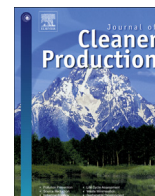


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Review

A comprehensive review of full cost accounting methods and their applicability to the automotive industry

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ABSTRACT

Full cost accounting has been applied in many industrial settings that include the oil and gas, energy, chemical and waste management industries. Presently, it is not known how it can be applied in an automotive industry context. Therefore, the objective of this paper is to review existing full cost accounting methods and identify an appropriate approach for the automotive sector. This literature review of 4381 papers extracted ten full cost accounting methods with a diverse level of development and consistency in application. Based on a careful examination and critical analysis of each approach and existing automotive sustainability measures, the Sustainability Assessment Model developed by British Petroleum and Aberdeen University has been proposed as a well-developed and potentially practical tool for automotive applications. The Sustainability Assessment Model can be used by both academics and practitioners to translate a range of conflicting sustainability information into a monetary unit score. This is an effective way of communicating trade-offs and outcomes for complex and multi-disciplinary sustainable decisions in the automotive sector. It measures a broad range of economic, environmental, resource and social effects (internal and external), which is currently lacking in existing automotive systems. Its other strengths are the ability to provide both monetary and physical metrics for sustainability assessment, its flexibility and the ability to combine multiple sustainability dimensions. Furthermore, this paper provides helpful clues for researchers interested in exploring full cost accounting in the future by reviewing, analysing and synthesising the broad range of relevant sources from diverse fields in this topic area.

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1. Introduction

In the last half century, cars have become an important part of our lives and provide personal mobility with speed, comfort and

convenience. The use of private cars has seen a large increase compared to other transport modes such as buses, trains, metro and bicycles (Geels et al., 2011). However, this expansion of car-based transport has brought a wide range of environmental and social impacts, for example, the depletion of natural resources, contribution to global warming, acidification of the atmosphere, congestion, accidents and noise (Graedel and Allenby, 1998; Mildenerger and Khare, 2000; Mayyas et al., 2012). As a result of these impacts, the automotive sector is under increasing pressure from policy-makers and other stakeholders to consider environmental and social values in their operations.

Examples of strategies used by automotive organisations to mitigate social and environmental effects include investment in clean technologies, design for sustainability and creating value for local and global communities (MacLean and Lave, 2003; Mayyas et al., 2012). In order to manage these strategies economically, there is an increasing demand for robust decision-making tools that measure and inform managers about the economic, environmental

Abbreviations: CGS, Corporate Genuine Saving; CICA, Canadian Institute of Chartered Accountants; CWRT, Center for Waste Reduction Technologies; EC, European Commission; ELU, Environmental Load Unit; EMA, Environmental Management Accounting; EP&LA, Environmental Profit and Loss Account; EPD, Environmental Product Declaration; EPS, Environmental Priority Strategies; ExternE, External Costs of Energy; FCA, Full Cost Accounting; FFF, Forum for the Future; GHG, Greenhouse Gases; IPA, Impact Pathway Analysis; ISO, International Organization for Standardization; LCA, Life Cycle Assessment; LCC, Life Cycle Costing; MCA, Multi-Criteria Analysis; PPP, Polluter Pays Principle; PSI, Product Sustainability Index; SAM, Sustainability Assessment Model; SCC, Sustainability Cost Calculation; SV, Sustainable Value; TBL, Triple Bottom Line; TCA, Total Cost Assessment; USEPA, United States Environmental Protection Agency.

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and social consequences of their decisions (Steen, 1999; Fiksel, 2009; Mayyas et al., 2013). This paper proposes the Full Cost Accounting (FCA) concept as a practical tool to deal with the complexity of triple bottom line decisions in the automotive environment. It embraces both internal and external sustainability impacts and translates them into the widely known and accepted business language of 'money' (Bebbington et al., 2007).

FCA is not a new concept; it has been applied in many different settings such as the energy industry (USEPA, 1996), oil and gas industry (Baxter et al., 2003), chemical industry (Taplin et al., 2006) and urban development (Xing et al., 2007). However, it is not known if it is applicable in an automotive context. This paper aims to answer two research questions: (1) What FCA methods have been developed to date? and (2) What FCA method is appropriate for the automotive setting? A comprehensive review with a systematic approach has been conducted to identify all the FCA methods which have been developed to date. Critical analysis of the methods identified selects the one that fits the specifications and needs of an automotive business.

This article begins with a background section that explains the concept of FCA and related issues. A brief description of the decision-making issues in automotive organisations and how FCA can assist in supporting these decisions are then discussed. The next section describes the research methods used for the review of FCA studies. The results of the review are synthesised and reported in the following section. Finally, the discussion section interprets the results and discusses the implications of the review for the automotive industry.

2. Background information and major issues

This section introduces the reader to the concept of FCA, specifies the related terminology and identifies major methodological issues that should be considered when applying FCA. It will be taken as the basis to determine relevant key words for searching the literature and creates a theoretical framework which will be used for assessing studies included in the review.

2.1. The concept of FCA

FCA, like life-cycle costing, cost-benefit analysis, balanced scorecard for sustainability and material flow cost accounting, is classified under the umbrella of Environmental Management Accounting (EMA) tools and systems (Jasch and Savage, 2009; Qian and Burritt, 2009). The purpose of EMA is to assist the internal planning and decision-making process within an organisation by measuring environmental information and making it more visible for decision-makers (Schaltegger and Burritt, 2000). EMA identifies, collects and analyses both physical information (e.g. use and flows of materials, energy, water and waste) and monetary information on environment-related earnings, costs and savings (Burritt et al., 2002; Jasch and Savage, 2009). The majority of EMA tools place particular emphasis on measuring direct environmental costs such as the use of energy, materials and water, and waste generation as they are directly related to a number of environmental impacts caused by organisational operations (Jasch, 2003). What distinguishes FCA from other EMA tools is that it has been developed to measure both an entity's direct costs and indirect costs (Canadian Institute of Chartered Accountants (CICA), 1997). It also captures external costs, which are defined as the damages or negative effects of an entity's activities and decisions borne elsewhere in the system by parties not responsible for causing these effects in the first place (Bebbington et al., 2001; Russell, 2011). The most obvious external costs are the various forms of air, water and

soil pollution such as greenhouse gases (GHG), sulphur dioxide, volatile organic compounds (VOCs) and toxic substances.

The following terms are used as synonyms of FCA in the literature but they embody the same concept: full environmental cost accounting (Epstein, 1996), total cost accounting and total cost assessment (Centre for Waste Reduction Technologies (CWRT), 1999). The term FCA is also used interchangeably with full cost pricing but it is important not to confuse the nature and purpose of these two tools. FCA provides useful input information for the decisions on pricing an entity's products and services by identifying, measuring and monetising the costs that may be considered when moving towards the full cost pricing structure. These costs can then be incorporated into the prices of goods and services through full cost pricing (CICA, 1997).

2.2. Cost allocation and boundaries issues

FCA was developed to adjust the existing prices of products and services by monetising and incorporating both internal and external impacts (positive and negative), including environmental and social externalities (Bebbington et al., 2001). For example, a typical petrol car releases pollutants that contribute to acid rain and climate change as well as contributing to negative health effects resulting from reduced air quality. These externalities are real costs to society but they are not reflected in the price of petrol (Bent and Richardson, 2003). Hence, in the existing system, the cost of external impacts is borne by society and neither companies nor customers pay the full cost of production and consumption (Howes, 2002). If the market prices of products and services were to reflect the full cost (including social and environmental externalities), there is a possibility that consumers would switch their consumption to less environmentally and socially damaging products and services (Russell, 2011). Only when companies get their prices right and start paying for the external costs of their operations can profit be considered as environmentally and socially sustainable (Howes, 2000; Russell, 2011).

For this system to function effectively, the problems of boundaries and allocating a specific impact to the particular activity or organisation would have to be resolved. When applying FCA, organisations need to make decisions on which impacts to exclude from the assessment and account for. According to the polluter pays principle (PPP), an organisation should be accountable only for direct impacts which it has the ability to control (Howes, 2000). If this principle were to be applied equally and consistently, all producers in the supply chain (including customers) would be responsible for the direct environmental and social impacts resulting from their own production processes and consumption decisions (Howes, 2002). To avoid the danger of double counting, all producers and customers would have to calculate their own sustainability cost by using the same narrowly defined system boundaries (Howes, 2000).

The PPP is difficult to apply in practice as it requires the concerted action of everyone along the supply chain (Russell, 2011). Furthermore, the problem of allocating a specific impact to a particular activity or organisation would have to be resolved. To illustrate the issue, Bebbington et al. (2001) provided an example of sulphur dioxides that, once released into the atmosphere, form acid rain, which then acidifies water reservoirs and subsequently damages fish stocks. A water reservoir can be chemically restored to its original state and restocked with fish; however, it is difficult to estimate the link between the company's emission of sulphur dioxide, reservoir acidification and the cost of restoring the environment. Hence, it becomes a challenge to scientifically allocate responsibility or benefits unless they are related to consequences (Steen, 1999). At the organisation level, appropriate decisions need

to be made as to which economic, environmental and social flows should be allocated to the specific product system or systems (Luo et al., 2009). Industrial processes are usually multifunctional and their output comprises more than one product (Guinée et al., 2002); hence, several products or product systems share the same resource flows and emissions (Steen, 1999).

An alternative approach is to incorporate wider life cycle impacts and extend the boundaries both upstream and downstream in addition to including the entity's own effects (Bebbington et al., 2001). According to Bebbington (2007), an assessment of an activity which is blind to upstream and downstream effects cannot fully address sustainability. A sustainable organisation cannot operate in an unsustainable economy (Howes, 2002) and therefore organisations should at least consider incorporating life cycle impacts. Bent and Richardson (2003) concluded that as long as sustainability accounting is a voluntary exercise, the issue of selecting between narrow and wide system boundaries ultimately rests in the decision of the individual organisation.

2.3. Monetising environmental and social impacts

A number of valuation techniques exist that can be used to turn social and environmental effects into monetary values (see e.g. Milne, 1991; Bebbington et al., 2001; Howes, 2002). They can be grouped into two main categories: dose–response techniques and behavioural methods (Milne, 1991).

Behavioural methods (such as contingent valuation, hedonic pricing and travel costs) measure the money value of a specific impact directly from the preferences or behaviour of the affected stakeholder (Bebbington et al., 2001; Bent and Richardson, 2003). Information can be obtained directly from surrogate market data or indirectly from an individual using questionnaires, surveys or experimental techniques (Milne, 1991). These methods have wide applications and can be relatively straightforward and uncontroversial if they are based on actual behaviours and market prices (i.e. hedonic pricing relies on variations in housing prices as an indication of the value of local environmental attributes) (Bebbington et al., 2001). However, behavioural methods may also be subject to a number of inherent biases. For instance, the contingent valuation method relies on the stated preferences of individuals obtained by questioning people about the amount they would be willing to pay for specific environmental or social services or the amount of compensation that they would accept to give up these services. Contingent valuation is thus based on what people would hypothetically do, as opposed to being based on observation of their actual behaviours, raising the issue of its validity (Milne, 1991; Bent and Richardson, 2003).

Dose–response techniques, unlike some behavioural methods, are considered as indirect valuation techniques because they do not rely directly on individuals' preferences (CICA, 1997). They are divided into the damage function approach (damage costs) and the cost of control approach (avoidance, restoration, abatement and maintenance costs), which are considered as two alternative methods (Milne, 1991). The damage function estimates damage in monetary terms caused by a specific pollutant from a specific site through scientific, statistical and behavioural valuation methods (CICA, 1997). However, the fact that it is based on scientific evidence is also considered its weakness because it is limited in terms of data availability (USEPA, 1996; Cavanagh et al., 2007). It is also complex and time-consuming to apply in practice and it is based on a number of judgements and assumptions (CICA, 1997). Damage cost for major pollutants can be found in scientific studies (see e.g. Bickel and Friedrich, 2004; Tol, 2009), but more estimates for the effects are required. Antheaume (2004) recommended that input

from diverse research fields is required to better understand the physical impacts of flows and their costs.

The cost of control approach provides monetised values for the cost of installing and operating pollution control mechanisms that will control (reduce, eliminate, avoid) the pollution to a prescribed level (CICA, 1997). According to Howes (2002), this approach is less controversial than the damage function and provides more reliable estimates because it uses 'real' market prices for existing technological solutions to avoid, restore or control pollution. It is consistent with the United Nations recommendations for environmental adjustments to the national accounts (Howes, 2002). However, these methods are useful only if technologies exist for the restoring or avoidance of an impact (Bebbington et al., 2001). Antheaume (2004) concluded that avoidance cost for a number of pollutants is difficult to calculate due to the limited availability of solutions on the market to avoid the release of these pollutants. Furthermore, cost of control methods produce a surrogate figure since they do not estimate the real damage of the entity's activities. Hence, the method does not define the link between the specific emission and the damage caused (Antheaume, 2007).

The limitation of all the methods presented is that they are not accurate and provide only a crude estimate of the potential environmental and social costs (Antheaume, 2004; Bebbington, 2007). Usually, a range of numbers is calculated for a given impact. For example, Tol (2009) calculated based on 232 published estimates that the social cost of carbon should range from \$25 to \$50 per metric ton of carbon. Clearly, different conclusions can be drawn from an FCA exercise depending on which estimates and evaluation techniques are selected (Bebbington et al., 2001). Furthermore, monetisation of environmental and social flows is subjective in nature and many impacts such as human and ecological health have not been determined scientifically which brings into question the reliability of such an exercise (Schmidt and Sullivan, 2002). An independent audit is required in order to provide assurance as to the reliability, fairness and completeness of FCA estimates (CICA, 1997). However, as long as no generally accepted standards for producing such information exist, the possibility of auditing FCA results is limited. Also, the ability of a single monetary technique to value all possible social and environmental externalities is another problem. Primary monetary methods (such as dose–response methods) provide estimates for a limited number of flows and impacts (Antheaume, 2007). Despite the lack of widely accepted standards, Bickel and Friedrich (2004) recommended the damage cost method as the primary technique for valuing externalities. If damage cost estimates involve too many uncertainties then cost of control methods should be used. Behavioural methods should only be considered if dose–response methods cannot be applied or as a supplement for dose–response methods to assign monetary value to all important externalities of an object.

2.4. FCA and sustainability

The Triple Bottom Line (TBL) theory describes sustainability in three dimensions: economic, environmental and social (Elkington, 1999). These dimensions strongly influence each other and should be integrated and balanced to pursue sustainable development. Hence, if FCA is to be a powerful tool (or at least a means as suggested in the European Commission's (EC) Fifth Action Programme) which can lead towards a more sustainable economy (Bebbington et al., 2001), then it becomes critical that FCA should address financial, environmental and social issues. However, up until the late 1990s, the environmental and economic aspects of sustainability were dominant in FCA studies (see e.g. Huizing and Dekker, 1992; Rubenstein, 1994; USEPA, 1996). The social dimension was ignored and the first calls for incorporating the social sphere into

FCA studies were recognised by [The International Federation of Accountants \(1998\)](#) in their definition of FCA. [Bebbington et al. \(2001\)](#) also emphasised that it is intellectually and morally indefensible to be entirely blind to social externalities. Therefore, they recommended that social FCA is a subject area where future work is much needed if FCA is to be a tool that recognises and captures all sustainability issues.

This section has provided a definition of FCA and distinguished this term from other related EMA concepts. Important methodological issues have been discussed, such as cost allocation, system boundaries, monetisation of social and environmental impacts and links with the TBL theory which will be used as the theoretical framework to assess FCA methods in the following sections.

3. Motivation for applying FCA in the automotive industry

This section provides a brief overview of the decision-making issues in automotive organisations. It explains how FCA can assist in supporting these decisions and what benefits it can bring to the business.

3.1. Decision-making in automotive organisations

Automobiles have extensive ecological and social impacts (e.g. energy consumption, contribution to global warming, waste, noise and accidents) at every stage of their life cycle. These impacts begin with the extraction of minerals to produce raw materials and components, moving to car manufacturing and assembly, usage and eventually end-of-life disposal ([Graedel and Allenby, 1998](#); [Mildenberger and Khare, 2000](#); [Mayyas et al., 2012](#)). Due to the high ecological and social footprint of the automotive sector, car manufacturers are under pressure from policymakers and other stakeholders to improve the sustainability performance of vehicles at every stage of the life cycle (see [Fig. 1](#)).

Automotive organisations use similar approaches and strategies to meet the requirements of sustainability legislation. Examples of these strategies include reducing weight, improving aerodynamics,

improving conventional internal combustion engines, developing clean and new technologies, improving recyclability and improving safety ([Mildenberger and Khare, 2000](#); [MacLean and Lave, 2003](#); [Mayyas et al., 2012](#)). Each strategic approach intended to improve the environmental and social performance of a car is driven by a series of techno-economic issues and decisions ([Mayyas et al., 2012](#)). Design engineers and managers in the automotive business sometimes need to consider a large number of conflicting environmental, social and economic factors ([Mayyas et al., 2013](#)), although win–win scenarios are possible. For example, it is estimated that a 10% reduction in a vehicle's weight translates into an increase in miles per gallon of 5% ([Mayyas et al., 2011](#)). However, in some cases, improvements in one area require trade-offs in other areas. The selection of materials for a reduced car body weight may have financial implications for the company, mainly in the form of increased expenses by changing the design, manufacturing and recycling processes ([Mayyas et al., 2012](#)). Managers and design engineers in the automotive business need to estimate the magnitude of these trade-offs before they can make a decision. Hence, in order to make the best possible choices, they need effective and credible measurement tools to understand all of the economic, social and environmental impacts of their decisions as early in the product design cycle as possible ([Fiksel, 2009](#)). Vehicle design and development is considered to be the most important stage of the automobile life cycle because it determines the lifetime costs and overall sustainability performance such as fuel consumption, materials composition, safety and emissions ([MacLean and Lave, 2003](#)). The decisions made at this point have economic, environmental and social implications throughout the entire lifetime of the vehicle.

3.2. Applying FCA in the automotive business

Design engineers and managers in the automotive business need to formulate some kind of mathematical function to assess all conflicting objectives before making decisions ([Mayyas et al., 2013](#)). It becomes extremely difficult when conflicting factors are

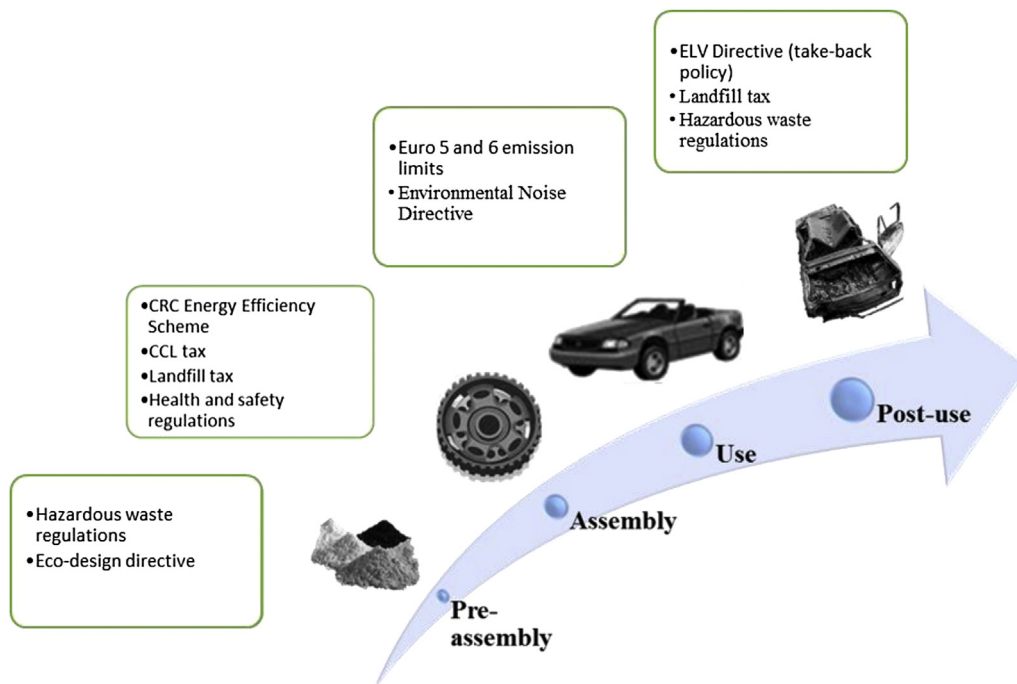


Fig. 1. Examples of sustainability requirements imposed on British car manufacturers at different stages of a car's life cycle.

measured and presented in different units. For example, a widely accepted tool to assess the environmental performance of a vehicle from the cradle to the grave is Life Cycle Assessment (LCA) (Khan et al., 2004). LCA techniques provide physical information about the internal and external environmental impacts of automobiles such as tonnes of carbon dioxide, sulphur dioxide, nitrogen oxides, cubic metres of water or megawatts of energy (Guinée et al., 2002). When compared against each other, it becomes difficult to decide which performance indicators are more or less relevant (Bickel and Friedrich, 2004). For example, an annual emission from an average passenger car is approximately 10.5 kg of VOCs, 112 kg of carbon monoxide, 8.3 kg of nitrogen oxides and 4416 kg of carbon dioxide (USEPA, 2008). Although the emission of carbon dioxide appears to be the most significant if considering the volume, the direct comparison of all these impacts is complex because 1 kg of carbon dioxide causes different social and environmental impact severity than 1 kg of nitrogen oxides (Friedrich and Bickel, 2001).

An optional function in LCA is a weighting step where numerical factors are assigned to each assessed impact category according to their relative importance (Bickel and Friedrich, 2004). The weighting stage is based on value choices and since there is no recommended method, it can take the form of money value, standards or expert panel (Guinée et al., 2002). FCA can be used in automotive organisations as a weighting algorithm by translating a range of conflicting information into a single, monetary unit score (Steen, 1999). The advantage of this approach is that monetary units are conceivable and the importance of an impact can be directly and intuitively grasped (Bickel and Friedrich, 2004). Bringing all the sustainability information into monetary values facilitates the decision-making process by providing a more transparent picture about the sustainability performance of a product, process or the whole organisation (Bent, 2006; Taplin et al., 2006; PUMA, 2010). It is an effective way of communicating trade-offs and outcomes for complex and multi-disciplinary sustainable decisions.

FCA not only allows us to identify trade-offs between alternative objectives, but also to communicate this information in an effective way to other parts of the business (Steen, 1999). In large organisations such as automotive, different management levels and business functions require different sustainability information (Lynch and Cross, 1995; Burritt et al., 2002). For example, boards of directors, top management and accounting and finance departments primarily understand the language of money, therefore they require monetary data to make strategic decisions. Middle management must be bilingual as they need to convert physical information generated by LCA to monetary terms for top management and vice versa to supply lower management and engineers with physical information so that they can understand the implications of strategic decisions made by senior management. Thus, FCA supports strategic choices and improves communication between different management levels and departments by turning sustainability into the most understandable and widely accepted business language of 'money' (Bebbington et al., 2007).

There is also a business case for applying FCA in any type of business, including automotive. A measurement system based on FCA can expose new business or investment opportunities by measuring internal and external sustainability costs and benefits. This is of particular importance for car manufacturing which is resource and energy-intensive, representing a significant cost element of a car and exposing a company to additional costs such as 'green' taxes, penalties and fines. Measuring internal impacts may provide immediate financial gains in the form of lower costs from reduced waste sent to landfill, water and energy consumption or carbon emissions. For example, Toyota saved approximately 38 billion yen (equivalent to half a billion US dollars) between 2008 and 2010 mainly by reducing energy consumption, reducing waste

processing costs, selling recyclable goods and utilising other environmentally-friendly technologies (Zokaie et al., 2013). As with carbon dioxide, externalities can be internalised at a certain point in time, therefore they are considered as future costs (CICA, 1997). Knowing and anticipating them before they arise can assist in a company's strategic planning and risk management (Howes, 2000).

Although there is potential for applying FCA in the automotive business, it is still unknown which FCA approach is potentially practical for automotive applications. Past experiments with FCA have provided different methods in this field. The following sections explore these methods by systematically reviewing the available FCA literature.

4. Research methods

Review papers on FCA exist in the wider literature (see Bebbington et al., 2001; Antheaume, 2007) but a systematic review has not been undertaken. This is needed to identify all of the methods that have been developed to date and make recommendations. The advantages of this approach over the conventional review are objectivity, transparency, minimised risk of bias in the results and its methodological and standardised approach (Denyer and Tranfield, 2009; Booth et al., 2011; Jesson et al., 2011). The method used to survey the literature and select papers is reproducible and explicit, which allows researchers to obtain similar results when the procedure is repeated (Denyer and Tranfield, 2009; Pickering and Byrne, 2013). Examples of these methods in application can be found in Ceulemans et al., 2015, Klewitz and Hansen (2014) and Stechemesser and Guenther (2012).

The review process in this paper followed the review protocol (Table 1) that contains information about the review question, inclusion criteria, search strategy, data extraction, quality assessment and data synthesis (Petticrew and Roberts, 2008; Booth et al., 2011). Diversity and heterogeneity of the FCA literature required a combination of different techniques at different stages of the review process.

4.1. Review question and inclusion criteria

A review question represents the scope of the literature review and its characteristics provide inclusion criteria for identified papers by considering the four PICO elements: population (a specific group), intervention, comparison (optional for two or more interventions) and outcome (Petticrew and Roberts, 2008; Booth et al., 2011). The review question and inclusion criteria for the systematic review of FCA studies are presented in the review protocol (see Table 1).

The primary publications included in the review process were full papers in peer-reviewed journals. However, a great quantity of FCA evidence exists in resources other than scientific journals (e.g. government publications, research, business or industrial reports); therefore, a wide range of published and unpublished studies (including grey literature) have been accepted in the review process with the exclusion of presentations, book reviews and comments. The review includes only studies reported in English because the majority of FCA studies have been conducted in native English-speaking countries such as the United Kingdom (UK), New Zealand, the United States of America (USA) and Australia, which minimises the risk of language bias in the results.

4.2. Searching the literature

Existing techniques for scoping and searching the literature include database and grey literature searching, reference list checking, citation searching, hand searching and contacting experts

Table 1
Review protocol designed for the literature review process.

Step	Research question/Methods
Review question	What FCA methods have been developed to date?
Inclusion criteria	Population: Studies representing the FCA concept Intervention: No intervention in the research question Comparison: No comparison in the research question Outcome: Studies that represent, constitute or strengthen any FCA method
Exclusion criteria	Presentations, book reviews, comments and all studies reported in non-English language
Searching the literature	Methods: database searching, grey literature searching, reference list checking, citation searching and consultation with an expert Databases searched: Google Scholar, ScienceDirect, Emerald Insight, Wiley Online, Web of Science Keywords for database searching: 'full cost accounting', 'total cost accounting', 'full environmental cost accounting', 'total cost assessment' and a combination of the following terms: 'accounting', 'valuing', 'externalities', 'external cost', 'social accounts' and 'environmental accounts'
Quality assessment	Methods: hierarchy of study design (experimental, observational, expert opinion) and quality checklist (lists of questions appropriate to the research question)
Data extraction	Data extraction form with developed categories from relevant studies: title, authors, year of publication, place of study, type of industry, type of focus (industry, organisation, project, product or process), and brief methodology description Software used for extracting data: Microsoft Access
Data synthesis	Methods: narrative synthesis, developed categories from a detailed examination of all FCA studies Presentation methods: tables, matrices and qualitative thematic analysis

(Wilson, 1992; Booth et al., 2011). A single technique is not sufficient to conduct a systematic review. A multiple approach is needed with a combination of search techniques to make sure that all relevant research has been identified (Petticrew and Roberts, 2008; CRD, 2009; Booth et al., 2011).

The primary method for mapping the FCA literature was database searching for original research papers in English language journals. Well-known and highly relevant studies were reviewed in order to isolate appropriate databases and search terms on each database (e.g. CICA, 1997; Atkinson, 2000; Bebbington et al., 2001; Taplin et al., 2006). The following databases were considered appropriate for searching FCA papers: Google Scholar, Science Direct, Emerald Insight, Wiley Online and Web of Science. Keywords used for the searches of each database were 'full cost accounting', 'total cost accounting', 'full environmental cost accounting', 'total cost assessment' and a combination of the following terms: 'accounting', 'valuing', 'externalities', 'external cost', 'social accounts' and 'environmental accounts'. Database searching was supplemented by grey literature searching, reference list checking and citation searching to reduce the impact of publication bias. Finally, the identified list of studies was sent to a highly respected expert on FCA for consultation to make sure that all relevant studies had been found.

4.3. Quality assessment

No single and universal approach to assessing methodological quality exists; therefore, the assessment should be restricted to studies of a specific type that are best suited to address the research question of the review (CRD, 2009; Denyer and Tranfield, 2009).

An initial quality evaluation was based on the type of study design being used and its hierarchy (experimental trials, observational studies, expert opinion). However, grading studies based on the study design hierarchy does not provide an adequate quality assessment because it ignores variations in quality among studies with the same design (CRD, 2009). Therefore, a detailed quality assessment of each study was based on 'quality instruments' which can take the form of checklist or quality scores (Kitchenham and Charters, 2007; Petticrew and Roberts, 2008; Denyer and Tranfield, 2009). Many quality checklists have been developed for different types of empirical studies (see Kitchenham and Charters, 2007), but no standard and agreed set of questions exists. Therefore, Fink's (2014) suggestion has been adopted, which is to review available lists of questions in the context of this study and select

those quality evaluation questions that are appropriate to the research question in the review process. The checklist for the quality assessment of FCA studies considers individual aspects of the quality of FCA methods.

4.4. Study selection process

The process of selecting FCA studies based on the review protocol is presented in Fig. 2.

The combination of different search techniques provided 4381 records in total. Initial screening and examination of the titles and abstracts excluded 4276 records where FCA was only mentioned (book reviews, comments or papers not related to FCA) or was of secondary importance. The full text had to be assessed against the inclusion criteria when the relevance of the study was impossible to judge based only on the title and abstract. After more detailed examination another 53 papers were excluded from the review process. Consultation of the remaining papers with an expert on FCA resulted in one more FCA study being identified and added to the review. Fifty-three publications were selected for the quality assessment and each study was examined in detail to assess the validity of its evidence base. The quality assessment based on study design excluded three observational qualitative studies from the review process due to their inability to answer the research question. Four other studies did not provide sufficient information about the method (system boundaries) and were also excluded from the review. Forty-six FCA studies were selected for the review process including 35 empirical (experiments and case studies) and conceptual FCA applications.

4.5. Data extraction

Data from 46 papers were extracted through the data extraction form. A typical data extraction form contains the following details: author and publication details, paradigm, aim and focus of the paper, method details, theory or models (Jesson et al., 2011). The data extraction form for FCA studies included title, authors, year of publication, place of study, type of industry, type of focus (industry, organisation, project, product or process) and a brief method description. The database of FCA studies was then built with the help of Microsoft Access software and based on the selected categories. Furthermore, a short summary of each study was uploaded into the database after detailed examination.

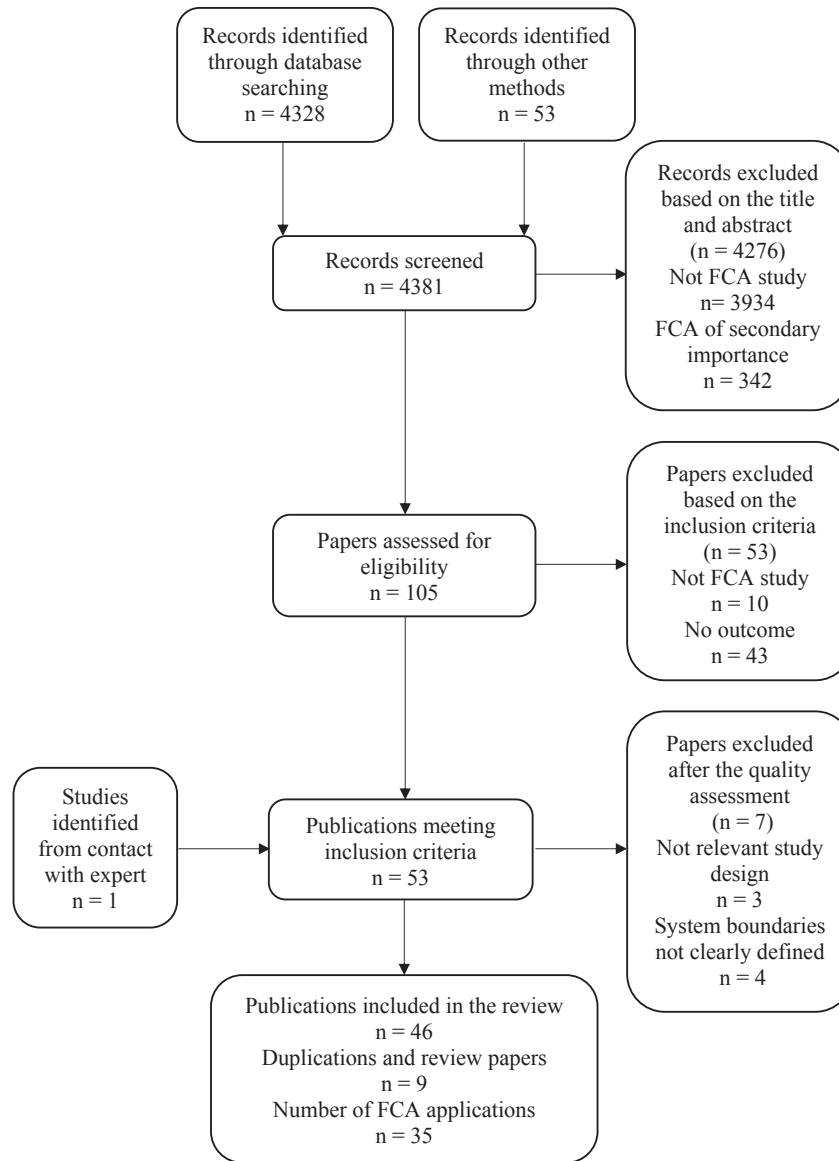


Fig. 2. The FCA study selection process used in the literature review based on the review protocol.

4.6. Synthesising and analysing studies

The main intention of synthesising studies is to recognise patterns in the evidence base; meta-analysis, narrative synthesis and thematic synthesis are examples of the many approaches that can be applied to the systematic review process (Booth et al., 2011; Jesson et al., 2011). The quality assessment of FCA studies indicated heterogeneity of the literature which prevents the meta-analysis being applied for synthesising FCA studies. Hence, narrative synthesis was applied to fully interpret the collected evidence. The narrative synthesis process was broken down into three steps: organising the description of studies into logic categories, analysing findings based on each category and synthesising findings across all studies (Petticrew and Roberts, 2008; Booth et al., 2011).

There is no single approach for developing categories to organise studies (Petticrew and Roberts, 2008); therefore, the most meaningful categories for this review were driven by the review question and detailed examination of all FCA studies. Four major categories have been developed as the framework for the study assessment and these are:

- Cost focus** – FCA study should include both internal and external impacts when assessing the performance of an object.
- System boundaries** – although defining system boundaries is always the choice of a specific company, it is also a distinctive factor between FCA methods. A simple two-point scale (narrow and wide boundaries) was assigned to each study to facilitate the analysis. The authors' interpretation of narrow boundaries is that a company focuses only on its own impacts (i.e. it follows the PPP principle). Wide boundaries are interpreted as the extended system that may include downstream impacts, upstream impacts or take the full life cycle approach.
- Valuation techniques of social and environmental impacts** – different FCA methods favour different valuation techniques.
- Sustainability dimensions** – FCA methods can focus on a single dimension, a combination of any two dimensions or all three dimensions of sustainability.

Clear and detailed tables were developed based on these categories to increase the transparency of the review. Each category was then described in a qualitative thematic analysis. Tabulating the study findings is an important step in the systematic review process and in the narrative synthesis (Petticrew and Roberts, 2008; Denyer and Tranfield, 2009; Jesson et al., 2011). Tables present the essence of the study characteristic and highlight the differences and similarities between the included studies (Jesson et al., 2011).

The final steps of the narrative synthesis were cross-tabulating and cross-study synthesis (Petticrew and Roberts, 2008) to explore any analogies, similarities and differences between FCA methods. Studies were first grouped together based on the common features in the developed categories. Then, a closer examination of each study within the group was performed to identify how a given study relates to other studies within the group. It allowed for the isolation of stand-alone studies from others linked with a specific FCA method.

5. Results of the analysis

The results of the review are presented in this section. It begins with a bibliographic analysis of FCA studies. Then, the FCA applications are elucidated based on the developed criteria. Finally, the FCA methods are identified through cross-study synthesis and their main features are described.

5.1. Bibliographic analysis

Forty-six relevant FCA studies were identified in the wider literature (see Appendix A). Journal articles and grey literature constitute the majority of these studies (41.5% each) while books and book chapters account for 17%. The proportion of grey literature (such as technical reports, company reports, research reports and conference papers) is large, which indicates its significant contribution to the method's developments in this field.

From 46 FCA studies, 35 empirical (experiments and case studies) and conceptual applications have been identified in different settings (see Appendix B). The most intensive research has been conducted in waste management (six studies), energy (five studies) and oil and gas (four studies). Other sectors, such as forestry, water service, chemical, alcohol, automotive, coal, urban development, research and higher education report no more than one or two applications of FCA methods. Nearly 46% of these studies have been run at the organisational level including in such companies as British Petroleum, Interface Europe, BSO/Origin, PUMA, Volvo, AlCo and ChemCo. Project-level applications (e.g. energy technology and waste management projects) constitute 37% and industry-level applications (coal, oil and gas) 6%. Product-, process- and material-level assessments account for no more than 11% of the total FCA applications and these are mainly in the automotive, gas and chemical sectors.

5.2. The analysis of findings based on developed categories

Thirty-five FCA experiments (case studies) were assessed based on the developed criteria, which were: sustainability dimensions, system boundaries, valuation technique of social and environmental impacts and cost focus. This aided recognition of the similarities and differences between FCA methods (Table 2).

Up to 2003, the environmental and economic aspects of sustainability were dominant in FCA studies. The social dimension was ignored, with minor exceptions of including human health impacts in studies such as USEPA (1996) and Steen (1999). Bebbington et al. (2001) recognised the need for a more integrated approach and to

incorporate the social element of sustainability into FCA studies. Thus, since 2003 a number of studies have attempted to combine multiple sustainability dimensions into one decision-making tool (see e.g. Baxter et al., 2003; Figge and Hahn, 2005; Taplin et al., 2006).

Most FCA studies applied at the organisational level used narrow boundaries (see Table 3). Measuring upstream and downstream impacts is often difficult if not impossible and depends on the number of suppliers within the supply chain. Two exceptions relate to organisations that organise and control their activities on a project basis. For example, organisations operating in the oil and gas industry start with exploration drilling, the design of a drilling platform, construction of the platform, production of oil and gas, and decommissioning of the platform (Bebbington, 2007). Life-cycle thinking was dominant in the FCA assessment of projects, products and processes (Steen, 1999; Antheaume, 2004; Roth and Ambs, 2004).

The intention of FCA is to measure both internal and external sustainability effects. Therefore, the majority of FCA studies (28 applications) included both types of information, although the study focus and number of indicators varied across them. Internal effects were only measured by two studies, where all of them represented the USEPA's method for FCA. The remaining four FCA experiments (case studies) focused only on valuing external environmental and social effects, for example Antheaume (2004), Bickel and Friedrich (2004) and Epstein et al. (2011).

Dose-response techniques dominate as the major valuation methods used in FCA studies. The damage cost approach has been used in 17 FCA studies including Ontario Hydro (USEPA, 1996), PowerGen (Atkinson, 2000) and the coal industry (Epstein et al., 2011). Cost of control techniques account for nine of the total methods used. They have been implemented in BSO/Origin (Huizing and Dekker, 1992), the forestry industry (Rubenstein, 1994) and Landcare Research (Bebbington and Gray, 2001). Behavioural methods are rarely applied as the primary valuation technique and they usually complement dose-response techniques when the latter fail to provide estimates about the impact. The multiple valuation techniques have been implemented by Steen (1999), Bickel and Friedrich (2004) and PUMA (2010). Traditional market methods constitute five of the primary valuation techniques and are fundamental to the USEPA (1998) study for calculating up-front, operating and back-end costs of municipal solid waste management projects.

5.3. FCA methods identified to date

The outcome of past experimentation with FCA is the development of ten FCA methods with differing levels of consistency in their practical application (see Table 4). Most of these methods are still incomplete, with only a few practical applications. Some approaches are unique and stand-alone, while other methods have been built by a number of related studies over a number of decades. Table 4 indicates that the Sustainability Assessment Model (SAM) and Forum for the Future's (FFF) sustainability accounting are two of the most commonly used FCA approaches. As such, these two methods will be discussed in detail, with the other approaches being discussed at a higher level by identifying their main features.

5.3.1. The SAM

The SAM is the outcome of cooperative work between British Petroleum and the University of Aberdeen. It has been developed to make external costs more central to organisational decision-making (Bebbington et al., 2007). It articulates economic, resource, environmental and social issues in a project's evaluation

Table 2
Methodological approaches applied in FCA studies in chronological order (from the oldest to the most recent studies).

Year of study	Object of the assessment	Sustainability dimensions	System boundaries	Cost focus	Primary valuation methods	Studies
1992	Organisation	En	Narrow	Internal + External	Avoidance cost	(Huizing and Dekker, 1992)
1994	Organisation	Ec + En	Narrow	Internal + External	Abatement/Restoration cost	(Rubenstein, 1994)
1996	Organisation	En + HH	Wide	Internal + External	Damage cost	(USEPA, 1996)
1997	Project	En	Wide	External	Damage cost	(Bickel et al., 1997)
1998	Organisation	Ec	Narrow	Internal	Market methods	(USEPA, 1998)
1999	Project	Ec + En	Wide	Internal + External	Damage cost	(CWRT, 1999)
1999	Product	En + HH	Wide	Internal + External	Multiple	(Steen, 1999)
2000	Organisation	En	Narrow + tier 1 suppliers	Internal + External	Avoidance/Restoration cost	(Howes, 2000)
2000	Organisation	Ec + En	Narrow	Internal + External	Damage cost	(Atkinson, 2000)
2001	Organisation	En	Narrow + tier 1 suppliers	Internal + External	Restoration cost	(Bebbington and Gray, 2001)
2002	Organisation	En	Narrow	Internal + External	Avoidance/Restoration cost	(Howes, 2002)
2002	Organisation	En	Narrow	Internal + External	Avoidance/Restoration cost	(Howes, 2002)
2003	Industry	In	Wide	Internal + External	Damage cost	(Baxter et al., 2003)
2003	Organisation	In	Wide	Internal + External	Damage cost	(Baxter et al., 2003)
2003	Project	In	Wide	Internal + External	Damage cost	(Baxter et al., 2003)
2003	Project	In	Wide	Internal + External	Damage cost	(Bebbington and Frame, 2003)
2003	Material	In	Wide	Internal + External	Damage cost	(Baxter et al., 2003)
2004	Project	Ec + En	Wide	Internal + External	Damage cost	(Roth and Ambs, 2004)
2004	Process	En	Wide	External	Multiple	(Antheaume, 2004)
2004	Project	En + Sc	Wide	External	Multiple	(Bickel and Friedrich, 2004)
2005	Organisation	In	Narrow	Internal + External	Market methods	(Figge and Hahn, 2005)
2005	Project	In	Wide	Internal + External	Damage cost	(Cavanagh, 2005)
2006	Organisation	In	Narrow	Internal + External	Avoidance/Restoration cost	(Bent, 2006)
2006	Organisation/product	In	Narrow/wide	Internal + External	Avoidance/Restoration cost	(Taplin et al., 2006)
2006	Project	In	Wide	Internal + External	Damage cost	(Cavanagh et al., 2006)
2007	Project	In	Wide	Internal + External	Damage cost	(Cavanagh et al., 2007)
2007	Project	In	Wide	Internal + External	Damage cost	(Cavanagh et al., 2007)
2008	Organisation	In	Narrow	Internal + External	Market methods	(Figge et al., 2008)
2008	Project (Scheme)	Ec	Narrow	Internal	Market methods	(Karagiannidis et al., 2008)
2009	Project	In	Wide	Internal + External	Damage cost	(Davies, 2009)
2009	Project	In	Wide	Internal + External	Damage cost	(Xing et al., 2009)
2010	Organisation	En	Wide (excl. downstream)	Internal + External	Multiple	(PUMA, 2010)
2011	Industry	En + HH	Wide	External	Damage cost	(Epstein et al., 2011)
2014	Organisation	Ec + En	Narrow	Internal + External	Market methods	(Debnath and Bose, 2014)

Ec – Economic, En – Environmental, Sc – Social, In – Integrated, HH – Human Health.

in the form of 22 performance indicators (see Table 5). Data for the established performance indicators are collected in physical units (i.e. through LCA, eco-balance and ecological footprint methods) and then translated into monetary values using a variety of monetisation approaches under the broad heading of the damage cost approach (Frame and Cavanagh, 2009). A particular contribution and strength of the SAM is that it brings together all the elements of sustainable development into a single tool and provides a comprehensive monetisation of the broader environmental and social issues which occur in the project life cycle (Xing et al., 2009). Hereby, the SAM has the ability to indicate the interrelationships between all sustainability dimensions and communicate the trade-

offs and outcomes from a project in an effective and understandable format (Frame and Cavanagh, 2009). However, even though the SAM takes a broader approach compared to the other FCA methods, it is not an absolute measure of the complexities of sustainable development. The intention of the SAM is to enable ease of use as opposed to the performance of complex and accurate analysis (Bebbington, 2007).

The output of the assessment is a graphical presentation (called the SAM signature) of positive and negative impacts and an indicator (the SAMi) that measures the level of sustainability of the project (Baxter et al., 2003). An example of the SAM signature for an oil and gas field development project is presented in Fig. 3. Each colour on the graph identifies a different performance indicator in a given category measured in monetary terms. Bars above the horizontal line represent the positive outcomes from the project, while bars below the horizontal line represent the negative impacts of the project (Bebbington et al., 2007). The economic category measures a value generated by the project from different stakeholder perspectives (e.g. taxes paid to the government and dividends paid to shareholders). The environmental category has been divided into resource and other environmental pollution impacts due to the resource-extracting and resource-intensive nature of the oil and

Table 3
The system boundaries identified in FCA studies.

Assessment level	Narrow boundaries	Wide boundaries
Industry		2
Organisation	13	3
Project	1	12
Product/process/material		4

Table 4
FCA methods identified through the literature review.

Methodological stream	Type of assessment	Cost focus	Scope (boundaries)	Type of information	Related studies
1. SAM	Integrated	Damage cost	Wide	Internal and External	(Baxter et al., 2003); (Bebbington and Frame, 2003); (Baxter et al., 2004); (Bebbington and MacGregor, 2005); (Cavanagh, 2005); (Cavanagh et al., 2006) (Bebbington, 2007); (Bebbington et al., 2007); (Cavanagh et al., 2007); (Xing et al., 2007); (Davies, 2009); (Frame and Cavanagh, 2009); (Xing et al., 2009); (Fraser, 2012)
2. FFF's sustainability accounting	Environmental, Integrated (ALCo and ChemCo only)	Avoidance/Remediation cost, Damage cost (ALCo only)	Narrow	Internal and External	(Gray, 1992); (Huizing and Dekker, 1992); (Rubenstein, 1994); (Howes, 2000); (Bebbington and Gray, 2001); (Howes, 2002); (Bent and Richardson, 2003); (FFF, 2003); (Howes, 2004); (Bent, 2006); (Taplin et al., 2006)
3. USEPA's method	Economic (one environmental study)	Market methods	Narrow and wide	Internal (One external study)	(USEPA, 1997); (USEPA, 1998); (Karagiannidis et al., 2008); (Debnath and Bose, 2014)
4. Monetised LCA approach	Environmental, Human health	Multiple	Wide	Internal and External	(Steen, 1999); (Antheaume, 2004); (Epstein et al., 2011)
5. SV concept	Integrated	Opportunity costs	Narrow	Internal and External	(Atkinson, 2000); (Figge and Hahn, 2005); (Figge et al., 2008)
6. PUMA E P&LA	Environmental	Multiple	Wide (excluding downstream)	Internal and External	(PUMA, 2010); (PPR, 2012);
7. CWRT	Economic, Environmental	Damage cost	Wide	Internal and External	(CWRT, 1999)
8. Ontario Hydro	Environmental, Human health	Damage cost	Wide	Internal and External	(USEPA, 1996); (CICA, 1997);
9. Extended LCC	Economic, Environmental	Damage cost	Wide	Internal and External	(Roth and Amb, 2004)
10. ExternE	Environmental, Social	Multiple	Wide	External	(Bickel et al., 1997); (Krewitt, 2002); (Bickel and Friedrich, 2004)

Table 5
Impact categories used in the SAM (source: Baxter et al., 2003).

Economic impact	Resource impact	Environmental impact	Social impact
Money to contractors	Oil and gas	Emission to atmosphere and sea	Employment
Social investment	Water	Nuisance value (odour, noise)	Health and safety
Reinvestment	Energy	Footprint	Social impact of product
Dividends	Raw materials	Waste	Tackling poverty and social exclusion
Taxes	Intellectual property		Equip people with skills to fulfil their potential
	Physical infrastructure		Reduce the potential of unit housing stock
			Reduce crime and fear of crime

gas industry (Xing et al., 2009). The social category measures both the negative and positive social outcomes from the project (e.g. negative health and safety impacts and social benefits of jobs) (Bebbington, 2007).

The SAM was originally developed for the oil and gas industry but has since been applied in many different settings in the UK.

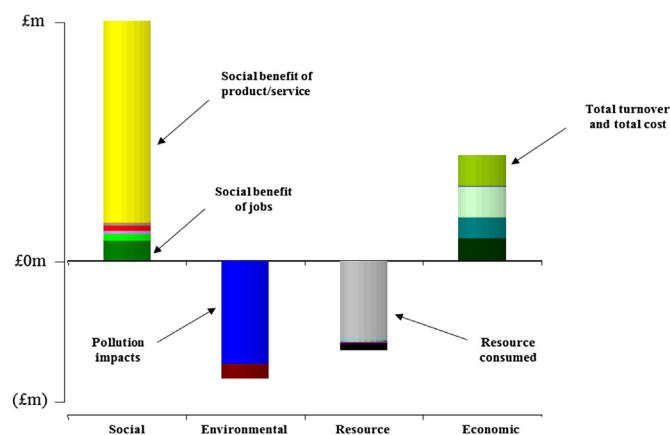


Fig. 3. The SAM signature developed for the oil and gas organisation (source: Bebbington et al., 2007).

These include offshore hydrocarbon development, landfill gas and tree-planting projects (Baxter et al., 2003), most recently in the urban development industry (Xing et al., 2009) and higher education sector (Davies, 2009). Furthermore, these ideas have been taken forward in other parts of the world. For example, most of the New Zealand FCA studies are focused on developing and experimenting with an Australasian version of the SAM, which has also resulted in collaborative studies (e.g. Bebbington and Frame, 2003; Bebbington et al., 2007). New Zealand's applications of the SAM include organic recycling, waste management, urban transport and housing developments (Cavanagh et al., 2007).

The SAM has been developed mainly for the purpose of project evaluation and internal decision-making (Bebbington, 2007), although it has been proven to be an ideologically open and flexible concept. SAMs have subsequently been applied in other settings and configurations including the assessment of the whole industry and at the organisational, project and material level (Baxter et al., 2003). Furthermore, there are no restrictions on taking this concept forward and extending the boundaries of the assessment at the policy, product, process or strategy level.

5.3.2. FFF's sustainability accounting

The origin of the FFF's method can be traced back to 1992 and its links with the early work of BSO/Origin (Huizing and Dekker, 1992), Rubenstein (1994) and the development of the sustainability cost calculation (SCC) concept (Gray, 1992; Bebbington and Gray, 2001).

The idea behind the SCC is to estimate the additional cost to an organisation of avoiding a deterioration in the condition of the planet as a result of its activities (Gray, 1992). In contrast to the SAM, the valuation method used in the SCC is avoidance cost. The FFF's method is broadly based on Gray's SCC but Forum took this concept forward by focussing on sustainability dimensions other than environmental, using restoration cost as the valuation method in addition to avoidance cost and expanding the traditional profit and loss accounts and balance sheets by recognising sustainability liabilities (Bebbington et al., 2001). These liabilities are measured and reported during the accounting period (usually one year). In traditional accounting, the profit and loss accounts, balance sheet and cash flow statements are used as communication tools between a company and external stakeholders (Atrill and McLaney, 2006). Hence, the FFF's method is classified as a financial accounting tool rather than a management accounting tool as in the case of the SAM.

In order to standardise the method, FFF created the Sigma guidelines for its implementation (see Bent and Richardson, 2003; FFF, 2003). The Sigma guidelines disaggregate the components of the triple bottom line of sustainability into five major capitals: manufacturing, financial, human, social and natural. Information about these capitals is provided in three different dimensions (Bent and Richardson, 2003):

- **Timing:** is it the flow of goods (services) or a snapshot in time of the stock?
- **Location of impact:** is the impact within or beyond the company's boundaries?
- **Type of impact:** is the impact economic, environmental or social?

Sustainability impacts are converted into monetary values through avoidance/restoration valuation methods and reported either in the extended profit and loss account or in the extended balance sheet (Bent and Richardson, 2003). Practical application of the Sigma guidelines can be found mainly at the organisational level, such as in Interface Europe (Howes, 2000), Anglian Water, Wessex Water (Howes, 2002) and AlCo (Bent, 2006). A single attempt at extending this system to the product level is recorded at ChemCo (Taplin et al., 2006).

In contrast to the SAM, FFF's method follows the PPP principle, therefore they are advocates of narrow boundaries (Howes, 2000, 2002). Although the Forum's FCA is the second major method in this field, it is still incomplete for use in a wider application, which has been recognised by the Forum itself. For example, none of the FFF's studies tackled wider economic impacts, and social effects were only included in the most recent applications (Davies, 2009). It has also shown less flexibility and adaptability to different configurations and settings when compared to the SAM.

5.3.3. The USEPA's method

USEPA defined FCA as 'a systematic approach for identifying, summing and reporting the actual cost of solid waste management' (USEPA, 1997). Its method is based on traditional market techniques to account up-front, operating and back-end costs of municipal solid waste management projects. This definition of FCA neglects the major principle behind this concept of allocating both direct and indirect costs. Instead, USEPA focuses only on costs that are relatively easy to value in the marketplace (primarily economic). Other important costs, such as property damage, injuries, costs of remediation, social costs, environmental externalities and up-stream and downstream LCA costs are not included. The USEPA handbook identifies and defines these costs but does not explain how to value them or incorporate them into the decision-making process (USEPA, 1997).

This concept has been narrowly designed for a municipal waste management project and examples of its further application can be found in the USA (USEPA, 1998), Greece (Karagiannidis et al., 2008) and India (Debnath and Bose, 2014). A municipal solid waste project in India is the only recorded attempt of extending the USEPA's method to environmental impacts.

5.3.4. Monetised LCA

The monetised LCA approach classifies all methods (not necessarily related to each other) that use LCA as the primary tool to identify externalities and a mixture of techniques to value these external impacts. This approach has been adopted *inter alia* by Antheaume (2004) in an FCA experiment applied to an industrial process, Epstein et al. (2011) in an assessment of the external effects of the coal industry and Volvo in its Environmental Priority Strategies (EPS) in product development (Steen, 1999).

The EPS system is based on the ISO 14040 series as a decision-making tool for the internal product development process, although it can also be used for external purposes in Environmental Product Declaration (EPD) (Steen, 1999). Certified EPD is a tool for communicating LCA-based information with external stakeholders (Steen et al., 2008a). The EPS system is used in EPD as a method for quantifying environmental impacts (Bogeskär et al., 2002); however, its primary intention is to support product design engineers by selecting components and subassemblies that minimise environmental impact (Graedel and Allenby, 1998). EPS assesses and aggregates the environmental impacts into a single unit called environmental load unit (ELU) per kilogramme of material used. ELU has been developed by Volvo as a rating method that compares the environmental impacts of any material to impacts resulting from 1 kg of methane (Mayyas et al., 2012). FCA methods (such as willingness-to-pay) have been integrated within this tool to facilitate the analysis and decisions by weighting competitive factors against each other (Steen, 1999). However, the results of the EPS analysis are still reported in ELU so that the EPS users would not attempt to apply a discount rate to numbers and to emphasise that there is something more behind the numbers than just 'dollars' (Resetar et al., 1998).

The main limitation of this approach is that it primarily values the environmental dimension of sustainability while social and economic elements are ignored, with the exception of human health impacts. In order to provide a comprehensive picture of sustainability effects, it would have to be supplemented by other tools that have the ability to integrate environmental, social and economic effects into a single framework.

5.3.5. Sustainable value (SV) concept

Figge and Hahn (2004) developed a valuation methodology which allows an estimation of the cost of sustainability capital and the sustainable value created by a company. The concept has been applied mainly in the oil and gas and automotive industries (see Figge and Hahn, 2005; Figge et al., 2008). The capital and value added approach is not a new concept and it was previously adapted by Atkinson (2000) in a corporate genuine saving (CGS) rate. The idea behind CGS is that a company should adjust its net profit (value added) to the environmental damage caused by its activities and eventually receive a green value added indicator. The innovation in the SV concept is that it integrates other forms of capital (social and financial) with the use of natural capital and applies traditional market valuation techniques (opportunity cost) to evaluate the use of all forms of capital (Figge and Hahn, 2005). Opportunity cost has been mainly applied in the valuation and allocation of economic capital. The authors of SV took this concept forward and employed it to estimate the value of environmental and social capital.

The main limitation of the SV concept is that it includes only nine indicators to assess sustainability of an organisation (one economic, six environmental and two social), which can be partly explained by the algorithm used for calculating the value added of each capital. One of the principles behind estimating SV is to calculate the efficiency of resources used by the company and its benchmark. The benchmark is usually represented by the weighted average of the whole industry in which the company operates. Hence, the SV calculations rely heavily on figures reported by other organisations. Therefore, the SV assessment is only as comprehensive as the data published by competitors in the industry.

5.3.6. PUMA environmental profit and loss account (E P&LA)

PUMA, with the assistance of Trucost and PricewaterhouseCooper, has developed the first-ever E P&LA by calculating the economic value of environmental impacts from PUMA's operations and supply chain. They used an economic Input–Output (I–O) model to calculate upstream impacts (see [Hendrickson et al., 1998](#); [Joshi, 1999](#); [Wiedmann and Lenzen, 2009](#) for details). The E P&LA includes the most significant company impacts: water usage, greenhouse gas emissions, other air pollution and waste production. The company's method used for the E P&LA met with a positive response from the general public. It also received positive feedback from the panel of experts who assessed the validity of this approach. They all agreed that this is the only currently available and acceptable method to measure upstream and downstream impacts of an organisation ([PPR, 2012](#)).

Although PUMA's approach is the first of its kind because it attempts to estimate the ecological footprint of the whole company's supply chain, experts have agreed that PUMA's method requires standardisation or a more accessible methodology should be developed to be used by other organisations ([PPR, 2012](#)). Furthermore, PUMA managed to collect only 16% of the primary data which questions the reliability of their assessment. Creating an E P&L account for more complicated industries (such as automotive or aerospace) has many hurdles, the most important being the size and complexity of the supply chain.

5.3.7. Other FCA methods

Ontario Hydro was a pioneer in applying damage cost and integrating social-related externalities (mainly human health effects) in FCA and hence, it could be an inspiration for other FCA practitioners. Certain similarities occur (besides adopting the damage cost function) in their approach to the SAM. Both use the full life cycle approach although Ontario included only impacts which are under control of the organisation. Furthermore, they both use, integrate or at least refer to the Multi-Criteria Analysis (MCA) methods in their approach (see [USEPA, 1996](#) and [Frame and Cavanagh, 2009](#)). However, a lack of further publications and willingness to talk about the experiment by Ontario Hydro makes it impossible to determine how this method has been further developed ([Bebbington et al., 2001](#)).

The Center for Waste Reduction Technology (CWRT) belongs to the American Institute of Chemical Engineers and they use the term 'Total Cost Assessment' (TCA) to define FCA. The intention of TCA was to provide the process of quantifying all environmental and health costs, both internal and external, associated with business decisions ([CWRT, 1999](#)). [Bebbington et al. \(2001\)](#) argued that TCA does not introduce anything new to the FCA literature apart from providing a wide range of external costs for any future FCA experiments.

The External Costs of Energy (ExternE) project is a major research programme launched by the EC at the beginning of the 1990s to provide a scientific background for quantifying energy-related externalities (including from transport) and guidelines on

how they can be internalised ([Bickel et al., 1997](#); [Bickel and Friedrich, 2004](#)). Over two decades of development turned the ExternE label into a well-recognised standard source of external cost data ([Krewitt, 2002](#)). The method uses an Impact Pathway Analysis (IPA) to calculate damage costs, which follows four major steps: pollutants from a specific site are measured; their atmospheric dispersion and increased concentrations in all affected regions are calculated; the physical damage (impact) from increased concentration is estimated; and the physical damage is converted into monetary units through multiple valuation methods ([Friedrich and Bickel, 2001](#)). The ExternE project represents a pragmatic and scientific-based approach but its applications are mainly focused on energy-related external environmental and social issues. Hence, companies from the energy sector can only use their approach and standards to value externalities. For other businesses it can be used as a source of damage cost figures for a number of environmental pollutants and human health impacts.

The final FCA method is an extension of the traditional Life Cycle Costing (LCC) tool developed to determine the cost of energy of 14 electricity generation technologies ([Roth and Ambs, 2004](#)). LCC identifies and quantifies all significant costs (acquiring, owning, operating and disposal) of physical assets throughout their useful lives ([Woodward, 1997](#)). [Roth and Ambs \(2004\)](#) took this concept forward by adding costs that are usually omitted in LCC evaluations, such as damage from air pollution, energy security and other environmental externalities. The need for incorporating externalities into LCC was also recognised by the Society of Environmental Toxicology and Chemistry (see [Steen et al., 2008b](#)) but the majority of examples provided in the book still represent the conventional LCC.

This section has presented all of the FCA methods identified through the literature review process. The next section discusses which of these methods is appropriate for the automotive setting.

6. Discussion

This section first critically analyses the existing applications of FCA in the automotive industry. It then proposes the SAM as a well-developed and potentially practical FCA method to be applied in the automotive industry. Finally, the key methodological considerations for applying the SAM in the automotive setting are discussed.

6.1. The automotive FCAs – need for a more comprehensive system

The literature review recognised two attempts to apply FCA in the automotive environment: Volvo's EPS system and the SV concept, although only Volvo truly applied FCA in the automotive organisation. The intention of the EPS system was to create a language understandable by everyone within the organisation to support sustainable decisions in the product development environment ([Steen, 1999](#)). The purpose of the SV concept was to compare the efficiency of various car manufacturers in using economic, environmental and social capital compared with their industrial peers based on widely available data from sustainability reports ([Figge et al., 2008](#)). It does not demonstrate how the SV concept can support automotive organisations in making complex, sustainable decisions. A completely opposite approach to FCA has been demonstrated by Ford in the development of Ford of Europe's Product Sustainability Index (PSI) ([Mayyas et al., 2012](#)). PSI is a simple sustainability management tool (also based on the ISO 14040 series) that aims to support engineers in making sustainable decisions when developing a car ([Schmidt, 2007](#)). PSI focuses on the major economic, environmental and social attributes of a vehicle which are under the control of the product development

department such as life cycle global warming, life cycle air quality potential, sustainable materials, restricted substances, drive by noise, safety, mobility capability and life cycle ownership costs (Schmidt, 2006). The results of PSI are not reduced to a single unit because, as the authors of PSI suggest, sustainability is not one-dimensional by definition and therefore should always be measured using different indicators (Schmidt and Taylor, 2006).

Both Volvo and Ford's systems demonstrate two alternative approaches for measuring sustainability in the automotive business but neither of them are without flaws. Volvo's EPS only covers the environmental burdens of the vehicle's life cycle and it uses the non-standardised ELU, which still lacks international approval to measure and aggregate environmental impacts (Mayyas et al., 2012). Although Ford's PSI attempts to reflect the triple bottom line vision of sustainability, it still suffers from a lack of complete coverage of sustainability metrics. Only eight sustainability metrics (five environmental, two social and one economic) have been incorporated into the PSI (Schmidt and Taylor, 2006). The authors of the PSI explain that it focuses only on key, controllable issues that are influenced by the design department (Schmidt, 2006). The idea is that the meaning of sustainability is then translated to other business functions (in particular manufacturing, human resources and external affairs) so that each department can concentrate on its own sustainability issues. This approach needs to be coordinated to avoid overlapping and double counting (Schmidt and Taylor, 2006). Ford suggested that the PSI fits perfectly within its own design process and culture but it is not necessary for it to fit other organisations (Schmidt, 2006).

The limitations of EPS and PSI indicate that a more comprehensive and complete system is needed for the automotive application to support sustainable decisions. This system can take a number of different forms but building it on the FCA concept has the major advantage of providing a complete picture about the sustainability performance of a car by measuring internal and external impacts and supplying organisations with both physical and monetary data depending on the organisation's needs and culture. Such a system can be aligned with some principles of Volvo's and Ford's approaches (e.g. taking the full life cycle perspective) and supplemented with FCA methods. The evidence shows that the SAM potentially represents a well-developed FCA approach available in the literature that can support the construction of such a system.

The SAM, in contrast to other FCA methods, provides a comprehensive picture of sustainability performance by covering and monetising a wide range of economic, environmental and social assessment criteria. The original SAM uses up to 22 impact categories in total, which is the optimal number to retain a manageable model and still provide a clear picture of the sustainability performance of a car. Other FCA methods cover only one or a mixture of two sustainability dimensions. Even if an integrated approach is adopted (for example, FFF and the SV concept), one or two metrics usually represent social and economic dimensions. Furthermore, the SAM is the only FCA method that represents the MCA approach rather than a pure accounting tool (Frame and Cavanagh, 2009). MCA technologies are characterised by their high flexibility and adaptability to a number of decisions which the SAM has certainly demonstrated in the last couple of years. Automobile manufacturers need flexible tools to support decisions at different levels and in different configurations, which include: product mix, manufacturing process design, assessment of transport modes, product disposal (recycling) strategies, comparing performance across facilities and assessing pollution prevention projects and technologies (Mayyas et al., 2012). The SAM can support all corporate functions by adapting assessment criteria to the characteristics and needs of a specific business unit.

Both EPS and PSI showed that life cycle thinking is deeply ingrained in the automotive industry. The SAM (opposite to the FFF's method) takes the full life cycle approach which creates a basis for assessing the sustainability of an automobile. An assessment of an activity which is blind to upstream and downstream effects cannot fully address sustainability issues (Bebbington, 2007). In industries such as automotive or oil and gas, the downstream sustainability effects are the outcome of decisions made before that point in time in the product chain. Furthermore, the life cycle approach eliminates the risk of shifting the environmental and social burdens from one part of the system to another in the supply chain. For example, replacing conventional cars with electric ones would eliminate air pollution from the customer use phase at the expense of increased pollution from power plants and battery manufacturing facilities (Friedrich and Bickel, 2001). Integrating the SAM with LCA technologies gives a scientific background to the assessment of a car by following the widely accepted ISO 14040 standards.

6.2. Applying the SAM in the automotive industry – methodological considerations

The original SAM was developed for the oil and gas industry; adapting this method to the conditions of the automotive industry will require focussing on the core sustainability issues facing automotive companies. Nowadays, a typical car has to be 95% recoverable and 85% recyclable based on the target set by the EU; therefore, significant resource impacts to be considered are the recyclable and non-recyclable materials used to make a car, vehicle life cycle energy consumed (Mayyas et al., 2012) and life cycle water consumption, mainly from production areas of die casting, mechanical processing and paint finishing (Enderle et al., 2012). Nearly 80% of the car's total impacts result from fuel combustion (Orsato and Wells, 2007), hence all the major forms of pollution (such as greenhouse gases, volatile organic compounds, chloro-fluorocarbons sulphur dioxides, nitrogen oxides and other toxic substances and heavy metals) associated with the life cycle energy and fuel consumption of a car should be distinguished (Graedel and Allenby, 1998; Mildenerger and Khare, 2000). Resource and environmental impacts of an automobile are mostly negative; however, the economic and social categories may also include positive flows. For example, Ford's PSI measures the economic performance of a car only from the cost perspective (Mayyas et al., 2012) while positive figures such as gross profit, revenues from selling parts, maintenance and financial service, are missing. All major positive and negative social effects of an automobile have been already captured by the PSI system, such as safety, mobility capability, exterior noise and vehicle interior air quality (Schmidt, 2006). The literature distinguishes other important social flows that should be considered, including car vibrations (Makhsous et al., 2005), human health impacts from the external air quality (Bickel et al., 1997) and product-based employment through the life cycle (Schmidt, 2007). The discussed assessment criteria are only proposals and they cannot be considered as comprehensive and exhaustive. They rather emphasise the importance of extending the existing systems (such as PSI and EPS) to other sustainability measures.

Regardless of whether the SAM is applied in the automotive or any other industry, the methodological limitations of FCA (such as monetisation, cost allocation, reliability and validity issues) should be considered. Solving the issues of measuring sustainability in a linear form is not straightforward and requires an individual approach. Volvo argues that there is nothing wrong in supplying sustainability information in monetary values for those who want to see it. The designers at Volvo claim that they make several

thousand decisions every year and that thousands of people are involved. Hence, it became critical to implement everyday language and thinking that could be understood in different business areas (Steen, 1999). Existing monetary techniques for valuing externalities may not be perfect and provide only rough numbers; however, as Rubenstein (1992) concluded, it is still better to be approximately right than precisely wrong. Any errors and uncertainties associated with environmental and social estimates in the context of specific decisions can be managed by applying statistical and mathematical models (i.e. sensitivity analysis) (Steen, 1999; Guinée et al., 2002; Bickel and Friedrich, 2004). Furthermore, the SAM does not insist on placing a monetary value on impacts for which monetisation is inappropriate and for matters of systems complexity and scientific uncertainty (Bebbington et al., 2007). A lack of widely accepted standards poses an issue for comparing and auditing the results of FCA exercises. However, as long as the company is transparent with its approach, assumptions and limitations and reports disaggregated data with both monetary and physical units, the results of valuing externalities can be verified (Bickel and Friedrich, 2004).

The allocation of sustainability impacts (costs) is an issue relating not only to the SAM, but is a common problem in many sustainability-measuring systems. For example, LCA borrows cost allocation methods from managerial accounting as the allocation procedure in a multiproduct system (Luo et al., 2009). Although LCA may resolve the issue of allocating a specific impact to the particular product, it does not reveal where in the entire process chain this impact occurred (Steen, 1999). LCA emphasises a precise accounting of all material flows (upstream and downstream) and since these flows occur at many geographically different points under a variety of different conditions, it is not possible to track the local details of all emissions (Friedrich and Bickel, 2001).

In LCA, all emissions throughout the entire process chain are aggregated into the specific impact categories and multiplied by site-independent impact indices (Guinée et al., 2002). In order to allocate a particular cost (impact) to a specific site or company, a detailed analysis is required (e.g. Impact Pathway Analysis) which can trace the passage of a pollutant from where it was emitted to the affected receptor (Bickel and Friedrich, 2004). In principle all life cycle costs and damages should be evaluated by a site-specific IPA but in practice this is time-consuming, expensive (the work requires input from a wide range of professions such as epidemiologists, ecologists, economists, dispersion modellers and engineers) and too complex for automotive organisations as they need to track a large number of downstream and upstream processes and flows (Friedrich and Bickel, 2001). Furthermore, the emissions from cars vary over time as well as by location, while the IPA methodology is time- and location-dependent; therefore, the recommendation of ExternE methodology is to use LCA in combination with IPA to get a complete assessment of external costs (Bickel and Friedrich, 2004). The SAM already utilises LCA as a means to generate input data, which can then be converted into monetary values. The advantage of this approach is that most automotive organisations report their sustainability performance in LCA format, thus they already have well-developed LCA capabilities.

This article proposes the SAM as a useful tool that automotive organisations should consider in their sustainability assessment toolbox to support more informed choices. The authors of the SAM explain that they developed a decision-supporting and not a decision-making tool. It is important to understand that the SAM does not provide the ultimate answer for decision-makers but rather facilitates the judgement and reasoning process (Bebbington, 2007). It is an effective tool to indicate the source and magnitude of issues within an organisation and provide the means

to sharpen analysis and discussion around these issues (Bebbington et al., 2007). It is intended to be relatively easy to understand for everyone within an organisation, to be run at minimum cost and be able to generate a quick view of sustainability performance in the early phases of the product (project) development (Bebbington, 2007), which is essential in a normal automotive product-developing environment (Steen, 1999).

7. Conclusions

This paper provides helpful clues for researchers interested in exploring full cost accounting by reviewing, analysing and synthesising the broad range of relevant sources from diverse fields in this topic area. A comprehensive literature review of 4381 papers related to FCA methods was undertaken. It used a systematic approach to extract ten important FCA methods and these were: the SAM, FFF's sustainability accounting, monetised LCA, SV concept, E P&LA, extended LCC, CWRT, Ontario Hydro, ExternE and USEPA's method. Based on a careful examination and critical analysis of each approach and existing automotive sustainability measures, the SAM developed by British Petroleum and Aberdeen University has been proposed as a well-developed and potentially practical tool for application in an automotive setting. The SAM can be used by both academics and practitioners to translate a range of conflicting sustainability information into a monetary unit score. This is an effective way of communicating trade-offs and outcomes for complex and multi-disciplinary sustainability decisions in the automotive sector. Its measurement of a broad range of economic, environmental, resource and social effects (both internal and external) is currently lacking within the automotive industry. Its other strengths are the ability to provide monetary metrics together with physical metrics for sustainability assessment, its flexibility and the ability to combine multiple sustainability dimensions.

The original SAM was developed for the oil and gas industry; therefore, applying this method in the automotive context will require the development of a new set of assessment criteria. Both Volvo's EPS and Ford's PSI methods do not offer complete coverage of the sustainability metrics. Consequently, future research should focus on developing a framework for the automotive SAM that will contain a comprehensive and complete coverage of impact categories for the sustainability assessment of an automobile. Assessment criteria mentioned in this paper (such as recyclable and non-recyclable materials, vehicle life cycle energy and water consumed, all the forms of air, water and soil pollution, gross profit, safety, mobility, noise, vibration, vehicle interior air quality, human health impacts from the external air quality and employment) are only proposals and cannot be considered as complete and exhaustive. The people who developed the original SAM suggest that sustainability metrics should be developed with the assistance of experts. Hence, specialists (both academics and practitioners) in the automotive industry should be consulted to refine and select sustainability assessment criteria which can be used as a framework for the construction of the automotive SAM.

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Appendix A. FCA studies identified in total.

Author (year)	Type of document	Published by
Books and book chapters:		
Antheume (2007)	Book chapter	Routledge
Baxter et al. (2004)	Book chapter	Earthscan
Bebbington (2007)	Book	The Chartered Institute of Management Accountants
Bent (2006)	Book chapter	Springer
Howes (2000)	Book chapter	Edward Elgar Publishing Limited
Howes (2002)	Book	The Chartered Institute of Management Accountants
Howes (2004)	Book chapter	Earthscan
Rubenstein (1994)	Book	Quorum Books
Journal articles:		
Antheume (2004)	Journal paper	European Accounting Review
Atkinson (2000)	Journal paper	Journal of Environmental Planning and Management
Baxter et al. (2003)	Journal paper	Offshore Europe
Bebbington et al. (2007)	Journal paper	Ecological Economics
Bebbington and Frame (2003)	Journal paper	Chartered Accounting Journal of New Zealand
Bebbington and Gray (2001)	Journal paper	Critical Perspectives on Accounting
Cavanagh et al. (2006)	Journal paper	Australasian Journal of Environmental Accounting
Debnath and Bose (2014)	Journal paper	Resources, Conservation and Recycling
Epstein et al. (2011)	Journal paper	Ecological Economics Reviews
Figge and Hahn (2005)	Journal paper	Journal of Industrial Ecology
Frame and Cavanagh (2009)	Journal paper	Accounting Forum
Fraser (2012)	Journal paper	Accounting, Auditing & Accountability Journal
Gray (1992)	Journal paper	Accounting Organisations and Society
Huizing and Dekker (1992)	Journal paper	Accounting Organisations and Society
Karagiannidis et al. (2008)	Journal paper	Waste Management
Krewitt (2002)	Journal paper	Energy Policy
Roth and Ams (2004)	Journal paper	Energy
Taplin et al. (2006)	Journal paper	Business Strategy and the Environment
Xing et al. (2007)	Journal paper	Accounting Forum
Grey literature:		
Bebbington et al. (2001)	Research report	Certified Accountants Educational Trust
Bebbington and MacGregor (2005)	Research report	RICS Foundation
Bent and Richardson (2003)	Technical report	Forum for the Future
Bickel and Friedrich (2004)	Technical report	The European Commission
Bickel et al. (1997)	Technical report	The European Commission
Cavanagh (2005)	Technical report	Environment Waikato - Regional Council
Cavanagh et al. (2007)	Conference paper	International Conference on Whole Life Urban Sustainability and its Assessment
CICA (1997)	Research report	The Chartered Institute of Canadian Accounting
CWRT (1999)	Technical report	American Institute of Chemical Engineers
Davies (2009)	Conference paper	1st International Conference on Sustainable Management of Public and Not For Profit Organisations
FFF (2003)	Technical report	Forum for the Future
Figge et al. (2008)	Research report	Sustainable Value Research Ltd
PPR (2012)	Company report	Kering
PUMA (2010)	Company report	PUMA
Steen (1999)	Technical report	Chalmers University of Technology
USEPA (1996)	Technical report	USEPA
USEPA (1997)	Technical report	USEPA
USEPA (1998)	Technical report	USEPA
Xing et al. (2007)	Conference paper	International Conference on Whole Life Urban Sustainability and its Assessment

Appendix B. Empirical and conceptual applications of FCA applied in different settings.

Industry/application	Assessment level	Study
Information technology	Organisation	(Huizing and Dekker, 1992)
Forestry	Organisation	(Rubenstein, 1994)
	Project	(Baxter et al., 2003); (Bebbington, 2007); (Bebbington et al., 2007)
Energy	Organisation	(USEPA, 1996); (CICA, 1997)
	Organisation	(Atkinson, 2000)
	Project	(Baxter et al., 2003); (Bebbington, 2007); (Bebbington et al., 2007)
	Project	(Krewitt, 2002); (Bickel and Friedrich, 2004)
	Project	(Roth and Ams, 2004)
Carpet manufacturing	Organisation	(Howes, 2000)

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(continued)

Industry/application	Assessment level	Study
Research	Organisation	(Bebbington and Gray, 2001)
Oil and gas	Industry	(Baxter et al., 2003)
	Organisation	(Baxter et al., 2003); (Bebbington and Frame, 2003); (Bebbington and MacGregor, 2005); (Bebbington, 2007); (Bebbington et al., 2007)
Hydrocarbon development	Organisation	(Figge and Hahn, 2005)
	Process	(Antheaume, 2004)
Water service	Material	(Baxter et al., 2003)
	Organisation	(Howes, 2002); (Howes, 2004)
Waste management	Organisation	(Howes, 2002); (Howes, 2004)
	Organisation	(USEPA, 1998)
Alcohol	Organisation	(Debnath and Bose, 2014)
	Project	(CWRT, 1999)
	Project	(Karagiannidis et al., 2008)
	Project	(Cavanagh et al., 2006)
	Project	(Cavanagh, 2005); (Frame and Cavanagh, 2009)
Chemical	Organisation	(Bent, 2006)
	Organisation/product	(Taplin et al., 2006)
Transport	Project	(Bickel et al., 1997)
	Project	(Cavanagh et al., 2007)
Housing development	Project	(Cavanagh et al., 2007); (Frame and Cavanagh, 2009)
Higher education	Project	(Davies, 2009)
Urban development	Industry	(Xing et al., 2007); (Xing et al., 2009)
Coal	Industry	(Epstein et al., 2011)
Sportswear	Organisation	(PUMA, 2010); (PPR, 2012)
Automotive	Organisation	(Figge et al., 2008)
	Product	(Steen, 1999)

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