The impact of tightening wastewater treatment drivers on sludge processing and its carbon impact

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Around the world, the production of sewage sludge is increasing. This is due to a growing population, movement of a fraction of this population to cities being connected by new sewage treatment facilities (as occurring in China), and also to a tightening of environmental regulation surrounding wastewater treatment. A study in the UK found that implementation of stricter environmental standards had a negative impact on energy consumption and consequent carbon impact. Reducing the BOD in the final effluent from a figure of 25 to 5 mg/l increased the energy required by the process by three times. The UK Environment Agency recently released a report saying that implementation of legislation like the European Union's Urban Waste Water Treatment Directive (UWWTD – 91/271/EEC) and the Water Framework Directive (WFD - 2000/60/EC) would increase the carbon footprint of the entire Water industry by nearly 3%. It further concluded that the carbon impact of several works would have to double to meet new wastewater drivers. The Water Industry is a large consumer of power and subsequently a large generator of green house gas emissions. In the UK, the Water Industry carbon footprint accounts for over 1% of the nations emissions and is only second to the power industry. Therefore, any legislation which could increase the impact of the Water Industry's carbon footprint has an inherent influence on a nation's carbon emissions. A trade-off therefore exists between improving the local environment whilst minimising impacts at a global scale.

In Europe, the implementation stricter aquatic standards, is resulting in configuration changes in wastewater treatment. As facilities upgrade to total nitrogen removal, primary sludge is often being used as a supplemental carbon source for denitrification. Not only does this remove easily biodegradable BOD from the sludge treatment train, it also decreases (or eliminates) the quantity of primary sludge produced as it is replaced by an increasing concentration of secondary sludge. Additionally, upgrading secondary treatment from carbon removal to nitrification results in increasingly extended aeration times during secondary treatment. Whilst it is well known that secondary sludge digests far poorer than that produced during primary treatment, recent work has shown that its digestibility degrades further as aeration time increases. Furthermore, phosphorous removal, using chemicals such as iron or alum, also generates larger quantities of sewage sludge but with decreasing calorific value. In summary, not only do tightening wastewater standards increase energy consumption in their acquisition, but they are also influencing the production and type of sewage sludge being produced. This sewage sludge is becoming increasingly difficult to process resulting in additional negative impacts on: renewable energy generation via digestion; dewatering and thermal processing. This paper highlights the results of modelling work which describes how the production of sludge alters with differing wastewater drivers, and what the potential impacts are for downstream processing of the sludge and its influence on carbon footprint.

Introduction

It has eventually and sometimes reluctantly, become understood that climate change is directly influenced by the anthropogenic release of what are known as "Green House Gases – GHGs". Their release into the earth's atmosphere has been correlated with an increase in global temperature which in turn, has been linked to weather change with potentially catastrophic impacts (ICCP, 2001). With such significant global impacts expected, it is therefore no surprise that a great deal of interest is being shown in tackling climate change. In Australia, to much local disapproval, the first tax on carbon has been proposed and will be implemented in July 2012. From that point onwards, any carbon emitted into the atmosphere will be initially taxed at a rate of $23/tonne with the introduction of a trading scheme after three years.

GHGs have been classified by the Intergovernmental Panel on Climate Change (IPCC), and include: carbon dioxide; methane; nitrous oxide; tetraflouromethane; sulphur hexafluoride; HCFs; CFCs, and other compounds. Carbon is continuously cycled between reservoirs in the ocean, on the land, and in the atmosphere, where it occurs primarily as carbon dioxide. The largest reservoir is the deep ocean, which contains close to 40,000 Giga tonnes (Gt) C, compared to around 2,000 Gt C on land, 1,000 Gt C in the upper ocean and 750 Gt C in the atmosphere (The Met Office, 2007). Therefore, a quasi-equilibrium exists as carbon is exchanged between these sinks. For example, plants absorb carbon dioxide from the atmosphere by photosynthesis, and it is returned via respiration. In these instances, carbon dioxide released to the atmosphere is considered “short-cycle” and thus is not counted as influencing climate change. This is because the carbon dioxide has been recently absorbed from the atmosphere and then returned, therefore there is no overall increase in atmospheric carbon dioxide. However, this does not apply to carbon dioxide release from sources where the carbon has been fixed over a long period of time. When fossil fuels are burnt, the carbon dioxide released is generated from carbon which has effectively been inert and not contributory to the carbon cycle equilibrium for many millions of years. Here, the carbon dioxide released increases the atmospheric concentration and is considered influential towards climate change. Carbon dioxide released in this fashion is termed “long-cycle”.

The biggest source of long-cycle anthropogenic carbon dioxide pollution is electric power generation from fossil-fuels, especially coal. Being carbon-rich, coal generates 70% more carbon dioxide per unit of energy produced than natural gas (Ashton, 2005). This is especially relevant in Australasia where most energy generation is from coal. In fact, it has been published that the power sector is responsible for 37% of all anthropogenic CO_2 in the UK (Ashton, 2005). Therefore, there is an implicit link between power consumption and carbon footprint. From various reports (NGER, 2010; Water UK, 2007), the Water Industry is a heavy consumer of power and resources. Water UK (2007) highlighted that the UK Water Industry, which consists of only 23 companies, accounts for 3% of all power consumed and nearly 1% of the UK’s entire carbon burden (Environment Agency, 2009a) Based on current data, this is equivalent to a carbon generation of 80 kg CO_2/person. Approximately 56% of emissions from water companies come from wastewater treatment, 40% from supply and the remainder from administration and transport (Environment Agency, 2009a). Of the fraction coming from wastewater treatment the vast majority comes from power costs for aeration systems and pumping (Soares, 2008).

Carbon footprint data for Australian companies is reported under the National Greenhouse and Energy Reporting (NGER) guidelines. In accordance with section 24 of the NGER Act, data is provided on companies whose total Scope 1 (direct emissions of greenhouse gases due to activities conducted by the company) and Scope 2 (indirect emissions due to power consumption) gases due to activities of the company) greenhouse gas emissions are above the 2009-10 threshold of 87.5 kilotonnes. (NGER, 2010). With respect to water and wastewater treatment reported sources of Scope 1 emissions include: nitrous oxide during denitrification; methane leaking from anaerobic digestion systems and infrastructure, methane release due to incomplete or inefficient combustion during co-generation, methane release during storage or lagoon treatment, methane release during landfilling of biosolids, and nitrous oxide release during incineration. Carbon dioxide is also released during numerous processing steps, especially during aeration, but it is considered short cycle and therefore generally not counted towards the determination of carbon footprint.

Figure 1 shows Scope 1 and Scope 2 emissions for Australian Water Companies which exceed the threshold limit under the scheme.

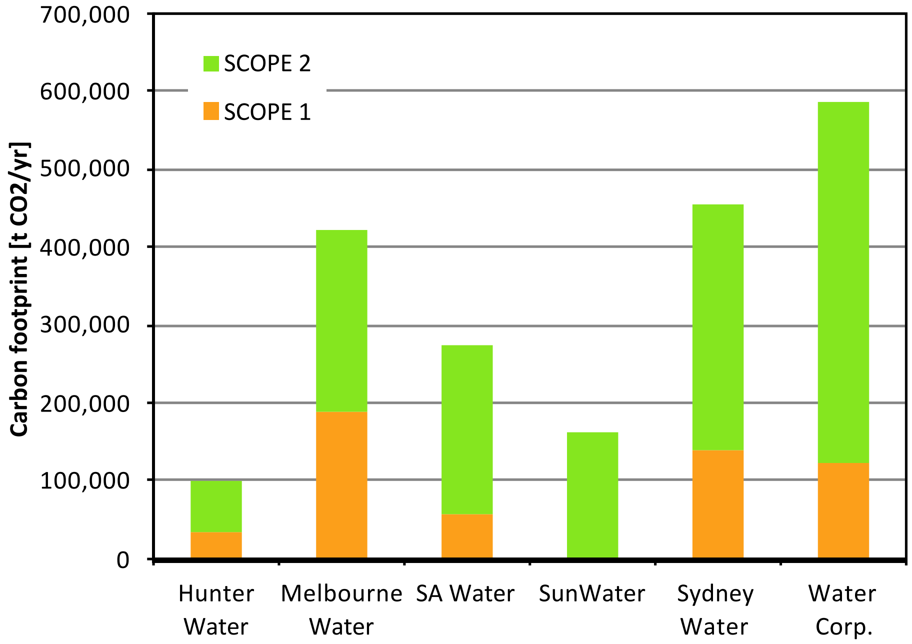

Figure 1. Scope 1 (orange) and 2 (green) carbon emissions of large Australian Water Companies

The data total approximately 2,000,000 tonnes of carbon dioxide per year excluding the companies who do not report under the scheme. Average carbon impacts range between 100 – 160 kg CO_2/population. The data appear high when compared to the UK, which has a carbon footprint of close to 5,000,000 tonnes but this is generated to provide treatment to over three times the population. As can be seen from Figure 1, the vast majority of the carbon emissions are Scope 2, i.e. from power consumption. Data from Sydney Water shows that power consumption accounts for nearly 70% of its emissions with 80% of that total coming from wastewater treatment and pumping. An obvious explanation of the higher data is that Australia gets most of its energy from coal, which has a high carbon emission, whilst the UK has a cleaner energy mix. However, this difference alone cannot account for the majority of the difference. With respect to power consumption, process configuration plays an important role. Aeration systems are popular in Australia primarily due to benefits associated with nutrient removal; however they have high energy consumption requirements to provide the oxygen required for treatment. Additionally, a large number of facilities have no primary sludge treatment (compared with the UK), so as to provide a carbon source for nitrate removal via denitrification. By removing primary treatment additional load goes to the secondary stage which therefore requires more oxygen (and inherent power and carbon) to treat. Removal of primary treatment has other impacts. Recent work by the University of Queensland (Batestone, 2011) has shown that anaerobic biodegradability of sludge decreases the more it is aerated. As legislation tightens, longer aeration times required by nitrifying organisms are necessary resulting in production of sludge which increasingly poor digestability characteristics. As well as digesting poorer than primary sludge (Winter and Pearce, 2010), aerated sludge also contains approximately a fifth less energy, meaning that even if digestability were improved there would be less potential for co-generation. Furthermore, work done by Melbourne University has shown that there is an implicit link between the production of extracellular polymers and dewatering potential (Scales, 2009), and that production of extracellular polymers was further linked to bacteriological activity which increases with aeration. The poor dewaterability of activated sludge has been well publicised (Evans, 2006) however, trials in the USA have shown that dewaterability of identical sludge before and after aeration resulted in a drop in performance (Murthy *et al*., 2010). As a consequence of increased energy demand and reduced co-generation due to aeration, Water Companies in the UK are looking at ways to enhance primary removal to assist with reducing their carbon impacts.

The increased production of activated sludge due to tightening of environmental standards is one of many factors which impacts carbon footprint. Subsequently meeting the requirements of various legislation such as: the Urban Wastewater Treatment Directive (91/271/EEC) The Water Framework Directive (2000/60/EC) in Europe; the Water (2007) and Water Amendment (2008) Acts (in Australia); and Resource Management Act 1991 (in New Zealand) creates a unique challenge for Water Companies to balance the benefits of local environmental improvements against the potential disadvantages of increased global carbon footprint. The potential impacts of this have been studied before. In the UK, the Environment Agency working with the Water Regulator and other key stakeholders has been leading efforts to quantify the likely carbon impacts which would result from implementation of the Water Framework Directive (Environment Agency – A low carbon water industry). The report concluded that, without intervention, the Directive would increase the industry's carbon emissions by 110,000 tonnes per year which is an increase of 2.2%. However, it was additionally observed that, whilst that figure may appear small, it would more than double the emissions of some individual works.

This paper presents results of a model developed to quantify the carbon footprint impacts of wastewater and biosolids treatment due to tightening legislation. A number of scenarios are modelled to meet various legislative targets. Based on these scenarios, aeration requirements are determined along with quantity and type of sludge produced. This data is then used to determine impacts on downstream anaerobic digestion and haulage for a number of biosolids recycling options.

Methods

Generally, the vast majority of the work involved in determining carbon footprints entails calculating the inputs required for carbon modelling. The inputs (e.g. power; transport; chemical consumption; quantity and type of building material used) are then multiplied by emission or conversion factors. The most well-known attempts to determine a Water Industry carbon footprint in the UK were made by UKWIR, which has developed a model entitled "Workbook for Quantifying Greenhouse Gas Emissions" (2005). The model includes Water Industry-specific data involving emissions of GHGs from wastewater treatment and application of sewage biosolids to land. The model has been the foundation for further work on carbon calculating (Entec UK, 2006). Since then, UKWIR is in the process of updating the workbook with revisions and additions, such as inclusion of embodied carbon calculating. This work is currently ongoing. The UKWIR model was used as the basis of this work, but with a number of modifications and additions (Barber, 2009). Sludge yield calculations were made using the kinetic and stoichiometric models presented by McCarty (1966, 1971), and these are shown in Figure 2.

For the purpose of this exercise the following scenarios were modelled:

Table 1. Modelled Scenarios

Scenario	1	2	3	4*
BOD [mg/l]	25	10	5	10
NH_4 [mg/l]	30	5	1	5
P [mg/l]	10	2	1	2
SS [mg/l]	35	10	10	10

* Scenario 4 is the same as scenario 2 except that primary treatment has been excluded in order to determine the impact of primary treatment.

A baseline plant treating 100,000 population equivalents was assumed with the daily loading rates presented in Table 2. The baseline also assumes anaerobic digestion with co-generation followed by land application of the biosolids. For the purposes of transport, a distance of 50 km has been assumed. Finally, coal is used to generate electricity.

Table 2. Daily loading rates

BOD	[kg/d]	6500
TSS	(kg/d)	7000
NH_4	(kg/d)	900
tP	(kg/d)	230

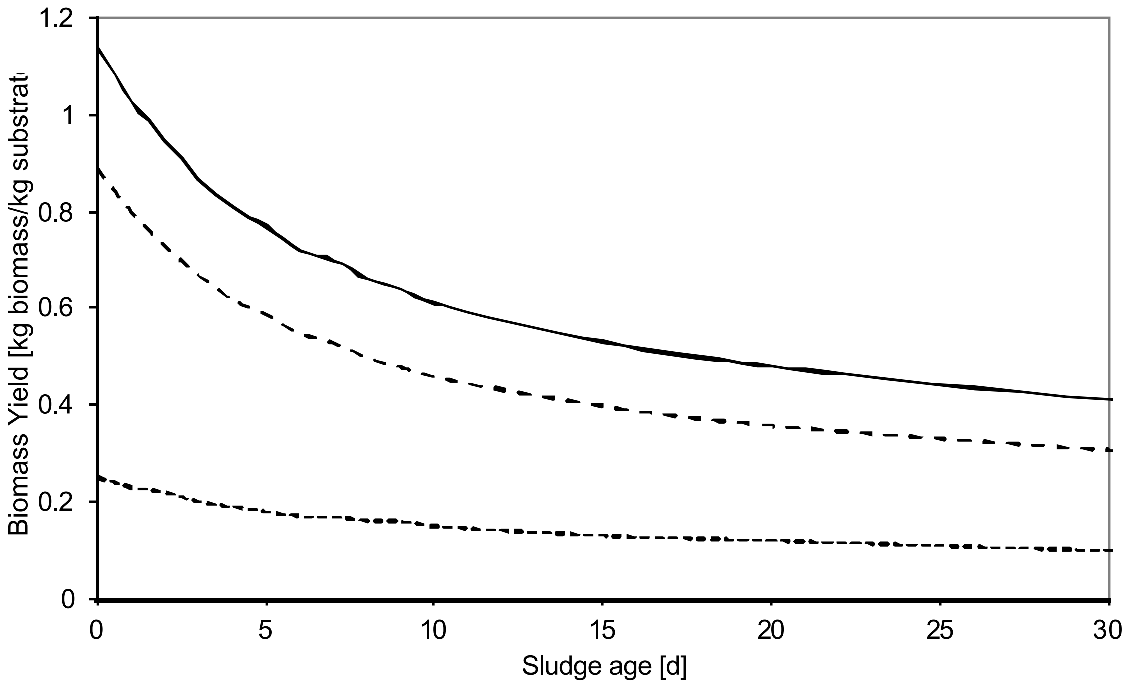

Figure 2. Impact of sludge age on biomass yield. Total biomass (full-line); carbonaceous biomass (dashed line); nitrifying biomass (dotted line).

Results

Figure 3 shows the operating carbon footprints for Options 1 to 3. The figure shows that as treatment levels increase so does the carbon footprint. This is consistent with previous findings which showed up to a threefold increase with tightening standards (UKWIR, 2002). Another study (EA, 2009b), looking at use of sand filters to remove nickel observed an order of magnitude increase in carbon footprint as it was removed to levels below 2 EQS. It was hypothesised that this could be due to increased competition for active sites from other substances. In terms of this study, tightening effluent standard from carbonaceous to one requiring nitrification increases carbon footprint by nearly 2.5 times, and by 3 times when phosphorous removal is added. Figure 4 shows the breakdown of the carbon footprints to show where the differences are realised.

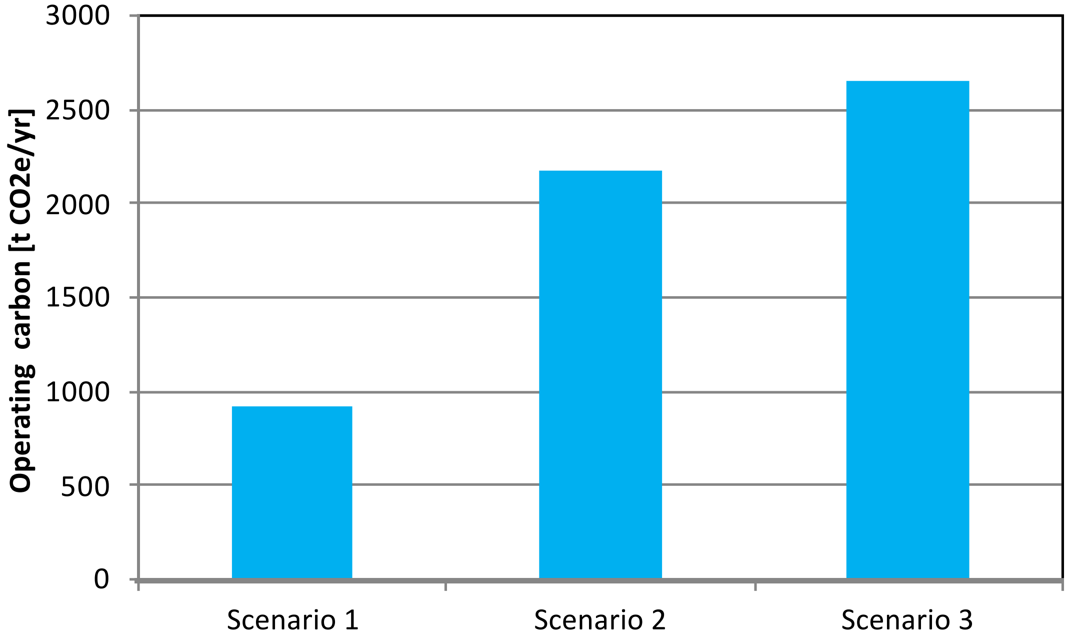

Figure 3. Operating carbon footprint of Scenarios 1 to 3.

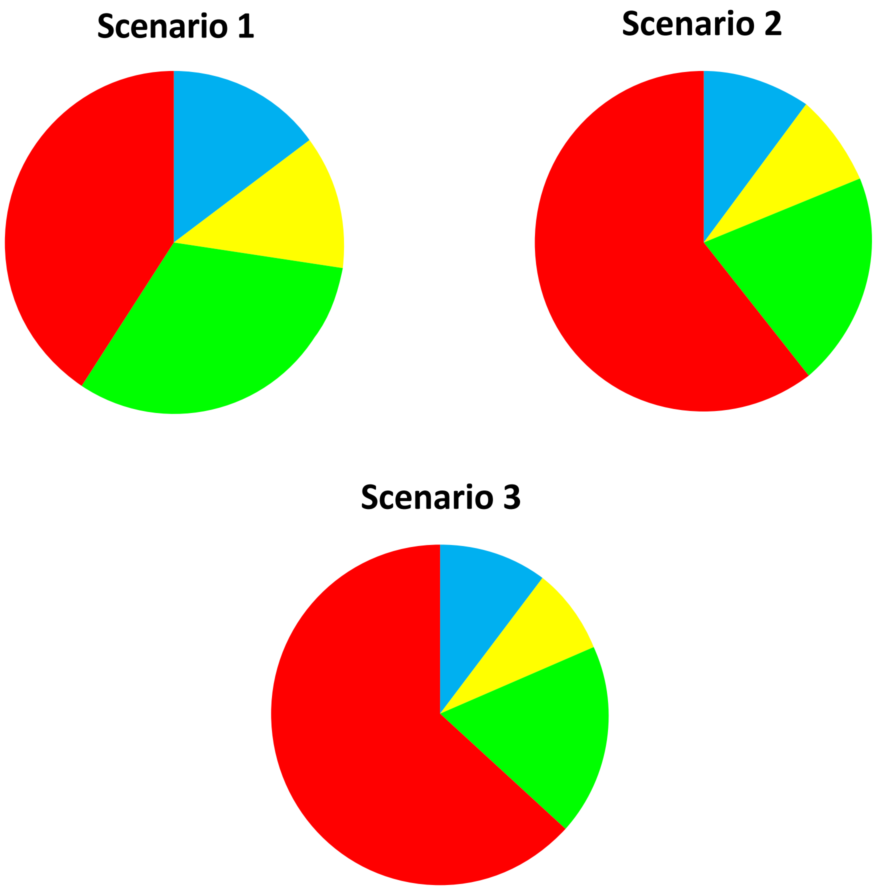

Figure 4. Breakdown of carbon footprints for options 1 – 3. Key: aeration energy (red); dew atering (inclusive of energy and polymer – green); biosolids transport (blue); and land application emissions (yellow).

Aeration is by far the greatest contributor to carbon footprint and contributes between 40% to between 60 – 70% for Scenarios 1 – 3. As less aeration is required in Scenario 1, the other factors become more influential with dewatering being the next influential contributing a third of the footprint. Land and transport emissions are less significant. As treatment standard tightens, aeration becomes more influential and the other factors less so. Nevertheless, dewatering remains the second most influential parameter.

As previously mentioned, a fourth scenario was modelled which was identical to option 2 apart from the fact that primary treatment was bypassed to enable nutrient removal. Figure 5 compares the carbon footprints of Options 2 (with primary treatment) and 4 (without).

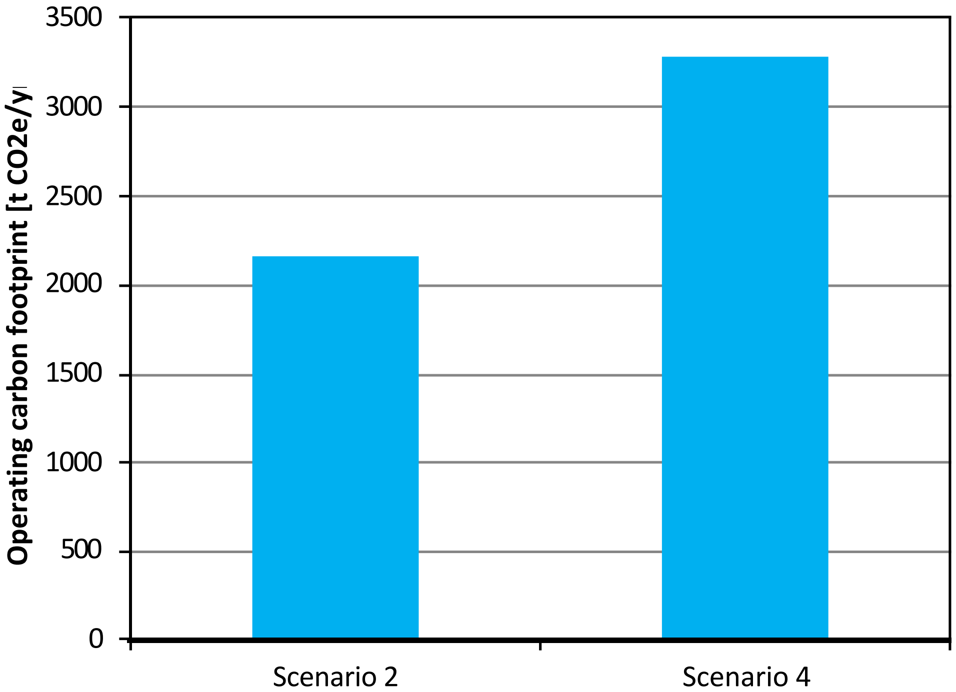

Figure 5. Influence of removing primary treatment. Scenario 2 (with primary treatment); Scenario 4 (without primary treatment).

The graph shows an increase of approximately 50% in carbon footprint when primary treatment is removed. A closer look at the data reveals that the increase is due to increased aeration requirements (55%of the increase) and lost biogas benefits (45%). This would suggest that the carbon in sludge can reduce carbon footprint of wastewater treatment than purchasing a carbon source can increase it.

However, Scenario 4 produced far less biosolids than Scenario 2 due to the extended aeration times required which further destroy biomass by endogenous respiration and the lack of primary sludge. When the carbon results are normalised to account for this they change to: 0.8 and 2.4 tonnes CO_2e/t biosolids produced. This is an increase of 3 times. This highlights the impact of primary treatment removal, as the carbon footprint is worse even though much less biosolids are produced.

The results show that tightening effluent standards have a detrimental impact with respect to carbon footprint. As well as this, a previous study (UKWIR, 2007) has shown that capital costs double in price when effluent BOD is tightened from 25 to 5 mg/l. However, there are a number of other parameters which also influence the combined carbon footprint of wastewater and biosolids treatment. These include: type of carbon source used;

configuration of activated sludge plant; use of intelligent control systems (which have seen reductions in energy content of approximately 30%); use of pre-treatment to improve the biodegradability of the activated sludge produced

Conclusions

A model was set up to determine the carbon impacts of tightening wastewater treatment standards on wastewater and biosolids treatment. The results are as follows:

- Tightening standards result in an increase in carbon footprint. Going from carbonaceous treatment to nitrifying increases carbon footprint by between2 and 3 times. This increases further as phosphorous removal is included;
- The vast majority of the carbon footprint is due to aeration which accounts for approximately 2/3rds of the combined footprint of treatment inclusive of biosolids digestion, treatment, transport and application;
- Removal of primary treatment increases carbon footprint of an identical facility in the region of 50%. However, when this is normalised for biosolids production, the increase in carbon footprint is almost three-fold.

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