Strategic trade-offs and sustainable supply chains

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Abstract
Supply chain management researchers typically do not concern themselves with social acceptance. This is paradoxical as processes of social acceptance shape supply chain networks, influence location decisions, and define the underlying values from which supply chain design principles are formulated. Through a case study of the UK electricity supply chain and the decision not to build the Navitus Bay wind farm this paper concludes that the decision was the result of political processes that marginalise or ignore genuine sustainability trade-offs. It is unlikely that a truly sustainable electricity supply chain can ever be designed if such practices continue.

Keywords: energy supply chain, trade-off, sustainability

Introduction
Should electricity supply chains be designed to utilise renewable energy sources such as wind power? In the light of many national and supra-national initiatives to reduce carbon emissions and to adopt a sustainability agenda, the answer to this question seems an obvious yes, but reality is more complex as 75% of wind power projects are abandoned at the consent stage and this despite a majority of the public being in favour of wind power (ReNews, 2015).

Social acceptance is a well researched subject in the social sciences but it has never been a subject of inquiry in supply chain management research. This is paradoxical because processes of social acceptance shape supply chain networks, influence location decisions, and define the underlying values from which supply chain design principles are formulated. There is a prolific literature on sustainable supply chain management that has historically focused on controlling for the environmental impacts of supply chains with very few works integrating the three dimensions of sustainability (Seuring and Muller, 2008). The research objectives of these papers could therefore be summarised by: 'given an existing supply chain, what can be done to make it greener?'. Translated into the energy supply chain context of this paper, a similar question would be: 'how many wind farms should be built in the UK to reduce carbon emissions by 25%'?

The answer to this question is easy to determine as it falls within 'substantive sustainability', i.e. questions that can be answered by applying scientific and engineering principles (Del Rio and Burguillo, 2008). As explained above, this is not currently where the challenge lays in terms of designing a sustainable energy supply chain. The challenge instead is with what Del Rio and Burguillo (2008) call 'procedural sustainability', the set of local social processes through which a decision to build (or not) a wind farm is made. A practical example of the impact of procedural sustainability is the fact that in the UK only 25% of planned wind farms are actually build, despite a public majority being in favour of wind energy. Bell *et al.* (2005) describes this discrepancy as the social gap, and contrasts it with the individual gap, the possibility that a supporter of wind energy will oppose a local development for personal reasons, a phenomenon widely documented in the literature as the NIMBY (Not In My Back Yard) effect. Bell *et al*. (2005) further argue that these two gaps have three explanations:

- The *democratic deficit* explanation is the fact that a small minority is powerful enough to oppose the majority's view. A minority of Wind power opponents can dominate the permitting process.
- The *qualified support* explanation is that opinion polls capture the support for wind power but do not document the conditions of this support. An example would be to oppose a wind farm if it has a negative impact on avian populations but to support developments that do not have such an impact.
- The *self-interest* explanation equates decision making with a multi-person prisoner's dilemma and propose that an individual decision maker may find the cost of his/her contribution (e.g. accepting the visual impact of a development) too high to justify the 'common good' benefits of the project (clean energy generation).

Bell *et al*. (2005) conclude that *'all three [explanations] may play some role in the generation of the social gap but further empirical research would be required to make a sound judgment about their relative importance'* (p. 466).

This paper's main proposition is that the task of understanding this relative importance can be performed through trade-off analysis (Da Silveira and Slack, 2001; Slack, 1998) and the theory of performance frontiers (Schmenner and Swink, 1998). This means that instead of addressing a traditional sustainable supply chain design research question such as 'how many wind farms should be built in the UK to reduce carbon emissions by 25%' this papers uses trade off analysis to better understand the social gap and to answer the following research question: 'what are the societal processes and values that currently stop us from improving the sustainability of the UK electricity supply chain'?

Electricity Supply Chains

Most of supply chain management research focuses on multi-echelon inventory systems and is concerned with the timely flow of physical goods from extractors/producers to end consumers. An electricity supply chain is similar but presents a number of unique characteristics. When compared with traditional manufacturing supply chains the key difference is that the product flow is continuous rather than discrete and that the product (electricity) cannot be stored. This statement is not entirely accurate as electricity storage is a key research area today. However, there are very few commercial electricity storage facilities in operation. In the UK, the only storage installations are pumped storage and they make up less than 1% of UK electricity supply. This means that to understand how the electricity supply chain works, it is easier to visualise a system where supply should match demand in a synchronous fashion. This means that balancing supply and demand has to be done in real time at a national/international level. In production planning terms, this means that a chase strategy is currently the only option. Given the real time nature of electricity demand volatility, this chase strategy appears extremely challenging, especially if one takes into account the fact that many power plants can take a long time to start up. Not being able to supply the right amount of energy would result in power cuts. Although demand is volatile, both daily and across seasons, it is fairly easy to predict when peaks and troughs will take place. This means that power stations can be scheduled to match demand variations. A second factor that facilitates the implementation of a chase strategy is frequency regulation. When demand exceeds supply, the frequency of the network will decline and energy reserves are released to compensate for this drop. Frequency regulation is used to smooth out small supply-demand gaps but cannot cope with a persistent difference between demand and supply.

Generation is the upstream end of an energy supply chain. The key supply chain design questions to address are which energy sources to use. There are many variables to consider: the availability of the raw material, its cost, the cost of the generation facility, the by-products of the process (e.g. CO_2, nuclear waste), etc. Countries have to identify what is their optimal energy sources portfolio. Historically the UK has relied heavily on coal power which represented nearly 70% of supply in 1990. This has reduced to about 30% today (DECC, 2015) due to the air pollution concerns. Both gas and nuclear power plants have grown in the UK portfolio to represent 30% and 20% respectively (DECC, 2015). The new energy source in the portfolio is wind with 10% of the total energy supply in the UK in 2014 (DECC, 2015). With wind, the raw material is free and production does not generate any air pollution. Wind is however an expensive energy source: this is because of the cost of wind farms but also because wind is an intermittent energy source. Electricity is only generated when there is wind. Most wind farms in the UK have load factors ranging from less than 20% to 50% of theoretical capacity. This means that wind energy only works if other sources can be used in the absence of wind. These 'standby' power generation sources are expensive as load factors are inevitably low. The remaining 10% of UK electricity comes from pumped storage, hydro, biomass, solar and imported electricity from interconnectors with France, the Netherlands, and Ireland.

The next two stages of the supply chain are transmission and distribution (Pansini, 2005). Transmission is the high voltage transportation of electricity from power plants to substations. Distribution is the low voltage transportation of electricity from substations to consumers. Network design and location decisions are the typically supply chain design issues for this part of the supply chain, but it is important to realise that it heavily constrains the development of new power plants. A new power plant is only possible if it is economical to connect it to the transmission network and if this trunk of the network has available transmission capacity.

Electricity retailing is the last stage of the supply chain before consumption. In many countries this is a monopoly market. In the UK, electricity retailing is a fully competitive market since 1999. The extent to which electricity retailers have created value for consumers is a debated matter though (Joskow, 2000). The retail market is characterised by its low sophistication in terms of revenue management as retailers use set prices and as there are no attempts to balance supply and demand through market-side mechanisms, at the exception of consumers using storage heaters.

Sustainable Supply Chain Management

Sustainable supply chain management has traditionally been defined by juxtaposing definitions of supply chain management with that of sustainability: '*To be truly sustainable a supply chain would at worst do not 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'* (Pagell and Wu, 2009, p. 38). In this respect, almost all sustainable supply chain research is based on the definition of the Brundtland commission's: to balance the needs of the present and the future by considering the 'triple bottom line': environment, economy, and society.

Through a review of the literature, Seuring and Muller (2008) note that the majority of sustainable supply chain research is focused on the environmental performance of supply chain, i.e. on making supply chains greener. Pagell and Shevchenko (2014) extend this commentary in a position paper where they argue that too much research on sustainable supply chain management is about unsustainable supply chains. They argue that past research has focused too much on the 'familiar' at the expense of radical innovation. In other words, too much research is based on inherited supply chain designs and does not attempt to challenge these designs. Pagell and Shevchenko (2014) conclude that extant research is about 'harm reduction' and not about 'harm elimination'. One reason why the scope of sustainable supply chain management is too narrow is what they call the 'primacy of profits', i.e. the fact that in practical decision making, the economic dimension is often given more weight than the environmental and social dimensions. This tends to narrow successful examples of sustainable supply chain to solutions that reduce cost whilst increasing environmental performance. Finally they identify the ability of measuring supply chain impacts as a key challenge, which is often linked to methodological issues.

Much of Pagell and Shevchenko (2014)'s argument can be observed in the electricity supply chain in the UK. Much of the focus of the energy policy literature is on the adoption of renewable energy sources, with wind energy in the limelight due to its technological maturity. As wind is free, naturally renewed, and produces nearly no carbon emissions, it may appear to be a case of 'harm elimination'. However, due to its intermittent nature, wind energy requires standby power generation if it used as baseline supply. Both the very low load factors of wind farms and the fact that standby power generation facilities are needed have a very negative impact on production cost. This is why wind energy is often criticised as being too expensive and why it is not really 'harm elimination'. It is estimated that through learning curves and the design of larger turbines that offshore wind energy will be competitive by 2020. Yet, the cost of wind energy has become a political issue and the withdrawal of subsidies and government backing is hurting the sector, suggesting that the 'supremacy of profit' is indeed at work in this sector, and that the electricity supply chain is an example of a supply chain where an improvement in environmental performance increases costs. When considering the cost of offshore wind electricity, Leseure (2015) argues that there are three alternative pathways to cost reduction to those considered by the industry. These three pathways are the reduction of transaction costs by reducing the cost of consenting, the reduction of transaction costs through better contracting practices, and the reduction of cost by increasing wind farm utilisation through sales and operations planning. None of these ideas are getting much traction with the industry because they challenge the 'familiar', even though there are also engineering reasons to challenge the existing transmission and retail network design. This complements the importance of the question raised in the introduction: the question is not so much how many wind farms the UK should built but how should the electricity supply chain be redesigned so that wind farms can become effective energy generation facilities. The engineering literature confirms that a more innovative supply chain based on a dynamic grid, storage facilities, and sales and operations planning capabilities would be a truly sustainable supply chain as defined by Pagell and Shevchenko (2014).

Linking Supply Chain Design to Social Preferences

The disconnect between supply chain research and social preferences is paradoxical because social acceptance is the shaping force of the familiar. If the familiar cannot be challenged and changed, truly sustainable supply chains cannot be conceived. It is also paradoxical because most of operations management's best practices are based on the principle of deriving design specifications (for product or processes) from customer needs. At a strategic level this is done through strategic trade off theory. Slack (1998) documented the concept of strategic trade-offs at the same time that it was used to develop the theory of performance frontiers by Schmenner and Swink (1998). These papers focus on what Da Silveira and Slack (2001) call the sensitivity of the trade-off, i.e. understanding the physical reality of the trade-off in operational terms. Leseure (2010) describes strategic trade-offs as the interface between the positioning decisions of marketing and the resource decisions made by operations managers. This second dimension of strategic trade-offs is what Da Silveira and Slack (2001) call the importance of the trade-off, i.e. the impact that it will have on overall competitiveness. Thus, strategic trade-off theory contains a means to both capture the voice of the customer by analysing the importance of product performance dimensions and the adequacy of an operations system to perform along these dimensions.

In order to use trade off theory to design sustainable supply chains we need to formalise what a general theory of strategic trade-offs would look like. Let us consider a supply chain whose performance is assessed collectively by a {K} set of stakeholders considering a {P} set of individual performance measures. The nucleus of trade off theory is sensitivity, which can be expressed as shown in equation 1:

$$\Delta p_i = -s\Delta p_j \tag{1}$$

Equation 1 shows that a change in one performance dimension will result in an opposite change along another performance dimension. The actual impact of one variable on the other is captured by the parameter *s* which measures the sensitivity of the trade-off as defined by Da Silveira and Slack (2001). Note that this trade-off relation is not a function of the views of stakeholders as it relates to physical characteristics of the system. It is possible for *s* to be nil, and it is possible that not enough scientific evidence is available to determine what the value of *s* is. Figure 1 illustrates equation 1 by looking at the trade off between the cost of electricity generation from different sources and their lifecycle CO_2 equivalent. Figure 1 shows that if coal is replaced with onshore wind a relatively small change in price will result in a substantial decrease in CO_2 emissions. This high sensitivity is significantly decreased if the cost of standby generation is taken into account. This is an example where computing *s* is complex as the right way to estimate the lifecycle cost of standby generation is much debated amongst experts. A regression analysis on figure 1's data reveals that the aggregate *s* value in figure 1 is 6, meaning that a one unit increase in the price of energy from adopting cleaner sources leads to a decrease of the lifecycle CO_2 equivalent by 6 units.

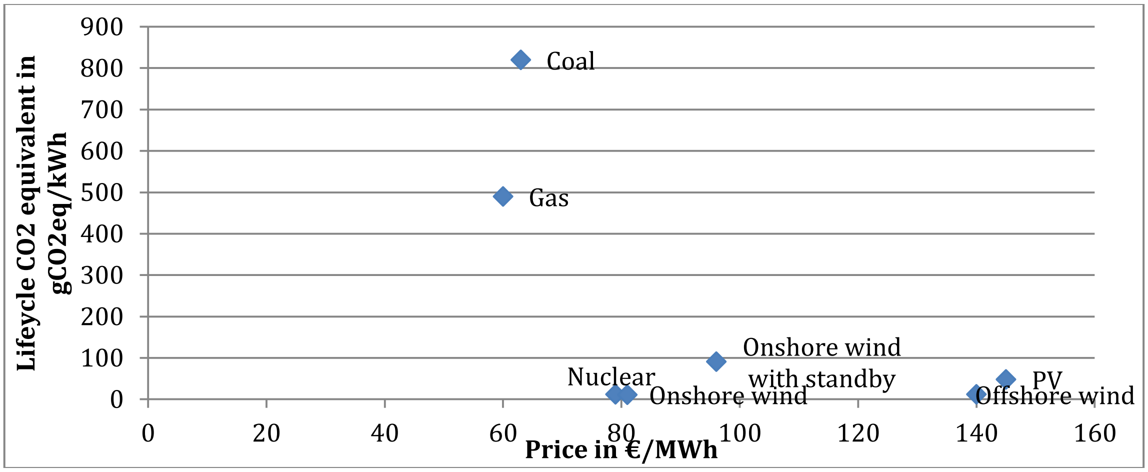

Figure 1. Price vs. Lifecycle CO2 equivalent trade-off.

A general formulation of trade-off theory needs to also take into account the importance of the trade off as perceived by the different stakeholders. w_i^k is the importance of performance dimension *i* according to the stakeholder *k*. The perceived utility *U* of a supply chain to society can be defined as shown in equation 2.

$$U = \sum_{i=1}^{N} \sum_{k=1}^{K} V_k \, w_i^k u_i p_i \qquad (2)$$

U_i is a utility unit conversion factor as the performance measures are typically expressed in different units. It could be a factor converting all factors to a cost measure or the weights of a multi-attribute utility function. V_k represents the weight of the voice of stakeholder group *k*. This could be voting rights if a democratic process is used, or a measure of the strength of the voice of these stakeholders. This later notion captures the respective engagement/participation of different stakeholders but also the ability of political processes to make a stakeholder voice more powerful through legitimacy and mobilisation processes. When Pagell and Shevchenko (2014) force of familiarity is strong, the product $V_k W_i^k$ will be high. Note that other formulations of equation (2) are possible: they are not presented in the interest of space.

Case Study

In order to illustrate the way in which social processes shape supply chains and their sustainability, this paper uses the recent UK government decision to refuse permission to build the Navitus Bay wind farm (BBC, 2015). The Navitus Bay project was a large wind farm project off the coast of Dorset and the Isle of Wight to be developed by Eneco Wind UK Ltd. and EDF Energy. If built, this would have become the largest commercial offshore wind farm in operation, although there are plans to build larger wind farms in the North Sea in the future. A first public consultation was launched in 2012 and resulted in a reduction of the size of the project. Public opposition gained momentum and a 'Challenge Navitus' interest group was created. Further consultations led to further changes to the project and the planned number of turbines was reduced again. The final revised plan was rejected by the Planning Inspectorate in September 2005 due the visual impact the development would have on this touristic region which includes a World Heritage Site. An historical record total of 2,700 representations were received by the Planning Inspectorate. The methodology used in this paper was to review systematically the arguments of the different stakeholder groups through the press, reports, and websites of these groups. Summary data is shown in appendix 1.

Analysis

In this section we analyse the content of appendix 1 (and the set of documents that it is derived from) from the perspective of equation 2. The key question is: if the positions expressed in table 1 were rewritten as an analysis of the strategic trade-off of the UK electricity supply chain, what would equation 2 look like? In table 1, there are basically 3 underlying answers to this question: the green answer, the social answer, and the social multi-criteria evaluation answer.

The green answer (stakeholders 2, 4, and 6) is typically constructed around a list of performance dimensions which is consistent with the energy policy literature. Higher importance weights are given to carbon emissions and local job creation. In this representation, equation 2 becomes equation 3:

$$U = W_{Carbon}p_{Carbon} + W_{Energy\ Industry}p_{Energy\ industry} + W_{cost}p_{cost} \tag{3}$$

As cost is never actually mentioned by the stakeholders it is reasonable to assume that they either view W_{cost} as very low or nil. As such, the green answer is a 'at any cost harm reduction' voice and as such wider sustainability concerns are not considered.

The social answer (stakeholders 1 and 3) is constructed in a similar but ideologically opposed fashion to the green answer. The most important performance dimension is the visual impact of the wind farm as measured by its knock-on effect on the tourism sector. A number of other dimensions are considered as shown in equation 4:

$$U = W_{view}p_{view} + W_{wildlife}p_{wildlife} + W_{noise}P_{noise} + W_{carbon}P_{carbon} \tag{4}$$

In this utility function, nearly all variables are rated in order to show that the project has a negative utility as the only positive variable which is explicitly considered by the social answer is carbon reduction. Although the P_{carbon} value of a wind farm the size of Navitus Bay would be very high, stakeholders 1 and 3 explicitly state that the W_{carbon} weight of this performance dimension is very low. They acknowledge in writing that they have received government directives to reduce carbon emissions but that these directives make reference only to *decentralised* initiatives and therefore, as the benefits of the wind farm would be national, that this performance dimension is not relevant to them. It is difficult to imagine a blunter expression of self-interest creating the social gap as described by Bell *et al.* (2005).

The social answer instead gives the ultimate priority to the view dimension, and their representation makes frequent recourse to the principle of familiarity. They state 'tourism is the future of Dorset' and 'energy has no place in this future'. Increasing W_{view} is reinforced by an internal research study that quantifies P_{view} with a loss of 5,000 tourism sector jobs out of 25,000. The product of these two factors is such that in equation 4, it would dominate all the other terms. It is noteworthy that there is a substantial body of academic literature on the impact of wind farms on tourism. All conclude that there is either no impact, or an impact for a small portion of potential tourists, and that in any case these impacts can easily be managed (Frantal and Kunc, 2011; Lilly *et al*., 2010; Riddington *et al*., 2010; Westerberg *et al*., 2013).

Finally the social multi-criteria answer (Stakeholder 5) is theoretically speaking the most elaborate as it is the only one that is based on an social criteria evaluation framework (Gamboa and Mundla, 2007) which is aligned with equation 2. Essentially this answer states that the project should be abandoned because $U_{North\ Sea} > U_{Dorset}$. The information presented in table 1 however shows that in writing these equations not all variables are considered nor are the views of the residents of East of England taken into account.

Conclusion

Pagell and Shevchenko (2014) state that "*the majority of ongoing research [in supply chain management] [...] at worst is research on [...] irresponsible supply chain management*" (p. 45). They state that this a facetious comment but the case study of the UK electricity supply chain and of Navitus Bay suggests that this may not be the case. By using a generalised formulation of strategic trade-off theory this paper shows that: (i) substantive sustainability variables are either ignored or based on questionable estimates; (ii) decision are based on perceptual sustainability variables -such as visual impact- that manage to gain a strong familiarity voice; (iii) the expression of opinions of different stakeholders is biased by a democratic deficit and truncated trade-off analyses; (iv) even when a social multi-criteria perspective is used it still lacks in objectivity and completeness. In the case of the UK electricity supply chain, the conclusion is that procedural sustainability dominate the decision making process and that participation in this process is driven by familiarity and self-interest. It is important to note that this paper does not take a position regarding the decision made about Navitus Bay: it only points to the fact that the way in which the decision is made is based on a social gap which excludes any possible input from supply chain management researchers by marginalising their voice and by rating performance measures objectively related to sustainability as not important. There is a significant research opportunity in supply chain management research in documenting with better measures the genuine trade-offs of sustainable supply chain design and reconciling conflicting positions more formally through multi-attribute utility theory. In the case explored in this paper, until this is done, it is unlikely that a sustainable electricity supply chain can ever be implemented.

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Stakeholder	Position	Trade-off specification
(1) Conservative MPs & Bournemouth Borough Council	Tourism is key to the region and the development would have been a 'blight on the landscape'. A study from Bournemouth Borough Council concluded that the negative impact on tourism would cost the area 5,000 jobs and £6.3bn in tourism revenue.	Key performance dimension is visual impact. A textual analysis of the report from Bournemouth Borough Council shows that: • The UK energy gap and energy security are not considered as variables • The supply chain discussion is restricted to a discussion of local impacts and used to stress that energy is not the future of Dorset. • Commitment to carbon emission reduction is discussed but only to state that the Borough's responsibility is to do so in a decentralised fashion. • Noise, wildlife impact are also performance dimensions with negative ratings.
(2) Isle of Wight Council	Key economic opportunities for the island in terms of developing a local supply chain/cluster are now lost.	Key performance dimension is local energy industry. This is viewed as a positive performance measure whereas the previous stakeholder rated it as negative.
(3) Bournemouth Tourism & National Trust	Tourism is key to the region and the development was putting at risk 25,000 jobs.	Similar position than stakeholder 1.
(4) East Dorset Friends of the Earth; other climate change interests groups	Decision is not consistent with government policy about reducing fossil fuel use and climate change.	Performance dimensions are aligned with national and international policies: reduced use of fossil fuels/energy security, carbon emissions.
(5) Challenge Navitus	Argues that the question is not whether or not wind farms should be built but where they should be built. Argues that the decision by the Crown Estate to designate Navitus Bay as an eligible area was flawed. Rejects the label of NIMBY and argues that their viewpoint is that there are better locations to achieve national objectives.	Accepts the importance of carbon emission reduction but only within the context of government plans relative to wind power. No references are made to wider consideration about the UK energy gap, energy security. The argument focuses on promoting the North Sea and suggests wind farm linkages within the North Sea. There is no acknowledgement of environmental issues in the North Sea, nor any acknowledgment of the need to have a geographically diverse portfolio of wind sources to avoid intermittence issues. Repeats the tourism and environmental arguments of stakeholder 1. Tourism argument is reframed by stating that the community should not be asked to take a risk. Further argues that North Sea community do not take such as risk. Adds navigation issues as another negative performance.
(6) South West Labour MP	Decision is not consistent with government policy about reducing fossil fuel use and climate change	Similar to stakeholder 4 and stakeholder 2.

Appendix 1. Content Analysis of Stakeholders Perspectives