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Sustainable development model for measuring and managing sustainability in the automotive sector

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Abstract

A growing number of organizations across a variety of industries are now pursuing sustainable management business goals to improve business efficiency, manage stakeholder expectations, or for legislative compliance. This is also the case for automotive manufacturing organizations who are under pressure from their stakeholders to manage and improve sustainability performance. This requires the development of credible measurement tools and systems to enable capture and monitoring of sustainability. This paper describes the development process for an innovative model, named the Automotive Sustainability Assessment Model (A-SAM), to drive sustainable decision-making in the automotive sector. The process of developing the model consisted of four major steps, each of which contained series of intermediate steps, individual objectives, and research methods. The model measures, quantifies, and translates a broad range of external effects (both positive and negative) into their monetary equivalents, enabling large car manufacturers to evaluate options, identify win–wins, and optimize trade-off, while making complex and multidisciplinary sustainability decisions. It allows managers and design engineers in the automotive sector to develop a better understanding of the environmental, resource, and social impacts of their activities, products, processes, and materials used, while still ensuring cost-effectiveness when making decisions. The A-SAM shows promise as an effective tool for supporting sustainability decisions in a business environment. Although developed in the context of the automotive industry, it can be adapted by organizations of any type, operating across many different sectors for managing sustainability in a more holistic, comprehensive, and integrated manner.

KEYWORDS
automotive industry, business sustainability, sustainability assessment, sustainable development

1 | INTRODUCTION

Sustainability has become one of the greatest challenges for manufacturing organizations in the 21 century. Nowadays, stakeholders are more anxious about social and environmental issues and expect organizations to include sustainable values in their operations. Governments encourage businesses to support social and environmental initiatives through new legislation (e.g., regulation and taxes). Financial institutions incorporate sustainability criteria in their risk assessment and investment decisions procedures. Businesses also

have a responsibility toward shareholders who expect financial returns. Thus, companies feel pressure from many stakeholders to find and implement solutions to balance long-term profitability and productivity against environmental and social impacts.

Due to the high ecological and social footprint, such as noise, congestion, accidents, air and water pollution, climate change, and resource depletion (see Allenby & Graedel, 1998; Mayyas, Qattawi, Omar, & Shan, 2012), the automotive sector is especially exposed to pressure from policymakers and other stakeholders to manage and improve the sustainability performance (Jasiński, Meredith, & Kirwan, 2016). For example, the End-of-Life Vehicles Directive (2000/53/EC, n.d.) requires automotive companies to think more broadly about future costs (for instance, recycling, disassembly, disposal costs) from current production. Progressively tighter emission limits, such as Euro 5 and 6 (2019/631/EU, n.d.), place liability on car manufacturers for negative effects from the use of vehicles and thus pushes the whole industry toward electrification (Iken, Morel, & Aggeri, 2019). A number of national regulations oblige automotive organizations to reduce their environmental and social costs at their manufacturing sites (e.g., the UK's Carbon Reduction Commitment Energy Efficiency Scheme, Climate Change Levy tax and landfill tax). All these legal requirements put the responsibility on car manufacturers to improve the social and environmental impacts of their products at every stage of their life cycle.

Managing sustainability is not easy, especially when sustainability actions often involve capital-intensive investments or voluntary activities. This can be discouraging and can give the impression that it is costing resources but not providing any value to businesses. However, leading companies have found ways to incorporate sustainability at the heart of their businesses and still be profitable by introducing innovative strategies and business models. For example, in 2010, PUMA – a global sportswear provider – calculated that the environmental impact from its own operations (excluding all downstream and upstream impacts) can cost the company €8 million annually in the future (PUMA, 2010). The company has since put a lot of effort to turn this cost into an opportunity by constantly working on improving its environmental impact (e.g., reduction of carbon emissions, water usage, waste and air pollution in own offices and across supply chain) (PUMA, 2017). The Swedish furniture giant IKEA has recently announced that it plans to invest €200 million to speed up action to become climate positive by 2030. IKEA commits to make all its products by using only renewable (like wood and cotton) or recycled materials across its entire range by 2030 (IKEA, 2018). Unilever PLC announced a new series of sustainability measures and commitments, including reaching net zero emissions from all its products by 2039. The company's brands will collectively invest €1 billion in a new dedicated Climate and Nature fund, which will be used over the next decade for projects including landscape restoration, reforestation, carbon sequestration, wildlife protection, and water preservation (Unilever, 2020).

The above examples represent just a few potential sustainability strategies adapted by organizations. If captured and managed properly, they could push a company toward new business models where environmental and social values will be aligned with financial ones (Chang & Kuo, 2008; Lozano, 2018). This approach is known as a triple bottom line (TBL), and it assumes that sustainability can be achieved only through full integration and balance between financial, environmental, and social bottom lines (Elkington, 1997). This, however, represents a key challenge for organizations where decisions are often made based on economic rationale rather than other influences that may impact on total value. The sustainability-related business model innovation requires the measurement and assessment of economic, environmental, and societal impact and values (Boons & Lüdeke-Freund, 2013; Evans et al., 2017; Geissdoerfer, Vladimirova, & Evans, 2018). When the TBL approach is applied, there may be alternative strategies, products, or services which present an overall higher value or longer-term sustainability.

This article describes the journey of development of an innovative model for assessing and managing sustainability in the automotive sector. The work presented in this article is the outcome of the Engineering Doctorate (EngD) research project sponsored by WMG – the department of the University of Warwick – and a British car manufacturer Jaguar Land Rover (JLR). Although the model itself was developed in the context of the automotive industry, the methodological approach presented in this paper can be adapted by organizations of any type and operating across many different sectors to develop own methods and tools for managing sustainability in a more holistic, comprehensive, and integrated manner.

The article begins with a background section that explains the key enablers for business sustainability and underlines the importance of performance measurement and assessment as an indispensable element of any change and management process. The next section describes the methodological process used to develop the model for measuring and managing sustainability in the automotive sector. The results are synthesized and discussed in the following section.

2 | BACKGROUND LITERATURE

The TBL mechanism imposes on organizations the responsibility to focus not just on the economic value they add but also on the environmental and social value they either add or destroy (Khalili, 2011). The major problem with this concept is that organizations do not operate in a vacuum. They form part of a larger socio-economic system in which they interact with different stakeholders (e.g., suppliers, competitors, governments, society, customers, local communities, etc.) including the natural environment (Stubbs & Cocklin, 2008). Although some changes are possible at the organizational level, the sustainability-driven innovation needs to move beyond the transformation of a company's internal business processes, practices, and policies. A sustainable organization cannot operate in an unsustainable economy (Howes, 2001), and the whole socio-economic environment needs to contribute to global sustainability development (Morioka, Evans, & DE Carvalho, 2016).

Transformation of the global economy toward sustainable development is a very long-term process that requires the concerted action of all stakeholders in, for example, promoting and switching consumption to sustainable products, the transformation of taxation and accounting systems, the development of long-term sustainable value

chain systems, or investing in infrastructure for a sustainable system (Lozano, 2018; Stubbs & Cocklin, 2008; Young, Hwang, Mcdonald, & Oates, 2010). Transitioning the world onto a sustainable consumption and production trajectory is likely to take years if not decades. The International Energy Agency (IEA) predicts that although electric and fuel cell vehicles (FCVs) will most likely be dominant by 2050, people will still be using internal combustion engines to power their cars (Tanaka, 2011). For this reason, sustainability should not be considered a goal or complete solution; rather it is a process of constant commitment, innovation, and improvement (Jørgensen, 2008; Kiron, Kruschwitz, Haanaes, Reeves, & Goh, 2013).

Ongoing improvement and learning should be part of any organization's life and is central to many popular schools of management such as Business Process Reengineering (BPR), Lean Management, or Total Quality Management (TQM) (Bond, 1999; Koenigsaecker, 2012; Schonberger, 2014). Similarly to Lean or TQM concepts, the adoption of sustainability in organizations requires a widespread organizational change and development of critical capabilities, which can be also considered as enablers of business change for sustainability. There is a wealth of literature on creating internal capabilities to manage the transformation process toward sustainability (Bhanot, Rao, & Deshmukh, 2017; Dunphy, 2011; Eccles, Perkins, & Serafeim, 2012; Hall & Wagner, 2012; Khalili, 2011; Kiron et al., 2013; Lozano, 2018; Pinelli & Maiolini, 2017), and they are summarized in Table 1.

Although unlikely to be exhaustive, all of these enablers are essential for creating capabilities for change and supporting the implementation of sustainability. However, robust and innovative business models for sustainability cannot exist without an appropriate system of performance measurement (Boons & Lüdeke-Freund, 2013; Sherman, 2012; Wikström, 2010). The development of a robust sustainability measurement system should be central to any organizations wishing to incorporate sustainability into its DNA or the heart of its business. It is an indispensable element of any change and management process. The popular maxim of management guru Peter Drucker—"*what cannot be measured cannot be managed*"—is also relevant for business sustainability. The Lean, TQM, and Six Sigma concepts confirm that continuous improvement is about the constant measurement and improvement of organizational performance (Fryer, Antony, & Douglas, 2007; Koenigsaecker, 2012). The transformation toward sustainability is the continuous process of making strategic and operational decisions about appropriate strategies, technologies, practices, or activities (Sherman, 2012). There is hence an urge for the development of credible measurement tools and systems that allow to capture, monitor, and manage sustainability in organizations at the wider all-function level (Boons & Lüdeke-Freund, 2013; Geissdoerfer et al., 2018; Jasinski, Meredith, & Kirwan, 2015; Upward & Jones, 2016). Businesses that develop an appropriate system for measuring and assessing the most significant internal and external impacts are more likely to gain a competitive advantage over static competitors by, for example, identifying new business opportunities, improving customers' loyalty and company's reputation, exploiting niches in sustainability conscious markets, anticipating and responding quickly to changing circumstances and legislation (Howes, 2001).

TABLE 1 Key enablers for business sustainability

Sustainability enablers	Description
Sustainability vision and mission	Sustainability has to be approached in the same way as any other business idea or influence. Companies need to consider sustainability during the strategic planning process and incorporate it into their business strategy and goals. Only then can it be implemented appropriately across an organization through business models, roadmaps, or operational plans.
Sustainability culture	Sustainability has to be an element of a company's culture in order to influence all people in an organization. It should provide opportunities and implications for all business activities, including the design of new products (services), manufacturing processes, the building of new facilities, and even supplying offices. Sustainability needs to become part of people's everyday conversations, thinking, and the fabric of doing their job.
Leadership support	Embedding sustainability in an organization's culture requires strong commitment and support from executives. They hold the power to effect change and create a culture of sustainability to embed these values in the minds of key stakeholders.
Stakeholder management	Any transition toward sustainability needs to be carried out in collaboration with stakeholders. Collaboration with stakeholders can draw attention to issues not previously raised and identify credible, meaningful, and feasible sustainability objectives that go beyond appearing as marketing spin.
Performance measurement system	Sustainability decisions cannot be reduced to an exclusively economic rationale. Instead, they should evaluate and consider other influences that may affect the total value (e.g., human, social, natural, and intellectual capital). Any business striving for sustainability should be equipped with some form of algorithm, indicator, or financial mechanism that will incorporate these other influences into its everyday decision-making.
Innovation	A transition toward sustainability is about doing things differently and doing different things. It requires completely new thinking about the discovery and development of new products, technologies, production processes, and institutional and systemic arrangements, as well as existing business models.

The next section describes the development process of a model for an integrated, holistic, and comprehensive assessment of sustainability in the automotive sector. Although the key focus of the model is car manufacturing, the mixed research methods design, both
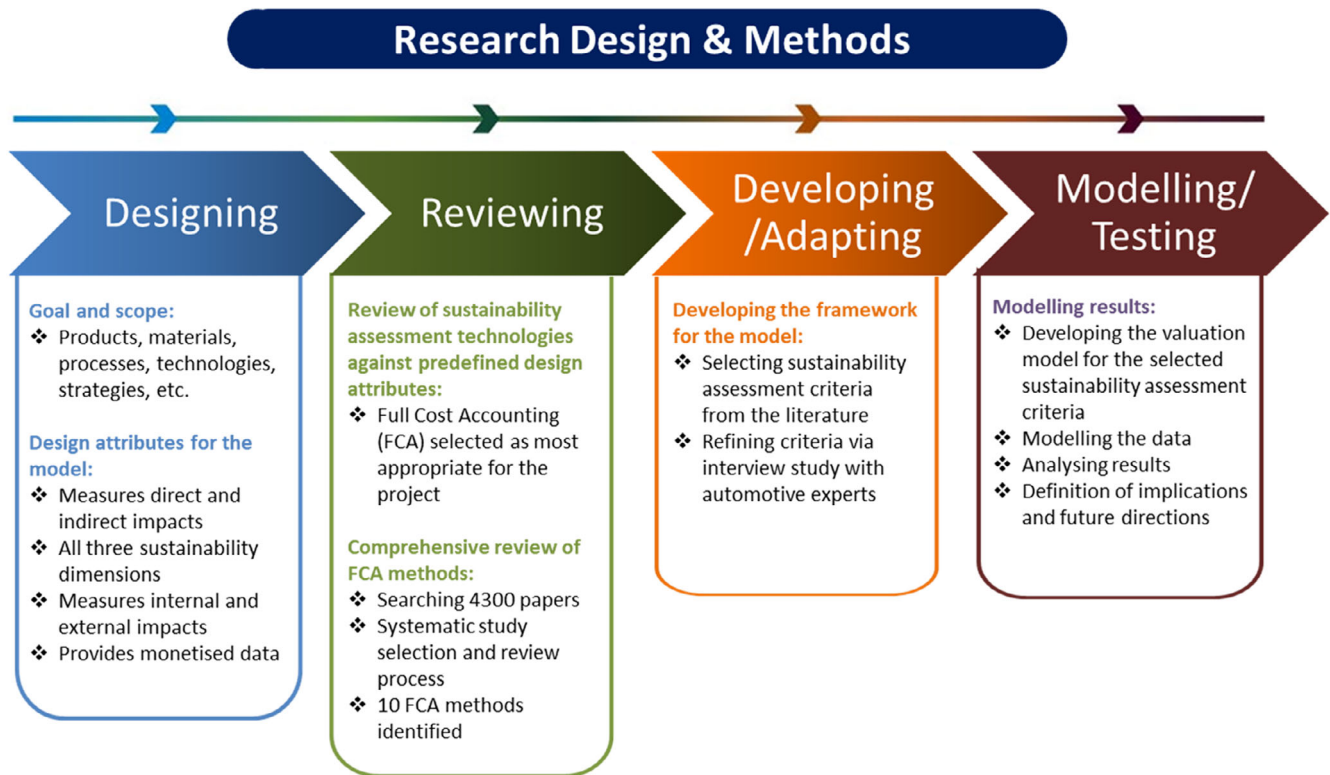
Research Design & Methods

Designing

Goal and scope:
- ❖ Products, materials, processes, technologies, strategies, etc.

Design attributes for the model:
- ❖ Measures direct and indirect impacts
- ❖ All three sustainability dimensions
- ❖ Measures internal and external impacts
- ❖ Provides monetised data

Reviewing

Review of sustainability assessment technologies against predefined design attributes:
- ❖ Full Cost Accounting (FCA) selected as most appropriate for the project

Comprehensive review of FCA methods:
- ❖ Searching 4300 papers
- ❖ Systematic study selection and review process
- ❖ 10 FCA methods identified

Developing /Adapting

Developing the framework for the model:
- ❖ Selecting sustainability assessment criteria from the literature
- ❖ Refining criteria via interview study with automotive experts

Modelling/ Testing

Modelling results:
- ❖ Developing the valuation model for the selected sustainability assessment criteria
- ❖ Modelling the data
- ❖ Analysing results
- ❖ Definition of implications and future directions

FIGURE 1 Development process of the automotive sustainability assessment model [Colour figure can be viewed at wileyonlinelibrary.com]

qualitative and quantitative, and the type of integration used can serve as a guideline to develop a wide range of sustainability assessment methods and tools for organizations of any type, operating across many different sectors.
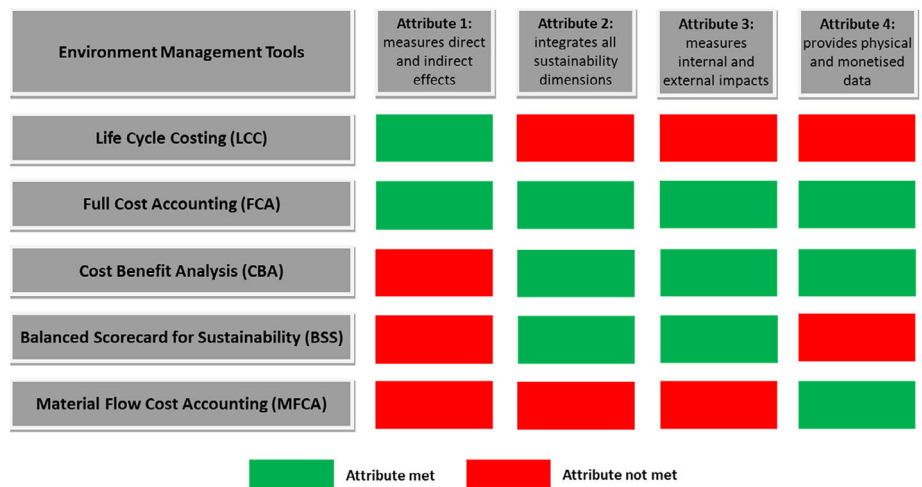
3 | RESEARCH MATERIAL AND METHODS

The process of developing the model consisted of four major steps (see Figure 1), each of which contained series of intermediate steps and individual objectives.

3.1 | Step 1 deigning the model

A versatile and ideal tool or method to assess sustainability is difficult, if not impossible to establish, since every evaluation differs in terms of a specific goal, focus, type of data, and needs of stakeholders. Hence, the appropriateness of sustainability assessment methods for automotive decision-making was evaluated by considering the characteristics and needs of the automotive sector reported in the literature (Arena, Azzone, & Conte, 2013; Jasinski et al., 2015; Mayyas et al., 2012; Schmidt & Taylor, 2006; Steen, 1999), followed by consultations with sustainability engineers and managers in JLR. By adopting this approach, the following four design attributes for the automotive sustainability assessment system were defined:

- **Attribute 1**: the system should capture both internal (e.g., the use of energy, materials and water, and waste generation) and external sustainability impacts. External impacts are the damages or negative effects of an entity's activities and decisions borne elsewhere in the system by parties not responsible for causing the effects in the first place (e.g., various forms of air, water, and soil pollution) (Bebbington, Gray, Hibbitt, & Kirk, 2001). As with carbon dioxide, externalities can be internalized at a certain point in time and are therefore considered as future costs.

- **Attribute 2**: life cycle thinking is deeply ingrained in the automotive industry. 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. Hence, car manufacturers are under pressure from policymakers and other stakeholders to measure and improve both the direct and indirect (upstream and downstream) sustainability performance of vehicles.

- **Attribute 3**: based on TBL theory, all three sustainability dimensions strongly influence each other and should be an integral part of the business's decision to pursue sustainable development.

- **Attribute 4**: sustainability is measured and presented in different units (tonnes of carbon dioxide, sulphur dioxide, nitrogen oxides, cubic meteres of water, or megawatts of energy). When compared against each other, it becomes difficult to decide which performance indicators are more or less relevant. Despite heavy criticism in the literature (Schmidt & Sullivan, 2002), monetization is an

FIGURE 2   A comparison of EMA tools against the design attributes defined for the automotive sustainability assessment system [Colour figure can be viewed at wileyonlinelibrary.com]

Environment Management Tools	Attribute 1: measures direct and indirect effects	Attribute 2: integrates all sustainability dimensions	Attribute 3: measures internal and external impacts	Attribute 4: provides physical and monetised data
Life Cycle Costing (LCC)	Met	Not met	Not met	Not met
Full Cost Accounting (FCA)	Met	Met	Met	Met
Cost Benefit Analysis (CBA)	Not met	Met	Met	Met
Balanced Scorecard for Sustainability (BSS)	Not met	Met	Met	Not met
Material Flow Cost Accounting (MFCA)	Not met	Not met	Not met	Met

Attribute met | Attribute not met

effective weighting method that enables a range of conflicting information to be translated into a single monetary unit score. For example, 1 kg of carbon dioxide creates a different severity of social and environmental impact than 1 kg of nitrogen oxides. Once converted into monetary units, these impacts are conceivable, and their importance can be directly and intuitively grasped by different areas of the business.

There is a broad range of sustainability assessment methods and tools in the literature. They were categorized in seven groups during the European Union (EU) project named "Sustainability-A" (De Ridder, Turnpenny, Nilsson, & von Raggamby, 2010): (1) assessment frameworks, (2) participatory tools, (3) scenario tools, (4) sustainability accounting tools, (5) physical analysis tools and indicator sets, (6) model tools, and (7) Multi-Criteria Decision Analysis (MCDA). Amongst these seven, only sustainability accounting, also known as Environmental Management Accounting (EMA), tools have the ability to provide monetized sustainability information. EMA encompasses the following five principal tools and systems: Life-Cycle Costing (LCC), Full Cost Accounting (FCA), Cost–Benefit Analysis (CBA), Balanced Scorecard for Sustainability (BSS), and Material Flow Cost Accounting (MFCA) (Qian & Burritt, 2008). These five EMA tools were evaluated against previously defined design attributes for the automotive sustainability assessment system (see Figure 2).

Out of five EMA technologies, only the FCA method met all four attributes and thereby was potentially an attractive option to form a structure for the automotive sustainability assessment. FCA was designed to adjust the existing prices of products and services by monetizing and incorporating into the equation both internal and external impacts (positive and negative), including environmental and social externalities (Bebbington et al., 2001; Bebbington, Brown, & Frame, 2007). It is an attractive option to support business decision-making due to its ability to capture more than just financial values and embrace both internal and external sustainability impacts (Russell, 2013). The designers and managers in the automotive organization 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. FCA translates a range of conflicting sustainability information into a monetary unit score which is an effective way of communicating trade-offs, win–wins, and outcomes for complex and multi-disciplinary sustainability decisions.

3.2 | Step 2 reviewing the FCA literature

FCA is not a new concept with a number of methods developed to date; therefore, the next step involved a comprehensive review of existing FCA methods to identify an appropriate approach for the automotive sector. A systematic literature review of 4,381 papers has been conducted in order to identify all available FCA methods developed to date and select the one that fits the specifications and needs of an automotive business. A systematic review aims to bring together all known knowledge on the given topic area by systematic, exhaustive and comprehensive searching, appraising, and synthesizing research evidence (Booth, Sutton, & Papaioannou, 2016). The advantages of this approach over the conventional review, which lacks an explicit intent to maximize scope or analyze data and therefore is open to bias by not questioning the validity of statements made, potentially omitting significant sections of the literature or by selecting literature that represents a specific world view (Booth et al., 2016), are objectivity, transparency, minimized risk of bias in the results, and its methodological and standardized approach (Denyer & Tranfield, 2009; Jesson, Matheson, & Lacey, 2011).

The literature review revealed 10 FCA methods with a diverse level of consistency in practical applications (see Jasinski et al., 2015 for more details about the review of FCA literature). The comparison of the FCA methods suggested the Sustainability Assessment Model (SAM) as the most complete FCA approach available in the literature and potentially attractive option for automotive organizations. The SAM is the outcome of cooperative work between British Petroleum (BP) and the University of Aberdeen. It articulates economic, resource, environmental, and social issues in a project's evaluation in the form of performance indicators which are then translated into monetary
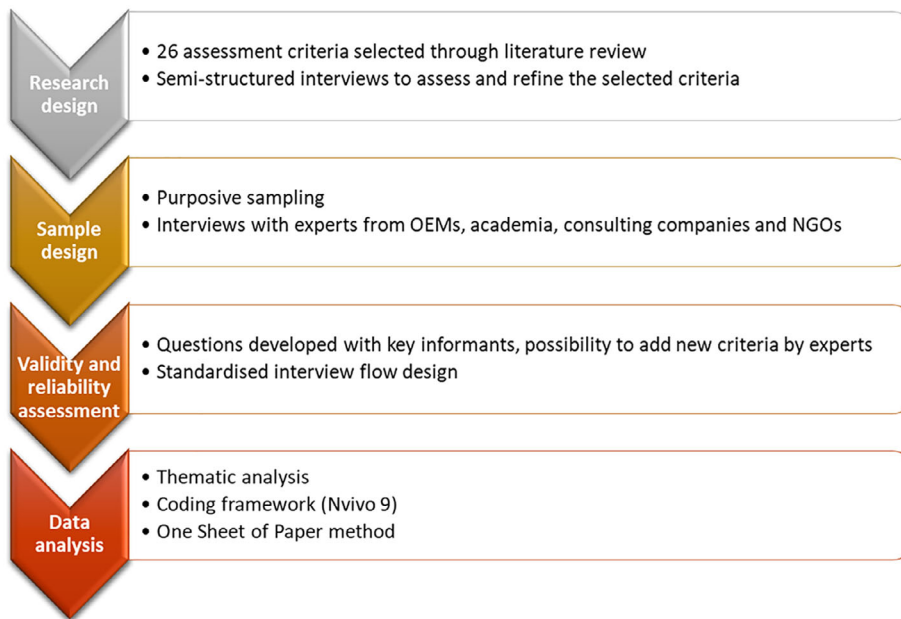
FIGURE 3 A summary of the research methods used for the interview study [Colour figure can be viewed at wileyonlinelibrary.com]

units. The output of the assessment is a graphical presentation (called the SAM signature) of positive and negative impacts (see Bebbington et al., 2007 for the SAM overview).

The SAM, in contrast to other FCA methods, provides a comprehensive picture of sustainability performance by covering 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. Furthermore, the SAM has demonstrated high flexibility and adaptability to a number of decisions over years (see Bebbington et al., 2007; Jasinski et al., 2015). 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). Finally, the SAM takes the full life cycle approach which creates a basis for assessing the sustainability of an automobile and is in line with the widely accepted ISO 14040 standards (Arena et al., 2013; Schmidt & Taylor, 2006).

The SAM was presented to Sustainability Engineering and Corporate Social Responsibility departments in JLR in order to obtain their feedback. Both departments showed interest in the SAM and appreciated its holistic approach and potential to enhance business decision-making for sustainability. Furthermore, both departments appreciated that the SAM is an ideologically open and flexible concept, which can be subsequently applied in different configurations and decision levels, including the policy, project, product, process, material, or strategy level. Hence, the next steps were focused on adapting the SAM to the automotive setting which required the development of a new set of assessment criteria.

3.3 | Step 3 developing the framework for the model

Sustainability assessment criteria and indicators almost always play a fundamental role in any evaluation of sustainability (Cinelli, Coles, Sadik, Karn, & Kirwan, 2016; Singh, Murty, Gupta, & Dikshit, 2009). Although automotive sustainability assessment criteria can be found in the literature (Arena et al., 2013; Rivera & Reyes-Carrillo, 2016; Schmidt & Taylor, 2006; Steen, 1999), there has been no clear consensus among automotive experts and other stakeholders on which criteria are critical and which framework should be used as a standard. Hence, the development of a framework for the A-SAM involved two major steps. Initially, a set of sustainability assessment criteria was selected from the literature to create a conceptual draft of the framework. These criteria were then critically evaluated and refined by a multidisciplinary panel of automotive experts. Figure 3 summarizes the research approach and methods used for the interview study.

Existing frameworks and models, company reports, original theoretical and practical research papers, and recommendations from relevant institutions such the European Commission were first reviewed to create a conceptual draft of the framework for the A-SAM. The framework was then critically evaluated by a multidisciplinary panel of automotive experts to ensure the credibility, transparency, and robustness of the process (Carrera & Mack, 2010; Ramos & Caeiro, 2010). Interviews with high-level experts within the automotive industry (both practitioners and academics) were selected as the most appropriate method to support development of a framework for automotive sustainability assessment. Qualitative interviewing provides a level of depth and complexity not available to other research instruments (Silverman, 2011). Open-ended and flexible questions are more likely to receive a considered response than closed questions and therefore provide better access to individuals' perceptions, views, values, opinions, understandings, and experiences (Gray, 2013; Silverman, 2011).

Fifty experts in the field of sustainable mobility were identified and invited to participate in this study by using the following criteria:

- decision influencers in original equipment manufacturers (OEMs) (e.g., directors, heads of department, senior managers, leaders, technical specialists) with a minimum of 3 years' professional experience in the area of sustainable automotive systems;
- academics who publish extensively on the topic of green and sustainable automotive systems;
- consultants and advisory bodies with a proven track record of working with automotive organizations in the area of sustainability; and
- leaders of influential governmental and nongovernmental organizations (NGOs) with expertise in the area of sustainable mobility.

Of the 50 experts invited to participate in this study, 24 were interviewed, representing different sectors, organizations, roles within their respective organizations and their number of years' professional experience (see Appendix A for details). Potential interviewees were selected mainly from the developed countries, such as the UK, Germany, Italy, Sweden, France, Switzerland, and the USA. This is due to the fact that the world's largest car manufacturers are located in developed countries and therefore experts from these countries were easier to identify and access. The duration of interviews ranged from 19 to 42 min, excluding introduction but including discussion of other topics.

The principal technique used for encoding qualitative information is thematic analysis (Boyatzis, 1998; Braun & Clarke, 2013). All interviews went through a process of word-for-word transcription. Once all interviews had been transcribed, they were read several times to obtain a broader understanding of the data and to generate initial ideas regarding all of the themes and categories. All interview data were coded with the assistance of NVivo 9 (QSR International). A "one sheet of paper" (OSOP) analysis, a method developed by the University of Oxford for interpreting qualitative data (Ziebland & Mcpherson, 2006), was performed in order to better understand the data and to potentially reduce the number of themes and categories. An interview study with automotive experts allowed to refine sustainability assessment criteria selected from the literature for the construction of a framework for the A-SAM. The whole interview process description, as well as full results of the interview analysis, can be found in Jasiński et al. (2016).

A particular contribution of the A-SAM is that it is intended to translate a range of sustainability information, often expressed in different units and hence incomparable, into a single monetary unit score, which was the aim of Step 4.

3.4 | Step 4 modeling and testing

There are a number of accounting techniques to help in the translation of social and environmental impacts into monetary values, including damage cost, cost of control, contingent valuation, hedonic pricing, and travel cost methods (Bebbington et al., 2001; Bickel & Friedrich, 2005; Jasinski et al., 2015). Most of these techniques are classified as nonmarket valuation methods because environmental goods and services typically lack a market and therefore do not have the value expressed in a market price (Bickel & Friedrich, 2005). The lack of market price makes the valuation of environmental and social impacts complex, time-consuming, and expensive. The work requires input from a wide range of professionals, such as epidemiologists, ecologists, economists, dispersion modelers, and environmental engineers. Hence, in order to develop a complete set of valuation indicators for the A-SAM, PricewaterhouseCooper (PwC)—a consulting company with proven expertise in the valuation of environmental and social impacts—was contracted by JLR. PwC was involved in the development of PUMA and KERING's Environmental Profit and Loss Account (E P&LA) methodology (KERING, 2018; PUMA, 2017). The methodology quantifies and monetizes a broad range of environmental impacts, such as water consumption, water pollution, waste, air pollution, greenhouse gas (GHG), and land use, by using the damage cost approach. The damage cost function estimates damage in monetary terms caused by a specific pollutant from a specific site through scientific, statistical, and economic valuation methods. Although no widely accepted standards and guidelines exist, it is recommended as the primary technique for valuing environmental and social impacts (Bebbington et al., 2001; Bickel & Friedrich, 2005; Korzhenevych et al., 2014).

A mixture of other valuation methods had to be used for those impacts that reliable and credible damage cost estimates were not available (or could not be delivered by PwC) and which were of high importance for the automotive sector. For example, technological improvements and regulations over recent years have focused on the reduction of tailpipe emissions as a top priority. As a result, responsible material use and impending resource scarcity have the potential to grow proportionally to become a major source of environmental impacts across the lifetime of a vehicle (Mayyas et al., 2012). The best contribution with regard to valuation methods and coefficients of the global impacts of resource depletion comes from the Life Cycle Assessment (LCA) field of research, including the ReCiPe method (Goedkoop et al., 2009; Vieira, Ponsioen, Goedkoop, & Huijbregts, 2016). The ReCiPe assesses the impact on resource scarcity based on the surplus cost concept, defined as a global future cost increase due to marginal resource use (Ponsioen, Vieira, & Goedkoop, 2014). If compared with the current production costs, the surplus cost can indicate whether the problematic price increases of a mineral are possible (or is unlikely) over time, if the latest technological trends and consumption patterns will continue (Jasiński, Meredith, & Kirwan, 2018).

The surplus cost method expresses resource depletion in economic terms, which was more applicable in the context of understanding mineral demand and availability from an industry perspective and was in line with the FCA approach. Surplus cost was also selected by the EC-JRC (Hauschild et al., 2011) as showing promise and as the best of the existing measures available for capturing resource depletion at the endpoint level. It was hence selected an appropriate
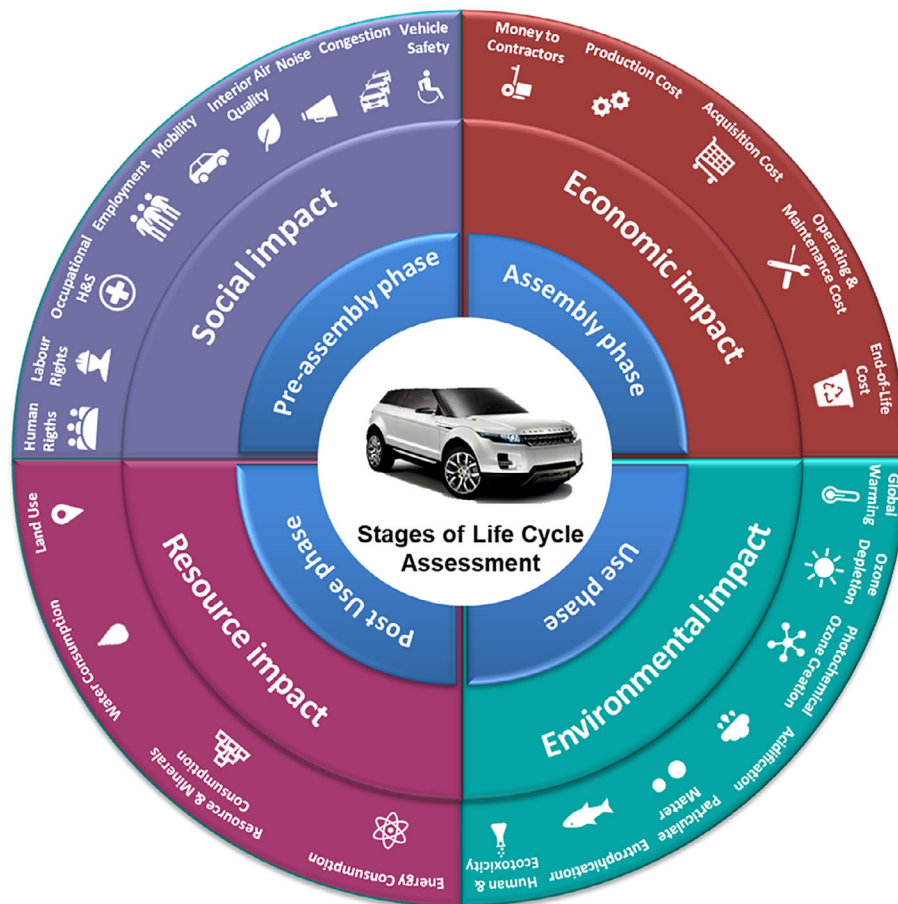
FIGURE 4 The Automotive Sustainability Assessment Model (A-SAM) [Colour figure can be viewed at wileyonlinelibrary.com]

method for testing in the context of the A-SAM to capture the external impacts of resource depletion.

4 | RESULTS AND DISCUSSION

4.1 | The automotive sustainability assessment model (A-SAM)

The combination of literature review with the inputs from automotive experts and the consulting company PricewaterhouseCoopers, allowed to construct an innovative model for automotive sustainability assessment which consists of 26 sustainability assessment criteria representing the life cycle sustainability performance of a vehicle (see Figure 4). The A-SAM represents the Elkington's (1997) triple bottom line approach to sustainability and distinguishes three major areas of sustainability: economic, environmental, and social. The automotive industry is one of the most resource-intensive industrial systems in the world (Mayyas et al., 2012); therefore, for practical reasons and similarly to the original SAM, assessment criteria have been grouped into four major categories. Five criteria measure the economic dimension through life cycle costing, which is the common approach applied to measure the economic impacts of products (Swarr et al., 2011). The environmental criteria cover the environmental impact (pollution) and

the environmental damage caused by automobiles. Resource criteria measures the external impacts of resources consumed by an automobile that are not fully accounted for in the economic impact section. This includes all renewable and nonrenewable resources that once used cannot naturally be replaced and employed for alternative uses in the future. Finally, the social criteria cover the social impacts (negative and positive) of an automobile.

Twenty-one impact categories, representing environmental, resource, and social performance, required the development of valuation models for the completion of A-SAM. Valuation models for 10 assessment criteria have been delivered to JLR through PwC and these included: global warming potential, photochemical ozone creation, acidification potential, particulate matter formation, eutrophication, water consumption, land use, mobility capability, employment, and occupational health and safety (only from company's operations). Although the valuation coefficients developed by PwC are the intellectual property of the company, the valuation methods and tools that the company uses are publicly available (see Kering, 2013). Those 10 assessment criteria were supplemented by the surplus cost models developed through this doctorate project (see Jasiński, Meredith, & Kirwan, 2018 for surplus cost modelling) to measure the external impacts of energy consumption and resources and minerals consumption. Valuation models for nine assessment criteria (stratospheric ozone depletion, ecotoxicity, human toxicity, vehicle safety,

TABLE 2 Comparison of energy consumption and GHG emission between primary and secondary platinum (source: Saidani et al., 2019)

	1 kg of primary platinum	1 kg of secondary platinum
Energy demand (GJ/kg)	200	10
GHG emissions (t CO$_2$-eq/kg)	40	2

congestion, noise and vibration, vehicle interior air quality, labor rights, and human rights) were still subject to development by the time this study was completed.

To demonstrate how the A-SAM could work in practice, a hypothetical example of business strategic decision in automotive sector is presented below. The automotive sector uses a broad range of different minerals (metals and metalloids) for car manufacturing (see Jasiński, Cinelli, Dias, Meredith, & Kirwan, 2018). Nuss and Eckelman (2014) investigated and compared 63 metals on a per kilogram basis and revealed that Platinum Group Metals (PGMs) (next to gold) display the highest environmental burdens. PGMs are the primary metals utilized in catalytic converters in both diesel and gasoline engines. They are of strategic importance to the automotive sector because aside from the fact that they are rare and expensive; there are currently no substitutes to replace PGMs in autocatalysts (Espinoza et al., 2015). One way to secure the supply of PGMs for car manufacturing and minimize the environmental impact of their primary production is recycling (Saidani, Kendall, Yannou, Leroy, & Cluzel, 2019). It is estimated that the recycling rate of platinum is 50–60% (Hagelüken, Lee-Shin, Carpentier, & Heron, 2016), which is still surprisingly low considering the relative price levels of precious metals and the fact that 98% of the PGM content of spent automotive catalysts can be repeatedly recovered (Saidani et al., 2019). A simplified analysis focusing on selected criteria (global warming, resource depletion, acquisition cost, employment) will demonstrate whether there is a case for the use of recycled platinum in catalytic converters and how it could enhance the sustainability performance of an automotive organization.

The averaged global values from different LCA studies of energy consumption and GHG emissions of the primary and secondary production of platinum are presented in Table 2. The values cover the processes from the extraction of the raw materials in the earth (compared to the secondary production) to the finished products ready to be shipped from the factories. The emission of harmful pollutants from the use phase is not considered in this study since the use of secondary material should not compromise the performance of catalytic converter in reducing vehicle emissions (Saidani et al., 2019).

Power consumption during mining and ore beneficiation has been identified as the major impact (72%) of the production of PGMs on the environment. PGMs are largely mined in South Africa, the power grid mix of which consists in more than 90% from the combustion of hard coal which has a high carbon content (Bossi & Gediga, 2017). The secondary production is not that energy intensive as in PGMs mining and is typically composed of two processes (1) smelting or

dissolving to bring the PGMs into a solution and (2) similarly to the primary production, refining to recover the individual metals separately in a pure form (Bossi & Gediga, 2017). For years, the United States and Europe were considered the world's leading source of recovered PGMs (Wilburn & Bleiwas, 2004, Johnson Matthey, 2013). The main source of energy in the US and Europe is a mix of oil, natural gas, renewables, and coal, the combination of which is considered "cleaner" in terms of the amounts of GHGs they emit in relation to the energy they produce than relying only on coal (IEA, 2018).

Tol (2012) estimated the mean of the social cost of carbon based on a meta-analysis of 232 estimates published in the literature. The mean social cost of carbon is 49 euro/t of CO$_2$, which, once converted to USD per kilogram and adjusted for inflation, is US$2019 63.35 per tonne of CO$_2$. An average PGMs loading per light duty vehicle is 5.38 g (Nguyen, Andress, Troops, & Sujit, 2014), which is assumed mostly platinum for the purpose of this study. The surplus cost estimates for platinum, as well as oil, natural gas, and coal, were taken from Jasiński, Meredith, and Kirwan (2018) and Ponsioen et al. (2014) and adjusted for inflation. The average price for primary platinum in 2019 is USD 27.9 per gram (Johnson Matthey, 2019). Greater reuse of platinum should bring this price down since the costs of secondary production is expected to be lower compared to primary ore extraction (Fornalczyk & Saternus, 2013). Alonso, Field, Roth, and Kirchain (2009) tested statistically the effect of progressive platinum recycling on the market behavior and material prices. The simulations showed that the dynamic secondary use of platinum in products reaching end-of-life could reduce the market by around 25%. Information about the employment in the PGM mining sector was sourced from the Minerals Council South Africa (2019). South Africa is responsible for over 70% of global supply of PGMs (Johnson Matthey, 2020). Information on employment in recycling is limited because the statistical employment data are not structured with a focus on recycling. Usually, data on recycling activities (e.g., collecting recyclable materials and activities enabling the use of recyclables in manufacturing) are aggregated with other activities (European Environment Agency, 2011) and hence could not be distinguished for the purpose of this study.

Nonetheless, a simplified A-SAM signature for using platinum in the automotive catalytic converter is presented in Figure 5.

PGMs are considered rare and expensive, and hence the economic impact of using platinum in autocatalysts is the greatest compared to resource, environmental, and social, despite whether it comes from the primary or secondary production. Resource impacts are relevant mostly for the primary production and extraction of platinum from the ground. Each kg of platinum extracted today will likely result in the increase in mineral production costs in the future if the latest technological trends in the automotive sector will continue. This will also depend on the discovery of new deposits and the ability of new technologies to push these costs down over time. What is also interesting is the fact that in the case of platinum, the social cost of depleting the mineral far exceeds the social cost of climate change resultant from its extraction. Hence, the scarcity of platinum should be of greater concern to decision makers than the CO$_2$ emissions

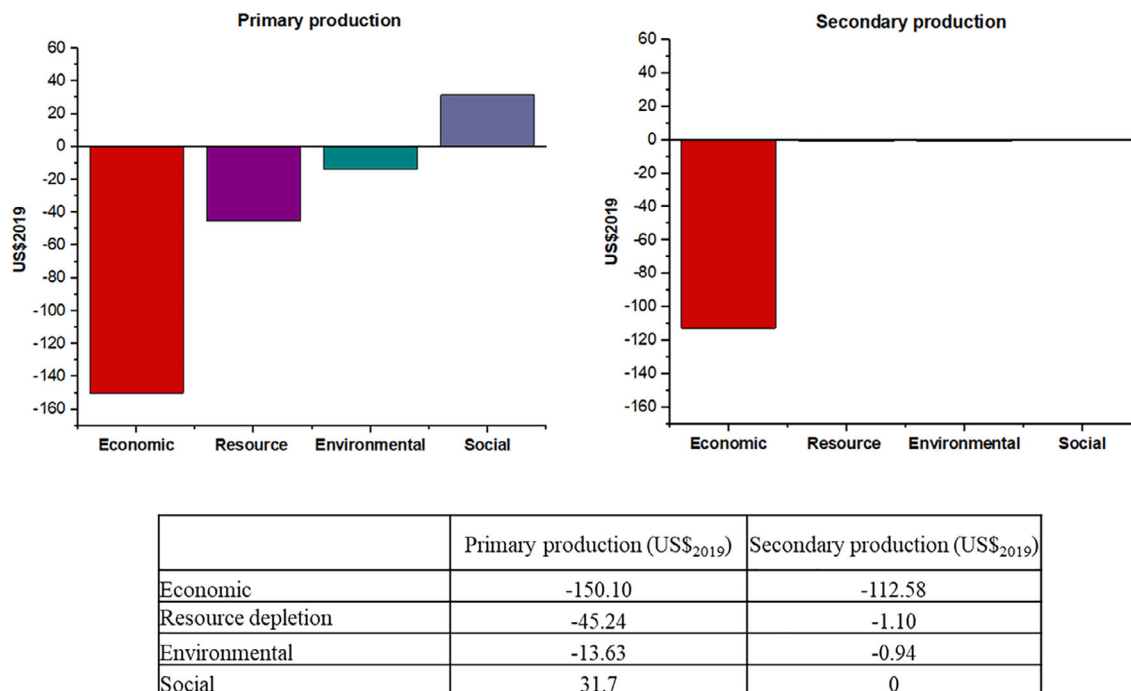|	Primary production (US$_{2019})	Secondary production (US$_{2019})
Economic	-150.10	-112.58
Resource depletion	-45.24	-1.10
Environmental	-13.63	-0.94
Social	31.7	0

FIGURE 5   The A-SAM signature for the primary and secondary platinum used in a catalytic converter [Colour figure can be viewed at wileyonlinelibrary.com]

associated with the production and of this mineral. For the mining industry, policymakers, and scientists, climate change was always of far greater concern than resource depletion (Ponsioen et al., 2014).

The surplus cost for the secondary production is negligible, and it is associated mostly with the use of energy from fossil fuels like oil, natural gas, and coal. The environmental impact is also greater for the primary production which is the result of high-energy consumption and associated GHG emissions during platinum mining. Other harmful emissions from the production phase, such as HC, CO, NOx, and PM, would most likely also be higher during the primary production, but the use of a catalytic converter would outweigh the emissions generated during the production of the catalyst (Bossi & Gediga, 2017). The LCA study of the International Platinum Group Metals Association (IPA) revealed that the emissions of CO, HC, NOx, and PM from the production of catalytic converter are counteracted after a vehicle reaches 40,000 km in EURO 5 systems. Hence, the emission of air pollutants over the vehicle life cycle is in fact net-positive if one considers the functionality of catalytic converters in the vehicle. The negative economic, resource, and environmental impacts from the primary production are, to some extent, offset by the positive social impacts from employment in the mining sector. Of course, the recycling sector also generates employment through activities like reverse logistics, collecting, dismantling, separating recyclable materials, and converting into new products. This, however, was not considered in the model due to the difficulty of finding the employment data for the autocatalyst recycling market.

From the sustainability perspective, the A-SAM clearly favors the secondary production of platinum for catalytic converters over the primary production. Despite its positive employment impact, the economic, resource, and environmental consequences of extracting PGMs from the ground are far greater than if they would be recovered from the closed-loop systems. This brings new opportunities for the automotive sector, especially that PGMs are almost indefinitely recyclable and the resource and environmental impact of PGMs primary production will subsequently decrease with each recycling round (Bossi & Gediga, 2017). Extrapolating the numbers to over 500,000 vehicles sold per year (mostly petrol, diesel and plug-in hybrids each of which uses a catalytic converter) (Jaguar Land Rover, 2020), sourcing platinum from recycling could bring JLR US$18.7 million of cost saving in materials, as well as reduce the company's resource and environmental footprint by US$22 million and US$6.3 million, respectively.

4.2 | The practicality of A-SAM for sustainable decision-making

The path toward development of an appropriate sustainability measurement system is not uniform and can vary from one organization to another. The literature in sustainability assessment is vast with a broad range of methods, tools, frameworks developed to date (De Ridder, 2006; Ness, Urbel-Piirsalu, Anderberg, & Olsson, 2007; Sassanelli, Rosa, Rocca, & Terzi, 2019; Sharifi & Murayama, 2013), each of which having its own strengths and weaknesses. To the authors' best knowledge, the one-size-fits-all solution does not exist, and the ideal sustainability assessment system can take a number of

different forms. The A-SAM fits perfectly within the JLR's design process and culture; however, it not necessarily needs to fit other organizations.

Although the A-SAM does not yet account for all of sustainability effects, it still provides a comprehensive view about the sustainability performance of a car, which was still lacking in existing automotive systems. When introduced to JLR, the concerns expressed by some engineers were that the A-SAM is too broad and too complex to make simple and quick decisions at the engineering level. Achieving this level of understanding is not easy and the risk of having too many metrics is that they might be difficult to balance and may overload engineers. The common practice in the automotive company is that LCA specialists usually make the decision for engineers about what the most important factor is and then to let them design to that factor. Since the introduction of regulation concerning CO_2 in 1995, this factor is global-warming potential measured in the currency of CO_2 equivalent. Hence, if an impact can be expressed in CO_2 equivalent, engineers stick to that theme across the life cycle without trying to complicate things too much by adding in other factors. However, the idea behind the A-SAM was to start from the most comprehensive understanding as possible, define gaps and weaknesses, and then develop novel capabilities to fill the identified gaps and weaknesses. The model sets the guidance on what needs to be measured in an integrated and comprehensive sustainability assessment of vehicles and leaves the choice of what to include in the decision-making process to the discretion of a person that is making decisions.

Another important strength of the A-SAM is also its flexibility and adaptability to support decisions at different levels and in different configurations. This is especially important for automobile manufacturers that need flexible tolls which can be subsequently applied in different configurations and decision levels, including the policy, project, product, process, material, or strategy level. The SAM can support all corporate functions by adapting assessment criteria to the characteristics and needs of a specific business unit. Flexibility and adaptability also allow for maintaining compatibility with other legacy assessment systems. One of such systems is LCA methodology introduced in 1995 (Guinée, 1995), which has since become fundamental to all types of sustainability assessment tools, models, and frameworks. Life cycle thinking is deeply ingrained in the automotive industry; therefore, the A-SAM was also built on the methodology and principles of LCA. In fact, the A-SAM goes one step further by taking an integrated approach to sustainability incorporating all three components of the TBL concept. The A-SAM should not be considered as a replacement of LCA; instead, these two tools are complementary. The A-SAM fulfils the weighting function, which is an optional step in LCA methodology, where numerical factors are assigned to each assessed impact category according to their relative importance (Bickel & Friedrich, 2005). The weighting function can take the different forms, for example, single unit score, standards, expert panel, and so forth. In the A-SAM, these are the algorithms that translate a range of sustainability information, often expressed in different units and hence incomparable, into a single, monetary unit score. This, on the other hand, enables to easily grasp the relative importance of different

sustainability effects by different areas of the business. The model was first picked up by the JLR's Sustainability Engineering team that currently uses it as an internal mean of accounting and prioritizing, although other departments and engineers have been gradually engaged for the wider adoption and use of the developed model and techniques. It serves as a discussion platform for considering environmental, resource, and social implications alongside the financial business case in day-to-day operations. A particular strength of the A-SAM is that it is a quantitative tool, which adds a scientific background and more objectivity into the discussion as opposed to relying on opinions which are subjective in nature.

Although the A-SAM was built on the limitation of existing FCA methods, this paper acknowledges that it does not resolve all the problems for which the FCA concept has been criticized. The main argument against FCA is that it proposes a linear approach to something that is not linear from definition (Schmidt & Sullivan, 2002); thus, any model developed based on this concept will have to share the same criticism. Indeed, the imperfection of existing monetary techniques for valuing externalities requires to treat the results with caution. For JLR, monetization is justified to compare strategies and make business decisions using quantified data, as well evaluate the total impact of each decision and choice they make; however, monetization was never intended to be used in exchange for a common sense. The company acknowledges that the A-SAM is not a tool for delivering ultimate answers for decision-makers but rather to facilitate the judgment and reasoning process for complex sustainable decisions. Furthermore, similarly to the original concept (see Bebbington et al., 2007), the A-SAM does not insist on placing monetary value on impacts that could be inappropriate, too complex or of scientific uncertainty.

Out of 21 impact categories, representing environmental, resource, and social performance, valuation models for nine impact categories were still missing by the time this study was completed. Apart from time and resources, the level of complexity involved and the imperfection of existing measurement tools was an obstacle to delivery of a complete set of valuation coefficients for the A-SAM. For example, LCA is capable of measuring all of the environmental and resource criteria proposed in the model, although the method's reliability varies from one criterion to another. Impact assessment methods for human toxicity (such as the USEtox model) are less certain than, for instance, scientifically robust climate change impact assessment models (Hauschild et al., 2013). Also, some social impacts, such as human and labor rights and occupational health and safety, are difficult to detect because the problems are more likely to occur in the complex automotive supply chain rather than other stages of the vehicle life cycle (Traverso et al., 2013). Although some progress has been made over the last years in the development of Social LCA methodology (see Benoît-Norris, Traverso, & Finkbeiner, 2020 for new S-LCA guidelines) and tools (see Ciroth & Eisfeldt, 2016 for the first Social LCA database), the concept remains in its infancy and is therefore limited if one wishes to conduct an accurate social LCA. Other social criteria, such as vehicle noise, safety, interior air quality, and congestion, are being monitored by different business units in automotive organizations (for instance, noise and vibration

performance is measured by the NVH department, while vehicle safety performance is in hands of the Safety Attribute department). Hence, the development of valuation models and coefficients for these social impacts required the support and commitment from different business units within JLR, not all of which were prepared to participate in this study either due to the ethical reasons or simply due to the lack of interest in the FCA concept.

5 | CONCLUSIONS

This study has developed and proved, using real-world data, an innovative model named the Automotive Sustainability Assessment Model (A-SAM) to drive sustainable decision-making in the automotive sector. The model measures, quantifies, and translates a broad range of sustainability effects (both internal and external) into their monetary equivalents, enabling large car manufacturers (like JLR) to evaluate options, identify win–wins, and optimize trade-off, while making complex and multidisciplinary sustainable decisions. It allows managers and design engineers in the automotive sector to develop a better understanding of the environmental, resource, and social impacts of their activities, products, processes, and materials used, while still ensuring cost-effectiveness when making decisions. It can expose new business or investment opportunities for automotive organizations, in line with the principles of sustainable development, by making them more transparent and visible for decision-makers.

Although not without flaws, the A-SAM shows promise to be a potentially effective tool for supporting sustainability decisions in a business environment. The system currently focuses on 17 of the most common sustainability metrics for the automotive sector, for which scientific knowledge is more advanced. It serves as the basis for this system to expand as the knowledge for the remaining nine metrics develops.

The A-SAM is a step forward in a holistic, comprehensive, and integrated sustainability assessment of products. It demonstrates one way (from many alternatives) how manufacturing organization can capture, monitor, and manage TBL performance at the wider all-function level to find a balance between long-term profitability and productivity and environmental and social impacts. The mixed research methods design presented in this paper, both qualitative and quantitative, and the type of integration used can serve as a guideline to develop a wide range of sustainability assessment methods and tools for managing sustainability in a more holistic, comprehensive, and integrated manner. The process can be adapted by organizations of any type, operating across many different sectors to develop new or improved models that can account for the total sustainability impacts or value that organizations create or destroy.

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APPENDIX A: ANONYMISED LIST OF EXPERTS THAT PARTICIPATED IN THE INTERVIEW STUDY

Participant identifier	Interview date	Sector	Role in organisation	Years of experience
A1	15/04/2015	Academia	Director of Automotive Research Centre	20+
A2	15/04/2015	Academia	Co-Director of Automotive Research Centre	20+
A3	24/04/2015	Academia	Lecturer—Consultant	5
A4	06/05/2015	Academia	Associate Professor	20
A5	07/05/2015	Academia	Programme Manager	5
A6	15/05/2015	Academia	Research Fellow	18
A7	18/06/2015	Academia	Professor—Vehicle Powertrain	20+
A8	25/06/2015	Academia	Adjunct Professor—Environmental System Analysis	20+
C1	18/05/2015	Consultancy	Vice President Mobility	20+
C2	29/06/2015	Consultancy	Managing Consultant	16
C3	10/07/2015	Consultancy	Principal Consultant	15
C4	15/07/2015	Consultancy	Director	20+
N1	08/06/2015	NGOs	Principal Adviser—Sustainable Mobility	20
N2	10/07/2015	NGOs	Managing Director	20+
N3	17/07/2015	NGOs	Head of Sustainable Business	3
N4	20/07/2015	NGOs	Programme Manager	20+
O1	05/05/2015	OEMs	Sustainability Engineer	14
O2	05/05/2015	OEMs	Sustainability Engineer	11
O3	05/05/2015	OEMs	Sustainability Engineer	3
O4	22/05/2015	OEMs	Director Sustainability	20+
O5	26/05/2015	OEMs	Safety Attribute Senior Manager	20+
O6	02/07/2015	OEMs	Group Environmental Strategist	15
O7	04/07/2015	OEMs	Head of Corporate Responsibility	10
O8	22/07/2015	OEMs	Principal Engineer NVH	14