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# The mapping of maximum annual energy yield azimuth and tilt angles for photovoltaic installations at all locations in South Africa

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## **Abstract**

*Photovoltaic (PV) technology is fast emerging as a viable energy supply option in mitigation against environmental degradation through the burning of traditional fossil fuels. The cost of the technology, however, still poses a major challenge, as the efficiencies are generally still quite modest. Current research efforts to improve efficiency are mainly focused on component physics and manufacturing technologies. Little attention seems to be paid to improved system design at field level. Traditionally it is assumed that a panel installed at a tilt angle that is equal to the latitude at a location should achieve maximum annual energy yield for a non-tracking installation. However, in practice, due to a number of factors such as wind speed, wind direction, air temperature, global and diffuse irradiation and other climatic factors, the optimum azimuth and tilt get more convoluted. In this paper the optimum angles (azimuth and tilt) to maximise annual energy yield for fixed angle PV installations at all locations in South Africa have been tabulated. Climate data software together with solar design software were used in determining the angles. The availability of these tables will offer an additional support tool to the country in promoting the growth of PV as a viable alternative energy generation technology for both urban as well as the most secluded rural areas that are not grid connected.*

*Keywords: photovoltaics, South Africa, tilt, azimuth*

## **1. Introduction**

South Africa is currently facing a range of energy related problems that include energy reliability, environmental sustainability and tariff hikes (Sebitosi *et al.*, 2008; Sebitosi & Pillay, 2008; Sebitosi & Pillay 2008). The Department of Energy

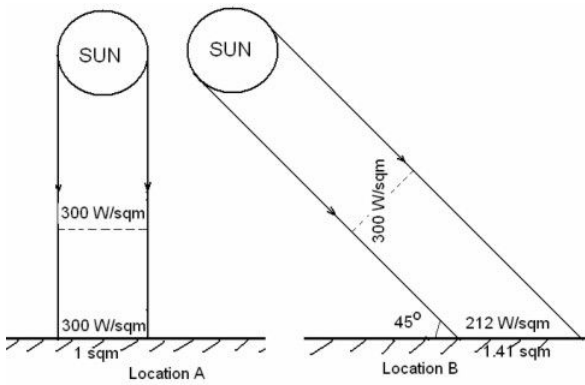
also identifies access for all to electricity as one of the primary goals of South Africa's energy policy. The need to integrate non-grid technologies into the Integrated National Energy Planning (INEP) as complementary supply-technologies to grid extension has been particularly highlighted (DME, 2003). Solar energy is a most readily accessible resource in South Africa and potentially offers an ample opportunity for alternative power generation that is also clean. In addition, there is a growing photovoltaic (PV) manufacturing sector in the country with annual panel-assembly capacity totalling 5MW. Despite this great potential, solar PV installations are still very expensive for ordinary users, more especially those in rural South Africa. Thus, this cost is one of the major limiting factors to the full utilization of PV technologies.

## **2. Motivation**

Designing an installation to yield maximum annual energy helps to minimise the necessary installed capacity and reduce the cost of equipment. To achieve this, a generic solar collector must be mounted at right angles to the sun's rays. Ideally this is achieved by mounting the collector on a two-axis tracker that continuously tracks the sun by the hour and through the seasons. In practice, however, the method is quite cumbersome and inconvenient. Thus, the majority of installations are with fixed mountings. Figure 1 illustrates the reduction in solar intensity at location B that receives the sun at a smaller angle than location A.

Traditionally it is assumed that a collector that is mounted at a tilt angle that is equal to the latitude of a location, combined with an azimuth angle that is parallel to the equator, should achieve maximum annual energy collection. In the case of photovoltaics, however, the situation is more complicated.

A basic PV panel consists of several solar cells.



**Figure 1: An illustration of the reduction of radiation intensity per square metre due to sun angle**

Each solar cell can be modelled as a basic p-n junction, and hence the classic diode equation can be used in modelling outputs for the solar panel.

The diode equation is given by equation 1.

$$I = I_o (e^{\frac{qv}{kT}} - 1) \quad (1)$$

Where T is the temperature of the solar cell.

From this, various models for the electrical energy output of a PV panel have been derived. One such model is presented in (Medica *et al.*, 1996):

$$P_1 = P_0 (1 - \gamma (T_1 - T_0)) H/H_0 \quad (2)$$

Where:

$P_0$  = Power at standard condition (25°C and 1000 W/m<sup>2</sup>)

H = Value of solar irradiance incident of the module (W/m<sup>2</sup>)

$H_0$  is reference solar radiation = 1000 W/m<sup>2</sup> (to the horizontal surface)

$\gamma$  = Power correction coefficient

$T_1$  = Panel temperature

$T_0$  = Standard temperature (25°C)

From the above, it is evident that the output power of the PV panel is directly proportional to the sun's radiation, but also inversely proportional to the sun's heat. Solar radiation is comprised of about 9% ultra-violet, 41% of visible radiation (which increases the output current) and about 50% infrared, which constitutes the heat. Therefore, in order to maximize the electrical energy yield of a PV panel, one must minimize the effect of the heat component while maximizing the effect of the light component.

Currently there is no known technology that can filter the infrared before the solar radiation can strike the PV panel. However, the presence of other climatic factors at a location can impact on the tem-

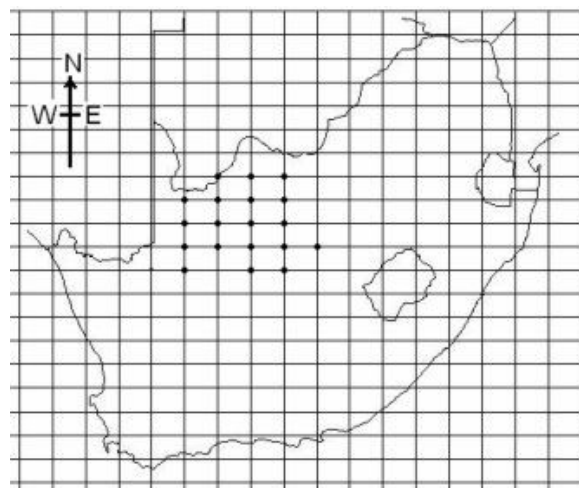
perature of the panel. These factors include wind speed, wind direction, humidity and due point. Consequently it may be necessary to rotate a panel slightly away from the position where it catches maximum radiation to one where catching a bit of a cool breeze (as well) results in more electrical energy yield.

The primary aim of this paper is to provide a comprehensive database of optimum tilt and azimuth angles to support PV installation engineers at any location in South Africa, regardless of how remote it may be.

### 3. Methodology

Initially an outline of a South African map was obtained and divided into grids. The intersection points of the grid lines were considered as the coordinate locations and used as locations for study. This is illustrated in Figure 2. These coordinates were used to generate climate data for each point on the map using *Meteonorm* climate simulation software. The simulated data contained the following output parameters namely, month, day of the month, hour, global radiation on a horizontal plane, diffuse radiation on a horizontal plane, air temperature, wind direction and wind speed. These are important in that they influence the overall performance of the PV module and need to be specified accurately for correct system design.

The climate data files were then inputted into PV Design Pro-S software and the annual energy yield for each intersection point was calculated. The design package allows the user to vary the azimuth and tilt angles of the panels used.



**Figure 2: A South African map demarcated into grids of coordinate points**

For a particular intersection point (coordinate location) the azimuth and tilt angle combination resulting in the highest annual energy yield was recorded. The rest of the parameters were kept constant. These included, the load profile, which was

kept at an average of 18 466 Wh per day for weekly load and 18 000 Wh per day for the weekend load. Thus, the only parameters varied throughout the investigation were the climate (determined by the location), the tilt and azimuth angles.

#### 4. Simulation results

##### 4.1 Azimuth angle and tilt

Initially the assumption made was that the tilt angle could be set at latitude as suggested by Bekker (2007). Thus, to obtain the optimum azimuth angle, the tilt was kept constant at latitude and only the azimuth was varied until the maximum possible annual energy yield was obtained. This was repeated for all the points indicated in the map shown in Figure 2.

Once the optimum azimuth angles were obtained, the process was repeated to find the optimum tilt angles. Using the optimum azimuth angles obtained earlier, tilt angles were varied to obtain new values that yielded the maximum annual energy.

Tables 1 and 2 give the results of the optimum azimuth and tilt angles respectively, for all point locations investigated in this project. Table 1 shows

a general trend of the azimuth angle increasing from west to east. This trend also holds in the case of the tilt angles as depicted in Table 2.

##### 4.2 A guide to using the optimum yield angle tables

In practice a given location is unlikely to be at the coordinates indicated in the tables but somewhere in between. To address that problem, a method to obtain the required azimuth and tilt angles for any location is illustrated in this section.

In South Africa the average distance between any given adjacent longitude, ranges between approximately 90 km and 111 km. The distance between latitude degrees remains constant at roughly 111km. In addition, the results obtained from both Meteororm and PV Design Pro-S are valid for a distance of approximately 40 km from the location where the results are obtained.

To obtain the coordinates of any location it is recommended that a GPS (global positioning system) be employed.

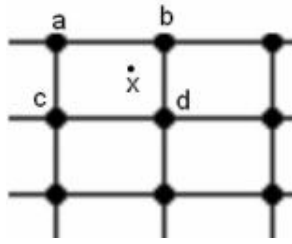
*Linear Interpolation* is a method of constructing new data points within the range of a discrete set of known points.

**Table 1: Optimum Azimuth in degrees at coordinate points in South Africa**

		Longitude																		
Coordinate	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	
Latitude																				
23												45.2	51	53.1	53	49.5	56			
24											42.3	50.6	45.2	46	49.2	50	55			
25					33	32.8	32.1	37	41.8	41	42	44.4	49.9	47.1	49.1	53	53			
26					34.3	38.7	35	41	38.5	42.8	43	45.1	48	50	46.9	53	49.7			
27					33.6	35.9	38.6	40	41.1	44	45	47	49	53	51.8	52.3	57.6	55		
28	26.3	28	28.2	28.6	32	32	41	36.7	38	45	46	44	42.2	50	49	52.8	57	55.3		
29	28.9	29	27.4	29.7	37.8	37	43.1	41	40	42	41.4	43	47	48.4	44.5	51	53	56		
30		26.7	33.9	31.6	34.2	35.4	35.8	37.0	41.2	41.9	44	50.4	47.7	50.3	45.5	55.1	56.5			
31		29.7	30.7	36.4	31.5	36.7	34.3	36.1	38.3	42.2	43.9	43.6	49	47.3	50.1					
32			35.7	34	30.8	34	40.9	39.1	40.7	42.1	43.2	45.2	45.7	48	50.1					
33			40.1	37.7	38.8	41	47.1	44	47	48.6										
34			38.2	38.9	42.8	40.3	41.8	41	45.1	44.9	48.2									
35				38.2					46.3											

**Table 2: Optimum tilt angles in degrees at coordinate points in South Africa**

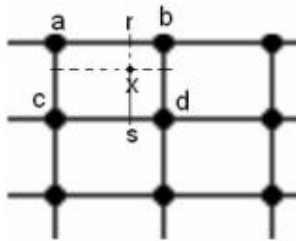
		Longitude																		
Coordinate	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	
Latitude																				
23												258	256	257	265	262	265			
24											252	255	259	267	263	263	264			
25					229	244	242	241	246	252	255	252	256	259	254	261	261			
26					231	232	235	255	251	243	255	260	254	256	256	256	266			
27					236	240	246	239	249	250	249	255	259	250	254	253	259	259		
28	230	232	216	220	226	233	228	251	250	246	250	251	256	255	259	259	259	267		
29	238	221	218	225	235	233	237	242	247	241	253	255	248	254	257	261	259	269		
30		217	227	235	234	225	232	251	243	248	251	243	256	258	259	263	261			
31		226	233	229	215	225	221	231	242	242	244	247	257	257	263					
32			232	217	230	218	223	235	245	235	243	242	257	262	265					
33			234	225	221	240	239	242	248	256	249	257	258							
34			232	229	235	239	245	251	249	250	252									
35				227						250										



**Figure 3: Coordinates a, b, c and d are given in the table but x is not**

Figure 3 illustrates a location, x, that is not listed in the azimuth and tilt tables. The explanation below will illustrate how to obtain the required angles for x.

The first step is to interpolate the angles at two new points, r and s as illustrated in Figure 4.



**Figure 4: Illustration of the interpolation**

Given the two known data points (a) and (b) in Figure 4, the required angle at r can be found as follows. Note that the closer r is to b the closer the values of their angles will be.

Let the angle at a be m and at b be n. (Assume that m is bigger than n).

Linear interpolation assumes that the values of the points from a to b decrease linearly from m to n. Then the total decrease between a and b is (m-n) units.

The decrease at r = [(m-n)ar / ab]

Where,

ar is the distance between points a and r

ab is the distance between points a and b

Therefore the value at r = m - [(m-n)ar / ab]

Next (using the method above) one finds the value at s using the angles at c and d.

Finally, using the values obtained at r and s, one interpolates the value at x.

#### 4.3 Verification of the Interpolation Method

Table 4 compares annual energy yield obtained from the interpolated yield angles with that of the simulated yield angles. Eight sample locations were considered. Also included, is the error between the two, calculated and simulated energy yield results.

From Table 3 it is clear that the percentage error in annual energy yield between the results obtained from the interpolated yield angles and simulated yield angles is small, thus negligible. Hence the interpolation method is accurate.

#### 5. Concluding remarks

The cost of PV technology remains high in South Africa and it is important to optimise system design and performance to minimise installation costs. Due to a number of climatic and location related parameters, traditional installations that are fixed at tilt angles dependent on latitude alone do not attain optimum annual energy yields.

In this paper the tables of optimum azimuth and tilt angles for locations in South Africa have been successfully produced. GPS tools are now readily available to consumers and can be used to determine the coordinates of any given location. In addition, the linear interpolation method for calculating the optimum yield angles at any location has been demonstrated and validated through simulation.

#### References

Bekker B., (2007). Irradiation and PV array energy output, cost and optimal positioning estimation of South Africa. *Journal of Energy in Southern Africa*, Vol. 18 No. 2 May 2007.

**Table 3: Comparison between calculated and simulated annual energy yield for sample points not on the map**

Location	Interpolated annual energy yield	Simulated annual energy yield	Error (%)
X1 (27°S – 24.5°E)	56.883	56.909	0.046
X2 (27°S – 25.5°E)	55.701	55.608	- 0.166
X3 (27°S – 26.5°E)	52.892	55.948	0.106
X4 (27°S – 27.5°E)	53.835	53.870	0.065
Y1 (27.5°S – 24°E)	56.574	56.565	- 0.016
Y2 (28.5°S – 24°E)	58.066	58.145	0.136
Y3 (29.5°S – 24°E)	56.490	56.459	- 0.055
Y4 (30.5°S – 24°E)	55.907	55.968	0.109

- DME (2003). White Paper on Renewable Energy, Department of Minerals and Energy Republic of South Africa, November 2003, Part 5. [www.dme.gov.za/energy/renewable.stm](http://www.dme.gov.za/energy/renewable.stm).
- Medica M., Jurin G., and Frankovic B., (1996). The analysis of PV power supply availability using the reference year data – Faculty of Engineering, University of Rijeka, 51000 Rijeka, Vukovarska 58, Croatia.
- Sebitosi A. B., (2008). Energy Efficiency, Security of Supply and the Environment in South Africa: Moving Beyond the Strategy Documents. *Energy*, Volume 33, Issue 11, November 2008, Pages 1591-1596.
- Sebitosi, A. B., and Pillay P., (2008). Renewable energy and the environment in South Africa: A way forward. *Energy Policy*, Volume 36, Issue 9, September 2008, Pages 3312-3316.
- Sebitosi A. B., and Pillay P., (2008). Grappling with a half-hearted policy: The case of renewable energy and the environment in South Africa. *Elsevier Energy Policy* Volume 36, Issue 7, July 2008, Pages 2513-2516.

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# Assessing regulatory performance: The case of the Namibian electricity supply industry

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## Abstract

*The power sector reforms that commenced in the 1990s led to the establishment of independent electricity regulators in more than twenty countries across Africa. The main purpose for these institutions was to create greater transparency in tariff setting and provide increased certainty for investors. At the same time regulators are charged with the protection of the interests of current and future consumers of electricity. During the initial stages of reform it was the expectation that the state owned incumbents that were traditionally vertically integrated would be unbundled and privatised. In practice there have been very few privatisations and what have emerged are hybrid markets where state-owned utilities remain dominant with independent power producers on the margin. In these markets regulation is a complex melting pot of incentivising the performance of state-owned utilities, attraction of private sector investment especially to fill gaps in generation capacity and making sensitive pricing decisions. Recognising that regulation is beginning to establish a track record, the African Electricity Regulator Peer Review and Learning Network, an initiative of the University of Cape Town, Graduate School of Business provides an opportunity for high level learning through the assessment of regulatory performance. We detail an assessment of regulation in Namibia where we find prices transitioning to cost reflectivity but question the sustainability of current arrangements in the distribution of electricity and the country's long-term generation adequacy.*

*Keywords: regulatory performance, regulatory impact, regulatory governance, regulatory substance, peer reviews, experiential learning*

## 1. Introduction

### 1.1 The peer learning network

This paper draws on the work of the African Electricity Regulator Peer Review and Learning Network (Peer Learning Network), an initiative coordinated by the Management Programme in Infrastructure Reform and Regulation (MIR) at the University of Cape Town's (UCT) Graduate School of Business (GSB).

The Network comprises the Chief Executive Officers of the electricity regulators in Ghana, Kenya, Namibia, Tanzania, Uganda and Zambia (the members) who assess regulatory performance in each others' countries. This is done through structured and comprehensive peer reviews that also provide opportunities for deep experiential learning by the network members. It is expected that the lessons learnt will enhance leadership and management capability amongst senior regulators in Africa, and lead to increased credibility, legitimacy, transparency and robustness in their decisions.

The first peer review was conducted in Windhoek, Namibia from 20 to 24 October 2008 and is the subject of this paper.

### 1.2 Approach

Over a one week period, five of the members of the Peer Learning Network evaluate, on site, the regulatory system in the country of the sixth member. Interviews are undertaken with all relevant stakeholders ranging from the responsible minister, regulatory commissioners (board members), utilities, investors, consumer groups, non-governmental organisations and journalists. During the interviews, the stakeholders are invited to give their views on their experience with and performance of the electricity regulator and the electricity sector as a whole. This is followed by in-depth interrogation of regulator staff on the processes and outcomes of regulatory decisions.

The method of evaluation is adapted from Brown, Stern, *et al.* (2006) where the regulatory system is defined as ‘the combination of institutions, laws, and processes that give government control over the operating and investment decisions of enterprises that supply infrastructure services.’ Brown, Stern *et al.*, (2006) observe that: ‘any regulatory system has two important dimensions: *regulatory governance* and *regulatory substance*.’ Regulatory governance, also referred to as the ‘how’ of regulation, is ‘defined by the laws, processes, and procedures that determine the enterprises, actions, and parameters that are regulated, the government entities that make the regulatory decisions, and the resources and information that are available to them’ (Stern, 2009).

Regulatory substance is the ‘what’, or content, of regulation referring to core regulatory actions and decisions in relation to licensing (i.e. market access), tariff setting and supply and service and standards. The desired outcome of the interaction between regulatory governance and regulatory substance, *regulatory impact*, can be distilled into four main themes: cost effective pricing; reliable and quality infrastructure (electricity) service; sector financial and economic viability; and the timely attraction of new investment. Based on the foregoing, the regulatory system can be depicted as shown in Figure 1.

## 2. A framework for assessing regulatory performance

### 2.1 Regulatory impact

Effective regulatory systems create a more predictable and less risky environment for private investment and ‘is a means to an end’ (Stern & Holder 1999). That end should be seen in the context of regulatory impact.

As shown in Figure 1, regulatory impact is influenced by the regulatory governance arrangements and the content of regulation (regulatory sub-

stance). Consistent with the desired outcomes of regulation enumerated in Section 1.2 i.e. cost-effective pricing, reliable and quality infrastructure service, financially viable utilities and the attraction of new investment, Stern (2009) observes that the ‘key objective of economic regulation of infrastructure industries is to ensure the continuous supply, over the long-term, of unspecified infrastructure services of defined quality at the minimum necessary cost (and prices) to the population and industry of the country.’ It is within this context that regulatory performance should be evaluated.

### 2.2 Regulatory performance

The determination of regulatory performance is however not a simple undertaking. As Brown, Stern *et al.* (2006) state, ‘it is virtually impossible in a single-country case study to calculate the separate effect of a new regulatory system on overall sector performance.’ This difficulty arises from the fact that regulatory reform tends to be part of a wider package of measures that may include restructuring, commercialisation, private sector participation etc. Faced with this limitation, our approach to understanding regulatory performance is two-fold; firstly, we gather data based on the desired sector outcomes and secondly, an interrogation of whether the specific elements of regulatory governance and regulatory substance in Namibia help or hinder sector performance is made.

### 2.3 Regulatory governance

Regulatory governance is ‘the institutional and legal design of the regulatory system and is the framework in which decisions are made’ (Brown, Stern *et al.*, 2006). Newberry (1977) presents the regulatory problem as the need to ‘agree a regulatory compact which assures investors that their sunk capital will be adequately rewarded, and they will be protected from populist pressure to reduce prices to

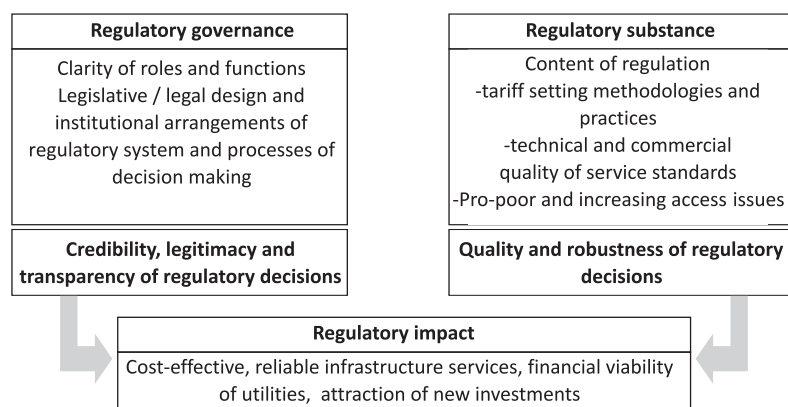
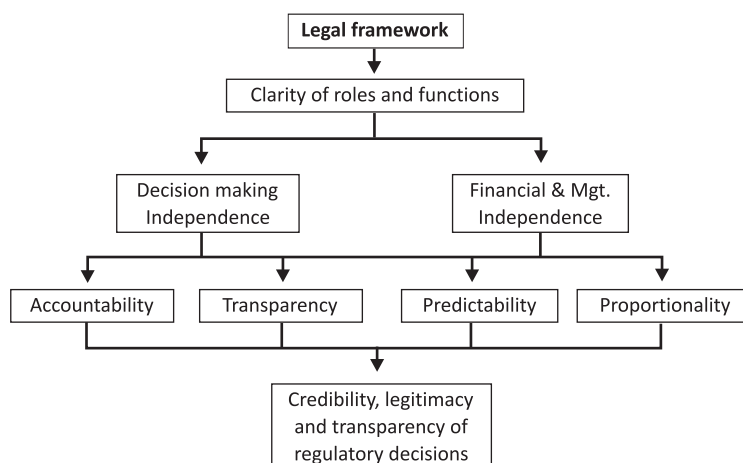


Figure 1: The regulatory system





**Figure 2: Regulatory governance**

avoidable cost.’ Such a regulatory compact should create more certainty and in effect reduce the amount of decision-making discretion available to the regulator, i.e. it should reduce arbitrary decision-making. Levy and Spiller (1994) define regulatory governance as being ‘the mechanisms that societies use to constrain regulatory discretion and to resolve conflicts that arise in relation to these constraints’. They further state that performance (in the sense of sustaining private sector investment) can be satisfactory, provided three complimentary mechanisms restraining arbitrary administrative action are in place, namely: ‘(a) substantive restraints on the discretion of the regulator, (b) formal or informal constraints on changing the regulatory system, and (c) institutions that enforce the above formal-substantive or procedural-constraints’. This might imply that full regulatory commitment is exhibited through regulators having no discretion. But as Stern and Cubbin (2005) observe: ‘in practice, it is virtually impossible for regulatory agencies to avoid interpretation of their objectives and to avoid discretion. The issue is then how to establish governance procedures that allow for the inevitability and desirability of a non-trivial degree of bounded and accountable discretion.’ To achieve this, Stern and Holder (1999) contend that governance arrangements should be such that they ensure transparency and predictability, two attributes that are anchored on accountability. They present accountability as comprising two aspects; formal and informal. Formal accountability refers to the formal legal basis in which the regulator operates, effectively in the tradition of the call for restraint presented by Levy and Spiller (1944) whereas informal accountability is the degree to which the regulatory process ‘encourages debate and open discussion; involves all relevant parties; leads to justification by the regulator of decisions and methodologies; and generally leads to a clear

understanding of the “rules of the game” (Stern, 1977).

From the foregoing regulatory governance can be depicted as shown in Figure 2 which provides the basis for the Peer Learning Network’s evaluation of this dimension of the regulatory system.

#### **2.4 Regulatory substance**

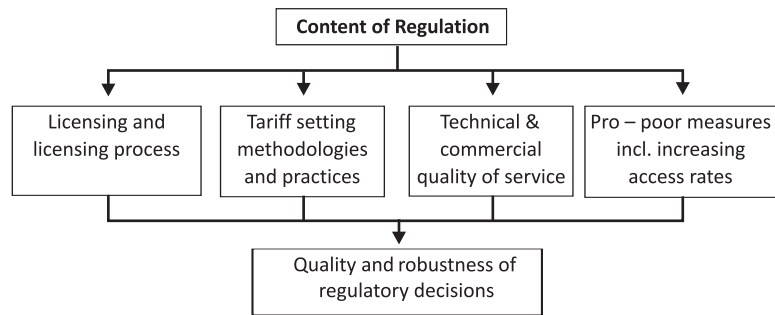
Brown, Stern *et al.* (2006) define regulatory substance as the content of regulation, the actual decisions, whether explicit or implicit, made by the regulatory entity. The network and natural monopoly characteristics of many infrastructure industries, such as electricity transmission and distribution, mean that economic rent may be extracted by operators at the expense of consumers, and that economic regulation is necessary. There is a large body of literature on economic regulation and tariff setting. It is not intended that a review of various pricing methodologies is made here, suffice to state that regulators have various well tested means at their disposal to determine tariff levels and tariff structures.

Regulatory substance is primarily about pricing decisions. It is also about determining market access, through licences. A further dimension is the development and enforcement of technical and commercial quality standards, and resolution of disputes between utility and consumer and amongst utilities. Other substantive issues that are of special importance in Africa are pro-poor measures that facilitate access to, and affordability of, electricity services. Figure 3 depicts regulatory substance.

### **3. The Namibian electricity industry**

#### **3.1 Policy and regulation**

Policy direction for the Namibian electricity industry is provided by the Ministry of Mines and Energy. Following the enactment of the Electricity Act in

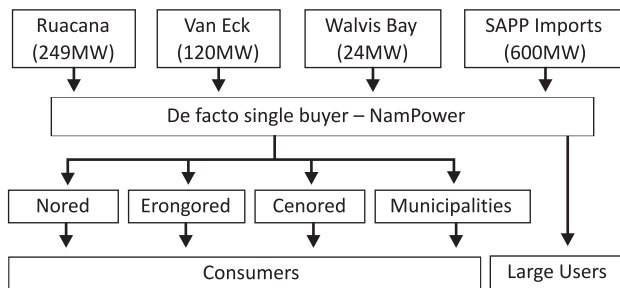


**Figure 3: Regulatory substance**

2000, an independent regulator for the industry, the Electricity Control Board (ECB), was established. In 2007 the Electricity Act was amended, making provision for private participation in the sector.

**3.2 Industry structure**

At the time of the peer review the structure of the Namibian electricity industry was in transition and is shown in Figure 4.



**Figure 4: Existing structure of Namibia electricity industry**

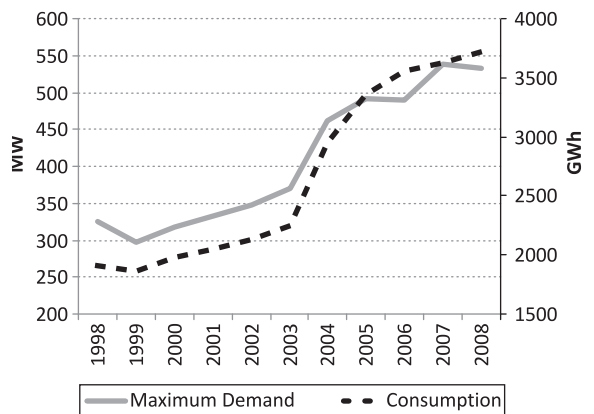
Matters that remain outstanding with respect to the structure include the location of the single – buyer function, currently retained *de facto* by NamPower, and its roles, obligations and governance structure, particularly as they relate to the need to assure prospective Independent Power Producer (IPP) investors of a ‘level playing field’. In addition, whether IPPs should exclusively trade with the single – buyer, or have bilateral access to local and international parties, has been a matter of debate.

In distribution, the formation of two REDs one covering the area served by the Windhoek Municipality, the other in the south of the country, remains outstanding. The proliferation of municipal authorities that are to be augmented in the formation of the two outstanding REDs coupled with the problematic local authority surcharge present sizeable challenges in reaching the expected end state structure of the industry.

**4 Understanding regulatory performance in Namibia**

**4.1 Key regulatory issues**

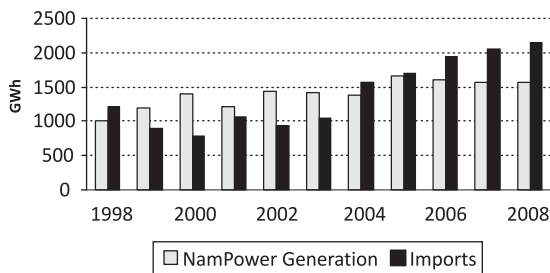
The Namibian ESI faces four main regulatory issues. Firstly, as is the case in the rest of sub-Saharan Africa (Eberhard, Foster et al., 2008), end-use electricity tariffs do not reflect the full cost of generation, transmission, distribution and supply. Secondly, access to electricity is low. 2001 figures show that while for urban areas access was an enviable 67.6%<sup>1</sup> (less than a quarter of households in sub-Saharan Africa have access), rural access remained at a low 9.5% resulting in an overall country access rate of 32%. Thirdly, peak demand at 533 MW<sup>2</sup> (which had grown at an annual average rate of 5.3% over the period 1998 – 2008, Figure 5); outstrips the country’s installed capacity of 393 MW and is forecast to almost double over the next ten years (NamPower, 2009). This has led to Namibia being increasingly dependent on electricity imports from its neighbours in the Southern African region as shown in Figure 6.



**Figure 5: Namibia demand and consumption**

However, the region as a whole is experiencing a generation deficit and the Southern African Power Pool (SAPP) forecasts that this shall be the case until 2013 at the earliest (Southern African Power Pool, 2009). As a result, the Government of Namibia (GoN) is keen that new indigenous generation

capacity is built. While a pipeline of new generation projects has existed for some time, none have yet been realised. The earliest that any new generation is expected to come on stream is now 2012 when the fourth 92MW unit at Ruacana Power station enters commercial operation. The flagship Kudu gas-to-power project which is crucial for the country's goal of self sufficiency in generation has faced delay and due to conceptual design changes has now been resized from its initial 800 MW to 500 MW and might only be commissioned in 2014.



**Figure 6: Indigenous generation vs imports**

The fourth issue is the number of small and non-viable electricity distributors. For a country with a population of two million and with an access rate of 32%, it is somewhat surprising that there are 22 entities licensed to distribute electricity. This places an inordinate amount of required regulatory effort on the industry regulator, the Electricity Control Board (ECB). In addition, municipal-owned electricity distributors electricity are permitted to a discretionary tax known as the Local Authority Surcharge (LAS), which adds considerably to the cost of electricity.

#### 4.2 Regulatory governance

While the mere establishment of an independent regulatory agency does to some extent signal regulatory commitment, the achievement of desired outcomes is dependent on the design of the regulatory system. A key finding for Namibia was that although the Electricity Act was unambiguous in its allocation of roles and responsibilities, quite a significant degree of final decision-making authority that would ordinarily reside with the regulator had been retained by the Minister. For example, the Minister, rather than the regulator, approves licences and regulations, thus compromising the independence of the regulator. ECB officials that were interviewed did however not find these clauses to be problematic but rather claimed that the arrangement gave rise to a degree of political legitimacy and had in fact worked well so far. The reason for this appeared to be more on account of personnel as opposed to the systems in place. For this reason it was questionable whether this good working relationship would be sustained over time.

Procedurally it was unclear how the Minister would make the relevant regulatory decisions and hence the required degree of bounded and accountable discretion, referred to in section 2.3, which is absent. In any case, given that the ECB has final decision making authority over what is ostensibly the most contentious of regulatory matters, tariffs, it was surprising that the remaining regulatory responsibilities had been left to Ministerial discretion.

Formal accountability requires that there is a mechanism through which regulatory decisions can be appealed. While parties to an ECB decision had the inalienable right to approach the courts of law for judicial review, it was found that there was no internal procedure that could be used to appeal to the ECB directly. The regulator had noted this anomaly and was in the process of developing a procedure.

Effective regulatory governance should 'encourage debate and open discussion' (Stern, 1997) as part of its informal accountability attributes. An avenue that regulators regularly use to achieve this is the holding of public hearings on key issues such as for tariff applications. This was however not the case in Namibia. Public hearings could lead to greater public awareness of the regulatory process and engender a better understanding of regulation including matters such as the methodologies employed for tariff setting. The absence of public hearings in Namibia could in part explain why there was no organised lobby that, in a sustained manner, made representations before the regulator on behalf of general electricity consuming public.

#### 4.3 Regulatory substance

##### 4.3.1 Cost-effective pricing

Namibia's Energy Policy (1998) sets out the following guiding principle for the setting of tariffs:

- Sound economic principles;
- Cost reflectivity (as far as possible);
- Should reflect long run marginal costs of supply; and
- Grant existing and potential industry participants a level playing field.

Even though NamPower is a vertically integrated utility, tariffs for generation, transmission and distribution in Namibia are determined separately. For generation, the ECB uses an inefficient import parity pricing (IPP) regime that prices local generation at the cost of imported electricity. The rationale for this is the country's high dependence on electricity imports especially from South Africa. However, the effect of this regime is to excessively reward the low cost to the Ruacana hydro plant. The regulator was of the view that these windfall gains can then be used to subsidise the higher cost coal-fired Van Eck power station and the Paratus diesel power plant. In recent years, primary energy costs have risen significantly (e.g. NamPower coal costs rose 378%

between 2003 and 2008 – Figure 7) and the import parity derived average generation price has been insufficient to meet the cost of increased generation at NamPower’s two thermal plants. As a result, the ECB has suspended the import parity regime and instead takes into account actual fuel costs. In future it is intended that the Revenue Requirement approach, which is already in use for transmission and distribution, shall be adopted for the generation sector.

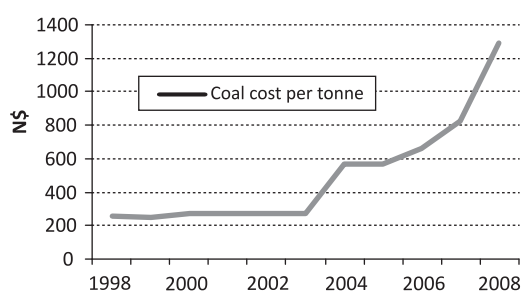


Figure 7: NamPower coal cost

#### Cost reflectivity

Theoretically the Revenue Requirement calculation – based on rate of return on assets plus depreciation and operating and maintenance costs, allows for full cost recovery. However, this has yet to be achieved. The Namibian government has a stated objective of reaching cost reflectivity in bulk tariffs by 2010/11, but progress has been difficult, mainly because of the increase in fuel prices (Figure 8).

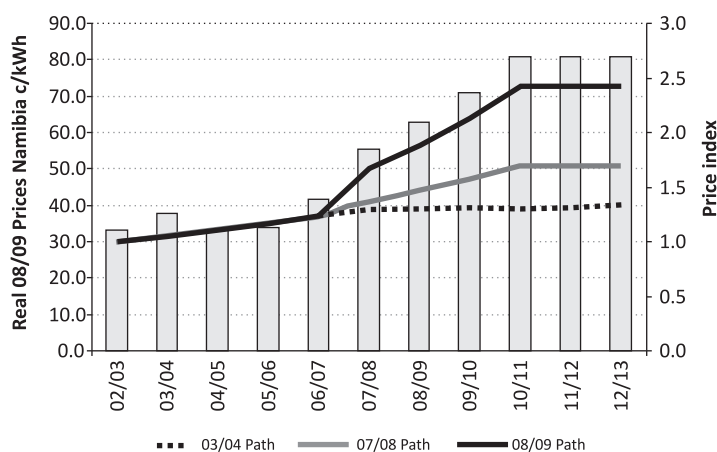


Figure 8: Path to cost reflectivity (N\$)

Source: Electricity Control Board

Although tariffs are yet to reach cost reflective levels, it is commendable that over the period 2002 to 2007, NamPower’s average price had not been eroded by inflation and had in fact risen in real terms, as shown in Table 1. The effect of this is that consumers will be shielded from excessive tariff increases as the government’s policy of cost reflectivity is implemented.

#### Asset valuation

A progressive feature of the economic regulatory methodology employed in Namibia, is its use of current or replacement asset values when determining the rate of return in its revenue requirement calculation. Most countries in the region rely on historical, depreciated asset values. In contexts of high inflation, with long intervals between investments, this can lead to average prices well below those required to support new investment. Namibia’s use of replacement values, implies that prices will rise to close to long-term marginal costs and hence be at levels sufficient to attract new IPP investments.

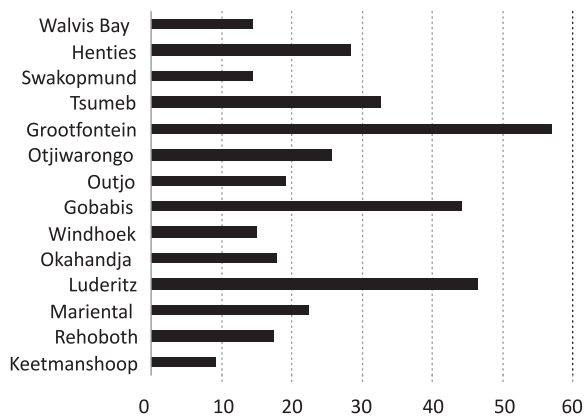
#### Efficiency incentives

One of the disadvantages of rate-of-return, or cost-of-service regulation is that it provides few incentives for operators to reduce costs (see Averch and Johnson (1962)). The ECB was aware of this deficiency and for the distribution sector has capped non-technical losses at a stringent 1.25% of total revenue, or at the level for the previous year whichever was lower. For technical losses these were capped in a range of 10 – 15% depending on nature and location of the particular distributor. The ECB did however treat requested maintenance expenses favourably during tariff revisions.

It is also noteworthy that for a country with a population of just over 2 million, the ECB approves 32 distribution tariffs of varying structures. This places an inordinate amount of work on the regulator and also presents a challenge for performance monitoring and benchmarking. This challenge is not eased by the distortionary impact of the discretionary local authority surcharge, which varied from N¢9.19/kWh to N¢56.98/kWh in 2007/08 across the fourteen municipalities that apply it as shown in Figure 9.

Table 1: NamPower average price

	2002	2003	2004	2005	2006	2007
Average price per unit (N\$-cents/kWh)	21.56	27.63	30.11	33.77	34.71	38.38
Average price per unit (US\$-cents/kWh)	2.05	3.67	4.67	5.27	5.04	5.34
Average annual price increase (%)	n/a	28.2	9.0	12.2	2.8	10.6
Average annual inflation (%)	11.4	7.1	4.2	2.3	5.1	6.7



**Figure 9: Local authority surcharge (N¢/kWh)**

#### 4.3.2 Adequacy and security of supply and the attraction of new investment

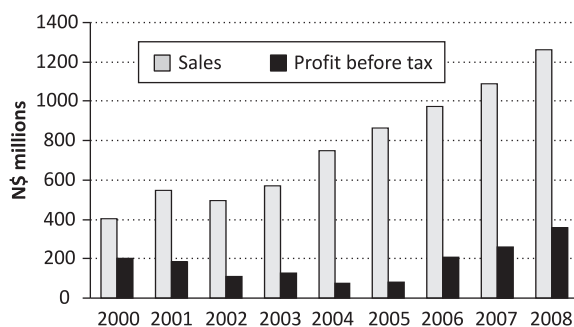
Although the number of consumer groups met in Namibia was by no means representative, there was general contentment with the existing level of electricity quality and reliability. However, future reliability of electricity supplies was at risk since the biggest concern for Namibia remained the looming shortages of electricity supplies as a result of the reduced availability of electricity imports, the absence of IPP investments, increased economic activity and the forecast demand for electricity in the country.

The peer review made five recommendations aimed at enhancing security and reliability of supply. Firstly, it was noteworthy that there was no electricity security supply standard for Namibia. Such a standard if based on an agreed Loss of Load Expectation (LOLE) could introduce more objectivity in the determination of the country's reserve margin, import requirements and the opportune time at which to increase generation and transmission capacities. Secondly, responsibility for monitoring and reporting on this security standard needed to be allocated to the regulator. Thirdly, there appeared to be uncertainty on where the responsibility for the National Integrated Resource Plan (NIRP) lay. During the peer review it was found that while NamPower was undertaking an NIRP, this process had not been recognised by the ECB who intended to undertake a separate planning process. Clearly such duplication was not the most optimum use of otherwise scarce resources. With the attendant need of attracting new generation into the sector, clarification of this responsibility would only aid the process. Lastly, it was noted that most expressions of interest in new build opportunities that were received were unsolicited.

The peer review recommended that international competitive bidding processes be initiated in time to meet the supply requirement indicated in the NIRP. Criteria and processes also needed to be developed for assessing unsolicited bids.

#### 4.3.3 Financial viability of utilities

NamPower, the state owned vertically integrated utility and dominant player in Namibia's electricity industry remains a financially viable entity and has been profitable over the last 10 years (Figure 10).



**Figure 10: NamPower financial performance**

This is in part due to the ECB's commitment to cost reflectivity. More recently, government's N\$1Billion recapitalisation programme (N\$250 million in 2007 and 2008 respectively with the balance expected in 2009) has significantly aided NamPower's financial health. In addition, government has approved an annual grant of N\$120million to support the running of expensive thermal generation to ensure security of supply over the period 2008 to 2010. Consequently, on account of these and other factors such as Namibia's (the country) own sovereign rating, rating company Fitch in March 2009 reaffirmed NamPower's BBB-investment-grade rating. Interestingly, in its assessment of NamPower's operating environment the rating agency makes the following comment: 'The regulator continues to make progress towards bringing regulation more into line with developed market standards' (Fitch, 2009).

In the distribution sector however, challenges remain. A 2006 benchmarking exercise revealed that all the REDs had failed to perform satisfactorily against set benchmarks, with the best performing having only been satisfactory in three of the specified nine specified performance measures shown in Table 2. In interviews with the Chief Executive Officers of two of the REDs, it was revealed that at current tariff levels there was insufficient revenue being generated to earn an adequate rate of return or to fund the depreciation expense. While no evidence was presented to support this assertion, the ECB's own admission that tariffs were at below cost levels lent it credence. It would however, appear that there was also need for internal efficiency improvements within REDs to lower costs.

**Table 2: Key performance indicators**

<i>Performance indicators</i>	<i>Benchmark</i>
<b>Financial</b>	
Return on revalued assets	≥4%
Operating margin	≥17%
Current ratio	
Quick ratio	
Liquidity	≥1
<b>Technical</b>	
Energy conversion efficiency	≥90
<b>Commercial</b>	
Debtor days	≤51
Operating cost / sales	≤30%
Bad debts	<0.3%
<b>Efficiency</b>	
Customers / employee	>300
Energy sold / employee	≥6000kWh

#### *Pro-poor initiatives*

A special challenge in a country such as Namibia is the need to widen access to electricity services. For a country with an overall access rate of 32% of which rural access was 9.5%, it was surprising that the regulator did not play an active role in this area. This could be through tariff structures that target the poor, incentivising the extension of the grid by utilities or encouraging the development of off-grid electricity supplies for rural communities.

The peer review found that the only structured initiative for rural electrification was the annual grants disbursed to distributors from central government, which were in themselves insufficient to meet the electrification targets set out in the National Development Plan. Separately, NamPower also provided a subsidy for rural electrification. Interestingly, interviews with the ECB revealed that this subsidy was not recovered in the tariff and that instead 'NamPower absorbs any cost mismatches within itself.'

## **5. Conclusion**

This paper reports on the successful application of the regulatory evaluation framework developed by Brown *et al.*, (2006). Peer reviews provide an effective means for undertaking such evaluations as well as affording unique experiential learning to the peer review participants as they compare and share knowledge and practices in the country being reviewed with their own country contexts.

Effective regulation should lead to cost-effective tariffs, reliable and quality infrastructure service, financial viability of utilities and the attraction of new investments. We find that in the case of Namibia, the regulatory system has encouraged cost effective pricing, although full cost reflectivity is yet to be reached. The pricing regime for generation could be made more efficient and distribution tariffs streamlined. The financial viability of the distribution sector and the attraction of new generation

investment do however, present challenges for the long term sustainability and quality of electricity supplies.

## **Notes**

1. 2001 figures, source Electricity Control Board, Namibia.
2. Source NamPower Annual reports – includes the Scorpion mine which is supplied from the South African grid.

## **References**

- Averch H. and Johnson L. L. (1962). Behaviour of the Firm Under Regulatory Constraint. *American Economic Review* 52(5): 1053-1069.
- Brown A. C., Stern J., et al. (2006). *Handbook for Evaluating Infrastructure Regulatory Systems*, The World Bank.
- Eberhard A., Foster V., et al. (2008). *Underpowered: The State of the Power Sector in Africa*. Africa Infrastructure Country Diagnostic, World Bank.
- Fitch (2009). *Namibia Power Corporation (Proprietary) Limited*.
- Levy B. and Spiller P. T. (1994). The Institutional Foundations of Regulatory Commitment: A Comparative Analysis of Telecommunications Regulation. *Journal of Law, Economics, & Organization* 10(2).
- Ministry of Mines and Energy (1998). *White Paper on Energy Policy*: 39.
- NamPower (2009). *NamPower Investor Update*.
- Newbery D. (1997). Rate-of-Return Regulation Versus Price Regulation for Public Utilities.
- Southern African Power Pool (2009). *Overview of the Southern African Power Pool*. SADC-SAPP-RERA Investors Roundtable. Livingstone, Zambia.
- Stern J. (1997). What Makes an Independent Regulator Independent? *Business Strategy Review* 8(2): 67-74.
- Stern J. (2009). *The Regulatory and Institutional Dimension of Infrastructure Services*. Department of Economics Discussion Paper Series, City University, London.
- Stern J. and Cubbin J. (2005). 'Regulatory Effectiveness: The Impact of Regulation and Regulatory Governance Arrangements on Electricity Industry Outcomes.' World Bank Policy Research Working Paper (3536).
- Stern J. and Holder S. (1999). *Regulatory Governance: Criteria for Assessing the Performance of Regulatory Systems - An Application to Infrastructure Industries in the Developing Countries of Asia*. *Utilities Policy* 8: 33-50.

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# Life cycle inventories to assess value chains in the South African biofuels industry

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### Abstract

The South African government ratified a new biofuels industrial strategy at the end of 2007. The feasibility study that forms the basis of the strategy highlights the potential environmental implications of such a strategy. However, at present there is no structured approach to evaluate the environmental profile of the scenarios within the strategy. This paper introduces life cycle inventories whereby the environmental profiles of biofuel value chains may be evaluated meaningfully. The scope of the paper focuses on the seed extraction biodiesel production scenarios of the strategy. The inventory analysis shows that the inputs and outputs of the farming unit process are sensitive to the type of crop and region of produce. Water usage is a highly variable parameter, which emphasises the importance of rainfall and irrigation to the overall burden of the biodiesel system on water resources. Crop yields may differ by a factor of two, which is a significant difference in terms of land and non-renewable energy resources requirements. The oil and meal/cake content of the seed proves to be the most important parameter that influences the initial unit processes of the value chains; almost all the inputs and outputs of the farming unit processes, for all the crops, range in the order of a factor of two due to this parameter. The uncertainties associated with the logistic system in the value chain also have major implications. Further, should there be no market offset for the meal/cake co-products, the waste treatment requirements would be highly uncertain. Very little uncertainties were detected in the biodiesel production unit process, although the energy efficiency, and sustainability, of the overall production

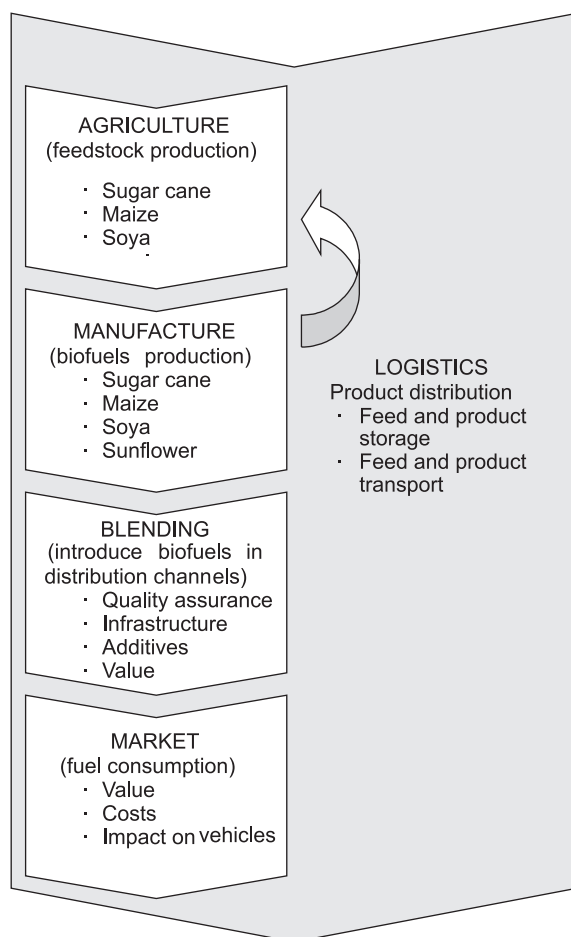
system remains questionable. The paper identifies a number of limitations with inventory sets that need to be addressed through further research efforts to improve the environmental evaluations of a biofuel value chain in South Africa for policy-making purposes.

*Keywords:* biofuel, biodiesel, life cycle inventory, life cycle assessment, environmental profile

### 1. Introduction

The South African government (DME, 2007) ratified a biofuels industrial strategy in December 2007. The strategy aims to achieve a biofuels average market penetration of 2% of liquid road transport fuels, namely petrol and diesel, in the country by 2013. This biofuels target will contribute up to 50% to the 2013 national renewable energy target of 10 000 GWh (DME, 2003). It is envisaged that the target is achievable without excessive economic support by utilising surplus agricultural capacity. The target is based on local production, both agricultural and manufacturing, to provide the benefits of employment, economic growth and Black Economic Empowerment (BEE) through the value chain (see Figure 1) (NBTT, 2006).

The South African biofuels industrial strategy is primarily based on a feasibility study of the National Biofuels Task Team (NBTT, 2006), the viability of which has been critiqued (Brent *et al.*, 2009). The feasibility study briefly describes the perceived environmental impacts associated with the biofuels



**Figure 1: Diagram of the biofuels production value chain**

Source: NBTT, 2006

value chain, and mainly focuses on feedstock of sugar cane and maize, for bioethanol, and soybean and sunflower, for biodiesel.

Some key conclusions from the feasibility study are as follows (NBTT, 2006):

- Increased cultivation of energy crops could have additional impacts on South African soils; conservation agriculture (Derpsch, 2005) should be adopted by all farmers as it makes more economic sense, through fewer inputs, and improves soil fertility and thereby greater yields.
- Biodiversity can be threatened through the expansion of cultivation as mono-cropping (Scholes and Biggs, 2005), use of pesticides and fertilisers, and the release of genetically modified or alien crops into nature all impact negatively; an analysis of the potential impact on biodiversity of expansion of the cultivation areas in South Africa, beyond the targeted surplus agricultural capacity, should be undertaken.
- An extended energy crop industry could further increase pressure on South Africa's limited water resources (Berndes, 2002), not only for irrigation production, but also with rain fed produc-

tion of both annual and perennial crops; and biofuels processing needs to be carefully assessed for its impact on the water reserves in a given catchment.

- An introduced biofuels value chain could lead to increased pollution to natural resources; biofuels processing needs to be assessed against industrial pollution regulations to determine whether the processes are adequately covered, and health and safety regulations need to be assessed for their ability to adequately deal with the challenges of potential small-scale processing plants.
- The biofuels value chain is not carbon neutral; and a life cycle approach should be used when considering support for programmes that are chosen based on their capacity to mitigate climate change.

## 2. Objectives of the paper

Life cycle assessment studies have been conducted on bioenergy production from biomass (Jungmeier *et al.*, 2002; Pro *et al.*, 2005), and on bioethanol (Kim and Dale, 2006; von Blottnitz and Curran, 2007) and biodiesel (Spirinckx and Ceuterick, 1996; Kim and Dale, 2005) production in particular. However, these types of studies have not been conducted to increase the understanding of the environmental implications of the South African biofuels industrial strategy.

This paper subsequently set out to develop South African life cycle inventories of biodiesel production as a first step towards comprehensive analyses of biofuel value chains. The paper focuses on commercial-scale seed extraction biodiesel production, although it is envisaged that the inventories will be developed further for small-scale and other distributed and co-production routes. The paper also considers the environmental impact profiles of such inventories for policy-making purposes.

## 3. Scope of the study

In the short-term, the feasibility study of the National Biofuels Task Team (NBTT, 2006) focuses on conventional food crops, namely first-generation biofuels production. Three crops were subsequently chosen as likely feedstock for a commercial biodiesel value chain in South Africa (Nolte, 2007): soybean, sunflower, and canola. For these three crops, the total biodiesel value chain production costs are estimated to be below 1US\$ per litre (Nolte, 2007). The biofuels industrial strategy envisages that the crops will be produced in the Mpumalanga, KwaZulu-Natal, Eastern Cape and Western Cape Provinces (see Figure 2).

### 3.1 Functional unit and reference flow

The choice of functional unit depends on the focus of life cycle assessment studies. If the intent is to





**Figure 2: Envisaged biodiesel feedstock production in South Africa**

examine the environmental performances of different cropping systems, then an area of land planted has been used as a functional unit (Kim and Dale, 2005). When fuels are compared, then the functions of the fuel products are normally used; for example, the work delivered by a diesel engine or a certain mass transported over a distance (Sheehan *et al.*, 1998).

Since the aim of this paper is to establish environmental profiles of biodiesel products, a unit of product, over a one-year production period at a commercial-scale facility, was chosen as reference flow, namely 19 500 tonnes of 100% biodiesel (B100) produced per annum (19.5 kt/yr). This equates to a 2 500 kg/hr production facility, which is deemed an optimum biodiesel plant size for commercial purposes in the South African context (Nolte, 2007).

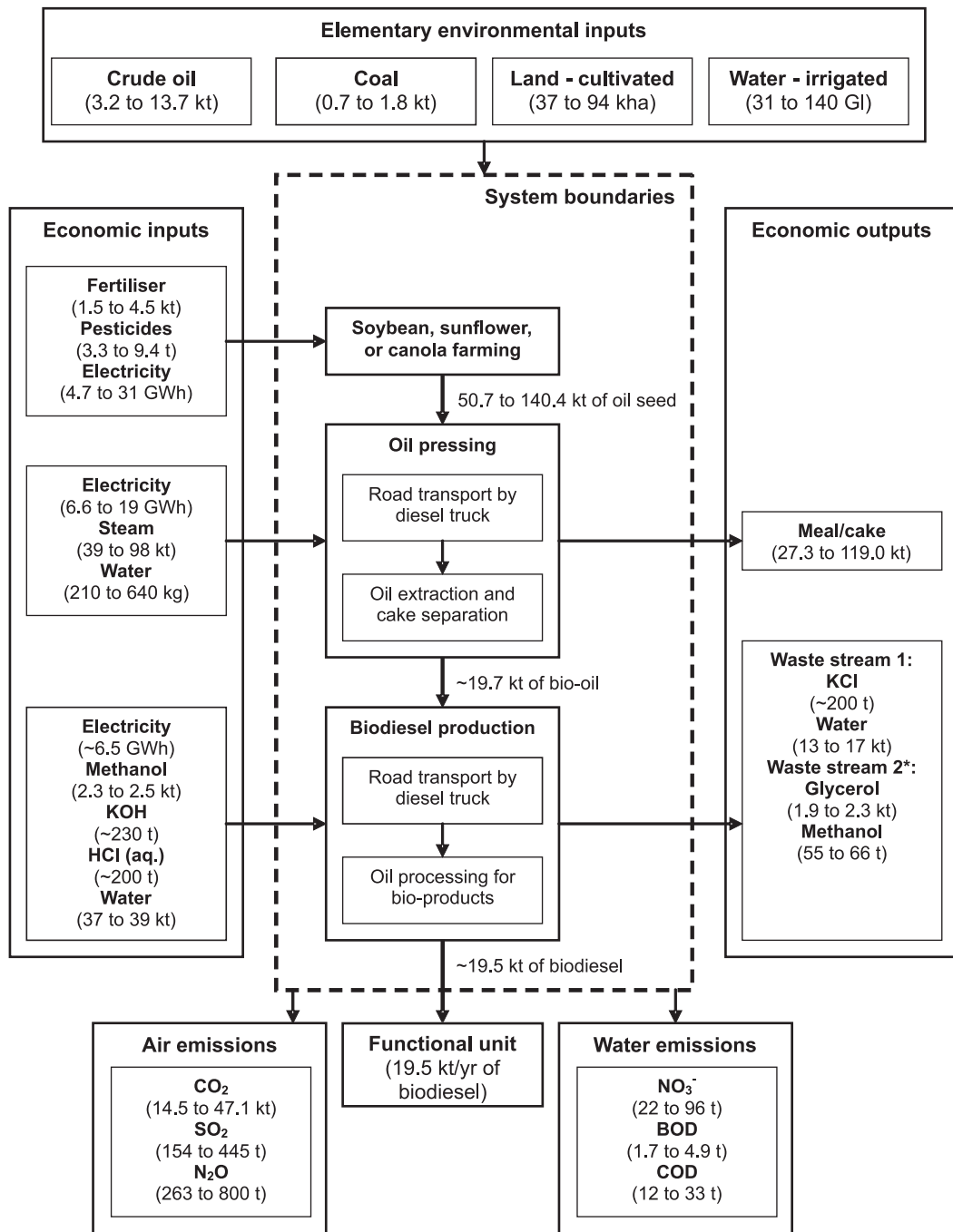
### 3.2 Initial system boundaries and data quality

The unit processes that were included in the initial system boundaries and the main system flows are depicted in Figure 3. A large-scale commercial biodiesel industry has yet to be realised in South Africa (Nolte, 2007). Indeed, it is perceived that under the current dispensation, a large-scale biofuels industry is not sustainable unless the government provides more attractive incentives to encourage private sector investment (Tait, 2005). The study therefore required the postulation of a hypothetical commercial biodiesel industry, based on the current South African soybean, sunflower and canola production and crushing industries and fuel

transportation infrastructure, and (First World) methyl ester transesterification technology (Harding *et al.*, 2008). These life cycle phases of conventional seed extraction biodiesel production were considered only, namely the use phase was excluded. To this end, the environmental implications of using the blended biodiesel and conventional petroleum diesel, as per the national biofuels industrial strategy, have not, until now, been investigated in detail in the South African context, although the required blending ratio is deemed to play a minor role in changing the environmental impacts of the use phase.

Industry and national data was primarily used for the farming, oil pressing, and biodiesel production (Harding *et al.*, 2008) unit processes, and a field trip was conducted to update some of the process parameters based on current practices and planned developments. The field trip included agricultural associations in South Africa, farmers, oil press operators, and future biofuels production developers.

The economic inputs to the three main unit processes were included in the system boundaries. However, since industry and national data availability was a constraint for these inputs, international databases and biodiesel studies (Sheehan *et al.*, 1998) were used. The consequence is that certain economic inputs are reported directly as elementary flows, or environmental inputs; for example, crude oil and coal inputs due to diesel and gasoline usage in the farming equipment. The economic outputs, namely the meal/cake from the oil pressing unit process and the two by-products/waste streams



\* Glycerol, and also potentially methanol, can be recovered and sold; therefore, stream 2 may not constitute a waste, but a by-product

**Figure 3: General biodiesel production system**  
(Details of the variations in the values are provided in Table 2)

from the biodiesel production unit process, were excluded from the system boundaries.

The exclusion of these outputs is important from an allocation perspective. A recent publication (Guinée and Heijungs, 2007) has shown that different allocation methods could (potentially) generate large differences in allocation factors and consequently also at the level of environmental impacts

of fuel chains. Much of the literature discusses the choice of parameter to base allocation on; for example, mass, economic, or energy (calorific) value of the (by)-products.

For this life cycle inventory, allocation was not considered, namely all the economic and elementary environmental flows are allocated solely to the biodiesel product. Assumptions will subsequently

have to be made with future studies that utilise this inventory, especially since the meal/cake, at present, is the most important economic product from the feedstock production for some crops, particularly for soybean.

Similar to previous biodiesel studies (Sheehan *et al.*, 1998), the environmental flows associated with producing capital equipment and facilities in the life cycle were not considered. For petroleum diesel life cycles, these flows have been shown to be negligible (Sheehan *et al.*, 1998). In the case of biodiesel, the biomass resources are less energy dense and concentrated and the energy embodied in the construction of the equipment and facilities in the life cycle may be more significant. However, to be consistent with other fuel chains, these life cycle flows were excluded from the inventory.

### 3.3 Description of unit processes' data

Table 1 summarises the key parameters for the farming unit process. The yields of the soybean, sunflower, and canola feedstock crops were estimates for the 2005/6 growing season, which were obtained from Grain South Africa, a non-profit organisation, and from a study of the University of Pretoria. Fertilizer application for each crop was provided by the Fertilizer Society of South Africa, a non-profit company that represents the interests of the fertilizer and agricultural lime industries in South Africa. The different fatty acid methyl esters (FAME)

densities were obtained from literature (Pischinger *et al.*, 1982; Schwab *et al.*, 1987).

For uncertainty analyses, minimum and maximum percentages of oil and meal/cake in the seed were derived from international data (Sheehan *et al.*, 1998). The maximum amount of water needed, as extracted from a catchment area, was assumed to be the requirement of the crop for optimal growth. The minimum water needed was assumed to be the irrigation requirements only, as the rainfall of the regions, which was obtained from the South African Department of Environmental Affairs and Tourism, was subtracted from the requirement of the crop. Minimum and maximum calculations of all the other flows to and from the farming unit process were based on the differences in oil in the seed.

The transportation, from the farming unit process to the oil presses, was calculated by assuming that trucks greater than 32 tonnes would be utilised. According to the Road Transport Annex in the EMEP/CORINAIR Emission Inventory Guidebook (EEA, 2006), for a fully loaded articulated truck travelling between 40 and 60 km/h at 0% gradient and for European emission standards in the 1980s, approximately 0.55 litres of diesel would be needed per kilometre. For the same truck carrying no load, 0.3 litres/km would be needed. An average of 0.43 litres/km was assumed for this study. It was further assumed that oil presses would be located in

**Table 1: Key parameters for the farming unit process (2005/6 growing season)**

Parameter	Unit	Crop		
		Soybean	Sunflower	Canola
Area grown	'000 ha	120	640	20
Average yield – South Africa <sup>a, b</sup>	tonnes/ha	1.70	1.31	1.42
Fertilizer consumption – N <sup>c</sup>	kg/ha	7	15	40
Fertilizer consumption – P <sup>c</sup>	kg/ha	25	21	7
Fertilizer consumption – K <sup>c</sup>	kg/ha	8	2	36
Fertilizer consumption – total <sup>c</sup>	kg/tonne crop	25.0	24.1	58.5
FAME density	kg/kl	880	884	920
Minimum meal percentage	%	78.5	56.0	59.0
Maximum meal percentage	%	84.5	75.0	72.0
Minimum oil percentage	%	15.5	25.0	28.0
Maximum oil percentage	%	21.5	44.0	41.0
Minimum water required – irrigation <sup>d</sup>	l/tonne crop	0.56	0.36	0.65
Maximum water required – irrigation <sup>d</sup>	l/tonne crop	1.40	1.10	1.20

a Food and Agricultural Policy Research Institute (FAPRI), University of Missouri College of Agriculture Food and Natural Resources, University of Pretoria, (2004): Final report for the University of Missouri South African education program. FAPRI-UMC Report #07-04, [www.fapri.missouri.edu/outreach/publications/2004/FAPRI\\_UMC\\_Report\\_07\\_04.pdf](http://www.fapri.missouri.edu/outreach/publications/2004/FAPRI_UMC_Report_07_04.pdf)

b Grain South Africa, [www.grainsa.co.za](http://www.grainsa.co.za)

c Fertilizer Society of South Africa, [www.fssa.org.za](http://www.fssa.org.za)

d South African Department of Environmental Affairs and Tourism, [www.environment.gov.za/enviro-info/prov/rain.htm](http://www.environment.gov.za/enviro-info/prov/rain.htm)

the provinces, within 500 km of the farming activities, but at an average distance of 100 km; this is in line with findings elsewhere (Sheehan *et al.*, 1998). Similar distances and modes were assumed for the transportation from the oil presses to the production plant. The petroleum resource requirements are directly reported as elementary flows of crude oil and coal.

The energy usages in the oil pressing and biodiesel production unit processes were mostly derived from international data (Sheehan *et al.*, 1998), but updated with site-specific and design information in the South African context. Specifically, electricity and steam usages reflect the situation in South Africa. Similarly, the other chem-

ical material inputs in the biodiesel production unit process were obtained from detailed South African designs and models.

The emissions to air and water were primarily obtained from international databases (Sheehan *et al.*, 1998).

### 3.4 Description of data categories

The data was categorised into economic flows and elementary environmental flows. The economic flows are reported as such in the inventory and are not converted to elementary flows. Thereby local and region specific information may be used to expand the elementary flows; for example, the electricity (Koch and Harnisch, 2002) and water (Lan-

**Table 2: Comparative summary table for the different feedstock (for a production year)**

Flow	Soybean		Sunflower		Canola	
	Min / 19.5 kt	Max biodiesel	Min / 19.5 kt	Max biodiesel	Min / 19.5 kt	Max biodiesel
<i>Economic inputs</i>						
Electricity [GWh]	32	39	26	44	18	29
Steam [kt]	59	98	39	59	39	59
Methanol [kt]	23	25	23	25	23	25
KOH [t]	230	230	230	230	230	230
HCl (aq.) [t]	200	200	200	200	200	200
Fertiliser [kt]	1.6	3.7	1.5	2.7	2.9	4.5
N [kt]	0.3	0.7	0.6	1.1	1.4	2.1
P [kt]	1.0	2.3	0.8	1.5	0.3	0.4
K [kt]	0.3	0.8	0.1	0.2	1.3	1.9
Pesticides [t]	6.8	9.4	3.3	5.9	3.5	5.1
Water -processing [kt]	37	39	37	39	37	39
<i>Economic outputs</i>						
Bio-diesel [kt]	19.5					
Meal/cake [kt]	80.0	119.0	27.3	66.3	29.3	54.6
<i>Waste stream 1</i>						
KCl (aq.) [kt]	0.2	0.2	0.2	0.2	0.2	0.2
Water [kt]	13	17	13	17	13	17
<i>Waste stream 2</i>						
Glycerol [kt]	1.9	2.3	1.9	2.3	1.9	2.3
Methanol [kt]	0.06	0.07	0.06	0.07	0.06	0.07
<i>Elementary inputs and outputs</i>						
Land – cultivated [kha]	41	94	37	70	37	53
Water – irrigated [Gl]	78	140	31	55	49	64
Crude oil [kt]	9.2	13.7	4.1	8.9	3.2	6.4
Coal [kt]	1.4	1.8	0.7	1.2	0.8	1.1
CO <sub>2</sub> [kt]	38.0	47.1	14.5	30.1	16.9	29.1
SO <sub>2</sub> [t]	263	445	154	238	158	210
N <sub>2</sub> O [t]	710	800	263	530	265	476
NO <sub>3</sub> <sup>-</sup> (water) [t]	22	37	41	45	96	96
BOD (water) [t]	3.5	4.9	1.7	2.9	1.7	2.5
COD (water) [t]	25	33	12	21	12	18

du and Brent, 2006) supply scenarios.

For the farming unit process, all the data of the economic inputs reflect South African values, except for the pesticides requirements. The elementary flows are primarily based on international data (Sheehan *et al.*, 1998) except for the land and water usage, which are South African specific. For the oil pressing and biodiesel unit processes, the economic flows reflect South African practices and design models, but the elementary flows were obtained from published data (Sheehan *et al.*, 1998).

In terms of the elementary environmental flows, the chosen inputs and outputs were based on the availability of data, the quality of published background information, and the main environmental categories that have been considered by various life cycle assessment publications (Weiss *et al.*, 2007):

- Non-renewable resources usage, i.e. crude oil and coal, which are aggregate for the three main unit processes.
- Land usage, as existing agricultural land for the farming unit process.
- Water usage, of a quality deemed suitable for agricultural irrigation in terms of the South African water quality guidelines (DWAF, 1996).
- Global warming potential (GWP).
- Acidification potential (AP).
- Eutrophication potential (EP).
- Other damages to water resources.

#### 4. Life cycle inventory analysis and discussion

The detailed inventory dataset is provided elsewhere (BIOISSAM, 2010: [www.biossam.org/wp-content/uploads/2010/08/Life-cycle-inventory-data-for-biodiesel-scenarios.pdf](http://www.biossam.org/wp-content/uploads/2010/08/Life-cycle-inventory-data-for-biodiesel-scenarios.pdf)) and summarised in Table 2. For the farming unit processes, data values are provided for the reference flow of the unit process, namely 1 tonne of produced oil seed, and for the functional unit of the complete life cycle, namely 19.5 kt/yr of biodiesel product. Per reference flow, the variations in the data reflect differences between the Provinces, except for canola where country average values were used. Per functional unit, the variations in the data reflect uncertainties throughout the life cycle.

For the oil pressing unit processes, which include the transportation from the respective farming unit processes, the data values are again provided for the reference flow of the unit process, namely 1 tonne of processed oil seed, and for the functional unit of the complete life cycle. Variations in the data per reference flow are due to the potential differences in the oil and meal/cake content of the oil seed. Per functional unit, the uncertainties across the value chain are reflected in the variations of the data.

Data values are provided for the biodiesel pro-

duction unit process, which includes the transportation from the oil pressing unit processes, per a reference flow of 1 tonne of biodiesel produced, and per the functional unit of 19.5 kt/yr. Uncertainties are due to the location of the facilities, which has a minor influence, and the interactions between unit processes in the value chain.

##### 4.1 Sensitivity and uncertainty analyses

The farming unit process showed significant sensitivity to the type of crop and region of production. For example, the inputs and outputs of sunflower, except for water usage, do not differ much between the Provinces, but due to yield differences in soybean production, the values may differ by a factor of two. Such variability has also been reported elsewhere (Landis *et al.*, 2007).

The availability of data, and how it is reported, also plays a significant role. For example, energy usage on the farm is often reported per hectare and emissions, in international databases, per tonne produced. The consequence is that emissions may not seem sensitive to feedstock production yields, although, of course, they should. The water usage ranges by a factor of two for soybean and canola, and by a factor of nearly three for sunflower, which highlights the importance of rainfall in a region in terms of the requirement to extract water from a catchment.

The oil and meal/cake content of the seed produce influences the elementary flows associated with the transportation requirements to the oil pressing unit process, although the South African field trip data suggests that it is not a very important factor in terms of energy usage at the oil pressing facilities. However, the oil and meal/cake content proves to be the most important parameter that influences the unit processes in the initial life cycle phases. Almost all the inputs and outputs of the farming unit processes, for all the crops, range in the order of a factor of two due to variations in this parameter.

Section 3.2 indicates that, at present, the meal/cake co-product has an economic value, often more than the fuel product. However, should there not be an offset market, the production system would face a significant waste stream; between 27 and 120 kilo tonnes for 19.5 tonnes of biodiesel. This, together with the other waste streams, most notably KCl (around 200 tonnes) and glycerol (2 kilo tonnes), would necessitate a separate waste management systems in the economy (see Figure 3).

The uncertainties associated with the logistic system in the value chain have major implications. For example, should the distances from the farming activities to the oil pressing unit process, and to the biodiesel production unit process, increase by a factor of two, then the energy balance may be negative

(with soybean as feedstock). Indications are that average distances should not exceed 300 km in the product value chain.

Very little uncertainties were detected in the biodiesel production unit process. However, the energy efficiency of the overall system needs due consideration. On average, the 19.5 kilo tonnes biodiesel product has an energy-content in the order of 800 TJ; the energy demand of the system is in the order of 400 to 1100 TJ. This means that the nearly half of all the production may be an energy sink, which is clearly unsustainable.

#### **4.2 Interpretation and limitation of the inventory dataset**

From the sensitivity and uncertainty analyses, it would seem that the most important system parameters that need attention in terms of accuracy to establish an environmental profile are:

- The crop yields, and therefore land usage;
- The water usage;
- The oil and meal/cake content of the seed produce; and
- The logistics system.

There are, however, a number of limitations with the inventory. For example:

- The geographical representation of available data remains a problem for most of the elementary flows and for the initial unit processes of value chains, especially in the South African context (Brent *et al.*, 2002).
- Farming practices are not captured in the flows of such a simplified inventory. For example, crop rotation is vital to preserve soil quality in most regions of South Africa, and the chemicals used may differ significantly between regions (Brent *et al.*, 2009).
- The inventory focuses on the scenarios of the biofuels industrial strategy of South Africa in that existing agricultural land, for cultivation, is occupied for the crop production (Brent *et al.*, 2009). The potential requirement to transform land is not captured, which, in turn, may have a significant influence on ecosystems' structure and functioning (Achten *et al.*, 2007).
- The temporal scale of the inventory dataset is problematic in that values for certain harvest years are utilised, but there are great variations in wet and dry periods in South Africa that would increase the uncertainty of the inventory (Brent *et al.*, 2009).

#### **5. Implications for environmental impact profiles of South African biofuel value chains**

The limitations of the inventory dataset (BIOSSAM, 2010) highlight the challenge with deriving comprehensive impact assessment profiles for biodiesel production. Much emphasis has been placed on

energy balances and air emissions of such life cycle systems, but the following aspects are yet to be addressed:

- Although frameworks of land use are in development (i Canals *et al.*, 2007), the conventional definition of land usage flow, in life cycled assessment terms, is deemed inadequate to reflect changes in the quantity and quality of land resources in these studies. However, biodiversity indexes have been proposed to evaluate land usage changes (Scholes and Biggs, 2005) that could be used to define appropriate land usage flows.
- The definitions of the water usage and effluent flows in the inventory datasets are deemed inadequate to reflect changes in the quantity and quality of water resources (Brent, 2004). Similar to the land resources, the diversity at microbial level has been proposed as an index that can be utilised to define water usage and release flows (Surridge and Brent, 2008).
- There is currently no approach to handle the solid waste streams of biofuel value chains.

With respect to the air emissions, the life cycle inventory compares reasonably to other studies (Rollefson *et al.*, 2004; Beer *et al.*, 2007). For example, CO<sub>2</sub> emissions are in the same order of magnitude. However, the emissions of N<sub>2</sub>O are very high with a contribution to global warming potential (GWP) in the order of three-hundred times that of CO<sub>2</sub>; the consequence is that the variability in overall GWP is between 4.5 and 14.5 tonnes of CO<sub>2</sub> equivalent per tonne of biodiesel produced (see Table 3). This highlights the necessity to also refine the accuracy of the conventional flows in the inventory dataset for the South African context.

#### **6. Conclusions**

The introduction of the new biofuels industrial strategy in South Africa has emphasised the need to understand the potential environmental implications of biofuel scenarios in the South African context. As yet there is no structured approach to establish environmental profiles of the envisaged value chains in the scenarios of the strategy.

This paper consequently aims to provide a foundation for the further development of comprehensive life cycle inventories of biofuels production. The paper focuses on commercial-scale seed extraction biodiesel production, although it is envisaged that the inventory dataset will be developed further for small-scale and other distributed and co-production routes. Three crops are currently included in the strategy for biodiesel production, namely soybean, sunflower, and canola. Comparative LCI analyses were conducted for these crops for a 19.5 kt/yr production facility, which is considered to be an optimal capacity in the South African context.

Table 3 lists the overall inventory per tonne of biodiesel produced.

### 6.1 Emphasis for policy-makers

The inventory analysis shows that the inputs and outputs of the farming unit process are sensitive to the type of crop and region of produce. Water usage is a highly variable parameter, which emphasises the importance of rainfall and irrigation to the overall burden of the biodiesel system on water resources. Crop yields may differ by a factor of two, which is a significant difference in terms of land and non-renewable energy resources requirements. The oil and meal/cake content of the seed proves to be the most important parameter that influences the

initial unit processes of the value chains. Almost all the inputs and outputs of the farming unit processes, for the all the crops, range in the order of a factor of two due to this parameter. The uncertainties associated with the logistic system in the value chain also have major implications. If no market offset is available for the meal/cake co-products then due consideration is necessary of the necessary waste treatment uncertainties, which is also true for the other waste streams, most notably KCl and glycerol. Very little uncertainties were detected in the biodiesel production unit process, although the energy efficiency of the overall production system remains questionable.

A number of limitations are identified with the

**Table 3: Overall inventory per tonne of biodiesel produced**

Flow	Soybean		Sunflower		Canola	
	Min /tonne	Max biodiesel	Min /tonne	Max biodiesel	Min /tonne	Max biodiesel
<i>Economic inputs</i>						
Electricity [kWh]	1640	2000	1330	2260	923	1490
Steam [t]	3.3	5.0	2.0	3.0	2.0	3.0
Methanol [kg]	118	128	118	128	118	128
KOH [kg]	11.8	11.8	11.8	11.8	11.8	11.8
HCl (aq.) [kg]	10.3	10.3	10.3	10.3	10.3	10.3
Fertiliser [kg]	82.1	190	76.9	138	149	231
N [kg]	14.9	33.8	30.8	56.4	71.8	108
P [kg]	51.3	118	43.1	76.9	12.8	19.0
K [t]	16.9	39	4.0	8.2	66.7	97.4
Pesticides [g]	349	482	169	303	179	262
Water-processing [t]	1.9	2.0	1.9	2.0	1.9	2.0
<i>Economic outputs</i>						
Biodiesel [t]			1			
Meal/cake [t]	4.1	6.1	1.4	3.4	1.5	2.8
<i>Waste stream 1</i>						
KCl (aq.) [kg]	10.3	10.3	10.3	10.3	10.3	10.3
Water [t]	0.7	0.9	0.7	0.9	0.7	0.9
<i>Waste stream 2</i>						
Glycerol [kg]	97.4	118	97.4	118	97.4	118
Methanol [kg]	2.8	3.4	2.8	3.4	2.8	3.4
<i>Elementary inputs and outputs</i>						
Land – cultivated [ha]	2.1	4.8	1.9	3.6	1.9	2.7
Water – irrigated [M]	4.0	7.2	1.6	2.8	2.5	3.3
Crude oil [t]	0.5	0.7	0.2	0.5	0.2	0.3
Coal [kg]	71.8	92.3	35.9	61.5	41.0	56.4
CO <sub>2</sub> [t]	2.0	2.4	0.7	1.5	0.9	1.5
SO <sub>2</sub> [kg]	13.5	22.8	7.9	12.2	8.1	10.8
N <sub>2</sub> O [kg]	36.4	41.0	13.5	27.2	13.6	24.4
NO <sub>3</sub> <sup>-</sup> (water) [kg]	1.1	1.9	2.1	2.3	4.9	4.9
BOD (water) [kg]	0.2	0.3	0.1	0.2	0.1	0.1
COD (water) [kg]	1.3	1.7	0.6	1.1	0.6	0.9

inventory dataset. For example, published emissions data are often reported per reference flow and do not reflect geographical differences. Certain elementary environmental flows are not captured such as the impacts on soil quality due to farming practices. Also, the elementary flow for land usage is regarded to be occupied agricultural land for cultivation as per the biofuels industrial strategy. Cognisance must be taken where a biofuel value chain requires the transformation of ecosystems. Finally, the temporal scale of the inventory dataset is problematic. The annual variations in agricultural production are large in South Africa, which, together with expected behavioural changes due to the introduction of the biofuels industrial strategy, makes comprehensive uncertainty analyses difficult at present.

The paper also considers the implications to assess the environmental impact profiles for further decision-making purposes. To date, much emphasis has been placed on energy balances and air emissions of such bioenergy systems, but certain aspects are raised that must be addressed; specifically pertaining to land use, water use, and solid waste streams. The global warming potential category is also used to highlight the necessity to improve the accuracy of the conventional flows of the inventory dataset in the South African context. For the biodiesel value chain N<sub>2</sub>O emissions, especially, need to be refined to reduce the uncertainty. Although the global warming potential of agricultural activities are estimated on a global aggregate level (IPCC, 2007), major uncertainties are still reported in the current national emissions inventory (Taviv *et al.*, 2007).

## References

- Achten, W.M.J., Mathijs, E., Verhot, L., Singh, V.P., Aerts, R., and Muys, B., (2007). Jatropha biodiesel fuelling sustainability? *Biofuels, Bioproducts and Biorefining*, 1: 283-291.
- Beer, T., Grant, T., and Campbell, P.K., (2007). The greenhouse and air quality emissions of biodiesel blends in Australia. CSIRO Report Number KS54C/1/F2.27, [www.csiro.au/resources/greenhouse-air-quality-emissions-biodiesel-blends.html](http://www.csiro.au/resources/greenhouse-air-quality-emissions-biodiesel-blends.html), accessed 24 August 2010.
- Berndes, G., (2002). Bioenergy and water: The implications of large-scale bioenergy production for water use and supply. *Global Environmental Change*, 12: 253-271.
- BIOSSAM (Bioenergy Systems Sustainability Assessment and Management portal) (2010). Life cycle inventories to analyse biodiesel value chains. <http://www.biossam.org/case-studies-and-pilot-programmes/biodiesel/life-cycle-inventories/>, accessed 24 August 2010.
- Brent, A.C., Wise, R., and Fortuin, H., (2009). The viability of the South African biofuels industrial strategy. *International Journal of Environment and Pollution*, 39(1/2): 74-91.
- Brent, A.C., (2004). A life cycle impact assessment procedure with resource groups as areas of protection. *International Journal of Life Cycle Assessment*, 9(3): 172-179.
- Brent, A.C., Rohwer, M.B., Friedrich, E., and von Blottnitz, H., (2002). Status of life cycle assessment and engineering research in South Africa. *International Journal of Life Cycle Assessment*, 7(3): 167-172.
- Department of Minerals and Energy (DME) (2007). Biofuels industrial strategy of the Republic of South Africa. Directorate of Clean Energy and Energy Planning, [www.dme.gov.za/energy/documents.stm](http://www.dme.gov.za/energy/documents.stm), accessed 24 August 2010.
- Department of Minerals and Energy (DME) (2003). White Paper on Renewable Energy. [www.dme.gov.za/energy/documents.stm](http://www.dme.gov.za/energy/documents.stm), accessed 24 August 2010.
- Department of Water Affairs and Forestry (DWAF) (1996). South African water quality guidelines. [www.dwaf.gov.za/Dir\\_WQM/docsFrame.htm](http://www.dwaf.gov.za/Dir_WQM/docsFrame.htm), accessed 24 August 2010.
- Derpsch, R., (2005). The extent of conservation agriculture adoption worldwide: Implications and impact. Proceedings of the Third World Congress on Conservation Agriculture: Linking Production, Livelihoods and Conservation, Nairobi, Kenya.
- European Environment Agency (EEA) (2006). Road Transport Annex, Group 7: Road Transport. EMEP/CORINAIR Emission Inventory Guidebook, Brussels.
- Guinée, J.B., and Heijungs, R., (2007). Calculating the influence of alternative allocation scenarios in fossil fuel chains. *International Journal of Life Cycle Assessment*, 12(3): 173-180.
- Harding, K.G., Dennis, J.S., von Blottnitz, H., and Harrison, S.T.L., (2008). A life-cycle comparison between inorganic and biological catalysis for the production of biodiesel. *Journal of Cleaner Production*, 16(13): 1368-1378.
- Canals, L.M., Müller-Wenk, R., Bauer, C., Depestele, J., Dubreuil, A., Knuchel, R.F., Gaillard, G., Michelsen, O., and Rydgren, B., (2007). Key elements in a framework for land use impact assessment within LCA. *International Journal of Life Cycle Assessment*, 12(1): 5-15.
- IPCC (2007). Changes in atmospheric constituents and in radiative forcing. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf](http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf), accessed 24 August 2010.
- Jungmeier, G., Werner, F., Jarnehammar, A., Hohenthal, C., and Richter, K., (2002). Allocation in LCA of wood-based products: Experiences of Cost Action E9 - Part I. Method-



- ology. *International Journal of Life Cycle Assessment*, 7(5): 290-294.
- Kim, S., and Dale, B.E., (2006). Ethanol fuels: E10 or E85 – Life cycle perspectives. *International Journal of Life Cycle Assessment*, 11(2): 117-121.
- Kim, S., and Dale, B.E., (2005). Life cycle assessment of various cropping systems utilized for producing biofuels: Bioethanol and biodiesel. *Biomass and Bioenergy*, 29(6): 426-439.
- Koch, M., and Harnisch, J., (2002). CO<sub>2</sub> emissions related to the electricity consumption in the European primary aluminium production: A comparison of electricity supply approaches. *International Journal of Life Cycle Assessment*, 7(5): 283-289.
- Landis, A.E., Miller, S.A., and Theis, T.L., (2007). Life cycle of the corn–soybean agroecosystem for biobased production. *Environmental Science and Technology*, 41(4): 1457-1464.
- Landu, L., and Brent, A.C., (2006). Environmental life cycle assessment of water supply in South Africa: The Rosslyn industrial area as a case study. *Water SA*, 32(2): 249-256.
- National Biofuels Task Team (NBTT) (2006). National biofuels study: An investigation into the feasibility of establishing a biofuels industry in the Republic of South Africa. [www.dme.gov.za/energy/documents.stm](http://www.dme.gov.za/energy/documents.stm), accessed 24 August 2010.
- Nolte, M., (2007). Commercial biodiesel production in South Africa: A preliminary economic feasibility study. Masters Degree Thesis, University of Stellenbosch, <http://scholar.sun.ac.za/handle/10019.1/1797>, accessed 24 August 2010.
- Pischinger, G.M., Falcon, A.M., Siekmann, R.W., and Fernandes, F.R., (1982). Methyl esters of plant oils as diesel fuels, either straight or in blends. *Vegetable Oil Fuels*, American Society of Agricultural Engineers Publication 4–82, St. Joseph, MI, USA.
- Pro, B.H., Hammerschlag, R., and Mazza, P., (2005). Energy and land use impacts of sustainable transportation scenarios. *Journal of Cleaner Production*, 13: 1309-1319.
- Rollefson, J., Fu, G., and Chan, A., (2004). Assessment of the environmental performance and sustainability of biodiesel in Canada. National Research Council, Canada, [www.greenfuels.org/biodiesel/res/2004\\_11\\_NRCBiodieselProjectReportNov04.pdf](http://www.greenfuels.org/biodiesel/res/2004_11_NRCBiodieselProjectReportNov04.pdf), accessed 24 August 2010.
- Scholes, R.J., and Biggs, R., (2005). A biodiversity intactness index. *Nature*, 434: 45-49.
- Schwab, A.W., Bagby, M.O., and Freedman, B., (1987). Preparation and properties of diesel fuels from vegetable oils. *Fuel*, 66: 1372-1378.
- Sheehan, J., Camobreco, V., Duffield, J., Graboski, M., and Shapouri, H., (1998). Life cycle inventory of biodiesel and petroleum diesel for use in an urban bus. Final report, NREL/SR–580-24089 report, [www.nrel.gov/docs/legosti/fy98/24089.pdf](http://www.nrel.gov/docs/legosti/fy98/24089.pdf), accessed 24 August 2010.
- Spirinckx, C., and Ceuterick, D., (1996). Biodiesel and fossil diesel fuel: Comparative life cycle assessment. *International Journal of Life Cycle Assessment*, 1(3): 127-132.
- Suridge, A.K.J., and Brent, A.C., (2008). Development of a water state index to assess the severity of impacts on and changes in natural water resources. *Water Science and Technology*, 58(8): 1595-1600.
- Tait, B., (2005). Requirements and viability for bio-fuels in South Africa. *Fertilizer Society of South Africa Journal*, 25: 27-28.
- Taviv R., van der Merwe M., Scholes R.J., and Collet G., (2007). Non-energy emissions: Agriculture, forestry and waste. LTMS Input Report 2, Department of Environmental Affairs and Tourism, [www.environment.gov.za/HotIssues/2009/LTMS2/AgricultureForestWaste.pdf](http://www.environment.gov.za/HotIssues/2009/LTMS2/AgricultureForestWaste.pdf), accessed 24 August 2010.
- Von Blottnitz, H., and Curran, M.A., (2007). A review of assessments conducted on bioethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. *Journal of Cleaner Production*, 15(7): 607-619.
- Weiss, M., Patel, M., Heilmeyer, H., and Bringezu, S., (2007). Applying distance-to-target weighting methodology to evaluate the environmental performance of bio-based energy, fuels and materials. *Resources, Conservation and Recycling*, 50: 260-281.

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# Bioenergy use and food preparation practices of two communities in the Eastern Cape Province of South Africa

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## **Abstract**

A study was undertaken in two communities that use firewood in the Keiskammahoek area of the Eastern Cape Province of South Africa to understand their behaviour with regard to energy use during food preparation as well as the extent of practising efficient cooking habits. The results showed that despite the high level of electrification, firewood was used in most households ( $\geq 60\%$ ) for cooking while electricity was mostly used ( $\geq 90\%$ ) for lighting. Firewood is also preferred for cooking food that takes a long time to prepare, while more convenient sources of energy such as electricity is used for short periods of cooking and re-heating of food. Secondary sources of energy used for cooking included paraffin, dung, leaves and twigs. The study found that there was some deliberate use of energy saving techniques in both communities, although limited and not necessarily practiced with a view to saving energy. Less than half of the respondents soaked hard grains and beans before cooking; while all of them cut food into smaller pieces before cooking commenced. A third of respondents had utensils ready before cooking commenced in one village while two thirds placed utensils and food together before they commenced food preparations in the other village. Pots were covered with lids and water was added in small amounts as required. The heat from fire was not monitored, but fires were extinguished after use. The greatest potential for improvement exists around cooking appliances; where all households were found to be using three-

legged pots on open fires when cooking with biomass energy. Open fires are highly inefficient and the use of efficient biomass cook stoves would increase efficiency. It is recommended that in order to reduce the use of biomass-derived energy consumption and expenditure in low-income households, the use of multiple energy sources and portable energy efficient firewood stoves should be promoted. In addition, there should be an aggressive dissemination of information on further processing of fuelwood into forms that can easily be stored and used; and various forms of pre-treatment of hard foods.

**Keywords:** household energy, biomass energy, cooking, energy efficiency, food preparation, cooking equipment

## **1. Introduction**

While there is widespread agreement that rural communities desperately need to improve their access to modern energy sources (World Bank, 2000), it has been reported that about 550 million people (75% of the population in Sub-Saharan Africa) depend on traditional biomass (wood, charcoal, cow dung, etc.) due to lack of access to elec-

tricity or any kind of modern energy service (Ejigu, 2008). In other parts of the Southern Africa region, firewood use in households has been estimated at 5-7 tonnes of dry wood per household per year (Grundy *et al.*, 1993; Coote *et al.*, 1993).

Fuelwood use has an impact on the socio-economics of a rural community as it is the main energy source in rural settings; and all cooking and most food processing depends on fuelwood. Thus, fuelwood supply can influence the amount of food prepared or cooked. Cecelski (1984) reported that in Somalia, refugees fed their bean rations to their livestock or discarded them because they could not afford the fuelwood to cook them; illustrating the fact that despite having food, without adequate cooking energy, the food was not useable since whole grains and legumes are inedible without cooking.

A very large percentage of rural households in South Africa are still dependent on firewood and paraffin for food preparation (Shackleton *et al.*, 2007). For example, in the Limpopo and Eastern Cape Provinces, more than 50% of the households relied on firewood and paraffin for cooking (SSA, 2007). A significant number of households are expected to use firewood to some extent for decades to come, especially those marginalized either geographically or financially (Shackleton *et al.*, 2007). Other energy sources for food preparation include paraffin, coal, liquid petroleum gas (LPG), cow dung and other biomass fuels such as crop residue. The use of more than one fuel and a range of cooking appliances is a common feature in many low income households (SPARKNET, 2004). This pattern of energy use is also referred to as multiple fuel use, meaning that households use a range of appliances and fuels interchangeably.

The implementation of appropriate kitchen management and energy savings techniques has been identified as a major contributor to energy savings, especially where these techniques are introduced in conjunction with energy efficient devices (Inter Academy Council, 2007). The objective of this study was to establish the extent to which cooks implement efficient kitchen management strategies in their daily cooking activities in rural households in two communities in the Eastern Cape Province. The Eastern Cape province of South Africa is one of the poorest provinces and more than 50% of households still rely on firewood for their energy needs (SSA, 2007).

## 2. Materials and methods

### 2.1 Study area and sample communities

The study was conducted in the Eastern Cape Province of South Africa. The two villages selected for the survey (Cata and Tshoxa) are located in the Amahlathi Municipality (within the greater Amathole District Municipality) and are close to the

town of Keiskammahoek. The Human Development Index (HDI) measured by life expectancy, literacy and income for Keiskammahoek was found to be 0.50, which is below the average for the Eastern Cape, estimated at 0.56. It is estimated that 69.6% of the people in the Keiskammahoek area are living in poverty. Average unemployment for 2000 was estimated at 68.5%, which is slightly below the estimated unemployment level of 76% for the Amahlathi Municipality in 2001. (Amahlathi IDP, 2007). Table 1 also illustrates that the 96.7 % of the inhabitants of the Amahlathi Municipality earned less than R 1 600 per month in 2003. The population growth rate for Keiskammahoek is estimated at 1.4% and this is likely to be representative of the situation at Cata and Tshoxa.

The Cata community (32°36'2"S; 27°7'10"E) is situated on the southern slopes of the Amathole Mountains, 15 km from Keiskammahoek in the Eastern Cape and can be classified as a rural community. There are 450 households in this village. Cata has, however, one of the highest levels of electrification in the Amahlathi Municipality with 84% of households having access to electricity (average percentage in Amahlathi Municipality is 67%) (Amahlathi, IDP, 2007). Cata has multiple forest resources including 800 ha of indigenous forest, approximately 300 ha of pine plantations and jungle wattle areas (Ham, 2003). The Tshoxa community (32°41'25"S; 27°9'15"E) is located approximately 2 km from Keiskammahoek and can be classified as peri-urban. There are 600 households in this village. Unlike Cata, only 56% of households have access to electricity; and the Tshoxa village does not have any forestry activities. The area is dry and characterized by shrubs, *Acacia Karoo* thorn trees and some indigenous species such as sneezewood (*Ptaeroxylon obliquum*) and yellow wood (*Podocarpus falcatus*).

### 2.2 Methodology

A survey method involving interviews based on a structured questionnaire was considered the most appropriate data collection method for this project (Babbie, 2004). The unit of analysis for the questionnaire surveys was individual households (Bless & Higson-Smith, 1995) and the target population was the 450 households at Cata and the 600 households at Tshoxa. A sample of 60 households per village was selected for the survey. The selection of an equal number of households per village makes comparisons between villages easier (Nel, 2008). The samples represent 13% of the households at Cata and 10% of households at Tshoxa. Households were selected based on interval or systematic sampling whereby only a certain number of houses per street were randomly selected to ensure that the survey covered the entire village (Bless & Higson-Smith, 1995).

### 2.3 Data analysis

The average number of people per household interviewed at both Cata and Tshoxa was four with a minimum of one at both villages and a maximum of 11 at Cata and 12 at Tshoxa. The 60 households at Cata represent 261 persons, while the 60 households at Tshoxa represent 251 persons. Results from the data analysis were presented as descriptive statistics based on the percentage of respondents (households) who replied to the individual questionnaire questions. At both villages, percentages were calculated based on a sampling population (n) of 60 households. Chi-square tests were used to compare responses of the households surveyed in the two communities using a 95% confidence interval.

## 3. Results

### 3.1 Source of energy for cooking, lighting and heating

The study showed that there was a significant difference ( $p < 0.001$ ) in sources of energy for cooking with the majority of respondents at Cata relying on firewood (77%) as a primary energy source for cooking, while 42% of the respondents at Tshoxa use firewood. At Tshoxa, 38% of respondents use electricity for cooking, while 18% of respondents at Cata use electricity. At Tshoxa, 17% of respondents use paraffin, while only 5% at Cata rely on paraffin for cooking energy (Table 1). Respondents also indicated that they use these primary energy sources in combination with secondary energy sources. Both at Cata (48%) and Tshoxa (60%), respondents indicated that they would use paraffin as a first choice, secondary energy source (in combination with, for instance, firewood and electricity). Cow dung was also listed as a second choice alternative to primary energy sources by 30% of respondents from Cata and 43% of respondents from Tshoxa.

**Table 1: Primary sources of energy for cooking at Cata and Tshoxa**

Source of energy	% of respondents	
	Cata	Tshoxa
Fuelwood	77 (46)*	42 (25)
Electricity	18 (11)	38 (23)
Paraffin	5 (3)	17 (10)
Gas	0	3(2)
P-value	0.001	

\* Figures in brackets are the number of respondents

There was no difference in the source of lighting for the two sites, with most of the respondents at both Cata and Tshoxa using electricity for lighting (93%) followed by paraffin (5%) and candles (2%), respectively. However, there was a significant difference ( $p < 0.04$ ) in source of energy for heating

between the two areas. At Cata, 78% of respondents rely on firewood, 8% on electricity and 13% on paraffin while at Tshoxa 55% rely on firewood, 10% on electricity and 32% on paraffin. Three percent of respondents at Tshoxa indicated that they do not heat their homes.

### 3.2 Cooking equipment

There were significant differences ( $p < 0.001$ ) in the cooking equipment at the two areas when preparing food. As many as 77% of respondents at Cata use an open unshielded wood fire compared to only 42% at Tshoxa. Fireplaces consist of a flat metal base (made from for example, the lid of an oil drum or zinc roofing material) that can be moved around to cook either outside or inside the house. At Tshoxa, 40% of respondents make use of an electric stove compared to only 18% at Cata (Table 2).

There were no significant differences in the type of pots used at the two sites. All respondents who use firewood for cooking also use three-legged pots that are placed over the fires. Respondents who use gas, paraffin or electric stoves use flat bottomed aluminium pots for food preparation. Most respondents use at least two pots to prepare food. A larger pot (9 to 13 litres) is normally used in combination with a smaller (3 to 6 litre) pot.

**Table 2: Types of stoves and pots that respondents use for food preparation at Cata and Tshoxa**

Type of stove	% of respondents	
	Cata	Tshoxa
Open wood	77 (46)*	42 (25)
Electric stove	18 (11)	40 (24)
Paraffin stove	5 (3)	15 (9)
Gas stove	0	3(2)
P-value	0.001	
<i>Pot type</i>		
Three legged pot	77 (46)	42 (25)
Flat bottomed pot	23 (14)	58 (35)
P-value	0.001	

\* Figures in brackets are the number of respondents

### 3.3 Food preparation

There were significant differences ( $p < 0.0002$ ) between the sites in preparation before cooking commenced in that at Cata, 65% of respondents indicated that all the food and cooking utensils are assembled compared to only 32% at Tshoxa. All respondents indicated that they cover the pot with its lid during cooking. None of the respondents monitored the heat of the fire during cooking at

both sites but indicated that they extinguish the fire after cooking. On average, fewer respondents (41%) indicated that they pre-soak hard grains (sorghum and maize) and beans prior to cooking. Most people (89%) at both sites did not pound hard grains before cooking; while nearly all indicated that they cut food into smaller pieces before cooking.

Although not significant, more people at Cata (40%) used fuelwood for warming compared to Tshoxa (20%). On average, however, 68% of the respondents tended to favour the convenience of electricity and paraffin over firewood for the reheating of food. Additionally, respondents were asked to indicate their preferred energy source for the preparation of samp (boiled whole kernel white maize), pap (grounded maize porridge), meat, bone meat, vegetables and bread (see summary in Table 3).

There were significant differences ( $p < 0.01$ ) between the sites in the energy preference during the cooking of samp, bread, bones and meat (Table 3). More people used fuelwood (95%) at Cata during the preparation of samp compared to Tshoxa (60%), with some people in Tshoxa preferring to use electricity (17%) and paraffin (13%). A similar trend was observed in the preparation of bread, where more people at Cata (87%) used fuelwood compared to Tshoxa (57%); and some preferred the use of electricity (22%) and paraffin (13%).

For the cooking of bones, most people (90%) at Cata used fuelwood while those at Tshoxa used a mixture of fuelwood (60) and electricity (26%). Interestingly, during the preparation of meat, people at Tshoxa used electricity and fuelwood equally (40%), while there was still more use of fuelwood at Cata (68%). There were, however, no differences between the two areas in the preferred energy source for the preparation of pap and vegetables but the predominant energy sources were either

fuelwood or electricity and paraffin to some extent (Table 3).

## 4. Discussion

### 4.1 Sources of energy for cooking

Cata is representative of rural villages with readily accessible firewood resources in the form of plantations, woodlots and natural forests. Tshoxa represents more urbanised villages with limited access to firewood resources. This difference was highlighted in the survey where respondents from Cata clearly prefer to use firewood for cooking while respondents from Tshoxa use a variety of energy sources for cooking. The difference in energy preference between rural and peri-urban villages has also been documented by Ham and Theron (2001); who found that in urban villages in the Eastern Cape residents use a larger variety of energy sources than in rural villages where firewood is the dominant energy source.

Although more than 80% of households at Cata have access to electricity, they prefer to use firewood as it is considered a cheaper form of energy. This mirrors the general trend in most developing countries where the introduction of electricity has not necessarily resulted in a switch from the use of fuelwood (Shackleton et al., 2007). Several studies in South Africa have shown that while South Africa consumes over 60% of the electricity on the African continent, 90% of South Africa's rural households use fuelwood energy (Shackleton et al., 2007; Davis 1998, Shackleton et al., 2004). Shackleton et al. (2007) further indicated that even with a subsidized national household electrification programme, most newly electrified households continue to use fuelwood because they cannot afford the appliances and/or the monthly costs of electricity.

While the energy policies in South Africa promote the use of renewable energy, energy strategies

**Table 3: Energy source preference for the various foods at Cata and Tshoxa**

Energy source	% respondent											
	Samp <sup>1</sup>		Bread		Bones		Meat		Pap <sup>2</sup>		Vegetables	
	Cata	Tshoxa	Cata	Tshoxa	Cata	Tshoxa	Cata	Tshoxa	Cata	Tshoxa	Cata	Tshoxa
Dung	0	2	0	2	0	7	0	0	0	0	0	0
Electricity	2	17	8	22	0	26	20	40	28	43	33	45
Fuelwood	95	60	87	57	96	60	68	40	53	38	50	30
Gas	0	3	2	2	0	0	0	3	0	4	0	3
Paraffin	3	13	3	13	4	0	12	17	19	15	17	20
Leaves and twigs	0	5	0	4	0	7	0	0	0	0	0	2
P value	0.0001		0.01		0.01		0.01		NS <sup>3</sup>		NS	

Notes:

1. Samp is a mixture of dried beans and dried whole maize kernels.

2. Pap is a stiff porridge made from ground maize flour.

3. NS denotes non significance at  $p > 0.05$

based on biomass energy will have to focus on a sustainable supply of biomass as well as the optimal use of biomass energy. It is estimated that between 9 and 11 million tons of wood are used for fuel per annum, of which about 6.6 million tons are estimated to be harvested from natural woodlands (RSA, 1996). Firewood consumption per household in the Kentani area of the Eastern Cape, for instance, was estimated at 3 700 kg per annum (Ham, 2000). The challenge for energy strategies would be to reduce the overall volume of firewood used per annum by promoting more efficient ways of using firewood and to promote the cultivation of woodlots.

#### 4.2 Cooking equipment and food preparation

The general use of an open fireplace configuration is not very energy efficient and allows unrestricted airflow that can channel heat away from the pot. The inadequate availability of modern technologies for wood-based energy systems poses a major problem to the rural communities. The present inefficient use of fuelwood is not sustainable. Besides having low energy efficiency, open fire cooking places are a source of indoor air pollution (Masera et al., 2000).

Considering these factors, the need to develop technological solutions that address the problems of open fires is critical. Energy efficient stoves could play a role in improving energy transfer. Since the mid-1970s, a number of models of improved wood-burning cook stoves (ICS) have been developed that address the two main drawbacks of open fires, by including a combustion chamber and a tube to take the smoke outdoors (Troncoso et al., 2007). Recent developments in stove design by Bosch, Siemens and Phillips indicate an interest in designing and producing a highly efficient stove that despite using biomass as a fuel source, can deliver clean, convenient and cheap energy for cooking in low-income households (Hegarty, 2006).

An aspect highlighted in the survey is that households would use cheaper energy sources such as firewood to cook foods that require long preparation times, while using more expensive (but more convenient) energy sources to prepare foods that require short cooking times and for re-heating food. It would seem from this study, the other forms of energy sources were easier to access compared to other developing countries. Hence, there was a limited use of other energy saving practices such as soaking or pounding grains before cooking.

When energy efficient behaviour in the two villages is examined, Cata, where 77% of the respondents use firewood, more households were found practising some form of energy efficient measures (see Table 4) than in Tshoxa. A possible explanation

could be related to fuelwood collection and its associated hardship (Chirwa et al., 2008). Households, which rely on fuelwood, try to minimize usage to reduce the need for fuelwood collection. At Tshoxa, where electricity use is more prevalent, cost of electricity is the only incentive for energy saving practices.

**Table 4: Use of energy efficient cooking measures**

Energy efficient practice	Household practising (%)	
	Cata	Tshoxa
Pre-soaking hard grains	42	40
Assembling cooking utensils before cooking commences	65	32

#### 5. Conclusion and recommendations

The study found that although the rural and semi-urban communities in South Africa are relatively well electrified, they still use fuelwood as the main form of energy for cooking and heating; and that there is limited use of energy saving techniques in their kitchen management. The study highlighted a number of factors that can be recommended for consideration in the reduction of biomass-derived energy consumption and expenditure in low-income households including the use of multiple energy sources which is already prevalent; and the promotion of portable energy efficient firewood stoves that would make it possible to cook inside and outside the house.

There is also a need to disseminate and/or promote information on further processing the fuelwood into forms that can easily be stored and used; (e.g. charcoal and/or briquettes) and various forms of pre-treatment of hard foods in order to improve energy efficiency in cooking procedures.

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#### References

- Amahlathi, I.D.P. (2007). Amahlathi Municipality Integrated Development Plan 2007/08 – 2011/12. Amahlathi Municipality.
- Babbie, E. (2004). The Practice of Social Research. Wadsworth, Belmont, CA.

- Bless, C. & Higson-Smith, C. (1995). *Fundamentals of Social Research Methods – An African Perspective*. Second edition. Juta and Co, Ltd, Cape Town.
- Cecelski, E. (1984). *The rural energy crisis, women's work and basic needs: Perspectives and approaches to action*. ILO, Rural Employment Iblicity Research Programme, Geneva.
- Chirwa, P.W. Ham, C. & Maphiri, S. (2008). *Baseline study determining consumer behaviour with regard to kitchen management and efficient cooking habits in South Africa*. Report prepared for The Programme for Basic Energy and Conservation (ProBEC) by Stellenbosch University.
- CIA Word Fact book, (2009). *Map of South Africa* [Online] Available at [www.cia.gov/library/publications/the-world-factbook/print/sf.html](http://www.cia.gov/library/publications/the-world-factbook/print/sf.html) - Accessed 29 May 2009.
- Coote, H.C., Luhanga, J. & Abbot, P.G. (1993). *Community use and management of indigenous forests in Malawi: the case of three villages in the Blantyre City Fuelwood Project Area*. FRIM Report 93007, Forestry Research Institute of Malawi, Zomba.
- Davis, M. (1998). *Rural household energy consumption: The effects of access to electricity – evidence from South Africa*. *Energy Policy* 26: 207–217.
- Ejigu, M. (2008). *Toward Energy and livelihoods security in Africa: Smallholder production and processing of bioenergy as a strategy*. *Natural Resources Forum* 32: 152 – 162.
- Grundy, I.M., Campbell, B.M., Balebereho, S., Cunliffe, R., Tafangenyasa, C., Fergusson, R. & Parry, D. (1993). *Availability and use of trees in Mutanda Resettlement Area, Zimbabwe*. *Forest Ecology and Management*, 56: 243-266.
- Ham, C. (2000). *The importance of woodlots to local communities, small scale entrepreneurs and indigenous forest conservation– A case study*. Instruments for sustainable private sector forestry, South Africa series. *International Institute for Environment and Development and CSIR-Environmentek*, London and Pretoria.
- Ham, C. & Theron, F. (2001). *Community Forestry Resources: A Case Study of Selected Woodlots in the Eastern Cape Province*. *Southern African Forestry Journal* No. 191.
- Ham, C. (2003). *Facilitation and Support for the Planning and Licensing of the Chata Afforestation Project*. Report prepared for the Department of Water Affairs and Forestry.
- Hegarty, D. (2006). *Satisfying a burning need*. *Phillips Research Magazine* 28:28-31. Available at <http://www.research.philips.com/technologies/projects/woodstove.html> - Accessed 01/07/2009.
- Inter Academy Council, (2007). *Lighting the Way: Toward a sustainable energy future*. <http://www.interacademycouncil.net/Object.File/Master/12/063/2.%20Energy%20Demand%20and%20Efficiency.pdf> - Accessed 29/05/2009.
- Masera, O.R., Saatkamp, B. & Kammen, D. (2000). *From Linear Fuel Switching to Multiple Cooking Strategies: A critique and Alternative to the Energy Ladder Model*. In: *World Development*, Vol. 28, London.
- Nel, D. (2008). *Personal communication*, July 2008. Centre for Statistical Consultation (CSC), University of Stellenbosch.
- RSA, (1996). *White Paper on Sustainable Forest Development in South Africa*. Government Printer, Pretoria.
- Shackleton, C.M., Buiten, E., Annecke, W., Banks, D.A., Bester, J., Everson, T., Fabricius, C., Ham, C., Kees, M., Modise, M., Phago, M., Prasad, G., Smit, W., Twine, W., Underwood, M., Von Maltitz, G. & Wenzel, P. (2007). *Exploring the options for fuelwood policies to support poverty alleviation policies: evolving policy dimensions in South Africa*. *Forests, Trees & Livelihoods*, 17: 269-292.
- Shackleton, C.M., Grundy, I.M. & Williams, A. (2004). *Use of South Africa's woodlands for energy and construction*. In: Lawes, M.J. Eeley, H.A. Shackleton, C.M. & Geach, B.G. (eds). *Indigenous forests and woodlands in South Africa: policy, people and practice*. University of KwaZulu-Natal Press, Pietermaritzburg. pp. 337–363.
- SPARKNET, (2004). *South Africa Country Report Synthesis* [Online] Available at <http://db.sparknet.info/goto.php/SouthAfricaCountrySyntesis> - Accessed 12 August 2008.
- SSA, (2007). *General Household Survey 2006. Statistical Release P0318*. Statistics South Africa.
- Troncoso, K., Castillo, A., Masera, O. & Merino, L. (2007). *Social perceptions about a technological innovation for fuelwood cooking: Case study in Rural Mexico*. *Energy Policy* 35, 2799 – 2810.
- World Bank (2000). *Energy and Development Report 2000: Energy services for the World's poor*, World Bank, Washington, DC.

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# An introduction to BLOSSAM – the South African BIOenergy Systems Sustainability Assessment and Management portal

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The global bioenergy industry is advancing rapidly. New technologies and potential feedstocks are being proposed that aim for bioenergy to contribute to a wider range of economic, social, and environmental objectives. However, these advancements all require tradeoffs between potential technical advantages, and socio-economic and environmental consequences. Despite technological advances, a number of project failures have been noted with the development, design and implementation of such renewable energy systems in Africa.

The problems that need to be addressed are:

- How to screen bioenergy options based on technical feasibility, economic and financial viability, and social and environmental acceptance. This should be a first phase to prioritise and choose from the potential range of bioenergy options, in terms of their robustness and resilience;
- How to best implement technically feasible solutions, in an integrated manner, within the country's prevailing political, socio-economic and social-ecological systems; and
- How to monitor the implementation of bioenergy programmes to ensure the sustainable adoption and operation of the chosen options.

The main problem is, therefore, how to ensure that policies and decision-making on bioenergy options result in localised social-ecological advantages that outweigh disadvantages. The complex behaviours that both socio-economic and ecological systems exhibit exacerbate this problem, primarily because of the fundamental uncertainty associated with them; these behaviours must be recognised and approaches are required to assess and manage behavioural uncertainties in a sustainable way. Therefore, both public and private sector policy-makers, decision-makers, and technology developers, operating from the regional and national levels to the local level, require robust methods to guide structured assessments and the subsequent

management of proposed bioenergy systems; before they can make sound recommendations relating to bioenergy supply interventions.

In other words, developed methods must be practical for all levels of policy- and decision-makers, and technology developers, yet they must ensure that the sustainability of the integrated bioenergy supply systems are assessed comprehensively; appropriate information must be provided on technical, financial, socio-economic and environmental considerations so that the users can take informed decisions that lead to sustainable bioenergy interventions.

The BIOenergy Systems Sustainability Assessment and Management (BLOSSAM) portal, which is the outcome of a three-year parliamentary grant to the CSIR, aims to provide the comprehensive and holistic assessment, monitoring and management of bioenergy interventions in order to plan for sustainable development. BLOSSAM is a participatory and transparent process to decision-making that involves multi-stakeholder engagement coupled with expert and public opinion.

This helps to ensure stakeholder buy-in as well as general trust brokering that facilitates the process of technology transfer and increases the long-term success of bioenergy interventions. The BLOSSAM portal ([www.blossam.org](http://www.blossam.org)) is an information hub and an analytical framework with a toolbox of decision-support systems for the assessment, monitoring and management of bioenergy for sustainable development.



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In 2001 he joined the Department of Electrical Engineering at the University of Cape Town and

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He has published 14 papers in international journals including Elsevier's Energy Policy and IEEE Transactions on Energy Conversion as well as 13 conference proceedings. He is also a reviewer for several international journals and the National Research Fund (NRF) of South Africa.

He is a corporate member of the Institution of Engineers and Technology (UK), a corporate member of the Institution of Engineers of Kenya, a member of the Institution of Diagnostic Engineers (UK) and a member of the Institution of Electrical and Electronic Engineers (USA), as well as Secretary to the ICSU-ROA Scoping Group on Sustainable Energy for sub-Saharan Africa.

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Since re-joining the University of Cape Town as a staff member in 1998, he has introduced sustainable development into the curriculum at undergraduate and postgraduate level, and 14 Masters and 3 PhD students have completed their dissertations under his supervision.

# Forthcoming energy and energy-related conferences and courses: 2010–2011

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## NOVEMBER 2010

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**ENERGY AND SUSTAINABLE DEVELOPMENT  
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Contact: Heidi Tait or Sandra Jemaar, Continuing  
Professional Development  
Programme, Faculty of Engineering & the Built  
Environment, University of Cape  
Town

Tel: +27 (0)21 650 5793

Fax: +27 (02)1 650 2669

E-mail: [ebe-cpd@uct.ac.za](mailto:ebe-cpd@uct.ac.za)

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