Abstract Number: 015-0578

Title: Developing a Configuration Perspective for Sustainable Supply Network Design

Authors: David Allan Kirkwood, Dennis John Lewis, Jagjit Singh Srai

Affiliation: Institute for Manufacturing, University of Cambridge

Corresponding Author Address:

Dr David A. Kirkwood

Institute for Manufacturing,

17 Charles Babbage Road,

Cambridge,

CB3 0FS

United Kingdom

Tel: +44 1223 760504

Email: dak39@cam.ac.uk

POMS 21st Annual Conference

Vancouver, Canada

May 7 to May 10, 2010

Abstract:

The design of global supply networks (SNs) has developed in recent years from traditional lowest landed-cost analysis to the more strategic concept of SN configuration that support the selection of particular archetype structures, i.e. supply networks that enable a broader set of strategic and operational capabilities to be met. These approaches have required the development of supply chain mapping tools that support SN analysis and design.

Whilst industrial systems are a driver in raising global quality of life, they are also a major influence on the global environment. Multinational corporations (MNC's) are placing an increasing level of emphasis on the reporting of their sustainability performance, however a framework does not exist for the holistic measurement of environmental impact across the supply network.

This paper evaluates potential sustainability assessment methods as part of an overall supply network design methodology, and presents an initial approach to developing an integrated view on sustainable supply network design. The paper discusses an exploratory case study of a leading automotive manufacturer, and involves the use of a combination of supply network configuration mapping tools integrated with an ERW (energy resource waste) framework.

1 Introduction:

In this paper, an initial approach to developing a 'sustainable supply network design' methodology is presented, focused on the automotive sector, taking an OEM focal firm perspective. The aim of the research is the development of a generic (cross-sector) approach, that captures the energy, resource and waste footprint of a supply network, together with other strategic and operational considerations (cost, quality, speed, dependability), as part of an integrated network design toolset.

1.1 Supply Networks

The understanding of the importance of supply networks as a critical element of the industrial system has developed enormously from the original functional concepts of logistics and supply chain management. At the same time, changes in the industrial landscape arising from the twin impacts of globalisation and the dissolution of the vertically integrated value chain has led to the understanding that to be truly competitive, innovative and operate in a sustainable manner, the supply network can be a key source of leverage. Numerous studies have shown how innovation is linked to a variety of properties of the supplier network, for example in terms of complexity and understanding of production dynamics [1, 2], whilst the concept of a sustainable supply chain has been understood in terms of cradle to grave (or cradle to cradle in some more recent re-usable life cycle applications) operations management and life cycle analysis (see for example [3]).

Recent work by Srai and Gregory [4] has demonstrated how supply network configuration can influence capability and performance of firms. Supply network configuration may be described in terms of four primary constituent elements, namely the network structure (upstream and downstream); the relationships and governance between network partners; the dynamics of the flow of materials and information between firms; and the way in which the product itself is configured. Initial work examined the ways in which the configurations of these elements were linked to the relative performance of the firms involved, across a range of industrial sectors. More recently, the applicability of supply network configuration theory analysis has been demonstrated in the domain of emerging industries, through exemplifying how successful industrial emergence can, in part, be understood through the ability of key focal firms to reconfigure their supply network to insert successfully into an emerging value chain [5].

In addition, the emergence of new forms of supply network, such as network integrators (e.g. fabless manufacturing) and single product clusters have also provided new testing grounds for the ability of supply network configuration to be linked to industrial performance [6]. In particular, the recent move towards cluster structures within the semiconductor industry, in an attempt to address R&D issues with new technology, can be argued to have had the effect of reducing supply network competitive forces and in part be responsible for the lowering of margins within the sector. What is less well understood is the impact which these new operating paradigms have from the perspective of the sustainable industrial system – for example, rapid mass customisation may lead to reduced waste and WIP, but does it also reduce modularity and the capacity to re-use or re-cycle the products at end-of-life?

1.2 The Sustainability Challenge and Industrial Reporting

The imperative to address the sustainability agenda has been described as one of the greatest challenges for the human race over the coming decades. The combined pressures of rapidly expanding population with increasing expectations of standard of living are at present mutually incompatible. The natural biological capacity of the Earth has been estimated to be on the order of 2.1 global hectares per person – currently usage is on the order of 2.7 global hectares per person on average. This is not a static situation - the population is increasing monotonically, as are people’s expectation for increased standards of living.

It is widely recognised that industrial systems have been a major driver in raising the quality of life of peoples around the world, however it is also understood that manufacturing systems are a major influence on the deterioration of the global environment. Some experts suggest that the industrial system can account for 30% or more of greenhouse gas generated in industrialised countries. Businesses, governments and consumers are beginning to react, but the complexity of the problem and diversity of views make it difficult to identify widely acceptable courses of action. This confusion occurs at a time when the window of opportunity for action is rapidly closing [7].

In response to these concerns, many manufacturing businesses, in particular larger MNCs, are on an ever increasing basis reporting their sustainability performance. There is however no uniform consent across industrial sectors as to the level of sustainability reporting required. Some reports go well beyond compliance reporting and an increasing number are using third party reporting structures e.g. the Global Reporting Initiative (GRI). Many however focus on those items which can be easily addressed, such as delivery optimisation, as are often easily measured and optimised. The UK government's Carbon Trust Initiative, and support for Carbon Trading schemes, etc. are all beginning to shape the terrain over which business conduct themselves to addresses the sustainability agenda. Year on year improvements on various sustainability metrics are supported by a wide array of practical initiatives, and reported improvements of the order of 40+% in some metrics over five year periods are not unusual.

Another initiative which has received international recognition is the Greenhouse Gas Protocol Initiative. This is a multi-stakeholder partnership of businesses, non-governmental organizations (NGOs), governments, and others convened by the World Resources Institute (WRI), a U.S.-based environmental NGO, and the World Business Council for Sustainable Development (WBCSD), a Geneva-based coalition of 170 international companies. Launched in 1998, the Initiative's mission is to develop internationally accepted greenhouse gas (GHG) accounting and reporting standards for business and to promote their broad adoption.

The GHG Protocol Initiative comprises two separate but linked standards:

• GHG Protocol Corporate Accounting and Reporting Standard (this document, which provides a step-by-step guide for companies to use in quantifying and reporting their GHG emissions)

• GHG Protocol Project Quantification Standard (forthcoming; a guide for quantifying reductions from GHG mitigation projects). Various global market organisations, such as the FTSE and the American equivalent, have attempted to provide quality standards for sustainability.

Using these standards, national initiatives such at the Carbon Trust's footprinting specification have been derived and gained international validity.

1.3 The Sustainable Supply Chain

Recent years have witnessed an increasing body of literature dedicated to the sustainable supply chain, and have been addressed in several recent reviews and journal special editions [3]. One of the key ideas which have come to the forefront of corporate thinking in the last decade is that of the triple-bottom line (TBL) [8]. This concept is designed to act as a mechanism for amalgamating the environmental, economic and societal impacts of the industrial system. There is however still debate on how this can be implemented and measured in practical terms by industrial practitioners. A recent article by Skouloudis et al. has proposed a promising method for integrating it into GRI guidelines which are extensively used, in particular by North American based corporations [9]. A fully integrated TBL reporting framework would be the desired goal of most companies, however at a practical level focussing on a particular element of the industrial system, such as energy utilisation or carbon footprint, may be a more accessible option, the successful execution of which would form a robust basis for approaching full TBL reporting.

Recent activities undertaken by the IfM have uncovered the following key concepts for making the supply chain greener: design for sustainability and sustainable sourcing options for materials; manufacturing location decisions; storage and distribution regimes; in-use and end-of-use product life cycle analysis. This may be addressed by key activities along the value chain of a product or service, as shown below in figure 1. Currently there exist a number of challenges in the execution of these policies, including competitive pressure limiting scope to change supply network strategy, unstable energy costs preventing informed location decisions, or inefficient distribution networks. Through the utilisation of a supply network configuration approach, the above may be classified into industrial archetypes that will allow supply chain managers and strategic planners the ability to adopt the lowest risk solution to attaining a configuration which minimises waste, optimises resource allocation and allows correct adoption of energy strategy.

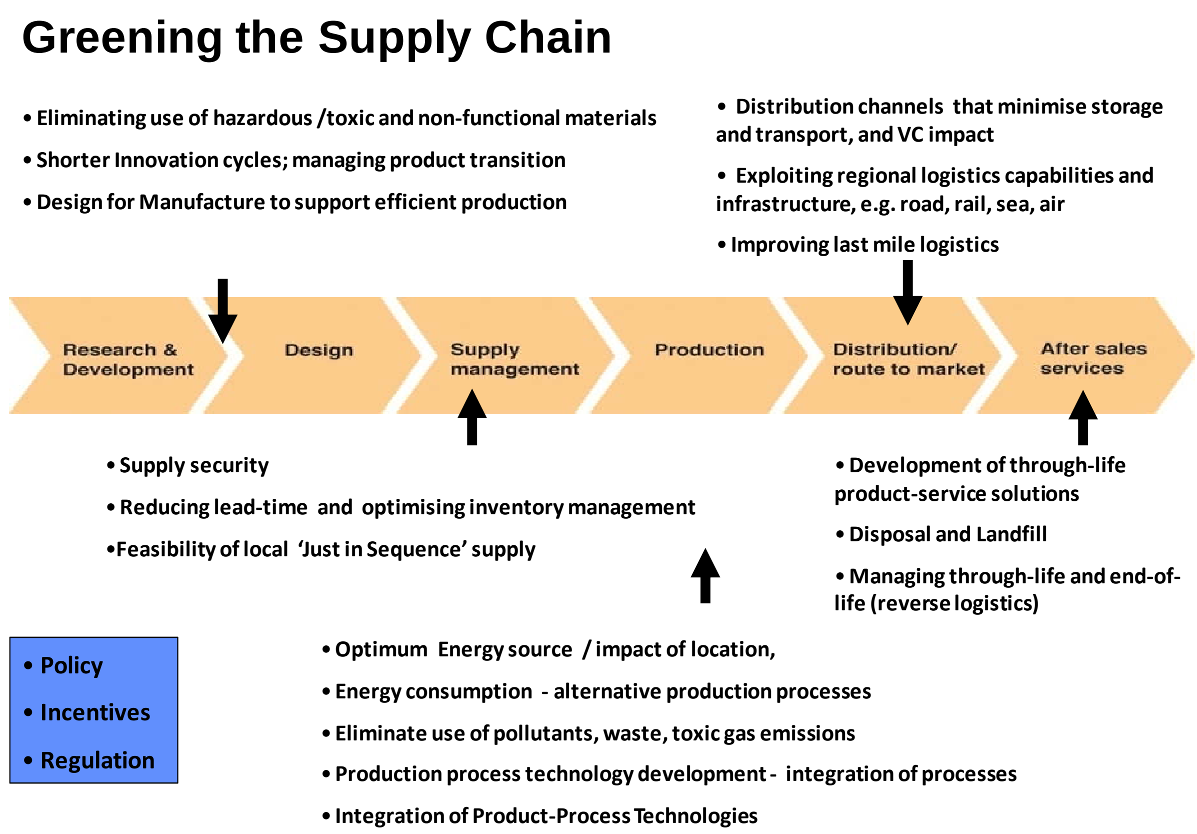

Figure 1: Greening the Supply Chain

1.4 The Automotive Sector

From the perspective of the automotive industry, legislative pressure, especially in the EU zone, has driven car manufacturers to measure and reduce the emissions from vehicles, which at a product level has driven the industry in a particular direction. Intensive R&D effort is being expended by most automotive companies in developing alternate powertrain technologies, with hydrogen fuel cells and electric vehicles under consideration [10]. Indirectly this technological push could have a sustainability benefit in a wider context than the reduction of CO_2 emissions. Other, smaller scale initiatives to reduce and regenerate "wasted" energy include concepts such as Kinetic Energy Recovery Systems (KERS), which have recently seen adoption in Formula 1 racing.

At a regional level, a recent report examined the potential for the adoption of a greener automotive industrial system in Australia [11]. This report summarised the first phase of a 6-part plan to produce a greener automotive industry in Australia by 2020. From a comprehensive stakeholder impact analysis, including the context of the global financial crisis, climate change, and the growing demand by consumers for "green" products, it led to recommendations on how to achieve the goal from a product-oriented perspective – namely a move towards the production of large, powerful, zero emission cars for export. By breaking down the product into major modules and analysing the technology needs of each, whilst independently assessing the regional capabilities to meet these needs as a function of trends and drivers (efficiency and emissions; energy scarcity and security; industrial capability; external market/competition; technical advances; government support and infrastructure) & critical to quality (CTQ) requirements for customers, it was possible to produce "grids" of opportunity. From the gap analysis, a roadmap for the production of sustainable automotive solutions was generated. This method, applicable to any regional automotive cluster, provides useful guidance at a product level, but also requires consideration of the extended supply network, and indeed the sustainability of the industrial systems from the perspective of triple bottom line reporting.

In the UK, the automotive cluster has been studied from the perspective of its supply network configuration in a key region, and has shown that sourcing and location decisions are driven by standard cost analysis with serious sustainability considerations largely focused on product technology only.

2 Methodology

In order to understand the holistic impact of sustainability on the global network of operations, an exploratory case study approach was adopted. The case study approach is particularly suitable due to the volume and complexity of data that will require to be analysed in order to map the sustainability impact on a complex MNC supply network.. The work described here has recently commenced in collaboration with a major global automotive manufacturer (both passenger vehicles and trucks). Initially the approach to mapping the supply network of the focal company will be outlined, then the potential metrics by which this supply network may be assessed from a sustainability standpoint will be examined, initially through a first pass analysis at the current best practice reporting guidelines in other sectors, followed by an in-depth analysis of some cross-sector footprinting techniques which have found traction in a broad range of industries.

One of the primary concerns of the focal firm was understanding the real energy utilisation efficiency and cost of its network, and as such it was decided that the first phase of the collaborative venture would be to produce an energy map of its network of operations, in order to highlight opportunities to either reduce usage or source energy from viable alternatives to traditional grid power.

One of the principal challenges in trying to generate an energy map of an operations network is the different fiscal and regulatory policies which exist in different regions and countries. As such, boundary conditions for the research are established such that only one particular region is considered in the initial analysis, with a view to extending this globally in subsequent analysis once the initial work has been completed.

2.1 Supply Network Configuration Analysis

The supply network configuration has been defined as “that particular arrangement or permutation, of the supply network’s key elements including, the “network structure” of the various operations within the supply network and their integrating mechanisms, the flow of materials and information between and within key “unit operations” the “role, inter-relationships, and governance” between key network partners, and the “value structure” of the product or service delivered”. Within this definition the four key elements which constitute the foundation of the configuration are:

- **Supply network structure**; network tier structure and shape, composition, ownership, levels of vertical and horizontal integration, location, co-ordination, manufacturing processes, optimum sequence, complexity, flexibility, etc.
- **Material and Information Flow**; Both intra- and inter-key unit operations; value and non-value adding activities, process steps, optimum sequence, levels of flexibility, network dynamics (e.g. replenishment modes), infrastructure, and enabling IT systems.
- **Relationships and Governance**; The role, inter-relationships, and governance between key network partners; the nature of these interactions or transactions, number, complexity, partner roles, governance and trust.

- **Product/Service value-structure**; composition and product-structure (including components, sub-assembly, platforms, modularity), product replenishment mode (e.g. is the product make-to-stock, make-to-order, configure-to-order), SKUs, products as spares, and through-life support and services.

For each of these four configuration elements there exists a suitable "mapping" tool to enable this configuration to be visualised. An example is shown below in figure 2 – this depicts a generic template for the visualization of the supply network structure.

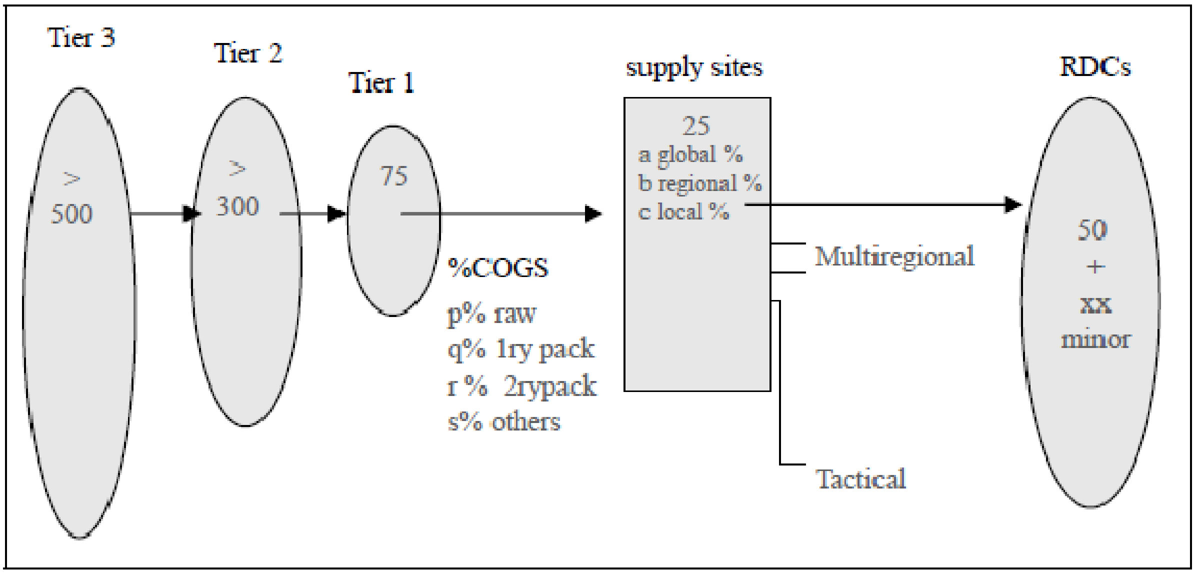

Figure 2: Template for capturing network structure

This template allows an "at a glance" capture of the global footprint of the focal firm; the upstream supplier hierarchy and the downstream distributors. Similarly, the other 3 configuration elements have tools which may be represented using a related template structure. A fundamental output of the research described here is the modification of these tools to become decision tools for assessing sustainability options, through the provision of a footprint for the network that captures the energy, resource, and waste elements for each particular configuration of the network.

2.2 Sustainability Performance

Many MNCs now include sustainability in their annual report, often under the auspices of “green” or Corporate Social Responsibility (CSR) agendas. In general, these reporting initiatives focus largely on the distribution of goods and materials, couched in the phraseology of carbon footprint reduction. In the food industry, companies such as Tesco have been able to claim large reductions in carbon footprint associated with their groceries through sourcing local produce and improving logistics operations. In the electronics goods industry however, competitive pressure on margins has resulted in many western companies, such as Philips, ceasing to source electronic sub-assemblies locally and instead moved their production wholesale to Asia, with companies such as PNE in Malaysia now providing a substantial fraction of this part of the supply chain. Whilst the impact on carbon footprint from a supply chain perspective is undoubtedly to increase it, other impacts on the triple bottom line are difficult to assess without a fully integrated network analysis.

There are many methods for the assessment of sustainable performance for MNCs to use as a reporting tool. Many of these typically focus on footprinting, in particular carbon footprinting. In the UK, the Publicly Available Specification approach, PAS 2050, has been proposed by the governmental and non-governmental agencies such as DEFRA (the Department for the Environment, Food and Rural Affairs), the Carbon Trust and BSI (British Standards Institute). Table 1depits a selection of the current extent of sustainability reporting for a small, diverse set of MNCs. It can be seen that none of these currently use the Carbon Trust (CT) footprinting framework. Some, for example Philips, utilise their own methodology, which like the CT framework is built on the international GHG (green house gas) protocol and use carbon footprinting as an equivalent metric to represent energy utilisation. Unilever make no explicit mention of the method used to calculate CO_2 emission, although state that the end user is the largest single source in the value chain of the product and hence product design is used to minimise this impact. Packaging reduction is also highlighted as a major sustainability opportunity.

Table 1: Selected Examples of Sustainability Reporting

Company	Sector	Business	Ref	Report Date	Sustainability Reporting Elements	Certifications
Tesco	Retail	B2C	[12]	2009	Energy utilisation; distribution footprint	None?
Unilever	Fine Chemicals	B2C / B2B	[13]	2008	Sustainabile sourcing of raw materials; energy efficiency (measured by carbon footprint); water utilisation	Rainforest Alliance; FTSE4Good Score 5
Siemens	Industry; Energy; Healthcare	B2C	[14]	2009	Carbon emissions	DowJones SI #1
Philips	Multiple	B2C	[15]	2008	Green innovation; Green products; energy efficiency (measured by carbon footprint)	GRI B+ (self-assessed); ISO 14001 certified (95% sites)
Intel	Semiconductor	B2B	[16]	2008	GHG emissions; water use	GRI B (self-assessed); DJSI ranked
Company A	Automotive	B2B / B2C	[17]	2008	Recyclable product elements; Energy; Water; Waste	None?

Some recent research has argued that MNCs must focus on fiscal sustainability before they can realistically expect to tackle issues pertaining to the triple bottom line [18]. However financial performance is an integral part of the TBL approach, and it is the interaction(s) between the three elements which needs to be addressed. To date, very limited data is available from the automotive industry in regards to the sustainability of its supply chain, and this research gap is an area which this paper outlines our attempts to address.

In addition, whilst it is theoretically straightforward to generate carbon footprints for products, there are a number of limitations in the approach, many imposed for practical necessity or due to lack of agreement between principal stakeholders in its construction.

There are also controversies regarding the green manufacturing credentials for renewable energy solutions. The amount of steel required for wind turbines, and the associated processes required have been highlighted, as have the environmental impact of the use of dopant gases and purification chemicals such as silane, arsene and boron trifluoride used in the manufacture of crystalline silicon solar cells. Hence when considering energy provision alternatives, it is vital to assess the impact of the entire value chain which underpins that provision and a full TBL approach.

From the perspective of corporate reporting, two closely related systems in the USA and the UK have gained increasing recognition during the last decade. The DJSI (Dow Jones Sustainability Index) and the FTSE4Good have been employed by companies as a framework for reporting matters related to sustainability. The DJSI in particular currently has in excess of 70 licensees managing over $8b in 16 countries around the world, and provides an assessment framework for corporations wishing to publish sustainability reports (note there are several industries which are excluded from participating in this scheme). Operating at a regional level within the UK, schemes such as those organised by Business in the Community (BITC), a charitable organisation which aims to provide guidance to smaller scale industrial practitioners.

2.2.1 PAS 2050 Approach

As of November 2009, it was estimated that 75 PAS 2050 mapping projects with industry had been undertaken by the Carbon Trust, covering more than 5,500 products footprinted and sales revenue of footprinted products £2.7 billion. This relates specifically to projects that the Carbon Trust has been involved with to certify against PAS 2050 and Footprint Expert™. There are obviously many further projects that have been undertaken by companies directly themselves or by consultants or academics.

What this does demonstrate is that PAS 2050 has been widely taken up throughout the world, and is currently the *de facto* standard for measuring product carbon footprints. For example, it has been translated into Chinese and Japanese, and is being used as a key document in the development of both the WRI protocol for measuring product carbon footprints and for the developing ISO14064 standard.

Primary limitations on the PAS 2050 include that fact that it is product rather than network oriented, which markedly increases the initial complexity of the problem as, for complex products with a high number (>1e4) piece parts, the anticipated workload in integrating all the necessary information becomes daunting to the industrial practitioner. This has been reported as a significant barrier to adoption by many companies. Additionally, it makes several assumptions on issues such as aircraft transportation emissions, movement of human resource, capital equipment utilisation and land use changes that some practitioners do not agree with.

From the perspective of the automotive sector, it is worth noting that in the literature review undertaken at the start of this work no major automotive manufacturers were found to have adopted the PAS 2050 approach to carbon footprinting. The reasons for this are not well understood, however it is likely that the complexity of the supply network which underpins car manufacturing, with tens of thousands of component parts from a widely distributed network of small suppliers, makes undertaking the PAS 2050 methodology a daunting proposition without having a well understood framework in place before hand. It should however be noted that this paper does not propose to constitute a full review of the automotive sector’s approach to sustainability, and that the possibility cannot be discounted that a regional or global automotive manufacturer does indeed have a holistic approach to measuring the sustainability profile of its supply chain in a manner that has not been well publicised.

2.3 Carbon Footprinting as a route to Energy Utilisation Mapping (EUM)

From a combination of the methods outlined in sections 2.1 and 2.2 above, a framework that uses a proven method of assessing supply network performance and integrate it to a footprinting strategy but which is focussed around energy utilisation at the network level rather than CO_2 emission at a product level (as in the PAS 2050 approach).

To enable this framework, it will require key nodes in the supply network to be identified, and to produce energy utilisation data for each site of operations, in addition to all energy expended in the transportation of goods or resources. This latter point is an important issue for consideration, since at a top-level view the building of a new plant, or sourcing a new supplier, which have excellent green credentials in terms of plant operations, may result in unacceptably high impacts in the upstream and downstream logistics.

2.4 Factory Level Analysis – the ERWC Framework

For each node within the automotive supply network there exists a production or assembly site which will utilise resource, consume energy, generate waste and emit greenhouse gases which may be measured in terms of a carbon footprint. In the US, recent government policy implementations such as the Department of Energy's industrial technology program have focused on how manufacturers can reduce energy consumption and propose alternatives to traditional energy consumption methods [19]. Recent publications have shown that the ERWC framework is an effective means of measuring the environmental impact of a firm at the local factory level [20]. This approach is oriented at the micro-level, and whilst useful for identifying practical gains in sustainable processing at the factory level, is concerned with too high a degree of granularity to be accessible at the network level when making decisions regarding the overall environmental, economic and societal impact of the industrial system. We propose to utilise an element of the framework, the energy usage, and make it a key node metric which we will then integrate to the network hierarchy configuration elements to allow us an understanding of the overall energy footprint of the product value structure under investigation.

In future work it is planned to integrate other node elements from the ERWC methodology and indeed those that emerge from other areas of a TBL approach. The emerging methodology will therefore progressively ensure the best sustainability decisions are being addressed.

2.5 Key considerations for adoption of renewable energy solutions.

At a superficial level, it would seem that from a holistic point of view the adoption of renewable energy provision and integration of this into an overall supply network review is a “low hanging fruit” which many companies could adopt in order to green their supply chain without necessarily requiring extensive internal restructuring, new process adoption, or other potentially costly methods. However, there are several factors which act as barriers to adoption of this solution. The critical metric governing the fiscal feasibility of renewable energy adoption is the levelised cost of electricity (LCoE). This metric is commonly evoked in discussions regarding the viability of utilisation of alternatives to energy derived from fossil fuel, however it is a complex parameter that is heavily dependent on method of calculation and of regional or local fiscal incentives in place to encourage adoption. It is closely linked to the concept of grid-parity – this refers to the situation in which renewable energy solutions have the same financial burden as traditional energy sources such as coal, gas or nuclear. However, the cost of these solutions varies on a state-to-state and even as a function of time of day.

Regions of the US, such as California, which have high levels of insolation, are often used to highlight the applicability of solar PV or solar thermal renewable energy solutions [21]. Here the continuous supply of electricity is provided by nuclear or oil fired power stations, which provide a base level of provision at a cost with which renewable sources cannot at present compete. During peak demand times, in this case during the day when demand for air conditioning is very high, so-called ‘peaker’ plants come on line to meet this additional demand. The cost of this electricity is comparatively high, and high volume manufacture PV can compete with this at present, with the current fiscal stimuli in place.

Hence from an energy perspective, it would make sense to construct or relocate new manufacturing sites to those regions or states with the appropriate stimuli in place. However, there is no guarantee of their long term viability – the recent example in Spain of the fiscal issues caused by the over-generous provision of the Feed-in Tariff (FiT) is a classic example of how this can go badly wrong. It is generally, if tacitly, accepted within the energy provision sector that FiT’s are not sustainable indefinitely by regional governments, and that to provide an economically viable solution further step changes in manufacturing cost and/or module efficiencies (in the case of solar photovoltaic solutions) are required.

For existing manufacturing sites, there are however several short term options such as retrofitting BIPV (Building Integrated Photo-Voltaics) to factory sites, or installing wind farms. Depending on the micro-economics of the region in which these sites are situated, these may either be used to provide additional power to the plant thereby reducing the amount of power required from the grid, or indeed for a suitable scale of renewable generation, selling electricity back to the grid. The financial viability of the latter option again exhibits a strong regional dependence – in Germany for example, it is possible to sell the electricity back to the grid for a profit, whereas in California the current scheme under discussion simply allows offset at the current wholesale energy price which is considerably lower.

To make informed decisions on this adoption, it is necessary to understand where the energy is being consumed across the entire supply network – for example, it may be the case that the final assembly plant is not a significant contributor to overall consumption and thereby time and effort expended to making these particular sites "greener" has limited overall impact on the sustainability profile of the MNC.

New elements of risk analysis are also required to address the likely (or indeed inevitable) variation over time in terms of the viability of energy options and of the legislative and fiscal infrastructures that exist to support these new solutions. Without full visibility of the options and associated likelihood of change, it will be a significant challenge for any MNC, whether in the automotive sector or otherwise, to successfully adopt a robust long term energy solution.

3 Analysis of an Automotive MNC – Initial Case Analysis

The exploratory case study is a multinational automotive manufacturing company. At present some 85% of the materials utilised in their vehicles are recyclable, and a key dimension of their environmental reporting has to date focussed on a product-centric "green vehicle" initiative – whether through use of fuel alternatives to increasing fuel economy of the product. Alternate powertrains employing electric batteries or hydrogen fuel cells are currently in development. From a manufacturing perspective, solutions have focussed on energy utilisation reduction (and sourcing from renewable), emission reductions (in terms of CO_2) from production sites, water utilisation reduction and waste production reduction. Understanding the impact of the entire supply network behind a complex product such as an automobile presents more of a challenge, as the industrial system involves many stakeholders external to the firm.

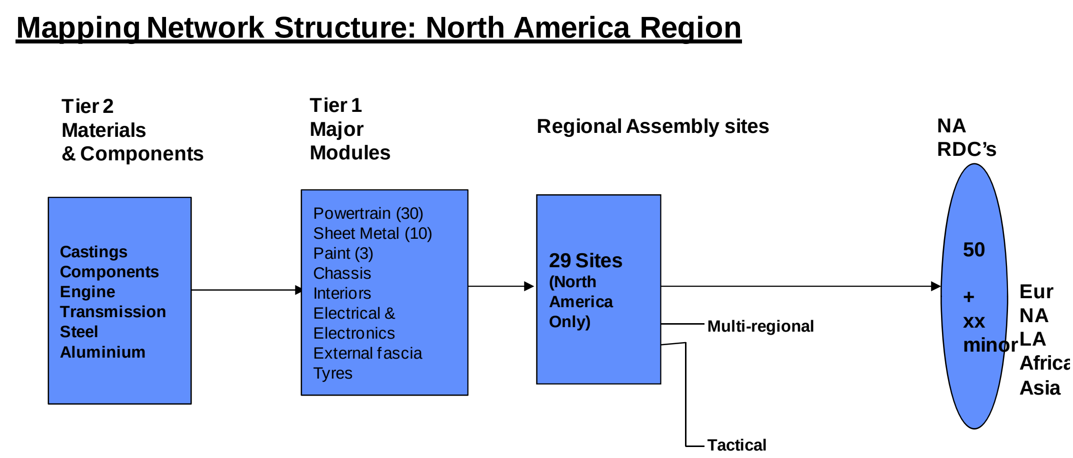

Figure 3: Regional Supply Network Hierarchy

Figure 3 depicts an initial analysis of the tier structure of the upstream supply network for the automotive focal firm. The mapping of ERW elements lends itself well to a network level analysis that will allow an ERW "footprint" map to be generated from a product category perspective.

The current operational flow of materials and goods is shown in figure 4. This represents a network view of the process. At the factory level, a process involving over 40 individual steps is required to produce each car. Initiatives to reduce energy consumption at the plant level may be segmented into two distinct phases – reducing the energy requirement per phase, and reducing the number of steps. For the former, initiatives such as changing the type of bonding material such that the thermal processing steps require lower thermal budget are readily achievable short term targets, whilst in the longer term fitting kinetic energy recovery systems to robots represents a means to reduce energy consumption but requires technological innovation. For the latter, reducing the number of steps may be achieved through advances in polymer technology and utilising alternate structural materials.

The tier-structure mapping approach will be used to capture the ERW flows at an inter-firm level and used to inform configuration options i.e. a comparison of alternate configuration states.

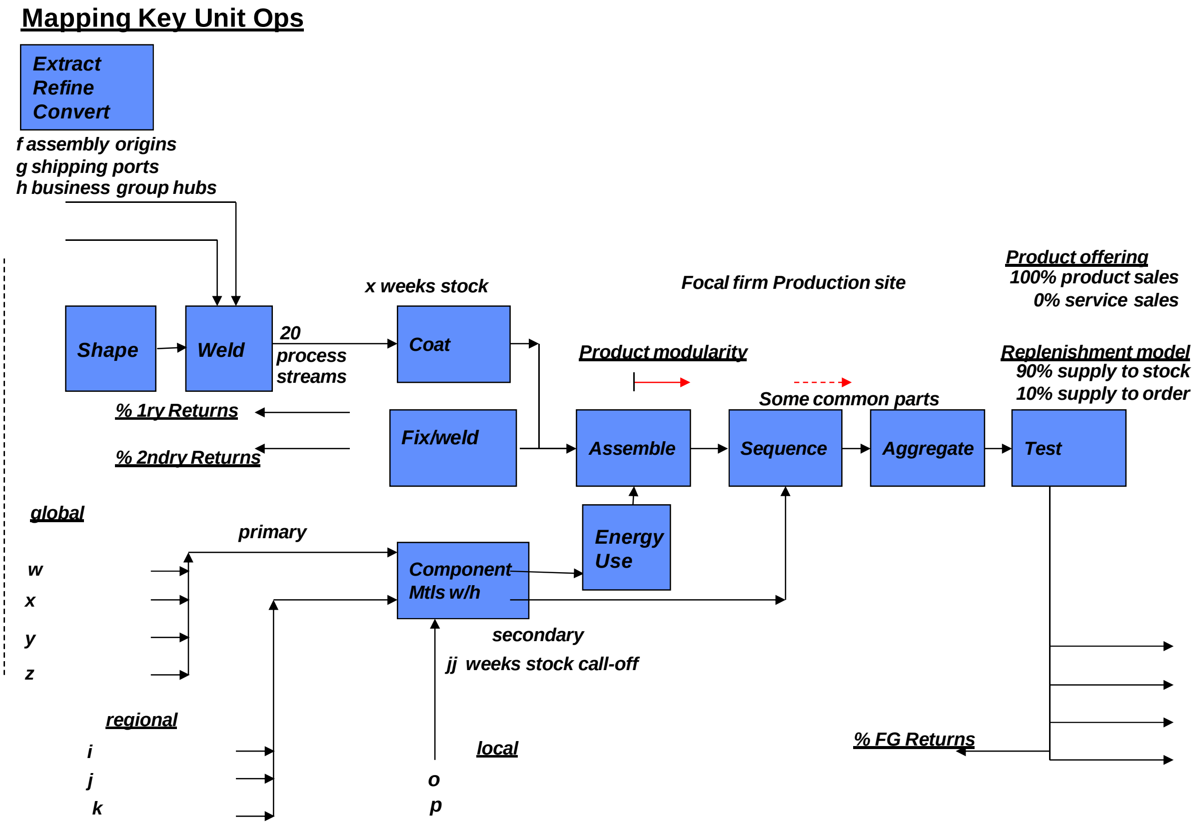

Figure 4: Key unit operation configuration map

Once the interactions between key unit operations have been mapped and understood, and then coupled to the geographical information provided by the network structure map, it is possible to start to evaluate where the major energy intensive steps are in the value chain, and what the cost is of using that energy. At the network level this latter aspect is normally complex to analyse for the following reason. Whilst the power consumption per site location can readily be monitored, the cost of that energy is strongly dependent on regional factors. Due to the different fiscal and regulatory environments which are prevalent across the global value chain, making meaningful comparisons between plants operating in different countries is non-trivial. As such, the work described here focuses on one particular region, North America, in order to minimise the impact of these fluctuations. It should be noted however that even in one continental area, different regulations at a local level make judging the value of adoption of renewable energy solutions difficult to assess.

The unit operation mapping approach will be used to capture the ERW flows at plant level (or intra-firm level), and used to inform configuration options i.e. comparing configuration I with an alternative configuration II in terms of efficient ERW options.

4 Conclusions

Previous supply network configuration analyses have been focussed on a largely "cost-plus" perspective and this approach aims to develop further by expanding this to a "cost-plus and ERW", perspective, using the complementary methods and tools described above and contextualised in figure 1. The fundamental question which we desire to answer is "Is there a more sustainable way in which to configure the supply network". Through a pilot study of the manufacturing stage of an automotive MNC, the utilisation of network configuration tools to provide an ERW footprint assessment will be evaluated, across the supply network in a specific region, and used to map the dynamics and flows of major unit operations in terms of their sustainability metrics. Furthermore, by moving to a consideration that does not focus solely on energy, it should mitigate against producing sub-optimized solutions (from an overall sustainability standpoint).

Here a framework for analysis of the energy footprint of a supply network in the automotive sector has been proposed. The framework proposes to commence with one key element of sustainability – namely energy provision and utilisation – and will then be progressively rolled out to encompass other key sustainability metrics. Further method application will involve a full case study mapping exercise in collaboration with the industrial partner, in terms of identifying the major sources of energy utilisation in the extended network (tier-level analysis) and assessing opportunities both for energy utilisation reduction and methods by which the network can reconfigure its operations (plant-level analysis) to reduce its overall energy footprint.

5 References

[1] Choi, T. Y., Krause D. R., “The supply base and its complexity: Implications for transaction costs, risks, responsiveness, and innovation”, Journal of Operations Management Vol. 24, 637, (2006)

[2] Kamath, N. B. & Roy, R. “Capacity augmentation of a supply chain for a short lifecycle product: A system dynamics framework”, European Journal of Operational Research, 179(2), 334, (2007)

[3] Jayaraman, V.; Klassen, R.; Linton, J. D. “Supply chain management in a sustainable environment”, Journal of Operations Management, 25, 1071, (2007)

[4] Srai, J. S. & Gregory, M. “Supply Network Configuration Perspective on International Supply Chain Development”, International Journal of Operations and Production Management 28(5), 386, (2008)

[5] Kirkwood, D. A. & Srai, J. S. “Charting Industry Emergence from a Supply Network Perspective”, Journal of Manufacturing Systems, *in press*

[6] Srai, J. S. “Supply Chains Emerging Models”, Manufacturing, 32, (2007)

[7] Evans, S.; Bergendahl, M. N.; Gregory, M.; Ryan, C. “Towards a sustainable industrial system”, Cambridge University, (2009)

[8] Elkington, J. “Cannibals with forks: the triple bottom line of the 21st century”. Capstone Publishing, Oxford (1997)

[9] Skouloudis, A; Evangelinos, K.; Kourmousis, F. “Development of an Evaluation Methodology for Triple Bottom Line Reports Using International Standards on Reporting”, Environmental Management, 44, 298, (2009)

[10] Zapata, C. & Nieuwenhuis, P. “Exploring Innovation in the Automotive Industry: New Technologies for Cleaner Cars”, Journal of Cleaner Production, 18(1), 14, (2010)

[11] Doolan, M. (editor) “Automotive Australia 2020 Vision”, AutoCRC (2009)

[12] “Tesco Annual Review and Finance Summary 2009”, www.tesco.com

[13] “Sustainable Development 2008: An Overview”, www.unilever.com

[14] “Sustainability Report 2008”, www.siemens.com

[15] “Philips Annual Report 2008”, www.philips.com

[16] “2008 Corporate Responsibility Report”, www.intel.com

[17] “General Motors Corporation 2007 Annual Report”, www.gm.com

[18] Robért, K.-H. “The Natural Step Story: Seeding a Quiet Revolution”, (2008)

[19] Aronson, R. B. “The Emerging Energy Industry”, Manufacturing Engineering, 142(2), 47, (2009)

[20] Tridech, S. & Cheng, K. “An investigation on the framework for EREE-based low carbon manufacturing”, *in press*

[21] Various articles available online from www.caiso.com