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Carbon Footprint of Agricultural Development: the Potential Impact of Uptake of Small Electric and Diesel Pumps in Five Countries in Sub Saharan Africa

Catherine Sugden

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Catherine Sugden

Stockholm Environment Institute
Kräftriket 2B
SE 106 91 Stockholm
Sweden

Tel: +46 8 674 7070
Fax: +46 8 674 7020
Web: www.sei-international.org

Head of Communications: Robert Watt
Publications Manager: Erik Willis
Layout: Richard Clay

Cover Photo: Farmer filling irrigation basin by small motorpump in
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EXECUTIVE SUMMARY

This pilot study aimed to compile a first estimate carbon footprint resulting from the current and potential operation of smallholder diesel/electric water irrigation pumps in the next 10-15 years for five Sub Saharan African countries including; Burkina Faso, Ethiopia, Ghana, Tanzania and Zambia. The rationale behind this study was a statistic published by Shah (2009) which stated that four to six per cent of India's carbon dioxide emissions resulted from the use of these pumps. All agricultural development potentially has both positive and negative impacts; this study will contribute to the overall understanding of what impacts may be associated with the mechanisation of smallholder farming in various Sub Saharan countries beyond water abstraction for irrigation.

This study followed the methodology used by Nelson and Robertson (2008) when estimating carbon dioxide equivalents for smallholder irrigation pump use in India, but assuming all pumps are diesel powered and below 10 horsepower. The results of this study suggested that in contrast to India the emissions from water irrigation pumps were not and are not likely to become a significant proportion of the countries carbon dioxide emissions. The emissions from pumps in 2010, in all cases were significantly less than one per cent of the country's current agricultural sector emissions. Furthermore, even with the development of a hypothetical scenario in which every smallholder is a pump user the resultant carbon dioxide emissions were still less than one per cent of the current agricultural sector total.

However, cross checking the water abstraction rates for these pump numbers suggested that water resources (using the renewable national water resources as an indicator) are much more likely to be of environmental concern, especially at the local level. Further suggestions to improve these estimates are to ensure better monitoring of farmer adoption rates, and possibly consider ways of improving pump efficiency. This would benefit both the farmer and the environment, as a shift to other energy sources (hydropower electricity and coal electricity) may affect the estimated carbon dioxide values presented in this report.

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Acknowledgements

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1 INTRODUCTION

Smallholder farming systems are undergoing fast improvement in many developing countries. One identified pathway to improve these farming systems is the adoption of small-scale diesel or electrical pumps that enable farmers to grow more valuable crops such as vegetables and off season crops, and sometimes generate income due to their rental to neighbouring farmers. In the AgWater Solutions Project, national consultations in several countries identified small pumps as a major agricultural water management pathway to enhance smallholder production and income. However, some concerns have been raised that this adoption may also be associated with environmental impacts such as indicated by Shah (2009), which stated that around 4-6 per cent of India's total carbon emissions were as a result of smallholder irrigation pumps.

The purpose of this study was to supplement ongoing contributions by the StockholmEnvironment Institute (SEI) to the AgWater Solutions Project led by the International Water Management Institute (IWMI). The study's focus was smallholder diesel/electric irrigation pumps in several Sub Saharan African countries: Burkina Faso, Ethiopia, Ghana, Tanzania and Zambia. This was a pilot study that aimed to make a first estimate of the carbon footprint associated with the current use and a potential estimate of adoption of these pumps within the next 10-15 years, using a method applied by Nelson and Robertson (2008).

There are approximately 33 million small farms in Africa (Nagayets, 2005)and historical trends suggest that small farms will continue to dominate the agricultural landscape in the developing world especially in Africa for at least the next two to three decades (Nagayets, 2005). Irrigation on these small-scale farms in most Sub Saharan African countries is starting to shift towards a system based on motorised pumping (Baba, 1993). Thus due to the huge number of smallholder farms and the possibility of a large scale adoption of these technologies, smallholder pumps may potentially become a sizeable contribution to Africa's total greenhouse gas emissions as has been the case in India. Nonetheless no study has been done specifically on this topic to date.

The scope of this study was to include all smallholder farmers cultivating approximate land area of five hectare or less. There are various definitions of smallholder that include variable land sizes for example the Tanzanian Government Website defines smallholder farmers as those cultivating an average farm size of between 0.9 ha and 3.0 ha each whereas Cornish (1998) refers to a smallholders land area as five hectare or less. However, taking into consideration data constraints the second definition emerged as the most appropriate for this study. This study also intended to include all pumps that are 10 horsepower or less; it was proposed by doing so this would incorporate all pumps owned/rented both individually and communally (De Fraiture, 2010). Finally, the scope of this study was to include only the carbon and carbon dioxide emissions resulting from the operation of the pumps. The results do not include other ensuing greenhouse gas emissions or - carbon dioxide from processes related to the manufacturing of the pump or energy supply.

2 BACKGROUND INFORMATION

In India the adoption of motorised irrigation pumps began in the 1970s (Shah, 2009). Shah (2007) stated that motorised pumps revolutionised irrigation agriculture in India and dubbed the period 1975-2000 the ‘Golden Age’ of smallholder irrigation in India**;** however their overall growth peaked in 1986-7 (Scott, 2009). Electricity is the major energy source for pumps in India.

In contrast to India the adoption of motorised pumps in Sub Saharan Africa began later. The adoption of pumps was mentioned in literature with reference to Sub Saharan Africa in the early 1990s for example Baba (1993, p.47). However in some parts of Sub Saharan Africa, for instance Zambia, the development from treadle pumps to motorised pumps was not seen until the early 21st Century (Kodamaya, 2008).

Unlike India where electricity is an option in many rural parts, it is rarely so in Africa and electric pumps are rarely available (Carter and Howsam, 1994). The adoption of these diesel pumps in many countries has been facilitated by the countries governments. For example the Zambian Government in 2008/9 removed taxes on agricultural equipment including water pumps (FASAZ, 2009) and the Ethiopian Government has allowed the import of thousands of pumps free of custom duties, sur-tax, VAT and withholding tax (Tadesse, 2010, p.20). There is also evidence that the adoption of these technologies is desired by the farmers themselves. Interviews of farmers in Tanzania proved that many currently using buckets and treadle pumps have a strong desire for motor pumps and almost all the farmers interviewed said that when they could afford a pump they would invest in one (Keraita *et al.*, 2010).

Another difference between India and Sub Saharan Africa is that the vast majority of pumps in Sub Saharan Africa are imported rather than manufactured locally. Pumps are most commonly imported from China, Japan and India (Keraita *et al.*, 2010; Perry 1997). The most common brands of pumps in Ghana for instance include Honda, Yamaha, Agromec and Maturs (Namara, 2009). Currently pumps in Sub Saharan Africa are commonly targeted at high value crops such as okra, tomatoes, fruits etc.

3 METHODS

The methodology used in this study closely mirrored that used by Nelson and Robertson (2008) and partially by Shah (2009) when calculating the carbon emissions from the use of smallholder pumps in India. Nelson and Robertson's method involved first calculating the separate carbon emissions from a diesel and electric pump when pumping 1000 m^3 of water over one metre. This knowledge was subsequently applied to data regarding the total water abstraction and the depth over which the water was pumped; this gave the total carbon emissions from water irrigation pumps in India. Finally, Nelson and Robertson (2008) compared their results to the total country carbon emissions; this gave an indication of the contribution from water irrigation pumps to India's overall carbon footprint.

Carbon release when lifting 1000 m^3

The first step in this study in accordance with Nelson and Robertson's method was to calculate the carbon released by a pump lifting 1000 m^3 of water over one metre. It was assumed that there were very few electric pumps in Sub Saharan Africa due to the lack of rural electrification; hence it is important to note that the amount of carbon released by pumps in this study was only calculated for diesel powered. Nelson and Robertson calculated the carbon released as follows: they stated that one litre of water weighs one kilogram and therefore 1000 m^3 of water weighs 10^6 kg. The energy requirement to lift this mass is accordingly:

$$10^6 * 9.8\ \text{m/s}^2 * 1\text{m} = 9{,}800{,}000 \text{ or } 9.8*10^6\ \text{J} \quad (1)$$

(9.8 m/s^2 is the acceleration due to gravity)

This was then converted to into kilowatt hours (kWh). Next they stated that a watt measures the rate of energy usage and one watt is equal to one joule per second and therefore one kilowatt hour is:

$$1000 * 1\text{J/s} * 3600\text{s/hour} = 3{,}600{,}000 \text{ or } 3.6*10^6\ \text{J/kWh} \qquad (2)$$

Using the above information, the joules needed to lift 1000 m^3 of water one metre can be converted into kilowatt hours by dividing the answer from equation (2) by that of equation (1):

$$(9.8*10^6\ \text{J})/(3.6*10^6\ \text{J/kWh}) = 2.722\ \text{kWh} \qquad (3)$$

Therefore, according to Nelson and Robertson (2008), 2.722 kWh referred to the energy required to lift 1000 m^3 of water one metre if a pump operated at full efficiency. Once the energy requirement had been calculated this was converted into carbon emissions. To convert the energy requirement to pump 1000 m^3 of water one metre into carbon emissions Nelson and Robertson (2008) stated that a litre of standard diesel contained approximately 0.732 kgC and had an energy content of approximately 10.01 kWh. This was confirmed using other sources, see appendix 1 for details. Equation (4) below shows the application of these figures to convert the energy requirement to carbon emissions using the result from equation (3):

$$(0.732\ \text{kgC}*2.722)/10.01 = 0.199\ \text{kgC} \qquad (4)$$

The above figure refers to a pump lifting at full efficiency and over one metre. However, that is unlikely to be the case. Nelson and Robertson (2008) chose to convert this figure to a pump operating at 30 per cent efficiency and at depths of 15 metres for a shallow well and 75 metres for a deep well; Shah (2009) chose to convert this figure to a pump operating at 40 per cent efficiency and over 10-15 metres. Due to the lack of a consensus on the operational efficiency of water irrigation pumps this study calculated a range of figures for efficiencies from 30-60 per cent. With regards to pumping depths, it is decidedly unlikely that in Sub Saharan Africa pumps would lift from such great depths; evidence from the countries Situation Analyses suggested that the maximum pump depths were eight metres, so a range of pumping depths were also calculated: one metre, four metres, and eight metres (FASAZ, 2009; Namara, 2009; Kerita *et al.,* 2010; Tadesse, 2010).

Estimated pump numbers and water abstraction

The next step was to determine the number of pumps in each country and consequently the amount of water they lifted, yet there was a severe lack of available data on the subject. Approximate pump numbers were known for Ghana and Burkina Faso; they were 50,000-100,000 and 11,000-50,000 respectively (De Fraiture, 2010). Additionally, the number of smallholder farmers in each country were detailed in the country's Situation Analyses, with the exception of Burkina Faso whose smallholder numbers were not known (FASAZ, 2009; Namara, 2009; Kerita *et al.,* 2010; Tadesse, 2010). Using the available information, it was calculated that two to four per cent of smallholders in Ghana were pump users, assuming that one farmer owns/rents one pump. The assumption was then made that the same proportion of smallholders in each of the countries had access to a pump and an upper and lower boundary pump number was calculated for each country. This gave an approximate set of values for numbers pumps in 2010.

The next stage was to calculate the total amount of water the pumps abstracted per year. This was done on the basis of two statistics: one published by Shah *et al.* (2003) and the other by Kortatsi (1994). The first statistic stated that the average abstraction from pumps in India was 7,900 m^3/year and the second statistic stated that pump abstraction in the Southern Volta Region of Ghana varied between 1.0-22.6 m^3/day with irrigation occurring everyday by low powered pumps (this gave a range of between 365-8,249 m^3/year). The two figures were very similar, with 7,900 m^3/year falling within the range suggested by Kortatsi (1994), so this range was used to calculate an upper and lower bound for water abstraction by pumps. Multiplying the upper and lower bounds of water abstraction per pump by the upper and lower bounds of pump numbers gives four scenarios of water abstraction per country in millions of metres cubed:

- water lifted if abstraction was at its lowest and pump numbers were at their lowest,
- water lifted if abstraction was at its lowest and pump numbers were at their highest,
- water lifted if abstraction was at its highest and pump numbers were at their lowest,
- water lifted if abstraction was at its highest and pump numbers were at their highest.

Once the figures for the cumulative pump abstraction per country per year for 2010 were estimated, the figures were compared with information regarding the current total water withdrawal for the agricultural sector, the total water withdrawal and the total renewable water resource for each country according to the FAO's AQUASTAT. The calculated figures were converted in kilometres cubed to allow for this comparison and this confirmed whether the estimates appeared sensible.

Scenarios for carbon dioxide release

The next step was to calculate water abstraction from 2010 until 2025, however there was no information in the literature regarding current estimates of adoption of water pumping technologies. Therefore to do this a pump adoption rate of a factor of two every five years was assumed, allowing the water abstraction to be estimated until 2025 by doubling every five years the amount of water lifted. These figures were then multiplied by the various carbon release values according to pumping efficiency and depth. This gave the carbon emissions for each scenario according to pumping depth, efficiency and year in kilograms of carbon.

Once this had been calculated the results were compared to the county's total carbon dioxide emissions and agricultural sector carbon dioxide emissions. In order for a comparison to be made between these results, the results must first be converted into metric tonnes by multiplying by 0.001, and then converted into carbon dioxide by multiplying by the fraction 44/12 i.e. 44 the molecular weight of carbon dioxide divided by 12 the molecular weight of carbon (Carbon Trust, 2008).

The emissions values used in the comparison were taken from the World Resources Institute's Earth Trends Website (2005) and referred to the emissions released in 2001. This site detailed each country's total carbon dioxide emissions and the percentage of the total carbon dioxide emissions which were accounted for by the agricultural sector. From this the actual carbon dioxide emissions from agriculture were calculated in metric tonnes. Table 1 details the emissions values used in these comparisons.

Carbon dioxide emissions assuming every smallholder farmer was a pump user

The final step of the methodology, in addition to Nelson and Robertson's method, was to calculate the carbon dioxide emissions assuming that every smallholder owned one diesel pump. This was done for all countries with the exception of Burkina Faso for which there was no data regarding the number of smallholder farmers. The numbers of smallholder farmers were multiplied by the upper and lower bound of possible water abstraction to give the range of water abstraction that this number of pumps would generate. The total water abstraction in millions of cubic metres was then multiplied by the carbon release values according to pumping depth and efficiency; this gave a number of figures of carbon release in kilograms of carbon. In order for an effective comparison with the country's total emissions these figures were converted into metric tonnes of carbon dioxide using the method detailed above. This stage gave an indication of what might be expected to be the largest possible adoption of diesel pumps in each country, representing the maximum carbon dioxide emissions.

Table 1: Country's total and agricultural sector carbon dioxide emissions taken from the World Resources Institute's Earth Trends Website (2005)

Country	Country's total CO_2 emissions (millions metric tonnes)	Percentage of CO_2 emissions by agricultural sector *	Calculated emissions resulting from agriculture (metric tonnes)
Burkina Faso	-	-	-
Ethiopia	3.3	0.0	0.0
Ghana	6.2	9.9	613,800
Tanzania	2.8	3.3	92,400
Zambia	1.9	6.9	131,100

*This includes the sum of emissions from fuel combustion used in agriculture, forestry, fishing and commercial activities.

4 RESULTS

This section details the main results generated at each stage of the study. This study developed four scenarios for each country (as listed in Section 3.2) and within each scenario emissions were calculated according to various efficiencies and pumping depths, giving a range of 12 possible emissions amounts per scenario.

Carbon release when lifting 1000 m^3

The first set of results generated was a range of carbon emissions resulting from a diesel pump lifting 1000 m^3 of water over various depths and at varying efficiencies (see figure 1). The graph clearly showed that as the efficiency of a pump increased the carbon emissions as a result of its operation decreased. Additionally, as the depth over which the pump lifted increased the carbon emissions increased; this increase was linear.

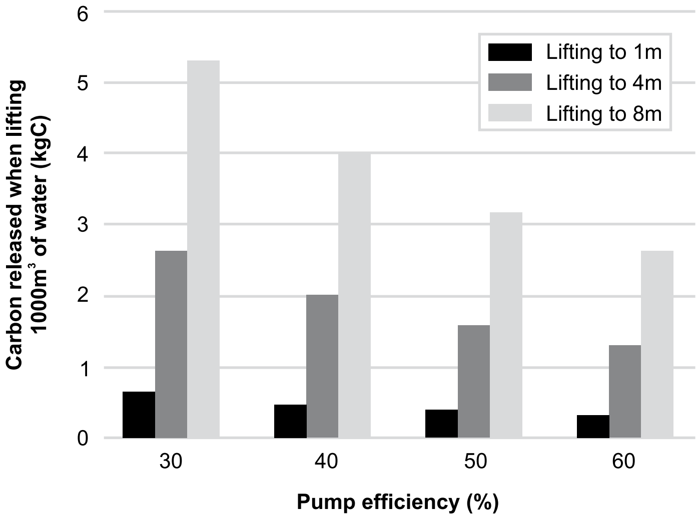

Figure 1: Graph showing the varying amounts of carbon released when a diesel pump lifts 1000 m^3 of water operating at various efficiencies and depths

Estimated pump numbers and water abstraction

The results generated for Section 3.2 were the 2010 (starting values) of pump numbers. These were generated using smallholder numbers and information on the number of pumps in Ghana. The results are displayed in table 2.

Table 2: The estimated number of pumps for each country to the nearest thousand in 2010

Country	**Number of Small-holders***	**Calculated number of pumps (lower boundary)**	**Calculated number of pumps (upper boundary)**
Burkina Faso	-	11,000*[1]	50,000*[1]
Ethiopia	9,374,455	187,000	375,000
Ghana	2,740,000	50,000*[1]	100,000*[1]
Tanzania	2,904,241	58,000	116,000
Zambia	1,056,000	21,000	42,000

*Number of smallholders according to the situation analyses for each country

*[1] pump numbers provided by De Fraiture (2010)

The pump numbers listed above were also displayed graphically in figure 2. From this it was apparent that the estimated pump numbers for Ethiopia were far greater than in the other four Sub Saharan African countries.

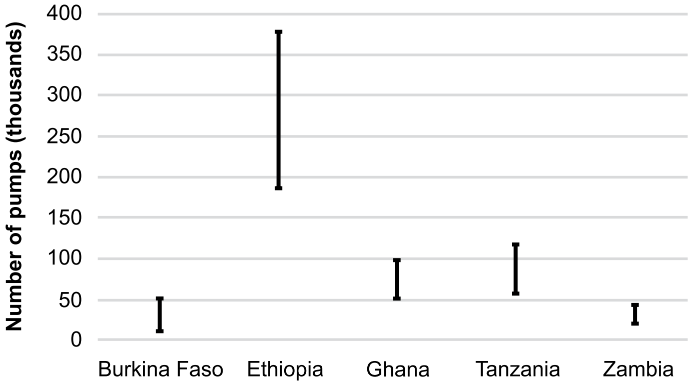

Figure 2: Graph showing the estimated range of pump numbers for each of the five Sub Saharan African countries

Once pump numbers were estimated the total amount of water abstracted was then calculated, and these estimates were detailed in table 3. According to this table it appeared that the estimates were sensible because with the exception of Ghana’s highest estimate of 0.82, the estimates were below the total water withdrawal for the agricultural sector and fell considerably below the country’s individual total renewable water resource. Table 3 also showed that the estimated amount of water abstracted was the greatest for Ethiopia and smallest for Burkina Faso.

Table 3: The estimated amount of water lifted by pumps in each country in km^3, compared with the water withdrawal for the agricultural sector, the total water withdrawal and the total renewable water resource for each country

Country	**Estimated amount of water abstracted by pumps in 2010 (km^3/year)**	**Total water withdrawal by the agricultural sector (km^3/year)***	**Total water abstraction per country (km^3/year)***	**Total Renewable water resource (km^3/year)***
Burkina Faso	0.004 - 0.04	0.69	0.8	12.5
Ethiopia	0.06 - 3.01	5.204	5.558	122
Ghana	0.02 - 0.82	0.652	0.982	53.2
Tanzania	0.21 - 0.96	4.632	5.184	99.27
Zambia	0.01 - 0.35	1.32	1.74	105.2

*Statistics taken from AQUASTAT country factsheets (2000/2002)

Figure 3 graphically displayed the current amount of water abstracted by pumps in each country as a percentage of the country's total renewable water resource. From this it was inferred that pumping in Burkina Faso used the largest proportion of total renewable water resources and Zambia the smallest.

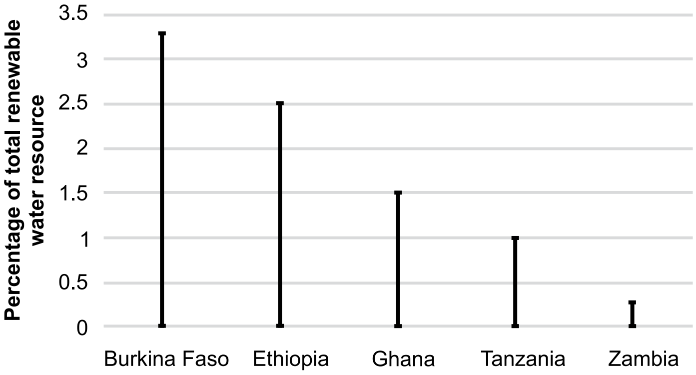

Figure 3: Graph showing the estimated range of water abstraction by diesel irrigation pumps in each county in 2010 as a percentage each country's total renewable water resource

Scenarios for carbon dioxide release

The data generated in section 3.1 and 3.2 was then used to generate scenarios for carbon dioxide emissions resulting from the operation of water irrigation pumps. Figures 4-8 below detailed the carbon dioxide emissions for the four scenarios mentioned in section 3.2 assuming they lift at a depth of four metres and at a 30 per cent efficiency.

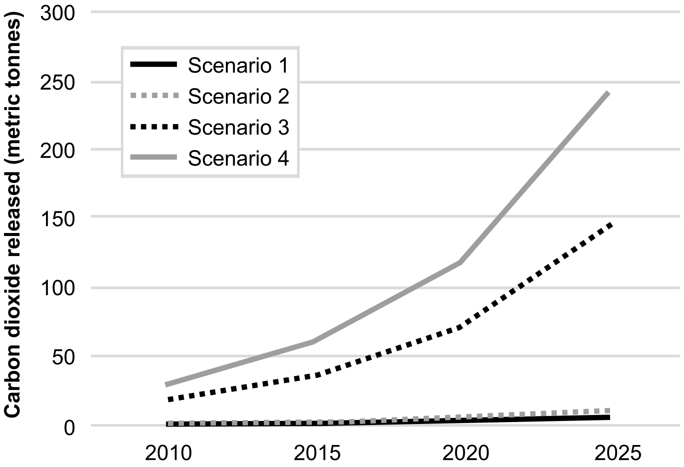

Figure 4: Graph detailing the carbon dioxide emissions for scenarios 1-4 for Burkina Faso assuming pumps operate at a 30% efficiency over 4 m

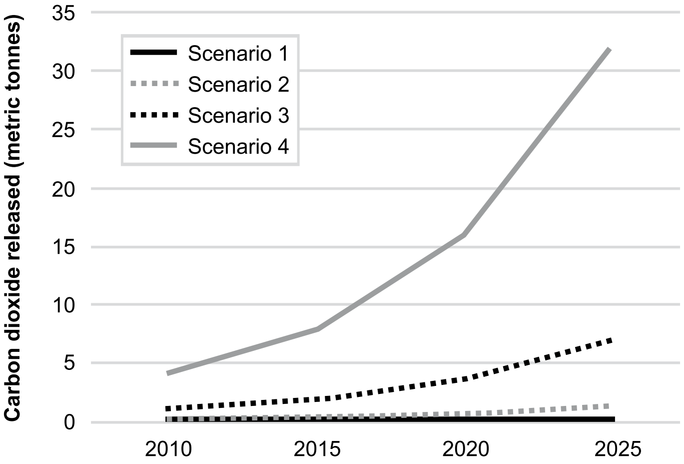

Figure 5: Graph detailing the carbon dioxide emissions from scenarios 1- 4 for Ethiopia assuming pumps operate at a 30% efficiency over 4 m

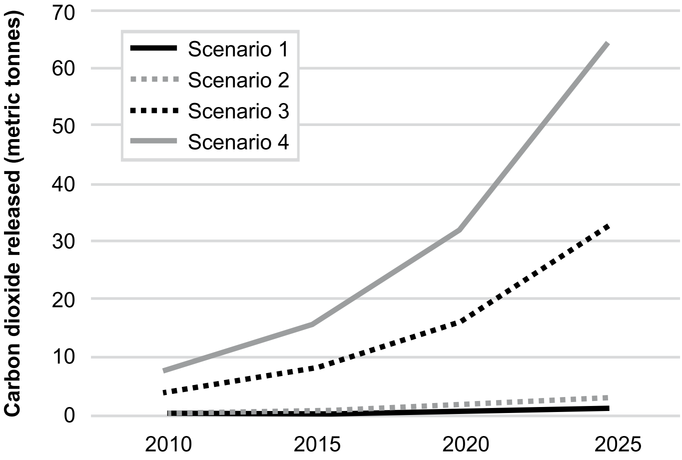

Figure 6: Graph detailing the carbon dioxide emissions from scenarios 1 - 4 for Ghana assuming pumps operate at a 30% efficiency over 4 m

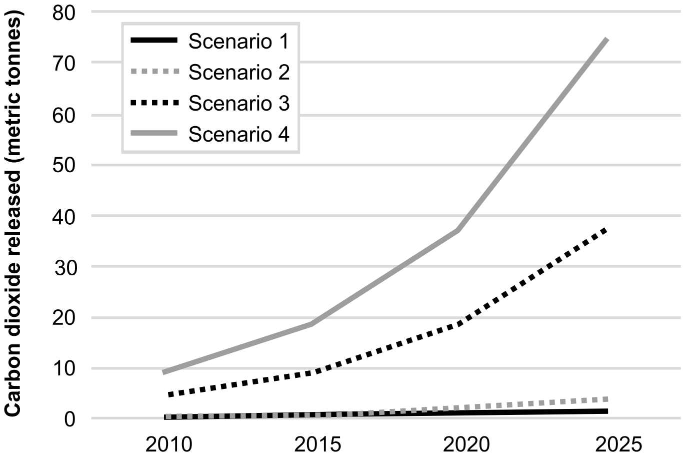

Figure 7: Graph detailing the carbon dioxide emissions from scenarios 1- 4 for Tanzania assuming pumps operate at a 30% efficiency over 4 m

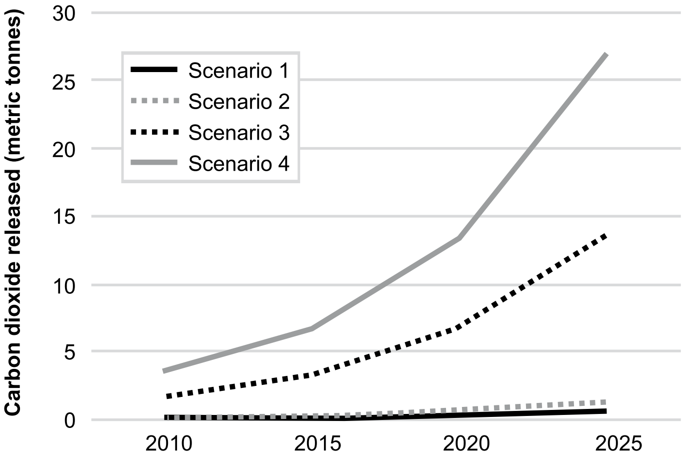

Figure 8: Graph detailing the carbon dioxide emissions from scenarios 1 - 4 for Zambia assuming pumps operate at a 30% efficiency over 4 m

Figures 4-8 showed that the carbon dioxide emissions as expected increase over time. Furthermore, emissions also increased according to the scenario, with scenario 1 generating the lowest possible emissions and scenario 4 the highest. Due to the same pump adoption rate being applied in every country each graph displayed the same pattern regarding emissions, it was the quantity of the emissions that varied. The difference in emissions between scenarios 1 and two was much smaller compared with the difference between scenarios 3 and 4. Scenarios 1 and two referred to the application of the lower abstraction rate (365 m^3/year/pump), whereas scenarios 3 and 4 referred to the application of the higher abstraction rate (8,249 m^3/year/pump). On comparison of the graphs it appeared that Ethiopia has the potential to emit the greatest total emissions as a result of diesel pump irrigation. A selection of raw data on carbon dioxide released is displayed in appendices 2-6.

Table 4 below shows the upper and lower bounds of carbon dioxide emissions for each country in 2010 and 2025. Additionally it details the carbon dioxide emissions in 2010 as a percentage of current agricultural sector emissions. In the case of Ghana, Tanzania and Zambia emissions from pumps accounted for a miniscule amount of the total agricultural emissions. For Burkina Faso and Ethiopia there is no result from the percentage of agricultural emissions. In the instance of Burkina Faso this is due to there being no record of emissions (see table 1). However for Ethiopia, as can be seen from table 1 in the methods section, there were zero emissions from agriculture. Therefore in affect the emissions from smallholder pumps account for the entirety of the country's carbon dioxide emissions from agriculture. It is important to note when analysing at these results that the current agricultural sector emissions used as a comparison were as of 2001, as this was the most up to date values that could be found from the available literature.

Table 4: The range of carbon dioxide emissions for each country in 2010 and 2025 and the percentage of current agricultural sector emissions this represents for a pump lifting at 30% efficiency over 4 m

Country	Carbon dioxide emissions 2010 (metric tonnes)	Percentage of current agricultural sector emissions	Carbon dioxide emissions 2025 (metric tonnes)
Burkina Faso	0.04 - 4.0	-	0.3 - 32.1
Ethiopia	0.8 - 30.1	-	6.4 - 240.8
Ghana	0.2 - 8.0	0.00003 - 0.001	1.4 - 64.2
Tanzania	0.2 - 9.3	0.0004 - 0.01	1.7 - 74.5
Zambia	0.1 - 3.4	0.00008 - 0.003	0.6 - 27.0

Carbon dioxide emissions assuming every smallholder farmer was a pump user

The scenarios developed in the section above indicated that carbon dioxide emission from water irrigation pumps were small, therefore a hypothetical scenario was generated. This scenario calculated the total carbon emissions assuming that every smallholder was a pump user; below are the results.

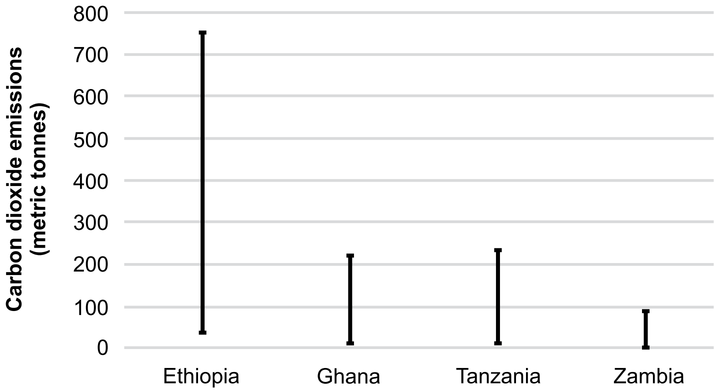

Figure 9: Graph showing the range of carbon dioxide emissions for a hypothetical scenario in which every smallholder is a pump user

Ethiopia again, displayed the highest potential carbon dioxide emissions, with the other three Sub Saharan countries displaying very similar levels of carbon dioxide emissions. There is no estimate of emissions for Burkina Faso as numbers of smallholders in this country were not known.

Table 5 below displayed the hypothetical carbon dioxide emissions as a percentage of the current agricultural sector emissions. It showed that even with every smallholder farmer having access to a pump the carbon emissions were still very small in comparison to the current emissions from agriculture.

Table 5: Carbon dioxide emissions from a scenario that assumes every smallholder is a pump user as a percentage of the current agricultural sector carbon dioxide emissions: (1) Referring to the lower emissions estimate and (2) referring to the upper estimate

Country	Percentage of current agricultural sector emissions (1)	Percentage of current agricultural sector emissions (2)
Ethiopia	-	-
Ghana	0.002	0.034
Tanzania	0.001	0.025
Zambia	0.003	0.065

5 DISCUSSION

The first step in this study calculated carbon emissions from a pump lifting at various efficiencies and from a variety of depths and as it would be expected the emissions rose as the lifting depth increased and the emissions decreased as the efficiency rose. Emissions from diesel pumps calculated in this study were significantly smaller than the emissions calculated for diesel pumps by both Nelson and Robertson (2008) and Shah (2009) in India. The major difference between the calculations at this stage was pumping depth. According to the two studies, pumps in India pump at a greater depth than those operating in Sub Saharan African countries. Nelson and Robertson (2008) stated that pumps lifted at depths of 15 metres for a shallow well and 75 metres for a deep well and Shah (2009) stated that pumps lifted over 10-15 metres. From the individual country's Situation Analyses it was determined that pumps in Sub Saharan Africa generally did not lift below eight metres (FASAZ, 2009; Namara, 2009; Kerita *et al.,* 2010; Tadesse, 2010).

Section 3.2 of the study involved making estimates of pump numbers and pump water abstraction. For all the included Sub Saharan countries the estimated numbers of pumps were small in comparison to India's 19 million (Purohit and Michaelowa, 2005). Ethiopia appeared to have the largest number of pumps and Zambia had the smallest; these numbers were proportionate to the smallholder population. The water abstraction figures in comparison to India were very small, most likely as a result of the much smaller number of pumps operating in these countries. Burkina Faso was highlighted as the country whose abstraction from pumps was the greatest proportion of the country's total renewable water resource. It was evident from table 3 that Burkina Faso had the smallest total renewable water resource at only 12.5 km^3/year and therefore this explains why pumps in this country utilised a greater proportion of the resource than pumps in others. However, the current water abstraction was low; not more than 3.5 per cent (although this is quite high for a semi-arid country).

Despite this falling outside the remit of this study, it is important to note that whilst abstraction was not calculated to be a large proportion of Burkina Faso's total renewable water resource this may not be the case in the future; especially if the assumed adoption rate for pumps in this country is accurate. The highest estimate of abstraction for Burkina Faso was just under 3.5 per cent of the country's total renewable water resource, yet if abstraction doubled every five years by 2025 the amount of water lifted could be approximately 28 per cent. This would be a very large proportion of the country's total renewable water resource. The value of the national renewable water resource is a country average and therefore water can be in abundance in some places, and in deficit in others. Evidently local water resources and water stress may emerge as the adoption of small pumps grows beyond a certain level. These landscape boundaries must be determined at a local scale. The comparison of withdrawal used here is only a first estimate to cross check potential impacts.

The generation of the multiple emissions scenarios for each country revealed large differences in absolute carbon dioxide. Figures 4-8 in the results section showed as expected that emissions displayed a pattern of increase over time. This pattern was in contrast to the estimates by Nelson and Robertson (2008) in India where emissions from both shallow electric and diesel wells decreased over time up to 2050. This was the case in India due to the assumption that there would be no growth in the availability of water from these sources. Again Ethiopia was highlighted as the country with the potential for the largest carbon dioxide emissions, up to 250 million metric tonnes in 2025; and Zambia was the country highlighted as contributing to the smallest emissions just over 25 metric tonnes by 2025. This was proportionate to the country's smallholder numbers. It is should be noted that these scenarios do not account for a growing smallholder population, but only a growing adoption rate among the current population.

A ‘worst-case’ and very unrealistic scenario regarding emissions from pumps assuming every smallholder was a pump user was also estimated. Interestingly it indicated that the carbon dioxide emissions even with such a large number of pumps were unlikely to be a large proportion of the countries emissions. This is a very positive outcome. This result was in great contrast with the calculations for India. This is possibly due to the smaller number of total smallholder farmers in India or the method of energy generation most commonly used.

There were some weaknesses in the data underlying the estimated current and potential carbon dioxide release; the first being the lack of relevant, available and up-to-date data in particular on existing pump numbers, their efficiency and possible adoption rates. This study was not alone in experiencing difficulties regarding agricultural data in this region, for instance Awulachew *et al.* (2005: p.46) stated that there was very little knowledge of modern irrigation like the motor pump and that it was one of the main knowledge gaps in Ethiopian agriculture. Additionally, Turner (1994) stated that the reliability of data on small-scale irrigation was generally lacking, with many governments in developing countries keeping only records of large-scale systems. However these data issues were also noted by Shah (2009) for the carbon footprint of Indian pumps where data is more widely available.

The shortage of appropriate data for this study led to a large number of assumptions being made. These were made to the best of available knowledge and data; and in consultation with local expertise in the AgWater Solution Project, but the data is associated with high levels of uncertainties. One issue brought to attention was the numbers of electric pumps in use. This assumption of poor rural electrification in many Sub Saharan African countries led to the exclusion of electric pumps from the carbon release calculations. However, contact with researchers in Africa suggested that for Ghana in particular this may not be the case. Namara (2010) stated that electric pumps were extensively used in the east coast part of the Volta Region. It is also possible that pumps in semi urban settings can access electricity in various countries in Sub Saharan Africa. Nonetheless, as no quantitative information on use or current adoption of electrical pumps is available for the countries in this estimate only diesel pumps were assumed.

There are several improvements which could be made to increase the veracity of this study. The first being the inclusion of electric pumps which could either increase or decrease the carbon emissions depending on the type of power generation for the electricity. The table below details the emissions from electricity generation and the emissions factors, given in kilograms of carbon as in the diesel pump calculations, which could be used as a replacement for the diesel emissions values if electric pump numbers and energy sources were known. This table used information regarding energy generation from Yale’s Environmental Performance Index 2010 Website. The estimates included a five per cent transmission loss as adopted by Nelson and Robertson (2008) and a 25 per cent transmission loss as adopted by Shah (2009) in their estimates for India. See appendix 7-9 for further details on how this data was calculated.

Table 6 represents an electric pump lifting at 30 per cent efficiency. Diesel pumps also operating at this efficiency emit 0.66 kgC when lifting 1000 m^3 of water over one metre. Therefore in the majority of cases diesel pumps appeared to release less carbon than electric pumps. This was also found by Shah (2009) in India, and the reasoning behind this in Shah’s study was the transmissions losses.

It is important to consider if using the statistics detailed in table 6 that these emissions values only refer to electricity generated from fossil fuels, not hydropower. Yet, any change in emissions would be dependent on the source of energy responsible for electricity generation i.e. coal fired or hydropower. Table 7 gives an indication of the proportion of electricity generated from each source according to CARMA (Carbon Monitoring for Action Website). The table suggested that in the majority of the

Table 6: Carbon dioxide emissions associated with electricity generation in the various countries and the emissions resulting from one electric pump operating at 30% efficiency lifting 1000 m^3 of water 1 m with a 5% and a 25% transmission loss

Country	**Emissions from electricity generation (gCO_2 per kWh)***	**Emissions with a 5% transmission loss lifting 1000 m^3 of water over 1m (kgC)**	**Emissions with a 25% transmission loss lifting 1000 m^3 of water over 1m (kgC)**
Burkina Faso	729.441	1.895	2.255
Ethiopia	36.265	0.094	0.112
Ghana	359.634	0.908	1.112
Tanzania	247.603	0.643	0.776
Zambia	6.6688	0.017	0.021

*Statistics taken from Yale's Environmental Performance Index Website

countries, with the exception of Burkina Faso, hydropower was the dominant energy source, therefore electrically driven pumps could be a cleaner option in Sub Saharan Africa but further investigation is needed to ascertain this.

Table 7: The proportion of power in each country generated by either fossil fuels or hydropower

Country		**Percentage from fossil fuels**	**Percentage from hydropower**
Burkina Faso	2000	68.92	31.08
	Present	82.33	17.52
Ethiopia	2000	1.2	96.44
	Present	2.17	96.49
Ghana	2000	7.76	88.57
	Present	11.51	83.98
Tanzania	2000	10.1	85.35
	Present	6.99	87.85
Zambia	2000	0.29	98.83
	Present	0.26	98.96

A second improvement which could be made to this study should consider the fact that throughout their lifetime the operational efficiency of diesel engines decreases due to wear and tear etc. In a study by Reidhead (2001) in India even following rectification measures to improve efficiency within several months efficiency had fallen by an average of five per cent. This study also suggested that the operational efficiency of these pumps may be lower than assumed in this study. Reidhead (2001, p.138) stated that if diesel pump operated perfectly i.e. per design specifications, the maximum achievable efficiency in the field was approximately 20 per cent and observed efficiencies could be as low as five per cent.

Finally, additions could be made to this study with the inclusion of emissions from all stages of the life cycle of these pumps. Current emissions estimates only include carbon dioxide from the operation of these pumps, yet the definition of carbon footprint is as follows: a measure of the exclusive total amount of carbon dioxide that is directly and indirectly caused by an activity or is accumulated over the life stages of a product (Wiedmann and Minx, 2007). The inclusion of all associated carbon dioxide emissions would give a truer picture of the carbon footprint of the pumps.

It is possible to improve the efficiency of diesel irrigation pumps and this would further decrease the already low operational emissions. It would also have benefits such as reducing pump running costs. Efficiency is defined as the ratio of work being done by the pump to the power or energy being supplied, and an appropriate pump size is vital to increase efficiency (Smajstria, n.d.). Other causes of substandard performance which should be tackled in order to improve efficiency include the pump being unsuitable for present conditions, wear and corrosion etc.

Energy for irrigation pump use in the future may come from renewable sources such as biofuels. Roseblum (2000) in a study regarding irrigation in India stated that the use of biodiesel (a type of biofuel) would reduce carbon dioxide emissions. Therefore any shift in their favour should decrease the carbon dioxide estimates. Additionally, biodiesel could have the added advantage of increasing economic activity through its production and utilisation, and would increase energy independence. The switch from petroleum-based diesel to biodiesel could be a smooth one, with no engine modifications needed for this transition (Roseblum, 2000).

It may be useful to develop other methods of calculating the operational carbon footprint of these pumps to compare with these estimates. Just as the different studies for India produced differing results this may be the case in Africa also. Information is known on the amount of diesel used to irrigate land in Ghana and Burkina Faso: 250 and 1000 litres per hectare per year respectively (De Fraiture, 2010). These figures could be applied to a different methodology to estimate emissions considering that the carbon content of a standard litre of diesel is known. Nonetheless, these figures could not be utilised in this study due to a lack of information regarding the areas irrigated in each of the countries.

6 CONCLUSIONS

In conclusion, from the calculations in this study it appeared that carbon dioxide emissions as a consequence of the use of water irrigation pumps in the Sub Saharan African countries are currently only a miniscule proportion of the overall carbon dioxide emissions of the countries. Additionally, it appeared that in the next 10-15 years these carbon dioxide emissions although increasing would remain only a small proportion of the country's total emissions under the optimistic emissions scenarios used in this pilot estimate. However, more energy efficient small scale pumps would reduce farmers running costs (increase benefits) as well as keep carbon dioxide emissions at a low rate even if adoption quadrupled. Perhaps a more pressing environmental issue with increased adoption will be stress on available surface and groundwater resources at the local scale. This study was based on a range of assumptions and highly uncertain data, thus it was only intended as a pilot estimate for future research. More research is essential in this study area especially into exact pump numbers in use, as once this can be firmly established a truer picture of the carbon footprint of diesel pumps for irrigation can be established.

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APPENDICES

Appendix 1: Lists sources and stated carbon emissions per litre of diesel

Carbon content per litre of diesel	Source	Date Accessed
0.732 kgC (2,778 grams/USgallon)	www.epa.gov/oms/climate/420f05001.htm (2005)	07/07/2010
0.731 kg (2.77 kg/USgallon)	http://bioenergy.ornl/gov/papers/misc/energy_conv.html	07/07/2010
0.739 kgC (12.2 kgCO_2/gallon)	http://timeforchange.org/what-is-a-carbon-footprint-definition	07/07/2010

Appendix 2: Details the carbon release in metric tonnes of pumps lifting over 8 m in Burkina Faso

Year	30% efficiency	40% efficiency	50% efficiency	60% efficiency
2010	0.08 - 8.03	0.06 - 6.02	0.05 - 4.82	0.04 - 4.01
2015	0.16 - 16.06	0.12 - 12.04	0.09 - 9.63	0.08 - 8.03
2020	0.31 - 32.11	0.23 - 24.08	0.19 - 19.27	0.16 - 16.06
2025	0.63 - 64.22	0.47 - 48.17	0.38 - 38.53	0.31 - 32.11

Appendix 3: Details the carbon release in metric tonnes of pumps lifting over 8 m in Ethiopia

Year	30% efficiency	40% efficiency	50% efficiency	60% efficiency
2010	1.33 - 60.21	1.00 - 45.16	0.80 - 36.13	0.66 - 30.11
2015	2.66 - 120.42	1.99 - 90.32	1.59 - 72.25	1.33 - 60.21
2020	5.31 - 240.84	3.99 - 180.63	3.19 - 144.51	2.66 - 120.42
2025	10.63 - 481.69	7.97 - 361.26	6.38 - 289.01	5.31 - 240.84

Appendix 4: Details the carbon release in metric tonnes of pumps lifting over 8 m in Ghana

Year	30% efficiency	40% efficiency	50% efficiency	60% efficiency
2010	0.36 - 16.06	0.27 - 12.04	0.21 - 9.63	0.18 - 8.03
2015	0.71 - 32.11	0.53 - 24.08	0.43 - 19.27	0.36 - 16.06
2020	1.42 - 64.22	1.07 - 48.17	0.85 - 38.53	0.71 - 32.11
2025	2.84 - 128.45	2.13 - 96.34	1.71 - 77.07	1.42 - 64.22

Appendix 5: Details the carbon release in metric tonnes of pumps lifting over 8 m in Tanzania

Year	30% efficiency	40% efficiency	50% efficiency	60% efficiency
2010	0.41 - 18.63	0.31 - 13.97	0.25 - 11.18	0.21 - 9.31
2015	0.82 - 37.25	0.62 - 27.94	0.49 - 22.35	0.41 - 18.63
2020	1.65 - 74.50	1.24 - 55.88	0.99 - 44.70	0.82 - 37.25
2025	3.30 - 149.00	2.47 - 111.75	1.98 - 89.40	1.65 - 74.50

Appendix 6: Details The Carbon Release In Metric Tonnes Of Pumps Lifting Over 8 m In Zambia

Year	30% efficiency	40% efficiency	50% efficiency	60% efficiency
2010	0.15 - 6.74	0.11 - 5.06	0.09 - 4.05	0.07 - 3.37
2015	0.30 - 13.49	0.22 - 10.12	0.18 - 8.09	0.15 - 6.74
2020	0.60 - 26.97	0.45 - 20.23	0.36 - 16.18	0.30 - 13.49
2025	1.19 - 53.95	0.90 - 40.46	0.72 - 32.37	0.60 - 26.97

Appendix 7: Details the methodology used to calculated the emissions factors for electric pumps

- The carbon dioxide emissions from each country for electricity generation according to the Yale Environmental Performance Website are given in grams of carbon per kilowatt hour.

- From the previous calculations for diesel pumps it was known that a pump lifting 1000 m^3 of water over one metre at full efficiency would require 2.73 kWh of energy and at 30 per cent efficiency it would require 9.07 kWh of energy.

- In electricity generation there are additional efficiency losses known as transmissions losses. Therefore if a pump operates at a 30 per cent efficiency with a five per cent transmissions loss it would require 9.5235 kWh of energy, and a pump that operates at a 30 per cent efficiency with a 25 per cent transmission loss would require 11.3375 kWh of energy.

- The carbon dioxide emissions to pump 1000 m^3 of water over one metre was calculated by multiplying the energy requirements calculated in Step 3 by the figures for carbon dioxide released per kilowatt hour. This gave figures in grams of carbon dioxide which could then be converted to kilograms of carbon dioxide.

- Finally, these values were then converted from carbon dioxide to carbon to give emissions values. This was done by dividing by 44/12.

Appendix 8: Details the emissions values in both carbon dioxide and carbon for an electric pump lifting 1000 m^3 of water 1 m operating at a 30% efficiency with a 5% transmission loss

Country	Emissions from electricity generation (gCO_2 per kWh)*	Emissions from pumping 1000 m^3 of water over 1 m with a 5% transmission loss ($kgCO_2$)	Emissions from pumping 1000 m^3 of water over 1 m with a 5% transmission loss (kgC)
Burkina Faso	729.441	6.947	1.895
Ethiopia	36.265	0.345	0.094
Ghana	349.634	3.330	0.908
Tanzania	247.603	2.358	0.643
Zambia	6.6688	0.064	0.017

*Statistics from Yale's Environmental Performance Index Website

Appendix 9: Details the emissions values in both carbon dioxide and carbon for an electric pump lifting 1000 m^3 of water 1 m operating at a 30% efficiency with a 25% transmission loss

Country	Emissions from electricity generation (gCO_2 per kWh)*	Emissions from pumping 1000 m^3 of water over 1 m with a 25% transmission loss ($kgCO_2$)	Emissions from pumping 1000 m^3 of water over 1 m with a 25% transmission loss (kgC)
Burkina Faso	729.441	8.270	2.255
Ethiopia	36.265	0.411	0.112
Ghana	359.634	4.077	1.112
Tanzania	247.603	2.807	0.766
Zambia	6.6688	0.076	0.021

*Statistics from Yale's Environmental Performance Index Website

SEI - Africa
Institute of Resource Assessment
University of Dar es Salaam
P.O. Box 35097, Dar es Salaam
Tanzania
Tel: +255-(0)766079061

SEI - Asia
15th Floor Witthyakit Building
254 Chulalongkorn University
Chulalongkorn Soi 64
Phyathai Road Pathumwan
Bangkok 10330
Thailand
Tel: +(66) 22514415

SEI - Oxford
Suite 193
266 Banbury Road,
Oxford, OX2 7DL
UK
Tel: +44 1865 426316

SEI - Stockholm
Kräftriket 2B
SE -106 91 Stockholm
Sweden
Tel: +46 8 674 7070

SEI - Tallinn
Lai 34, Box 160
EE -10502, Tallinn
Estonia
Tel: +372 6 276 100

SEI - U.S.
11 Curtis Avenue
Somerville, MA 02144
USA
Tel: +1 617 627-3786

SEI - York
University of York
Heslington
York YO10 5DD
UK
Tel: +44 1904 43 2897

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