluation potential and limited knowledge of the advantages* offered by the LCA method for comprehensive impact appraisal among tourism policy-makers, managers and academics is deemed to be the key reason (De Camillis et al. 2010). LCA originates from energy and engineering studies and has explicit underpinning in natural sciences. Tourism has traditionally been considered from the standpoint of social science and economics [see, for example, the titles of these contributions by Gretzel (2011) and Hall (2005)]; this suggests that while many tourism policy-makers, managers and academics have a solid social science and economics background, they may have a lack of understanding of the purely scientific (natural sciences) context that has been put into the basis of LCA. More research on environmental effects of tourism, covering a broader set of impacts and examining the implications of these impacts for the different sectors of the industry alongside the destinations it operates in, can help rectify this gap. This is because tourism research becomes increasingly inter-disciplinary and now integrates contributions from scholars who have multi-disciplinary backgrounds and more natural science-related interests. It is crucial that the outcome of such inter-, cross- and multi-disciplinary studies is communicated in a clear and concise form and disseminated by leading

journals in the field of tourism management. This has potential to facilitate more rapid integration of the research outcome on life cycle related environmental impacts from tourism into tourism policy-making and management.

2. The tourism industry is *complex*; in fact, some academics argue that it cannot be defined as an 'industry' as such because it is made up by a large number of sectors and sub-sectors (McKercher and Prideaux 2014), such as hospitality (which, in turn, consists of the tourist accommodation sector, catering sector, cruise sector, etc.), transportation, activities and events. Furthermore, tourism is closely related to retail, sports, entertainment and banking services; given the complexity of the inter-connections between tourism and other, related sectors, it is often referred to as a 'system' (Leiper 1990). From the standpoint of LCA applicability in tourism, this may seem to be a significant advantage: given that the method of LCA is underpinned by a 'systems analysis approach' (Andersson 2000), this makes tourism an ideal object for life cycle analysis. On another hand, however, this may also be considered as a substantial disadvantage. This is because many tourist systems are too complex for comprehensive appraisal. There are a number of 'composite' tourism products and services which are represented by multi-level structures, often with extensive supply side industries. Examples include holiday packages, hotels and all-inclusive resorts, to mention a few. Supply chain of tourist accommodation facilities can, for example, be of infinite order with some suppliers being difficult, or even impossible, to identify (Filimonau et al. 2011a). Furthermore, it is not unusual for specific elements of some composite tourism products and services to be operated by different providers or sub-contractors over which the company that officially 'owns' this product or service may have limited control (Raju 2009). All this underlines the complexity of tourist systems and suggests that the data required for LCA of some tourism products and services can be laborious to procure. The situation further complicates if the supply chain industries are based overseas, particularly in developing countries, which is not an unusual situation for many tourism products and services. For example, World Wild Fund-UK (2002) has demonstrated that 73 % of foodstuffs consumed by tourists in Majorca (Spain) are internationally sourced with 17 % arriving from outside Europe. This adds complexity because the life cycle inventories of environmental impacts employed by LCA and the related life cycle databases (utilised, for instance, by the international standards for carbon accounting and reporting, see Chap. 3) have the primary focus on developed states, largely EU countries, North America, Australia and New Zealand. Despite the ongoing research efforts aiming to develop life cycle databases of environmental impacts for developing markets, LCA of tourism products and services which are offered in or rely upon the destinations outside Europe, North America and Australia may have restricted accuracy.
3. LCA *can be expensive*; it is not unusual that a comprehensive, in-depth appraisal of a product or service may cost $50,000 and more (Loijos 2012). The cost of acquiring life cycle inventory databases and purchasing specialised LCA software packages purposefully designed to simplify life cycle analysis may serve

as another significant limitation (Bala et al. 2010). Due to the large time and efforts invested in collecting and systemising life cycle data on different environmental impacts as attributed to a variety of industrial processes, materials, products and services, the price of leading LCA software packages varies between £1000 and £20,000, depending on the type and duration of the user license and software functionality (LinkCycle 2013, also see Table 2.1). While large companies can potentially afford to bear these costs, small and medium enterprises (SMEs) whose financial and labour resources are limited may struggle to pay high subscription fees. This issue is of particular relevance to tourism where the lion's share of companies is represented by small and medium, or even micro, businesses (Keller 2004). Simplified LCA can be used to tackle this drawback as it enables companies to perform environmental impact appraisals of products and services at lower costs, subject to these appraisals meeting the requirements of the simplified method (see Sect. 2.4.1 for details). Another solution would be to develop life cycle datasets for the key industrial processes, materials, products and services which would be representative of specific markets, and provide these in free access. The European reference Life Cycle Database (ELCD) represents a significant advancement in this direction (see Sect. 2.3 for details). Such initiatives are however rare; more importantly, the business awareness about these free-to-access life cycle related data remains to be low and should be reinforced. There is a need to develop purposefully-designed intervention policies which would aim to better disseminate the advantages of applying life cycle thinking in environmental assessments of products or services and incentivising businesses willing to integrate life cycle considerations in their product and service development procedures.

4. The high costs of compiling and maintaining commercially managed LCA databases determine their *irregular updates*; this represents another shortcoming of the method that needs to be overcome (Filimonau et al. 2014). Again, the ELCD initiative represents a substantial step forward in this respect due to its novelty; its effectiveness is however reduced due to the issues discussed above. The international standards for corporate carbon accounting and reporting are LCA-based and undergo updates on a more regular and frequent basis compared to, for instance, the Ecoinvent life cycle inventory database (Filimonau et al. 2013). These are however best applied to appraise the carbon significance of tourism businesses while the value of these standards to assess the non-carbon impacts attributed to tourism product and service systems is restricted (see Chap. 3 for details).
5. *Data intensity* of LCA analysis and associated significant *time requirements* for the life cycle related data collection and systematisation may provide another partial explanation to the yet limited adoption of the LCA method in tourism (Frankl and Rubrik 2000a). Labour and financial resources available to tourism enterprises are often restricted; hence, it can be difficult to collate the necessary data which would concurrently be of acceptable quality. Lack of in-house expertise to compile data and carry out LCA can intensify this issue further. Recruitment of third party auditors or consultants possessing the required

knowledge and qualifications to run a LCA-based analysis can be expensive. Furthermore, businesses may be reluctant to provide and disclose life cycle data on their industrial processes, materials used and products or services offered because these can be perceived as business sensitive or confidential information. Moreover, LCA based on confidential data are impossible to replicate in other business or geographical contexts as the data are usually provided on the grounds of their non-dissemination (Hendrickson et al. 2006). The outcome of such studies remains the property of the client who has commissioned LCA and does not therefore appear in the public domain. Lastly, tourism companies may be unwilling to engage in new, more comprehensive, life cycle related environmental impact appraisals. This is because, due to the more holistic assessment undertaken, these are likely to reveal more significant, or larger than conventionally accepted, environmental pressures associated with organisations' operations which may negatively affect their corporate image and diminish competitive advantage (Filimonau et al. 2013).

6. *Data inaccuracies* associated with the use of LCA may also play a role (Finnveden 2000). For example, some categories of life cycle data inventories, such as carbon impacts from short-haul air travel in Europe, lack precision due to the inconsistencies attributed to the definition of flying distances in Europe and North America alongside inaccurate assumptions applied when defining maximum load factors and average occupancies (Filimonau et al. 2013). More accurate estimates can be obtained when LCA figures are combined with the numbers extracted from more specialised (for example, Europe- or country-specific) environmental impact inventories, such as DEFRA (see Sect. 3.1.4 for details). This has enabled development of 'hybrid' approaches to life cycle based assessments which strive to reduce the weaknesses and capitalise upon the strengths of LCA and alternative approaches for impact appraisal in tourism as reported, for instance, in Filimonau et al. (2013, 2014) and Pereira et al. (2015). The feasibility of employing such 'hybrid' techniques in real-world tourism business practice should be a subject for future research inquiry.
7. The LCA method has been originally designed and is therefore best applied for appraisal of environmental impacts; it is therefore often referred to as 'Environmental LCA' or 'E-LCA'. The potential of E-LCA to holistically assess *the socio-economic effects* attributed to product or service systems is less established (Schianetz et al. 2007). This may represent a significant barrier to its adoption by the tourism industry given the large number of adverse, intangible, non-environmental effects attributed to tourism development globally (Page 2011). It is important to note that this shortcoming can be addressed in the foreseeable future. This is because LCA is flexible in terms of design which means it can be structurally extended or modified to enable full-scale sustainability assessment. This would combine E-LCA with Life Cycle Costing (LCC) (which strives to appraise the magnitude of economic impacts associated with a life cycle of products or services and covers such aspects as labour cost, price of raw material and investments, to mention a few) and social LCA or S-LCA (which aims to define and assess the social implications of a product or

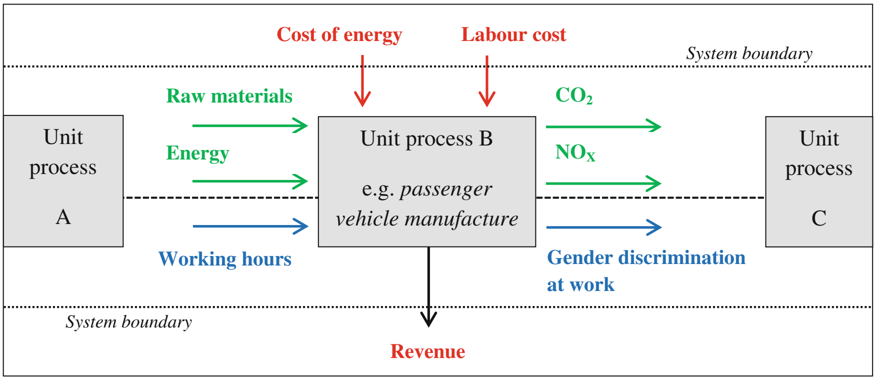

Fig. 2.3 Example of life cycle sustainability assessment (LCSA) inventory data for a unit process within a product or service's life cycle. *Green colour* depicts environmental inputs to and outputs from the system (part of E-LCA analysis). *Blue colour* stands for socio-cultural consequences (part of S-LCA analysis). *Red colour* shows the economic implications (part of LCC analysis). *Source* Adopted from: Benoît et al. (2010); UNEP/SETAC Life Cycle Initiative (2011)

service's life cycle and covers such aspects as job creation, equal pay for women, child labour, etc.) (Finkbeiner et al. 2010; UNEP/SETAC Life Cycle Initiative 2011). Such integration is feasible because LCA operates a 'systems analysis approach' and holistically reviews *each* unit process within a product or service system from the standpoint of its environmental significance (Andersson 2000). Similar type of analysis can be conducted but with a focus on the economic and socio-cultural implications instead (Benoît et al. 2010), Fig. 2.3. These analyses could then be subsequently integrated into a final, all-in-one impact appraisal tool which has been referred to in literature as Life Cycle Sustainability Assessment (LCSA) (UNEP/SETAC Life Cycle Initiative 2011). According to Finkbeiner et al. (2010) who apply the principles of the Maslow's hierarchy of needs when evaluating the relationships between the different life cycle thinking based impact assessment approaches, LCSA sits at the head of the pyramid of sustainability appraisals and may represent the top of the LCA methodological framework which all impact assessment projects should ideally strive to reach. While the potential of LCA to incorporate all impacts into its assessment is acknowledged, the LCSA method is currently under scrutiny as the development of such composite impact appraisal tool requires significant data, labour and time inputs which hampers more rapid uptake of the LCSA concept by the industry professionals and policy-makers (Wolf et al. 2012).

8. Similar to the alternative tools for environmental impact appraisal in tourism, LCA involves a *subjective* element. This finds reflection in the setup of system boundaries, selection of the method to allocate environmental impacts for processes with several products and by-products, and choice of specific impact

categories and impact indicators for assessment (Hendrickson et al. 2006). This subjectivity element has potential to affect the appraisal outcome and it is not unusual that LCA studies conducted on very similar products or services may demonstrate different results (see, for instance, Svanes et al. 2011), Box 2.8. To overcome this limitation, all subjective decisions made in the process of impact appraisal as part of LCA should be properly documented and justified (PE INTERNATIONAL 2015b). The issue can also be partially addressed by applying a sensitivity and scenario analysis which is an integral feature of the LCA method (Paulsen and Borg 2003). To run these analyses, specialist knowledge may be required which relates back to such shortcomings of the method as the lack of in-house expertise and the high cost of assessment highlighted above.

Box 2.8—Subjective Element in LCA and Its Role in Interpreting the Outcome of Environmental Impact Appraisals

The invention of disposable nappies (or 'diapers' as they are known in some countries) has not only simplified life for parents, but also imposed large impacts on family budgets and the environment. It is estimated that, only in the UK, circa 2.5 billion disposable nappies are sold and discarded annually (Aumônier and Collins 2005), costing an average British family circa £400 a year (Canter 2015). The production of disposable nappies is characterised by the significant inputs of energy and material; substantial space (in countries where landfilling represents a primary waste treatment technique) and energy (in the case of waste incineration) is required at their end of their life frame. Reusable cloth nappies (diapers) are therefore considered as a more economically feasible and, most importantly, as a more environmentally benign product alternative (Canter 2015). Attempts have been made to demonstrate the environmental advantages of reusable cloth nappies via the application of life cycle thinking and the method of LCA.

Surprisingly, while LCA-based studies undertaken on this topic have produced some commonalities, they have also generated a number of controversies. LCA analysis shown, for instance, that while disposable nappies require 20-times more raw material and generate as much as 90-times more waste, reusable cloth nappies consume 3-times more energy and create 10-times more water pollution (Ayres 1995; Priesnitz 2010). This is due to the significant electricity, water and detergent requirements for their laundering. Detailed analysis implies that while disposable nappies are indeed more environmentally significant under certain impact categories, their product alternative, i.e. reusable cloth nappies, have equal or even higher environmental loads under a number of other impact categories. LCA analysis therefore suggests that, if *all* environmental impacts are holistically appraised, none of the nappy product alternatives can be considered being more environmentally beneficial than the other.

While this case study demonstrates a shortcoming of applying the method of LCA for environmental impact appraisal of product and service alternatives, it also reveals its value. This is because LCA analysis is capable of pinpointing the factors which can make one product alternative a preferred option. In the case of reusable cloth nappies, for example, LCA shows that their use patterns make a dramatic effect on the environmental pressures they produce (Cordella 2015). Washing reusable nappies in full loads, line-drying them outdoors and reusing them on a second child has the potential to significantly diminish their environmental significance, thus making reusable cloth nappies a better product alternative from the environmental viewpoint (Priesnitz 2010). In the case of disposable nappies, their environmental impacts can be reduced by substituting the raw material currently utilised in their production with a more environmentally friendly alternative, and incinerating them instead of landfilling which enables energy recovery (Cordella 2015).

The case of nappies is employed to concurrently demonstrate the limitations and the value of LCA analysis; it is also used to highlight the role of subjective decisions and showcase the power of multi-impact appraisal. The case of nappies is often referred to as 'the diapers dilemma' in LCA related literature (Ayres 1995).

Another example of a public controversy which is more tourism and hospitality-related is the McDonald's case involving a choice between paper-made and plastic-made hamburger shells (Ayres 1995). Driven by the 'green' intentions, this world-famous catering company has decided in favour of the former as, intuitively, it does indeed seem to be a more environmentally benign option given the use of a more natural material, i.e. paper, in its manufacturing. LCA shows that this assumption is true when applied to such impact categories as release of toxic substances and occupation of landfill space. However, LCA also indicates that paper shells are more environmentally significant under such impact categories as energy use and water consumption which suggests that the choice of a product alternative is not always simple and intuitive.

These two examples demonstrate that the outcome of LCA studies is truly holistic as it covers a broad range of impact categories; however, they are also a clear indicator that LCA results can be interpreted in a number of different ways and adjusted according to the needs of a specific project. This in turn signifies the importance of unbiased judgements and conclusions made in LCA analysis.

2.7 Conclusions

The chapter has introduced the concept of life cycle thinking and the method of LCA and critically evaluated their major advantages and disadvantages in light of prospective application for environmental impact appraisal of tourism products and services. Despite the number of shortcomings, LCA has a set of significant strengths and it is argued that the broader adoption of this tool by tourism managers, policy-makers and academia should be encouraged to enable progress of the industry towards the goal of sustainability. Subsequent chapters will provide an overview of the key alternatives to LCA as utilised for environmental impact appraisal in tourism, highlight the evidence of LCA application by tourism enterprises and discuss the future outlook for LCA development within the industry in question.

2.8 Further Reading

Useful general overviews of the concept of life cycle thinking and the LCA method include:

- Baumann, H., & Tillman, A.M., (2004). *The hitchhiker's guide to LCA: An orientation in life cycle assessment methodology and applications.* Lund, Sweden: Studentlitteratur.
- Curran, M.A. (Ed.), (2012). *Life Cycle Assessment Handbook: A Guide for Environmentally Sustainable Products*. Scrivener Publishing LLC.
- EPA—Environmental Protection Agency. (2006). *Life Cycle Assessment: Principles and Practice.*. Available at: http://www.epa.gov/nrmrl/std/lca/lca.html. (Retrieved Aug 5, 2015).
- Guinée, J. B. (Ed.), (2004). *Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards.* Kluwer Academic Publishers, Dordrecht.

A more recent, detailed introduction into LCA which has been written specifically for students:

- Curran, M.A. (Ed.), (2015). *Life Cycle Assessment Student Handbook.* Wiley.

There is also a comprehensive, free-to-use for non-commercial purpose LCA textbook that has been adopted in 25 North American Universities for the purpose of undergraduate and graduate level teaching and research:

- Matthews, H. S., Hendrickson, C. T., & Matthews, D. H., (2015). *Life Cycle Assessment: Quantitative Approaches for Decisions That Matter.* Available at: http://www.lcatextbook.com/. (Retrieved Aug 5, 2015).

The Life Cycle Initiative is a joint project by UNEP and SETAC which was launched in 2002 with the purpose of promoting life cycle thinking and the method of LCA internationally and facilitating knowledge exchange about 'best practice' of their practical implementation worldwide. The website provides access to a number of useful resources, including industry-specific reports and training materials, which can be utilised to develop better understanding of LCA and the advantages offered by the application of this method for real-world business practice and policy-making.

http://www.lifecycleinitiative.org/.

http://www.springer.com/978-3-319-26222-2

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