Industrial Ecology opportunities between CHP and Arable Farming in Alloa, Scotland

Oportunidades de la Ecología Industrial entre la generación eléctrica y la agricultura en Alloa – Escocia

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Abstract

This paper addresses the potential for Industrial Ecology application at Alloa, Clackmannanshire, Scotland, between a consortium of arable farmers *KATT Agricultural Ltd* and the energy company *Eco-Waste Solutions Ltd.* For improved onsite production, the average annual energy required to maintain KATT´s proposed 3 ha greenhouse at optimal temperature (21°C during the day and 16°C at night) was calculated as 1448.8 MJ/m^2. The coldest temperatures in February result in an energy requirement of around 3000 MJ/m^2. The optimal quantity of carbon dioxide for the proposed 3 ha glasshouse equates to 4032 kg of CO_2 per day. In addition, the fertiliser produced by *Eco-Waste Solutions* will reduce the pesticide and chemical based nitrogen/potassium demand. The authors identified that the heat, carbon dioxide and fertiliser produced at the proposed 10 MW CHP plant could be utilised by the consortium to produce higher quality food products in a symbiotic manner.

Keywords: symbiosis; industrial ecology; sustainable agriculture; scotland.

Resumen

Este artículo presenta el potencial para la aplicación de Ecología Industrial en Alloa, Clackmannanshire, Escocia, entre el consorcio de granjeros *KATT Agricultural Ltd* y la empresa de energía *Eco-Waste Solutions Ltd*. Para mejorar la producción, la energía promedio requerida propuesta para mantener 3 ha de invernaderos de KATT a una temperatura óptima (21°C durante el día y 16°C en la noche) fue calculada como 1448.8 MJ/m^2. Las temperaturas más bajas que se experimentan fueron encontradas durante febrero y esto resulta en un requerimiento de energía de alrededor a 3000 MJ/m^2. La cantidad óptima de dióxido de carbono para las 3 ha de invernadero equivale a 4032 kg of CO_2 por día. Adicionalmente, el fertilizante producido por el generador de energía reducirá la demanda de nitrógeno/potasio en forma de químicos y pesticidas. Los autores identifican que el calor, el dióxido de carbono y el abono producidos por el generador de energía propuesto de 10 MW podrían ser utilizados por el grupo agrícola para producir mejor calidad de productos alimenticios en una manera simbiótica.

Palabras clave: simbiosis, ecología industrial, agricultura sostenible, escocia.

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Introduction

KATT Agricultural Ltd (KATT), as a sustainable consortium of arable farmers, is considering an increase in its share of the Scottish agricultural sector with a new site at Alloa, Scotland which will operate in symbiosis with *Eco-Waste Solutions Ltd*. *Eco-Waste Solutions Ltd* is a small energy generator that uses the (dried) sludge from the neighbouring wastewater treatment plant as its prime material. The company has proposed a 10 MW Combined Heat and Power (CHP) plant to be built towards the southern edge of the town adjacent to *Alloa Wastewater Treatment Works*.

The proposal of a CHP plant, using organic waste as its source of energy, is an opportunity for an agricultural and industrial symbiosis which can support local energy production and potentially feed into the UK National Grid. By diverting waste away from landfill to produce higher quality foodstuffs, the project deals with those issues raised in the *2009 National Food and Drink Policy* and works towards the much needed practice of Industrial Ecology.

Project Proposal

The energy company *Eco-Waste Solutions Ltd* has applied for planning permission to Clackmannanshire Council for the construction of the 10 MW CHP plant identified in figure 1. In the event that the CHP plant plans are rejected KATT will withdraw its own application. However, should it be approved KATT will submit a Proposal Description in accordance to an EIA and Planning Application, as required under law. KATT's development consists of four main components:

- Underground 400m steam pipeline and associated network installations.
- Underground 400m carbon dioxide pipeline and associated network installations.
- 3 ha glasshouse.
- 25 ha poly-tunnels.
- 200 m road link to A907.

In addition, KATT has taken into consideration data acquired by the Scottish Environment Protection Agency (SEPA) regarding areas vulnerable to flooding by rivers and sea (figure 2). This proposed threat is likely to increase with time as records indicate that the average global sea level has increased by 3 mm pa since 1993 (Lowe & Hardy, 2008). Anticipated rises in Scotland could reach 20-28 cm higher in 2080 than the current datum level (Scotland Northern Ireland Forum for Environmental Research [Sniffer], 2008) – enough to submerge half of Alloa (Macleod, 2007). KATT together with *Eco-Waste Solutions Ltd* must ensure that precautions are taken to prevent the CHP plant and other proposals from being affected by sea level rise.

In accordance with the above, the construction of the glasshouse, as shown in figure 1**,** will be as near to *Eco-Waste Solutions Ltd* site boundary as possible, minimising the length of pipeline whilst also reducing potential energy losses out-with areas susceptible to flooding (figure 2). Due to their low construction and maintenance requirements, coupled with high manoeuvrability, the poly-tunnels will be situated in areas identified as having a higher potential flood risk.

Worthy of note, is the fact that KATT must conduct an EIA as the proposed development at Alloa falls into numerous Schedule II defined installation criteria (table 1) as recognised by the screening process of the *Environmental Impact Assessment (Scotland) Regulations 1999* and the *PAN 58* planning guidance:

Table 1. Classified Schedule II Installations

Schedule II Installation	Rationality	Colour on Map in accordance to figure 1
Road greater than 1 hectare	A feeder road into the A907 to help reduce the impact of agricultural traffic associated with KATT's, including construction traffic	Orange Line
Industrial Installation for carrying CO_2 gas, steam/hot water	The pipeline between *Eco-Waste Solutions Ltd* and the KATT consortium will transfer steam and CO_2 produced in the CHP plant	Red Line
Agricultural Projects for the use of semi-natural purposes where the area exceeds 0.5 ha	The glasshouse 3 ha and the poly-tunnels 25 ha in size. Some of the area that KATT require has been classified on the most recent land use survey as semi-natural	Purple Area – Glasshouse Dark Blue Area – Poly-tunnels

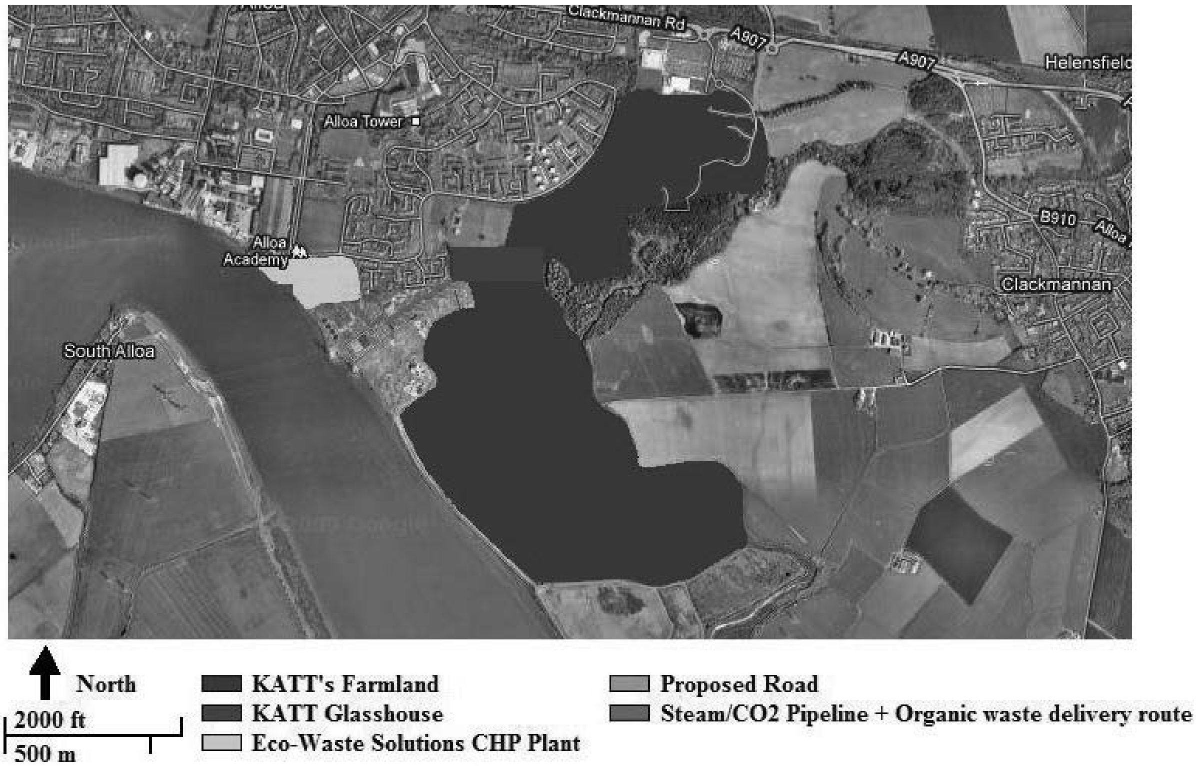

Figure 1. KATT proposed development plans

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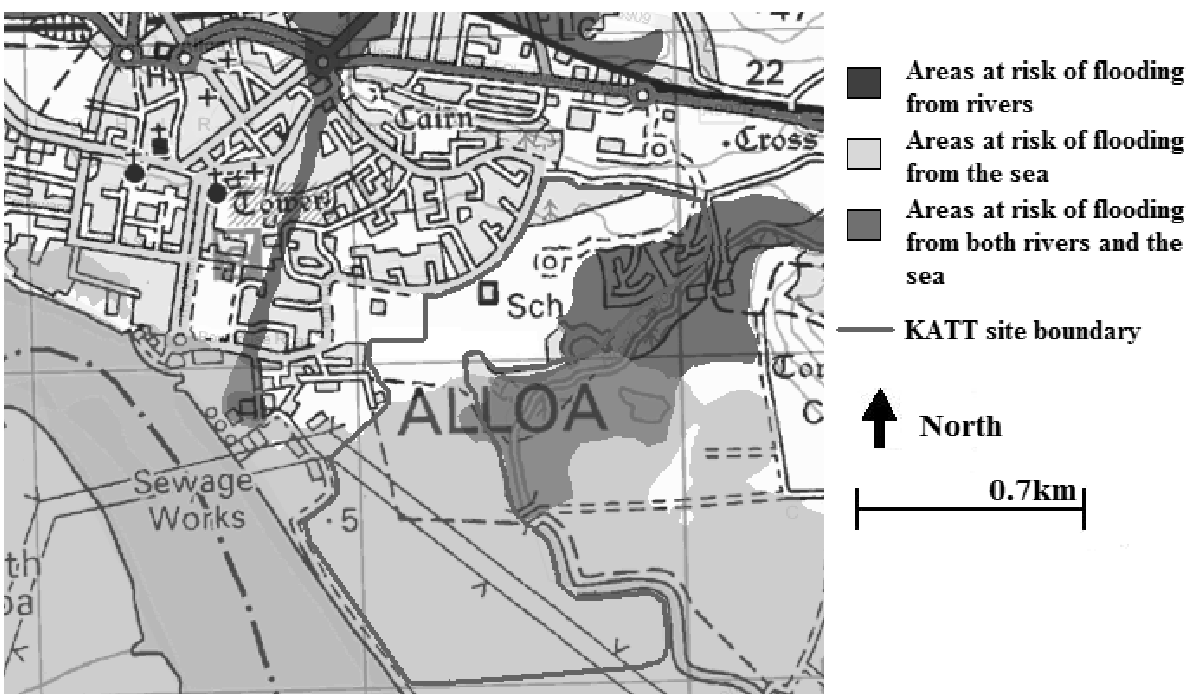

Figure 2. Indicative river and coastal flood map of Alloa, Clackmannanshire

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Utilisation of Eco-Waste Solution's Ltd By-Products

The transfer of steam from *Eco-Waste Solution Ltd* will occur in an underground pipeline system that connects all agricultural structures to optimise food production. The feeder pipeline between the two site boundaries is expected to be 400 m in length. The glasshouses are situated closest to the CHP plant to maximise heat transfer efficiency. After passing through the glasshouse the temperature drops sufficiently and the steam, now water, flows to a network of pipes that will heat the 25 ha of poly-tunnels. The cooled water once circulated through the poly-tunnels is then returned back to the system and recycled within the CHP plant forming a continuous cycle (figure 3).

KATT is looking to benefit from the carbon dioxide (CO_2) formed during the stages of methane (CH_4) combustion within the CHP plant. Natural gas is normally burnt in glasshouses to produce CO_2 to optimise crop yield**.** This has been highlighted as an unnecessary cost given that the CO_2 produced by the CHP plant has been identified as a viable and appropriate source. The reduction in carbon emissions should also be seen as a welcome innovative solution by *Eco-Waste Solutions Ltd*.

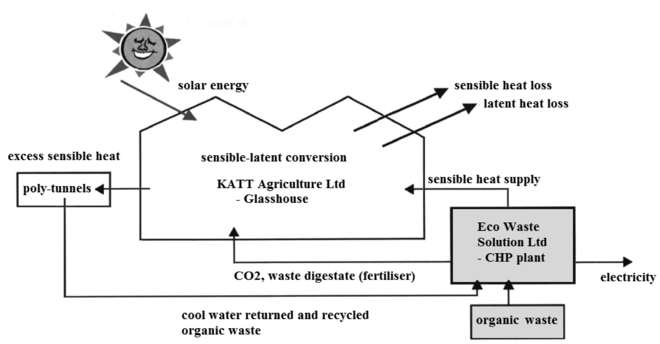

Figure 3. Symbiosis between KATT and Eco-Waste Solutions Ltd.

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Carbon dioxide is an additional useful by-product from *Eco-Waste Solutions Ltd* CHP plant as both an abundance of heat and CO_2 are required in optimum plant growth. Indeed the latter is widely used within the glasshouse industry to increase productivity. The addition of CO_2 can help to achieve 30 percent more marketable fruit and vegetables compared with crops grown in the absence of this method. It is seen as one of the key methods in achieving the high production rates of tomatoes (60 kg/ha) in the Netherlands. To achieve a 30 percent increase in yields, 56 kg/ha of CO_2 is to be dosed each hour to enrich the concentrations within the glasshouse to around 1000 v.p.m. (2.0 g/m^3) (Slack and Calvert. 1972). This equates to 168 kg per hour and 4032 kg of CO_2 each day for a 3 ha glasshouse. Waste digestate, a by-product formed within the CHP plant will also be utilised by KATT as it is a valuable fertiliser.

Gas capture would be conducted by *Eco-Waste Solutions Ltd* personnel on site and the subsequent gas transferred by pipe. This process would make the current practice of natural gas combustion to generate higher CO_2 concentrations obsolete. It should help reduce emissions from the CHP plant and cut the carbon footprint accordingly.

A Pioneer and Innovator of Scottish Agriculture

At KATT, the use of renewable sources to generate heat will not only improve energy security but also food security, as it enables seasonal production to become a 24 hour, 7 day a week process. This development improves the local availability and affordability of high value food products that currently are imported. Food production is set to grow by 70 percent to feed the additional three billion that will exist by 2050. If current estimates are correct the 2030 globe will require up to 50 percent more energy (Scottish Government, 2010). Such statistics place KATT in an increasingly important position, as the company and its competitors strive to generate food in a sustainable manner, whilst also increasing yields.

Responding to Demand: Glasshouses and Poly-Tunnels

Glasshouses (greenhouses) and poly-tunnels are a means of protecting crops from adverse weather conditions and uncertainty whilst securing farmers a stable income and a sustainable future. In 2004, Europe accounted for around 23 percent of the world's greenhouses. The majority of which are situated in Italy and Spain (Heuvelink, 2005). The Netherlands has around 10,000 ha of glasshouses which account for around 25 percent of the global total (Bot, 2001). The latter currently achieves around 60 kg/m^2 of tomato production compared to the Spain´s 28 kg/m2, despite lower levels of insolation (Heuvelink, 2005). Such high levels of growth rates are attained due to advanced technology such as well conditioned computer controlled glasshouses. They are not solely reliant on natural light intensity.

KATT identified the Netherlands as a source of inspiration for the high level of technology and food production. The company aims to bring sound technological practice and knowledge to Scotland. In 2004, the UK had a total of around 1,860 ha of glasshouses (Heuvelink, 2005). Scotland's use of glasshouses has been significantly lower than the rest of the UK. In 1982, they accounted for around 51 ha and by 2005 this figure had decreased to around 24 ha (Scottish Executive, 2006a). Tomato production, in particular has seen a synonymous decline. From 1982 to 2005 there has been a reduction in the land used by greenhouses to produce tomatoes from 28 ha to 3 ha respectively (Scottish Executive, 2006a). In Alloa, the glasshouse will contain tomatoes all year round whilst the poly-tunnels, given their structure will be predominately used for the seasonal growth of berries. In winter due to unpredictable weather and ground conditions they will be temporarily taken down.

On Site Renewable Energy Requirements

The Renewable Obligation (Scotland) Order 2007 commits Scotland to generate 18 percent of all electricity from renewable sources, rising to 40 percent by 2020 – a figure which was subsequently raised in September 2010 to 80 percent (BBC News, 2010). Some of this renewable energy will come from waste to energy facilities and it is expected that investments in such technologies will promote the national economy as stated in the government's Renewable Action Plan (Scottish Government, 2009). The potential of combining anaerobic digestion of organic waste to create energy, whether heat or electricity, should not be overlooked, particularly in the agricultural sector.

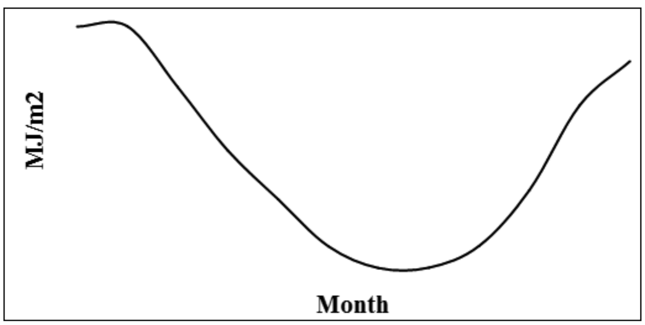

Figure 4. Energy required (MJ/m^2) to maintain a temperature of 21^{o}C during the day and 16^{o}C during the night in a glasshouse using average Leuchars, Scotland weather conditions (1971 to 2000)

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The production of sustainable high value food crops requires energy. The energy requirements for KATT's business operations (the glasshouse) are based upon a simple calculation model derived by Wass & Barrie (1984). The equation utilised data collected by the MET Office from 1971-2000 at Leuchars, Scotland. The whole process was calculated for each month and repeated 100 times with a resultant average calculated below. Figure 4 shows the annual variation of energy requirements during the whole year to maintain constant day and night time temperatures. The average annual energy required was calculated as 1448.8 MJ/m^2. The coldest temperatures experienced are in February and this results in an energy requirement of around 3000 MJ/m^2. KATT would like to ensure that the minimum baseline of 3000 MJ/m^2 is kept constant. During the summer months the energy demand to heat the glasshouse drops to around 500 MJ/m^2. Any excess energy that the greenhouse does not require would be diverted to the network of poly-tunnels used to grow berries.

Assuming initial waste heat estimations arising from the CHP plant are 24,997,350 kWh, an energy output of around 89,990,460 MJ could be produced. This suggests an approximate energy demand of 30,000,000 MJ/ha. Therefore the total output of 89,990,460 MJ, can sustain a glasshouse of 3 ha in size. Excess heat will be transferred to the network of 25 ha of poly-tunnels.

The equation used to calculate the glasshouse requirements is:

$$Q = A\ (U\ F\ (Ti - Ta) - K^* - Qg)$$

Where;

Q is the energy required to heat the greenhouse to maintain 21^{o}C during the day-time and 16oC during the night-time (MJ m-^{2})

A is the ground area (m^2) of calculated area

U is a heat transmission coefficient calculated using the following equation, where Ur is wind speed (m/s): $U = (5.82 + 0.375Ur) \times (Ti - Ta)$

F is the glass to floor ratio, assumed as 1.6 for all calculations

Ti is the internal temperature of greenhouse (K), 294K during day and 289K during night

Ta is the external temperature of greenhouse (K); assumes a random temperature based upon maximum and minimum monthly temperatures, with upper half being used for day-time calculations and lower half for night-time

*K** is the net short-wave radiation (MJ/m^2) using the following equation, where K is calculated as 0.75% (FAOUN. 1998) of daily sunshine hours, night-time value is assumed at -1.066 MJ/m2: $K^* = 0.46\ K - 1.066$

Qg is the ground flux of heat (MJ/m^2) from ground, structure and contents which was calculated using the following equation: $Qg = 0.152\ (Ti - Ta)$

Example calculation based on january data day

A = 1 F = 1.6 Ti = 294 Ta = 278

U = (5.82 + 0.375 x 5.865) x (294 – 278) = 128.31 where 5.865 is the wind speed (m/s), 294 = Ti and 278 = Ta

*K** = 0.46 (0.75 x 1.9) – 1.066 = -0.411 where 1.9 is the number of sunshine hours per day

Qg = 0.152 (294 – 278) = 2.432 where 294 = Ti and 278 = Ta

Day Q = 1 (128.31 x 1.6 x (294 – 278) – -0.411 – 2.432) = 3283 MJ/m^2

Night

$A = 1\ F = 1.6\ Ti = 289\ Ta = 274$

$U = (5.82 + 0.375 \times 5.865) \times (289 - 274) = 120.29$ where 5.865 is the wind speed (m/s), 289 = Ti and 274 = Ta

$K^* = -1.066$

$Qg = 0.152\ (289 - 274) = 2.28$ where 289 = Ti and 274 = Ta

$$Night\ Q = 1\ (120.29 \times 1.6 \times (289 - 274) - -1.066 - 2.28) = 2886\ MJ/m^2$$

An average is value between the *Day Q* and *Night Q* time results is calculated:

$$Average\ Q = (3283 + 2886) / 2 = 3084.5\ MJ/m^2$$

Internal Climate Control

Controlling the climate is an integral part of harvesting a reliable food product. There are a number of key elements that need to be addressed to achieve the desired climatic conditions.

- **Temperature** will be regulated at 21°C during the day and 16°C during the night. As previously discussed the temperature will be maintained via the use of heat from the *Eco-Waste Solutions Ltd* CHP plant. To help decrease the energy demand for heating the glasshouse, high insulating covers will be used. These covers must adequately manage temperature fluctuations (i.e. trapping thermal heat during the winter and preventing overheating during summers). Silica Aerogel is an excellent material for insulation due to its vast surface area and porosity, a single inch can insulate as effectively as 32 layers of glass (Insite, 2010).
- **Vapour pressure deficit**; the difference between the current air moisture and the maximum it could hold, is optimum at 4-8 millibars in relation to temperature and humidity for the growth of tomatoes (Heuvelink, 2005). Humidity can be regulated by implementing a series of cooling surfaces where condensation can occur, removing moisture from the air (Bot, 2001).
- **Air Circulation** is essential to maintain uniformity of climatic conditions throughout the glasshouse. Traditional fans are expensive to maintain due to high electrical demand. The glasshouse will be designed to implement natural circulation of air. The cooling surfaces (used to remove humidity) and heating pipes (heat from CHP) can also act as a method of encouraging natural air movement by creating temperature imbalances within the glasshouse (Bot, 2001).
- **Carbon Dioxide:** the addition of CO2 via a 400 m pipeline connecting the CHP plant to the site boundary to increase level concentrations will be constructed.
- **Innovative Computer Monitoring System**: to ease the management of climatic conditions, computers which analyse data inputs from sensors (temperature, humidity and CO2 levels) will be used throughout the glasshouse. The computer system can utilise a series of different models to calculate the operational costs and resultant yield to maximise productivity for the growth of the tomato crop (Bot, 2001).
- **Electricity Demand** within the glasshouse is low. The cooling surfaces designed to remove excess air moisture content and the computer monitoring system which controls climate have the highest requirement. These two technologies are essential for modern glasshouse tomato crop production.

Reducing Nutrients, Pesticides & Water Demand

For the agriculture sector cutting carbon is only one of the challenges of climate change. Other greenhouse gases, including two of the most potent- nitrous oxides and methane are prevalent within agriculture. Other practices such as the application of pesticides and water abstraction for irrigation can be equally damaging to the environment.

For the growth of one tonne of tomatoes around 2.5 kg of nitrogen is required assuming a 75 percent root up-take. In order to achieve three harvests per annum, tomatoes, require 45-55 kg/ha of phosphorus during the early stages of growth.

Potassium, essential for fruit colouring, taste and firmness, should be applied at 2.9-4.2 kg per tonne (Heuvelink, 2005). All nutrients could have a negative impact should they be introduced into the surrounding environment.

KATT will utilise waste digestate produced from the *Eco-Waste Solutions Ltd* CHP plant as a fertiliser. In the first year of fertilisation, 37.5 tonnes of waste will be required per hectare for both the glasshouse and poly-tunnels. To fully fertilise the combined 28 ha of agricultural land, 1050 tonnes be required. After the initial application only 18.75 tonnes/ha are required per year, equating to 525 tonnes for the full 28 ha (Hargreaves, Adl, & Warman, 2008).

KATT, naturally concerned about the application of nitrogen based fertiliser due to its contribution to atmospheric nitrous oxide concentrations – a gas 310 times more potent than carbon dioxide, goes beyond legal compliance in its creation of a *Fertiliser Management Plan* as identified in *The Action Programme for Nitrate Vulnerable Zones (Scotland) Regulations 2008*. In addition, due to KATT's commitment to the environment, BAT nutrient re-circulating systems will be implemented within the glasshouse. Such systems have been shown to decrease the cost of fertiliser by around 30-40 percent whilst the recycling of water can reduce usage by around 50-60 percent (Heuvelink, 2005) —also diminishing the likelihood of leachate into the surrounding environment.

Typically irrigation within glasshouses growing tomatoes ranges from 1-5 l/m^2 (Heuvelink, 2005). KATT will implement rainwater catchers on the roof to utilise rainfall to irrigate crops within. Water use within the poly-tunnels for soft berries such as strawberries, varies from 1,500-2,300 m^3/ha within the UK and is highly dependent upon climatic conditions (Federal Department of Economic Affairs [FDEA], 2009).

Water is continuously monitored and adjusted before being recycled into the glasshouse. Electrical conductivity, pH and less frequently a chemical analysis of the water is also undertaken. Water is only released whenever the sodium ion concentration reaches the crop threshold, which in the case for tomatoes is 8 mol/m^3. This leads to a ratio of around 20-30 percent between water supply and drainage (Massa et al., 2011).

Prevalence of pesticides within the agricultural sector is heavily associated with adverse impacts on the natural environment. Accordingly, KATT is minimising dependency and will strive to implement the following measures as a sustainable alternative (International Finance Corporation [IFC], 2007):

- Using naturally pest resistant strains of tomatoes and berries.
- Mechanical weeding systems.
- Use of, protection and promotion of beneficial organisms such as insects, birds, mites that provide a natural biological control.
- Use of mechanical controls such as traps, barriers, light and sound to inhibit pests.

Working with Waste

The Scottish Government, as part of the Zero Waste initiative, is predominately concerned with waste prevention and minimisation in preference to waste recovery. Waste to energy installations are however extremely important in diverting waste away from landfill not least due to the reduction of methane emissions, one of the principal gases involved in global warming. Scotland's quota of this gas stems from waste and agriculture - at 29 percent and 51 percent respectively (Scottish Executive 2000, 2011).

Zero Waste Scotland was developed in response to targets set in *Climate Change (Scotland) Act 2009* where the precautionary principle was applied:

> Over 2 million tonnes of food waste is produced every year from all sectors in Scotland. If just half of this food waste was captured and treated through anaerobic digestion, the electricity generated could power a city the size of Dundee for six months, provide heat for local homes and businesses and produce enough fertiliser for ten percent of Scotland's arable crop needs. This is just one example of how the move to a zero waste society will create real environmental benefits, new economic opportunities and contribute to the creation of green jobs in the Scottish economy.

In relation to KATT specifically, the consortium can provide, if necessary, some of the biomass material to supplement the *Eco-Waste Solutions Ltd* biogas process. These additions will also serve to safeguard business operations by ensuring efficiency whilst sustaining a constant flow of gas. It is also logical to assume that in solving business needs one is also meeting those of the surrounding community. KATT will effectively remove its waste burden from Alloa before the ban on organic waste entering landfill is implemented in 2015 according to the Draft Low Carbon Scotland Proposal and Policy.

Further waste reductions for Alloa and local surrounding residents could be realised if household waste is segregated and managed appropriately by *Clackmannanshire Council*. The organic component, for instance could be collected and diverted into the *Eco-Waste Solutions Ltd* system rather than being disposed of in landfill which can cause various environmental issues especially regarding methane gas and water pollution caused by the generation of leachate (Jones, Williamson, & Own, 2006; Dijkgraaf & Vollebergh, 2004). Landfill disposal means residents would be paying twice – for the initial disposal and for the clear-up operation. It is obviously beneficial to deal with the waste in a manner that generates heat which can be immediately utilised locally.

Studies suggest that around 1.5-4.4 percent of tomatoes produced end up as organic waste (Riggi & Avola, 2008). With an assumption that tomato production will be 60kg/m2, the annual production of waste will be around 27-79.2 tonnes. Assuming that the 25 ha of poly-tunnels is used to produce strawberries with an annual yield of 1.5-2.3 kg/m3 (FDEA, 2009), this will generate 5.6-25.3 tonnes of organic waste. Combining both waste produced within the glasshouse and poly-tunnels results in total annual organic waste output of 32.6-104.5 tonnes.

Conclusion

The potential symbiosis between *Eco-Waste Solutions Ltd* and the KATT arable farmers consortium has been identified as a viable and sustainable option from a technical perspective. It has added the benefit of promoting the local economy and supporting Scottish governmental policy and targets. This paper also provides a strong foundation for subsequent reports and investments such as the Environmental Impact Assessment and the acquisition of Best Available Techniques which will serve to further protect local interests and the global environment.

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