Department of Mechanical and Aerospace Engineering

Project Title: *Implementation of Industrial Symbiosis for the minimisation of energy use through industry network formation*

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Copyright Declaration

Signed: Sanaa Ahmed   Date: 25/08/2017

Contents

Abstract

With many challenges facing the industrial sector as we move towards creating a more sustainable future, this report looked to tackle two main challenges facing the industries around us; climate change and clean energy use. The aim of the project looked to bring together the practise of Industrial Symbiosis in creating two networks showing how the industries identified could work together and reduce both emissions and waste whilst implementing clean energy within the networks. The approach taken involved thorough research of successful case studies along with the Industrial Symbiosis practise in order to approach the challenge in the best way. A number of various industries were identified and assessed in order to establish the best network for both industries and environment. Once completed, both networks created were successful in showing the improvements made within energy used and emissions diverted. Network 1 successfully diverted 14000 tonnes of CO2 whilst producing over 4 million kWh energy. Network 2 diverted 6000 tonnes of wood, produced 25000 MWh of clean energy whilst also diverting 405,000 tonnes of CO2 from entering the atmosphere. The networks created showed huge potential energy savings by industries working together and paving the way to producing a cleaner, more efficient and sustainable future.

1. Introduction

(i) Background - A shift towards a more Sustainable Future

With year 2030 fast approaching, the target year set by the United Nations in which to meet their ‘Sustainable Development Goals’ draws ever closer with attention focused on the changes and steps taken by member states to successfully achieve these goals (1). The goals set out by the United Nations aims to address 17 challenges currently being faced throughout the world and help tackle the issues for both the planet and the people (1). The 17 goals reflect areas of human life where changes need to be made soon in order to create a

sustainable way of living and equality for both present and future generations. The goals agreed and set out to meet this agenda are shown below:

Figure 1 - United Nations Sustainable Development Goals (1)

Through the 17 different goals set out by the above agenda it can be seen that the three main aspects of achieving strong sustainability are covered through various targets: Economic, Environmental and Social (2). This allows changes to be made to the way countries develop for the future from ensuring basic needs such as food and water to innovative ideas on how a country can progress economically without increasing emissions and raw material consumption. With the period in which these need to be met fully underway, the United Nations ensured that monitoring of countries developments for each goal will be undertaken throughout this time to ensure compliance by each country to each goal (1). This has allowed countries to set up targets and plans to ensure that work is being done in each sector in line with meeting both their own and international targets allowing a number of new ideas flourish through these developments. With the UK being a member state of the UN, the government outlined a framework of how the country will ensure that these goals are implemented into the nation's development by creating 'Agenda2030' (3). An agenda as such allows the government to interact with the people to ensure that the country as a whole including households, small businesses and industries have the same targets to reach with various ways in which these can be met being explored.

(ii) Targets set within the UK

The 'Agenda2030' created by the UK Governments 'Department for International Development' allowed a framework to be set out by the government including targets to be set to ensure that progress could be monitored through the years. The agenda mentions a number of programmes put in place for each goal such as projects currently underway overseas in helping countries in tackling poverty along with work within charities in the UK (3). A number of targets were also set mainly in the energy focused agendas in order to easily monitor the energy industry and help ensure compliance to both UK and UN goals. The goals with an energy focus with set targets mentioned within 'Agenda2030' include Goal 7 –Clean Energy and Goal 13 – Climate Action (3). In order to achieve the Goal of clean energy within the UK, the agenda focuses on the importance of innovation within the Energy industry along with the continued development of renewable energy (3). The UK government plans on investing £2 billion within this sector which will help back the emergence of new developments and research and bodes well for the future in this sector (3). Another target which was emphasised in ‘Agenda 2030’ was for 30% of electricity produced to be generated by renewable sources by 2020, with support being given to new projects (3).

Along with energy production, the importance of climate action was highlighted in Goal 13, which aims to reduce pollutants emitted into the atmosphere. Highlighted by ‘ Agenda2030’ was the importance given to reducing greenhouse emissions by reinforcing the UK Climate Act 2008 which aims to tackle this issue and ensure compliance set by UK standards (3).

With the release of the ‘Sustainable Development Goals’ in 2015, the Scottish Government also ensured that their commitment to achieving these goals was shown by the creation of the ‘National Performance Framework’ (NPF) in the same year (4). This framework underlined a number of objectives which would be monitored and where tracking was also available to ensure that the public had open access to ongoing developments (4). Included in the NPF were similar targets to that shown by ‘Agenda2030’ such as reductions in GHG emissions and increase in clean energy promotion and production. However there were also a number of targets specific to the framework in Scotland such as to ensure the reduction of waste and the creation of sustainable communities (5). Scotland has also pledged to 10 energy commitments with the intention of promoting clean energy developments along with setting targets for Scotland’s renewable energy generation (6). Along with these commitments, the Scottish Government set out new targets in their Energy Strategy published earlier this year which tie in with fulfilling the goals of producing clean energy and taking action on climate change seen in the UN ‘ Sustainable Development Goals’ (SDG), these are as follows (7):

- ‘50% of Scotland’s energy demand should be generated through renewable energy sources by 2030’ (8)
- ‘66% decrease in GHG emissions in Scotland by 2032’ (8)
- Renewable energy sources to meet 11% of Scotland’s heat energy used by 2020 (9)

(iii) Problems to be addressed

Following on from the challenges identified within the UN 'Sustainable Development Goals'(SDG), it is clear to see through the agendas set by both Scotland and the UK as a whole the main issues which need to be addressed within the Energy sector. As highlighted within the '2030 Agenda' and Scotland's 'National Policy Framework' it is seen that the focus of energy targets and goals have been aimed towards reducing GHG emissions, reducing waste and increasing the amount of energy produced by renewable sources. These three challenges fall mainly into two of the 'SDG', helping identify the problems which will therefore be addressed and the goals looking to be achieved from each agenda.

The problems on which this report will focus on will be as follows:

Goal 7: Affordable & Clean Energy (1)

- Increase renewable energy use for energy production
- Innovative energy developments

Goal 13: Climate Action (1)

- Reduction in Greenhouse Gas Emissions to atmosphere
- Reduction in waste

Greenhouse gas emissions such as Carbon dioxide and Methane and their release into the atmosphere and the effect of these emissions on the change in climate are serious issues which this goal is focused on. With a global temperature of 0.99°C in 2017, it is clear to see from the graph below the direction at which the global temperature is heading and the trend seen since the early 1900's:

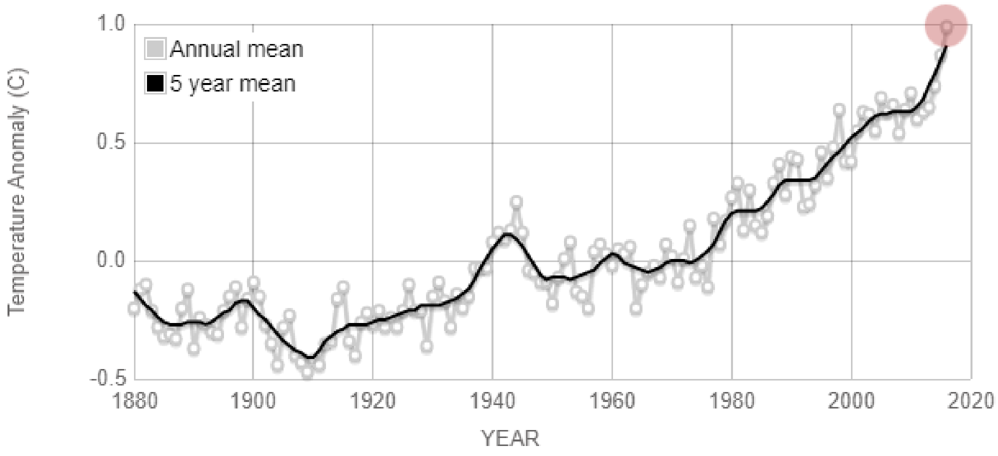


Figure 2 - Global temperature trend - NASA (10)

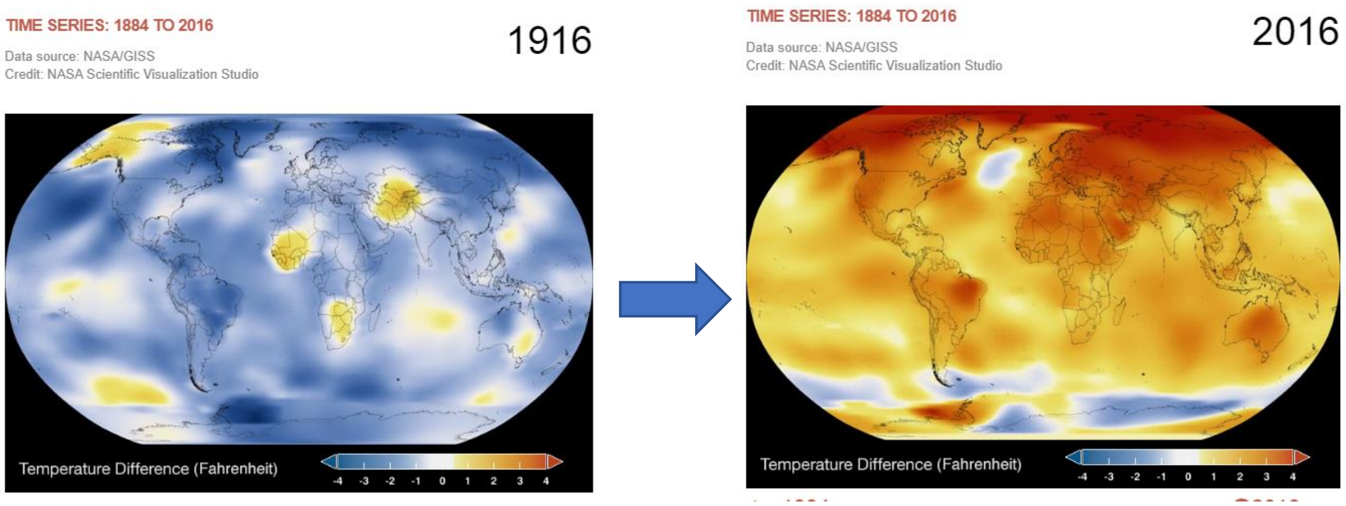


Figure 3 - Visual reference to change in global temperature - NASA (10)

From Figure 2 it can be seen that throughout the 20th and 21st century the rise in the global temperature poses a serious threat to our planet where change is required in our daily lives to help ensure that emissions polluting the atmosphere are either significantly reduced or eliminated. This is further emphasised by the visual comparisons provided by NASA showing the difference in the earth's surface temperature within a century. Globally CO2 emissions have risen by over the last three decades by 50% which once again emphasises the problem being faced and changes which need to be made together (11).

Within Scotland the Climate Change Act was introduced in 2009 to ensure that this problem was handled and taken seriously within Scotland to ensure the reduction of emissions through compliance and the meeting of set targets (12). Scotland has so far been able to meet and reduce their set targets of GHG emission reductions with a 40% decrease of emissions seen between 1990 and 2015 (13).

Although emissions within Scotland have reduced significantly over the last decade, it can be seen from the following graph that there is still a wide scope of possibilities of further reducing Scotland's emissions from various sectors:

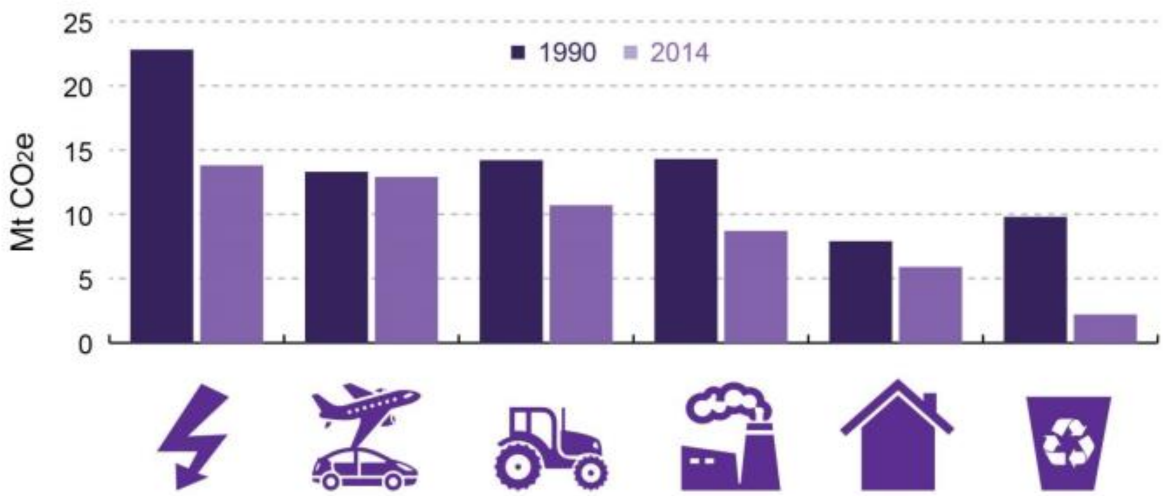


Figure 4 - CO2 emission changes by various sectors (14), (15)

On a global scale the Industrial sector plays a vital role in ensuring that CO2 emitted to the atmosphere is reduced as this sector alone is responsible for around 35% of global CO2 emissions along with being heavily energy intensive (16).

Within Scotland around 20% of CO2 emissions arose from industries, in Glasgow alone 40% of CO2 emissions arose from this sector in year 2014, the split in sectors is shown below (17)(18):

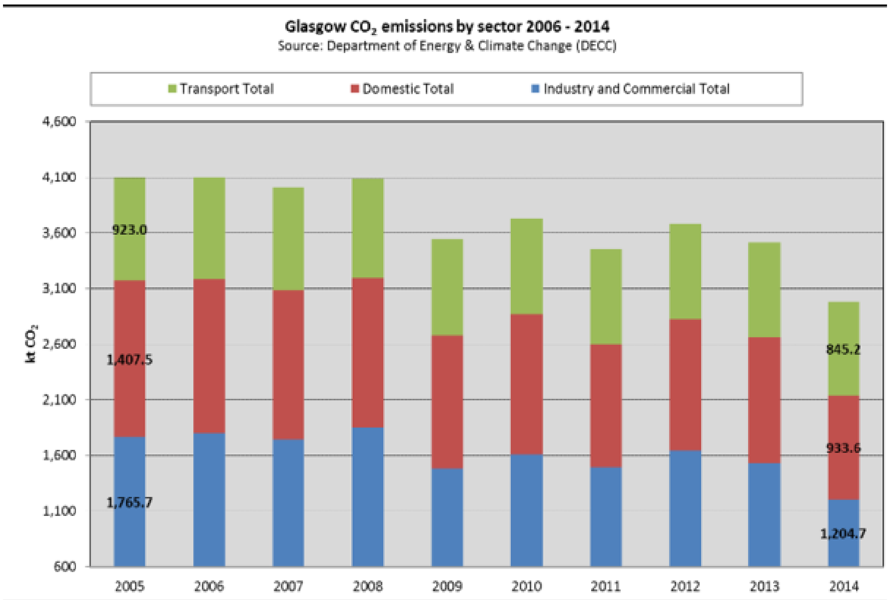


Figure 5 - Sector splits for CO2 emissions in Glasgow (18)

(iv) Aim of work

As was seen from Section 1(iii) above, the role of industries in future developments is vital to ensure that the industrial sector plays a part in meeting the goals and addressing the problems

mentioned in Sections 1(ii) and 1(iii). Therefore this project will aim to bring various industries together in order to help meet the goals of reducing GHG emissions into the atmosphere and producing clean energy. This will allow the challenges addressed in Goal 11: Sustainable communities to also be brought into problems being addressed (1):

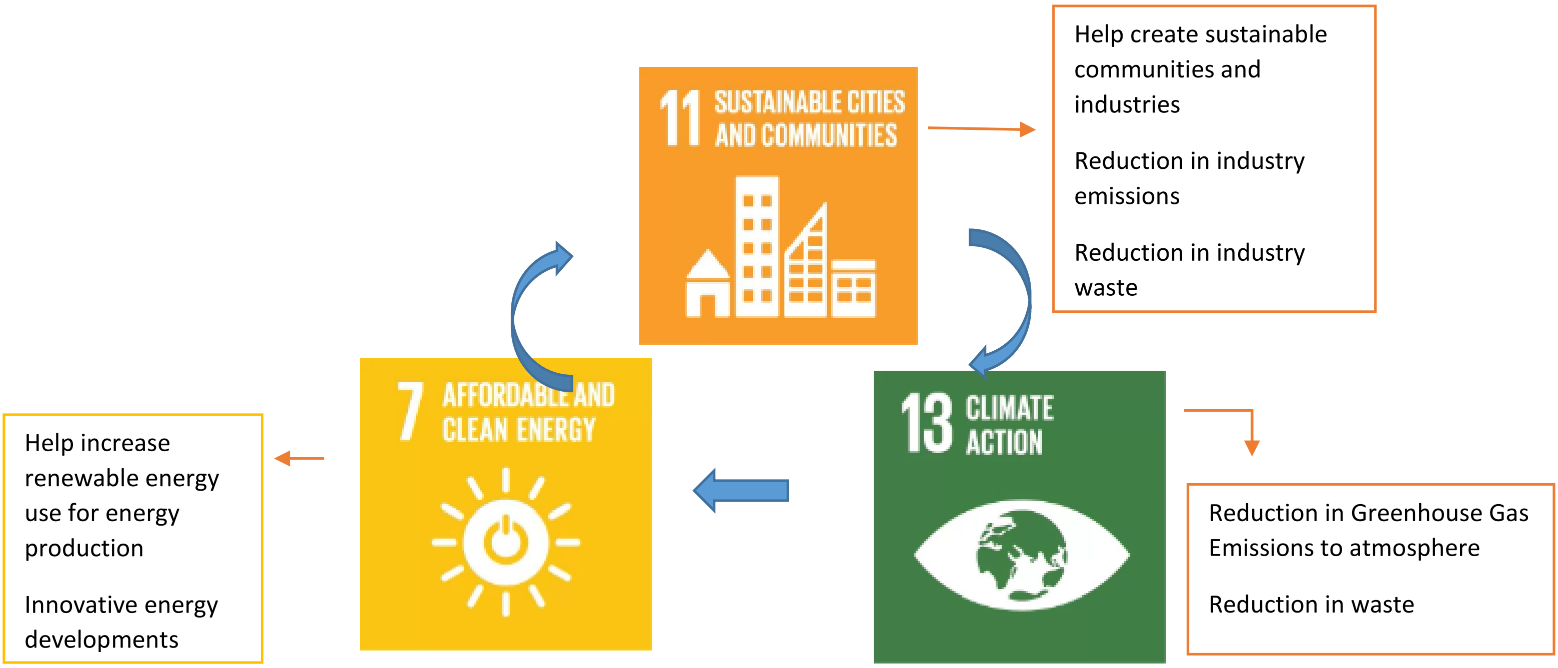


Figure 6 - The coming together of three of UN 'Sustainability Development Goals' to help overcome the issues faced in each

In order to be able to create a network such as the one shown above, the idea of Industrial Symbiosis will be used to identify possibilities and gaps within specific industries. Industrial Symbiosis is when industries collaborate and the waste from one industry is used as a feed for another, to ensure waste is diverted from either being a pollutant or being gathered to emit pollutants (19). The use of Industrial symbiosis has been very successful in countries such as China and Denmark in creating a network of industries to work together which can range from two or more (20). The creation of large networks of Industrial symbiosis can take a long time such as the 'Kalenborg network' in Denmark' which took around ten years to form and come together as a large network (21). Therefore previous industrial symbiosis cases will be examined through literature reviews to ensure that a successful partnership is examined and to help bring the idea of industrial symbiosis to Scottish Industries. The industrial Symbiosis network created will use examples of Scottish industries which could benefit from forming a network as a case study to help show the use of waste in the industries chosen. The network created will aim to bring together two to three industries with different waste/emissions in order to show how some of the issues shown above in Figure 6 could be tackled and developed in the long term.

For the project being undertaken, the work will aim to show how the aspects mentioned above can be brought together to create sustainable engineering developments. As identified in Section 1(iii) industries can help play a role in ensuring that sustainable measures are brought about in the industrial sector to help achieve a more energy efficient future. By identifying the key challenges in the Energy sector through the agendas raised by the UN 'SDGs', the focus of the key areas within this project have been narrowed to focus on tackling the issues of Clean energy, Climate Action and Creating sustainable communities. These key areas have been used to set the scope of the work being undertaken through this project, the aims of work and objectives of this project are therefore as follows:

(V) Aim of Project:

The creation of an industry network using Industrial Symbiosis to show energy & material exchanges for Sustainable Engineering Developments

In order to achieve the aim of the project, a number of objectives were set out to help ensure that the right steps are taken to help tackle the issues identified earlier and bring these into the work being completed. The objectives set are as follows:

(VI) Objectives:

1 ⟹ *Identify industries with high emissions or high energy use which can form a network to achieve energy minimisation*

2 ⟹ *Show how renewable energy systems can be implemented within the industry network to further reduce energy use from current sources*

3 ⟹ *Create implementation model which can be used by industries to help form a network with other industries*

The objectives mentioned above will ensure that the agendas of reducing emissions to atmosphere and promoting clean energy are brought into the project and tie in with creating the sustainable industry network development. To ensure that these objectives are met, a methodology was created to break down the steps required for the scope of work being completed. This will also identify the key steps to be taken within each section in order to approach the issues within the project in a methodological manner in order to fulfil the objectives which have been set out.

(VII) Approach/ Methodology

The approach taken to ensure all tasks required to meet the objectives and overall aim of the project were undertaken was to split the key stages of the project into sections, helping identify the actions required and outcomes of each stage. The key stages to the project and the methodical approach taken at each stage is as follows:

Step 1

Outcomes to reach by end of step 1:

- Clear understanding of the idea of Industrial Symbiosis and the key ideas behind the practise

- Identification of successful Industrial Symbiosis collaborations in place

Actions required to reach above outcomes:

- In order to gain a clear understanding of the practice of Industrial Symbiosis which will be used in this project, a literature review is required as a key initial step. Undertaking a literature review through the use of journals and articles will help identify the main ideas behind the use of Industrial Symbiosis in order to bring this to the work being completed.

- The identification of successful Industrial Symbiosis practices already in place uses the information gathered through literature reviews and helps identify case studies. Reviewing and identifying successful use of Industrial Symbiosis is key to ensure the practice has benefited industries already using the practise and to help bring the successful partnerships to new networks.

Step 2

Outcomes to reach by end of step 2:

- The identification of industry waste and emissions

- Network Creation of two/three industries

Actions required to reach above outcomes:

- In order to identify industry waste a review of industries within Scotland should be completed to help identify the potential of the waste of the identified industry.

- The creation of a network follows on from the above action. Once emissions and waste from the industry chosen has been identified, the use of this waste to another industry will be reviewed which will be helped by referring to the successful collaborations of Industrial Symbiosis identified in step 1.

Step 3

Outcome to reach by end of step 3:

- Use of renewable energy within the network created to aide meet energy demand within the network

Actions required to reach above outcome:

- In order to see the potential of renewable energy source/sources within the network, the most suitable renewable source will be identified once the network in step 2 has been created. The renewable energy potential can only be seen once the industries have been identified, examples of such use would be to identify the potential of solar PV/ biofuels and the benefit to meeting the energy demand within the network. If applicable to the renewable energy source identified, software will be used such as Homer to help identify the potential energy from the source.

Step 4

Outcome to reach by end of step 4:

- Feasibility study of identified network, identification of gains to industries and community

Actions required to reach above outcome:

- In order to evaluate the feasibility of the network, both social and environmental impact assessments will be carried out to identify both negative and positive impacts of a possible collaboration. This will ensure that the impacts of industries and the development for the future are noted and the wider community and environment is acknowledged through such developments.

Step 5

Outcome to reach by end of step 5:

- Implementation Model to aide use of such practise for industries

- Further developments for creation of sustainable engineering developments

Actions required to reach above outcome:

- In order to create an implementation model which can be followed by industries, the key stages which industries should follow will be identified to help industries work together. Further developments to both the network created and the practise in general will ensure that there is the possibility for future developments within this area which can be taken forward. Challenges which may be faced by industries will also be identified along with what the future could hold if such industries are successful in collaborating with one another for achieving sustainable developments within our communities.

The 5 steps mentioned above provide the framework of approach taken to ensure that the key areas within the project are identified and undertaken in a methodical manner. The overall methodology taken is summarised below:

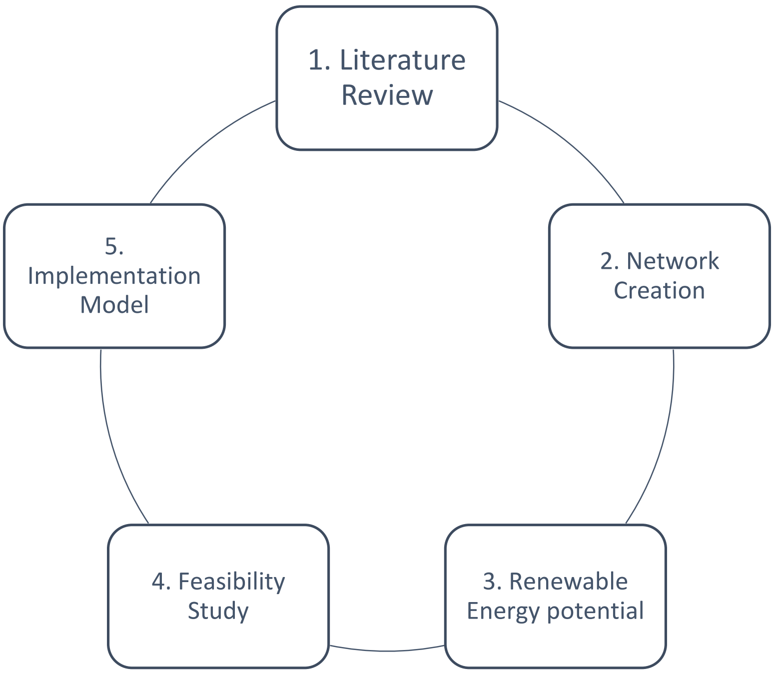
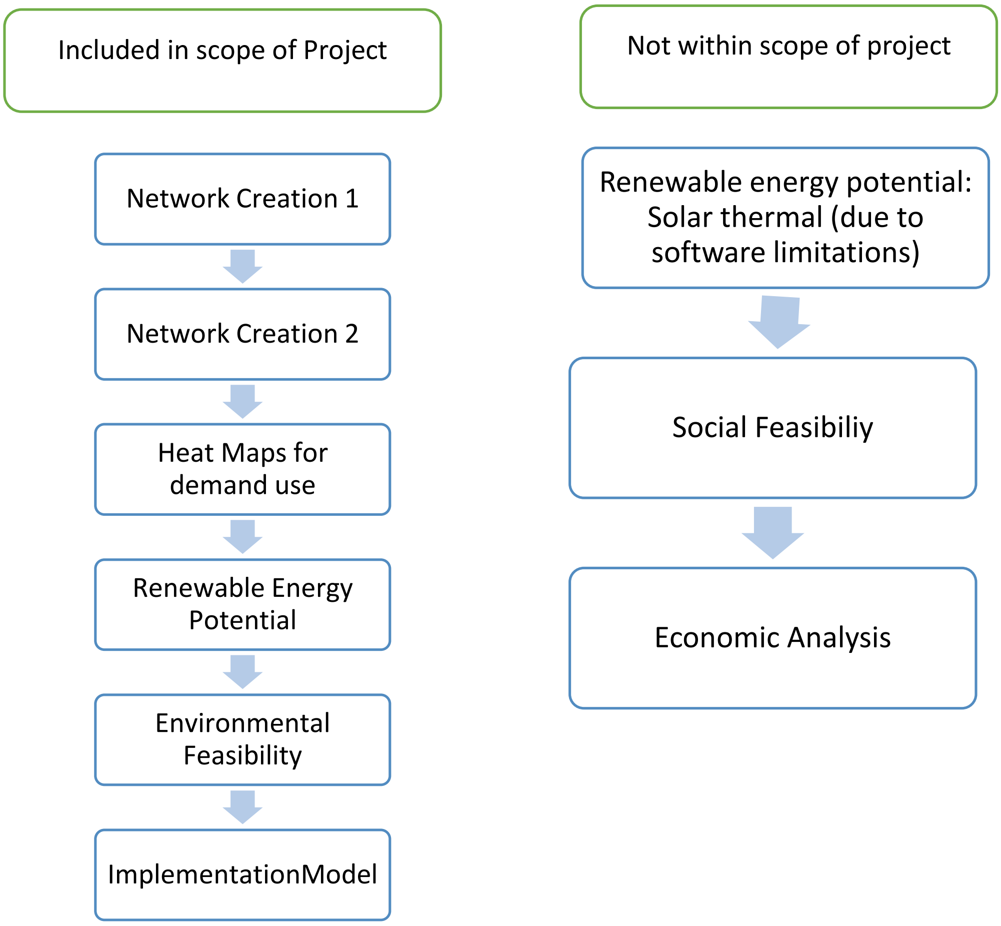


Figure 7 - Framework of approach taken to undertake the project

Scoping

The project aims to focus on the creation of two networks; aimed to tackle the issue of both climate change and clean energy use. However due to time constraints, the project will not go into an economic analysis using the Industrial Symbiosis network. However this is n assessment which would be taken forward for future analysis in order to determine savings in the industries involved. Shown below are the area which will be covered and those for future research:



2. Network Creation

(i) Network 1

Using the methodology mentioned in Section 1(Vi), the first step in creating a network is to identify potential industries within the Industrial sector from which waste or emissions can be identified and used as the first industry. In order to identify a potential industry, the issues which this step aims to help overcome were referred back to, to ensure that these issues would be met by this step. From Section 1(iv), it is seen that the first industry should help overcome the challenges addressed in UN'SDGs' Goal 13, which will help assist the first industry chosen within the network. The approach taken to assist the identification of the first industry is summarised below, keeping in mind the agenda of this step:

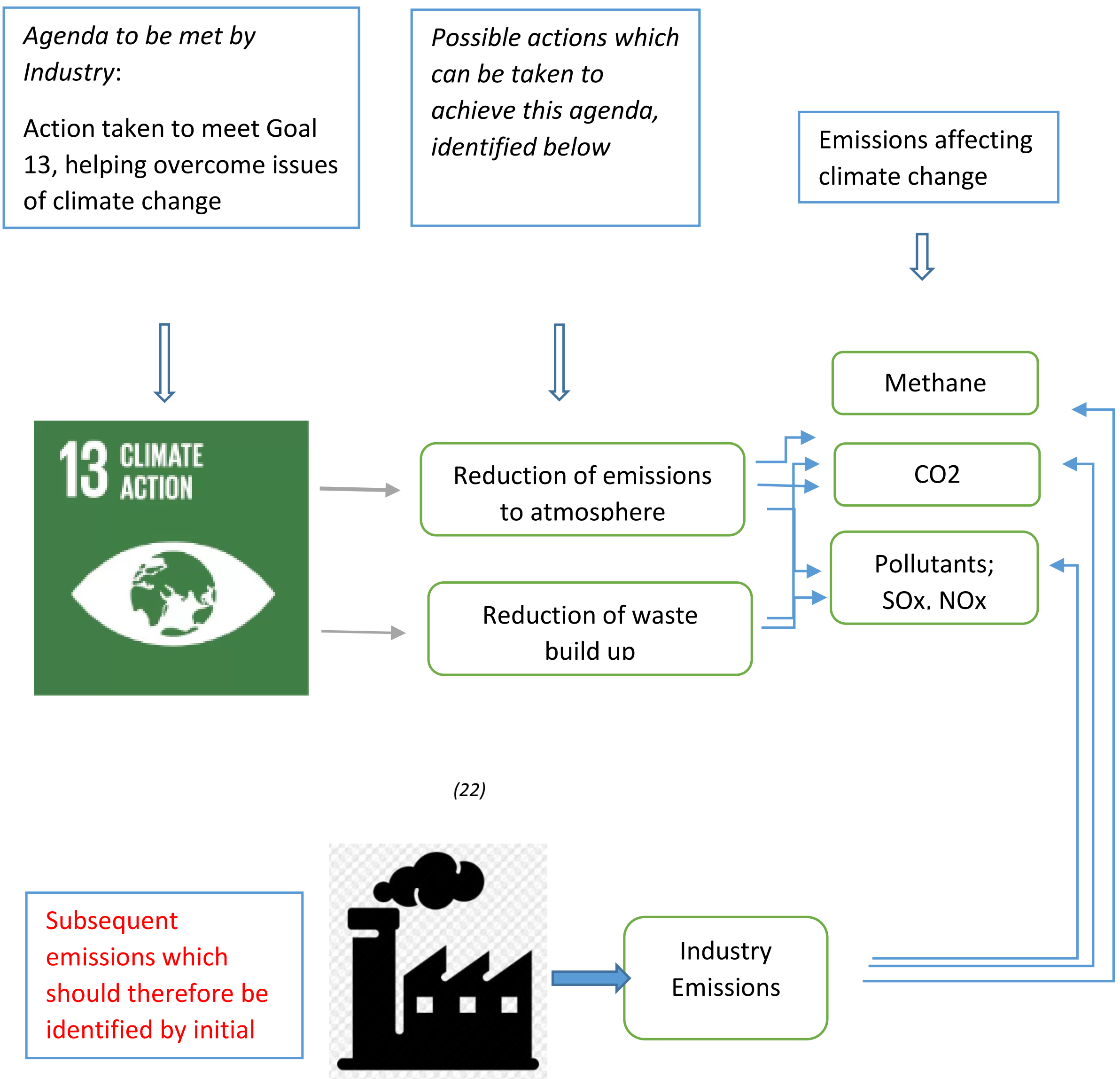


Figure 8 - Relationship between agendas and Industry 1 (22)

With the above emissions identified, the next step involved identifying industries with emissions of either Methane, CO2 or other pollutants responsible for climatic changes. Through literature review it was identified by use of data available from the 'Office of National Statistics (ONS)' that within the UK, around 85% of emissions in 2013 was made up of the release of Carbon Dioxide (23):

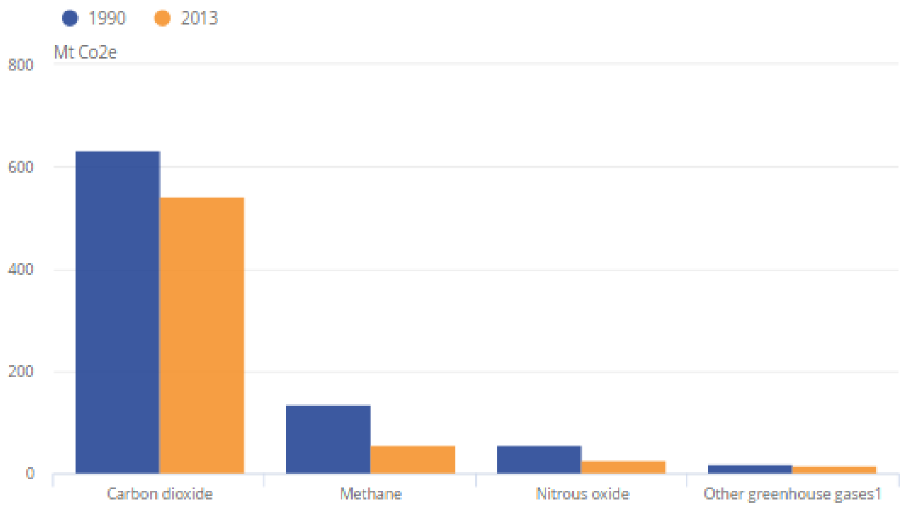


Figure 9 - UK ONS statistics of emissions 1990/ 2013 (23)

With this identified, the focus of industry emissions was then focused on those industries releasing carbon dioxide emissions, where change could be brought within the industry identified. Within the industrial sector, it was seen that globally the industries highlighted as emitting highest CO2 to atmosphere whilst also being highly energy intensive were as follows; Chemical/ Process plants, Paper production and Iron & Steel manufacturing (24). From within these industries, the Iron and Steel manufacturing facilities accounted for the majority of these emissions and were responsible for over 30% of these emissions in 2015 (25)(26). Using this information it was decided that the Iron and Steel facility would be chosen as the first industry within the network, this was to ensure that a global issue was addressed rather than only focusing on an industry with high CO2 emissions within Scotland. This would allow such a network to be used globally and especially in developing countries where iron and steel manufacturing is greatest along with CO_2 emissions from this industry (27)(28).

With Scotland being used as a case study location, an inventory tool available through 'Scottish Environment Protection Agency (SEPA)' was used to analyse the pollutant release of the Iron and Steel facilities within Scotland , using the SPRI data available (29). This helped identify and breakdown the industrial sector and analysed the pollutants from various sites across Scotland. The tool identified the following plants within Scotland and the sectors in which the plants were associated:

Figure 9 - Interactive tool highlighting SEPA 'SPRI' data

Using the interactive tool, around 813 sites were identified within Scotland where the release of emissions/ pollutants had been recognised (29). Within these sites, analysis showed around 13 plants involved in metal production, helping narrow a site for use in the network being created. After researching the sites and the focus of the metals being produced, the plant chosen was a steel production plant 'Liberty Steel Dalzell', this was due to the focus on Iron and steel production at this site and the central location which would ensure easier waste exchange (30). The location of Liberty Steel Dalzell can be seen on the map below:

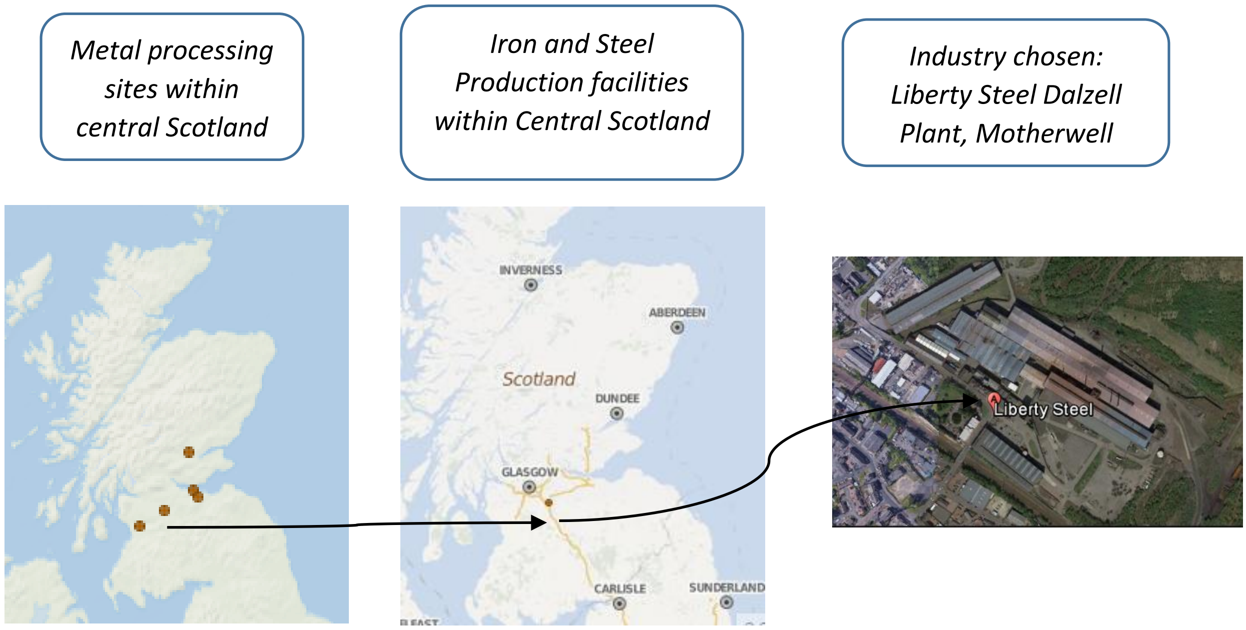


Figure 10 - Location of iron/steel production plant within Scotland (29), (31)

The next step involved an analysis of the emissions from the site in order to be able to then identify how either these could be reduced or diverted from polluting the air. The Scottish Pollutant Release Inventory Data (SPRI) was then analysed in order to identify the emissions from the Liberty Steel Production site and to see whether this was similar to pollutants from global Iron/steel production plants which had been researched through the literature review in Section 2(i) (29).

Through the use of the interactive inventory data, the emissions found to be leaving the Dalzell Steel plant were CO2 and Nitrogen Oxides, however on closer analysis it was seen that nitrogen oxides had only been emitted in 2008 therefore focusing the attention back to the CO2 emissions from the plant (29). Shown below are the emissions from the site from year 2007:

Emission of nitrogen oxides from site since 2007(29):

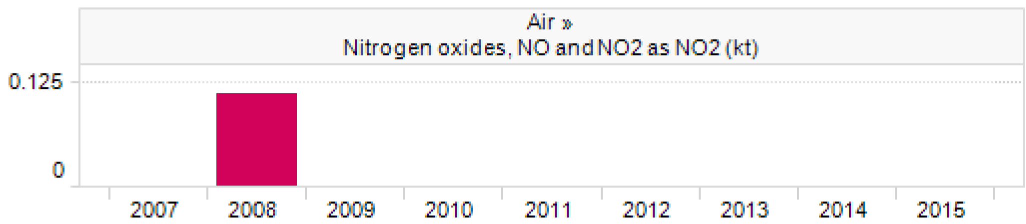


Figure 11 - NO emissions from Dalzell Steel Plant (29)

Emissions of Carbon dioxide from site since 2007(29):

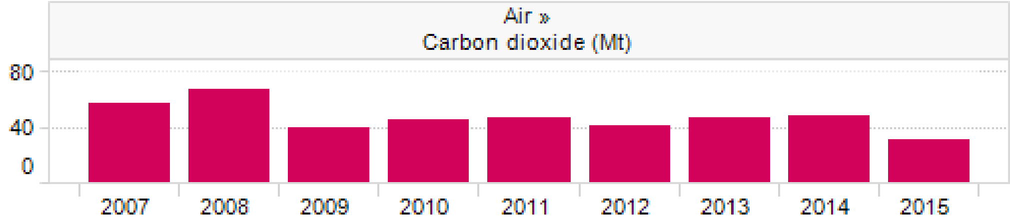


Figure 12 - CO2 emissions from plant (29)

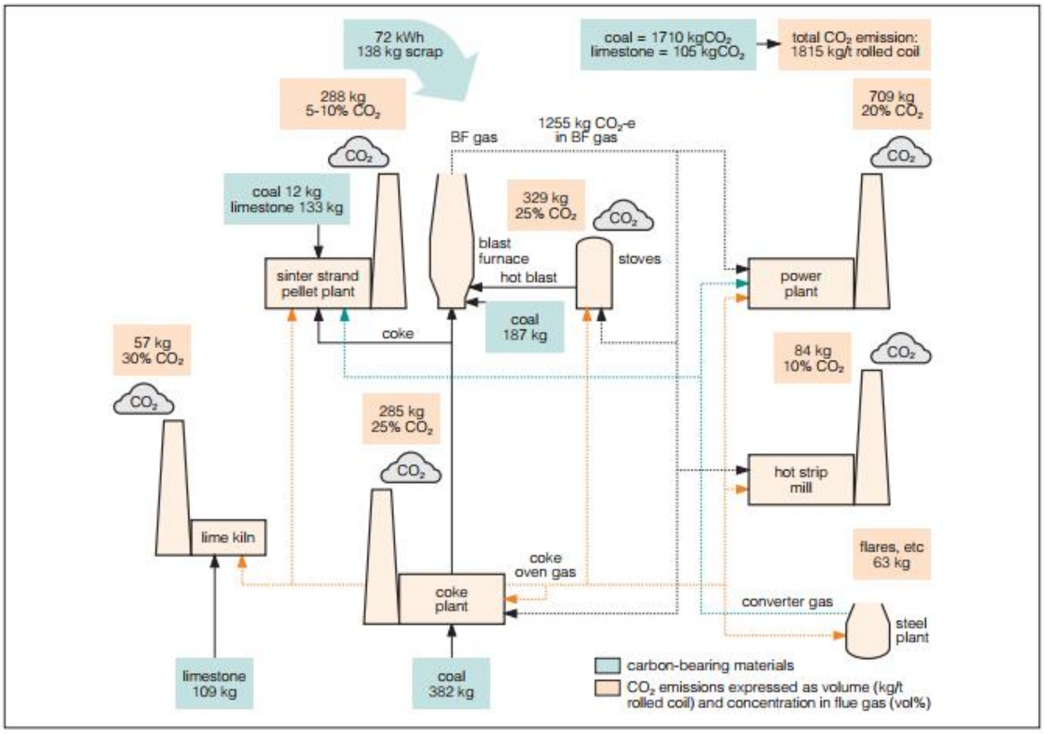
Emissions of CO2 from Dalzell Plant, using SPRI tool (29), (emissions rounded up):

Site	Pollutant released to	Industry	Emissions	2008	2009	2010	2011	2012	2013	2014	2015
Dalzell Steel Plant, Motherwell	Atmosphere	Iron/Steel Production	CO2 (Mt)	67	39	44	47	41	46	49	31
			NO	0.1	-	-	-	-	-	-	-

Figure 13 - CO2 emissions from SPRI data (29)

It can be seen from the Scottish Pollutant Release Inventory Data (SPRI) above that 31.7 Mt of CO2 was released in 2015 and although this decreased from 2014 the five years previous to that saw constant emissions between 40-50 Mt per year. With this information it is clear to see that emissions from this site are constant and therefore can be further analysed to see the possibilities of either reducing the emissions from the site or ensuring these emissions are diverted from polluting the air.

Looking further into the process used within Iron and Steel production, it was seen that the CO2 produced from Steel production mainly comes from the process itself. The stages of the process where the Blast Furnace and Basic Oxygen Furnace are used for melting produce one of the largest emissions of CO2 within the whole steel process (32), (25). Shown below are



the stages of steel production and CO2 emissions from the relevant stages:

Figure 14 - CO2 emissions from Iron/Steel Production, IEA Clean Coal Centre (25)

There are several different methods which can be taken to manage these emissions such as abating CO2 produced from the process itself through use of different unit operations or efficiency improvements. Alternatively the emissions produced can be managed by either diverting these from the atmosphere by CCS or finding how such emissions can be used elsewhere (25). In order to utilise the Industrial Symbiosis principle, how this waste CO2 can be used for use as a raw material for another industry will be the next step, to help reduce the emissions to the atmosphere.

Step 2:

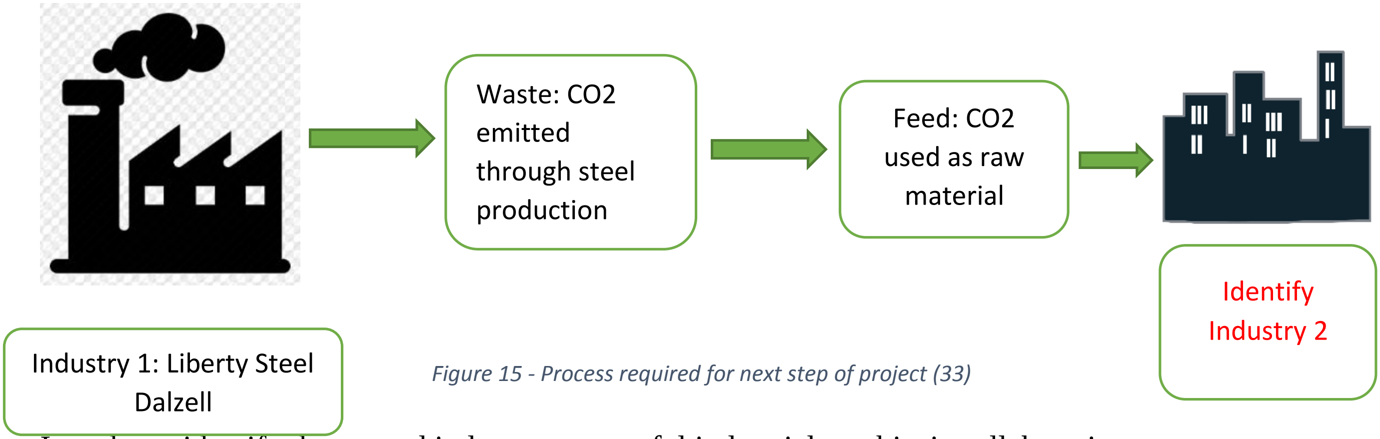


Figure 15 - Process required for next step of project (33)

In order to identify the second industry, successful industrial symbiosis collaborations were researched through literature reviews as mentioned within the methodology in Section 1(VII). Researching these collaborations helped to ensure that a waste/energy transfer which had proven to be successful could be implemented in a network such as the one being created. After case studies had been reviewed, a successful partnership through the 'National Industrial Symbiosis Programme (NISP)' was identified which showed that John Baarda Ltd who specialised in tomato growing had seen yield increases of 50% using waste CO2 within the companies greenhouses (34). As there had been a successful case of such use within a partnership, the next step looked to analyse how this could be done within Scotland and help identify where the emissions could help a similar industry flourish.

A number of fruit/vegetable growers and farms within Scotland were researched to identify the food being grown, the size of land and greenhouse sizes to choose the best fit for the network. Once this analysis had been completed, the farm chosen which highlighted the best possibility for the network was seen as John Hannah Growers, Gleghorn Farm (35). John Hannah Growers are a fruit growing business which have been expanding for the last decade, the farm is also situated just 30 minutes away from Liberty Steel Dalzell:

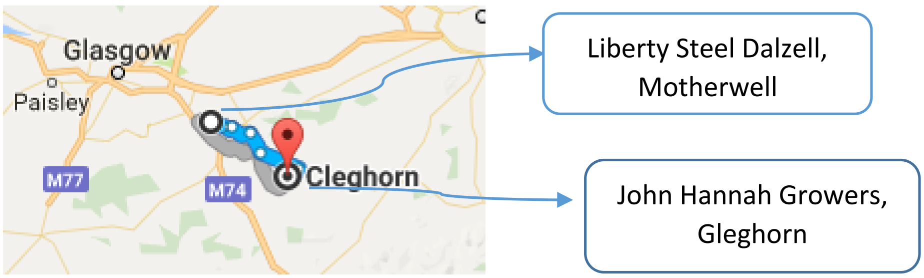
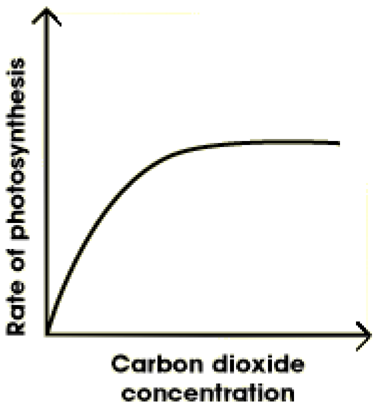


Figure 16 - Map showing the location of the two industries identified (36)

When using the practise of Industrial Symbiosis, the location of the industries relative to each other is not an issue and there have been many examples which have shown that industries far apart within the country are able to collaborate through energy/material exchange (37). However in this case, the location of the farm being close to Liberty Steel will pose a benefit to help begin a collaboration between the two businesses.

In order to calculate the benefit of Liberty Steels CO2 waste to the farm, further research was undertaken in the role of CO2 within the farm. Through literature it was identified that there are significant benefits to introducing the use of CO2 within greenhouses as there is a direct



link of CO2 accelerating the rate of photosynthesis:

Figure 17 - Relationship between CO2 concentration and photosynthesis (38)

This was further highlighted through a study completed within greenhouses, showing that CO2 enrichment increased the yield of fruit grown within the greenhouse by 19% (39).

The amount of CO2 which would be used by John Hannah Growers based on their current production was calculated as follows (35):

$$Size\ of\ greenhouse\ on\ farm = \frac{1}{2} acre$$

$$Plants\ currently\ grown\ within\ greenhouse = 20{,}000$$

$$Amount\ of\ CO2\ required\ per\ plant\ annually\ = 0.0416\ tonnes = \ {\sim}42\ kg$$

$$Amount\ of\ CO2\ required\ by\ greenhouse\ per\ annum = 42 \times 20{,}000 = 840{,}000\ kg$$
$$= 832\ tonnes$$

With the possibility of around 832 tonnes of CO2 being used annually at John Hannah Growers to maximise yields within the greenhouse, the scope was then extended to bring other farms together for the same benefit. Within Scotland there is over 80 square miles worth of fruit and vegetables grown, those that are ran businesses and farms are mainly owned by families with an average size of 1-2 acres (40)(41). Therefore four other farms were identified; Thomas Fruit Grower, Angus growers, Bruce farms and Stewarts of Tayside to assess how they could be brought together. The amount of CO2 which would then be used is as follows:

$$\frac{1}{2}\, acre\ greenhouse = 20{,}000\ plants$$

$$Average\ size\ taken\ for\ four\ farms = 2\ acres = 80{,}000\ plants$$

$$CO2\ required = 80{,}000 \times 0.0416 = 3328\ tonnes$$

$$CO2\ required\ by\ 4\ farms = 3328 \times 4 = 13312$$

$$C02\ therefore\ diverted\ if\ colaberation\ with\ 5\ farms\ across\ Scotland$$
$$= 13312 + 830 = 14{,}142 = \ {\sim}14{,}000\ tonnes$$

From this calculation it can be seen that by partnering with 5 farms around Scotland, around 14,000 tonnes of CO2 would be diverted from polluting the atmosphere. An average of 20,000 plants was estimated to be grown per ½ acre greenhouse taken from number of plants grown by John Hannah Growers (35). As this number may be more or less for the other farms noted, the amount of CO2 required could differ slightly and therefore a % error could be added to total calculated. However for simplicity this was rounded to 14,000 tonnes which will be used for the rest of the work when required.

The network created so far involving the two different industries can be seen on the following page

Network 1:

Industry 1

Industry: Iron/ Steel Production

Emissions/ Waste: Carbon Dioxide produced from process

Amount of CO_2 produced: 30.71 Mt (2015)

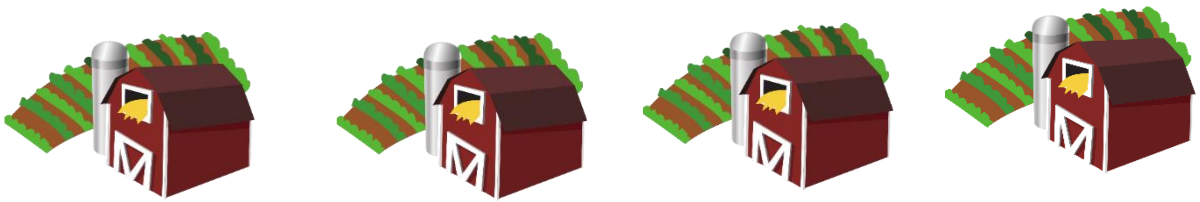
Waste: CO_2 emissions

Industry 2

Industry: Fruit Growers

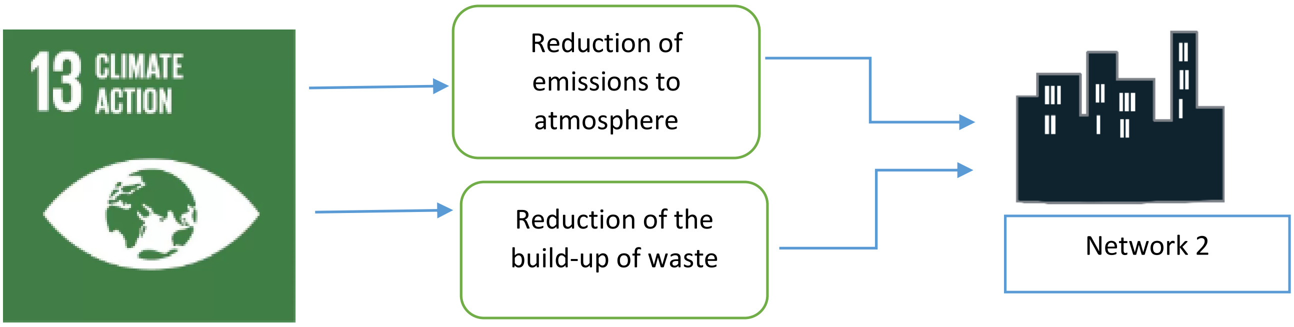
Raw Materials: CO_2 for plant enrichment within greenhouse

Amount of CO_2 required and therefore diverted from atmosphere: 14,000 tonnes. This includes the involvement of four other farms within Scotland



(ii) Network 2

Similarly to the method used to create the first network, the first step taken is to identify the agenda which is aimed to be met by this network. Looking back at Section 2(i), this was seen



to be the following:

Figure 18 - Goals to be met by Network 2 created

As Network 1 focused on tackling the issues of emissions directly emitted into the atmosphere through the initial industry, the focus of the first industry within network 2 will be on reducing waste build up. Through reviewing literature an issue which was highlighted was the build-up of waste wood from a number of various sectors, this was therefore used as the starting point of the second network (42). In the UK alone, around 4 million tonnes of wood waste was built up in 2016 ending up in landfills coming from sectors such as construction, demolitions and households (43), (44). The main issue associated with the build-up of wood waste is the decaying which occurs when wood is discarded as waste, example of such an occurrence is wood waste being sent to landfills in large quantities and left to decay. The process of decaying has seen the possibility of methane gas being released into the atmosphere, this poses a risk more severe than CO2 as methane is around 25 times greater in strength (45).

Through further research it was identified that the majority of waste wood came from the construction industry, in 2014 only around 1% of household waste was made up of wood waste within the UK as a whole (46). Within Scotland landfill data was evaluated in order to determine the amount of wood generated as waste within an average landfill, as not all council landfills could be considered only one council data was analysed. Through notices available through ‘Public Contracts Scotland’ on landfill data, it was seen that within Fife

Council around 12,000 tonnes of wood would be generated annually (47). As this council has two landfill sites, the average waste wood generated within one landfill annually was taken as 6000 tonnes (47).

Using data from ‘Zero Waste Scotland’, the Carbon Dioxide equivalent emissions produced by the waste wood generated annually within a landfill was calculated (48):

$$Material: Wood$$

$$Amount\ in\ tonnes\ sent\ to\ landfill\ as\ waste = 60000\ per\ landfill$$

$$Amount\ in\ kg\ sent\ to\ landfill\ as\ waste = 6000000\ per\ landfill$$

$$Conversion\ factor\ of\ kgCO2\ equivalent\ per\ kg = 0.792$$

$$Total\ emissions, kgCO2\ equivalent = 6000000 \times 0.792 = 4{,}752{,}000\ annually$$

If however this waste wood was instead recycled, the CO2 equivalent would be as follows:

$$Amount\ of\ wastewood\ recycled\ in\ tonnes = 6000$$

$$Amount\ of\ wastewood\ recycled\ in\ kg = 6000000$$

$$Conversion\ factor\ of\ kgCO2\ equivalent\ per\ kg = 0.285$$

$$Total\ emissions, kgCO2\ equivalent = 6000000 \times 0.285 = 1{,}710{,}000\ annually$$

$$Therefore\ by\ recycling\ amount\ of\ waste\ wood\ generated\ within\ a\ landfill\ per\ annum$$

$$total\ emissions\ reduced\ (kgCO2eq) = 3{,}042{,}000$$

As well as the option of the waste wood being recycled, another alternative would be to process the wood through a waste to energy plant. This would most likely be done on a larger scale, however it is the most likely way forward in order to process waste wood with future developments focusing on waste to energy. Through research it was found that within Scotland 2 waste to energy plants are in planning/ development stages, one in Fife and one in Aberdeen (49), (50).

Although these plants are large scale developments, the amount of energy which could be produced from the waste wood generated annually within a landfill was calculated to determine potential from one landfill site in Scotland:

$$Average\ amount\ of\ waste\ wood\ generated\ in\ one\ landfill\ annualy = 6000\ tonnes$$

$$Amountof\ waste\ wood\ in\ kg = 6000000$$

$$Calorific\ Heat\ Value\ for\ dry\ wood\ (dry\ wood\ value\ used\ in\ this\ calcualtion)$$

$$1kg = \ \sim 20MJ$$

$$Efficiency\ of\ process, waste\ to\ energy: Through\ research\ it\ was\ found\ that\ waste\ to\ energy$$

$$plants\ need\ to\ reach\ atleast\ 65\%\ efficiency, with\ some\ reaching\ over\ 95\%,$$ (51) (52)

$$Efficiency\ taken\ as\ an\ average\ of\ lowest\ to\ highest\ expected = \frac{0.65 + 0.95}{2}$$

$$= 0.80 = 80\%$$

$$Energy\ in\ MJ = 6000000 \times 20 = 120{,}000{,}000MJ$$

$$At\ 80\%\ efficiency = 0.8 \times 120{,}000{,}000 = 96{,}000{,}000\ MJ$$

$$With\ 1\ joule = 2.78 \times 10^{-10}\ \ Mwh,$$ (53)

$$Therefore\ after\ coversion = 25000MWh$$

As mentioned earlier, the above energy potential for waste wood calculated is only for accounting for that within a landfill. With two new developments in planning and potentially in operation by 2021 the amount of waste processed would be significantly greater and ensure that the majority of an industry needs could be met by clean energy (50). With the first industry determined, the next step looks to identify another energy intensive business/ industry which would benefit from using renewable energy.

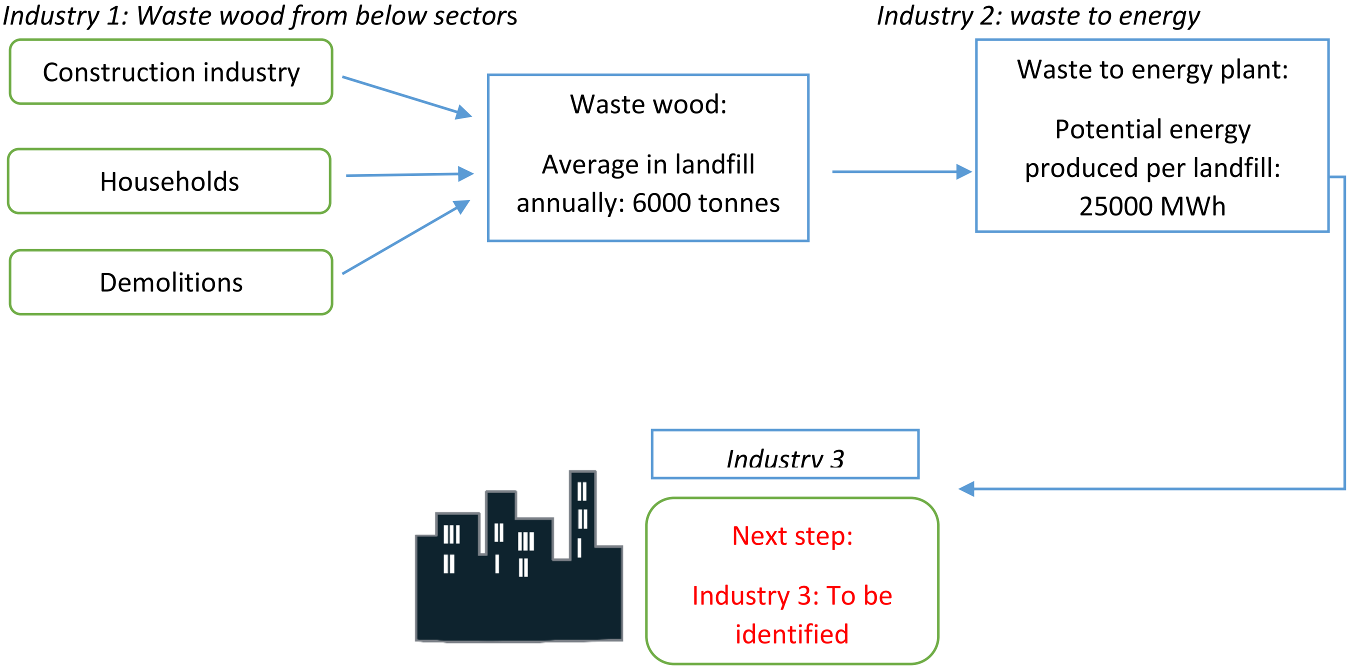


Figure 19 - Network 2, industries 1 and 2

In order to determine the third industry within the network which would benefit from obtaining its energy demand from a clean energy resource, an approach similar to that used in Network 1 was taken. It was mention in Section 2(i), that through literature a number of specific industries were found to be the highest emitters of CO2 whilst also being energy intensive, these were seen to be Iron & Steel, Process Plants, manufacturing and paper production (24). As a steel production site was used within the first network, this network looked to incorporate a different industry which could be used to tackle any global issues presented by that industry. Through further research it was identified that countries with high paper/pulp production had seen high CO2 emissions from this industry along with high energy use. An example of this is within the US, which has one of the highest paper production industries seen globally, however the paper industry is also the 4^{th} greatest CO2 emitter within the country (54)(55).

As mentioned before, the network creations aim to tackle global issues such as those set out by the UN'SDG' and therefore industries which are seen to be an issue globally with either emissions or energy use have been used. This will help ensure that the network has global use rather than specifically for the case study location of Scotland, however using Scotland as the study location helps show the international development potential both at home and internationally. In order to determine sites within Scotland associated with paper production, ‘Scottish Pollution Release Inventory (SPRI)’ available through SEPA was analysed to narrow down potential sites within Scotland (29). Through use of the interactive tool, 11 sites were identified, with 5 focusing on the production of paper processing. The site which was therefore chosen to assess further and bring within network 2 was Arjo Wiggins Stoney wood mill based in Aberdeen. This was chosen as the second industry identified earlier was a waste to energy plant in development which is also based in Aberdeen, once in operation a partnership with Arjo wiggins paper mill could provide to be a beneficial partnership within the city. Shown below are the sites of paper production and the location of Arjo wiggins Stoneywood mill (29):

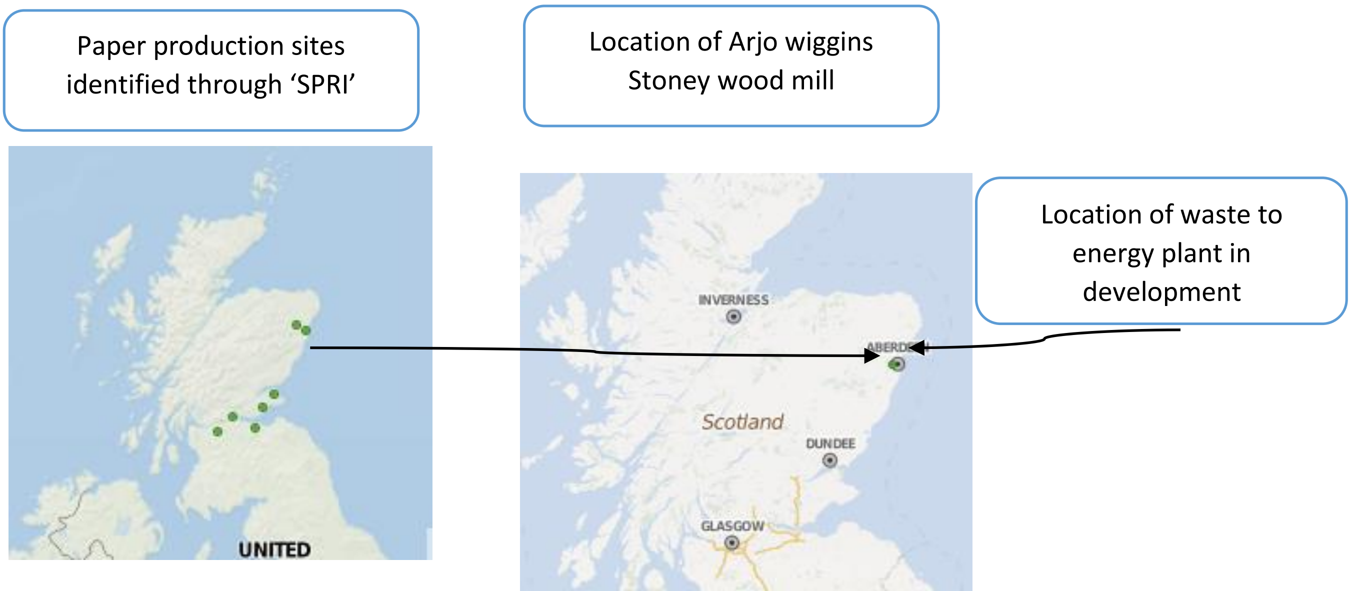


Figure 20- Location of industry 3

To assess further the pollutants being emitted by the site, the SPRI data and tool available through ‘SEPA’ was used to identify the quantity and type of emissions leaving the site (29). Through this assessment of pollutants, the following emissions was found to be emitted from the site from 2007 till 2015:

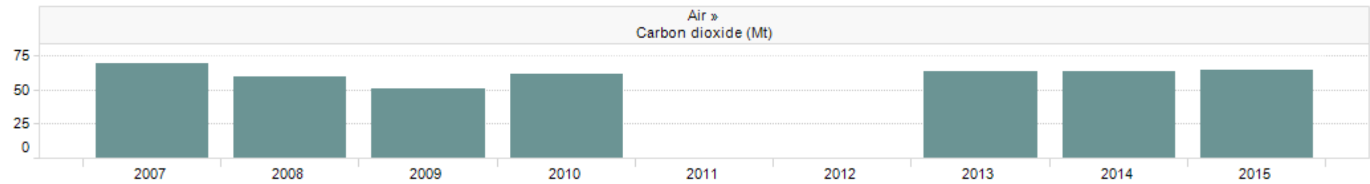


Figure 21 - Emissions from site, available through SPRI (29)

Data on emissions in years 2011 and 2012 were not available, however with the available emissions in the years before and after it was clear to see that CO2 emissions were generated through paper production at the site, these have more clearly defined in the following table (29):

Site	Pollutant released to	Industry	Emissions	2008	2009	2010	2011	2012	2013	2014	2015
Stoneywood Mill, Aberdeen	Atmosphere	Paper Processing	CO2 (Mt)	60	51	61	-	-	63	63	65
				-	-	-	-	-	-	-	-

Figure 22 - CO2 emissions per year from site, (29)

After identification of the emissions from the site, the next step looked to see how these could be managed. In order to manage emissions from the site as mentioned in Section2 (i), the option best suited for a business depends on where the emissions arise from. Investigating the process of paper production further it was found that similarly to steel production, the CO2 emissions mainly came from the process itself rather than power being used to operate the process. A breakdown of the stages with highest CO2 emissions can be seen below:

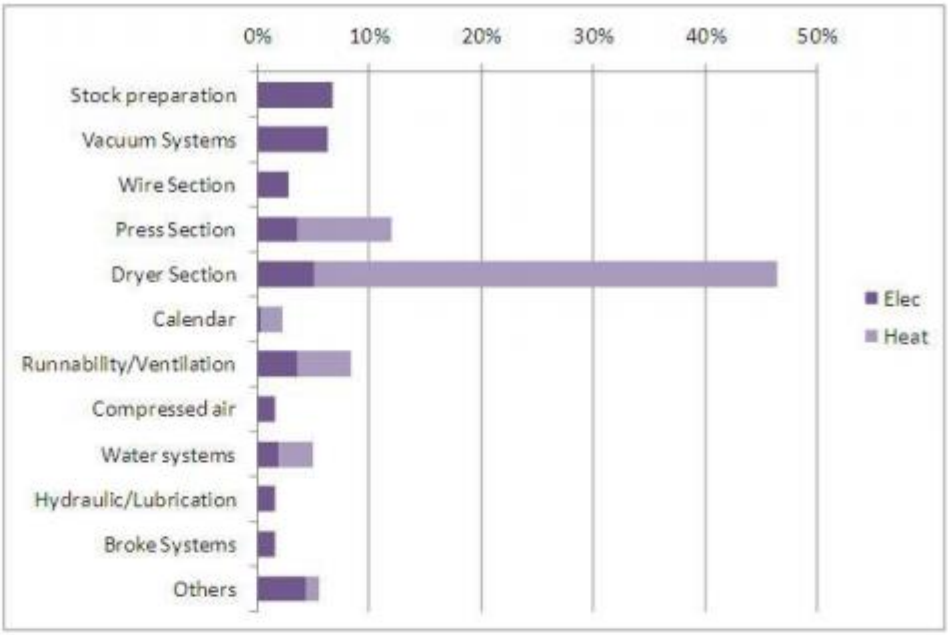


Figure 23 - Breakdown of stages within paper production and emissions (56)

As seen above, the highest emissions of CO2 are caused by the drying stage within paper production, in order to manage emissions the process itself would need to be further developed looking at heat recovery from within the unit operations or improving operations (56). Similarly to Network 1, as industrial symbiosis is being utilised within this project, the method of emission management explored further will be to utilise the CO2 within another industry to reduce emissions to atmosphere. Using the approach mentioned within the methodology, further cases of successful industrial symbiosis partnerships were explored in order to bring together a successful network.

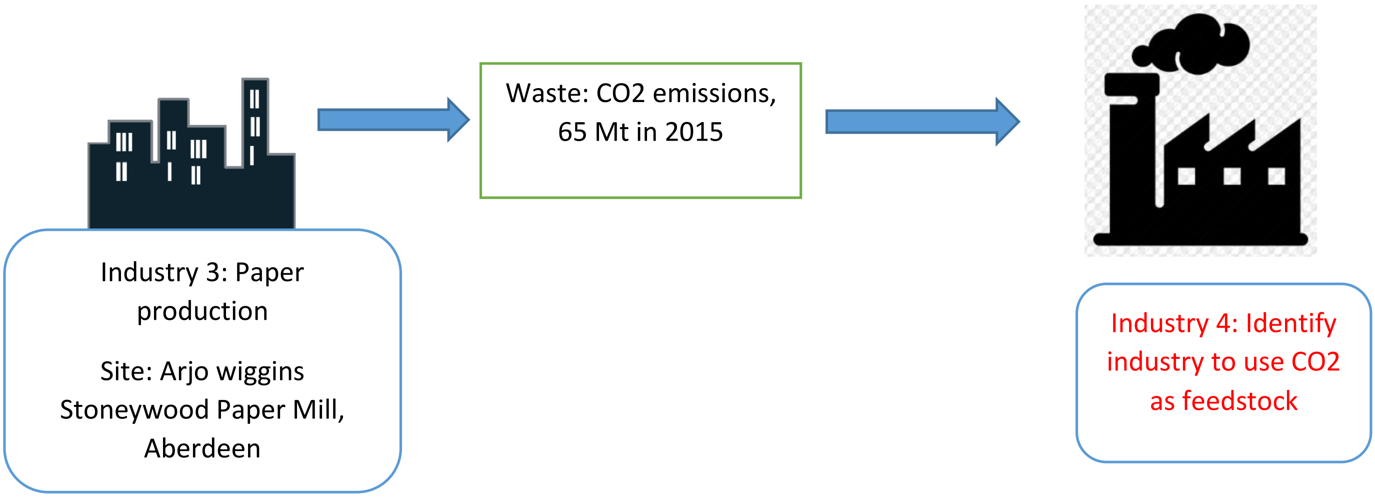
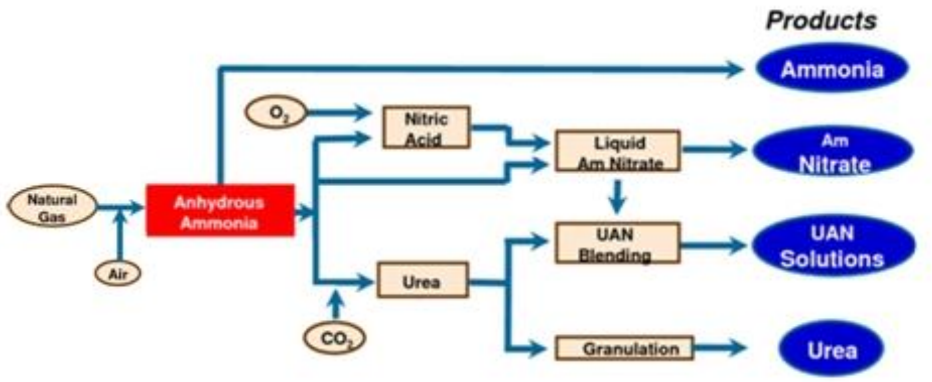


Figure 24 - Network between industries 3 and 4

In order to identify an industry which could make use of waste CO2, further research was undertaken to determine processes where CO2 could be utilised as feedstock within the site. Within the industrial sector, chemical/process plants require large quantities of raw materials in order to process chemicals on a large scale. To identify the possible benefits available to chemical processing plants, identification of chemicals produced within Scotland was carried out in order to identify industry 4 within the network.

From the research undertaken, the industry chosen to become part of the network being created was YARA fertilisers. YARA fertilisers has three sites situated within Scotland however only at one site does production occur which is situated in Perth (57). Within the process of fertiliser production, the raw materials required are mainly Ammonia and CO2 to



produce either solid or liquid fertilisers. A process flow diagram of fertiliser production is shown below:

Figure 25 - Flow diagram for fertiliser production (58)

An issue which arose in the next step of calculating the potential CO2 diverted came with the difficulty in finding the exact production rate of fertiliser within this specific plant. As this could not be found, the amount of fertiliser produced in an average fertiliser processing plant was used to show the amount of CO2 which would be used by this process. The amount of CO2 required as raw material within an average fertiliser processing plant is calculated below:

$$For\ urea\ fertilisers:$$

$$Production\ of\ 1\ tonne\ of\ urea = Requirement\ of\ {\sim}0.74\ tonne\ CO2$$ (57)

$$Production\ of\ fertiliser\ per\ plant\ per\ day = 1500\ tonnes$$

$$CO2\ required\ as\ feed\ per\ plant\ per\ day\ for\ fertiliser\ production = 1500 \times 0.74$$

$$Amount\ of\ CO2\ used\ as\ feedstock = 1110\ tonnes\ per\ day\ per\ plant$$

$$Annual\ CO2\ used\ as\ feed = 405{,}150\ tonnes$$

Therefore it can be seen that if a fertiliser processing plant such as Yara in Scotland were to use waste CO2 as the raw material within the process, around 405000 tonnes of CO2 would be diverted from entering the atmosphere. The exchange between industry 3 and 4 would look as follows

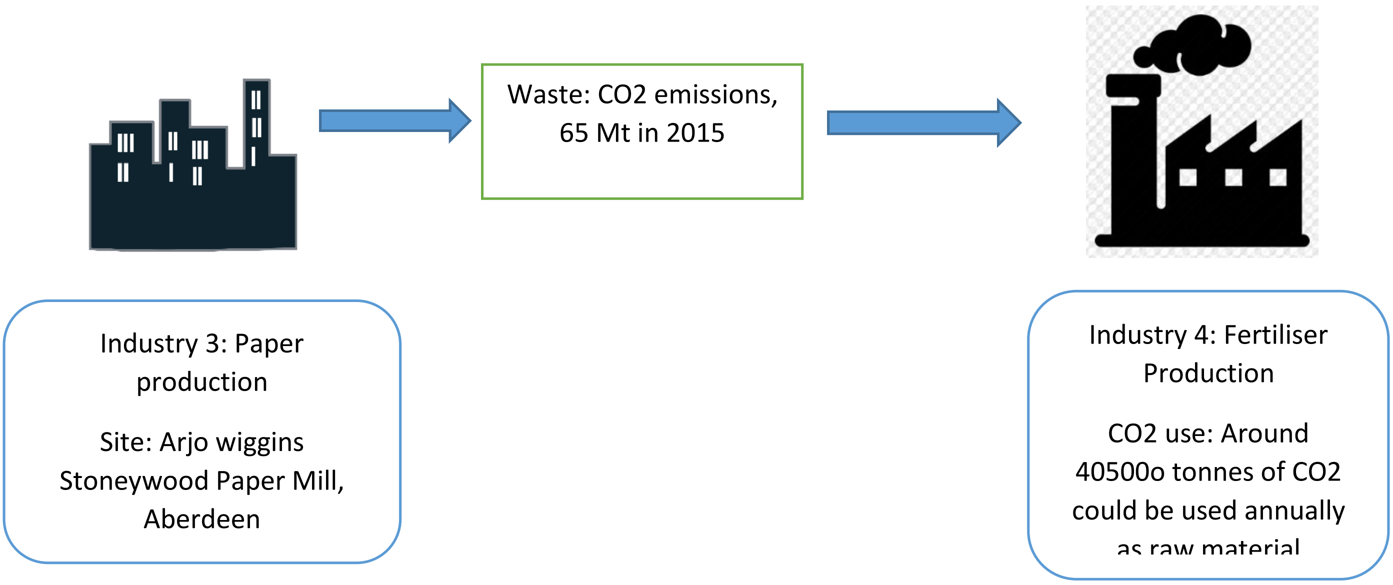
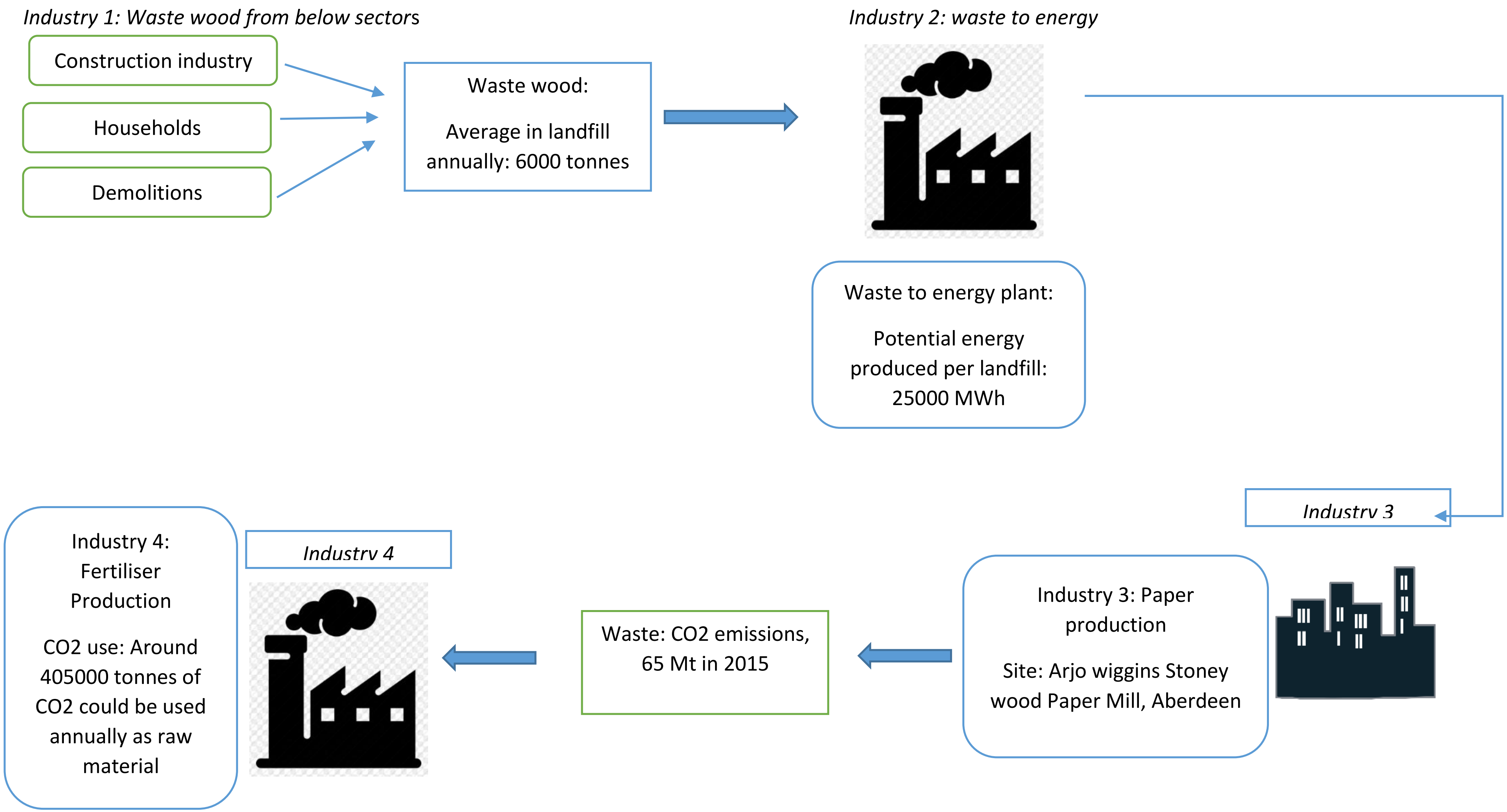


Figure 26- CO2 exchange between industries 3 and 4

All industries and there exchanges can now be put together, the second network created from this is shown on the following page:

Network 2


Industry 1: Waste wood from below sectors
Construction industry
Households
Demolitions
Waste wood:
Average in landfill annually: 6000 tonnes
Industry 2: waste to energy
Waste to energy plant:
Potential energy produced per landfill: 25000 MWh
Industry 3
Industry 3: Paper production
Site: Arjo wiggins Stoney wood Paper Mill, Aberdeen
Waste: CO2 emissions, 65 Mt in 2015
Industry 4
Industry 4: Fertiliser Production
CO2 use: Around 405000 tonnes of CO2 could be used annually as raw material

Steam exchange

With the creation of both networks, a further improvement was identified which could be made to network 1 in order to further use the waste produced by the steel production industry. The 1st network created in Section 2(i) can be seen below:

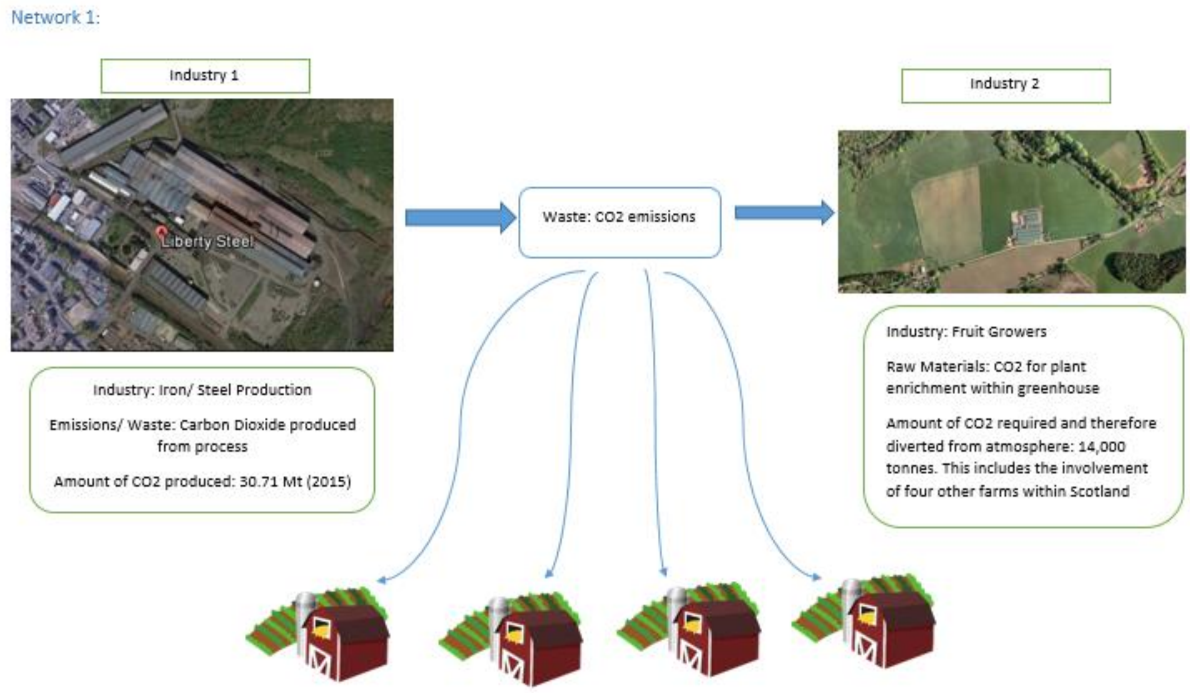


Figure 27 - Network 1

Whilst creating Network 2 it was seen the fertiliser production process required a number of heat exchangers as is the case with many chemical processing plant in order to heat the gas/ liquid during the process. A common heating fluid which is used within heat exchangers in chemical plants is steam, it was also found that during steam generation within steel production around 60 kt/year of steam is produced with the potential of being used by another industry (58). An additional exchange identified would therefore be waste steam from the liberty steel site identified within Network 1, and used as the heating fluid within the heat exchangers in the fertiliser processing plant, Yara identified in network 2.

For the next part of the project, only one network would be chosen to take forward and bring improvements in terms of implementing a renewable source within the network. The network which was chosen to improve was Network 1 mainly due to the areas of improvement which were seen and also as the industries associated were of a smaller scale which would be able to be easier implemented. On the following page Network 1 can be seen with the addition of steam exchange with Yara fertilisers, this allows the fertiliser plant to be introduced into the first network to improve the network

Network 1 + Steam exchange

Industry 1

Industry: Iron/ Steel Production

Emissions/ Waste: Carbon Dioxide produced from process

Amount of CO_2 produced: 30.71 Mt (2015)

Industry 3: Fertiliser Processing

Raw material: Steam waste from steel

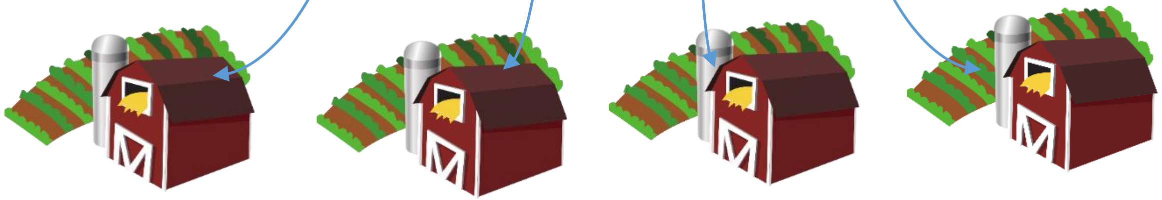
Waste: CO_2 emissions

Industry 2

Industry: Fruit Growers

Raw Materials: CO_2 for plant enrichment within greenhouse

Amount of CO_2 required and therefore diverted from atmosphere: 14,000 tonnes. This includes the involvement of four other farms within Scotland



3(i) Renewable Energy Potential

Following on from the creation of Networks 1 and Network 2 which looked at tackling the challenges highlighted by the United Nations' SDG' mentioned in Section 1 (iv), the next looks to address the agenda of Goal 7. As mentioned earlier in the report, the issues which Goal 7 aimed to tackle were as follows:

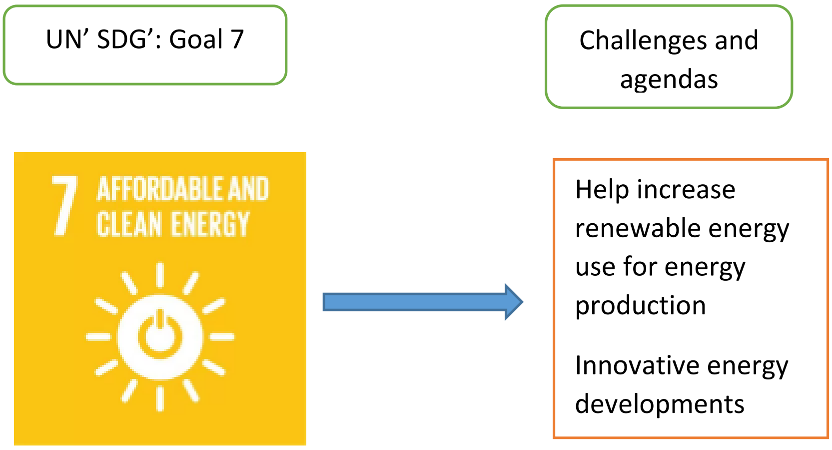


Figure 28 - UN'SDG' Goal 7 and the issues it aims to tackle

In order to determine the renewable energy source best suited for use, which would also be beneficial for use within the network, the industries within Network 1 were reviewed to help identify the best option. From looking at the industries within Network 1, it can be seen that the vegetable and fruit producers which make up industry 2 within the network are small businesses with farm focused dwellings. Through further research through literature, a number of best on- farm technologies were assessed, with focus on the benefit the technologies had within the farm. After reviewing case studies using various renewable technologies on farms, the technology with the most successful use was seen to be the use of anaerobic digestion (60)(61). This form of energy production was seen to be most popular mainly due to the many different waste products available on farms which could be used as part of the digesters (61). The process used within anaerobic digestion plants is shown in the diagram below (62):

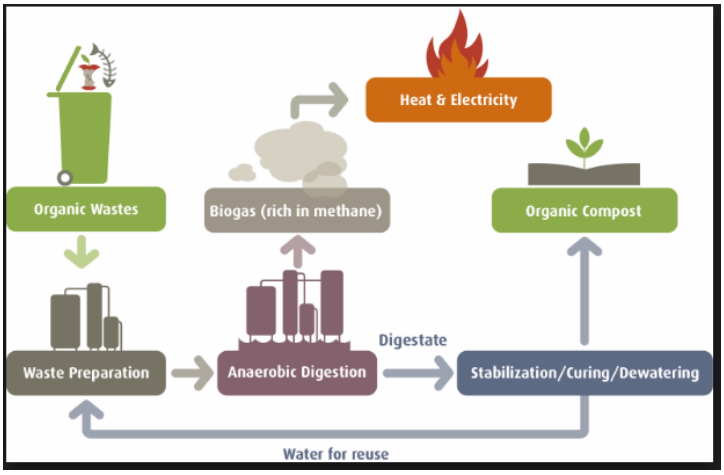


Figure 29- Anaerobic Digestion Process (62)

This section will therefore aim to bring new sources with energy production potential into Network 1 and look to assess how different forms of waste could produce energy to bring into the network and help meet demand within the network.

3(ii) Waste Source 1

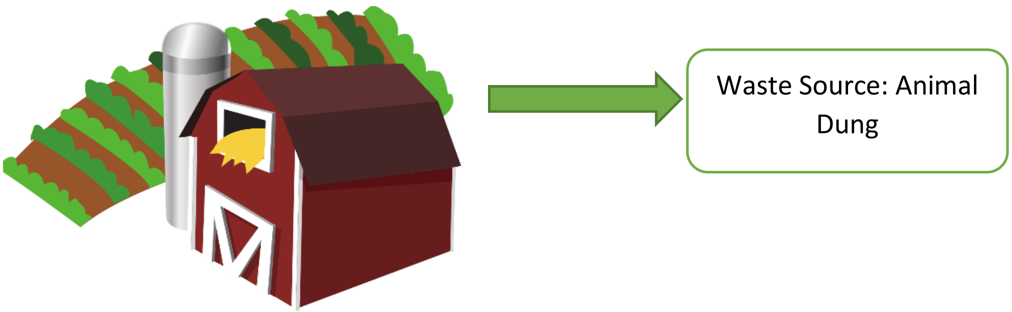


Figure 30- Waste to energy, source animal dung (63)

Source sites of animal dung: Processing farms, household farms, dairy farms, meat rearing farms

Current issue with waste source: An issue seen currently associated with animal dung was the build-up of dung when it has not been composted. When left exposed, manure will decompose releasing methane emissions from the matter during the decomposition stage (64). Another issue identified was through an incident occurring within 'High Auchensale Farm' in 2016, dung had been left within a tower on the farm over a few months. however due to an error the main door separated the dung/slurry and outside could not close resulting in heavy pollution of nearby water (65). With dung being collecting and being processed for energy use, situations such as the one described could be avoided and ensure sufficient use of the waste generated within the farm.

In order to assess the potential energy which could be generated from animal manure, data firstly used was to calculate the potential for beef rearing farms.

Firstly the overall energy potential available from Beef farms for the whole of Scotland was calculated, using information available for all cattle farms within Scotland (66). This would help assess the energy potential available for the whole of Scotland from only the use of animal manure:

$Total\ number\ of\ cattle\ of\ beef\ farms\ in\ Scotland = 430{,}000,$ (66)

$$Dung\ output\ per\ cattle\ per\ day = 10\ kg$$ (68)

$$Total\ dung\ output\ per\ day\ in\ Scotland = 430{,}000 \times 10 = 4{,}300000kg$$

$$\%\ of\ dung\ recoverable$$
$$= 70\%\ \ , this\ fraction\ is\ the\ \%\ accessible\ taking\ into\ consideration\ dung\ which\ cannot\ be\ collected\ due\ to\ weather$$

$$Therefore\ with\ 70\%\ recoverable, total\ dung\ output = 0.7 \times 4{,}300{,}000$$
$$= 3{,}010{,}000kg$$

$$Energy\ value, calorific\ per\ 1kg = 14\ MJ$$

$$Efficiency\ of\ process = 80\%$$ (51)(52)

$$Energy\ produced = 0.8 \times \left(14\frac{MJ}{Kg} \times 3{,}010{,}000kg\right)$$

$$= 33{,}712{,}000\ MJ$$

$$Number\ of\ cattle\ farms\ in\ Scotland = 9000$$ (66)

$$Therefore, average\ amount\ of\ energy\ produced\ per\ cattle\ farm = \frac{33{,}712{,}000 MJ}{9000}$$

$$= 3746\ MJ$$

$$Energy\ in\ kwh\ per\ farm = 1040\ (kwh)$$

Shown above is the amount of energy potential through Scotland from only dung as waste source, this has been broken down into average potential per farm based on number of cattle farms within Scotland (66).

With the potential energy throughout Scotland identified, the next calculation looked to identity the potential energy from one cattle farm which can be used as part of Network 1. The cattle farm chosen was the farm mentioned earlier 'High Auchensale Farm' in Renfrewshire, where the dung had been collected and escaped, this will help assess the potential energy of the farms manure:

$$Total\ number\ of\ cattle\ on\ High\ Auchensale\ Farm = 400$$ (69)

$$Dung\ output\ per\ cattle\ per\ day = 10\ kg$$

$$Total\ dung\ output\ per\ day\ on\ farm = 400 \times 10 = 4000 kg$$

$$\%\ of\ dung\ recoverable = 70\%\ ,this\ fraction\ is\ the\ \%\ accessible\ taking\ into\ consideration\ dung\ which\ cannot\ be\ collected\ due\ to\ weather$$

$$Therefore\ with\ 70\%\ recoverable, total\ dung\ output = 0.7 \times 4000$$

$$= 2{,}800kg$$

$$Energy\ value, calorific\ per\ 1kg = 14\ MJ$$

$$Efficiency\ of\ process = 80\%$$

$$Energy\ produced = 0.8 \times (14\ MJ/Kg \times 2800kg)$$

$$= 31,360\ MJ = 8711\ kwh$$

With around 31,360 MJ of energy being produced on High Auchensale Farm through the dung produced by the on farm cattle, this shows that there is potential for this energy to be used either by the site itself or sent to another site of use within Network 1.

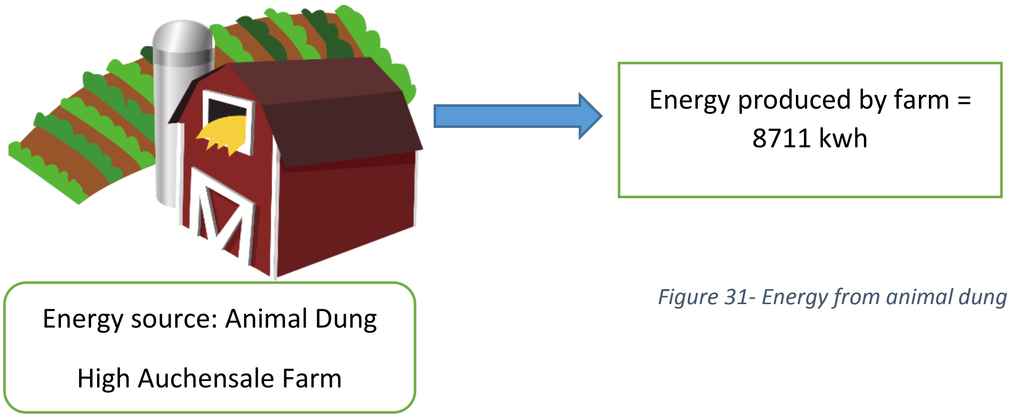


Figure 31- Energy from animal dung at chosen farm

With high energy potential available from within a farm holding, a second farm was also chosen to become part of Network 1. As High Auchensale Farm mentioned above is a cattle farm, the next farm chosen was a Dairy Farm: 'Bonaly Farm Daily'. The number of cattle within Scotland for beef rearing differ from the dairy cows, therefore the numbers used to calculate the energy potential will be of a typical dairy farm within Scotland (66) (70):

$$Total\ number\ of\ cows\ on\ average\ holding = 173$$ (66)

$$Dung\ output\ per\ cow\ per\ day\ (\ same\ as\ cattle) = 10\ kg$$

$$Total\ dung\ output\ per\ day\ on\ farm = 173 \times 10 = 1730kg$$

$$\% \ of \ dung \ recoverable$$

$$= 70\% \ , this \ fraction \ is \ the \ \% \ accessible \ taking \ into \ consideration \ dung \ which \ cannot \ be \ collected \ due \ to \ weather$$

$$Therefore \ with \ 70\% \ recoverable, total \ dung \ output = 0.7 \times 1730 \ kg$$

$$= 1211 \ kg$$

$$Energy \ value, calorific \ per \ 1kg = 14 \ MJ$$

$$Efficiency \ of \ process = 80\%$$

$$Energy \ produced = 0.8 \times (14 \ MJ/Kg \times 1211kg)$$

$$= 13{,}563 \ MJ = 3767 \ kwh$$

It can be seen from above that there is also high energy potential on dairy farms as well as beef farms, benefitting even those with a smaller number of animals on land. This therefore provides the second waste source into Network 1:

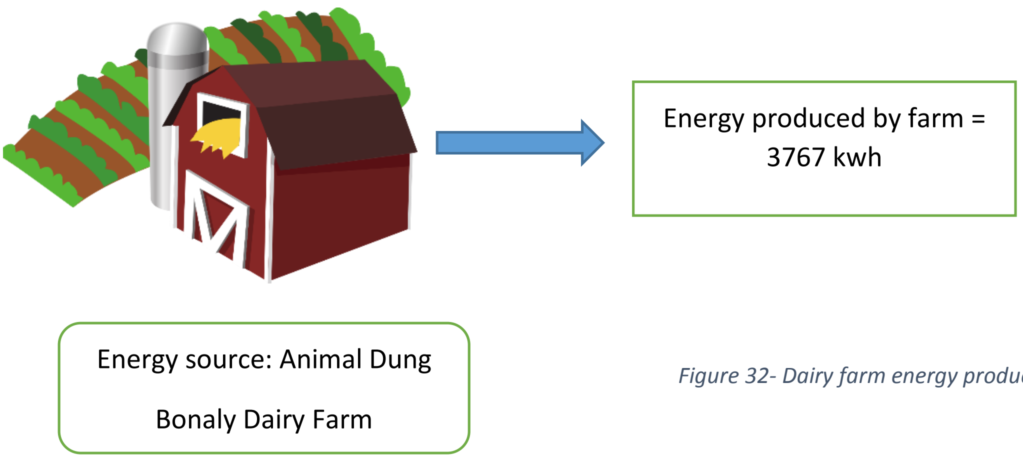


Figure 32- Dairy farm energy production through dung

3(iii) Waste Source 2

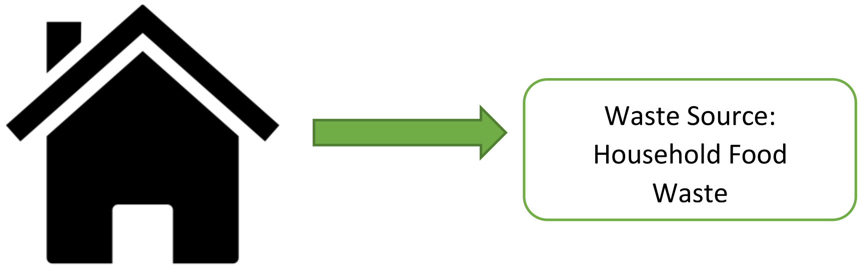


Figure 33 - Potential energy source from household waste

Source sites of household: Homes, Small food outlets, small businesses, landfills

Current issue with waste source: Current issues relate to the build-up and release of methane emissions from the decomposition of food waste sent to landfill. Also in Scotland, from 2021 a ban is coming into force stopping biodegradable waste being allowed into landfill sites (67).

To calculate the potential energy from organic household food waste, data was used from waste information available from the 'Scottish Environmental Protection Agency (SEPA)'. In order to make a reasonable waste to energy potential calculation, the amount of energy potential will be based on 100 households. This would help give a reasonable energy potential of waste from a number of houses within a neighbourhood, who would be able to work together to produce energy from their household waste:

$$Total\ household\ waste\ in\ Scotland\ in\ 2015 = 2{,}500{,}000\ tonnes \quad (71)$$

$$\%\ of\ food\ waste\ within\ household\ waste = 18\% \quad (72)$$

$$Therefore\ total\ food\ waste\ Scotland\ from\ households = 450{,}000\ tonnes$$

$$Based\ on\ example\ of\ 100\ households:$$

$$Number\ of\ households\ within\ Scotland = 2{,}400{,}000$$

$$Amount\ of\ food\ waste\ per\ household\ per\ year = \frac{450000}{2400000} = 0.187\ tonnes$$

$$0.187\ tonnes = 187\ kg$$

$$Food\ waste\ per\ day = \frac{187}{365} = 0.51\ kg$$

$$For\ 100\ households = 0.51kg \times 100 = 51\ kg$$

$$If\ the\ amount\ of\ food\ waste\ generated\ from\ 100\ households\ each\ day$$

$$was\ sent\ to\ landfill, the\ following\ emissions, kg\ CO2eq\ would\ be\ produced$$

$In\ landfill, per\ 1kg\ food\ waste = 0.45\ kgCO2\ equivalent\ emitted$ (73)

$$Therefore\ \ using\ conversion\ factor = 0.45$$

$$kgCO2e\ for\ 51\ kg\ food\ waste\ in\ landfill = 0.45 \times 51 = \ \sim 23kgCO2e$$

$$However\ when\ 51kg, converted\ to\ energy\ value:$$

$$Heating\ value\ of\ municipal\ waste, 1kg = \ \sim 9MJ$$

$$Energy\ produced\ from\ food\ waste\ from\ 100\ households = 9MJkg \times 51kg = 459MJ$$

From the calculation above it can be seen that from within food waste thrown out by households, there is significant energy potential which should instead be utilised. The above example showed the energy potential for 100 households as the food waste from only a small number of households would not be enough to generate a significant amount of energy. Also working together with either a community or neighbourhood in producing clean energy would encourage further use of this system and help reduce the generation of waste. As mentioned earlier, by 2020 a ban will be in place stopping biodegradable waste from entering landfill sites within Scotland, therefore the use of anaerobic digestion will likely be further promoted and should be encouraged by communities and industries (67).

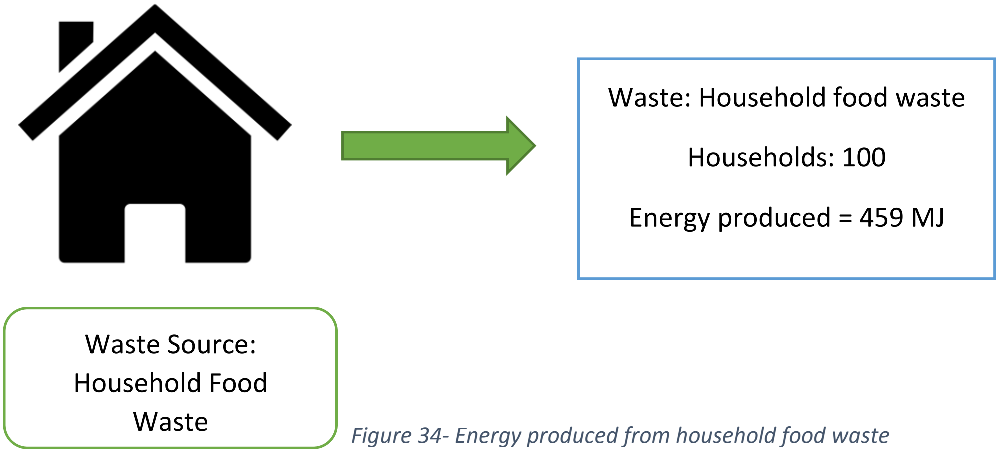


Figure 34- Energy produced from household food waste

3(iV) Waste Source 3

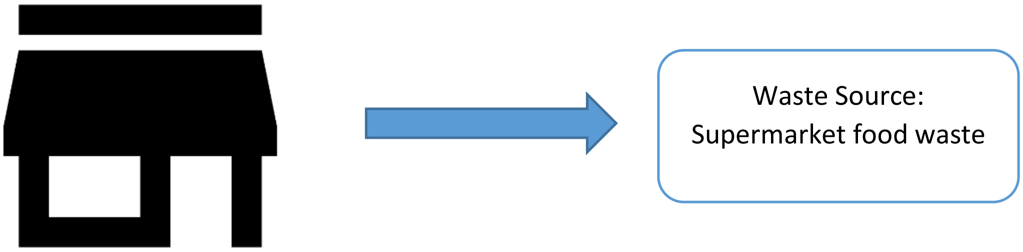


Figure 35- Waste to energy, supermarket food waste

Source sites of waste: supermarkets, large food stores

Current issue with waste source: Similarly to household food waste; issues relate to the build-up and release of methane emissions from the decomposition of food waste sent to landfill.

Also in Scotland, from 2021 a ban is coming into force stopping biodegradable waste being allowed into landfill sites (67).

From the information available on food waste from supermarkets, it was seen that 9 out of the 10 biggest supermarkets in the UK had between 10,000-60,000 tonnes of food waste generated (74). Therefore in order to identify the potential energy which could be generated from this waste, a Tesco store was used to identify energy potential:

$$Food\ waste\ generated\ from\ Tesco = 59{,}000\ tonnes\ (74)$$

$$\%\ biodegradable = 80\%, \qquad potential\ food\ waste = 47{,}200\ tonnes$$

$$Tesco\ stores\ in\ UK = 3{,}400$$

$$Average\ food\ waste\ per\ tesco = \frac{47{,}200}{3400} = 13.8\ tonne\ per\ year$$

$$(Average\ taken\ as\ waste\ data\ available\ was\ UK\ total, not\ specific\ stores)$$

$$Waste\ per\ day = \frac{13.8}{365} = 0.038\ tonne$$

$$0.038\ tonne = 38\ kg$$

$$Heat\ Calorific\ value, municipial\ waste\ 1kg: 9MJ$$

$$Energy\ produced = 38kg \times \frac{9MJ}{kg} = 342\ MJ/day$$

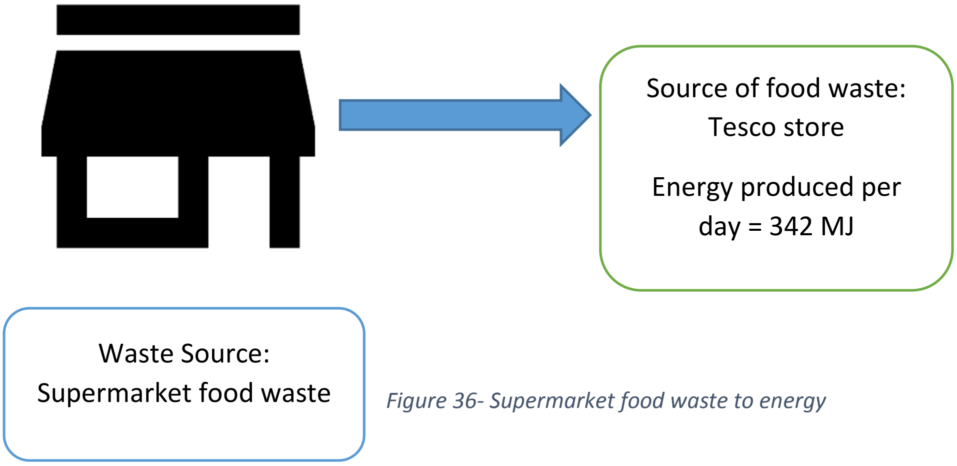


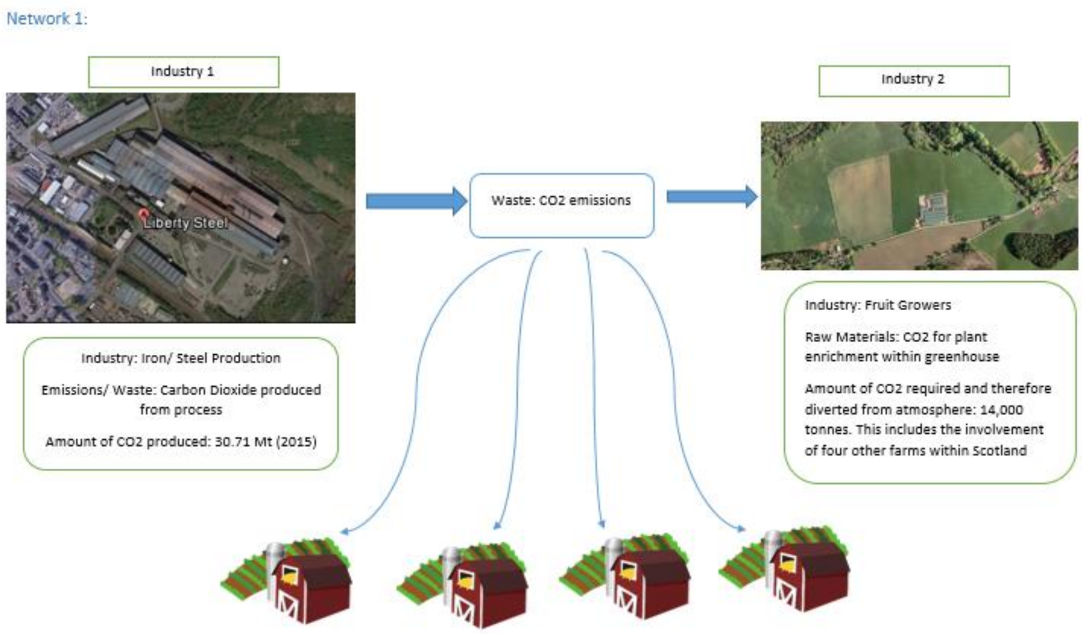
Figure 36- Supermarket food waste to energy

From this Section, 4 various waste sources have been identified with the potential clean energy produced from each calculated. Assessing these waste potentials, it is clear to see there is high potential for anaerobic digestion plants to bring businesses together using waste from a number of different business to help produce energy. The total energy supply found from the four waste sources per day are summarised below:

- Animal Dung, High Auchensale Farm, Energy supply calculated = 8711 kwh
- Animal Dung, Bonaly Farm, Energy supply calculated = 3767 kwh
- Household food waste, 100 households, Energy supply calculated = 122 kwh
- Supermarket food waste, Tesco, Energy supply calculated = 93 kwh
- *Total Energy supply from four waste sources = <u>12,693 kwh</u>*

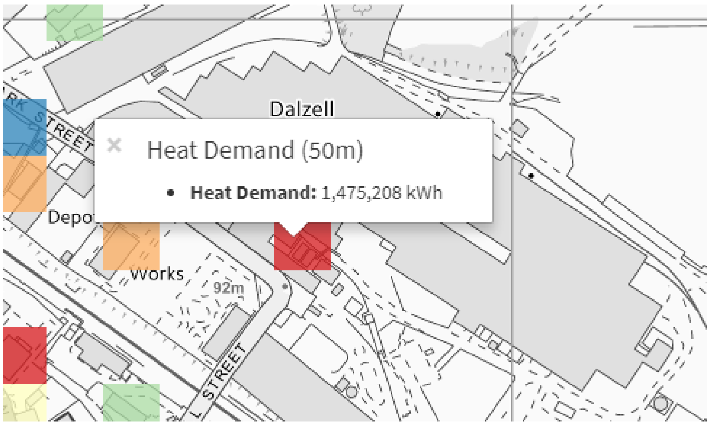
In order to use this energy within Network 1, the industries were assessed to find which site would benefit most from use of clean energy. Looking back at network 1, the main industry chosen was Dalzell steel production due to both the high CO2 emissions and high energy use. To assess the energy demand of the site, heat maps were used to locate and identify the Dalzell steel plant and its energy use, the following page shows the heat map used, the site of Dalzell steel and how the energy produced from the four waste sources could be used:

Dalzell Iron/Steel Plant with Network 1

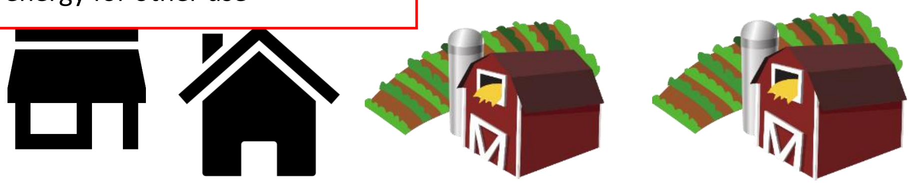


Heat Map used to identify heat energy demand by Dalzell.

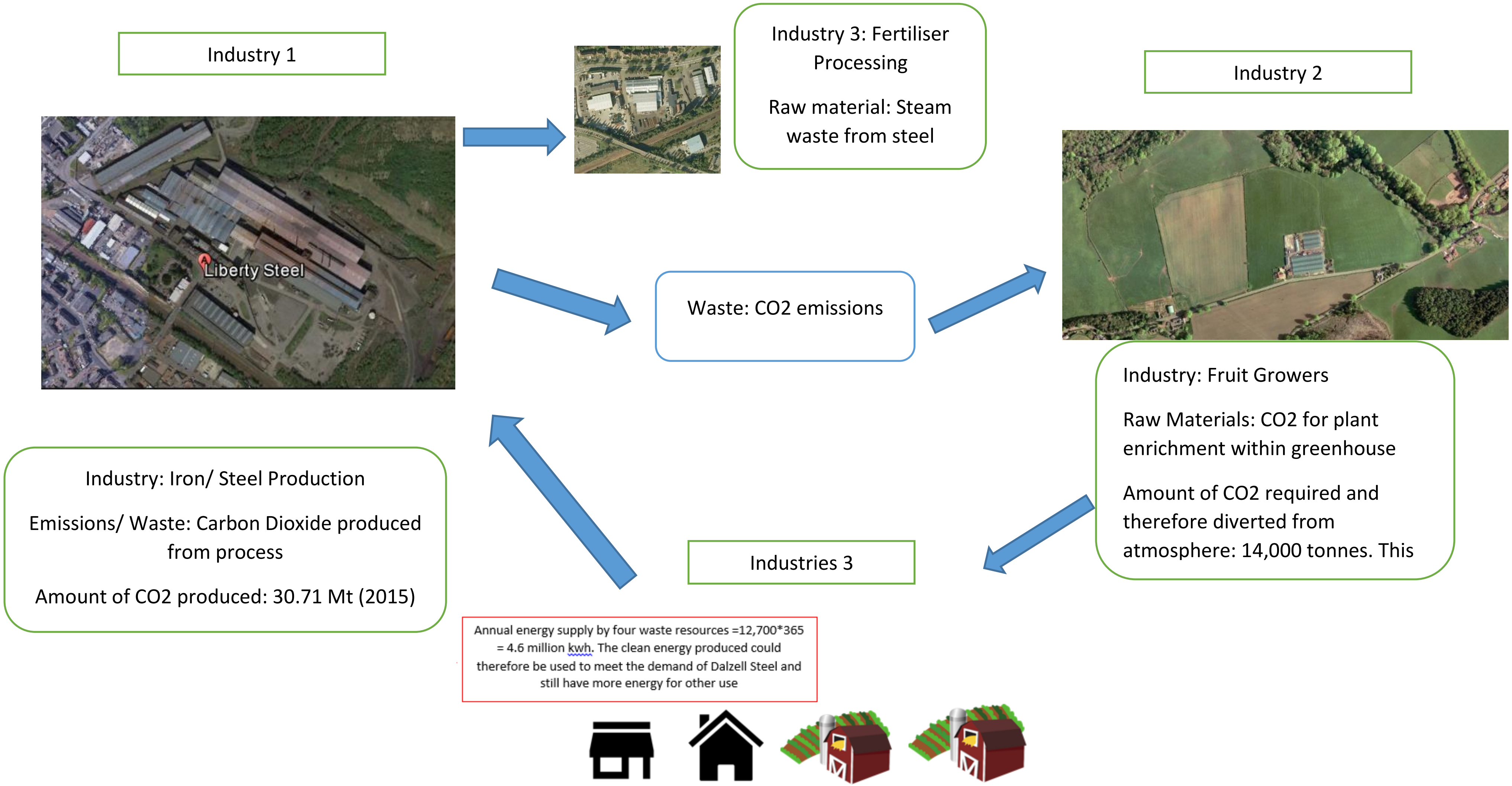
The demand for heat at Dalzell Steel is shown to be just under 1.5 million kwh



Annual energy supply by four waste resources =12,700*365 = 4.6 million kwh. The clean energy produced could therefore be used to meet the demand of Dalzell Steel and still have more energy for other use



Network 1 with renewable energy produced through new industries



4 Environmental Impact Assessment

As the use of Industrial Symbiosis aims to manage emissions, reduce waste and connect industries through heat/material/ flow exchanges an impact assessment will be carried out.

This will aim to identify the state for industry/environment before the project, the steps take, the state after and further actions if required. Both positive and negative impacts will be considered

Network 1

Industry	**Conditions before project**	**Action**	**Conditions after project**	**Further Actions**
Industry 1: Iron and Steel Production	-Global call for action on climate change, through United Nations ‘ SDG’ -Through Goal 13, it was identified that countries need to take action on emissions released to atmosphere -Iron/Steel production was seen to be in top five CO_2 emitting industries - CO_2 emissions from the steel production site chosen was shown	-In order to manage CO_2 emissions, a number of different methods can be used -As within Iron/steel processing the CO_2 emissions come from the process the best option seen was to manage the emissions after the process and before they are	-Through project, the CO_2 emissions were used as raw material within greenhouses on various fruit/veg farms -When CO_2 used within one green (depending on size and production), 840 tonnes was diverted per one greenhouse annually - When collaborated with	-Requirement of monitoring exactly how much CO_2 is diverted once exchange in place in order to examine more closely the benefits -With CO_2 enrichment being used within the greenhouse, need to be careful that these are contained

	through 'SEPA' to be 30.71Mt in 2015 -Iron/Steel processing also identified to be highly energy intensive -However within Scotland only six steel/iron processing sites identified, and may not be serious issue within Scotland as it would in a high steel processing country	release to the atmosphere -Action taken was to identify an industry which could use CO2 as its raw material	four such fruit/veg farms, around 14,000 tonnes CO2 diverted from atmosphere annually -Exchange of CO2 from plant to farm may cause emissions if CO2 is being transported, however in this case the farms and steel plant were shown to be close together and therefore any emissions will not be large	
Industry 2: Farms, fruit and vegetable growers	-Before project, CO2 enrichment not always used by farms or greenhouses -Within the farms themselves, no emissions from the greenhouses -Electricity use for farm and processes not usually from renewable sources unless solar PV have been implemented or AD plant on farm	- No action on electricity use to run farm processes -Addition of CO2 brought to farm to enrich plants and develop yields of fruit/veg	- No changes in emissions within the farm/fruit/veg producers as emissions not identified -CO2 will now be used on the site which needs to be carefully handled -Possibility of extra vehicles coming to farm for delivery of gas	-Again monitoring of gas being brought to site -Possible training required if it's a prcess farm have not been involved in previously -Careful containment of CO2 within greenhouse when used to enrich plants -CO2 monitoring/alarm

	--Possible emissions from farm waste on site		-Due to above may require road to be built or further developed, this work may cause noise pollution and possible dust/pollutant emissions due to road work	should be used within the greenhouse to notify of changes within level
Industry 3: Fertiliser processing	-Fertiliser processing industry are highly energy intensive -Dependent on end product, require highly saturated steam and high water use -For production of urea, process plant requires use of CO2 for end product, there is possibility of CO2 lost from process and being emitted into the atmosphere	-Within Network 1, fertiliser plant was introduced to use waste steam escaped/produced by Dalzell steel plant	- Instead of steam bought from a further source, which would itself cause emissions, a source close to the fertiliser plant can sell their steam -CO2 loss which is possible from the process was not looked into further and therefore does not change	-Steam exchange between Dalzell and Yara was only briefly touched on, scope for further improvements into this to improve any environmental concerns
Industry 4: (1) High Auchensale Farm	-Animal dung within farms either composted, stored or burned -From storing/burning, high methane emissions possible due to decomposing which	-Action taken was to use method of anaerobic digestion together with other 3 waste sources identified	-It was calculated that for the whole of Scotland there is huge potential within dung to produce energy	-Planning of dung collection on farm -Minimisation of disturbances to neighbours through work and development

	was identified to be a greater risk than CO2 to the atmosphere -Incident on farm last year, when dung was stored but due to fault in door leaked into nearby river, this caused heavy pollution to nearby land and landscape	in order to convert manure to energy	-Calculation showed over 9 million kwh possible from all farms -Through the use of anaerobic digestion, the dung does not lye around and therefore will not decompose in open air -Reduction of methane emissions to atmosphere -Reduction of smell of manure from generation -Farm land requirement to build the anaerobic digester, could cause visual/landscape issues with neighbours -Noise from plant/ work for developing plant could also be a disturbance to neighbours	

Industry 4(2): Animal Dung, dairy farm, Bonaly	-Estimated around 1211 kg of manure output per day from all cows on far - Emissions to atmosphere due to decomposing on manure -Smell of dung if left around and not collected	-As above, implementation of waste to energy anaerobic digestion using animal dung	- Calculated around 8711 kwh energy possible from manure on site -Reduction of emissions which may have been emitted due to dung generation -As above, due to development of AD plant possibility of noise and smog during development, affecting neighbouring buildings	-Assessment of work required to build AD plant and effects on surroundings -May require permit of building if plant is obstructing views -Monitoring of noise during development
Industry 4(3): Household waste	-Food waste being sent to landfill along with other household waste -Due to organic nature, decomposition of food causes methane emissions, as mentioned above pose higher risk to atmosphere than CO2 -Calculated that around 51 kg/day food waste generated for 100 households, this	Implementation of anaerobic digestion plant to work between households in order to produce energy from the food waste generated	-Calculated that from 100 households, 122 kwh energy possible to be generated - Reduction in methane emissions as food not sent to landfill -As food waste will be used straight away, no emissions from decomposing	-Collaboration required between either communities or a small neighbourhood -Possible workshop to communities on the advantages of AD plants which can be monitored and benefited by the community

	showed to be equivalent to GHG emissions of 23 kgCO2		either, although these emissions are very small normally -If small AD plant built within garden could affect neighbours through smells or noises -Building of AD plant near community may not be welcomed by all members of community	
Industry 4(4): Supermarket food waste	-9 out of top 10 supermarkets had food waste generation between 10000-60000 tonnes -When sent to landfill as mentioned above, methane emissions due to decomposing	-AD process of waste to energy, using waste from one supermarket	- Calculated that from one supermarket around 93kwh energy could be produced -Reduction in food sent to landfill, therefore reduction in emissions	-Requirement of understanding by larger businesses of emissions due to food waste

Network 2

Industry	**Conditions before project**	**Action**	**Conditions after project**	**Further Actions**
Industry 1: Wastewood generation	-Global call for action on climate change, through United Nations ' SDG' -Through Goal 7, it was identified that countries need to take action on emissions both directly from processes and from waste generated - Within Scotland's Agenda, it was highlighted through the national framework that reduction of waste was a key goal -Construction industry responsible for majority of waste wood into landfills Wood generated in landfills	- As initial industry within network 2, action was taken to identify use of wood to reduce wastage and emissions -Waste to energy plant was introduced into network 2 use the wood for energy	-Through using the waste to energy plant, it was calculated that around 25000 MWh could be produced from waste found in landfills -Reduction in emissions through wood decomposing within landfill -As waste-energy plant is a new development and of large scale within Aberdeen (to open in 2021), possible visual impact to landscape -Increase in noise within area due to waste to energy plant	-Full impact assessment required for waste-energy plant to ensure any disturbances are kept to a minimum -Monitor usage of energy and water of plant -Encourage should be given to industry's such as construction in order to reduce waste wood build up within landfills

	decomposes over time, potential release of emissions direct to atmosphere -Wood not being recycled causes more trees to be cut down for used within paper/manufacturing -Average generated wastewood within landfill found to be 6000 tonnes, this was seen to be equivalent to 1.7million kgCO2 eq			
Industry 2: Waste to energy plant	-Before project, wastewood would be generated and disposed in landfills s mentioned above -CO2 emissions huge concern globally -Waste generation causes smells within neighbourhoods and communities	- Bring waste to energy plant to network in order for waste to be utilised	As waste-energy plant is a new development and of large scale within Aberdeen (to open in 2021), possible visual impact to landscape -Increase in noise within area due to waste to energy plant	- Full impact assessment required for waste-energy plant to ensure any disturbances are kept to a minimum

Industry 3: Paper/ Pulp Processing Arjo wiggins stoneywood mill	-CO2 emissions a global, concern. Industries required to make a change in order for development within this sector -Paper processing highly energy intensive industry -Also one of the highest CO2 emitters -Within Scotland, only around 3-5 plants found and therefore not as great as a concern as US paper processing which is a much larger industry -Calculated that 65 Mt of CO2 emissions left this site in 2015	-Use of industrial symbiosis in order for the paper processing plant to collaborate with another industry.	- Calculated that around 25000 MWh of energy used within the paper processing plant could be obtained from waste-energy plant through waste wood use -This would in turn help reduce some emissions, although most emissions arose from the process equipment -Use of clean energy could potentially stop industries from reducing energy use as its coming from a clean resource	-Research further energy minimisations through the process being used and equipment/materials/tempe ratures etc -Help enhance industrial symbiosis by encouraging other paper/processing industries to collaborate with other businesses
Industry 4: Fertiliser Production	-Use of CO2 as raw material but from other sites -Possibility of some CO2 being lost within process	- Through industrial symbiosis, collaboration introduced with paper	-It was calculated that the industry could use 405,000 tonnes of CO2 annually from waste steam of the paper processing plant.	-Planning of a network between the two industries to ensure exchange of material suits both industries and can be done with reduced amount of hassle

		processing plant	-This use as raw material would reduce requirement of CO_2 being shipped and brought over, again reducing more emissions -Due to this CO_2 use, 405,000 tonnes of CO_2 is being diverted from polluting the atmosphere	-Further plan and encourage collaborations between chemical processing plant and other industries as many chemical plants are large users of raw material and energy -Monitor reduction of CO_2 from plant to atmosphere in order to help other companies using this information as how the collaboration benefits both industries and the environment.

5. Analysis

(i) Implementation Model

With the first four steps of the methodology completed, the analysis stage aims to review findings and create a framework of implementation which can be used by industries to determine the steps to take for similar projects. After reviewing the stages which were completed in order to create the two networks, the following framework has been created:

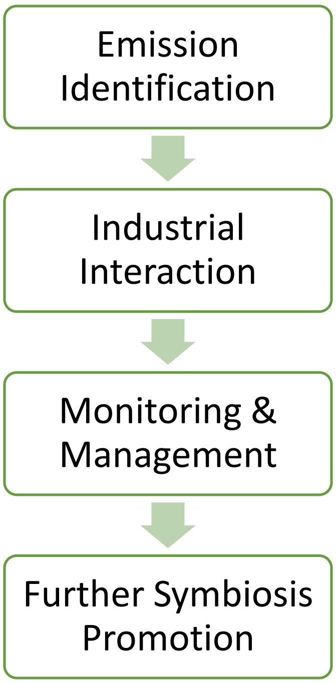


Figure 37- Framework of stages of Industrial Symbiosis implementation

After assessing the route taken in order to complete the creation of the two networks using the practice of Industrial Symbiosis, the stages concerned with the practice and its implementation became much clearer. As seen in Figure 37 above, the first step involved is the identification of emissions from the industry within you either work are involved in. When the project was started, understanding the emissions involved may be a little difficult as the emissions do not need to be only gases/liquids which are hazardous. Therefore understanding the process from within your industry is key in order to see the benefits this could have to other industries. As there have been many successful case studies using Industrial Symbiosis across the globe, especially in China and Denmark, reviewing industries from a number of different sectors and there collaborations will ensure that the initial stage is successful. This will provide a number of different options and opportunities tin which to begin the start of industrial symbiosis within the industry. Another key point within the first stage is to identify energy savings which are possible especially if the industry is energy intensive. Industrial symbiosis looks at the raw material as well as the waste from an industry, therefore if the industry can identify a source of clean energy to replace current sources then this would improve the benefits of the system.

The next stage of the framework looks at industry interaction, a key step within business partnerships. Within the current energy sector, there are many challenges along with many opportunities for development and improvement. As industries being one of the largest sectors in the world it is important that businesses small and big are able to interact with each other for the benefit of each industry. With renewable energy resources constantly being researched and improved for higher efficiencies and outputs, industries from within the industrial sector can help each other find better uses of materials/ heat/waste in order to carry on developing. A number of further methods could be utilised by industries close to one another such as harvesting/sharing water to reduce energy use and steam exchanges which was only briefly touched upon within this project. Therefore with industries interacting especially with an energy focus, determining minimisations and exchanges, huge gains could be made to the energy sector along with the industries themselves.

The third stage identifies the need to monitor the emissions produced from within an industry as well as the emissions diverted, in order to share the findings with similar industries. During this project, successful case study research was important to ensure that an exchange had been proven to be successful, this also ensures that an industry will not hesitate to begin a similar exchange with evidence of a working model. A case study with a model in practice, economic and social gains can also be assessed in order to identify the changes which may come financially or within the Industry.

The final framework stage involves determining further gains which can be made to either the industry or an industry close by. An industrial Symbiosis network has the potential to keep on expanding and looking at network 1 and network 2 there are also many improvements and gains that can be made, through either further clean energy promotion or expansion from the final industry. There was seen to be many possibilities of development for small businesses used within the network, this could open up the door to expansion and allow smaller businesses to flourish. It was also seen that large scale operations had the potential to divert a significant amount of emissions, if these emissions were used within the process due to the large amount of feed material required. This highlights the flexibility of industrial symbiosis to operations of any size, where gains big and small can be made but also have a significant effect on the resources and energy being used.

The framework was created to highlight the gains and potential gaps seen within each stage of the project, this could help an industry exploring the idea of creating a network with other industries by using Industrial Symbiosis and clean energy technologies. With a flexible approach, the opportunities available within the industrial sector are many and allow a difference to be made through exchanges and interactions within the sector.

5 (ii) Analysis and future developments

With an aim of tackling the issues of both climate change and clean energy use, the project looked to bring these challenges together and display a difference within the industries that can be found around the world. As these are global issues, the creation of two networks looked to demonstrate both a change in the emissions being emitted to atmosphere and an alternative source of energy for industries within the network.

The creation of network 1 started with an industry seen to be a high CO2 emitter, the iron and steel processing plant. Although this process was chosen, any industrial process which has shown to be highly energy intensive and high emitter of CO2 could be placed within this network in order to be used in another city/country. By waste/material/heat exchange it was important to identify the emissions being diverted to show the importance of the transfer. Within industry network 1, the partnership with small farms and fruit producers allowed the network to also make a difference to smaller businesses around the larger scale industries. With the collaboration of the Iron/Steel plant with five fruit/vegetable growers, around 14,000 tonnes of CO2 was diverted from atmosphere, however with 30.7Mt emitted by the steel process there is clearly room for involvement with a larger process plant. After Network 2 was created it was seen that there was scope within Network 1 to transfer some waste material to the fertiliser plant used within Network 2. Further research showed the emission of some steam from steel processing, with this in mind and knowing that steam is used within heat exchangers in heating up the feed as it passes through the process, the fertiliser plant was also established within Network 1.

The 1st Network created was also chosen to be taken forward instead of network 2 mainly due to the involvement which was possible between the smaller farms, in order to show how any industry could collaborate with each other and successfully. The implementation of renewable energy potential through anaerobic digestion was investigated due to the agendas mentioned at the start of the report. As governments look to promise the use of clean energy, it was assess the potential of a resource such as waste mainly due to the problems associated with waste generation and also the emissions which comes from decomposing matter. Identifying four various waste sources allowed somewhere as simple as a home to be involved in the process of clean energy production, with the ban on biodegradable waste from entering landfills approaching fast it is also important to find a way to utilise this waste and promote the method. With waste to energy implemented into network 1, it was seen that around 6,400 kg of waste was being diverted daily, being able to produce over 4.6 million kWh at year end. This amount of energy was found to be greater than the requirement of the steel processing plant through heat demand, with anaerobic digester easily implemented within farms, the potential of waste to energy looks promising.

Network 2 looked to identify industries a little different from that of Network 1, starting with construction waste to a paper processing plant. In countries known to be large paper producers the emissions from paper processing are a real concern. Within Scotland only around 3 were identified, however a network like this is easily implemented globally and therefore such industries were also included. Within Network 2, around 6000 tonnes of wood was diverted from landfill and producing around 25000 MWh which was useful for an energy intensive industry such as paper production. From here it was also seen that around 405,000 tonnes of CO2 was required as a feed material within fertiliser production, however with around 65Mt CO2 emitted from paper processing further work is required in order to identify a large scale use of CO2.

With the creation of the two networks, the next steps would involve putting into practise some of the potential industry exchanges within Scotland. This could even be between two industries or more, however as can be seen from Industrial Symbiosis networking in Denmark, building and putting into practise Industrial Symbiosis networks can take as long as ten years.

As it can be difficult to change ways once the industry has accustomed itself to specific process and method, an easier step may be to start using industrial symbiosis even before a process is built. This would be through the creation of Eco-industrial Parks which have already caught momentum in China, it involves a string of industries being built right next to each other, where from the day operation starts the industries are using each other’s waste products. This allows a long term sustainability development and also brings in the interaction between industries in order to tackle the global issues being faced currently by the planet.

5 (iii) Conclusion

With the challenges faced by an ever growing population clearly defined within the United Nations ‘Sustainability Development Goals’, this project aimed to tackle the two main issues seen within the energy sector: Climate Change and Clean Energy Resource use.

Along with tackling these issues, the project aimed to bring the practise of Industrial Symbiosis and identify how these two challenges could be met by incorporating these within a network. With this identified, two networks of industries using Industrial Symbiosis were created and can be seen below:

Network 1:

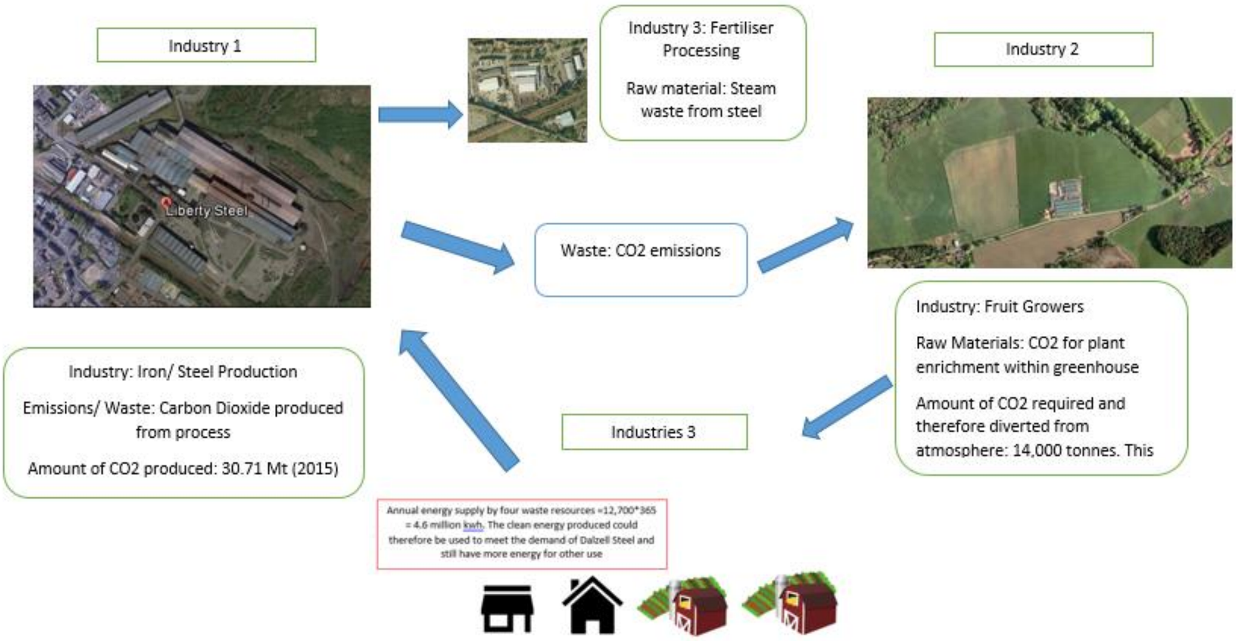


Figure 38 - Network 1

From Network 1 above, four industries were put together where the waste of one industry could be the feed for another. Along with using Industrial Symbiosis, renewable energy production through anaerobic digestion was calculated to assess the potential clean energy supply available through different waste sources.Through this network it was idenitifed that 14,000 tonnes of CO_2 was diverted and over 4 million kwh of energy was seen to be produced and used for the steel processing sites energy demand.

Network 2:

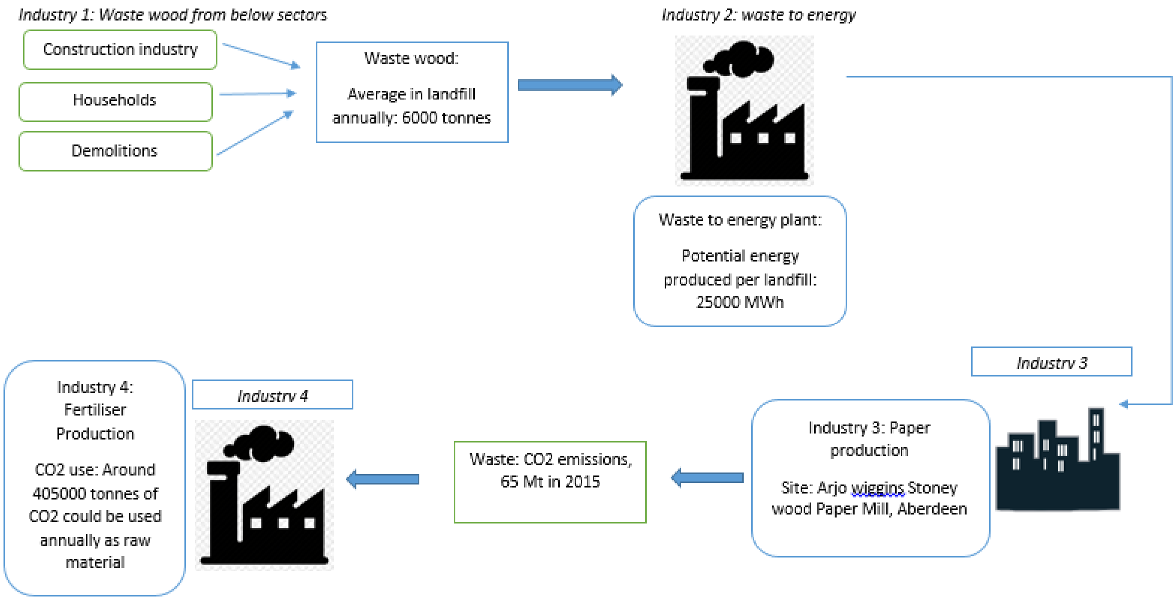


Figure 39 - Network 2

For Network 2 four different industries were put together, waste wood, processing, paper production and fertiliser production. From within this Network creation, 6000 tonnes of wood was diverted with 25000 MWh energy being produced. The energy was fed into the energy intensive paper plant with the fertiliser plant diverting 405,000 tonnes of CO_2 through use as raw material. From the creation of the two networks it was identified that there are many potential network exchanges and collaborations possible between different industries whilst also reducing emissions and energy use. For future developments, the interaction between industries could help change the way in which the industrial sector operates, for the benefit of both industry and global environment. The practise of Sustainable Engineering within an industry from the beginning could ensure significant changes are made to both the processes used today and the processes used within future engineering developments.

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