

# Supply Chain Environmental Analysis

A new system for delivering a low carbon supply chain



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## Publication date

November 2011

## Report no.

005

## Publisher

The Centre for Low Carbon Futures 2011  
For citation and reprints, please contact the  
Centre for Low Carbon Futures.

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# EXECUTIVE SUMMARY

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Debate on climate change issues is changing the policy environment, which has changed the regulatory environment for businesses. This trend is likely to continue in future. Business practices and processes are under increasing scrutiny for their impact on the environment and resource use. Thus, academic and business interest in greening the industrial supply chains is increasing. There is a paucity of applied knowledge, relevant industrial know-how and standardisation of measures and methods.

A review of available academic and practitioner literature reveals that there is big mismatch between business-cum-managerial needs from greening the supply chain and what is available in the market to satisfy them. The reason for this mismatch appears to be a lack of in-depth understanding of the scale and magnitude of the task and an inability to integrate a robust methodology into a comprehensive decision support system even where this understanding has been shown. Only a holistic framework, which we have termed 'balanced green supply chain system' (BGSCS), can encompass this scale and magnitude. A BGSCS is a system that adopts a comprehensive sustainability framework and tries to balance the performance of a supply chain in the context of economic, social and environment needs. In applied terms, this BGSCS can be showcased through the development of a decision support system now known as Supply Chain Environmental Analysis Tool (SCEnAT).

Based on the available evidence, this report establishes the need for a state-of-the-art SCEnAT for carbon emissions accounting and management mainly across the product supply chains by identifying methodological shortcomings in existing tools and proposing a supply chain (SC) framework which provide businesses with a holistic understanding of their supply chains and ensuring partners within supply chain collaborative networks have a shared understanding of their emissions. SCEnAT is a first step on the pathway in adopting a balanced green supply chain system approach.

The designed and developed SCEnAT has many unique and innovative features, which have been put into a comparative perspective vis-à-vis existing tools and software of different types. The methodological framework used to design and develop this SCEnAT integrates different individual techniques/methods of supply chain (SC) mapping, SC carbon accounting, SC interventions and SC interventions evaluation on a range of key performance indicators (KPIs).

The main benefits of using the SCEnAT are that the visible process of strategic emission reduction allows firms to promote their green credentials to supply chain partners and customers and provides a single easily accessible source of potential low carbon intervention solutions to companies across supply chains. This visibility and transparency is the key to the working of the SCEnAT as it clearly shows inputs

and requirements of product supply chains; a supply chain carbon map showing each input into the supply chain tagged with its associated lifecycle emissions including economy-wide Scope-3 emissions; identified carbon hot spots of the product supply chain; and the contribution of economy-wide lifecycle emissions (Scope-3 emissions) to the total emissions.

In essence, the SCEnAT provides a practical and evidence-based decision aiding tool for businesses demonstrated through the case study and a Triple Bottom Line (TBL) environmental, economic and social framework of key performance indicators, which is used to evaluate the impact of interventions on supply chain performance.

The case study examples of the SCEnAT illustrate how users initially take advice and guidance and then, where appropriate, provide their own case studies to further populate the database of low carbon interventions. For continuous improvement of the SCEnAT there is a need for businesses to further engage in its next developmental stages as users' experiences through feedback would not only enrich its system knowledge base but also increase its applied value.

The development of the SCEnAT has policy implications mainly at two levels:

- at the company level, the SCEnAT can serve as a tool to be used in environmental management systems and programmes with the impacts and implications reaching far beyond the organisational boundaries because of the collaborative nature of supply chains; and
- at a wider level, beyond the confines of supply chains, it has implications for the lifecycle assessments methods and standards, which in turn highlight the challenges of assurance and verification of data and results, thus making assurance or verification of data and reported carbon emissions a key policy.

# INTRODUCTION

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Urgent action is needed to address the climate change issues. With unsustainable supply of energy and the need to reduce carbon footprint, a new approach towards the decarbonisation and management of supply chain is required (United Nations, 2010).

Academic and corporate interest in this field has risen considerably in recent years. This can be seen by looking at the consistent increase in publications on this topic on international journals and the number of businesses integrating sustainability issues in their operations strategy. However, clear and well-accepted definitions about this field are still lacking. This calls for developing what we term as a Balanced Green Supply Chain System (BGSCS). A BGSCS is a system that adopts a comprehensive sustainability framework and tries to balance the performance of a supply chain in the context of economic, social and environment needs. By default it must also consider internal and external push and pull of stakeholders throughout the supply chains. Coupled with increased complexity, uncertainty and dynamics in a global supply chain, the two imperatives of energy supply reliability and the need to address the adverse impacts of energy use multiply the challenges to greening a global supply chain.

However, the zeal to accept and tackle these challenges should be guarded against the perils of leaping into the green agenda without a clear understanding of the impact of the green initiatives from a full supply chain perspective. In the age of modern day strategic alliances and under ever increasing profitability imperatives, it is largely supply chains, not companies, that compete against each other, hence it is important to understand how low carbon practices, technologies, management, legislations and so on impact on the supply chain.

The UK's regulatory framework and policy environment on climate change has contextualised this applied research of framing a BGSCS as it aims to reduce Kyoto greenhouse gas emissions by at least 20-24 billion tonnes by 2050. The development of a BGSCS in turn has been epitomised into an integrated decision support system now known as SCEnAT. Governments, industries, knowledge providers, intermediaries and agencies are playing an active role in the process of achieving this goal.

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In the Yorkshire and Humber region, through the Centre for Low Carbon Futures, this research project of developing a Decision Support System has provided an integrated platform to help accelerate the UK Government's goal of emissions reduction by pulling together critical mass of research, knowledge and innovation in multidisciplinary areas from sustainable science, social science, supply chain, engineering, environment, economics, energy, technology and policy work.

The BGSCS approach has considered a number of critical themes through the course of its development. This system incorporates developments in clean technology management, waste minimisation, eco-accounting and investment models and standards. Supply uncertainty, technology uncertainty, demand uncertainty, and risk propensity of industrialists and policy makers towards these uncertainties were debated and, where possible, mapped out in order to balance the green supply chain system. The development of the SCEnAT has considered the level of energy efficiency and conservation and CO<sub>2</sub> emissions – from these, informed assessments have been made by modelling the supply chain in different sectors. The performance output of this system has led to the consolidation of a set of green measures to assess readiness, resilience and adaptation to climate change throughout the supply chain. These measures can also be used to set up the criteria for establishing the Responsible Investor Standard (RIS) and Green Impact Assessment Matrix (GIAM) which also form part of the larger BGSCS framework.

# MARKET FAILURE

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As noted in the previous section, the concept of BGSCS has been operationalised through the development of SCEnAT. The theoretical development and evolution of green SCM in the relevant literature, along with imperatives of the current and future regulatory environment, formed the context in which the state-of-the-art regarding the various tools, software, methods and frameworks has been reviewed.

It is probably safe to assume that the emphasis coming out of the theoretical debates within the academia and of talk about regulatory measures in the public policy circles, particularly within the European context, has helped created a sort of market for methods and tools for carbon emission calculations that in turn help in mapping the carbon footprints. This demand for know-how and tools has, in turn, helped the mushrooming of tools and software packages for this purpose. This situation is mainly the result of lack of any standardisation on parameters and/or methodology. Very few calculation methodologies involve adherence to PAS2050 standard or some other sound methodology. Even this standard also does not take into consideration all the situations and demands, which is perhaps the result of limitation of methodology (CenSA, 2010, Berners-Lee et al., 2011). The development of the SCEnAT has also tried to address a major part of these limitations, employing a comprehensive approach to emission estimations and supporting the search for appropriate solutions.

From another perspective, the review of available material showed that a great majority of these carbon emission reduction/management tools and software were devised only with the focal firm in the focus. It is now widely accepted that a supply chain wide approach to address the problems of operational efficiencies associated with the delivery of a finished product is more effective than the piecemeal approach of focusing on the operations of an individual firm/link in the chain (Hameri and Paatela, 2005, Bayraktar et al., 2009).

There is also the issue of focus. Most of the tools available in the market space (internet) focus on carbon emissions calculations only; hence there is a need to distinguish between emission calculation and management with an emphasis on the latter. Furthermore, treating carbon calculation and carbon management separately, or as separate functions, encourages the modular approach, which does not fit comfortably within a supply chain framework and analysis, and aggravates the system boundary issue and data truncation problem further. In our opinion to avoid all these issues an integrative approach of carbon emission accounting and management along a supply chain is needed with a view to evaluate and upgrade its performance on a comprehensive sustainability metric. The range of the foregoing issues has also shaped our critical perspective with which we have reviewed the available carbon accounting literature and tools in the following paragraphs.



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There is little academic literature that specifically concerns the development or design of carbon accounting tools or calculators. Key word searches for this purpose returned little or no relevant literature. To complement this, internet searches were run with various key words and the assessment that follows is based on a review of the results of those searches, which threw up an array of types of carbon emission calculation calculators/tools. Taking an inventory of the search results and classifying them into major categories of tools was quite a difficult task. To handle such a large volume of data and make sense of the ensuing complexity, it was thought appropriate to categorise all the results into four methodology-based major leagues of tools.

First of these methodologies is a simple energy consumption based formula (which in turn is based on emission factors of certain energy types embedded into different formulae) to calculate the emission from certain activities. There are thousands of hits on the internet for such formula based calculator and no single calculator or tool can be considered as representative and competitor to the SCEnAT from this league. This approach to carbon calculation is also characterised by inflexibility and is exemplified by any carbon calculator available in the market space.

Focusing on a particular economy sector, the second methodological approach takes on building a database of greenhouse gas (GHG) emissions for major economic activities in that particular sector and, depending upon the particular requirement of a situation, flexibly manipulating that database and using the formula based calculator, noted for above league, to calculate the GHG emissions including carbon. Compare to first league or approach, this methodology affords some degree of flexibility in determination of carbon emission for different situational demands. A prototype of this approach is an Emissions Inventory Tool, (EMIT) developed by Cambridge Environmental Research Consultants (CERC) in the UK.

The third league identified in this research is a host of modelling software which take a supply chain view of emission calculation but stop short in its application beyond the sector it was developed or intended for. As its methodological engine it adopts LCA to cover the emission beyond the focal and over a good part of the upstream supply chain. An example of such software is a modelling package developed by AB Agri.

*It is our considered view that a tool or software should be judged on the strength and sophistication of the methodology it brings to the state of the practice in the fields of carbon emission management and greening of supply chains (sustainable SCM). The above literature review findings clearly demonstrate the failure of the market in conceptualising and developing a BGSCS and necessitated the conception, design and development of the Decision Support System.*

The last league can be said of those types of software which take both SC view, adopt LCA methodology and cover the more than one economy sector in its emission estimations. This approach can be regarded as quite comprehensive as it follows the emission estimation with suggestions of some interventions at macro level and tries to point to the environmental as well as economic impacts of interventions to be made. This research work was recently developed at the University of Manchester under a project called Carbon Calculations over the Life Cycle (CCaLC) of industrial activities. The SCEnAT, though quite sophisticated and advanced in comparison to the available options, can also be included in the category.

# NOVELTY AND INNOVATION

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This section identifies the novel and innovative features and aspects of the SCEnAT as a package. The gaps in features of the existing tools, as identified previously, provided us with the reason and insight to design and develop the SCEnAT. This section puts the SCEnAT into a comparative perspective vis-à-vis features of the existing types of tools (see Table 1) and highlights its unique and innovative features.

- Traditionally used LCA-based methodology is not very effective for carbon accounting across organisational/firm boundaries due to data truncation problems. By combining the traditional LCA with the environmental input-output LCA approach, which leads to the development of the robust hybrid LCA methodology used by the SCEnAT, it is possible to address the truncation problem in supply chain carbon accounting (Acquaye et al., 2011, Wiedmann et al., 2011).
- When fully functional, the SCEnAT offers complete flexibility, not only in terms of a firm's need for mapping, analysing, experimenting with and evaluating measure(s) to reduce carbon emissions along/across a firm's supply chain by providing state of the art knowledge and solutions at each step, but also complete behavioural flexibility when modelling a particular emission reduction strategy. The SCEnAT has been designed in such a way that a user would be under no compulsion to follow all the steps. Depending upon their needs, a user would have complete flexibility in terms of what they want to do with the SCEnAT.
- Most tools limit themselves to diagnosis and stop short of offering a solution. Few tools offer intervention options and only one of them offers intervention at three levels. The SCEnAT, when fully functional, is designed to afford interventions at four levels: product, process, firm and supply chain.
- The SCEnAT is also envisaged to be a living tool/system capable of learning and adapting itself through the experiences of its users by retaining these experiences in an inbuilt system knowledge base, which also functions as the storehouse/datamine for other pieces of system information and data. This is another unique and robust feature of the SCEnAT, which no other publically available tool in the market offers.
- Most tools available in the market, besides being only carbon calculators, are sector specific. As we know supply chains by default are cross-sectoral. Therefore, there is a market for a tool that covers the entire economy, or at least the principal sectors of an economy, without the distinction of services or manufacturing. Given the resources the SCEnAT has the potential to fill this market gap. The balanced green supply chain system approach, delivered via SCEnAT – Supply Chain Environmental Analysis Tool, is developed and inspired by 'adapting' evolutionary theory, open innovation, natural selection (disruptive, stabilising, directional), mutation to underpin a living system.

- A final unique and very advanced feature of the SCEnAT design and architecture is that it is also aimed at companies, whether TNCs or SMEs which have adopted Triple Bottom Line (TBL) accounting or thinking of doing so in the near future. It is expected that companies lagging in this regard would be forced to adopt TBL practice by the future regulatory environment. Only one other tool in the field offers this kind of evaluation of carbon reduction interventions but takes into account only environmental and economic parameters in an unstructured way. The SCEnAT design brings this feature to carbon reduction management practice not only in a structured and robust manner but also its design and methodology have the potential to provide evaluation of interventions on all three parameters, i.e. environmental, economic and social (see Table 1).

As detailed in the section on Market Failure, Type-1 calculators/tools consist of a simple energy consumption based formula. Type-2 tools are sector specific and rely on and work from emissions database for their output. Type-3 tools/software are characterised by a supply chain view but again are sector specific.

FEATURES	TOOL/SOFTWARE TYPE	TYPE 1	TYPE 2	TYPE 3	SCEnAT
CARBON CALCULATION		Yes	Yes	Yes	Yes
SC MAPPING		N/A	N/A	Not clear	Yes
CARBON HOTSPOT IDENTIFICATION		N/A	N/A	Not clear	Yes
METHODOLOGY		Emissions inventory & formula based calculations	Very Basic LCA	Comprehensive LCA	Process LCA + I/O analysis nased LCA
INDUSTRIAL ACTIVITY COVERAGE		Sectoral focus	More than one sector	More than one sector	Entire economy
BEHAVIOURAL FLEXIBILITY WITHIN THE APPROACH		Little oor no Flexibility	Some flexibility	Good flexibility	Complete flexibility
AVAILABILITY OF OPTION FOR INTERVENTIONS		No	No	Yes	Yes
LEVEL OF INTERVENTIONS		N/A	N/A	Three	Four
IMPACT ESTIMATION		No	No	Yes	Yes
TYPES OF IMPACTS		N/A	N/A	Environmental and economic	Social, economic, environmental
OPTIMISATION OF CARBON FOOTPRINTS		N/A	N/A	Yes	Yes
IN-BULT DATABASE		Yes	Not clear	Yes	Yes
CASE STUDIES		No	No	Yes	Yes
COMPREHENSIVE SYSTEM KNOWLEDGE BASE		No	No	No	Yes

Table 1: Decision Support Systems features in comparison to the existing types of tools

# MODEL AND METHOD

## INTEGRATED SUPPLY CHAIN MODULES OF THE DECISION SUPPORT SYSTEM

### Background

Businesses have become responsive to efforts that would help green their supply chains. However, there has been a general lack of holistic frameworks that integrate different supply chain modules and functionalities to aid and support decision making. Green supply chain management involves different supply chain modules, which must not be treated as separate functions but rather managed in a modular approach. The Supply Chain Environmental Analysis Tool (SCEnAT) designed within an integrated and practical supply chain modular framework can provide such insight and evidence to inform decision making in greening operations at a supply chain level.

The Decision Support System works on the principle that in order to decarbonise the supply chain for a product, the product lifecycle (including the sources and levels of carbon emissions) must be fully understood by all the actors within supply chains through a collaborative effort. The SCEnAT therefore promotes thought leadership in the understanding of decision science and environmental management on supply chain analysis that transcend organisational boundaries by carbon mapping, hot-spotting and carbon management.

The methodological framework used to design and develop the SCEnAT integrates different supply chain (SC) modules together, namely: SC Mapping, SC Carbon Assessment, SC Low Carbon Interventions and SC Performance Evaluation on a range of Key Performance Indicators (KPIs).

### I. SUPPLY CHAIN MAPPING MODULE:

The SC Mapping Module of the SCEnAT is devoted to the reproduction and representation of the operations flows across the whole supply chain, using information received from focal firm and suppliers and the use of validated secondary data.

Understanding the environmental impacts of a supply chain starts with a collaborative effort aimed at mapping the supply chain.

In producing a product supply chain map, a functional unit for the final product has to be established and all inputs that go into the production of the product (with respect to the specified functional unit) identified and traced down the supply chain. The mapping of supply chains provides very useful data, boundary and scope for the Carbon Assessment Module of the SCEnAT. In this project, the supply chain map is developed within a comprehensive system boundary ensuring that indirect inputs across the whole supply chain from every sector of the economy are captured. The supply chain map of the SCEnAT is updated after the Carbon Assessment Module of the SCEnAT has been implemented. The updated version of the supply

chain map leads to the production of a supply chain carbon map, with each supply chain input tagged with its associated lifecycle emissions. Furthermore, the supply chain carbon map identifies carbon hotspots of the product supply chain, providing information as to where efforts to green the supply chain should be targeted.

### II. SUPPLY CHAIN CARBON ASSESSMENT MODULE:

Carbon assessment of a product supply chain is the estimation of life cycle direct and indirect greenhouse gas emissions (GHG) from all inputs (at the whole supply chain level) that goes into the production of that product. It is undertaken using hybrid life cycle assessment (LCA). Hybrid LCA is seen as state-of-the-art in life cycle assessments and carbon footprint analyses. The LCA supply chain framework for a product, process or activity/operation can bring together the impacts of collaborative supply chain partners arising from extraction and processing of raw materials; manufacturing, transport and distribution; re-use, maintenance recycling; and final disposal, etc. LCA is therefore a holistic approach which brings environmental impacts into one consistent framework, wherever and whenever these impacts have occurred or will occur.

The Carbon Assessment Module of the SCEnAT is implemented using the most robust form of life cycle assessment methods: the hybrid LCA ensures the estimation of both direct and indirect supply chain emissions.

Emissions across a supply chain are either direct or indirect. By employing the hybrid LCA in the Carbon Assessment Module, the SCEnAT has the capability to estimate indirect emissions, which are usually unreported in carbon assessments. Further details on the carbon accounting method are provided in the section 'Carbon Accounting Method' of this report.

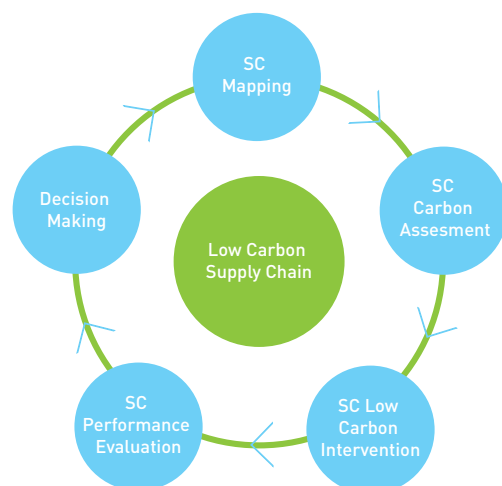


Figure 1: Integrated supply chain modules used in designing the SCEnAT

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### III. SUPPLY CHAIN LOW CARBON INTERVENTIONS MODULE:

The SCEnAT offers the functionality of providing a knowledge-database of supply chain low carbon intervention. In recognition that the SCEnAT is primarily interested in strategic emission reductions, we define a low carbon intervention as any decision or deliberate change that directly leads to a reduction in carbon emissions in a supply chain.

[The Supply Chain Low Carbon Interventions Module provides a knowledge-database of potential low carbon solutions, aimed at targeting carbon hot spots and reducing their emissions through appropriate strategic interventions.](#)

The knowledge-database of low carbon interventions is structured by a thematic typology developed in response to multiple calls from businesses requesting a source for information on low carbon practice from a single accessible location. The typology currently includes 16 broad intervention types (see Table 2) that cascade down into further sub-divisions of specific interventions. There are several specific interventions under each broad intervention type and for each of these the SCEnAT provides users with a brief general description of the intervention including, where possible, a quantification detailing the potential carbon reduction of implementing the intervention. These interventions are also classed as Soft or Hard interventions to indicate whether the emissions reductions that they produce are/will be quantifiable and thus able to provide, and substantiate, an accurate payback period calculation to support the business case for capital expenditure. Specific interventions are also illustrated by case studies collected by the project team and from external sources.

### IV. SUPPLY CHAIN LOW PERFORMANCE EVALUATION MODULE

It is imperative that an implemented low carbon intervention resulting in the decarbonisation of the supply chain does not risk the performance of the supply chain across other dimensions. This SCEnAT module is therefore implemented to track changes in supply chain performances due to the potential implementation of low carbon interventions. The Supply Chain Performance Evaluation Module is closely linked to the Supply Chains Mapping and Low Carbon Intervention Modules and consists of a set of performance evaluation measures representing Key Performance Indicators (KPIs).

[The Supply Chain Performance Evaluation Module is devoted to the assessment of the performance of the supply chain using key performance indicators satisfying the Triple Bottom Line of environmental, social and economic sustainability.](#)

This module provides an estimation of the impact of an intervention on a set of relevant KPIs. The development of this performance evaluation framework has been the result of a thorough literature review combined with a series of workshops with a range of MNEs and SMEs.

The performance evaluation measures are grouped into three categories:

- Economic and Efficiency Measures (including labour cost, net profit of focal firm within the supply chain, throughput time, percentage of late deliveries to the final customer, level of 1st tier suppliers defect rate).
- Environmental Measures (including carbon emissions, water, energy and electricity usage, percentage of waste sent to landfill, percentage of recycled waste, transportation usage).
- Social Measures (including measures capable of quantifying the impact of the supply chain on local communities in terms of jobs creation, expenditure on CSR and environmental training projects).

<b>BRAND INTERVENTION TYPE</b>	<b>DESCRIPTION</b>
<b>1. TECHNOLOGICAL</b>	Investment in more efficient technological equipment and machinery.
<b>2. ICT</b>	Green IT software and hardware solutions.
<b>3. BUILDING</b>	Methods of greening buildings (new builds and retrofitting).
<b>4. LOGISTICS AND TRANSPORT</b>	Options for reducing emissions relating to logistics (the transportation of goods, personnel, and delivery of services).
<b>5. ENERGY INTERVENTIONS</b>	Interventions relating to scope 1 and 2 emissions from energy production and consumption on site.
<b>6. PROCESS AND PRACTICE</b>	Alteration in process/practice within firm or supply chain to reduce energy used in comparison to old process.
<b>7. PRODUCT, PACKAGING, AND WASTE</b>	Reductions in emissions by product alteration and or the prevention/reduction of waste going to landfill throughout the supply chain.
<b>8. PROCUREMENT</b>	Reduction of supply chain emissions through environmental requirements and carbon reductions detailed within procurement contracts.
<b>9. OFFSETTING AND CARBON NEUTRALITY</b>	Quantifiable offsetting of overall CO2 emissions through offsetting (offsetting does not represent an actual reduction in CO2 emissions and therefore should not be reported as such).
<b>10. AWARENESS</b>	Interventions used to raise awareness of staff/supply chain partners enabling behavioural change with associated reductions in emissions.
<b>11. EMPLOYEE</b>	Formally employing personnel with environmental responsibility. Altering corporate governance structure to assign environmental responsibilities to existing staff.
<b>12. STRATEGIC</b>	Development of strategy and policy to enable an understanding of resource consumptive practice and activities in order to tackle carbon emissions.
<b>13. SUPPLY CHAIN/NETWORKED</b>	Intervention undertaken as part of a wider network or organisations.
<b>14. KNOWLEDGE BASED</b>	Interventions stimulated via consultancy, knowledge exchange, or other case based learning.
<b>15. BOLT ON</b>	Intervention that is not central to firms' carbon footprint.
<b>16. END USER</b>	Behavioural change at point of use. Use/disposal of product and/or service in a more environmentally aware manner.

Table 2: Topology of low carbon interventions

# CARBON ASSESSMENT METHOD

## OVERALL APPROACH

Life Cycle Assessment (LCA) is a scientific approach behind modern environmental policies and business decision support (European Commission, 2010). LCA is the methodology underpinning the environmental performance, evaluation and identification of carbon hotspots in the supply chains because it is the established method utilised to yield meaningful emissions values for products and services. LCA is governed by the ISO 14040 and 14044 standards which provides the framework under which assessments should be undertaken but does not specify with LCA methodology to adopt (International Standard Organisation, 1998). The lack of single global reporting standard exacerbates GHG accounting and reporting for companies (Deloitte, 2010).

The traditional approach to LCA is the process methodology (Guinée, 2002); this uses life cycle inventories compiled by estimating inputs and associated impacts into products and processes from cradle-to-grave (that is, from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). Refer to Figure 2 below.

The main limitation with this approach is that it is impossible to account for the infinite inputs into an LCA system, hence it results in the truncation of the LCA system boundary (Lenzen and Dey, 2000). For example, impacts associated with commercial buildings, capital equipment and service inputs, such as administrative services etc., may be missing. As such, the process LCA methodology is integrated with another lifecycle method; the Environmental Input-Output (EIO) LCA which is able to estimate the impacts of these indirect inputs.

EIO LCA takes an economy-wide perspective to carbon assessment (Wiedmann et al., 2011). The EIO LCA model is developed such that whole economy is taken as the system boundary and every input and associated impacts from any given sector of the economy that goes into any manufactured product can be estimated. For simplicity, the whole economy can be represented by 18 aggregated sectors, as illustrated in Figure 3.

LCA PHASES	INTERDEPENDENT LCA FRAMEWORK
STEP 1	Goal and scope definition
STEP 2	Inventory analysis
STEP 3	Impact assesment
STEP 4	Interpretation of results

Table 3: LCA framework according to the International Standard Organisation

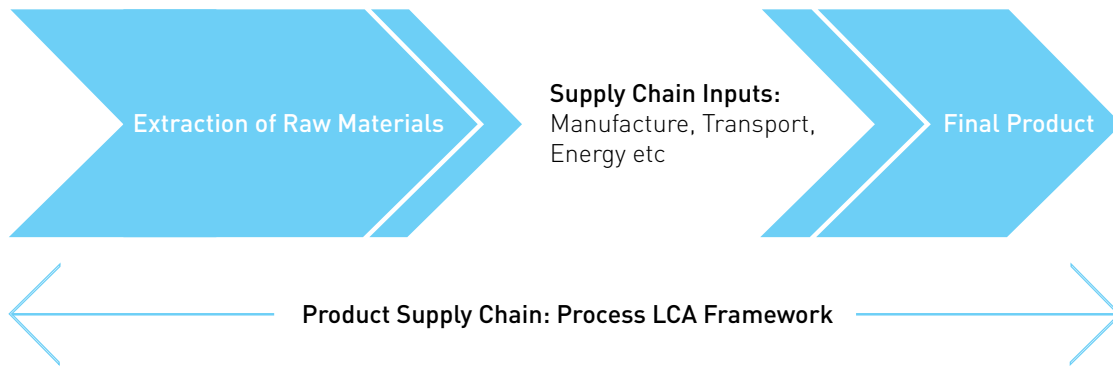


Figure 2: Process LCA perspective of Supply Chain Carbon Assessment

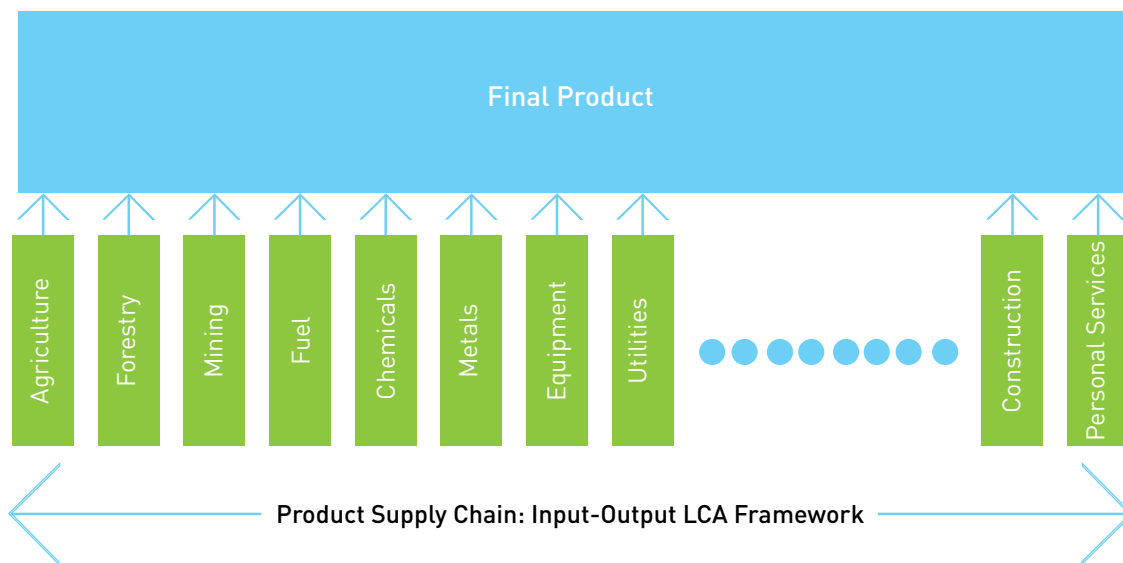


Figure 3: Environmental Input-Output LCA perspective of Supply Chain Carbon Assessment



The methodological basis underpinning the Supply Chain Carbon Assessment method in this project is the Hybrid LCA, which integrates the Process LCA method with Environmental Input-Output LCA method (Acquaye et al., 2011). The principle of the hybrid LCA methodology is that the more accurate process LCA is prioritised, but missing or unaccounted inputs are estimated using the EIO LCA.

In this project, the input-output model used is the Multi-Regional Input-Output (MRIO) model (Wiedmann et al., 2008). The MRIO links the input-output model of the UK to that of the rest of the world, thus creating a two region input-output model. As such, inputs into the product supply chain from imports into the UK can be accounted. The advantages of adopting the more robust hybrid LCA approach to Supply Chain Carbon Assessment are presented in Table 3.

The framework for the robust hybrid LCA approach therefore ensures that input-specific processes in LCA system is integrated into a generalised 2-region (UK and rest of the world) environmental-economic input-output model, ensuring that direct and indirect emissions are quantified and carbon hotspots within supply chain identified.

Three levels of data are required to implement the supply chain Hybrid LCA with priority given to company generated data in order to generate results that are specific to a company.

PROCESS LCA		ENVIRONMENTAL INPUT-OUTPUT LCA	
DISADVANTAGES	ADVANTAGES	ADVANTAGES	DISADVANTAGES
	More accurate		Less accurate
	Product and process specific		Generic and results are aggregated
Truncated system		Comprehensive system boundary	
Time consuming to develop inventories		Can assess impacts attributed to imports	
	Estimate Scope 1 and 2 emissions	Estimate Scope 3 (indirect) emissions	
<b>BENEFITS OF HYBRID LCA METHOD</b>			

Table 3: Supply chain data requirements and sources

TYPE OF DATA	DESCRIPTION	SOURCE
PRIMARY PROCESS DATA	Supply chain product and process specific data from company	Company
SECONDARY PROCESS DATA	Product and process specific data from validated database	Example: ECOINVENT
INPUT OUTPUT DATA	National and regional Input-Output Data	Office of National Statistics and Global Trade Analysis Project

Table 4: Advantages of Hybrid LCA methodology in Supply Chain Carbon Assessment

# SCEnAT CASE STUDIES

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The practicality of the SCEnAT is demonstrated in its application to the Malting Supply Chain for Muntons plc, Steel Ingot Supply Chain from Sheffield Forgemasters and Animal Feed Fat Supply Chain from Brocklesby Ltd. The case studies show how the SCEnAT intends to develop and evolve.

## **BENEFITS OF SCENAT MODEL**

In all cases, the following benefits in using the SCEnAT methodology and model to evaluate the whole product supply chain are highlighted as:

- It raises awareness of all the carbon emissions sources across the supply chain by allowing companies to identify carbon hotspots and be informed of the level of emissions.
- The SCEnAT provides a single easily accessible source of potential low carbon intervention solutions to companies across supply chains.
- This visible process of strategic emission reduction allows firms to promote their green credentials to supply chain partners and customers in an increasingly environmentally manner without greenwash.
- As part of a holistic approach to account, mapping, intervene and evaluate supply chain emissions the interventions database is intended to drive greater environmental accountability within businesses and their supply chains in order to mitigate their contribution towards climate change.
- Because the scope of the emissions assessment is wider than in traditional analyses, emissions reduction potential tends to be larger.
- Companies are able to understand the impact of low carbon interventions on a set supply chain TBL key performance indicators.

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## STANDARD OUTPUTS OF THE SCENAT

Each module of the SCEnAT has standalone capabilities, but on implementing every module and functionality, users can expect the following outputs and results:

- A supply chain map showing inputs and requirements of product supply chains.
- A supply chain carbon map showing each input into the supply chain tagged with its associated lifecycle emissions including economy-wide Scope-3 emissions.
- Identified of carbon hotspots of the product supply chain.
- The contribution of economy-wide lifecycle emissions (Scope-3 emissions) to the total emissions.
- A database of potential low carbon interventions targeted at identified carbon hotspots. In some specific cases, it is possible to quantify emission savings and thus able to provide, and substantiate, an accurate payback period.
- An estimation of the impact of the interventions on a set of supply chain KPIs.

# CASE STUDY 1: MUNTONS MALTING SUPPLY CHAIN

Muntons plc, based in Suffolk, are UK manufacturers of malt, malt extracts and malted ingredients. Over 90 years, Muntons has grown to become a significant international player in the supply of these products for beer and wine, flours and flakes and other malted ingredients relevant to the food and drinks industry. The company's malting complex manufactures 95,000 tonnes of malt per year. Each tonne of malt has the potential to produce around 15,000 pints of 4% vol. beer or 600 bottles of cask strength whisky.

Muntons is continuously looking at innovative ways to reduce its carbon footprint through many supply chain initiatives. Currently, Muntons ranks 20th in the Sunday Times Best Green Companies List and has ISO14001 certification for environmental management.

The case study is built around Muntons Malting Supply Chain. The functional unit adopted is one tonne of malt. The process LCA system encompasses all direct processes from agricultural production of barley on the farm to the malting process.

Primary process data for the malting supply chain was obtained from Muntons; this consisted of data on haulage, the malting process, storage, energy input and business travel. Secondary process data was obtained from Ecoinvent and include validated secondary data on agricultural production processes: work processes, seed, fertiliser, pesticide use.

The total lifecycle GHG emissions, estimated to be 655.65 kg CO<sub>2</sub>-eq per tonnes, can be divided into two: process GHG emissions and indirect GHG emissions. The process impacts are associated with direct supply chain inputs – this contributed 87% of the total emissions. Indirect GHG emissions estimated using the MRIO framework contributed 13% of total lifecycle emissions of the malting supply chain (Figure 5).

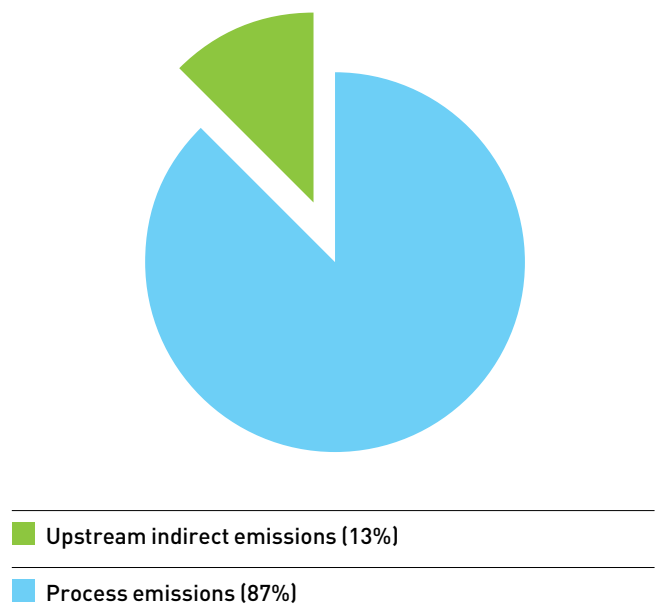


Figure 5: Breakdown of Supply Chain process and Upstream emissions

These indirect impacts across the MRIO economic sectors are aggregated across 18 sectors and illustrated on the SCEnAT generated supply chain carbon map shown in Figure 4.

The most significant carbon hotspots in the malting supply chain include energy inputs (gas 30% of the total lifecycle emissions; electricity 11.4%), fertiliser (28.5%), farm machinery (14.2%), and upstream emission from the agriculture sector (9.5%). The results of the carbon assessment module of the malting supply chain using Hybrid LCA is translated into a supply chain carbon map to identify carbon hotspots and quantify their impacts.

The following subjective scale is used in the ranking: Very High (colour coded in red, indicates inputs with emissions greater than 10% of the total lifecycle emissions); High (light red; 5-10%); Medium (1-5%); Low (green: less than 1% of total lifecycle emissions).

The low carbon interventions module within the SCEnAT serves as an evidence-based approach to reducing carbon emissions in the malting supply chain by targeting identified carbon hotspots in the supply chain after the carbon calculation. Muntons has already started a programme to decarbonise its supply chain and the information we have gained from them has been used within the SCEnAT database of low carbon interventions to inform other businesses from within and beyond the food and drink sector. At an intra-firm level investments have been made by Muntons in ensuring Best Available Technology is being utilised within one of the identified hotspot (gas inputs into the supply chain) by adopting energy efficient gas burners

As regards impact on the above-mentioned measures, this specific intervention has seen consumption reduced by 8% in the kilns, accompanied by an increase of the percentage of staff receiving environmental training at induction and a refresher every three years, with no relevant side effects on other KPI dimensions.

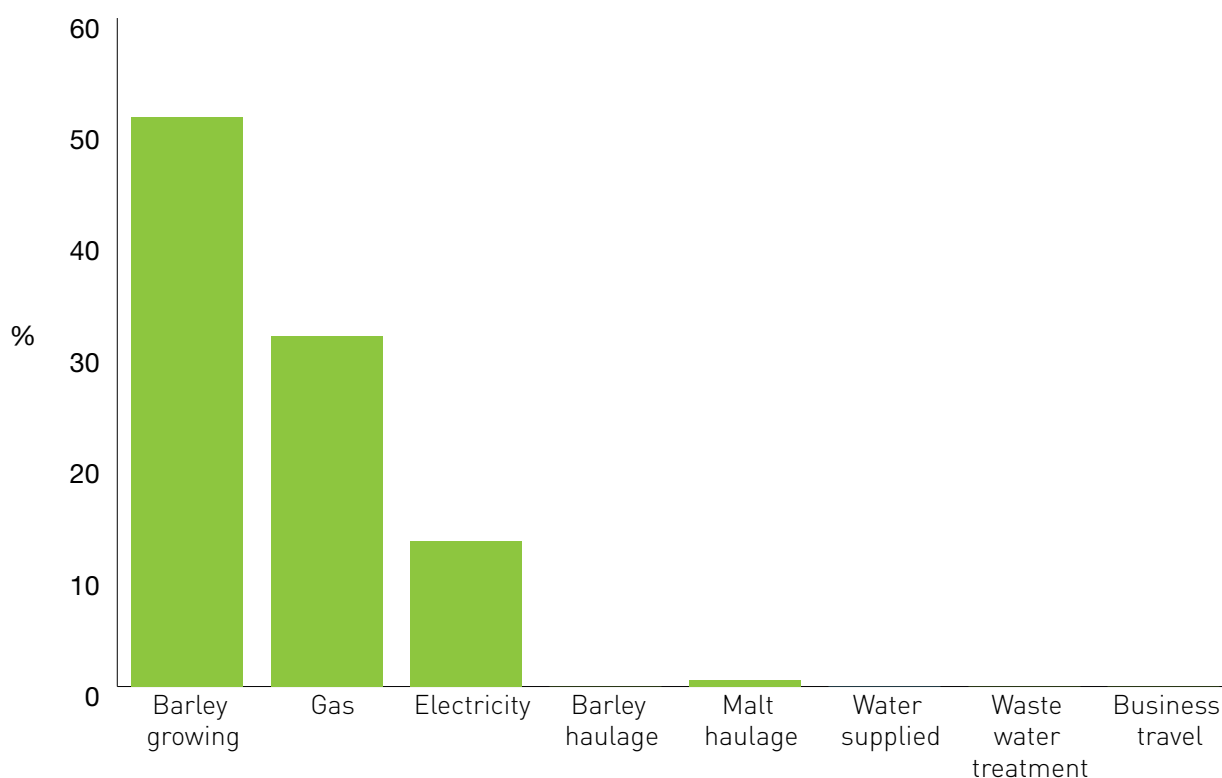


Figure 6: Lifecycle emissions of Malting Supply Chain

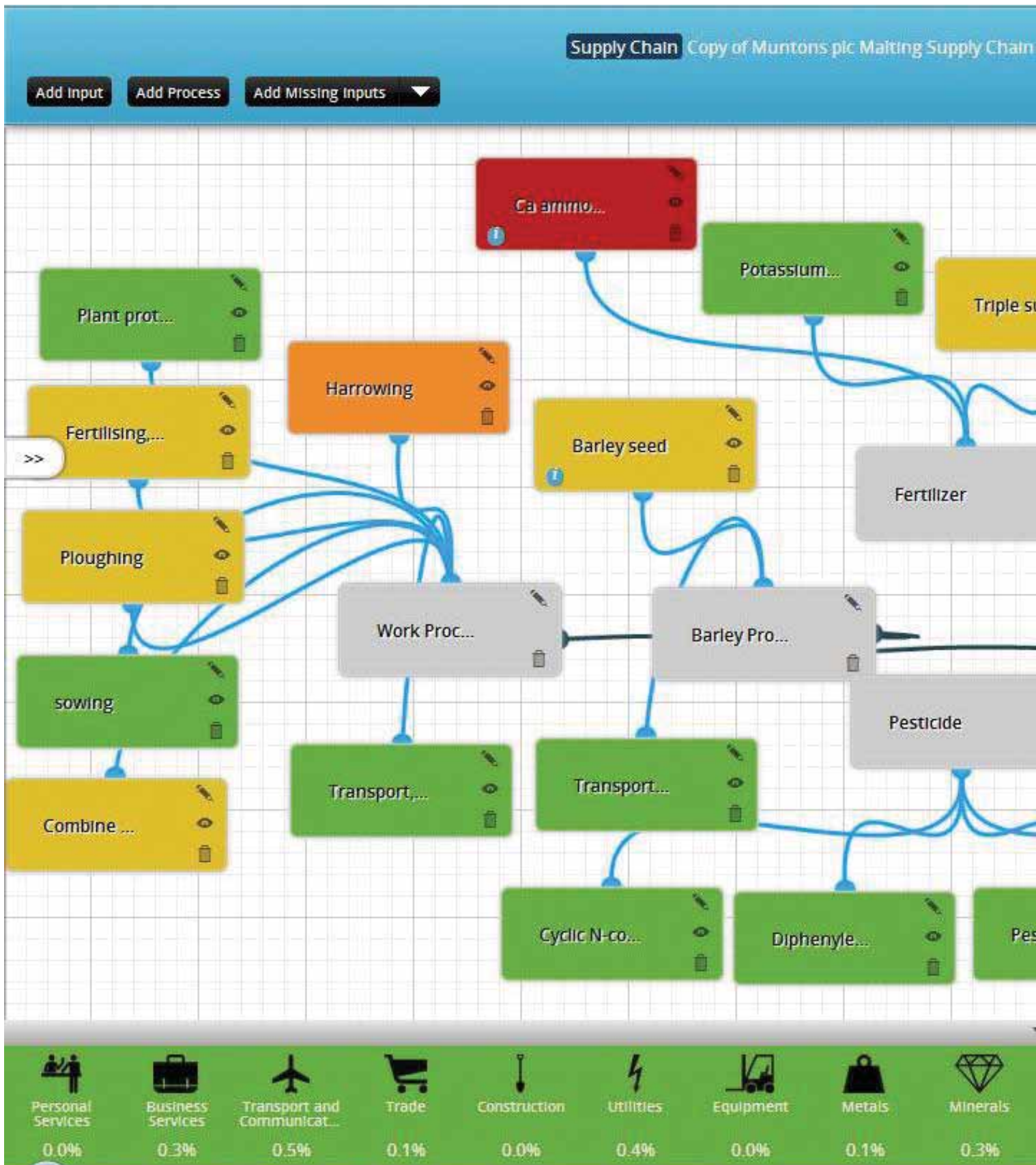
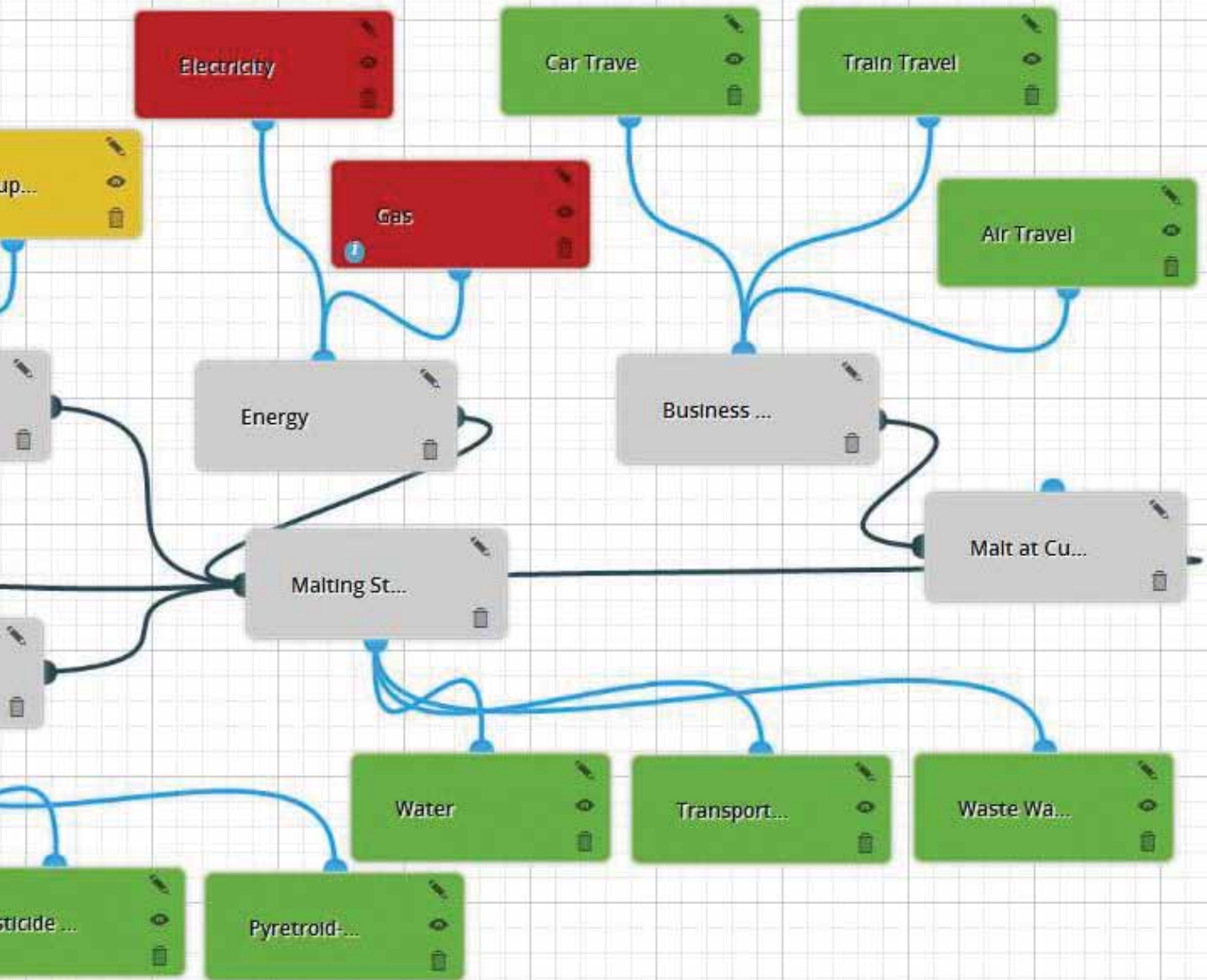


Figure 4: SCEnAT screen shot of Malting Supply Chain Carbon Map



Chemicals	Fuels	Wood and Paper	Textiles	Food	Mining	Fishing	Forestry	Agriculture
0.9%	0.1%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	9.9%

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Work has also been undertaken in collaboration with Muntons' supply chain to centralise barley drying and storage as well as crop movement.

In terms of impacts, this has saved 650 tonnes of CO<sub>2</sub> and reduced 1700 vehicle movements per annum, with no side effects on other dimensions. Results from the supply chain carbon map (Figure 4) have also highlighted other carbon saving opportunities for which interventions are being designed and implemented. For example, 45% of the malt supply chain emissions are derived from the growing stage – notably from fertiliser production and usage, and diesel consumed by farm machinery. Muntons is now targeting these emissions by engaging with its supply chain, promoting and trialing alternative fertiliser regimes, and precision farming techniques using GPS to ensure fertiliser is only applied where needed. Looking to the future, Muntons is considering further investments in on-site renewables, such as installing a wind turbine.

The payback for such schemes is considerable – further information and case study examples from within the SCEnAT's intervention database is helping Muntons recognise how its business can benefit, which is helping to develop the business case.

The example of Muntons illustrates how we intend the SCEnAT to develop and evolve. Users initially take advice and guidance and then, where appropriate, provide their own case studies to further populate the database of low carbon interventions.



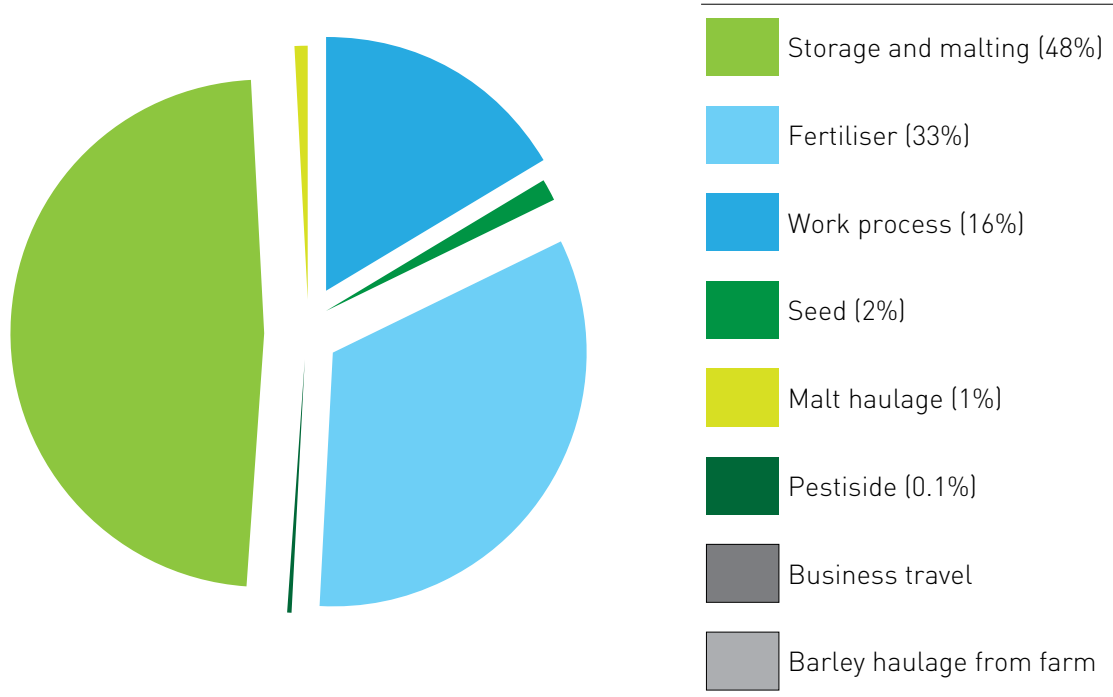


Figure 7: Further breakdown of process lifecycle emissions

# CASE STUDY 2: SHEFFIELD FORGEMASTERS STEEL INGOT SUPPLY CHAIN

Sheffield Forgemasters is an international steel producer specialising in the production of large bespoke steel castings and forgings, as well as standard rolls, ingots and bars to various global markets including nuclear, offshore oil and gas, power generation, mills and presses, defence and steel rolls. Sheffield Forgemasters dates back to the 1750s and is the successor to such famous Sheffield names such as Vickers, English Steel, Firth Brown and British Steel. In 2010, Sheffield Forgemasters produced 60,200 tonnes of ingot.

The company takes its environmental responsibilities increasingly seriously, having in place Environmental Management Standards certified to ISO 14001 since 2003.

The case study relates to steel ingot supply chain. The lifecycle assessment (LCA) results are based on the environmental impacts due to global warming potential of the steel ingot supply chain. The total lifecycle carbon impacts estimated to be 539 kg CO<sub>2</sub>-eq per tonne of steel ingot can be divided into two: process LCA impacts and indirect impacts. The process LCA impacts contributed 78% of the total lifecycle impacts of the steel ingot supply chain.

Indirect emissions associated with the supply chain were estimated to be 22% (Figure 8).

These indirect emissions into the steel ingot supply chain arise from emissions associated with indirect inputs from the industries aggregated across 18 sectors namely: agriculture, forestry, fishing, mining, food, textiles, wood and paper, fuels, chemicals, minerals, metals, equipment, utilities, construction, trade, transport and communication, business services and personal services.



■ Indirect LCA Emissions (22%) 110Kg CO<sub>2</sub> eq

■ Process LCA Emissions (78%) 419Kg CO<sub>2</sub> eq

Figure 8: Breakdown of supply chain process and indirect emissions

The lifecycle emissions of the steel ingot supply chain are presented below in the bar chart in Figure 9.

The results of the carbon accounting module of the steel ingot supply chain was estimated using the hybrid model and is translated into a supply chain carbon map to identify carbon hotspots and quantify their impacts. The concept of a supply chain carbon map within a complete system boundary provides insight to users and assists in the design of low carbon products and supply chains. This approach improves the effectiveness of carbon reductions in the overall supply chain by directing investment either to reduce emissions from internal processes or by helping supply chain partners and suppliers to reduce their own carbon intensity. The generated supply chain carbon maps within the SCEnAT (Figure 10) serves to provide evidence in order to adopt relevant low carbon intervention strategies in reducing CO<sub>2</sub> emissions in the steel ingot supply chain by targeting identified carbon hotspots after the carbon calculation.

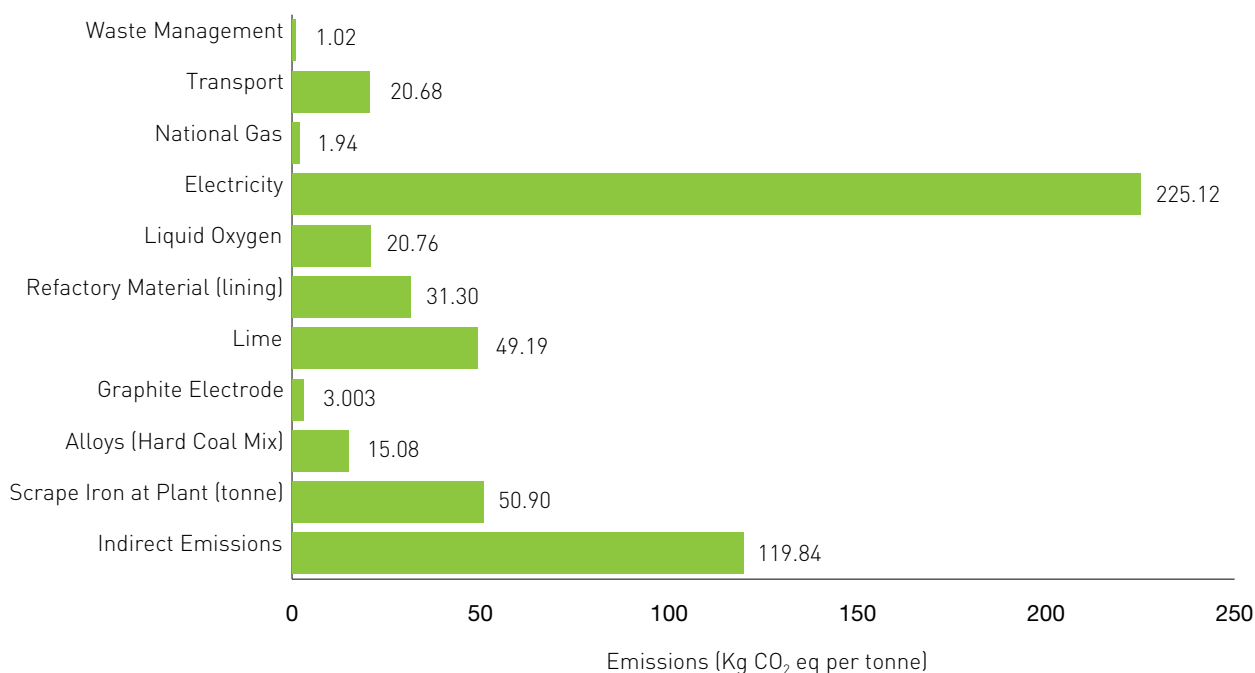


Figure 9: Lifecycle emissions for steel INGOT supply chain

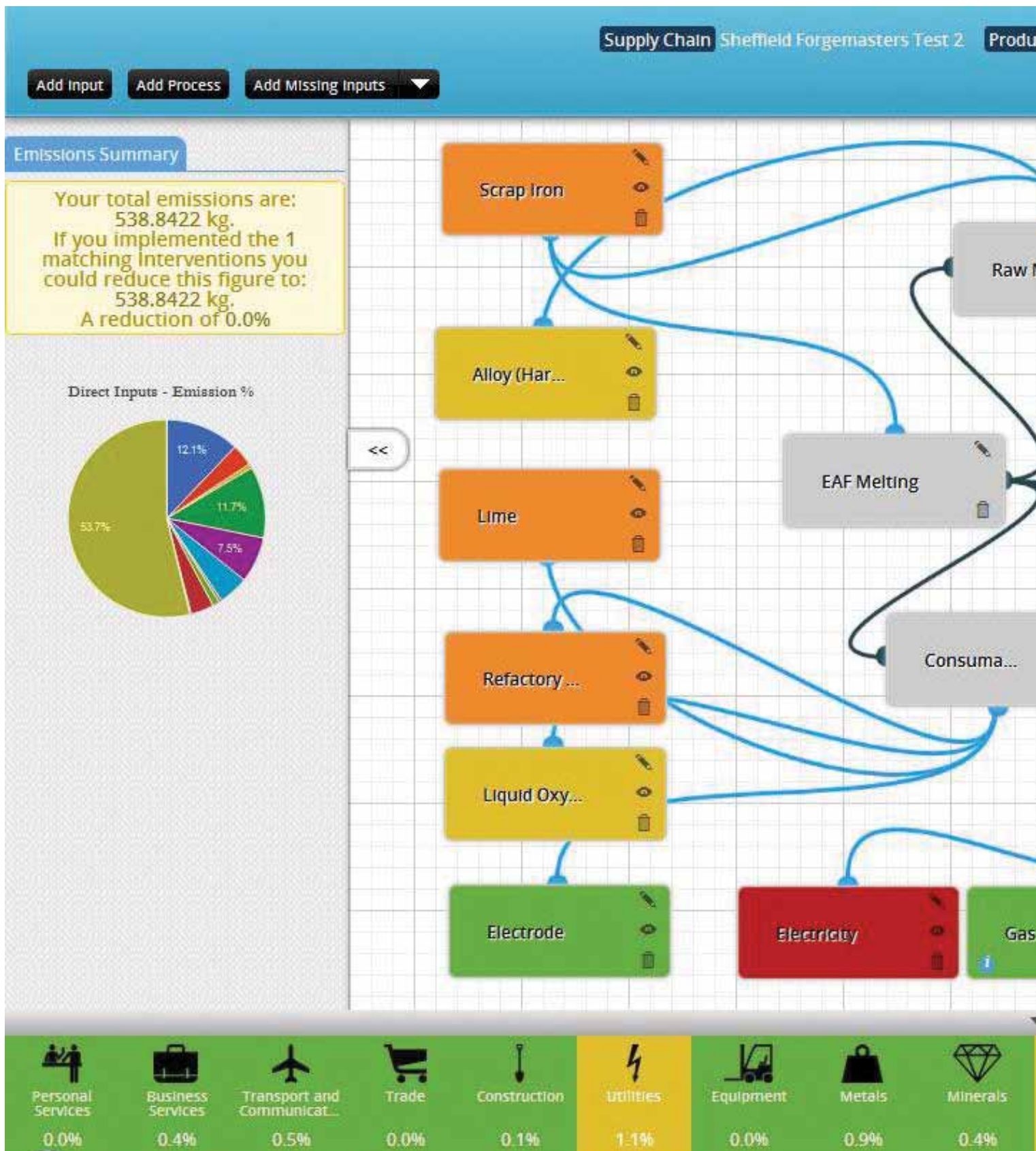
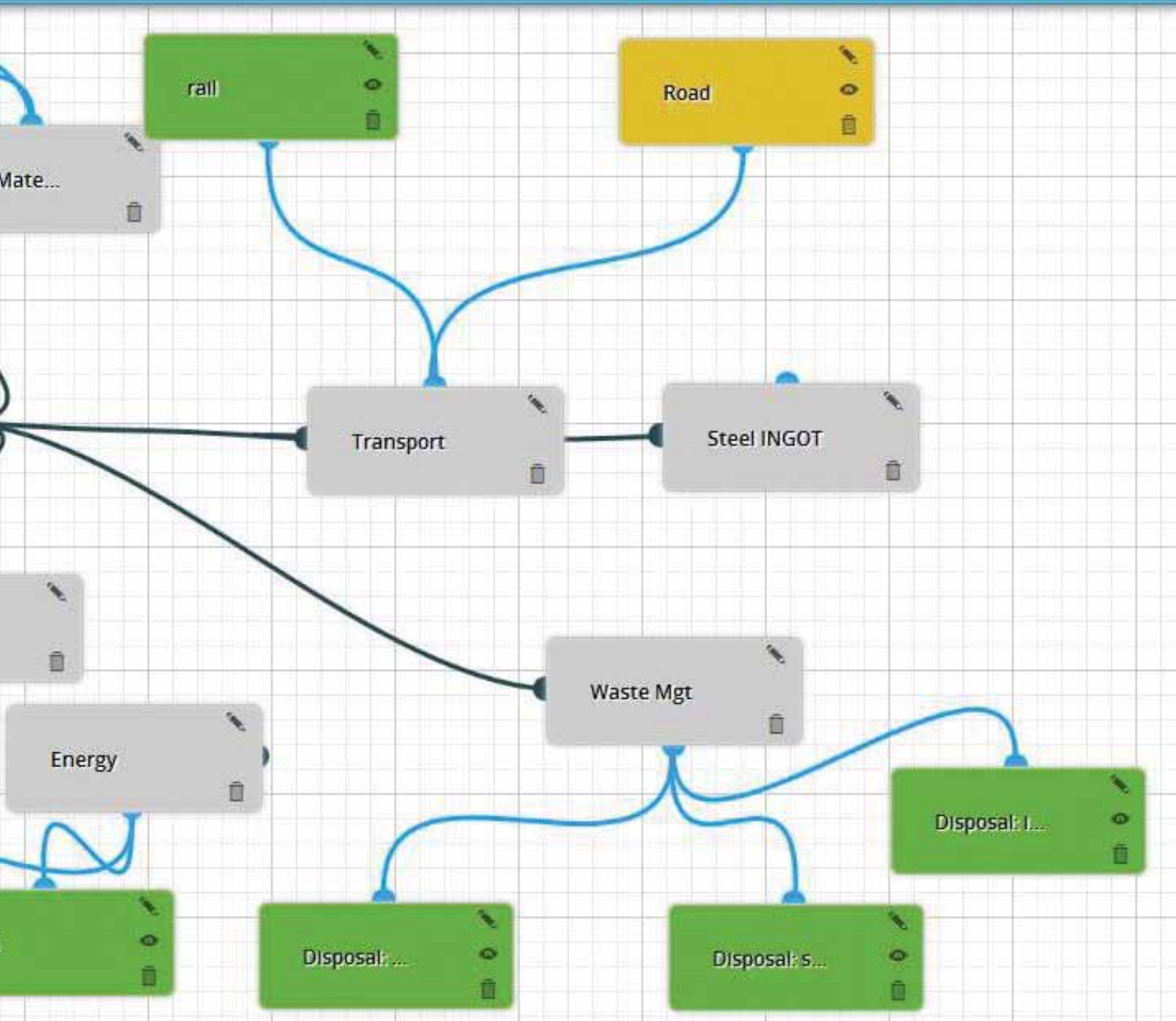


Figure 10: SCEnAT screen shot of steel INGOT supply chain



# CASE STUDY 3: BROCKLESBY'S ANIMAL FEED FAT SUPPLY CHAIN

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Brocklesby Ltd, an SME and a family owned company, based at North Cave in East Yorkshire, UK, is a recycling specialists involved in the production of animal feed fats, used cooking oil and fatty acids. Via a close collaborative business style, Brocklesby Ltd has developed considerable competence and expertise in these business sectors.

Brocklesby Ltd has cultivated strong links with a large number of food manufacturers in the UK and Ireland and provides a bespoke supply chain management service for all their waste vegetable oil streams. This recyclable material is then used as a prime ingredient for Brocklesby's animal feed customers who are established businesses within the UK pig, poultry and ruminant markets.

Brocklesby Ltd also works closely with the major UK retailers and process its used cooking oil into products primarily for use in the biofuels industry. Brocklesby also procures bio-diesel soap stock and allied products which it manufactures into fatty acids for technical use. The seven acre North Cave site has 2000mt of bulk storage capacity, works 24 hours a day, seven days a week and operates its own fleet of vehicles. Brocklesby produces a range of animal feed fats for all classes of farm livestock within the UK's pig, poultry and ruminant sectors under Feed Materials Assurance Scheme (FEMAS).

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The case study is Brocklesby animal feed fat supply chain. The functional unit adopted is one tonne of animal feed fat. Primary data obtained from Brocklesby consist of data on electricity, boiler fuel, water and diesel.

The total lifecycle GHG emissions of the animal feed fat supply chain were estimated to be 34.96 kg CO<sub>2</sub>-eq per tonne (69% process emissions and 31% indirect emissions, see Figure 11). Notable hotspots are electricity (46.5%), transport (13.7%) and indirect upstream inputs from the agricultural sector (29.1%).



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- Upstream Emissions (31%) 13.68Kg CO<sub>2</sub> eq
  - Process Emissions (69%) 21.28Kg CO<sub>2</sub> eq
- 

Figure 11: Breakdown of supply chain process and indirect emissions

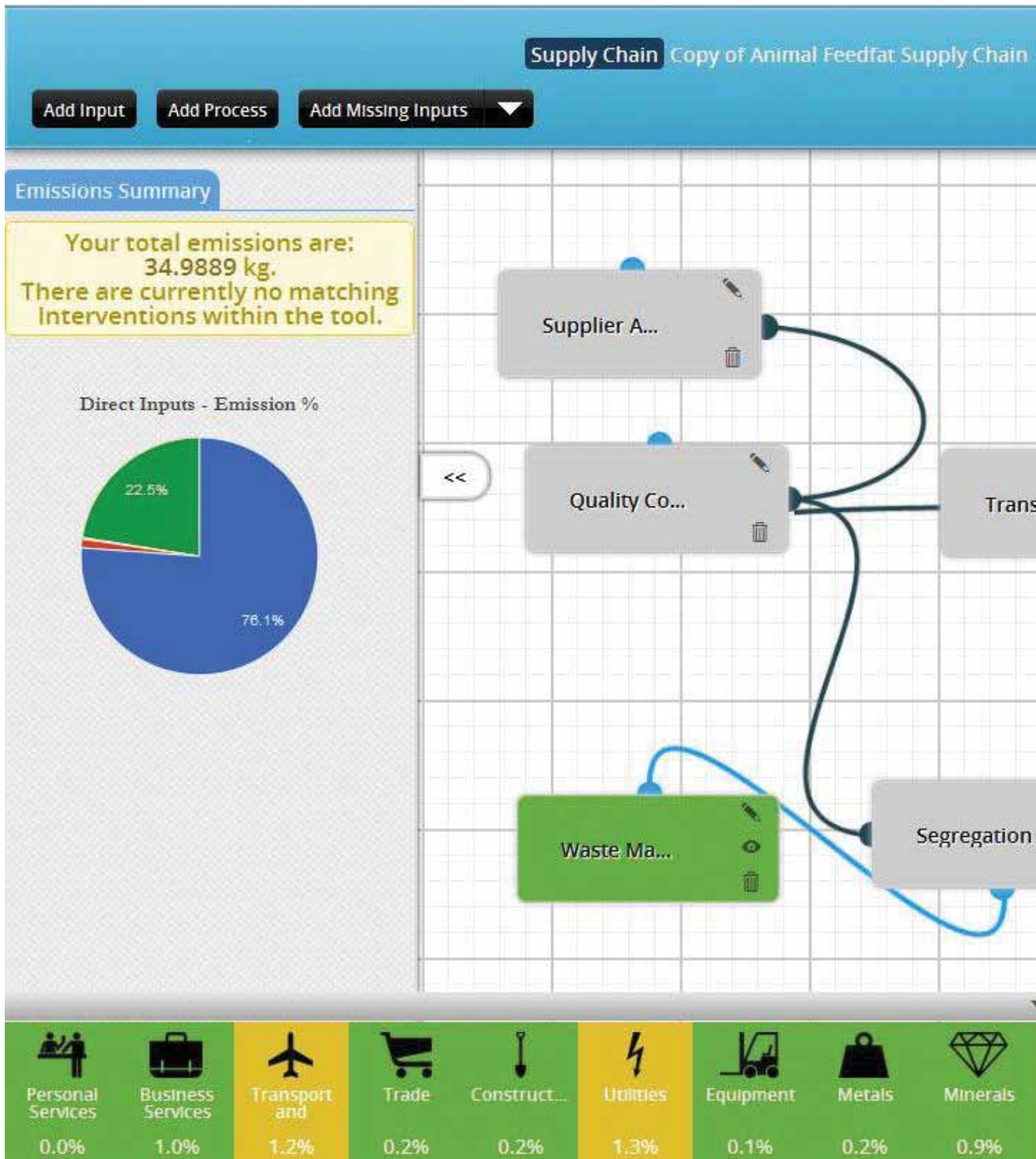
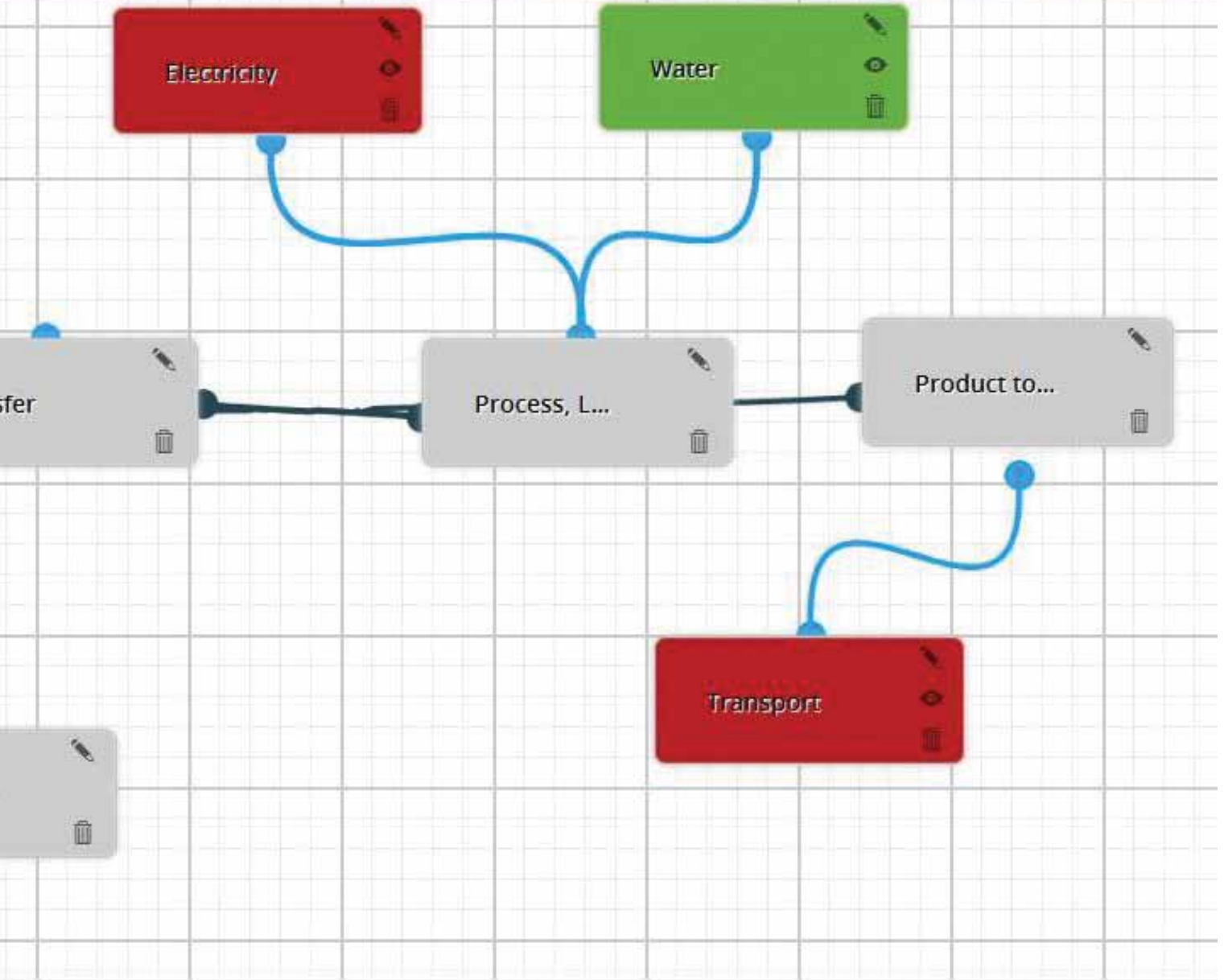


Figure 12: SCEnAT screen shot of Animal Feed Fat Supply Chain





 Chemicals 2.4%	 Fuels 0.3%	 Wood and Paper 0.1%	 Textiles 0.0%	 Food 0.1%	 Mining 1.9%	 Fishing 0.0%	 Forestry 0.0%	 Agriculture 29.1%
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# CONCLUSIONS AND RECOMMENDATIONS

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In recent years, issues of sustainability have become a focus in the management of business operations and supply chains. This is driven by various factors but the decarbonisation of supply chains is generally seen as a key reason why businesses seek information and actions to make their operations and supply chains more sustainable. However, there is a general lack of tools that can inform businesses on their operations such as the impact and management of their product supply chains.

The development of a Decision Support System within the Low Carbon Supply Chain Project proposes holistic and practical evidence-based framework that has been used to develop such a decision aiding system for the decarbonisation of supply chains. This framework consists of four integrated supply chain modules: supply chain mapping, supply chain carbon accounting, low carbon interventions and supply chain performance evaluation.

The novelty of the SCEnAT is that through the mapping of the product supply chains, companies gain an understanding of supply chain inputs and carbon impacts of their products. It also offers flexibility in the supply chain mapping, data input and automation of results (refer to Figures 4, 10 and 12). Through the use of the state-of-the-art robust Hybrid LCA methodology, direct and indirect carbon emissions are quantified and carbon hotspots within supply chain identified. After the SCEnAT maps, the supply chain carbon emissions are quantified and the carbon hotspots identified, the novelty of the SCEnAT is further shown through the use of the Low Carbon Intervention Module as a knowledge-database – this is called upon and applied to the carbon hotspots. Furthermore, the SCEnAT provides a practical and evidence-base decision aiding tool for businesses demonstrated through the case study and a Triple Bottom Line (TBL) environmental, economic and social framework of key performance indicators, which is used to evaluate the impact of interventions on supply chain performance.

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The SCEnAT, as explained in various parts of this report, is a novel supply chain management system and unique within the market place. In order to fulfil its potential, there is the need for continual development of the tool. It is recommended that:

- Businesses are further engaged in the developmental stage of the tool in order to improve it based on end user feedback.
- In order to further increase the usefulness of the knowledge-based database of low carbon intervention, businesses must be actively engaged to use and provide input into it.
- The development of the SCEnAT serves as a starting point to further develop and extend the scope of the Low Carbon Supply Chain (LCSC) project. The principles of the LCSC project, which adopts a linear approach to supply chain, can be adapted to a more circular economy approach to supply chains. This work is currently being pursued through the development of an FP7 proposal: 'ENV.2012.6.3-1 Innovative resource efficient technologies, processes and services' with other partners in Germany and the Netherlands.

# POLICY IMPLICATIONS

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The principles of the Low Carbon Supply Chain Project and the development of the SCEnAT have policy implications at two levels or scales; the company (or supply chain) level and at the wider national policy level in promoting emissions reduction measures. The UK aims to reduce greenhouse gas emissions by at least 20-24 billion tonnes by 2050. In order to achieve this goal, urgent action needs to be undertaken to cope with unsustainable supply of energy and the need to reduce carbon footprint from a new perspective, based on a holistic supply chain approach.

A concerted effort from individual companies who form part of supply chain networks would therefore have wider effects up and down the supply chain, with environmental implications also diffusing throughout the supply chain to the wider economy.

At the company level, the SCEnAT can serve as a tool/system to be used in environmental management systems and programmes. The SCEnAT can aid the evidence-based formulation of strategic supply chain policies, decision making and management. The impacts and implications of these reach far beyond an organisation boundaries because of the collaborative nature of supply chains. Even though green supply chain management has significant environmental motivations (together with other factors such as competitive and economic pressures), regulatory drivers play significant roles in its adoption across businesses and industries. Regulatory measures would drive the need for assessment and management tools such as the SCEnAT.

Measuring and reporting of carbon emissions by organisations is seen as a useful action in helping to reduce emissions and achieve energy and other resource efficiencies. However, corporate reporting of carbon emissions is not mandatory. Under DECC and DEFRA recommended guidelines, organisations are supposed to report as a minimum standard their Scope 1 and Scope 2 emissions. In the future, when Scope 3 emissions are required as a minimum reporting standard, the SCEnAT's robust emissions calculation capability would stand at a competitive advantage. The SCEnAT is therefore going to be a fundamental enabler and a game changer for organisations to take advantage of supply chain innovation towards low carbon economy, climate change, new industry, low carbon investment and energy agenda.

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The newly launched GHG Protocol Standard for Product Lifecycle and Scope 3 Emissions (World Business Council for Sustainable Development and World Resource Institute, 2011) supports strategies for companies to partner with suppliers and customers to address climate impacts throughout the value chain. The SCEnAT with its Scope 3 carbon calculation capability would ensure that it remains an innovative SC tool for businesses.

The International Standard Organisation, ISO 14040 and 14044 environmental management standards provides the framework for lifecycle assessments. However, these standards do not specify which methodologies are to be used. Hence, there is no statutory requirement to have environmental information (such as reported supply chain carbon emissions) audited. When the auditing of reported supply chain emissions becomes mandatory, it would highlight the challenges of assurance and verification of data and results. Assurance or verification of data and reported carbon emissions is therefore a key policy issue and imperative in order to uphold the integrity of data disclosed and reported emissions. Verification of data and models therefore has far reaching policy implications on carbon reporting and management at the supply chain and company level and it would be an integral part of promoting quality of data and results disclosures. As part of thought leadership in furthering the understanding of decision science and environmental management on supply chain analysis that effect on industry cross organisational boundaries on supply chain carbon mapping and hot-spotting; and SCEnAT has implications for the lifecycle assessments methods and standards which in turn highlight the challenges of assurance and verification of data and results, thus, making assurance or verification of data and reported carbon emissions a key policy.

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## ACKNOWLEDGEMENTS

We would like to thank the Centre for Low Carbon Futures for funding the Low Carbon Supply Chain Project.

We also wish to express our gratitude to the project's Business Advisory Group for their valuable advice in shaping the direction of the project and SME partners who have provided access to their company's data in undertaking the case studies.

DLA Piper LLP; Rolls-Royce plc; Tata Steel; Unilever; Muntons plc; Sheffield Forgemasters International Ltd; Brocklesby Ltd; Skanska; Mott MacDonald; Manufacturing Advisory Services (MAS); Sheffield Chamber of Commerce; Doncaster Chamber of Commerce; Barnsley & Rotherham Chamber of Commerce; NAMTEC; Sheffield City Region; South Yorkshire Green Business Club; Shaping Cloud

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CLCF is grateful for funding and support from Accenture, the Beijing Institute of Technology, the Energy Intensive Users Group, the Foreign and Commonwealth Office, the Regional Development Agency, the Trades Union Congress, the UK Department of Climate Change, the University of Hull, the University of Leeds, the University of Sheffield and the University of York.

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