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Sustainability Performance Frontiers

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Abstract: When the concept of strategic trade-offs was introduced by Skinner in 1969, an intense academic debate followed. On one hand, World Class Manufacturing proponents rejected the idea whilst others recommended the careful consideration of trade-offs when designing production systems. Today, history repeats itself, and the same debate exists in the field of sustainable operations management, with some researchers documenting trade-offs between economic and environmental performance, and others rejecting this view. This paper shows how this debate has profound implementation implications: the first view calls for incremental improvements, whereas the latter calls for radical innovation. This paper combines the behavioural theory of the firm with Schmenner and Swink's (1998) theory of performance frontiers to define sustainability performance frontiers. These frontiers define legitimate managerial boundaries for searching for sustainability and remove the perceived conflict between the two views of sustainability trade-offs.

***Keywords*:** behaviour, sustainability, strategic trade-offs, performance frontiers

1. Introduction

Skinner (1969) was the first operations management scholar to highlight the importance of strategic trade-offs. In his article about manufacturing being the missing link in corporate strategy, Skinner (1969) reported that there was a lack of recognition of design trade-offs by top executives. As a result, impractical strategic decisions were being made. This contribution led to strategic trade-off theory (Da Silveira & Slack, 2001; Slack, 1998), which states that managers deal with conflicting objectives when designing operations systems and that these conflicts form constraints to performance. For example, to achieve low-cost performance, managers must set limits to the quality of products. Conversely, products seeking differentiation through quality will be expensive.

In the 1990s, proponents of World Class Manufacturing initiatives used the example of the 1980s Japanese car manufacturers' competitive breakthrough in the US market to challenge this view (e.g., New, 1992). According to strategic trade-off theory, car manufacturers could compete on cost, quality, or flexibility, but could not perform well along all performance dimensions at once. The fact that Japanese cars were cheaper, of better quality, and offered more options than American cars in the 1980s was perceived as a counter-example that disproved strategic trade-off theory. For a while, the World Class Manufacturing experts argued that trade-offs did not exist: they were imaginary and customary constraints self-imposed by managers upon their operations system, i.e., a psychological bias stopping them from searching for better practice (the same criticism is often made today in the context of sustainability, e.g., Shevchenko et al., 2016).

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As more was learned about the Toyota Production System (Monden, 1983; Ohno, 1988), it gradually transpired that Japanese car assembly plants were significantly different in terms of underlying technology and capabilities. In other words, Japanese manufacturing managers' production systems were so different in terms of capabilities that they *apparently* did not face trade-offs.

Schmenner and Swink's (1998, p. 107) theory of performance frontier overcame this long-standing debate. They define a performance frontier as "the maximum output that can be produced from any given set of inputs, given technical considerations". The first frontier, the asset frontier, represents maximum performance under optimal asset utilisation, i.e., it describes reachable performance levels if assets are perfectly managed. The operations frontier, in contrast, represents achievable performance levels under current operations policies. The theory of performance frontiers argues that performance can be increased through two strategies. Improvement means adjusting processes to reach an operations frontier. Betterment, the second strategy, is about moving the operations frontier toward the asset frontier.

Figure 1 illustrates this theory with two generic performance measures, X and Y. In this example, we assume that the objective is to minimise quantities, for example, cost and defect rates. This means that the target performance is to move toward the origin (in this example, a product of very low cost with 0 defects). In Figure 1, a firm starts at point A, where its operations policy is poorly implemented. Through an improvement of its operations, the firm can move from A to B. During this phase of improvement, managers will conclude that there are no trade-offs as both performance measures are improved simultaneously. At point B, the performance of the firm is now constrained by the operating policy, i.e., X and Y cannot be increased simultaneously. This constraint is captured by the performance frontier and is illustrated by moving from point B to point B2: the firm successfully managed to reduce cost, but defect rates are increasing. Note that in Figure 1, the performance frontier is convex as the objective is to minimise the performance measures (if both objectives were to maximise the performance measures, the performance frontier would be concave and the target would move to the top right-hand corner). The policy that creates the frontier can be changed through the process of betterment, and in this case, trade-offs are removed until reaching point C on the asset frontier. Calic et al. (2020) explain that to managers, points B and C will be perceived as paradoxes, as past practices do not generate performance improvement any longer.

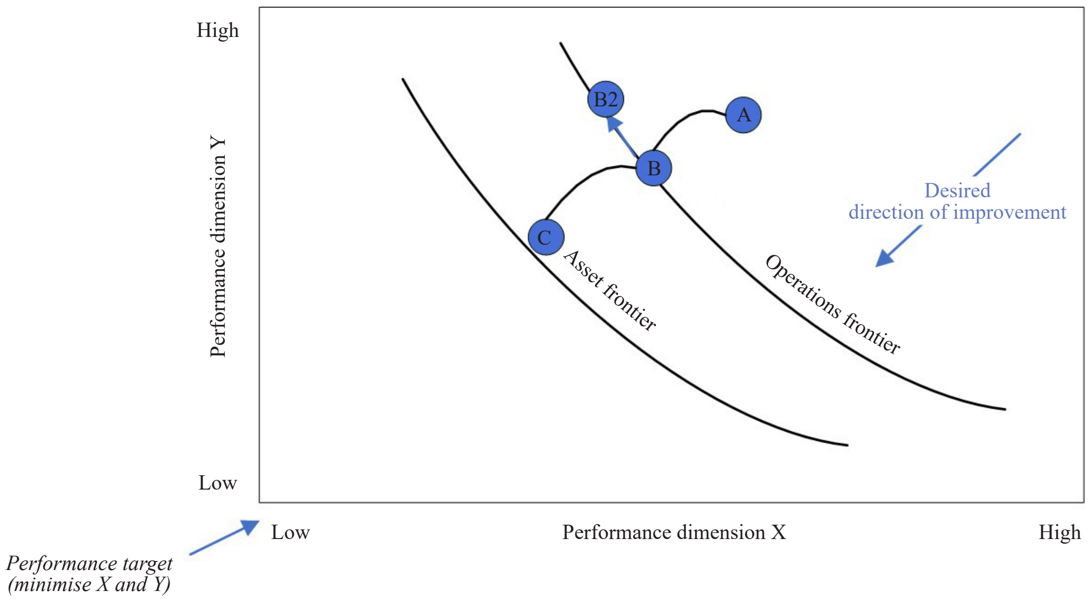


Figure 1. The theory of performance frontier

Given how famous and well-established the theory of performance frontiers is in operations management, the resurgence of this debate today is odd, as the same debate divides the sustainable operations management research community. Exploring why the debate thrives and why researchers do not invoke the theory of performance frontiers to resolve it forms the main research objectives of this paper. The next section provides evidence of the resurgence of this debate and is followed by the methodology section where the inductive case study approach used in this paper is described.

2. Sustainability trade-offs: Literature review

The idea that we should consider sustainability trade-offs is not new and full credit has to be given to Hahn et al's (2010) editorial where they challenge the "win-win paradigm" in the corporate sustainability literature. Hahn et al's (2010) editorial and Skinner's (1969) papers are essentially the same (but are written in different contexts and 41 years apart): a call to reason that corporate decision-making cannot continue by blatantly ignoring trade-offs.

The win-win paradigm rejects the notion of trade-offs and argues that firms can simultaneously achieve performance improvements in the social and environmental dimensions whilst maintaining or improving economic performance. It is referred to as the business case for sustainability (i.e., it pays off to invest in sustainability; Aragón-Correa & Rubio-López, 2007; Dyllick & Hockerts, 2002; Salzmann et al., 2005). A meta-analysis of the literature by Golicic and Smith (2013) confirmed that it does pay to be green.

Inevitably, adopting a business case approach to sustainability subordinates the social and environmental dimensions to economic matters, as only projects at the intersection of the three dimensions (Bansal, 2005) will be considered worthy investments by firms. Hahn et al. (2010) also stress that if viable projects are defined as those where a consensus is easily reached (as projects where trade-offs exist are never considered), this will result in watered-down, basic sustainability initiatives. In Figure 1, this means only looking for A-B improvement projects rather than the more complex and expensive B-C betterment projects. This concern is echoed by Pagell and Shevchenko (2014) in the context of supply chains with what they call "the primacy of profits" when they express concerns that sustainable supply chains cannot be designed and managed by focusing solely on profits as a performance measure.

In the operations management literature, the win-win paradigm is often translated as the lean and green concept, i.e., the idea that the adoption of lean practices will achieve not only efficiency (and thus profitability) improvements but will also provide environmental benefits. Extensive empirical literature exists to confirm this thesis (Belhadi et al., 2018; Duarte & Cruz-Machado, 2019; King & Lenox, 2000; Siegel et al., 2022). A variation on the same theme is the literature on eco-efficiency (Cagno et al., 2012; de Souza Costa et al., 2021; Prashar, 2021) where, again, improvement initiatives are defined at the intersection between economic and environmental performance. From a broader sociological perspective, the win-win paradigm finds a theoretical framework with Ecological Modernisation Theory (EMT; Carolan, 2004; Spaargaren & Mol, 1992), which stipulates that at a macro-economic level, national economies are better off by adopting environmental management indicators as performance targets.

There is an equal amount of scholarly work challenging the win-win paradigm and arguing that seeking environmental (or social) improvement conflicts with economic performance (Hahn et al., 2010; Margolis & Elfenbein, 2008; Pagell & Shevchenko, 2014; Pagell & Wu, 2009). In economics, Jevon's (1865) paradox describes the following phenomenon: any profit generated by eco-efficient investments is typically re-invested into increasing capacity/growth, and thus an initial decrease in emissions will result indirectly in a future increase in emissions. This is also called the "rebound effect" and remains a vibrant research programme (e.g., Lange et al., 2021).

As explained in the introduction, a debate about the existence of trade-offs is easily explained with the theory of performance constraints. Traditional operations improvement initiatives, even if designed without sustainability in mind, can be eco-efficient (de Souza Costa et al., 2021) but only up to a limit (the performance frontier). Thus, the research question explored in this paper is: why is research about sustainable operations management "immune" to the theory of performance frontiers?

3. Methodology and case study

The research presented in this paper started with an applied research project conducted for a UK-based local government body. The research presented in this paper involved two stages: the first stage is the applied research project which is about power source performance for a fleet of vehicles. In the course of the first stage, participants had to agree that the evidence documented an economic-sustainability trade-off. The ensuing process of trying to avoid and overcome this trade-off by searching for a win-win business case provides the empirical basis for the second stage of this research as a case study for this paper and a starting point for a discussion of the reasons for the resurgence of the trade-off debate.

Step 1: The Applied Research Project

Like all UK local government bodies, the focal organisation has been given a sustainability mandate from the UK government and the project was performed for the organisation's sustainability officer. The project focused on the fleet of service vehicles. Fleet managers currently face the following trade-off: they can either purchase cheap but polluting conventional fuel vehicles or expensive but clean electric vehicles. There has been a lot of engineering research comparing the performance of different power sources (Granovskii et al., 2016; Offer et al., 2010), where the challenge of bi-objective optimisation is removed by allocating weights to different criteria such as fuel cost, emissions, and vehicle range. For example, Granovskii et al. (2016) assume that cost, range, greenhouse gas emissions, and air pollution performance are equally important. With this assumption made, electric vehicles outperform conventional fuel vehicles.

The question for fleet managers is whether or not it is legitimate to assume that cost and emission performance are equally important and how this decision can be justified in a business case. In order to explore the possibility of electrifying their fleet of vehicles, the organisation decided to buy four electric vehicles and collect data to assess their cost and environmental performance when compared to existing conventional fuel-powered vehicles. It must also be stressed that, from the outset of the project, there was a perception that the cost of electric vehicles was exaggerated. Thus, there was an expectation that the four vehicles in the test project would demonstrate near cost parity and thus justify the decision to invest in more electric vehicles.

The purpose of the applied research project was not to duplicate existing power source research but rather to verify their findings in real-life settings. This echoes Bishop et al.'s (2011) concern with the fact that the power source literature tends to use manufacturers' specifications to compute performance figures rather than actual data.

The project involved two main actors in addition to the author. The first is the sustainability officer, who has to report at a strategic management level about the electric vehicles cost estimation project. The second is the fleet manager, who is in charge of managing the administration and daily operations of the fleet.

As the focus of this paper is on the second stage of the research, only essential details about the applied research project are provided below in order to provide enough context about the research. The project was based on a dataset of 80 vehicles: four electric vehicles, seven diesel vehicles, and 69 petrol vehicles. All vehicles were compact cars of similar sizes. The analysis performed in the applied research project was based on a customised version of the framework developed by Granovskii et al. (2006). For each type of vehicle, two performance measures are calculated:

- The total life cycle cost in £ per mile of using the vehicle. This is based on the actual utilisation of each vehicle during the data collection period. This includes the cost of the lease, maintenance and operations expenses, and fuel/electricity costs.
- The Greenhouse Gas (GHG) emissions in kg of CO_2 equivalent per mile. This includes the direct emissions of conventional fuel vehicles (based on actual utilisation). Electric vehicles do not have direct emissions. For both types of vehicles, indirect life cycle emissions, i.e., 'well-to-tank' emissions, are considered. Full life cycle emissions were computed for all types of vehicles, so that in addition to direct and indirect emissions associated with the use stage of the vehicles, emissions from the manufacturing and end-of-life treatment of the vehicles were also included. In the applied research project, no direct emissions could be measured, and therefore all figures are based on analytical estimates derived from Granovskii et al. (2006) and public sources. Indirect emissions caused by electricity production are estimated for different electricity generation scenarios in terms of fuel sources (nuclear, fossil fuels, and renewables).

Step 2: Inductive Case Study

The result of the applied research project was that electric vehicles were significantly more expensive to operate (see results in the next section). Their environmental performance was good but not perfect because of indirect emissions. This was disappointing to the sponsor of the project. Thus, this project is a case study where a trade-off was identified and empirically documented. Operating under a trade-off clashed with the original impetus for the project (hoping for a win-win set of results), and plans to invest in more electric vehicles were paused as there was no longer a "business case" for them. For this reason, it is an ideal case study to explore how the theory of performance frontiers can be used to visualise a trade-off and explore managerial options for improvements.

Welch et al. (2011) stress that case study research is a pluralist research methodology in terms of generating theoretical insights. In this paper, the positivist and inductive approach originally developed by Eisenhardt (1989) is used as the focus is on researching the search for meaning when managers are asked to improve the sustainability of their operations. The focus is on proposing an explanation for the evolution of the perception of fleet performance trade-offs as the applied research project unfolded. Although it is a single case study, the dilemma faced by the sponsor of the project and the fleet manager is typical of a wider population of operations managers, and thus, the proposition made in this paper can be generalised.

4. Case study results: Visualising performance constraints

Figure 2 presents the results of the applied research project. As car emissions are calculated based on the manufacturer's specifications, a type of car will always be at the same vertical coordinate in Figure 2, for example, all diesel cars have (life cycle) emissions $y = 0.23$ kg CO_2 equivalent per mile driven.

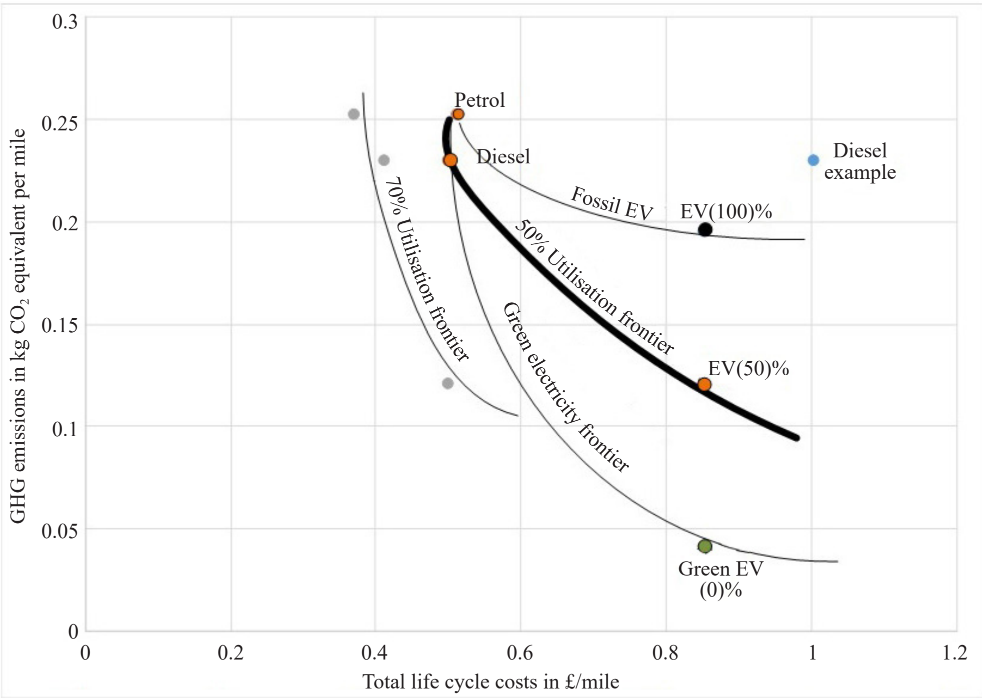


Figure 2. Fleet sustainability trade-offs (orange: average performance of car in the study; blue: example of one car in the fleet; green/black: recomputed value for electric vehicles (EVs) under different energy source scenarios; grey: simulated performance with 70% utilisation).

For this reason, to simplify the graphs, only the average performance of each type of car is shown in Figure 2. The orange points show the average performance of a car from the applied research project. For example, the orange point labelled 'diesel' represents the average performance of all diesel cars (the average is defined as an average utilisation of 50% of the maximum use as defined by the operating lease contract). A curve is manually fitted in Figure 2 to display the 50% utilisation frontier, which is shown as a thicker performance frontier. The practical interpretation of this performance frontier is that the fleet manager is constrained by that frontier in terms of reducing cost and emissions. The blue point labelled 'diesel example' represents the position of one single vehicle for one month (in that case, the low utilisation of that vehicle means a much higher life cycle cost in £/mile).

The 50% utilisation performance frontier represents the current operating frontier of the fleet. This performance frontier is shown in three versions based on the different scenarios of electricity generation sources used by Granovskii et al. (2006). The 50% utilisation performance frontier (bold curve) is based on a scenario similar to that of UK electricity generation today, where 50% of the electricity produced does not generate carbon emissions (e.g., 25% nuclear and 25% offshore wind). The 'fossil EV frontier' is based on a scenario where electric vehicles are powered by electricity that is exclusively produced from fossil fuels. It is fitted between the same 'petrol' and 'diesel' orange points, as the electricity source does not affect the emissions of these vehicles, and the black electric vehicles point, meaning electric vehicles charged with electricity generated 100% from fossil fuels. The 'green electricity' frontier means that only renewable energy sources are used to generate the electricity used to charge electric vehicles. It is fitted between the same orange points for 'petrol' and 'diesel' and the green electric vehicles point (electric cars being charged with 0% fossil fuels, i.e., 100% renewable energy). Whereas the 50% utilisation frontier is an example of an operations frontier, the green electricity frontier can be called a "technology frontier". It illustrates an improvement in performance that is induced by a technology improvement in a different industry. It is not an asset frontier, as the asset (power plants) does not belong to the focal organisation. The organisation pointed out that they owned a solar photovoltaic panels farm, and as such, they could claim that they were charging the electric vehicles with their own green power. This is a common argument in the electricity retail sector where retailers guarantee to their customers that they only make payments to green electricity producers. It is, however, impossible to trace the provenance of a kilowatt-hour, and this payment guarantee does not mean that the actual electricity used to charge a car is indeed green.

The organisation explained that a significant performance improvement could be achieved by trying to better utilise the vehicles. There were significant differences in utilisation rates between the vehicles. The diesel vehicles were the best-used vehicles with a high monthly average of 67% in one month. The electric vehicles were less used and it turned out that users were discouraged from booking them due to concerns over range and charging times, as for a few months in the first part of the trial period, electric vehicles could only be booked once per day over concerns that it had to be recharged fully before being used again.

Given the fact that a car in the fleet is driven on average 41 miles per day and that the range of an electric car is in excess of 200 miles, this was clearly an unnecessary operations policy that can only be explained through the concept of 'range anxiety' (Neubauer & Wood, 2014). This practice resulted in low utilisation, which is particularly counter-intuitive as electric vehicles have high fixed costs and low variable costs. In this fleet, the monthly lease cost of an electric vehicle was £4,325 per month and the variable cost was £0.03 per mile. For comparison, a petrol car's lease is £1,329 per month and the variable cost is £0.13 per mile. In this situation, it would be best to allocate users first to the cheaper-to-operate electric vehicles as this would reduce operating cash outflows. This point can be visualised in Figure 2 when comparing the slope of the 50% utilisation frontier with the simulated 70% utilisation frontier. The 70% utilisation frontier is fitted around the grey points, which assumes that all vehicles are driven for 70% of the miles allowed in their contractual agreement (and, for the electric vehicles, makes the assumption that electricity used to charge the car is 50% green). The much narrower horizontal footprint of the 70% utilisation frontier, when compared to the 50% utilisation one, shows how much the cost of using an electric vehicle is inflated by the fact that they are poorly utilised.

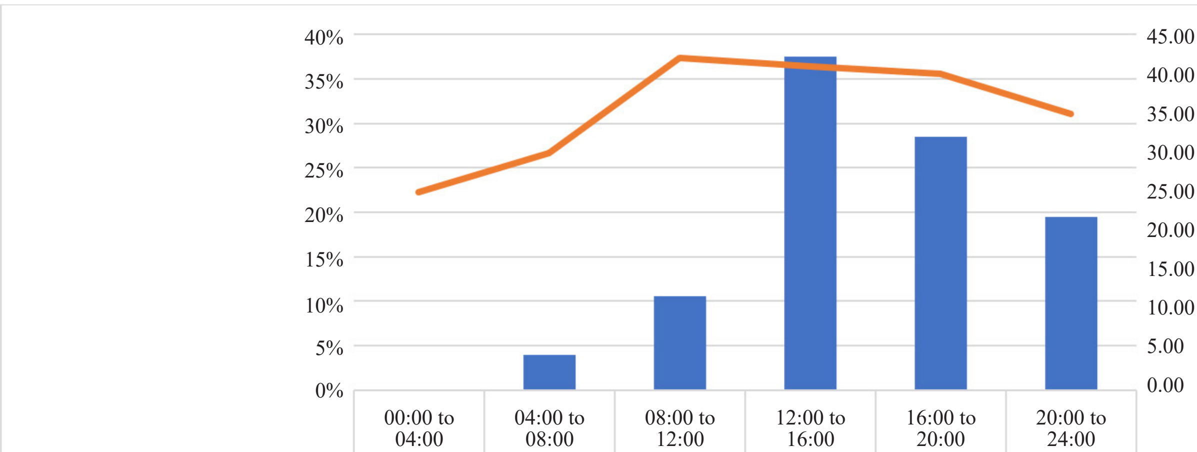
There are many reasons why utilisation was low, and it was discussed extensively with both the sustainability officer and the fleet manager. The typical pattern of use of a fleet vehicle is a day trip between two sites of the organisation. The vehicle is unused all day at the second site while the driver attends a meeting. The car is then returned to its original site at the end of the day. Given this type of use, it is difficult to generate significant improvements in utilisation. Based on the data and assuming that a different lease contract allowing fewer miles per year could be negotiated, it was estimated that the best possible performance would be an average utilisation rate of 70%. In Figure 2, the 70% utilisation frontier is therefore an example of an asset frontier.

Therefore, Figure 2 provides an empirical illustration of Schmenner and Swink's (1998) theory of performance frontiers as follows:

- An operations frontier (the thicker frontier in Figure 2): performance is constrained by the operations policy (the way in which cars are booked and for which purpose). In the applied research project, it was concluded that it is not currently possible to improve performance beyond an average utilisation of 50% with the existing policies.

- An asset frontier (the 70% utilisation frontier): Shifting performance to that frontier is achieved by changing the asset. In this case study, this would consist of revising the lease contract for the fleet by reducing allowable contractual miles.
- A technology frontier (e.g., the green electricity frontier): The improvement in performance in this example would be achieved by charging the electric cars in the fleet only with green energy. Although it is possible to compute the impact of this improvement and to draw the frontier, it is impossible to implement it until new technologies (e.g., energy storage and dynamic national grids) become available. Should this technology become available, performance would improve without changing the operations policy (how and when to book cars) and the asset (allowed mileage in the contract).

The fact that electric cars were used very conservatively raised another issue, illustrated in the charging pattern shown in Figure 3. Figure 3 shows the probability that an electric vehicle was being charged at different times of the day and compares it to the average electricity demand curve in the UK. It confirms the findings of other researchers (Eraut, 2016; Morrissey et al., 2016), as it shows that cars are being charged at the worst possible time from the perspective of an electricity producer. Ideally, electric car charging should take place off-peak in order to level out aggregate demand.



	00:00 to 04:00	04:00 to 08:00	08:00 to 12:00	12:00 to 16:00	16:00 to 20:00	20:00 to 24:00
Probability of charging	0%	4%	11%	37%	28%	20%
National demand (GW)	25.00	30.00	42.00	41.00	40.00	35.00

Figure 3. Probability of a car charging for different time intervals compared to national electricity demand pattern

Figure 2 suggests that an immediate follow-up project should concentrate on improving utilisation, for example by developing an optimal scheduling of a mixed fleet (Goeke & Schneider, 2015), considering environmental impact (Gusikhin et al., 2010), vehicle reservation (Lu et al., 2018), and recharging time windows (Macrina et al., 2019).

This idea did not generate much enthusiasm though. Instead, there was a much higher level of interest in the organisation about exploring the topic of energy integration (Hu et al., 2016), shifting the search on Figure 3. This idea had been discussed by all parties (including the author) from the outset of the project and is aligned with ongoing research projects, for example, the Energy Technology Institute's Consumer Vehicles and Energy Integration Project (CVEI; Eraut, 2016). The purpose of energy integration is to align local behaviour to address national concerns about electricity supply, such as the intermittence issue posed by offshore wind production. An energy integration approach advocates storing intermittent energy when it is available. For example, Coignard et al. (2018) recommend that electric vehicles in California should be used as large-scale distributed storage to help the state's grid to better utilise intermittent renewable energy production. In the context of the focal organisation, energy integration resulted in two questions: (1) how much savings could be generated by switching to a multi-rate electricity contract, and (2) could electric cars be used to resell electricity to the grid at peak times and by charging them off-peak?

Disappointingly, adopting a multi-rate electricity contract resulted in a 9% increase in the cost of charging cars. Figure 3 shows that cars are typically charged during the peak period, and using a multi-rate system means that charging is more expensive than a flat rate at that time. The time window where the rate is the lowest (22:00 to 07:00) is when almost no charging takes place.

A recommendation was made to postpone the charging of cars returning to the main site so that charging would start after the peak. This would result in a 16% reduction in charging costs. Finally, a simulation of reselling electricity to the national grid was performed. When cars are returned to the main site, their remaining battery power is sold to the grid. The cars are recharged later in the middle of the night. This would reduce the cost of charging the cars by 70%, assuming no changes in their usage patterns. However, it is important to stress that this cost reduction applies only to variable costs, i.e., £0.03 per mile. These variable costs represent only 4.4% of the life cycle cost per mile. In other words, the 70% cost reduction is so small in £/mile that it would result in a minor downward shift of the 50% utilisation performance frontier in Figure 2. Additionally, it is likely that the cost of setting up postponed charging operations and reselling electricity to the grid may offset this benefit.

The project ended with the conclusion that electric vehicles were currently more expensive to operate and that acquiring them was not a straightforward "win-win" business case.

4.1 *Reflection on the case study*

The behavioural theory of the firm has never been used to investigate management efforts to tackle sustainability. This paper argues that this is an oversight and that the behavioural theory of the firm offers many powerful conceptual lenses through which the relationship between strategy, management, and sustainability can be better understood. The narrative of the applied research project in the previous section is akin to a collective search process (Cyert & March, 1992), where different search directions have been explored in the hope of ultimately discovering a satisfactory solution. The applied research project is a perfect example of a "probe and learn" search process, as described by Lynn et al. (1996).

The key tenet of the behavioural theory of the firm is that managers cannot optimise profits by following a set "optimal" strategic plan (as the classical theory of the firm suggests). The argument can be extended to sustainability: for reasons to be discussed later, managers cannot transform their firms into perfectly sustainable businesses, but they can search for ways to become more sustainable. The applied research project is a case study of a coalition wanting to lower environmental impact by transforming a traditional fleet into an electric vehicle fleet. This was not possible in the absence of a business case, and therefore, a first direction of the search was initiated: that of searching for data that could be used to make this business case. As the results did not support a business case, a new direction of search emerged: that of linking the fleet to the solar farm operated by the local government organisation. Although it does not reduce the cost of the fleet, it would mean a significant decrease in environmental impact (cf. Figure 2). As this link was a moot point, the next direction of search was energy integration, which turned out to have even less of an impact on the organisation. This is not to criticise energy integration projects as energy integration is an important issue with operations implications, but the core benefits of these projects are incurred at the level of grid operators and society at large.

It is interesting to note how, despite the fact that a more promising direction of search (improving utilisation) had emerged, all parties preferred "pushing on" (Schelling, 1984). This means that until a point has been reached where the goal (cheap electric vehicles) has been reached, the actors just push on with the search. If not careful, this can easily result in an escalation of commitment to a course of action (Staw, 1981).

When assessing an organisation's management of sustainability, many will ask to see a sustainability strategy. If presented instead with the four electric vehicles probe described in this paper, it is likely that an external party may be quite critical. The results of the probe were indeed disappointing in many respects, but this does not mean that the probe performed by the organisation was a case of irrational behaviour (Brunsson, 1982) or that it was unnecessary, as much learning took place:

- The booking rules for the electric vehicles were changed during the project, and an increase in utilisation was achieved, reducing operating incremental cash outflows for the organisation and total annual fleet emissions.
- Further analysis (not reported in this paper) looked at charging infrastructure and the maximum number of electric vehicles that the fleet could have without affecting car availability.

- The fleet manager was planning to change the lease terms so that utilisation rates would become higher and the overall fleet cost would be reduced.

In the terminology of the behavioural theory of the firm, the research work performed in this case study was an experiential search that came to counterbalance the overly enthusiastic cognitive searches (Gavetti & Levinthal, 2000) stimulated by sustainability and energy policies which results in "pushing on" (Schelling, 1984) for technologies that have yet to become practical options. The performance frontier framework used in this paper shows how strategic initiatives seeking to improve sustainability can be structured in operations frontiers (which operations managers are accountable for reaching), asset frontiers (which require innovation backed by strategic investments), and technology frontiers (which should be part of strategic foresight exercises). If there are conceptual confusions between these different frontiers, there is a risk that managerial efforts will be misdirected or wrongly criticised.

Even though corporate efforts to become sustainable are often disappointing, the value of strategic initiatives underpinning searches for sustainable practices should be assessed not by bottom line and emissions reduction figures, but by the learning that took place. It can be argued that the discovery of second- or third-generation probe projects is more valuable than a short-term emission reduction if they result, over time, in a significant shift in the performance frontier.

5. Discussion

5.1 *The case for trade-offs*

It is common to see researchers criticise probe and learn projects as being unsustainable as they achieve too little. For example, Pagell and Shevchenko (2014, pp. 46-47) criticise sustainable supply chain management research that "focuses on the familiar" and that "reduces, rather than eliminates harm". Although it cannot be denied that corporate claims to sustainability can be controversial (e.g., Ihlen, 2009) and can amount to greenwashing, the research community should be careful about not recognising the value of seemingly "low impact" probe and learn sustainability initiatives. A probe and learn sustainability project is about learning where the constraints/performance frontiers are, documenting and measuring them (e.g., Figure 2), and preparing the next probe and learn project. For example, in this paper's case study, the directions of searches that were identified and explored were (i) the link to the solar farm, (ii) mathematical optimisation of fleet scheduling, (iii) energy integration, and (iv) improvement through booking rules and a change to the lease agreement. The organisation went for option (iv), which, to its credit, is the most practical and "in the money" search direction.

Going for option (iv) means better economic performance for the organisation, and a small improvement in environmental performance, as it encourages prioritising the use of electric vehicles. This win-win improvement can be visualised in Figure 2 by drawing an improvement path between the "diesel example" point and the "EV" point, or between the "diesel, 50%" point and the "EV, 70%" point.

This vehicle-level win-win effect does not mean, however, that it creates a business case for electrifying the whole fleet. In Figure 2, trade-off curves were stylised as curvilinear to follow the operations management research tradition. There is not enough data in this dataset to confirm the exact shape of the trade-off curves, but enough to compute an average (linear) marginal rate of substitution: a £2.79 increase in cost for a 1 kg reduction in CO_2 equivalent (on the 50% utilisation performance frontier). This is a much higher implied carbon price than the £30 per ton (£0.03 per kg) recommended by the Grantham Research Institute (2011) to achieve current target emissions. Even when using a carbon price of £70 per ton (the 2,070 recommended rate) and considering the difference between a conventional vehicle and a green electric vehicle with almost zero life cycle emissions, a rational manager would still be better off using conventional vehicles (adjusted cost including carbon price of £0.38 per mile) than an electric one (£0.5 per mile). In this case study, there are simply no large-scale, fleet-level, win-win alternatives. Trade-offs do constrain what the organisation can achieve in terms of performance.

5.2 *The resurgence of the trade-off debate*

The applied research project was sponsored by win-win advocates but performed by a researcher with an awareness of trade-offs. The project could be argued to be a microcosm of the wider sustainability research community, where advocates of both schools of thought coexist, each ignoring the evidence put forward by the other side. Based on the experience gained from this project, the theoretical proposition of this paper is that the root cause for the revival of the trade-off debate in the field of sustainability is an ontological divide created by the lack of a universal definition of what is meant by sustainability.

Although the United Nations (UN) Brundtland report definition of sustainability and the triple bottom line framework are commonly agreed upon in terms of providing a working definition, both Owen (2003) and Gray (2010) point out that there are many definitions of sustainability but little consensus around them. This ambiguity is why Pagell and Shevchenko (2014) and Shevchenko et al. (2016) focus their research on what they call 'true sustainability', implying much research is about flawed, or overly equivocal, conceptualisations of sustainability. True sustainability is defined by Pagell and Wu (2009) as follows:

> To be truly sustainable a supply chain would at worst do no net harm to natural or social systems while still producing a profit over an extended period of time; a truly sustainable supply chain could, customers willing, continue to do business forever (p. 38).

Measuring "net harm" can be difficult in practice, though, and a complementary perspective on defining sustainability is that of planetary boundaries (Rockström et al., 2009). These define a safe operating space for humanity by defining environmental thresholds that cannot be transgressed. The thresholds are, however, only meaningful at a planetary level, and translating them for smaller units of analysis (e.g., an industry or a supply chain) is challenging. Gray (2010) argues that translating them at the firm level becomes a meaningless exercise and challenges all corporate claims to sustainability on that basis. Gray (2010) departs from the pragmatic and tangible definitions discussed above but also argues that the concept of sustainability incorporates a "true" dimension. Instead of rooting definitions in physical phenomena (from which concepts such as thresholds and impact can be derived), Gray (2010) proposes that sustainability is an aspirational aesthetic ideal where economic, social, and environmental activities are assumed to be, one day, in a stable dynamic equilibrium.

The stark contrast between a tangible and practical definition (UN, planetary boundaries) and more aesthetic ones (Gray, 2010; Pagell & Shevchenko, 2014) explains why the topic of sustainability is so divisive. On one hand, a critical, technocratic realist school of thought invites researchers to look for constraints and trade-offs to document problems and challenges and reflect on what can be achieved. On the other hand, an aesthetic school of thought akin to the Romantics reject these practical considerations and seeks evidence of the win-win paradigm, the validity of EMT theory, and the attainment of true sustainability through the adoption of radically innovative approaches. This state of affairs, where different coalitions emerge when there is ambiguity around what the objectives of an organisation are, is a well-known phenomenon in the behavioural theory of the firm (Cyert & March, 1992).

From this perspective, efforts to become sustainable can be framed as a set of distinct search processes which are derived from different coalitions formed by different actors (e.g., firms or supply chains) that have adopted different principles of search (e.g., ecoefficiency, complying to a standard, offsetting, and innovating). Because of the ontological divide discussed above, some directions of search, such as those including incremental innovation, have been scrutinised and criticised for not seeking true sustainability (Khavul & Bruton, 2013; Shevchenko et al., 2016). An incremental innovation approach can indeed be perceived as a tedious and ineffective way to become truly sustainable. Yet, the behavioural theory of the firm suggests that a series of incremental probe and learn processes can be the best approach to achieving significant innovation (e.g., cellular phones and optical fibres; Lynn et al., 1996). Thus, the resurgence of the trade-off debate comes from two fundamentally opposed ontologies of sustainability that each imply a specific implementation process (incremental or radical innovation) through which firms and supply chains can become sustainable.

5.3 *Radical innovation: Facts and fantasy*

This paper thus argues that small-scale, low-impact sustainability initiatives can be valuable if they result in learning. The opposite view would be to argue that it is not the case and that only firms committing to radical innovation can become sustainable. How much confidence can we have in this latter argument?

Sorescu et al. (2003) state that past research has overlooked both the process and the financial value of radical innovation. The scarce returns to radical innovation have been a contentious issue for long enough to question the validity of well-established theories such as first-mover advantage (Golder & Tellis, 1993). Real options scholars have proposed counterpoints such as second-mover and follower advantage (Cottrell & Sick, 2002) that discourage the pursuit of radical innovation. Sorescu et al.'s (2003) insights from the pharmaceutical sector are that only a minority of firms engage in radical innovation and those that do experience very variable financial rewards. Xin et al. (2008) used event study to research the relationship between radical innovation and profitability as they are, like Sorescu et al. (2003), concerned that past research is based on self-rated measurements of innovation. Their results show that radical innovators are better able to maintain sales growth and profit margin, but not overall profitability, as measured by return on assets. Xin et al. (2008) results also show that firms experience a decline in profitability after the introduction of a radically innovative product.

One of the most poignant accounts of the ambivalent relationship between business success and radical innovation is Broustail and Greggio's (2000) historical analysis of French car maker Citroën before its acquisition by Peugeot. It shows that Citroën's business model was highly unconventional and based on a culture of radical innovation, entitled *le messianisme technologique* by Broustail and Greggio (2000). There was no corporate strategy, aside from the adherence to breakthrough innovations. These breakthroughs were achieved from the 1930s to the 1970s by hiring aerospace engineers rather than traditionally trained automotive engineers. There was no marketing department, and the new models were so innovative that they enjoyed very long maturity phases, often in excess of 20 years (50 years for the 2CV). There was no intent target market with most car models sitting across multiple segments targeted by competitors. Despite the poor reliability of products in the first years after their launch, Citroën benefited from a loyal customer base and generated profit as the long maturity phases offset the costs of radical innovation. It was nearly bankrupt before its acquisition by Peugeot, in a typical cash shortage-induced profitability crisis following the release of a new model, echoing the research findings of Xin et al. (2008). Broustail and Greggio (2000) describe at length Peugeot's corporate efforts to eliminate the innovation culture within Citroën post-acquisition in what is possibly the only ever published case study of change management seeking less innovation. Broustail and Greggio (2000) conclude that Citroën's approach to business was unique and valuable and that it ceased to exist because it could not withstand the competition of more careful incremental innovators. They, however, deplore this conclusion and conjecture that there must be a way through which a radical innovator like Citroën could prevail in industry, thereby only supporting in principle a well-rooted (possibly nostalgic) belief in popular thinking about the supremacy of radical innovators.

March's (1991) exploration vs. exploitation framework offers a behavioural perspective to challenge this conjecture. His conclusion is that there is an optimal trade-off between exploration and exploitation activities and that the optimal point does not imply a predominantly innovative behaviour. Shevchenko et al. (2016) develop a mathematical model to compare the innovation risk of a firm seeking true sustainability and firms offsetting controversial operational practices to avoid reputation risks. They provide a narrative of calculating and selfish managers who focus only on the bottom line and dismiss serious investment in sustainability because stakeholders' pressures are not sufficient to generate significant reputation risk.

However, when the same trade-off is considered in the light of the track record of radical innovation, the behaviour can be described as prudent and responsible rather than selfish. If the mathematical model was revised to consider the value of learning as in this paper's case study, the conclusion may not stand. This alternative interpretation is aligned with March's (1991) exploration vs. exploitation framework and amounts to stating that there is an optimal trade-off between exploring options to become sustainable while continuing business as usual. This interpretation is also consistent with the research of Du et al. (2013), who argue that in the context of sustainability, managers have to deploy innovative technologies that combine and balance the search for profits with the search for sustainability. A similar conclusion is reached by Calic et al. (2020), who argue that the apparent paradox of considering both financial and sustainability targets results in innovation opportunities.

Thus, the alluring idea that a series of radical innovations will lead us to the sustainable business ecosystems of the future in a clean and parsimonious 'leapfrog' industry transformation is, sadly, likely to be a fantasy. Firms operate in constrained environments and trade-offs exist at a corporate level (as documented in this paper's case study) but trade-offs also prevail at a macro-economic level. The ongoing debate in the research literature about whether or not it pays to be green (Ambec & Lanoie, 2008; Figge & Hahn, 2012; Orsato, 2006; Yadav et al., 2016), and the diversity of this debate (Goyal et al., 2013; Hussain et al., 2018), illustrates the compound risk that firms face when investing in innovative sustainability solutions: innovation is risky in its own right, but even more so when the payoffs are uncertain or not guaranteed by institutions and stakeholders at large (Shevchenko et al., 2016).

The implication of this compound risk is that radical innovation for sustainability if sought, would have to be orchestrated at the level of National Innovation Systems or global institutions. In contrast, managers do not necessarily have the foresight, knowledge, and innovative capability to solve the sustainability challenges that they face, as the root causes of sustainability issues may occur in remote supply chains and industries. This was illustrated in this paper's case study with the short-lived search for the benefits of energy integration.

6. Conclusions

Although the case study presented in this paper did not result in a significant environmental performance improvement, it was a useful probe and learn search process that helped participants to visualise economic-environmental trade-offs and identify directions for betterment and improvement. In this specific case, only traditional operations improvements were possible, and a betterment of environmental practices was only possible if major innovations occurred in other sectors. We argue that this case study is a realistic portrait of the sustainability challenges faced by most operations managers.

The vast majority of managers are financially constrained to seek win-win projects, and this in turn provides (self-fulfilling) evidence to researchers that "it pays to be green". A probe and learn project such as the one presented in this paper would be criticised either for failing to significantly improve environmental performance or for being too risk-averse in terms of innovation. Yet, it provides valuable learning insights both in terms of short-term performance improvement and in terms of planning for the fleet of the future.

There is an urgent need, both within the practitioner and research communities, to accept that Wickham Skinner's recommendations about only making investment decisions after considering trade-offs (and, by extension, performance frontiers) are topical today as we try to improve the sustainability of operations systems. Embracing the trade-off concept means better understanding what stops us from becoming sustainable, what we need to learn to progress the search for sustainability, and, at the policy level, identifying wider infrastructure changes that are required to provide collective, macro-level opportunities for improvement.

Declaration of interests

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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