BIOENERGY ATLAS

for South Africa

– Synopsis Report –

science & technology
Department:
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BIOENERGY ATLAS FOR SOUTH AFRICA

– Synopsis Report –

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Foreword by the Minister of Science and Technology

The global need to move to cleaner and more sustainable energy systems means that we should continuously evaluate various energy feedstock and generation pathways for heat, power and transport fuels. These include bioenergy-based options.

According to the REN21 (Renewable Energy Policy Network for the 21st Century) Global Status Report, bioenergy accounts for roughly 10% of the world's primary energy supply, and has remained at about this level since 2005. In developing countries, most bioenergy is consumed inefficiently when used for cooking and heating, and poses health hazards that include smoke inhalation. However, in most developed economies, bioenergy has been incorporated into modern energy services and is a significant contributor to the energy industry, and thus to the bio-economy.

As South Africa formalises the establishment of the bioenergy industry, the principles of inclusivity, addressing energy poverty and stimulating economic opportunities are among the key driving factors, as government continues exploring ways of providing energy to communities currently not receiving such services. This is in line with the Department's commitment of living up to its mandate, to use science and technology to improve the country's economy, create employment and improve the quality of life of all citizens. The Department's 2015-2020 Strategic Plan is part of the vision of the National Development Plan to tackle the interlinked challenges of poverty, inequality and unemployment.

"In most developed economies, bioenergy has been incorporated into modern energy services and is a significant contributor to the energy industry, and thus to the bio-economy."

The web-based *Bioenergy Atlas* will assist government by making available information on potential energy resources, their geographic spread, their proximity to infrastructure, and potential end users. This decision-support tool is expected to guide energy planning and investments, as well as the deployment of bioenergy-based technologies, including the co-firing of biomass, the use of residues to produce biofuels, and biodigesters for domestic energy needs.

The many requests for *Bioenergy Atlas* data by various players (policy makers, power utilities, industry and academia) in the national system of innovation during the development of the atlas have been encouraging, and government looks forward to its wider application.

The *Bioenergy Atlas* preliminary assessments (based on potential contributions by subsistence farmers, municipal organic waste, wastewater treatment works, agriculture, forestry residues, etc.) indicate significant potential in the Eastern Cape, Mpumalanga, KwaZulu-Natal, the Western Cape, Gauteng and Limpopo.

Development of a bioenergy industry could have a significant impact on job creation (seasonal and permanent) and improve energy access.

The bioenergy sector will be supported within a policy framework that ensures that bioenergy-based socio-economic development does not compromise food security, biodiversity or water security, and that will guide future energy infrastructure installations for both central and distributed generation.

My Department is very pleased to contribute to South Africa's transition to renewable energy, and will continue to support research to improve the competitiveness of local innovations in this sector.

Naledi Pandor
Minister of Science and Technology

Disclaimer

The outputs produced for the *BioEnergy Atlas* address several deficiencies in the assessment of bioenergy in the country, viz. ensuring that all comparisons of technology options and biomass sources are evaluated on the same basis, using the same assumptions, and taking aspects such as spatial distribution, location of infrastructure and economy of scale into account.

As such, the work is useful in that it eliminates poor choices and places realistic limits on the likely feedstocks, technologies and locations where feasible facilities can be developed. The scale of assessment (planning polygons of roughly 7 km square) is not fine enough to replace detailed feasibility studies for specific projects – these will have to be undertaken prior to any such investment being considered. Individual project options identified in this work serve as examples of techno-economic optima, and are not promoted or should not be construed as advice to develop a specific option or project.

Units of Energy and Power

Comparisons are difficult when the energy end products are not the same. Specifically, it is difficult to compare the energy value of intermediary products (such as biogas, wood pellets or pyrolysis oil) with finished products such as electricity or biofuel. For this *Synopsis Report* a convention has been followed whereby electricity end product is reported as MWe (Megawatt of electricity equivalent at 90% availability), and biofuels and biomethane are compared with this on the basis of conversion to electricity at an efficiency of 40%.

Currency Values

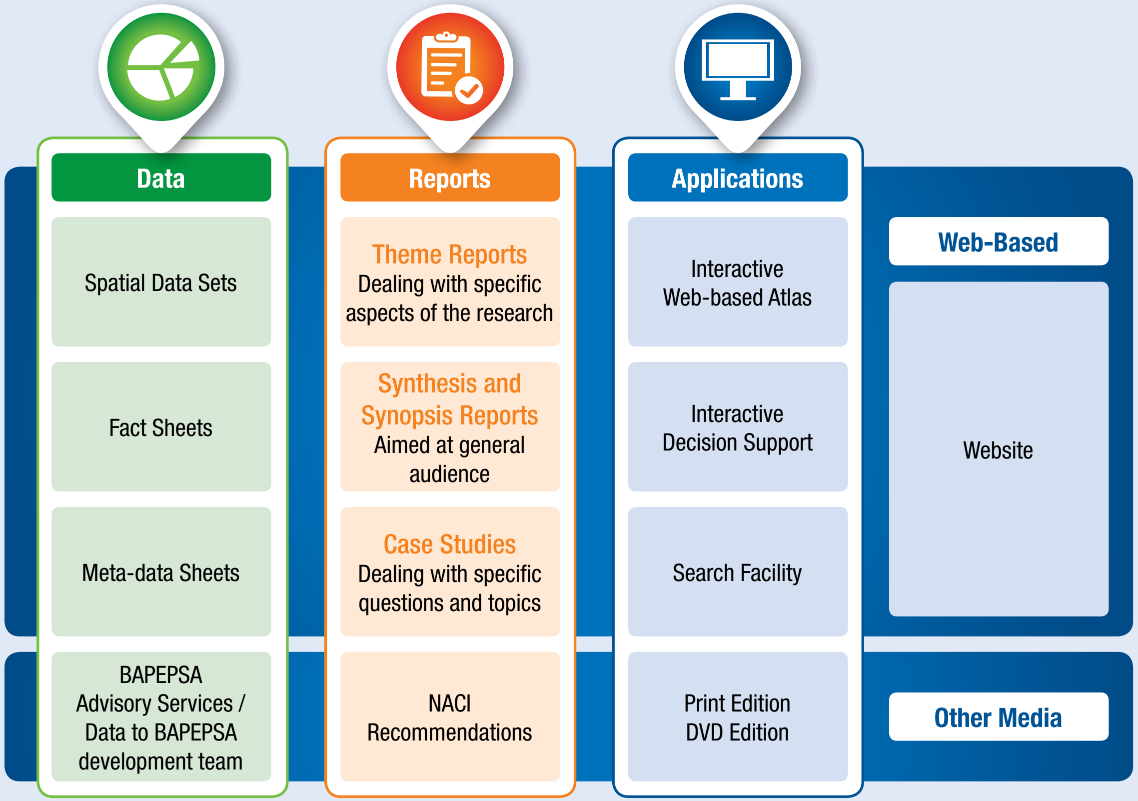
Unless stated otherwise, all monetary values are reported in 2014 South African Rand. All references to costs or value were adjusted from the year of reporting using historical inflation rates published by the South African Reserve Bank. Foreign currency values were adjusted to South African Rand using the exchange rate at the time of reporting, and then subsequently adjusted for inflation.

A Note on References

Directly quoted references are listed at the end of the report, but in general, the references and published material used to derive the findings of the report are not listed – these are found in the online materials supporting each key finding. A link to these supplementary materials is provided at the conclusion of each section.

Box 1: *BioEnergy Atlas* outputs and resources

Figure 1: *BioEnergy Atlas* outputs and resources



TYPICAL OUTPUTS AND RESOURCES

The *BioEnergy Atlas* project has produced a range of outputs, in both electronic and printed format. The data sets, attendant metadata and fact sheets (non-spatial data inputs) are all available online and can be accessed via an interactive web-based atlas, a search facility and an interactive decision-support tool. Reports dealing with the main themes of the Atlas, as well as case studies focused on specific questions, are available for download.

Theme reports, case studies, data views and work package results are available as a consolidated online report (*Synthesis Report*). An abridged, general-purpose version of the *Synthesis Report* constitutes this *Synopsis Report*.

Additional reports have been derived from the body of knowledge available in the Atlas, specifically inputs on biomass utilisation for NACI and for the collaborative project between the South African and the Netherlands Governments - BAPEPSA (Biomass Action Plan for Electricity Production in South Africa).

The *BioEnergy Atlas* is a living resource, and data sets, models and reports will be periodically updated in the future. Current data refinement projects involving SAEON and collaborators include (1) improved estimates of bush encroachment, invasive alien plants and fuelwood potentials, using recently published Carbon Atlas data, (2) efforts to improve our understanding of the distribution of livestock in South Africa, and (3) evaluation of energy crop estimates in the light of recently published water-use efficiency data for energy crops. In addition, SAEON is refining cost data for conversion processes, and is including uncertainty into the feasibility models.

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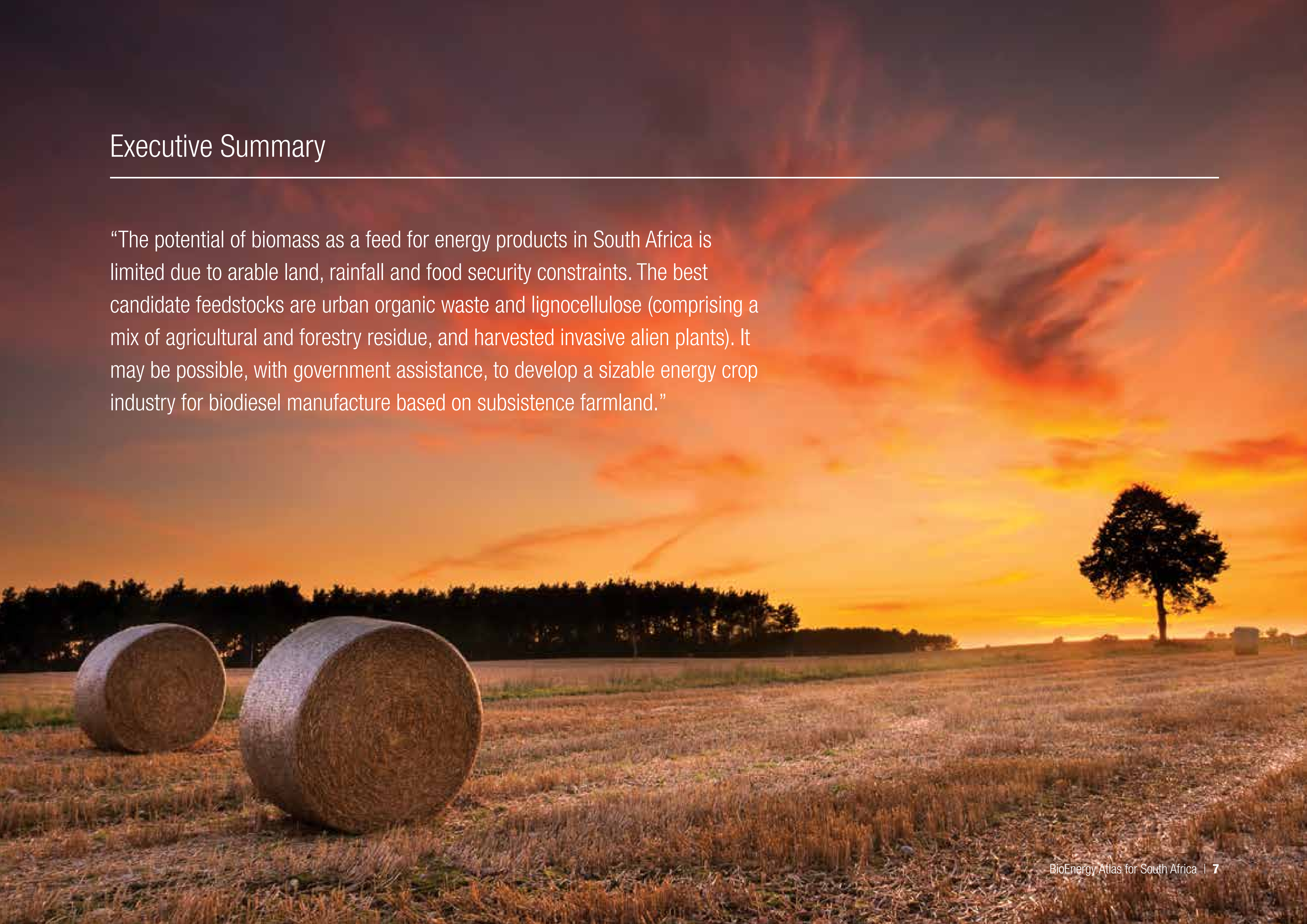


Executive Summary

"The potential of biomass as a feed for energy products in South Africa is limited due to arable land, rainfall and food security constraints. The best candidate feedstocks are urban organic waste and lignocellulose (comprising a mix of agricultural and forestry residue, and harvested invasive alien plants). It may be possible, with government assistance, to develop a sizable energy crop industry for biodiesel manufacture based on subsistence farmland."

The *BioEnergy Atlas* incorporates information on the basic factors involved in the production of biomass, potentials and yields for a variety of biomass resources, and assesses the techno-economic feasibility of energy products from these resources. It serves as an information resource on processes for energy production from biomass, and on the likely impacts of these value chains on social, economic and environmental indicators.

Bioenergy in South Africa has limited potential on account of relatively low primary productivity, largely constrained by rainfall and exacerbated by significant inter-annual variability (Schulze, 2007). These factors, together with an inevitable focus on food security, combine to limit the attractiveness of energy derived from biomass.

Despite these constraints, some potential does exist. Techno-economic assessment of options for biomass conversion to energy, and considerations such as job creation, impact on rural economies, greenhouse gas (GHG) mitigation and likely subsidies required to make energy products cost-competitive, were evaluated and resulted in the following set of feasible options for biomass utilisation:

- Utilisation of **all available urban domestic (household) organic waste**, from solid waste and from wastewater, is the most feasible option, with an acceptable end-product cost. Upgrading to biomethane typically doubles the cost, and electricity generation will result in efficiency penalties. The option requires intervention from government in respect of policy, accelerated permit processing for wastewater and solid waste facilities, and sponsoring of research and development of standardised large-scale digester and biogas upgrading technology. Some local authorities may elect to use wastewater biogas for *in-situ* electricity generation. **Estimated contribution from feasible project options: up to 1400 MWe.**
- Development of household or communal digesters in rural, unserviced areas in combination with cattle dung in areas where this is available. Government will have to identify and promote technology, implement programmes to promote acceptance and safe use, and possibly serve as a source of capital for initial investments. **Estimated contribution from feasible project options: up to 250 MWe.**
- Combination of **all available lignocellulose biomass** (invasive alien plants, plantation residues, sugar mill bagasse and agricultural residue – see Key Message 1: Availability of Biomass) can make a significant contribution to electricity generation in mid-size regional power stations (typical size 50-300MW). Projects may have a limited lifetime due to the objective of eradication of invasive alien plants[1] over a 20-year period. Some of the project options are in areas of poor electricity availability (rural Mpumalanga, Eastern Cape, KwaZulu-Natal) and will be able to underpin one or more rural electrification projects. Costs are comparable to new electricity from coal. **Estimated contribution from feasible project options: up to 1300 MWe.**
- It may be possible to develop an **energy crop industry on subsistence farmland** as a measure to improve rural livelihoods. The most feasible option is for biodiesel manufactured from groundnut oil or sunflower oil, with byproduct sales offsetting the cost of final products. Due to the need for some form of subsidy, projects are unlikely to attract private capital. In addition, it is likely that significant effort will be required to transform rural agricultural practice. With an oil price in the order of 50 USD/barrel, these options are not attractive, but the situation might improve should oil prices rise to recent highs of 100 USD/barrel. **Estimated contribution from feasible project options: 587 MW, 235 MWe as electricity equivalent, 570m l/a of biodiesel, approximately 5% of current diesel consumption[2].**

A number of project options for a variety of feedstock and processing combinations were evaluated. Not all of these combinations are feasible, generally since smaller facilities do not have the requisite economy of scale, or the combined feedstock and transport costs are too high. The feasible options identified, generally minimise the cost of production based on feedstock input, and transport costs and economy of scale, but in practice the logistics of supply and local variations in density and accessibility of feedstock might limit the size of a facility.

1 To benefit GHG emissions, the eradicated biomass will have to be replaced. Options include managed Category 2 invasive plants (such as Eucalyptus) or restoration of indigenous vegetation.

2 Sugar cane and sweet sorghum are attractive as energy crops due to high yields and large areas suitable for cultivation. Ethanol for E10 blends (5-10% ethanol added to petrol) needs to be near anhydrous and is expensive to produce, making it uncompetitive. E100 (95% ethanol and 5% water), as used in Brazil, is less expensive to produce but was not considered since it does not form part of the current Biofuels Strategy.

Impacts of the most feasible options, as described above, were also assessed in terms of environmental considerations (GHG emission mitigation, IAP eradication, better utilisation of degraded land), and socio-economic benefits (job creation, contribution to regional economy, and access to clean energy). It is clear from the assessment of these impacts that, in general, the following holds true:

- The conversion of organic waste in urban areas to biogas and possible refinement to biomethane has positive GHG emission impacts, is price-competitive with alternatives, and will result in the creation of a small number of sustainable jobs.
- The other options (based either on lignocellulose sources or on purposely cultivated energy crops) have limited or negative value in terms of GHG emission mitigation and the costs are the same or higher than those of fossil and renewable alternatives. Hence these projects will in all likelihood rather be undertaken in an effort to establish a national strategic intervention in rural areas that aims to –
    - improve water availability through eradication of invasive alien plants;
    - revitalise subsistence farming areas;
    - create jobs in extraction, harvesting and processing of biomass;
    - provide access to clean energy in some cases; and
    - develop the rural economy.
- Such a national scale strategic intervention would need to be integrated with existing government programmes (Agri-Parks, Working for Water, Working for Energy, Housing Subsidies, and programmes managed by DAFF).

To conclude:

- Bioenergy is feasible in South Africa at a relatively small scale, involving mostly processing of organic waste, residues from forestry and agriculture, and eradication of invasive alien plants.
- Feasible project options depend on the cost of feedstock, processing costs and transport costs. These factors are subject to economy of scale considerations. Furthermore, current low oil prices make bioenergy in general, and biofuel in particular, less attractive, with purposely cultivated crops being affected the most.
- Despite this, it is possible to determine short-, medium- and long-term strategies for bioenergy generation, which, in total, may be able to contribute approximately 3,500 MW of electricity equivalent to the national energy mix over the planning horizon of 20 years.
- Should accessible and sufficiently dense invasive alien plants be successfully eradicated over the planning horizon, it will have a significant impact on woody biomass availability and eventually reduce capacity by approximately 1,000 MWe. Negative greenhouse gas benefits ensue should the eradicated invasive alien plants not be replaced by more or less equally productive alternatives – either as managed short-rotation coppicing stands of Category 2 plants (such as eucalyptus), or with indigenous species.

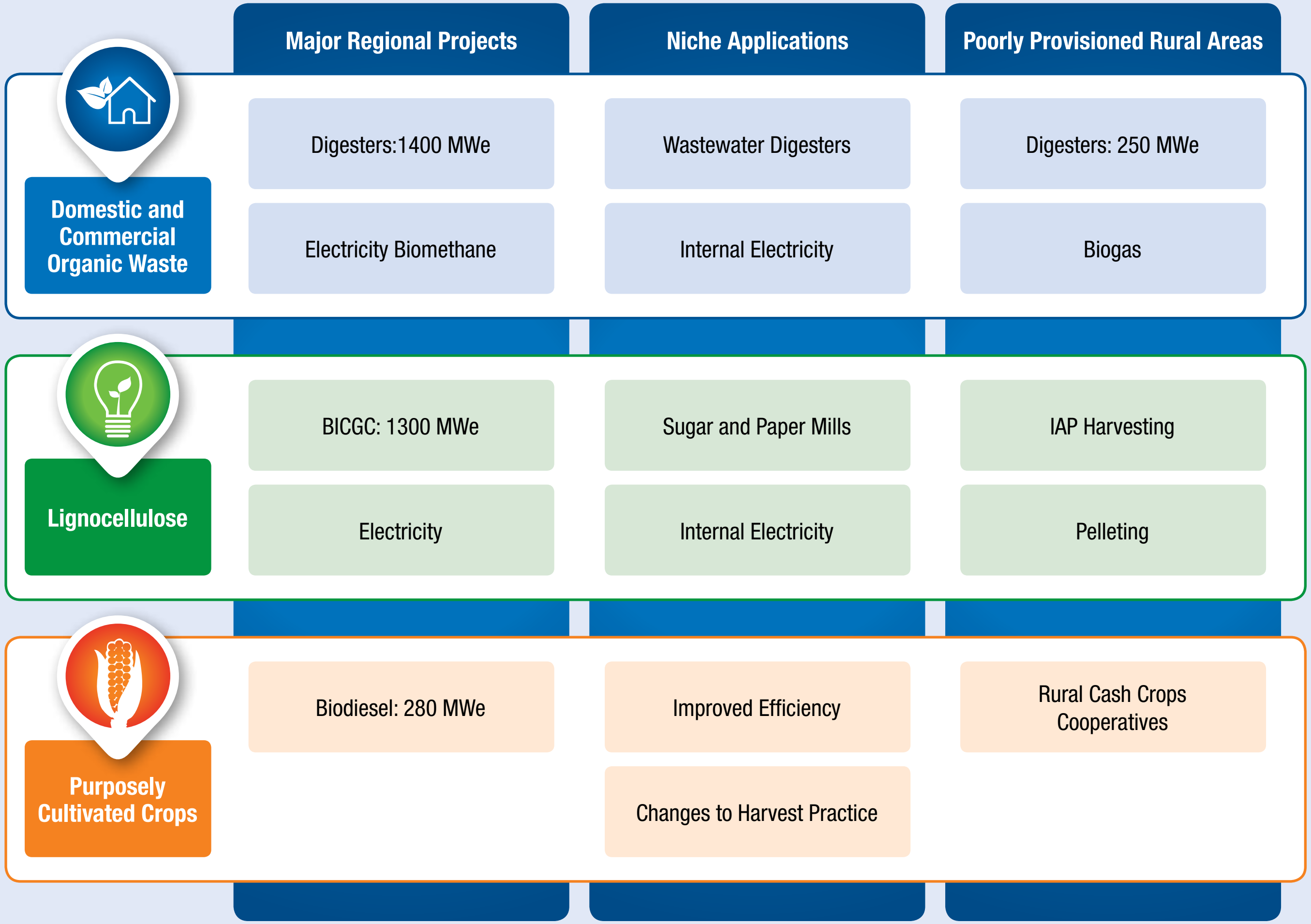
Box 2 summarises the major feasible options for bioenergy development in South Africa.

Read More:

The Executive Summary of the *Synthesis Report* can be found at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Box 2: Bioenergy Options

Figure 2: Summary of bioenergy options



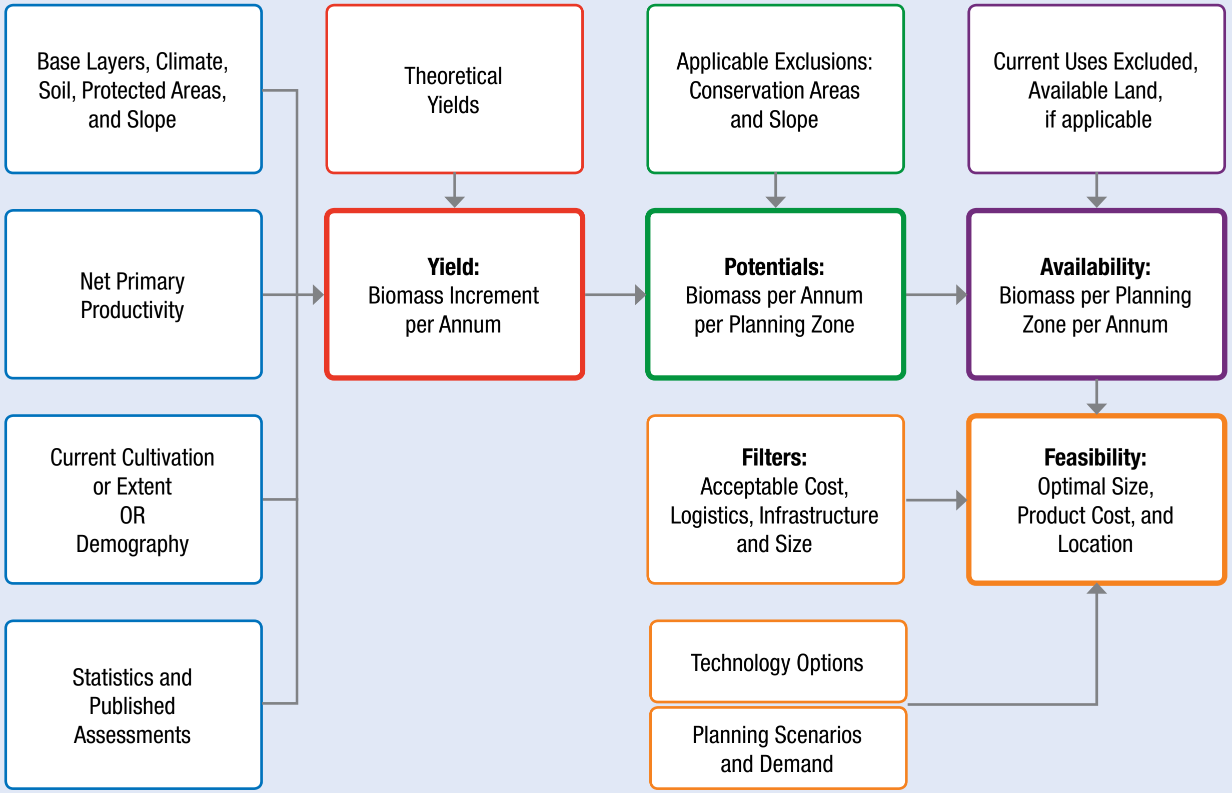
Applications include provisioning of energy in three situations:

- Major regional projects – involving utilisation of organic waste in larger urban areas and development of a biogas and biomethane energy stream, utilisation of invasive alien plants and residues from agriculture, forestry and sugar cane cultivation in regional electricity generation, and possibly the development of a biodiesel industry based on sunflower or groundnut cultivation.
- Niche applications – such as improved efficiency of electricity generation at sugar mills and sawmills, wastewater treatment works provisioning their own electricity needs, and possible changes to sugar cane harvesting practice to release additional biomass.
- Opportunities to assist poorly supplied rural areas – both through affordable clean energy alternatives based on communal digesters and pelleted fuel supplies, and through the creation of jobs and economic activity based on invasive alien plant eradication and cash crop cultivation.

Box 3: Methodology

"A methodology based on UK examples (Welfle *et al.*, 2014) was developed for the bioenergy opportunities reported here, using a successive set of environmental, technical and economic constraints applied to primary sources of biomass."

Figure 3: Methodology



Important design guidelines include the following:

- It is not only potential that should be focused on – determining the availability of biomass of various types, and evaluating the feasibility of conversion technologies for specific applications would be more useful.
- Studies at national or provincial scale tend to ignore potential effects of transportation costs and economy of scale.
- Finite resources (arable land, availability of water) imply that feasibility cannot be evaluated in isolation; options for exploitation compete against one another for these resources.
- Options should be evaluated on the same basis, and should be measured against the costs and feasibility of fossil fuels and other renewables such as wind, solar and micro-hydro power sources.

Using a given biomass resource to generate energy may not be the best possible application of such biomass: food, fibre, natural plant products and chemicals may all have a higher value to the economy. The assessment of optimal biomass allocation is not in the scope of the *BioEnergy Atlas* project, but there is a need to assess the best possible application of biomass, arable land and scarce water resources in the interests of the country.

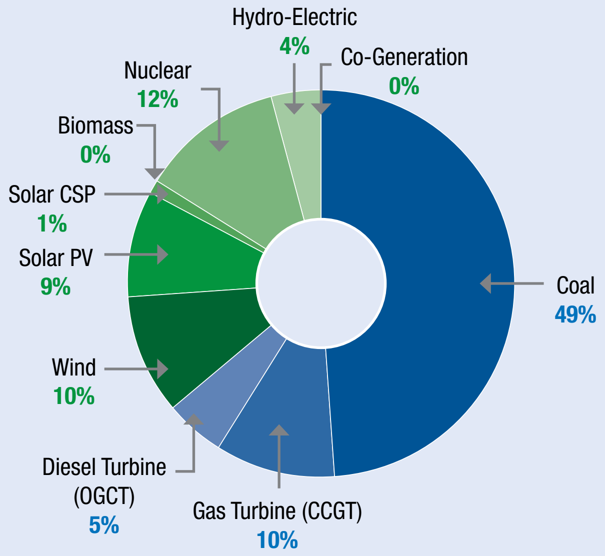
Read More:

Detailed Methodology forms part of the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Box 4: Context

"South Africa is an energy-intensive country, and economic growth, improvements to income levels, reduction in inequality, urbanisation and electrification programmes may all contribute to potentially large increases in energy demand, unless significant efficiency gains can be obtained. Government planning (RIRP, DoE, 2013) does not consider biomass as a significant future contributor to energy."

Figure 4: Contributions to future electricity generation



Bioenergy needs to be viewed within a context that includes the following considerations:

- The Revised Integrated Resource Plan – or RIRP (DoE, 2013) makes virtually no provision for electricity generation from biomass, except for very small digester/co-firing contributions – 63MW by 2030.
- South Africa is a signatory to several international agreements that places an obligation on government to reduce carbon emissions. If correctly managed, bioenergy potentially has a contribution to make to these obligations.
- Starting in 2011, South Africa introduced a managed bidding process for the procurement of renewable energy, known as the Renewable Energy Independent Power Producer Procurement – or REIPPP. Three programmes have been completed and the fourth is under way, with a fifth programme expected in 2016. Bioenergy does not form a major part of the capacity requested, and investors have been slow to bid for the capacity on offer (Table 1).
- Introduction of a carbon tax will make some bioenergy products more attractive.
- The Biofuels Industrial Strategy (DoE, 2007) envisaged a 2% penetration level for biofuels (400 mL/a). Sugar cane and sugar beet were recommended for ethanol production, and sunflower, canola and soybean for biodiesel production. Former homeland areas were proposed for such cultivation and an estimated 1.4% of arable land was implied to achieve a 2% penetration.
- A survey of public perception was conducted recently (DEA, 2012a). The responses are dependent on income levels and, to some extent, on race and geographic location, but in general, one can conclude that:
  - Price and low future cost of electricity is the most important consideration for the largest section of the population (30%), and only affluent responders rate environmentally responsible futures highly (11%).
  - Nuclear power (4%) and biomass (2%) have a fairly low acceptance rate across the population sampled.

Table 1: Status of REIPPP

Bid window	Capacity offered (MW)	Capacity awarded (MW)	Bioenergy (offered/ awarded) (MW)	Reference
1	3 625	1 415	25/0	DoE (2014), Eberhard *et al.* (2014)
2	1 275	1 043.9	25/0	Eberhard *et al.* (2014)
3	1 473	1 456	97/34	Eberhard *et al.* (2014)
4	1 105	1 121	65/0	DoE (2015)

Read More:
A full chapter on Context forms part of the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Key Message 1: Availability of Biomass

- South Africa has limited potential for bioenergy when taking rainfall constraints, food security and variability of supply into account.
- There will be some niche applications for cultivated energy crops, but the most attractive sources are organic waste and invasive alien plants (IAPs).
- IAPs can be supplemented by agricultural residues, plantation residues and sugar cane field residues, but these sources are not well understood in terms of sustainable extraction rates.
- Paper and pulp mill residues, sawmill residues and sugar cane bagasse are already used to generate power, and power generation can be increased through improved efficiency.

Refer to detailed maps in the Atlas section: Factors determining Biomass Availability, Agriculture and Forestry, and Biomass Availability.

Table 2: Availability of biomass for energy applications

Source	Estimates of availability or potential										
		Allocated already (dry mass)									
	Potential (dry mass) Tg/a	Re-use (Tg/a)	Unavailable (Tg/a)	Energy use (Tg/a)	Not available (dry mass) Tg/a	Available now (dry mass) Tg/a	Potential additional availability (dry mass) Tg/a		Energy density (PJ/Tg) (10)	Moisture content estimate (%) (11)	Energy equivalent available now (PJ/a)
Agricultural residues	36.22		30.42		30.42	5.80	2.90	1	10.00	42%	57.95
Sugar cane field residues	5.06		5.06		5.06	0.00	2.53	2	10.00	42%	0.00
Sugar cane bagasse	5.35	0.2		4.54	4.74	0.60	2.34	3	10.00	42%	6.02
Plantation residue	6.70		5.20		5.20	1.50	0.00	4	12.50	30%	18.75
Pulp and paper mill residues	0.69			0.69	0.69	0.01	0.35	5	12.50	30%	0.09
Black liquor	1.50			1.49	1.49	0.00	0.77	6	6.30	59%	0.00
Sawmill waste (bark included)	3.10	0.15		2.00	2.15	0.95	1.03	7	10.40	40%	9.88
Invasive species	11.30		3.23		3.23	8.07	1.16	8	14.70	20%	118.63
Fuelwood	14.00			10.00	10.00	4.00	12.00	9	14.70	20%	58.80
Organic solid waste component	6.47			0.65	0.65	5.82	0.00	12	10.00	20%	58.23
Organic sewage sludge	2.53			0.25	0.25	2.28	0.00	13	10.00	20%	22.77
Purposely cultivated crops	9.26				0.00	9.26	0.00	14	14.70	42%	136.12
Total	**83.91**	**0.35**	**43.91**	**18.72**	**62.97**	**20.92**	**23.08**				**487.24**

Column descriptions

Potential dry mass	Total existing dry mass
Re-use	Allocated: Composting, recycling, value-added products
Unavailable	Allocated: Unavailable so as to maintain soil productivity and condition, or not accessible
Energy	Allocated: Used already for energy applications
Not available	Total not available = Sum (allocated categories)
Available now	Available = Total potential – Not available
Potential additional availability	Additional biomass unlocked through various scenarios
Energy density	Specific energy content of biomass
Moisture content	Estimated moisture content of the biomass (air-dried, except in the case of black liquor)
Energy equivalent now	Total energy in dry biomass currently available

Notes

These assessments are subject to conservative assumptions: a scenario number in the column 'Potential additional availability' denotes options for relaxation.

The scenarios are:

1) **Agricultural residue:** Depending on the safe extraction rate assumptions (at present only residue in excess of 3 t/ha), biomass availability could be increased. The relaxed assumption is that 50% more can be extracted over and above the conservative extraction rate. Bear in mind that the variability of production of rain-fed agriculture in South Africa is significant – up to 50% inter-annual variation.
2) **Sugar cane residues** are not available due to current practice (burning cane before harvest). Changing practice to 'green' harvesting will make some of the residue available – say 50%, but will have a significant negative impact on rural livelihoods, since green harvesting is largely automated.
3) **Sugar cane bagasse** – all of the resource is currently used for low-efficiency energy generation. If efficiency can be improved from 33% to 50% through capital investment in new technology, the value shown is the equivalent biomass that will be liberated for additional energy generation.
4) **Plantation residue** – no additional potential is thought to exist.
5) **Pulp and paper residue** – all of the resource is currently used for low-efficiency energy generation. If efficiency can be improved from 33% to 50% through capital investment in new technology, the value shown is the equivalent biomass that will be liberated for additional energy generation.
6) **Black liquor** – all of the resource is currently used for low-efficiency energy generation. If efficiency can be improved from 33% to 50% through capital investment in new technology, the value shown is the equivalent biomass that will be liberated for additional energy generation.
7) **Sawmill waste** – all of the resource is currently used for low-efficiency energy generation. If efficiency can be improved from 33% to 50% through capital investment in new technology, the value shown is the equivalent biomass that will be liberated for additional energy generation.
8) **Invasive species** – the current estimate is based on a low annual increment of approximately 3% of standing biomass. There are significantly higher increments in the more productive areas of the country, and these are generally also more exploitable. Hence a relaxed assumption of a higher limit of 4.5% annual increment is defensible.
9) **Fuelwood** – all of the resource is currently used for very low efficiency energy generation. If efficiency can be improved from 15% to 33% through capital investment in new technology, the value shown is the equivalent biomass that will be liberated for additional energy generation.
10) "Dry mass basis" throughout these tables refers to air-dried biomass. In South Africa, average temperatures are high and humidity is low relative to most of the developed world, and air-dried lignocellulose materials have a moisture content of between 10% and 20%.
11) The moisture content of woody biomass against oven-dried wood can be estimated using a ratio of energy densities.
12) **Organic fraction of domestic solid waste** is reported here as the total available, minus an estimated 10% that is currently used for composting, electricity generation or biogas manufacture. Legal and service provision constraints on exploitability are discussed below.
13) **Municipal waste water** – The same applies to municipal sewage sludge.
14) **Purposely cultivated crops** are reported for the best available options in respect of biomass – this may not be feasible to process on techno-economic grounds. As stated before, the estimate takes only subsistence farmland into account. Figure 5 summarises the results of the evaluation of purposely cultivated crops as a feedstock for biofuels.

"From the evaluation of availability it is unlikely that biomass will make a major contribution to renewable energy requirements in South Africa, but that there are specific applications that are sizable and should be investigated."

- Municipal solid waste is a sizable resource, but has partial immediate potential for electricity generation, largely because of the low percentage of sites with proper permits, and because solid waste removal is not formalised for a sizable percentage of the population. Likewise, wastewater treatment works do not serve all of the population with water-borne sewage. This leads to three main considerations:
  - Combination of sewage sludge and solid waste organic component to increase the availability and improve the economy of scale of electricity generation from these sources;
  - There is significant upside potential should service delivery and permit processing improve in future; and
  - Options exist for deployment of community or domestic digesters.
- Several crop candidates (maize, sorghum, sweet sorghum, soybeans, groundnuts, sunflower and sugar cane) were evaluated. The potential availability of these crops (most of which are in competition for the same land) can be summarised as follows:
  - Maize, while constrained by policy in respect of application as an energy feedstock, shows significant potential for biofuel generation due to good yields, and availability of suitable underutilised farmland. Utilising improved yields from subsistence farmland to displace maize grown for cattle feed could open up additional sources of commercially produced maize for food and energy purposes.
  - Of oil-producing crops, groundnuts and soy oil are good candidates from a raw potential point of view, but oil and oilcake have a high alternative market value. Sunflower oil and oilcake have lower market values, and sunflower has a large area of potential cultivation.
  - Sugar from sweet sorghum can potentially be produced in sufficient quantities, but it may be difficult to establish a new industry in subsistence farming areas.
  - Conservation agriculture may contribute significantly to future GHG emission reduction – by improving the amount of soil carbon sequestered and reducing the need for fertiliser application.
  - Water use of crops grown for bioenergy is a concern. Recent work by Kunz *et al.* (2015) has estimated the extent to which energy crops exceed the water footprint of natural vegetation it displaces. On this basis, crops such as sweet sorghum, maize and sunflower are generally better choices.
- Electricity generation from residues at sawmills and sugar mills has some potential, but is unlikely to contribute much beyond the needs of the industry itself, unless capital is invested in improved efficiency. Sawmills, in particular, are already utilising a sizable proportion of residue biomass to supply internal energy needs.
- Invasive alien species represent a significant woody biomass resource, and programmes such as Working for Water and Working for Energy seem to be natural vehicles for a wider, energy-directed effort to utilise the biomass and control the problem. Options include:
  - Pelleting or chipping of lignocellulose biomass in areas close to existing coal-fired power stations, with a view to co-firing;
  - Supplementing or replacing coal- and gas-based refinery feed with lignocellulose biomass feedstocks; and
  - Development of small electricity-generating capacity in areas of poor provisioning and extensive rural firewood use, or replacement of fuelwood use by pelleted fuel and efficient pellet-burning stoves.
- A combination of feedstocks should also be considered:
  - All lignocellulose biomass (invasive alien plants, sawmill and sugar mill residues, plantation residue and agricultural residue) as a combined feedstock for electricity generation, lignocellulose fuel production, or GTL/CTL feedstock replacement.
  - Larger-scale organic waste production installations, combining the organic streams from wastewater and solid waste to generate electricity or biogas for vehicle fleets.

Read More:

Detailed Biomass Availability Assessment forms part of the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Key Message 2: Infrastructure

Infrastructure that serves the energy sector, and that could potentially be used in future, was evaluated in respect of proximity to economic activity, population (specifically looking at poor rural households) and availability of biomass.

Refer to detailed maps in the Atlas section: Infrastructure.

Figure 5: Proximity to infrastructure

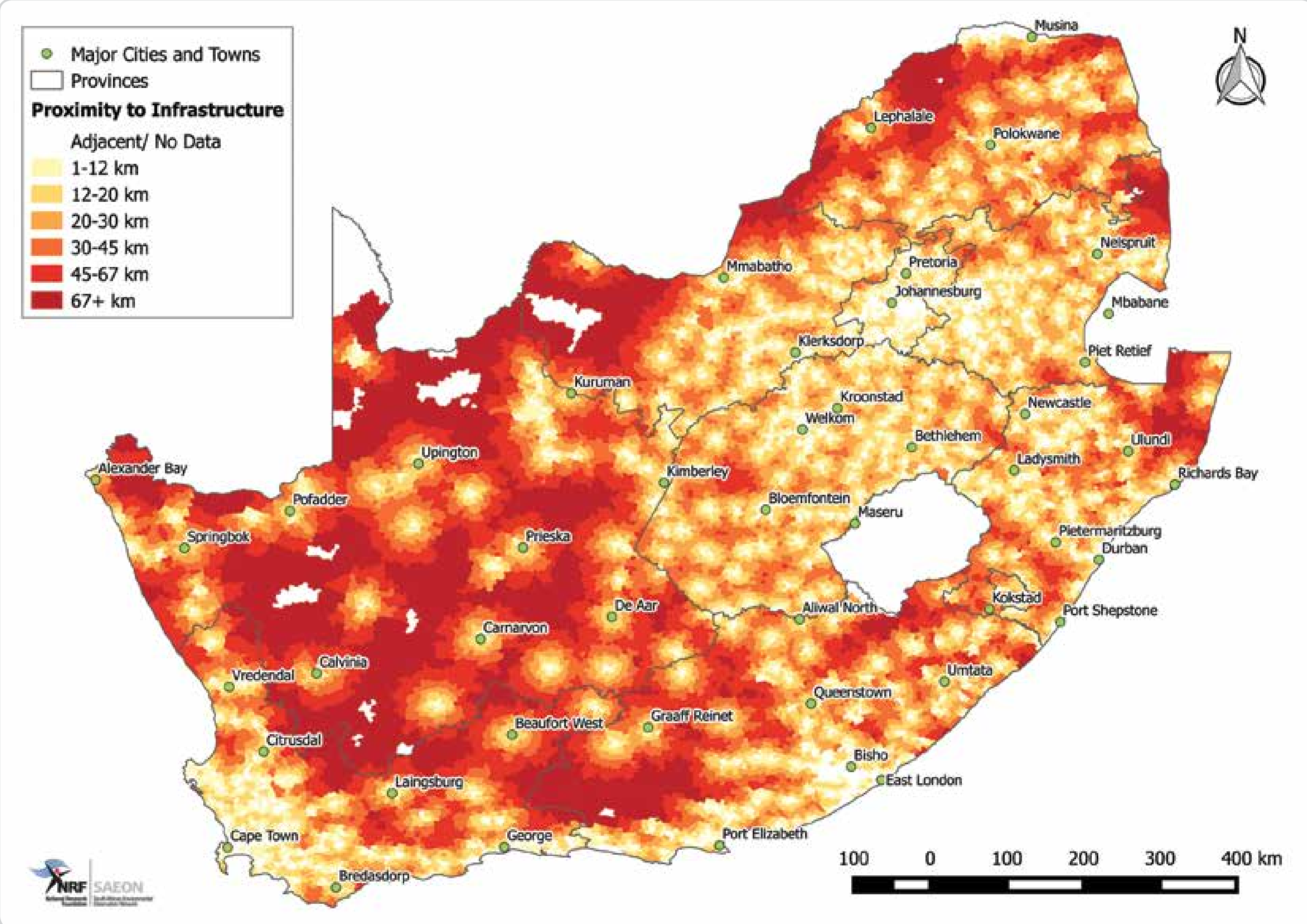


Figure 5 indicates the proximity of the closest infrastructure (of all types) to each location in South Africa, giving a sense of areas where new bioenergy-related investment will be relatively easy to link up with infrastructure, and areas where it will not be.

Infrastructure elements that were assessed include:

- Energy infrastructure (past, present, future)
  - Electricity generation/storage/power stations
  - Coal, hydro, solar, wind and biogas – including operational and decommissioned facilities, and planned facilities reflected by National Energy Regulator of South Africa (NERSA) permits; and
  - Transmission and distribution of electricity (existing and planned).
  - Gas and liquid fuels
  - Fuel and gas depots, and refineries as licensed by NERSA.
- Waste-processing infrastructure
  - Solid waste disposal sites (many of these do not have valid operating permits from the Department of Environmental Affairs); and
  - Wastewater treatment works.
- Agriculture infrastructure
  - Silos, sawmills and sugar mills.
- Logistics and transport
  - Pipelines;
  - Road and rail network; and
  - Ports.

The evaluation indicates that:

- Power stations and electrical transmission/distribution infrastructure are adequately placed in respect of economic activity, but less so in respect of population. Areas that are poorly served include pockets of former homelands in the Eastern Cape, KwaZulu-Natal and Limpopo.
- New transmission infrastructure planned by Eskom will traverse some of the remote areas, such as the rural Eastern Cape, the KwaZulu-Natal Midlands and western Limpopo.
- There is good infrastructure cover in areas where biomass production is high (with some exceptions in former homeland areas). Here it is prudent to extend and improve existing infrastructure where possible, whether such infrastructure is power-related, liquid fuels-related, agriculture-related or waste management-related. See Figure 7.

Locations that should receive special consideration:

- The Mpumalanga Highveld region has significant infrastructure (electricity, refinery/liquid fuel and agriculture) and also offers substantial agricultural residue/invasive alien plant resources. This is an attractive general location for bioenergy development.
- Northern KwaZulu-Natal is poorly served with infrastructure of any kind, has a relatively large rural population, and has above-average biomass potential (mostly for crop cultivation). Development of the liquid fuel feedstock industry (sugar cane, sweet sorghum or maize-based) can align well with existing sugar processing sawmill, or refinery infrastructure.
- Rural Eastern Cape has significant biomass resources (invasive alien plants and potential for energy-crop cultivation), but lacks infrastructure in some of the more remote areas. This may be an area suitable for development of new regional electricity and liquid fuel (biodiesel) infrastructure.

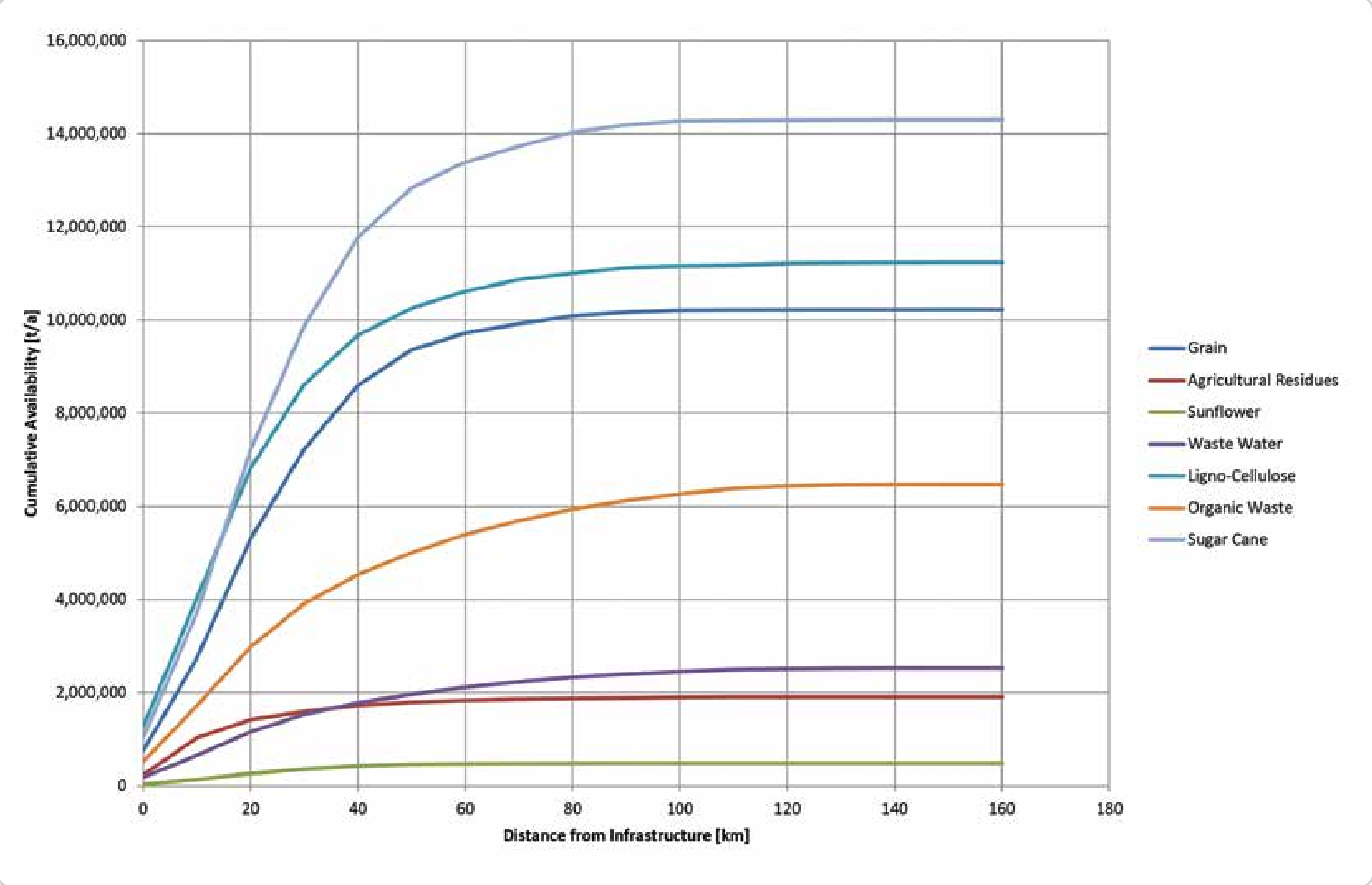
The extent to which existing infrastructure can be utilised was reviewed, and three typical cases were identified:

- Household organic waste, whether derived from solid waste or wastewater, was assigned to existing, permitted solid waste or wastewater treatment facilities, and hence makes maximum use of existing infrastructure. The penalty in transport cost is low, as these facilities are widely distributed and locations do not differ significantly from optimum locations for processing. It is feasible to create single, large facilities in each major urban area, but in practice each municipality or metro will probably implement their own projects.
- In the case of electricity generation from lignocellulose, new capacity is assigned to existing power stations, planned electricity-generating locations (including wind and solar), sawmills or sugar mills, irrespective of type, on the premise that these locations are suitable for inclusion of new capacity into the transmission network. In the case where facilities are not close (within 200 km), the selected location reverts to the optimal one.
- Biodiesel manufacture is allocated to refineries or fuel depots where these are close (within 200 km). Transport of final product over this distance is comparable to the current practice of depot and blending facility supply from a small number of refineries.

Read More:

Infrastructure Availability Assessment forms part of the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Figure 6: Cumulative availability of biomass as a function of distance from infrastructure



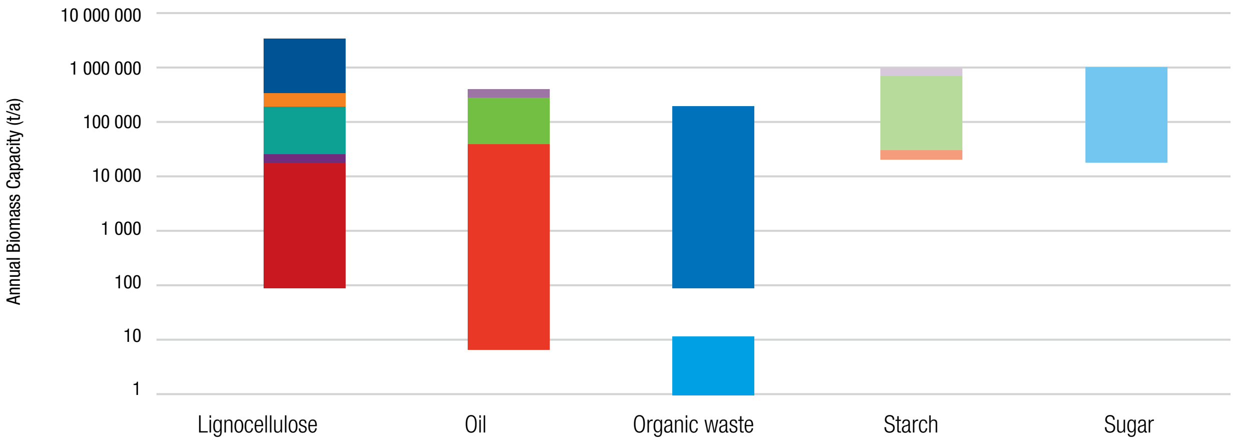
The bulk of available biomass is within 80 km of applicable infrastructure for location of new conversion facilities. Grain (maize, sorghum, wheat) is typically within close proximity of agricultural infrastructure such as silos, as is oil (sunflower) and maize and wheat residues. Waste water and municipal organic waste fractions are generated close to existing waste water and solid waste treatment or disposal facilities. Ligno-cellulose (invasive alien plants, plantation residue, and sawmill residues) are largely within reach of sawmills or existing, decommissioned, or planned electricity infrastructure.

Key Message 3: Processing Technology

A portfolio of 52 processing technologies was evaluated in terms of economy of scale and resulting processing costs across five major categories of feedstock (lignocellulose, oil, sugar, starch and organic waste).

Information was also gathered on process maturity, lead time to operational use, efficiencies, GHG emissions, job creation potential, and flexibility in respect of feedstock composition.

Figure 7: Lowest cost processing technology for feedstock categories



Note: Legend - see detail in Table 3.

This first-order screening process resulted in the following conclusions:

- Not all technology options are adequately mature and hence were not considered in feasibility assessments. A cut-off of five years or less to maturity was applied.
- Generally, complex industrialisation at high capacity and utilising third-generation conversion of biomass are more often not mature or proven. These candidates also tend to be more expensive, and hence optimal technology selection is biased towards more established first- and second-generation processes with small to medium-sized capacities (100 – 100,000 t/a).
- It was possible to identify the most appropriate low-cost technology for each of the five main feedstock categories across a range of feedstock volumes.
- Lower-cost technologies include:
  - Combined heat and power or combined gas cycle conversion of lignocellulose to electricity;
  - Biogas production in digesters from organic waste; and
  - Trans-esterification of seed and nut oils – processing costs are affordable, but input costs (feedstock costs) are high, and will need to be subsidised from oilcake sales.

Read More:

Detail on Technology and Processing Options forms part of the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Table 3 summarises the lowest processing cost option for each feedstock. The maximum cost usually corresponds with the minimum capacity due to economy of scale. The data exclude feedstock and transport costs, but illustrative feedstock and transport costs are included to indicate a typical end product cost.

Table 3: Lowest cost option(s) for each feedstock (2014 Rand)

Feedstock base	Technology option/conversion process		Minimum capacity (t/a)	Maximum capacity (t/a)	Minimum cost (R/kWh)	Maximum cost (R/kWh)	Typical feedstock costs (R/kWh)	Typical transport costs (R/kWh)	Average product cost (R/kWh)
Lignocellulose	COMB-Tri	Tri-Generation Systems	83	16 700	R0.05	R0.82	R0.32	R0.09	R0.85
Lignocellulose	COMB-CHP	Back Pressure Steam Turbine	12 900	3 300 000	R0.18	R0.54	R0.32	R0.09	R0.77
Lignocellulose	PY-EL	Fast Pyrolysis	19 000	340 000	R0.10	R0.40	R0.32	R0.09	R0.66
Lignocellulose	COMB-EL	Thermal Electricity	20 000	3 500 000	R0.17	R1.19	R0.32	R0.09	R1.09
Lignocellulose	TORR-2	Bio-Coal Torrefaction	30 000	200 000	R0.12	R0.18	R0.32	R0.09	R0.56
Lignocellulose	BICGC	Biomass Integrated Combined Gasification Cycle	50 000	3 500 000	R0.09	R0.39	R0.32	R0.09	R0.65
Oil	COMB-IC	Internal Combustion	6	40 000	R0.42	R2.15	R0.76	R0.09	R2.13
Oil	TRANS-2	Transesterification of Virgin Oil to Diesel	10 000	250 000	R0.36	R0.77	R0.76	R0.09	R1.41
Oil	HEFA-1	Hydrotreated Jet Fuel Process	100 000	500 000	R1.25	R1.86	R0.76	R0.09	R2.40
Organic waste	AD-1	Simple Anaerobic Digestion	2	10	R0.23	R0.56	R0.21	R0.09	R0.70
Organic waste	AD-2	Complex Anaerobic Digestion	125	200 000	R0.01	R0.42	R0.21	R0.09	R0.52
Organic waste	AD-3	Complex Anaerobic Digestion	125	200 000	R0.06	R1.17	R0.21	R0.09	R0.92
Starch	But-Starch	Fermentation of Starch to Butanol	20 000	700 000	R0.16	R3.16	R1.06	R0.09	R2.81
Starch	Eth-Starch	Starch to Ethanol	20 000	1 000 000	R0.60	R3.07	R1.06	R0.09	R2.99
Sugar	Eth-Sugar	Sugar to Ethanol	20 000	1 000 000	R0.35	R12.81	R1.12	R0.09	R7.79

Assumptions:
Energy content of lignocellulose - 4 kWh/kg, Conversion efficiency 33%
Energy content of organic oil - 11 kWh/kg, Conversion efficiency 92%
Energy content of organic waste - 3 kWh/kg, Conversion efficiency 30%
Energy content of grain - 4 kWh/kg, Conversion efficiency 68%
Energy content of sugar syrup - 5 kWh/kg, Conversion efficiency 41%
Average transport distance: 80 km at 1.50 R/t.km

Feedstock Costs:	
Invasive Alien Plants	R373.76
Organic Waste	R189.00
Maize Residues	R618.00
Sunflower Oil	R7 663.50
Maize Grain	R2 890.00
Sugar Molasses/Syrup	R2 286.12

Key Message 4: Feasibility

The feasibility assessment has confirmed the following broad outline in respect of bioenergy feedstocks and processing technologies. Bear in mind that availability is price-dependent:

- Utilisation of **all available urban domestic (household) organic waste**, from solid waste and from wastewater, appears to be the most feasible option, with an acceptable end-product cost (unrefined biogas at **between 0.26 and 0.36 R/kWh[3], 72.20-94.41 R/GJ**). Upgrading to biomethane typically doubles the cost, and electricity generation will result in efficiency penalties. The option requires intervention from government in respect of policy; accelerated permit processing for wastewater and solid waste processing sites; better utilisation of unserviced waste, and sponsoring of research and development of standardised large-scale digester and upgrading technology. **Contribution from feasible project options: up to 1400 MWe.**
- Development of household or communal digesters in rural unserviced areas in combination with cattle dung in areas where this is available – average cost is **0.38 to 1.01 R/kWh, 105.52-280.47 R/GJ**. Government would need to identify and promote technology, implement programmes to promote acceptance and safe use, and possibly serve as a source of capital for initial investments. **Estimated contribution from feasible project options: up to 250 MWe.**
- Combination of all available lignocellulose biomass (invasive alien plants, plantation residues, sugar mill bagasse and agricultural residue) can make a significant contribution to electricity generation in mid-size regional power stations (50-300 MW). Implemented facilities will have a limited lifetime due to the objective of eradication of invasive alien plants over a 20-year period. Some of these power stations will be located in areas of poor electricity availability (Mpumalanga, Eastern Cape, KwaZulu-Natal), and will be able to underpin a rural electrification project. Costs are comparable with new electricity from coal (**average 0.71-1.58 R/kWh, 194.39-438.77 R/GJ**). **Contribution from feasible project options: up to 1300 MWe.**
- There is an opportunity to develop an **energy crop industry on subsistence farmland** as a measure to improve rural livelihoods. The most feasible option is for byproduct-subsidised biodiesel manufactured from groundnut oil or sunflower oil[4]. Final product costs are offset by selling some of the by-product oilcake, with a resulting product price in the order of **1.55-2.75 R/kWh (430.43-763.67 R/GJ**). At 5% of the diesel fuel pool, these cost levels will add approximately 0.05 R/kWh to the final product cost – equivalent to the difference between the coastal and inland price of diesel fuel. Due to the need for some form of subsidy, projects are unlikely to attract private capital and will have to be financed through development funds. In addition, it is likely that significant effort will be required to transform rural agricultural practices. With an oil price in the order of 50 USD/barrel, these options are not attractive, but the situation might improve should oil prices rise to recent highs of 100 USD/barrel. **Contribution from feasible project options: up to 587 MW as power equivalent, 235 MWe as electricity, 570m l/a of biodiesel, approximately 5% of current diesel consumption.**

Refer to detailed maps in the Atlas section: Feasibility.

3 Costs refer to Levelised Cost of Energy – a discounted 20-year average cost for the product. Read More: Levelised Cost Calculations are discussed in the full report – http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002
4 Although maize conversion to n-butanol is the best option, it is not considered on the grounds of food security.

Invasive alien plants (IAP) represents the largest woody biomass resource, bearing in mind that the estimates of potential are based on eradication over a period of 20 years. Three cases have been evaluated to determine the feasible application of IAP:

- Determining the best possible locations for IAP processing to wood pellets, as a substitute for fuelwood or a feed for thermal electricity-generating processes;
- Determining the best possible locations for IAP feed into Combined Heat and Power (CHP) or Biomass Integrated Combined Gasification Cycle (BICGC) plants – with a view to the establishment of additional electricity-generating capacity;
- Determining the feasibility of establishment of electricity generation (either co-firing or co-generation) at existing, decommissioned, or future electricity-generation facilities.

The major areas of feasibility for conversion of lignocellulose to electricity include Mpumalanga (well-situated in terms of refinery and coal-fired power station infrastructure), and several locations in the rural Eastern Cape, KwaZulu-Natal and the Western Cape – mostly from invasive alien plant eradication. There is some potential in KwaZulu-Natal for forestry and sawmill residue and more efficient utilisation of sugar bagasse. Supplementing the eradication of invasive alien plants with residue from forestry, sugar plantations and agriculture is sensible and potentially useful, as it reduces the inter-annual variation in net primary productivity from these sources, but research is needed to confirm sustainable extraction rates.

Domestic organic waste is a sizable resource in total and can generally be classified into the following categories:

- Organic component of household waste – serviced and unserviced;
- Organic component of household wastewater – serviced and unserviced.

The unserviced component makes up a large proportion of the available biomass, given that many rural communities are not served, and that large informal settlements attached to cities are also not served.

The following options were assessed in terms of feasibility:

- Applying large-scale digesters in optimal locations to consume all available biomass from household sources;
- Using household or community digesters in locations where there is availability of unserviced biomass.

Organic waste streams that were not evaluated include cattle dung (both commercial and informal rangelands or feedlots), commercial and food-processing waste, and waste streams from piggeries and chicken farms. In all of these cases, work is needed to refine the availability of spatially explicit data with a view to location analysis. Estimates of total availability by province exist, but modelled feasibility cannot be performed at that scale.

In respect of biogas production, it is obvious that the largest feasible project options will be associated with the major metropolitan areas of the country – Gauteng, Cape Town and surrounds, eThekwini, Nelson Bay Metro, Buffalo City, and Mangaung.

In these areas, significant economy of scale can be realised with transport distances of up to 150 km. The implication is that in areas such as Gauteng, a single facility can be erected

to process wastewater sludge and organic municipal solid waste, but in practice, this will be difficult to implement due to multiple jurisdictions, and the likely outcome will be a portfolio of smaller facilities. In addition, use of the organic component of wastewater to generate *in-situ* electricity for wastewater treatment plants is becoming commonplace and it will be more practical to generate *in-situ* energy.

An evaluation was done to identify the most feasible way to supply the liquid fuel sector with biofuels from purposely cultivated crops. The crops that were evaluated are all summer rainfall crops, as this area covers the bulk of subsistence farmland in the country. Commercial farmland was not considered because of policy constraints. Hence the winter rainfall areas shown here as having mostly sugar cane as the most feasible summer crop should be disregarded in practice. Also note that all areas indicated have at least some proportion of subsistence farmland, but that outside traditional tribal areas this farmland is limited and production volumes will be low.

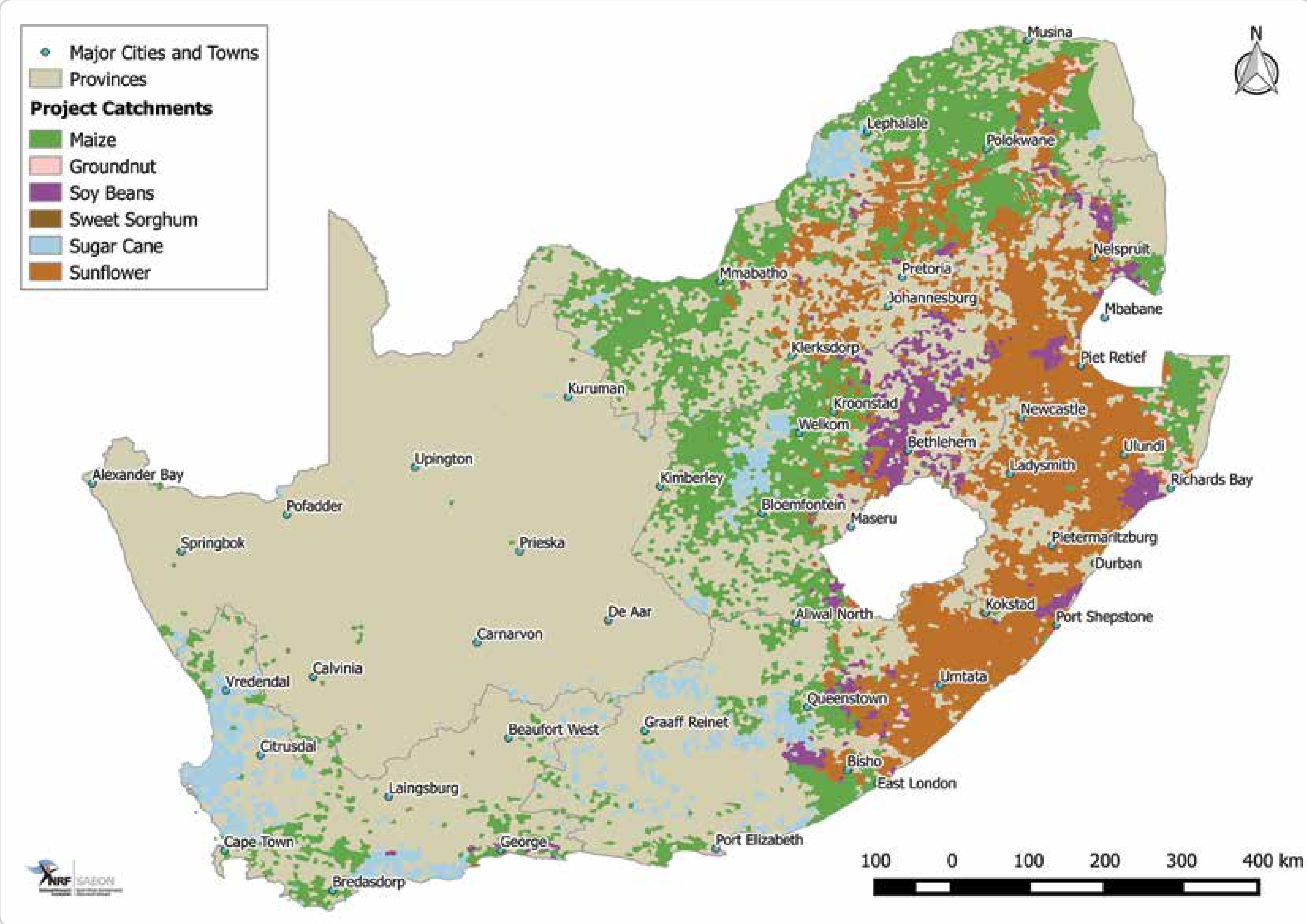
Six options were evaluated (soybeans, sunflower and groundnuts for biodiesel conversion, maize for butanol production, and sugar cane and sweet sorghum for ethanol production). These options have limited feasibility for two reasons: fuel-quality alcohol production is costly, and the alternative value for sugar and for oil-bearing crop produce (oil and oilcake) is high. As a result, the few feasible project options will have to rely on cost offsets through sale of oilcake by-product. Sunflower production is favoured if no offset is applied, while soybeans and groundnuts can be made more attractive if an offset is applied due to higher oilcake value.

While maize is shown to be the most feasible alternative in large parts of the country, production costs in these areas are high on account of low yields. Feasible biodiesel production can only be achieved in the higher productivity areas of the south-eastern and eastern coastal plains – roughly corresponding to the former homeland areas of Transkei and KwaZulu-Natal. In these areas, an option to be considered in future work includes the development of a livestock feed industry based on maize, assisting to divert the large proportion of commercial maize production that is routinely used for cattle feed (DAFF, 2014b) towards human consumption.

Figure 9 summarises the flow of biomass from available sources to energy end-products.

“Feasible biodiesel production can only be achieved in the higher productivity areas of the south-eastern and eastern coastal plains – roughly corresponding to the former homeland areas of Transkei and KwaZulu-Natal.”

Figure 8: Modelled distribution of the most feasible cultivated crops, based on techno-economic optimum location and appropriate technology – byproduct cost offsets included

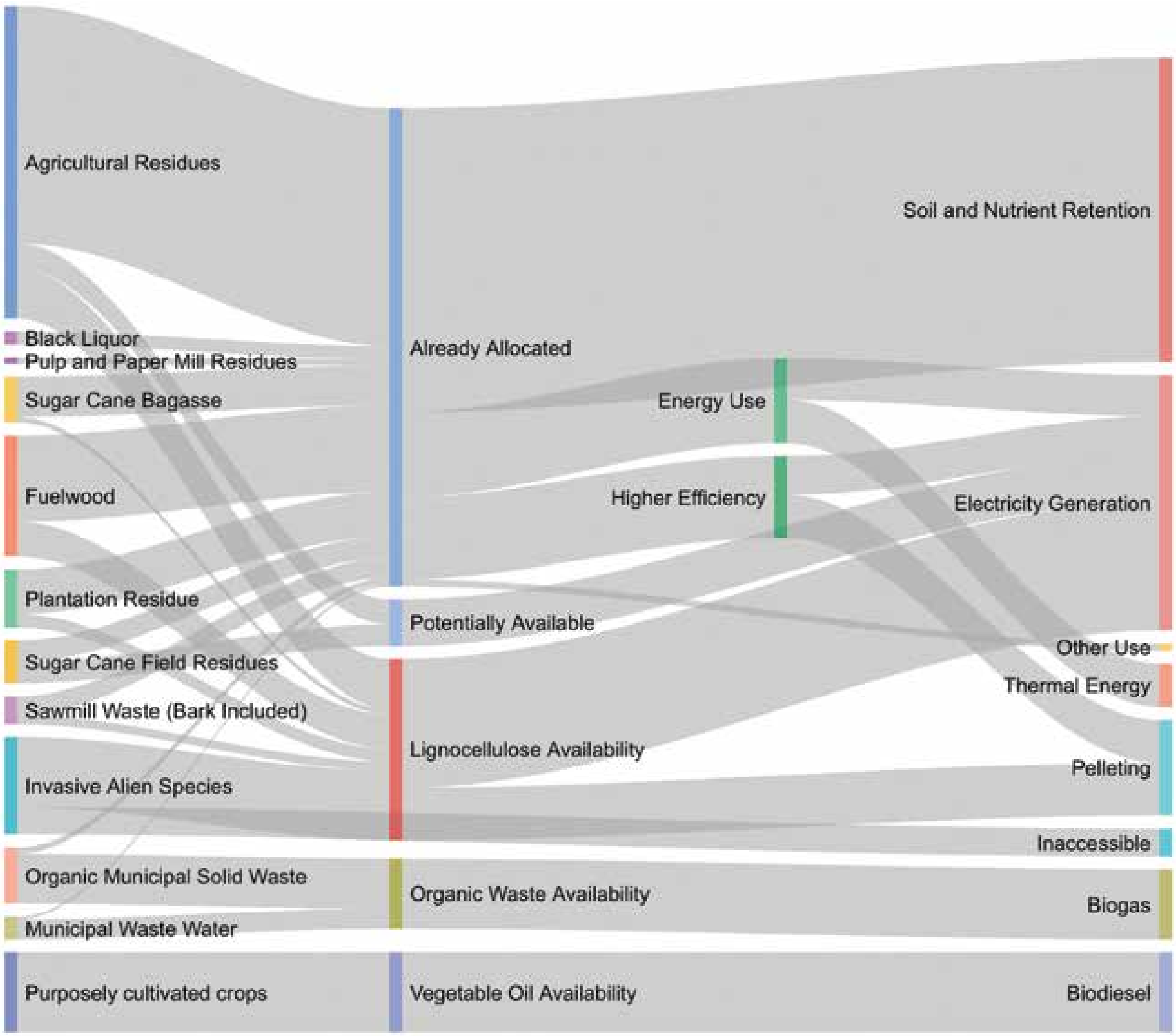


Notes:

These maps show the most attractive crop to cultivate for conversion to liquid fuel in each specific area. The cost of doing so may not be feasible in comparison to current fuel prices.

The specific example shows feasible crops for the case where end product energy costs are offset through byproduct sales.

Figure 9: Biomass flows for feasible options identified in this study



Box 5: Bioenergy Costs

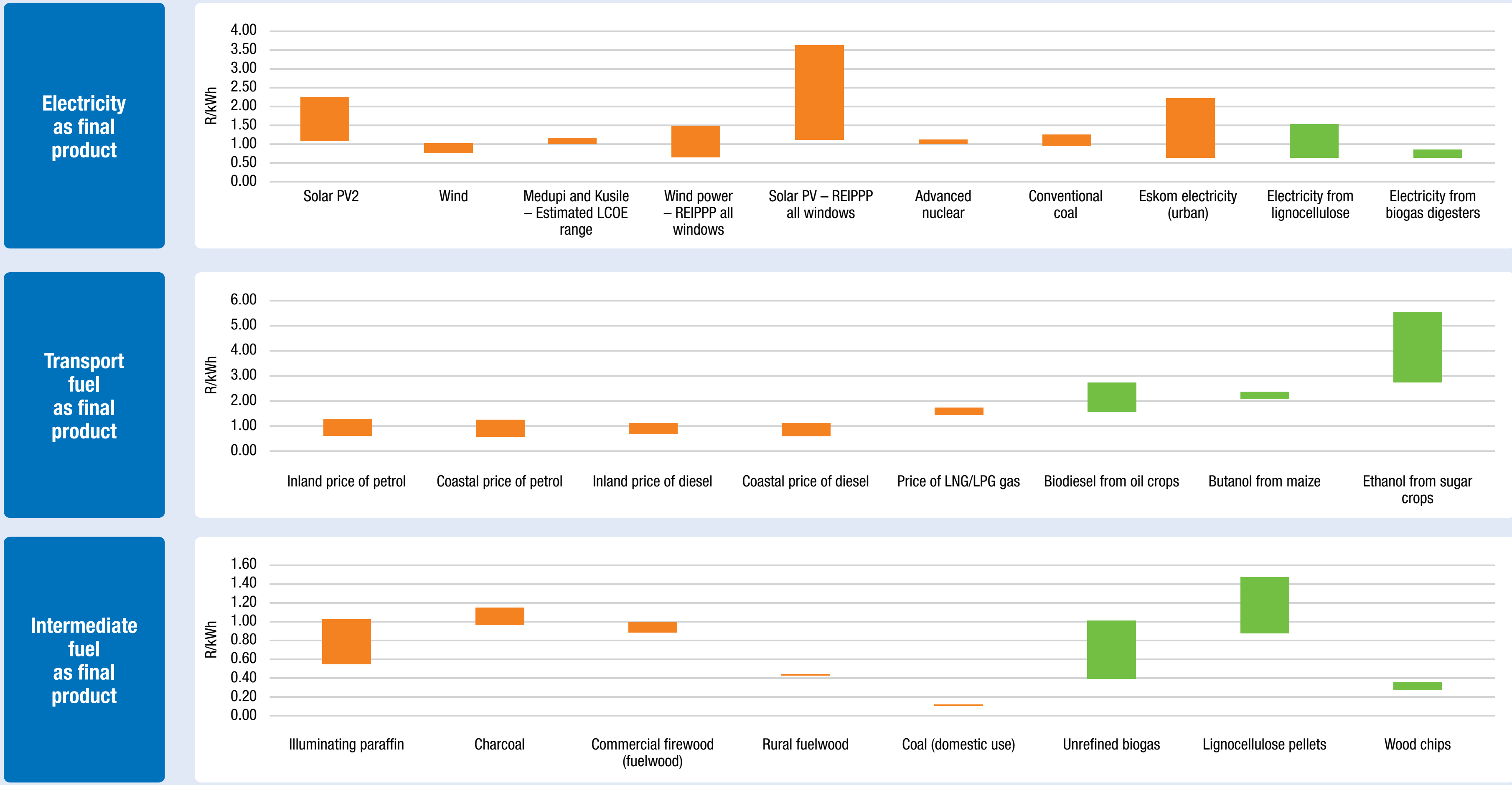
Bioenergy costs are dependent on a number of factors, including feedstock costs, transport costs, economy of scale in conversion processes, and distribution costs. In addition, bioenergy competes against other renewables and fossil alternatives.

Comprehensive feasibility assessments were performed during the course of the *BioEnergy Atlas* project, and these results are summarised below. Costs of energy products are expressed as a long-term cost of electricity or electricity equivalent ('levelised cost' or LCOE) so that options can be compared with each other irrespective of the final product.

Figure 10 illustrates the range of bioenergy costs derived from feasibility modelling performed for the *BioEnergy Atlas* project, and compares these with the cost range of both renewable and fossil alternatives. In each case, the cost range for the 10 most attractive project options is reported.

Read More:
Detailed Feasibility Assessment forms part of the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Figure 10: Costs of bioenergy options compared with fossil and renewable energy costs. Note that the costs for REIPPP bids in windows 1-4 are reported for 2016 Rand, while the other costs are 2015 Rand values. The costs reported for biodiesel assume that oilcake revenue can be used to subsidise the biodiesel product.



Box 6a: Options and Opportunities

Figure 11: Feasible options by province and feedstock

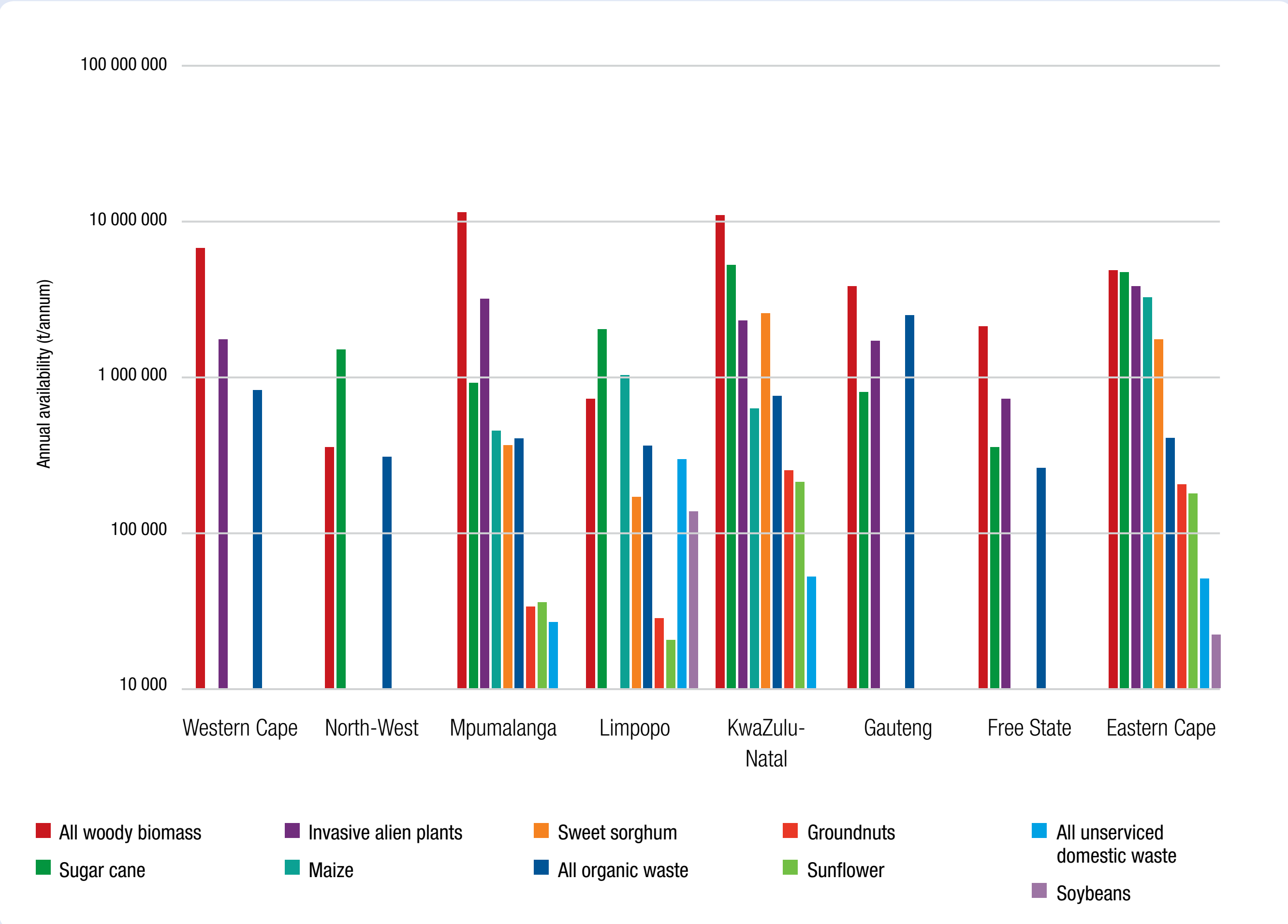
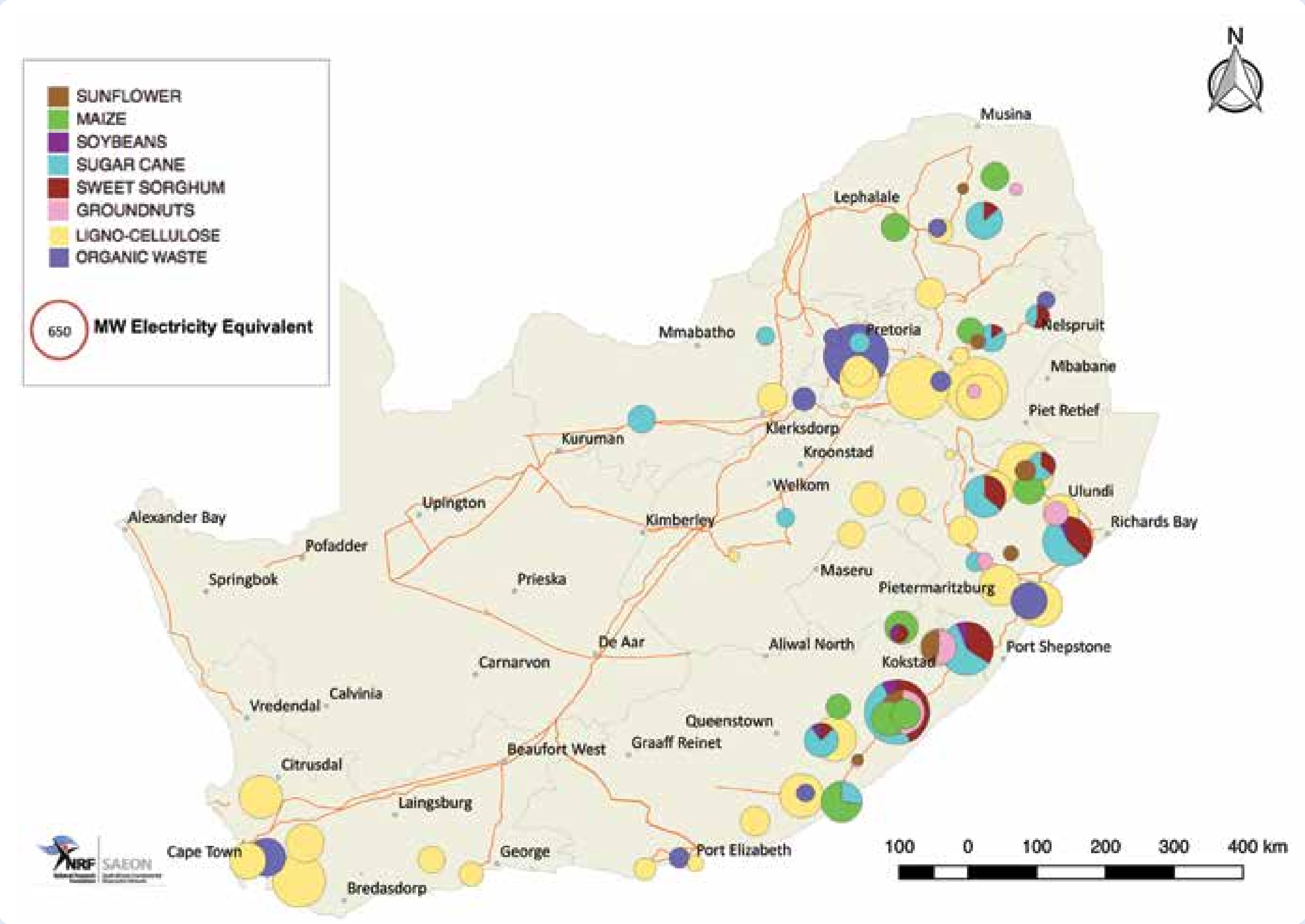


Figure 11 shows the distribution of feasible options by province and feedstock source. The following can be stated:

- KwaZulu-Natal, Mpumalanga and the Eastern Cape have the largest number of feasible options.
- The options are based on organic waste processing, lignocellulose biomass (in most cases chiefly invasive alien species), sugar cane or sweet sorghum cultivation, maize, or oil-bearing crops such as groundnuts or sunflower.
- There is a baseline of available biomass in feasible options derived from serviced organic waste (Gauteng, followed by Western Cape and KwaZulu-Natal, having the largest options).
- There is little potential, with the exception of organic waste utilisation, in North West and the Northern Cape.
- Note that the tonnages for oil-bearing crops are low, and are based on oil only, whereas maize is reported as grain, and sugar-bearing crops as syrup. Lignocellulose biomass and organic waste are reported as tons dry matter.

Box 6b: Options and Opportunities

Figure 12: Options by district municipality – based on optimal placement



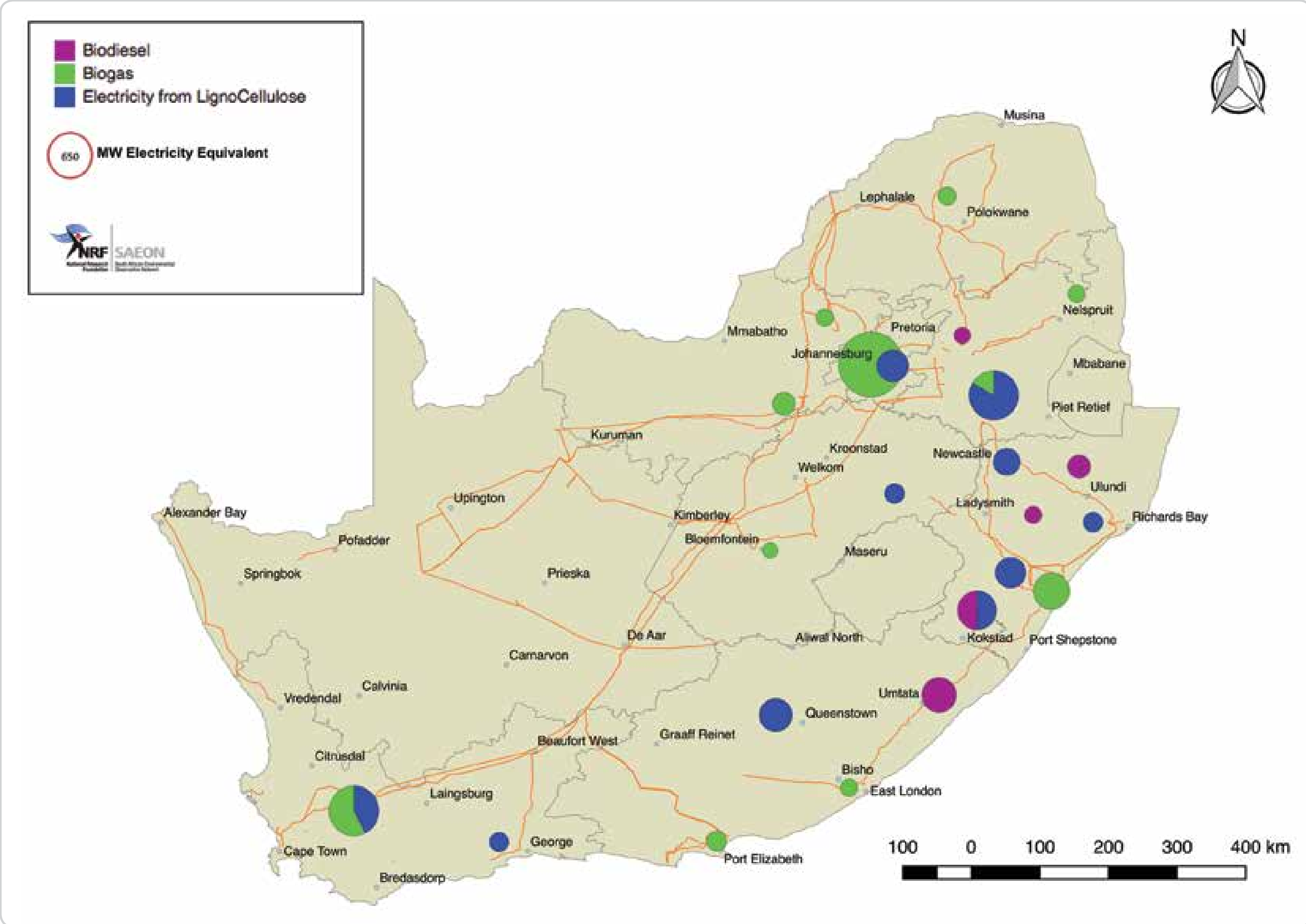
In order to determine the extent to which existing and planned market-directed infrastructure can be linked to the options identified as feasible, the following assessment was performed:

- Allocate the closest infrastructure from a portfolio of fuel depots, refineries, power stations, agricultural silos, sawmills and sugar mills, and waste management centres (solid waste and wastewater) to each feasible option.
- Aggregate options for types of feedstock assigned to each infrastructure based on the premise that the existing infrastructure sites are candidates for conversion or extension to renewable energy 'hubs'. * All options in excess of 1 MW were considered. The map aggregates the 10 largest options for each biomass feedstock.

Read More:

Detailed Feasibility Assessment forms part of the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Figure 13: Largest feasible project options by district municipality (MW electricity equivalent)



Notes:

The map shows the 10 largest feasible projects for each energy product, aggregated per district municipality. Feasibility is determined as a bioenergy product cost equal to or less than the most common alternatives, either from fossil sources or renewable sources.

Project options in the more arid parts of the country are not reported because of small size, high costs, or both. There will be small, feasible options for biogas production in most larger towns.

Key Message 5: Bioenergy Development Considerations

By assessing processing technologies that have not been selected on techno-economic grounds (costs too high, or not yet mature), a portfolio of research and development goals can be determined for the medium and long term, focusing either on accelerated commercialisation or applied research. Combining the results from this assessment with the technologies selected on techno-economic grounds, results in **emergent bioenergy development considerations**.

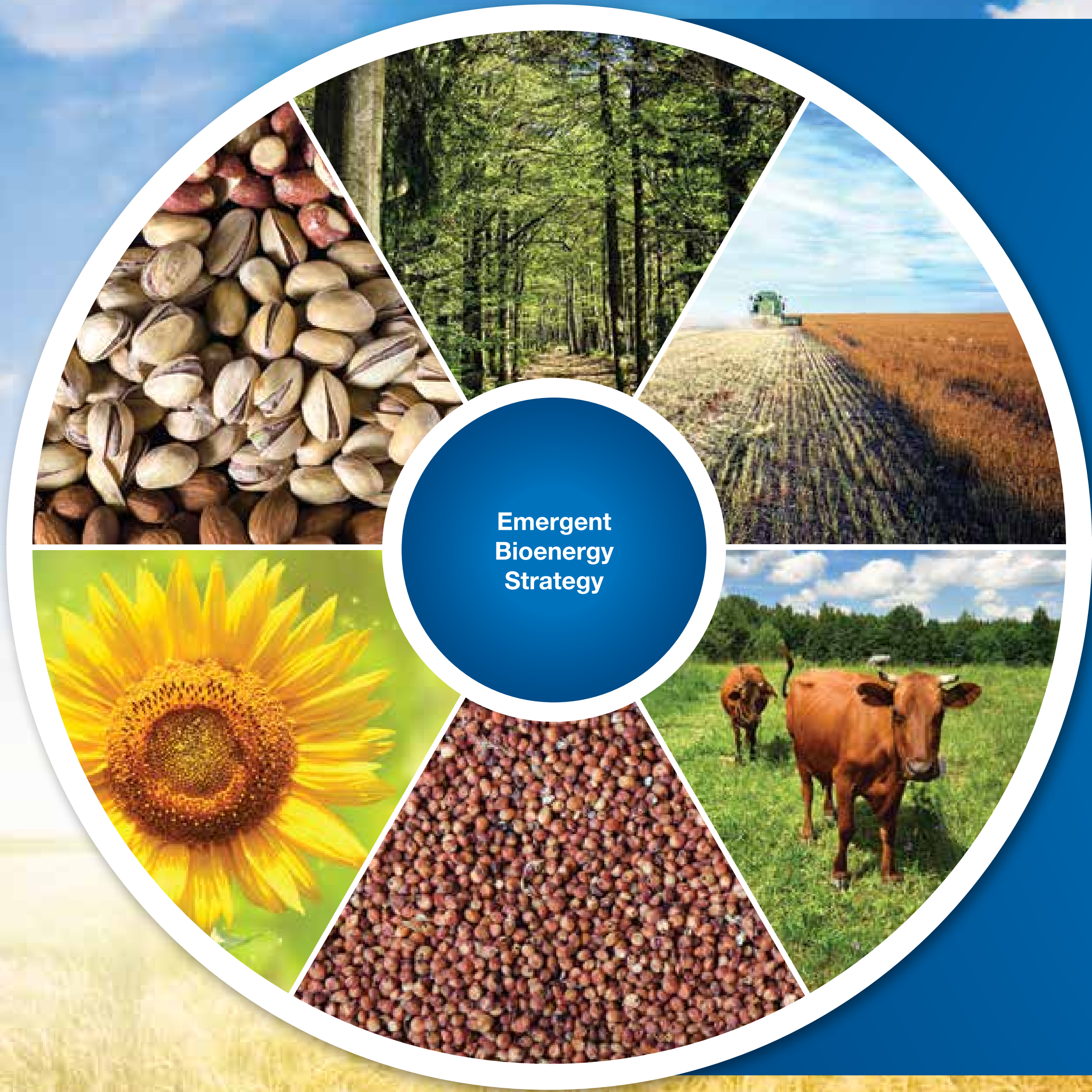


Table 4: Emergent bioenergy development considerations

<table>
<tr><th>Biomass source stream</th><th>Region</th><th>Short term (0-5 years)</th><th>Medium term (5-15 years)</th><th>Long term (15+ years)</th></tr>
<tr><td rowspan="2">Lignocellulose biomass (Invasive species, plantation and sawmill residue, sugar bagasse, agricultural residue).</td><td>Central and Eastern Highveld, Limpopo/Mpumalanga Lowveld, KZN Midlands and KZN Coastal Belt, North-Eastern and Eastern Cape.</td><td colspan="2">Utilise in co-located production/co-firing of electricity at existing power stations and sawmills/sugar mills, or use in high-efficiency regional electricity generation.

Chipping and pelleting for use in domestic rural households, replacing fuelwood.

Possible use as GTL refinery feedstock.</td><td rowspan="2">Invasive species source is eradicated or replaced, and electricity is increasingly generated from solar, wind and nuclear sources. Direct lignocellulose biomass to high-efficiency liquid fuel conversion via hydropyrolysis or similar, integrated with refinery infrastructure.

Import GTL feedstock from neighbouring countries.</td></tr>
<tr><td>Central and Western Eastern Cape, Southern Cape, Western Cape.</td><td colspan="2">Chipping and pelleting for local and export use.
Use in high-efficiency regional electricity generation.
Possible use as GTL refinery feedstock.</td></tr>
<tr><td rowspan="2">Organic waste</td><td>Country-wide urban environments (serviced wastewater and solid waste organic components).</td><td>Develop urban digester and electricity-generation complexes with a lifetime of 20 years to contribute to the electricity grid or generate biomethane. Residues are used as fertiliser.</td><td colspan="2">Start transitioning to transport fuels, either via compressed biomethane conversion of urban transport fleets, or by establishment of algae-utilising wastewater nutrients should this technology prove to be commercially viable.</td></tr>
<tr><td>Country-wide rural areas with significant informal cattle populations (mostly former homeland areas).</td><td colspan="2">Develop household and communal digesters for biogas used for cooking and space heating. Utilise domestic organic waste and cattle dung.</td><td>Urbanisation and electrification may reduce the need and the resource can be redirected to improve agricultural practice.</td></tr>
<tr><td rowspan="4">Purposely cultivated crops for liquid fuels (Sugar cane, sweet sorghum, maize, sorghum, groundnuts, soybeans, sunflower).</td><td>Eastern Cape and KwaZulu-Natal.</td><td colspan="3">Develop a rural agricultural economy based on oil-bearing crops (sunflower, soy beans, groundnuts), integrated with organic waste management. Biodiesel manufacturing can be decentralised to regional installations (fuel depots) without economy-of-scale penalties, allowing contributions to regional economy. Evaluate feasibility of sugar conversion to bio-ethanol should sugar prices drop and food consumption decline.</td></tr>
<tr><td>Mpumalanga Highveld and Lowveld.</td><td colspan="3">Either sunflower or maize can be used, attached to existing Secunda refinery as a processing point. Biodiesel or butanol production is preferred due to lower costs and absence of policy constraints.</td></tr>
<tr><td>Central and Western Highveld, Limpopo.</td><td>Limited scope due to low yields (leading to higher costs).</td><td colspan="2">If fossil fuel prices rise, exploitation may become viable based on conversion of maize to butanol. Policy aspects need to be clarified.</td></tr>
<tr><td>Western and Southern Cape.</td><td>Limited availability of subsistence farmland and/or low yields limits potential.</td><td colspan="2">South African wheat industry may be under increasing pressure from uncompetitive production costs – utilisation of wheat or triticale as a feedstock for biodiesel or syngas, located at the Mossel Bay PetroSA facility. Cultivate canola for biodiesel production – feasibility was not assessed in this project.</td></tr>
</table>

Read More: More on Strategies and Research and Development Focus can be found in the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Box 7: Policy, Institutional and Development Challenges

Energy Option	Policy	Social and Institutional
Lignocellulose to electricity	The project options are feasible, do not require any subsidy, and are well-aligned with existing expertise and infrastructure in respect of 'Working for Water' programmes. Integration with DEA's 'Working for Energy' required as well as incorporation into independent power producer (IPP) programmes. Agricultural residue availability for energy products is a contentious issue, and policy development and a national consensus on feasible extraction rates will be required.	There is a known and established job creation opportunity aligned with 'Working for Water' and 'Working for Energy'. Jobs are medium term, since eradication is planned over 20 years and the resource will be consumed. Job opportunities for clearing are transient and move from one suitable area to the next. This limits the ability to provide permanent employment without negatively impacting local communities. Not all households that may benefit from the availability of electricity will use it due to cost concerns.
Organic waste to biogas	The project options are feasible, require little or no subsidy, and can be implemented incrementally. Enabling policy, permits and regulation will be required to ensure safe handling of waste products, and IPP contributions to the grid must be possible. Best possible application of organic waste (for example in energy instead of compost) is an open debate and policy may be required. Waste is 'owned' by municipalities, who cannot normally enter into agreements exceeding three years with IPPs under current Public Finance Management Act (PFMA) provisions.	Job creation opportunities are limited, but jobs are more permanent and in fixed locations, spread countrywide. Large-scale waste sorting and processing may have a significant negative impact on informal jobs for recycling of waste.
Purposely cultivated energy crops	Policies may be required to align housing subsidies for rural poor with a subsistence farming programme, allowing development of some of the infrastructure required on a household or communal basis to be financed. Conversion of maize to butanol is cost-competitive and can be made available in large quantities, but this requires a policy adjustment in respect of utilisation of maize for energy products.	Conversion of subsistence farming in former homeland areas, with high reliance on cattle and maize, to a cash crop with side products for own consumption and cattle feed, will require significant community involvement and support infrastructure. Cooperative farming and marketing channels need to be investigated. Technical assistance programmes will be required.

Read More: Assessment of Challenges and Opportunities forms part of the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Box 8a: Important Technology Development Considerations

The most affordable conversion technologies, as determined in the feasibility assessment, are all focused on simpler (first-generation and partly second-generation) processes – largely due to the fact that the other processes either require some time to mature, or are currently too expensive.

It is worthwhile investigating two additional aspects of the technologies not considered by the initial feasibility assessment:

- Which technologies are not yet sufficiently mature for implementation in the next five years, but are cost competitive nonetheless?
- Which technologies promise high conversion efficiency (desirable from both a greenhouse gas mitigation and land area required for biomass perspective), and by what margin do these need to improve their costs to be competitive?

To answer the first question, the levelised costs for all technologies were calculated based on maximum capacity that can be supported (in other words, the best possible case for each technology). By doing so, the set of technologies used for feasibility (time to maturity less than five years) can be compared with the others.

Table 5: Technology research and development candidates

	Evaluated (if costs are lowest)	Accelerated commercialisation research and development	Long-term academic and applied research
Years to maturity	0-5 years	6-10 years	10+ years
Lignocellulose	• Back-pressure steam turbine • Pelleting • Fast pyrolysis • Biomass integrated combined gasification cycle	• Hydropyrolysis • Hydrothermal liquefaction	• Pyrolysis/Fischer-Tropsch
Starch	• Fermentation of starch to butanol	The specificity and yield of micro-organisms used for fermentation can be improved – hence focus should be on genetic engineering of more efficient yeast and bacterial strains	Genetic modification of micro-organisms
Sugar	• Fermentation of sugar to butanol • Fermentation of sugar to ethanol		
Oil	Transesterification of virgin oil to diesel	Hydrothermal liquefaction	• Reduction in production cost, and improvement in yields of oil-bearing algae • Algae that consume wastewater nutrients
Organic waste	• Small-scale digesters • Medium-scale digesters	• Operationalisation of small-scale and medium-scale digesters in rural and urban contexts • Use of biogas for electricity generation • Use of biogas as a fleet vehicle fuel • Hydrothermal liquefaction	

Box 8b: Important Development Considerations

An additional consideration is for technologies that show promise in respect of conversion efficiency, but are currently too expensive to implement: high efficiency is desirable both from a GHG and a feedstock land-area perspective.

Levelised costs for all technologies were calculated based on maximum capacity that can be supported (in other words, the best possible case for each technology). Technologies can then be ranked in terms of efficiency versus premium over the least expensive technology in the category.

Table 6: Technology candidates for improved efficiency

	No action (Costs are low, efficiencies are adequate)	Cost reduction (Efficiencies are adequate, costs are high)
Efficiency	34-100%	34-100%
Product costs	< R 1/kWh	> R 1/ kWh
Lignocellulose	• Chipping • Bio-coal torrefaction • Pyrolysis – Fischer-Tropsch (dispersed pyrolysis) • Bio-coal torrefaction • Back-pressure steam turbine • Tri-generation systems • Pelleting • Hydropyrolysis • Fast pyrolysis	• Ethanol from syngas • Fast pyrolysis with upgrading • Lignocellulose to ethanol • Fermentation of lignocellulose to butanol • Catalytic fast pyrolysis with upgrading • Synthesis gas fermentation • Aqueous phase reforming • Separated lignocellulose conversion • Fermentation to lipids into jet fuel • Free fatty acids to jet fuel
Starch	Biomass fermentation to hydrocarbons	Biomass fermentation to jet fuel
Sugar		
Oil	• Trans-esterification of waste oil to diesel • Trans-esterification of virgin oil to diesel • Hydrothermal liquefaction • Internal combustion • Hydrotreated jet fuel process	None
Organic waste	Complex anaerobic digesters	Hydrothermal liquefaction

Box 8c: Important Development Considerations

The *BioEnergy Atlas* project identified data and knowledge gaps that should be addressed. These are summarised in Table 7.

Table 7: Data and knowledge gaps

Theme or aspect	Improvements to collaboration and availability	Improved detail and accuracy of data
Base layers of productivity		• Updated land cover • Updated NPP data – Carbon Atlas (recently published)
Infrastructure	Publication of NERSA permits and IPP/REIPP bids as machine-readable data sets	Detailed periodic assessments of off-grid, renewable, and private power generation activity
	Improved data on solid waste disposal sites	
	Improved data on wastewater treatment works	
Agriculture	Improved access to detailed cropland typology, historical yields and style of farming/ownership	• Detailed spatial distribution of animal husbandry, especially cattle • Detailed data on impacts of automated sugar cane harvesting on jobs and the rural economy
	Improved access to studies on crop suitability and yields	Applied research to evaluate and confirm suitable energy crops per region – cultivation, economics, social context, water-use efficiency, and impacts of conservation agriculture
		Price data – for products
Waste		Detailed characterisation of non-domestic waste sources on meso-spatial scale
Agricultural residues		Definitive research to determine safely extractable residue removal for maize, wheat, sugar cane and commercial plantations
		Price data – for products and residues
Invasive alien plants	Availability of ownership data – especially types of ownership	Detailed municipal-level assessment of annual biomass increments, and changes in area covered by the biomass
	Detailed data on current Working for Water and Working for Fire locations and eradication statistics	Detailed assessment of major species
Bush encroachment		Detailed municipal-level assessment of annual biomass increments, and changes in area covered by the biomass
		Detailed assessment of major species
		Policy development in respect of mitigation strategies and approaches
Fuelwood		Volume of fuelwood use per household on fine spatial scale
		Estimates of fuelwood exploitation, species and mean annual increment nationally on a fine spatial scale
Impacts		Detailed assessment of land-use change impacts, especially in respect of intensified agriculture and eradication of invasive alien plants

Read More: Strategies, Gaps, Challenges, and Research and Development Objectives can be found in the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Key Message 6: Impacts

The assessment of alternatives includes the determination, as quantitatively as possible, of the following impacts:

Carbon cycle impacts

The driver for renewable energy is reduction in greenhouse gas emissions and/or improved sequestration. This is not trivial to evaluate: process efficiencies, land-use changes in respect of the biomass resource, fertiliser, and other industrial inputs all play a role in determining the long-term impact of an alternative on greenhouse gas emissions. These impacts need to be determined as CO_2 equivalent reduction over a 20-40 year horizon, because equilibrium processes and cycling between the atmosphere and biosphere can have a slow rate – especially for woody biomass.

Environmental impact

Estimates of the land impacted were determined in three distinct categories:

- Ecological impact – land that was subjected to change from a relatively natural state, or land that is designated as important from a threatened species, freshwater or ecosystem-services perspective.
- Area of land – as a sum total – of degraded land that was put to productive use.
- Biomass – as a sum total – of invasive species which were eradicated or consumed.

Socio-economic impact

This is measured in three ways –

- Job creation: This is a direct calculation for each process alternative.
- Contribution to regional GVA.
- Energy access: Especially important for poor rural households – number of households converted from fuelwood or dung to other sources of renewable energy.

The results from these assessments are discussed in Table 8.

Table 8: Summary of greenhouse gas, environmental, economic and social impacts of bioenergy

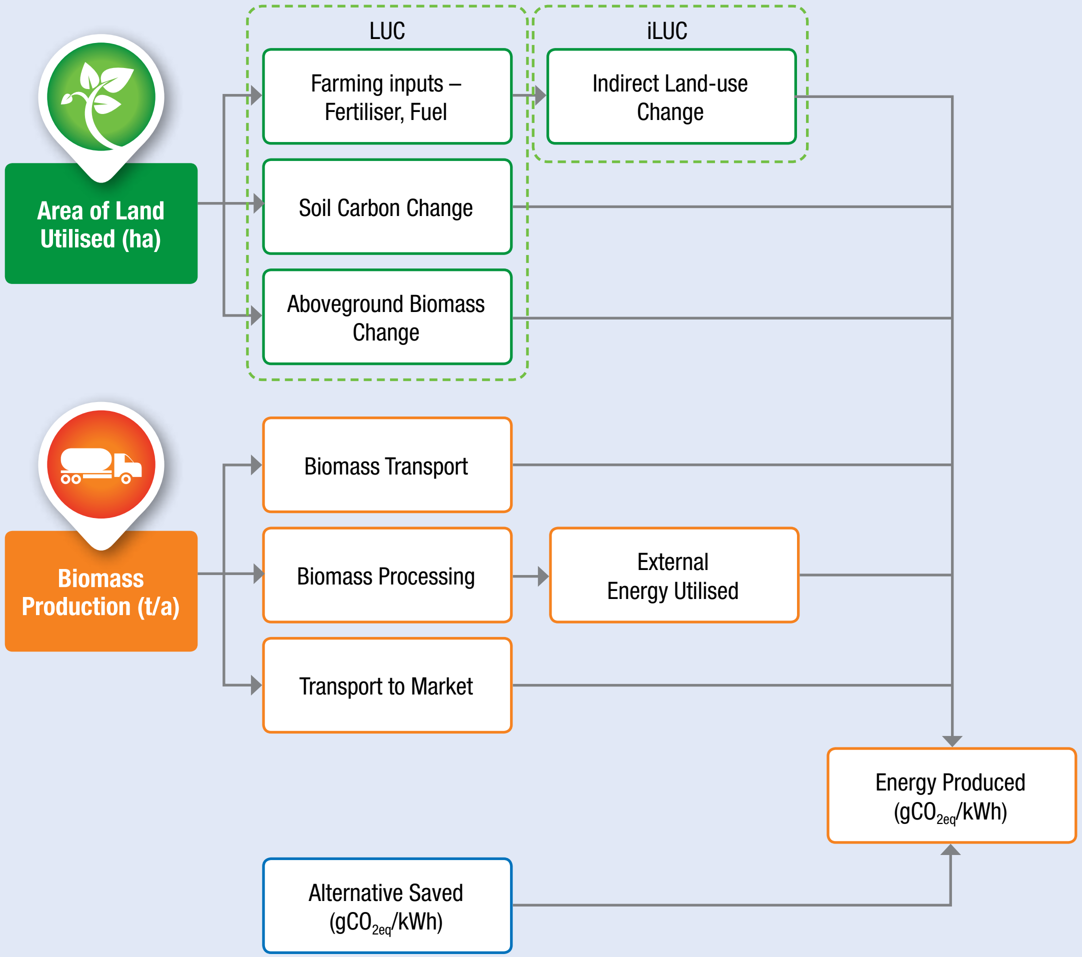
Aspect	Greenhouse gas impacts, carbon and nutrients cycling	Social and economic impacts	Environmental impacts
Cross-cutting impacts	For all project options under consideration here, there will be long-term benefits in carbon sequestration and soil quality due to the improvements to subsistence farms and eradication of invasive alien plants only if the transition is designed correctly and land is managed properly. Transition to conservation agriculture should contribute such benefits.		
General and common impacts	Conversion from fossil to biomass-derived sources carries a one-time debt of CO_2 release, usually due to land-use changes. If this debt, together with production emission deficit, is larger than the CO_2 production from equivalent fossil fuel energy, there is no GHG benefit. Until recently, it was often assumed without investigation that using renewable biomass would be carbon neutral in respect of the carbon in the biomass, but this has been shown not to be true.	Jobs are created, often in rural areas in need of economic activity and job creation. These jobs ultimately come at the cost of jobs in alternative (fossil) fuel sectors if the new energy sources are not aimed at growth. Jobs in the bioenergy sector are labour-intensive.	Due to the selection of land for bioenergy – based on rain-fed subsistence farmland, organic waste streams, residues from agriculture, sugar cane, forestry, and invasive species eradication, general impact on biodiversity will be negligible or positive. For energy crops, yield improvement may lead to increased water use, but depending on crop selection, water use could be similar to that of natural vegetation. It is generally accepted that IAP eradication will improve water availability.
Fire: Fire is a natural phenomenon in South African biomes (forests, savannah, fynbos).	This has implications for the one-time debt incurred by using biomass. If the rate of CO_2 production from energy application matches that of the natural fire frequency, the long-term carbon cycle remains in equilibrium.	Managed biomass extraction reduces fire risk. This reduces loss of resources and collateral damage to property and livelihoods. There is a small reduction in risk of injury or death.	Natural fire events are thought to be a powerful driver for long-term biodiversity in many biomes in the South African context, and interruption of the cycle through managed biomass extraction and reduction in fire events may have a negative impact.
Urban household and commercial organic waste	The bulk of these waste streams typically ends up in landfill at present, where large quantities of CH_4 are produced and ultimately released into the atmosphere. Interruption of the cycle to convert CH_4 to CO_2 and energy has immediate and long-term GHG mitigation benefits.	There are limited job creation opportunities, but the opportunities are long-term. Jobs are in urban centres.	Small positive impacts in that the need for landfill volume is reduced; and digestate by-product is a good fertiliser and soil conditioner with limited methane release.
Rural organic waste and animal dung	Animal dung and rural waste also contribute to CH_4 emission and conversion to energy has positive impacts.	Availability of biogas may improve time budgets of rural women and children, and has health benefits. There is limited economic benefit to biogas in respect of cost compared with fuelwood, unless government assists with capital costs.	Limited change in environmental impact. Removal of dung from the wider ecosystem will have some impact on soil condition and species dependent on dung as a source of food.
Invasive alien plants (IAP) and forestry residues	There is growing concern that conversion of forest biomass to energy does not confer any long-term GHG benefits and that, in the short term (10-30 years), it incurs a CO_2 debt that will not contribute to reduction targets. While the resource is renewable, and can result in equilibrium with near-complete CO_2 recycling over a long period of time, eradicated biomass would need to be replaced with species that provide the same mean annual biomass increment and the same levels of soil organic carbon.	Large numbers of jobs can be created as part of a systematic eradication and harvesting programme, essentially extending the 'Working for Water' concept. The jobs are transient in time and location, and hence not ideal from a sustainability perspective. Many of the processing and extraction activities will be in poor rural areas and will have a positive impact on the rural economy.	Positive effects can be achieved if IAPs are replaced by indigenous species, but these would need to have the same annual biomass increment to be carbon neutral. If the same annual increment is required, it is not clear that water resources will improve.

Aspect	Greenhouse gas impacts, carbon and nutrients cycling	Social and economic impacts	Environmental impacts
Grain agricultural residues	The extraction rate needs to be determined (based on yield) that will support a medium- and long-term equilibrium in the carbon and nutrient cycle. For annual crops, the cycling is acceptable if long-term soil carbon is preserved or improved and fertiliser use remains the same. In many parts of the country, residues are burnt anyway and this effect is not accounted for at present.	Limited job creation in energy production facilities, with the advantage of being in semi-rural or rural areas. Significant value added to agricultural residue, but this may have a negative impact on animal feed and fodder costs.	Land-use change (direct and indirect) will be negligible if sustainable extraction rates are applied, and biodiversity and ecosystem-service impacts have already been discounted.
Sugar cane residue	Sugar cane is burnt to facilitate manual harvesting and replacement of this practice with an energy application is likely to have little impact on the carbon cycle. Maximum extraction rate from a nutrient perspective needs to be determined.	The added value generated by sugar cane residue as energy is significant, but changes in harvesting practice (automation) will lead to a large reduction in rural seasonal jobs.	Land-use change (direct and indirect) will be small, and biodiversity and ecosystem-service impacts have already been discounted.
Purposely cultivated crops	Development of energy crops on subsistence farmland implies yield improvements that will not be achievable without intensifying agricultural practice – more fertiliser and accelerated soil carbon/nutrient cycling. These impacts are poorly understood and are often assumed to be carbon neutral, but this is not the case. In some cases it may improve the amount of soil carbon and cyclical above-ground biomass due to more intensive cultivation, and GHG benefits may ensue from the introduction of conservation agriculture in subsistence farming areas.	Significant income improvement potential (with some job creation in processing and manufacturing). Significant contributions to some rural economies.	Land-use change (direct and indirect) will be sizable, but biodiversity and ecosystem service impacts have been discounted already if only subsistence farmland and degraded land are used. Improved yields will in all likelihood require more water. Recent studies indicate (Kunz *et al.*, 2015) that crop selection is important from a water-use perspective, with good candidates being maize, sweet sorghum and sunflower.
Fuelwood	The use of fuelwood in rural households is already a renewable energy source, and provided the rate of use is sustainable and grows slowly in alignment with biomass availability (for example from bush encroachment), the net effect on the carbon cycle is close to zero. Efficiency improvement can have a large positive impact.	Formalisation of the resource as pellets to be used in high-efficiency stoves will have health benefits, but may not be acceptable price-wise. Pelleting operations will create permanent jobs in rural areas for fuelwood extraction and processing and contribute somewhat to the rural economy.	Ecosystem service and biodiversity impacts have already been discounted due to current extraction – but there is scope to improve impacts through better planning and scheduling of extraction, and reduction of overexploitation.

Read More: Impact Assessment details can be found in the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Box 9a: Greenhouse Gas Emissions

Figure 14: Methodology for GHG emission assessment



The approach for the calculation of GHG impact was developed from the BIOGRACE project (Neeft *et al.*, 2012), as well as general guidance from the European Commission (EU, 2010), the UK Government (CCC, 2011) and the Institute for European Environmental Policy (IEEP, 2012).

Figure 14 provides a high-level view of the aspects to consider in GHG emission assessments:

- **Land-use change** (LUC) is a result of changes to existing vegetation and the ensuing practices that are applied to the land. These effects are generally proportional to the land area in use and include the changes in soil carbon and aboveground biomass (not always negative), and the direct emissions due to biomass production or biomass extraction: fertiliser (largely NO_2 emission), fuel used in planting and harvesting, and fuel used to gather and extract residues.
- **Indirect land-use change** (iLUC) is the result of changes to land use caused by the application under assessment – for example by displacement of food production or wood extraction to an external location, or through an increased demand for seed or rootstock that has to be satisfied by increasing the production of agricultural materials somewhere else.
- **Transport** may impact GHG emissions in two ways – more often than not biomass has to be transported to processing facilities because the source is distributed, and the final product will probably require transport to market or distribution points.
- **Biomass processing** to energy in itself may cause emissions – either through leakages or as a product from the process (for example CO_2 production during fermentation of sugars to ethanol). In addition, the process may require external energy that has a greenhouse gas emission legacy.

Box 9b: Greenhouse Gas Emissions

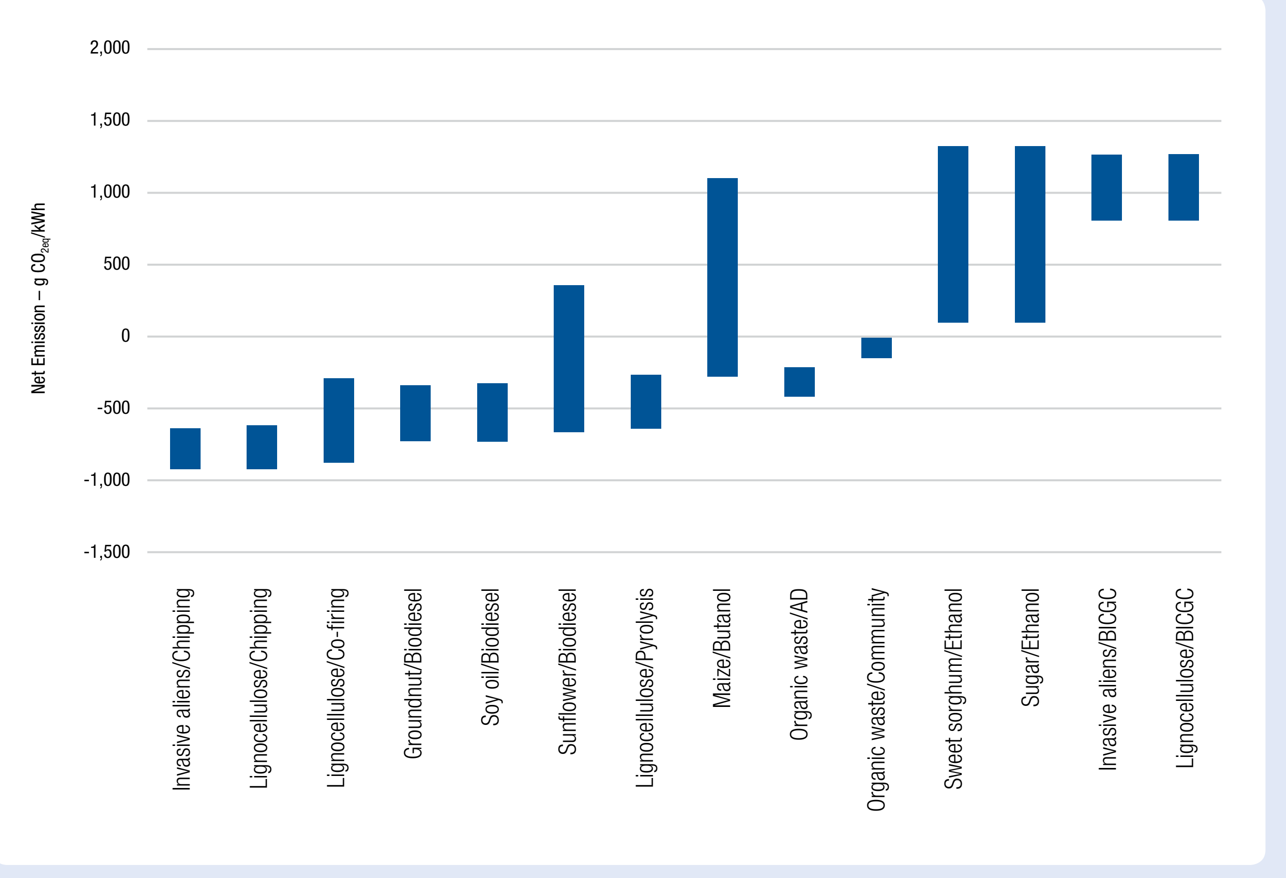
These factors combine to produce a final GHG emission rating for the energy produced – usually expressed as a CO_2 equivalent mass per unit of energy. Note that the CO_2 equivalent includes emissions of other greenhouse gases (notably N_2O and CH_4), expressed as the equivalent CO_2 emission that will result in the same greenhouse effect.

The final GHG emission factor is compared with the real alternative for the energy product (coal, gas, fossil fuels, etc.) over a long period (usually 40 years, called the life-cycle assessment or LCA), because land-use changes incur a one-time CO_2 debt that is redeemed over time. Hence a break-even point can also be used as an assessment of the desirability of a bioenergy product.

In some cases (for example the EU), an alternative bioenergy product needs to do better than a given minimum saving on the alternative – for instance have 60% or less GHG emissions over the LCA period.

LCA mitigation of greenhouse gas emissions, as evaluated using the above schema, is highly sensitive to the initial land-use change debts or benefits – this sensitivity is not reflected in the range of net CO_{2eq} emission factors in Figure 15. Here, only variability in process efficiency, process emissions, and savings of alternatives are taken into account.

Figure 15: Net CO_2 equivalent emissions from combinations of feedstock and processing options. Ethanol manufacture has poor mitigation prospects due to process penalties, as has Biomass Integrated Combined Gasification Cycle (BICGC) processes. Biodiesel is generally positive because process emissions are negligible and the process is efficient.



Read More: Impact Assessment details can be found in the *Synthesis Report* at http://dx.doi.org/10.15493/SAEON.BEA.DOCS.10000002

Case Study 1: The Rural Poor

The scope of opportunities available to assist the rural poor via biomass-derived energy was investigated based on the following measures:

- The extent to which areas where biomass-derived traditional fuel (fuelwood, dung) is in widespread use can be provisioned with cleaner and less time-intensive alternatives;
- The extent to which projects will contribute jobs in areas with high proportions of unemployed or poor households; and
- The relative contribution that such projects can make to the rural economy.

Areas with a high concentration of rural poor with limited access to electricity

The following district municipalities were identified to have a high concentration of rural poor households with limited access to electricity (StatsSA, 2011). These areas were selected based on the highest proportion of individuals with the lowest income from all district municipalities where the average electricity usage is less than 66%.

Table 9: Low income and limited electricity use

Province	District municipality	Low-income individuals	Electricity usage
Eastern Cape	Amathole	345 886	57%
Limpopo	Capricorn	371 816	59%
Mpumalanga	Gert Sibande	301 855	58%
Limpopo	Greater Sekhukhune	324 154	52%
Limpopo	Mopani	438 841	35%
Eastern Cape	O.R. Tambo	462 202	40%
Limpopo	Vhembe	418 015	34%
KwaZulu-Natal	Zululand	307 919	48%

Provisioning of cleaner alternatives

Three cleaner alternatives can be considered: development of regional power stations to supplement electricity supply in the area from lignocellulose sources; provision of household or communal digesters; and pelleting of lignocellulose biomass (including traditional fuelwood sources) to support more efficient and cleaner space heating and cooking facilities.

A summary of available options for regional electricity generation in the study areas is presented in Table 10. An indication of the number of households that will be served by the project option, and the number of households that may benefit from electricity availability is provided. The Gert Sibande district municipality in Mpumalanga can support a large project with significant electricity export potential.

Table 10: Regional electricity project options

Province	District	Municipality	Project size (MW)	Households served	Households need	Current electricity usage
Eastern Cape	Amathole	Mbhashe	10	12 500	49 289	57%
Eastern Cape	O.R. Tambo	Ngquza Hill	3	3 750	46 220	40%
KwaZulu-Natal	Zululand	Abaqulusi	26	32 500	36 950	48%
Limpopo	Capricorn	Polokwane	71	88 750	54 843	59%
Limpopo	Greater Sekhukhune	Elias Motsoaledi	3	3 750	42 140	52%
Limpopo	Mopani	Greater Giyani	7	8 750	38 399	35%
Mpumalanga	Gert Sibande	Msukaligwa	480	600 000	43 769	58%

The potential for household and communal digesters is shown in Table 11. The number of households that can be provisioned is typically in the order of a third of the households that require assistance with clean energy. In some areas, this can be boosted by the addition of cattle dung and other incidental biomass sources. Determining the spatial distribution of cattle in rural areas has proven particularly difficult, but Stafford (2013) has estimated substantial cattle populations in the Eastern Cape and KwaZulu-Natal (Table 12).

Table 11: Household and communal digester project options

Province	District	Organic waste used (t/a)	Aggregate project size (MW)	Number of digesters	Low-income households	Households using cattle dung	Potential users	Percent satisfied
		[A]	[B]	[C]	[D]	[E]	[F]	[G]
Limpopo	Vhembe	58 695	4.22	11 739	125 531	66%	82 606	14%
Limpopo	Greater Sekhukhune (1)	84 125	6.05	16 825	95 186	43%	40 994	41%
Limpopo	Greater Sekhukhune (2)	30 536	2.19	6 107	62 313	62%	38 635	16%
Limpopo	Mopani	74 043	5.32	14 808	72 658	34%	24 844	60%
KwaZulu-Natal	Uthukela	33 085	2.38	6 617	64 810	34%	22 019	30%
KwaZulu-Natal	Zululand	19 121	1.37	3 824	27 663	77%	21 423	18%
Limpopo	Mopani	18 881	1.36	3 776	30 977	68%	21 063	18%
Mpumalanga	Gert Sibande	26 560	1.91	5 312	41 795	49%	20 451	26%
Limpopo	Ehlanzeni	25 725	1.85	5 145	55 095	33%	18 166	28%
Eastern Cape	Amathole	48 632	3.50	9 726	95 219	19%	17 832	55%
Total		**419 403**	**30.14**	**83 879**	**671 247**	**46%**	**308 032**	**27%**

[A] Rural organic waste allocated to digester by feasibility modelling

[B] Typical power available from digesters in area of assessment

[C] Number of digesters required

[D] Number of low-income households in area of assessment

[E] Households using cattle dung in area of assessment - StatsSA (2011)

[F] Potential users (households) estimated as [D]x[E]

[G] Digesters as a percentage of potential users [C]/[F], on average 0.35kW per digester

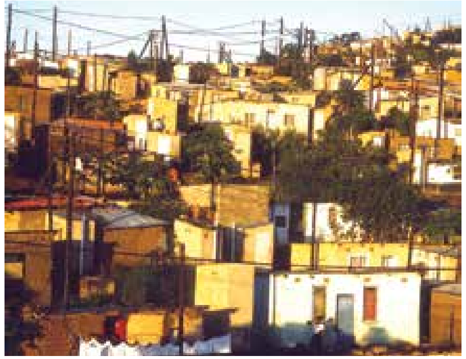


Table 12: Rural households with cattle dung potential

Province	Number of households with 4 or more cows	Total number of rural households	Percentage of rural households with biogas potential
Eastern Cape	224 417	692 775	15.8
KwaZulu-Natal	310 206	963 835	16.5
Limpopo	47 727	765 089	1.8
North West	27 740	362 091	3.1
Mpumalanga	22 327	359 240	2.8
Free State	22 770	132 736	4.9
Total	**655 187**	**3 275 766**	**9.5**

Table 13: IAP eradication and pelleting

Province	District	Low-income households in catchment	Harvesting jobs (1)	Processing jobs (2)	Jobs/Low-income households	Additional GVA (Rm) (2)	% of current GVA (3)
Mpumalanga	Gert Sibande	211 710	17 417	916	0.09	3 275	6%
Gauteng	Ekurhuleni	1 509 496	6 666	487	0.00	1 740	0%
Eastern Cape	Chris Hani	152 021	61 536	480	0.41	1 714	11%
KwaZulu-Natal	UMgungundlovu	613 521	14 968	479	0.03	1 712	1%
Eastern Cape	Alfred Nzo	226 961	55 328	408	0.25	1 456	8%
Western Cape	Overberg	386 253	3 219	272	0.01	971	1%
Western Cape	Eden	56 303	935	228	0.02	814	9%
Eastern Cape	Cacadu	267 735	9 870	226	0.04	807	2%
Free State	Thabo Mofutsanyane	75 287	2 548	204	0.04	728	9%
KwaZulu-Natal	Zululand	117 665	25 601	180	0.22	643	6%
Totals		**3 616 952**	**198 088**	**3 880**	**0.06**	**13 861**	**2%**

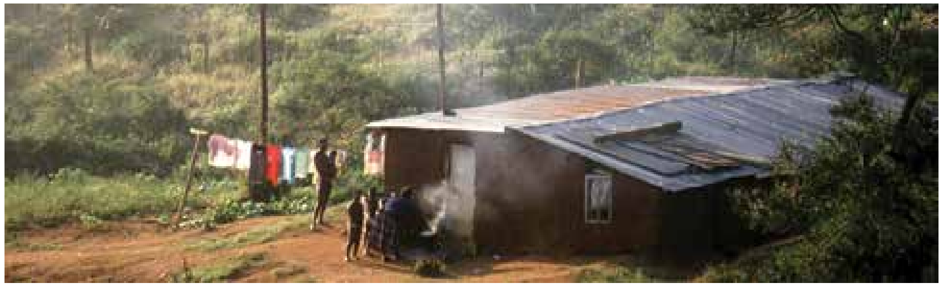
Notes and references: (1) Mugido *et al.*, 2013; (2) Haig and Görgens (2013); (3) Maritz and Le Roux, 2013.

Table 14: Impact of biodiesel crop cultivation

Province	District	Low-income households in catchment	Cultivation jobs (1)	Processing jobs (2)	Jobs/Low-income households	Additional GVA (Rm) (2)	% of current GVA (3)
Eastern Cape	O.R. Tambo	202 880	89 457	97	44%	1 678	15%
KwaZulu-Natal	Sisonke	181 376	47 559	60	26%	1 039	8%
KwaZulu-Natal	Zululand	195 681	36 932	43	19%	750	5%
KwaZulu-Natal	Umzinyathi	336 342	18 693	24	6%	406	1%
Mpumalanga	Nkangala	215 944	23 033	22	11%	386	1%
Limpopo	Vhembe	174 049	17 260	13	10%	221	1%
Eastern Cape	Amathole	50 841	14 822	13	29%	220	4%
Totals		**1 357 113**	**247 755**	**272**	**18%**	**4 699**	**3%**

Notes and references: (1) Estimate based on 0.4 ha per household; (2) Haig and Görgens (2013); (3) Maritz and Le Roux, 2013.

Table 13 shows the estimated impact of invasive alien plant (IAP) eradication and pelleting in the districts under study. In two cases – the Eastern Cape and KwaZulu-Natal – it is clear that such programmes can make a significant contribution to job creation and the regional economy. Table 14 reports similar metrics for biodiesel crop cultivation, in which case the number of jobs associated with cultivation and processing add considerably to the job pool and to the regional economy, particularly in the Eastern Cape.



Conclusions

- There is limited scope to improve the livelihoods of the rural poor through renewable energy, for two reasons:
  - The amount of biomass in the study areas is limited, and will serve only part of the need; and
  - The cost of alternatives is not substantially lower than electricity; many rural households have access to electricity but continue to use fuelwood and other biomass sources based on cost considerations.
- If livelihoods are to be improved, it will be from a combination of communal digesters, efficient pellet-burning stoves and/or regional electricity plants.
- Development of rural livelihoods based on harvesting of IAPs for eradication (i.e. massively expanded 'Working for Water'-type programme) and conversion of subsistence farming to oil-based cash crops present a more robust long-term strategy, allowing rural households to afford electricity through improvement in income.

Case Study 2: Supplementing Electricity Production

Introduction

Electricity supply in South Africa was again under severe stress in 2015, with frequent managed blackouts ('load shedding'). These events give rise to a significant direct and indirect cost to the economy:

- Direct cost to Eskom of supplementing electricity provision from expensive diesel-driven generators (Kumwenda-Mtambo, 2015; van der Nest, 2015);
- Direct cost to consumers of alternative measures, usually also via diesel generators in the short term, and possibly renewables (especially residential PV) in the medium term;
- Direct cost of lost productivity in the economy (Omarjee and Steyn, 2015);
- Indirect cost of wear induced in appliances and equipment due to frequent power-down and power-up; and
- Limits on economic growth due to unavailability of energy.

Under these circumstances, it would make sense to supplement electricity production under the following constraints:

- Reasonably quick implementation: remedies that take more than two to three years to implement will not make a material difference, since large coal-fired power stations will have come on stream by then (Steyn, 2015);
- Cost comparable to the cost of electricity generation from diesel via turbines (Steyn, 2015); and
- Low risk to existing electricity generation – this cannot accommodate downtime for refit or expansions.

Cost of no action

Not taking any action is characterised in terms of cost and contribution in Table 15. There are two considerations – the real cost of alternatives when Eskom electricity is under pressure or not available (diesel-generated power from Eskom, commercial and domestic sources, and capital investment in domestic solar power), and opportunity cost to the economy. As can be seen from Table 15, estimates of the opportunity costs are significant – up to 100 R/kWh not supplied (van der Nest, 2015).

From this assessment it is clear that any additional supply up to 4 GW of electricity at between 2 and 3 R/kWh competes with diesel-generated electricity at large Eskom gas turbine stations, and with power generated by standby generators in industry and commerce. Contributions by household solar power and by domestic generators, though low-cost in the case of the first, are small contributions at present and are therefore not considered.

Table 15: Relative cost of load-shedding mitigation

Alternatives	Capacity (MW)	Product costs (R/kWh)	Capital costs (R'm)	Year	Present value capital costs (R'm)	PV power capital ratio (Rm/MW)	Reference
Diesel-based turbines							
Ankerlig	1 338	R3.00	3 500	2007	5 171	3.86	[5], [0]
Gourikwa	1 150	R3.00	2 791	2007	4 124	3.59	[6], [8], [0]
Domestic generators							
Typical household	0.0023	R4.21	0.0034	2015	0.0034	0.68	[11], [12], [0]
Commercial generators							
18% of businesses	3 000	R2.70		2006	15 358	5.12	[3], [9], [0]
Domestic solar PV							
Typical household	0.00083	1.711	None	2012	0	0	[7]
Solar power	10	0.81	1815	2015	1815	182	[10], [0]
Opportunity cost							
Stage 1 load shedding	1 000	77.16		2015	170 271	170	[3], [0]
Stage 2 load shedding	2 000	77.16		2015	340 543	170	[3], [0]
Stage 3 load shedding	4 000	77.16		2015	681 085	170	[3], [0]

Notes and references: [0] Author's calculations; [3] van der Nest (2015); [5] Steyn (2015); [6] Eskom (2009; [7] Blog discussion (2012); [8] Barradas (2007); [9] van Es and Bennett (2007); Oxford (2015); [12] Ryobi (2015).

Conversion technologies

The following conversion technologies were evaluated using a portfolio of feedstocks:

Table 16: Possible conversion technologies

Process	Feedstock(s)	Locations
Pelleting	Invasive alien plants	Optimal locations
	All woody biomass	Optimal locations
		Power station infrastructure
		Refinery infrastructure
BICGC (Biomass Integrated Combined Gas Cycle)	Invasive alien plants	Optimal locations
	All woody biomass	Optimal locations
		Power station infrastructure (co-location)
		Torrefaction
Co-firing	All woody biomass	Power station infrastructure
Organic waste digesters (regional scale)	All serviced organic waste	Optimal locations

In essence, the following questions need to be answered:

- How much electricity can be generated from the available resources; and at what cost?
- What is the best alternative in respect of location, feedstock and conversion technology?
- Does non-optimal location (at power stations, refineries, etc.) have a material impact on the cost of electricity?
- How long will it take to establish the infrastructure?
- What are the other considerations – financial, social, environmental and institutional?

Best alternative

The best alternative from a techno-economic point of view for the provision of electricity, supplementing on location at existing or decommissioned power stations, is a fast pyrolysis process, but this process is not expected to be commercially mature for some time. The second-best alternative would be BICGC, averaging between 0.71 and 1.59 R/kWh for up to 6m tons of feedstock per annum.

The BICGC alternative can add a maximum of about 1,300 MWe of electrical power generation capacity, depending on the maximum price that can be sustained. If one should limit feedstock to invasive alien plants (IAP), this would fall to about 1,000 MWe. Specifically, it should be possible to locate such a facility in Mpumalanga, co-located with an existing coal-fired power station, that contributes up to 230 MWe based on IAP or IAP and maize residues. In practical terms, such a facility may not be available before new coal-fired electricity comes on stream. This leaves co-firing, which is also cost-competitive, as the only alternative that can be implemented reasonably quickly.

Location impacts

Each feedstock and conversion technology generates a set of optimal locations in the *BioEnergy Atlas* feasibility assessment, dependent on factors such as transport and feedstock costs, transport distances and economy of scale of the technology. These are obvious options for placement of generating capacity, but can sometimes be made unattractive by distance from existing generation, transmission or distribution infrastructure.

The following options were evaluated as potential locations for additional electricity-generation capacity, and compared with optimal locations:

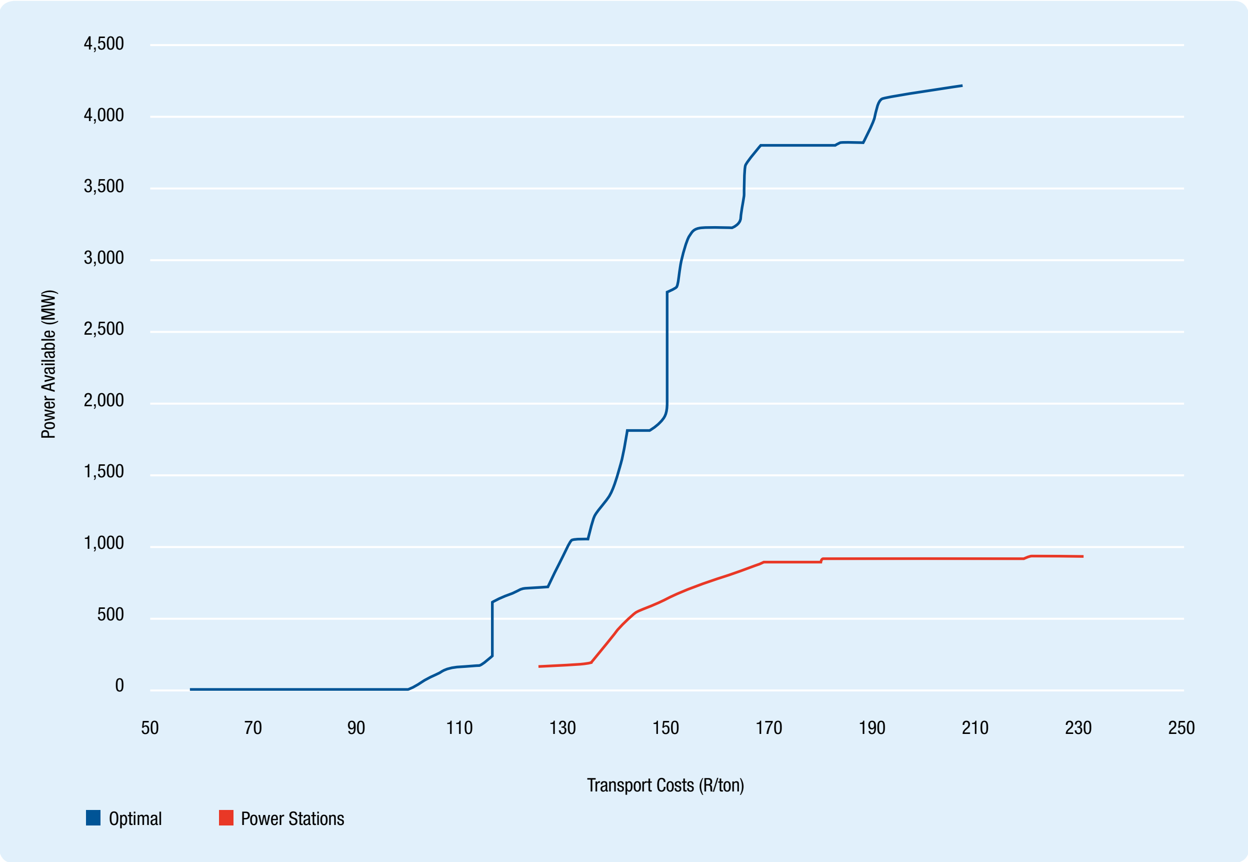
- Co-firing at existing Eskom power stations;
- Co-location at existing and decommissioned power stations, on the assumption that there will be some cost savings associated with such options (both in respect of site services and proximity to distribution or transmission infrastructure); and
- Co-location at planned new electricity infrastructure, irrespective of the type – again on the assumption that some distribution, transmission and site costs can be saved.

If current and decommissioned power stations were used as locations, the impact would be as follows:

- Economically exploitable power would be reduced to approximately 1,000 MWe; and
- Transport costs would be increased by an average of between R 50/ton and R 100/ton for the range of supply.

Adding 1 GWe of capacity should allow stage 1 load shedding to be avoided, with stage 2 and stage 3 load shedding to be mitigated, whereas adding 2 GW will allow stage 1 and stage 2 load shedding to be avoided while mitigating stage 3.

Figure 16: Impact of non-optimal location



Conclusions

- Eskom will be able to supplement electricity generation by about 1,000 MWe from lignocellulose conversion to electricity.
- Location is determined largely by existing and planned electricity infrastructure development, and this decision does not have a significant cost impact compared with optimum locations.

Case Study 3: Synthetic Fuel Production

Background

The PetroSA GTL (gas-to-liquids) refinery based in Mossel Bay, is experiencing difficulties in sourcing new gas deposits (Roelf, 2015). Supplementing or replacing gas with biomass-derived syngas is an option to be considered.

Syngas production rate for capacity of 21,000 bbl/d

A typical GTL plant consists of three major sections – gasification, Fischer-Tropsch (FT) synthesis and products upgrading. One can consider the efficiency of 60% for Low Temperature FT, while efficiency of High Temperature FT can be more than 85%. A rough estimate for efficiency of GTL plant from natural gas is 75% (de Klerk and Fuminsky, 2010). Considering these numbers, gasification should have an efficiency of about 85%.

To produce 21,000 bbl/d of finished product, the plant will require between **160,000 kg/hr and 180,000 kg/hr** of natural gas (Wood *et al.*, 2012). Based on $\mathbf{CH_4 + ½\ O_2 \rightarrow CO + 2H_2}$ and considering the efficiency of 85%, this will produce 296,000 kg/hr of syngas.

Required lignocellulose to produce syngas

195,000 kg/hr biomass will produce 296,000 kg/hr dry biomass-derived gas, which leads to 222,000 kg/hr feed to the FTS reactor after tar removal and purification. **259,000 kg/hr** lignocellulose is necessary to produce the required amount of syngas for this plant. The required lignocellulose will be **2.26 million tons per year**.

Cost

In order to compare the cost of syngas production from natural gas and lignocellulose, the operating cost of the GTL plant should be considered, but this is not available in literature. Biomethane production from organic waste is competitive with LPG costs, and raw lignocellulose costs are relatively low.

Hence, using lignocellulose for syngas production may be a solution for the PetroSA GTL plant. There is an added possibility of producing electricity that can be used in the plant, reducing its operating cost.

Alternative technology

Lignocellulose biomass conversion is slow to develop, but according to literature it can be inferred that a biomass-to-liquid (BTL) process is a viable, sustainable and renewable route of producing hydrocarbon fuels. The possibility of achieving a negative greenhouse gas (GHG) emission is driving the BTL technology. However, the main challenge is to improve the conversion of feedstock carbon to hydrocarbon. One possible way is to use co-processing that combines syngas and lignocellulose as raw material. The co-processing plant (biomass and natural gas to liquid – BGTL) is more competitive than the GTL process. There are two different ways of combining natural gas with lignocellulose as *direct* or *indirect* methods. Indirect co-processing will increase the FT syngas yield substantially.

Gardezi *et al.* (2013) estimates that an equivalently sized BGTL plant needs 115,000 kg/hr biomass with 29,000 kg/hr natural gas instead of 259,000 kg/hr biomass, which means reduction in the feedstock and operating cost. The BGTL process can be considered as a possible solution to meet the needs of the PetroSA GTL facility.

The required lignocellulose for this case will be **1.003 million tons per year.**

Availability of biomass

The PetroSA refinery is relatively inconveniently situated with respect to biomass, given that the direct hinterland is dry, with a low annual increment in biomass, and productivity is confined to a narrow coastal belt with mild summer temperatures. However, there are some resources within a transport distance of about 600 km:

- There is some availability of IAPs in the Western and Southern Cape, although the bulk IAP availability is further afield.
- Plantation residue in Southern Cape commercial forests provides a resource relatively close to the refinery (200-350 km).
- Wheat residues in the Western Cape may be used.

Although the availability of wheat residue in the Western Cape has been included – this is likely to add approximately 0.5 million tons/annum[5] – the current application of the residue as wheat straw for livestock feed and the need to retain residue as a soil conditioner might rule it out completely. As such, it has been included with caution as a biomass resource for the *BioEnergy Atlas*. Availability of 0.5 million tons per annum in the Overberg region will have a significant impact on feasibility.

Transporting biomass more than 500-600 km will start making it uneconomical – transport costs are approximately R1-1.50/ton.km for dry mass such as grains or wood chips. Costs for straw will be higher due to lower density.

A significant *future* source of biomass in a national context may be the conversion of subsistence farmland to semi-commercial farming, producing a range of crops with varying suitability in different regions. Sweet sorghum, which is used as a case study in the *BioEnergy Atlas*, produces sugar for ethanol production, grain for personal consumption, and a sizable lignocellulose bagasse that could be utilised as a source.

However, the possible availability of such biomass is concentrated in former homelands (Eastern Cape and KwaZulu-Natal), and may be too far away to be economically exploitable. Should such a resource become available, it is estimated that a sizable quantum of biomass can be obtained from the former homeland areas of the Eastern Cape – representing approximately 1m to 3m ha of underutilised, degraded and subsistence farmland. Should the land be fully utilised, up to six tons/ha/annum of dry mass bagasse can be produced, hence a third of such a programme will also suffice as a feedstock for the refinery.

Table 17: Potential sources of biomass for PetroSA

Within distance of (km)	Availability (t/annum)				
	IAP	**Plantation residues**	**Sweet sorghum**	**Wheat residue**	**Total**
100	13 684	540	0	272 268	286 492
200	108 702	4 079	0	338 470	451 251
300	278 440	54 957	0	378 267	711 663
400	390 009	59 232	16	503 093	952 350
500	442 336	65 285	16	509 631	1 017 268
600	487 720	85 536	16	510 290	1 083 562
700	507 095	85 544	16	510 290	1 102 945
800	507 892	85 544	16	510 290	1 103 742
800+	507 892	85 544	2 051 000	510 290	3 154 726

5 The total availability is about 1.0 million tons per annum dry mass.

Conclusions

In the immediate term, the best option would be to evaluate, in detail, how much lignocellulose can be diverted from **wheat residues** without impacting soil condition, nutrient retention, existing applications such as livestock feed and economic value of straw. The Western Cape Department of Agriculture may have the best estimate available; and it may be possible to extract up to 0.5 million tons per annum.

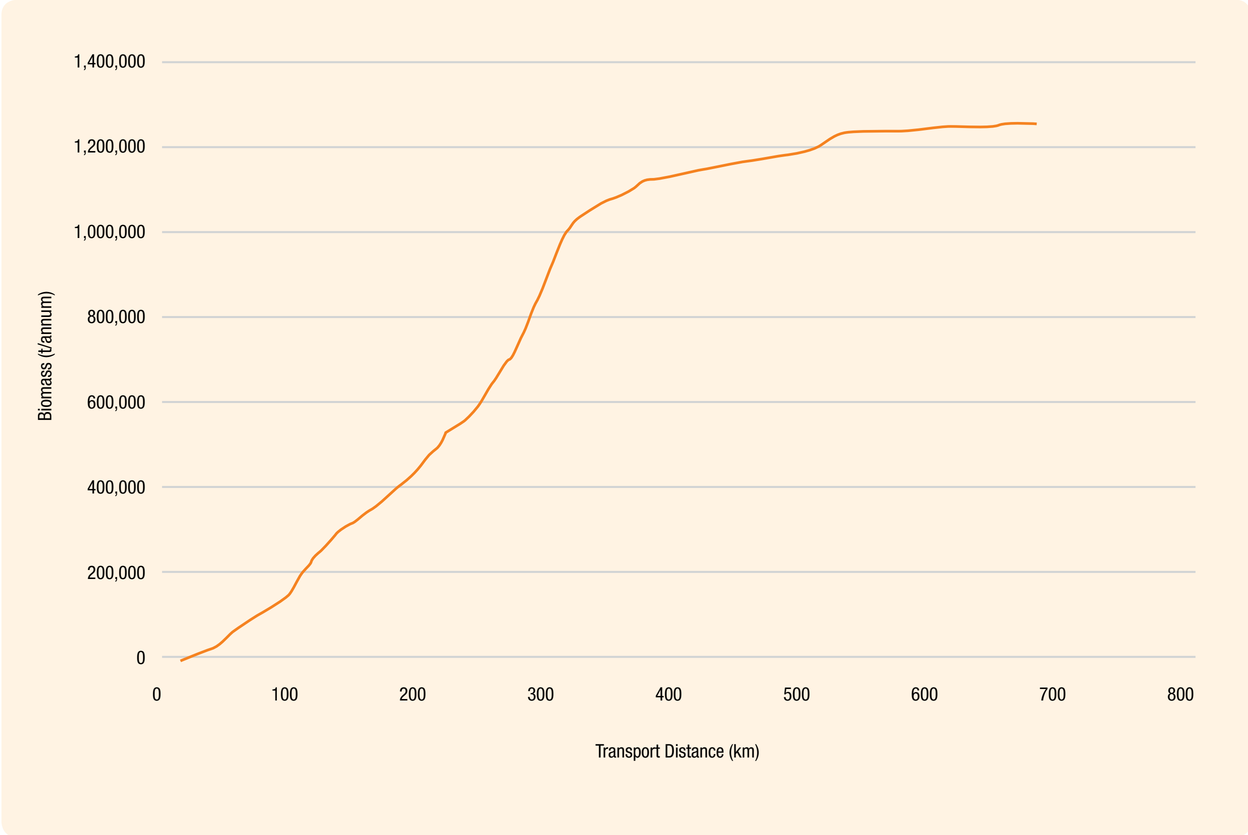
This can be supplemented by **plantation residue and invasive alien plants** (the latter harvested to eradication over 20 years). These sources have the major benefit that they are not seasonal and can act as a baseline for the feedstock. It is estimated that about 600,000 tons/annum would be available within 500-600 km.

These sources would be adequate to support the BGTL technology option within a range of approximately 400 km.

A future source of biomass could be the conversion of subsistence farming in former homelands to crop cultivation for bioenergy. The sweet sorghum option is considered here, but other options are also available. If transport cost is not prohibitive, such a conversion would contribute both ethanol from sugar and synthesis gas from lignocellulose. It is very difficult to estimate how successful such a programme might be – if a third of available subsistence farmland in the former homeland areas of the Eastern Cape is converted, it will yield about 2m tons of lignocellulose per annum, about 900 000 tons of sugar, and have an additional grain component for local use of about 450 000 tons per annum.

Future crop residue resources are at the outer limits of what is believed to be economically transportable distances by road (600-700 km). Any attempts to supply feedstock over lengthy distances may require **dedicated rail transport** or, in the case of intermediary feedstocks such as biogas or pyrolysis oil, **pipeline** or **shipboard** transport.

Figure 17: Biomass availability and transport distance – PetroSA



Additional considerations

- Sasol operates a Fischer-Tropsch facility and associated refinery at Secunda, producing in the order of 125,000 bbl/d of finished product. Replacement of 10% of its coal feed with biomass-derived carbon will require approximately 1.5 Tg/a of lignocellulose, which is not particularly difficult to supply in the Mpumalanga region from a combination of invasive alien plants and maize farming residue. Coal substitution with biomass is a far simpler way of introducing renewables into the liquid-fuels market than the creation of additional infrastructure for biodiesel or bio-ethanol production, blending, and associated logistics.
- Transport of low energy density feedstock such as lignocellulose limits the range of exploitable biomass for both PetroSA and Secunda, but this situation may be improved by the development of an intermediary processing industry, where bio-crude or biomethane is produced in distributed locations and high-energy density feedstock is transported to refineries.
- Studies are needed to evaluate the use of biomass further afield. Batidzirai *et al.* (2013) report significant potential for biomass of various types in Mozambique. Such resources may be used to generate biomethane, supplementing the feed from a recently commissioned gas pipeline from Temane (Mozambique) to Secunda (Sasol, 2015).

Table 18: Refinery capacities in South Africa

Refinery	Operator	Fuel capacity m3/d	Fuel capacity bbl/d	Percent	Biomass required Tg/a
Cape Town Refinery	Chevron	17 000	110 000	17.1%	
Engen (Enref)	Petronas	19 400	122 000	19.6%	
Sapref	Shell I BP	19 900	125 000	20.1%	
Sasol Secunda (CTL)	Sasol	19 900	125 000	20.1%	13.45
Natref	Total	17 250	108 500	17.4%	
Mossel Bay (GTL)	PetroSA	5 700	36 000	5.7%	2.26
Totals		**99 150**	**626 500**	**100%**	

Case Study 4: Maize Residues

'Corn stover' (maize leaves and stalks), as it is known in the USA, is a well-described feedstock for lignocellulosic bioethanol production. In South Africa, common practice in commercial farming operations involves baling the residues as hay, or the residues are typically directly used as livestock feed, or modified to reduce toxicity and improve digestibility (Chaudary *et al*., 2012).

Maize is South Africa's premier grain crop, and residues from maize farming are substantial. Annual grain production amounts to 10.924 Tg/annum (DAFF, 2014b) and the complete maize plant represents approximately 122 Tg/annum of total biomass at a moisture content of about 75%. Expressed as thermal energy based on dry matter, this represents a significant amount – the energy content of residues is approximately 15 MJ/kg. For the dry residue, the amount of energy available is 127 TWh/annum, roughly 7.5% of the country's current consumption.

It is highly unlikely, however, that a large proportion of the available biomass can be converted to energy, based on the following considerations:

- Some crop residue needs to remain on fields for a number of reasons: mitigation of soil and wind erosion, maintenance of carbon in the soil and retention of nutrients such as Nitrogen, Phosphorus and Potassium. Estimates of this requirement vary and depend on factors such as grain yield, soil types and rainfall intensities, but it is a large fraction of available residue given South African yield ranges (Jeschke and Heggenstaller, 2012). See detailed discussion below.
- There is a significant (but unknown) quantity of fodder, baled hay or ensilage – used for livestock feed – that needs to be accounted for.
- Not all available residue will be exploitable on an economic basis – low density of availability and logistics costs may eliminate significant quantities.

Based on the analysis in Table 19, it can be concluded that the maximum unconstrained potential is not likely to be higher than 20 TWh/annum – still a sizable proportion (up to 1%) of the total energy needs of the country if fully converted. Other estimates (Schulze and Walker, 2007) put the figure slightly higher (15% exploitable residue).

An estimate of the spatial distribution of maize residues has been prepared for the intensively farmed areas of South Africa – Gauteng, North West, Mpumalanga and Free State[6]. This area represents approximately 50% of the maize production in the country, and maize cultivation forms a major part of the agricultural crops in many parts of this area.

Table 19: Conversion of maize residues to thermal energy

Element or aspect	Units of measure	Value	Reference
Amount of maize residue (at full moisture content)	Tg/annum	122	Hugo, 2014
Moisture content	%	75	Gould, 2007 Igathinathane *et al*., 2006
Dry residue	Tg/annum	30.5	*Calculated*
Energy content (dry matter)	MJ/kg	15	DAFF (2014b)
Annual thermal energy value	MJ/annum	4.575 E+11	*Calculated*
	TWh/annum	127	*Calculated*
Requirement for soil maintenance	%	49%	Jeske and Heggenstaller, 2012
Estimated as livestock feed and waste	%	35%	*Estimate*
Exploitable percentage	%	15%	Mwithiga, 2013
Estimated exploitable energy (thermal)	TWh/annum	19	*Calculated*
Annual energy consumption	TWh/annum	1 700	Hugo, 2014b
Displacement of annual consumption	%	1%	Calculated

6 Detailed crop field types are not yet available for other provinces.

Exploitable maize residue

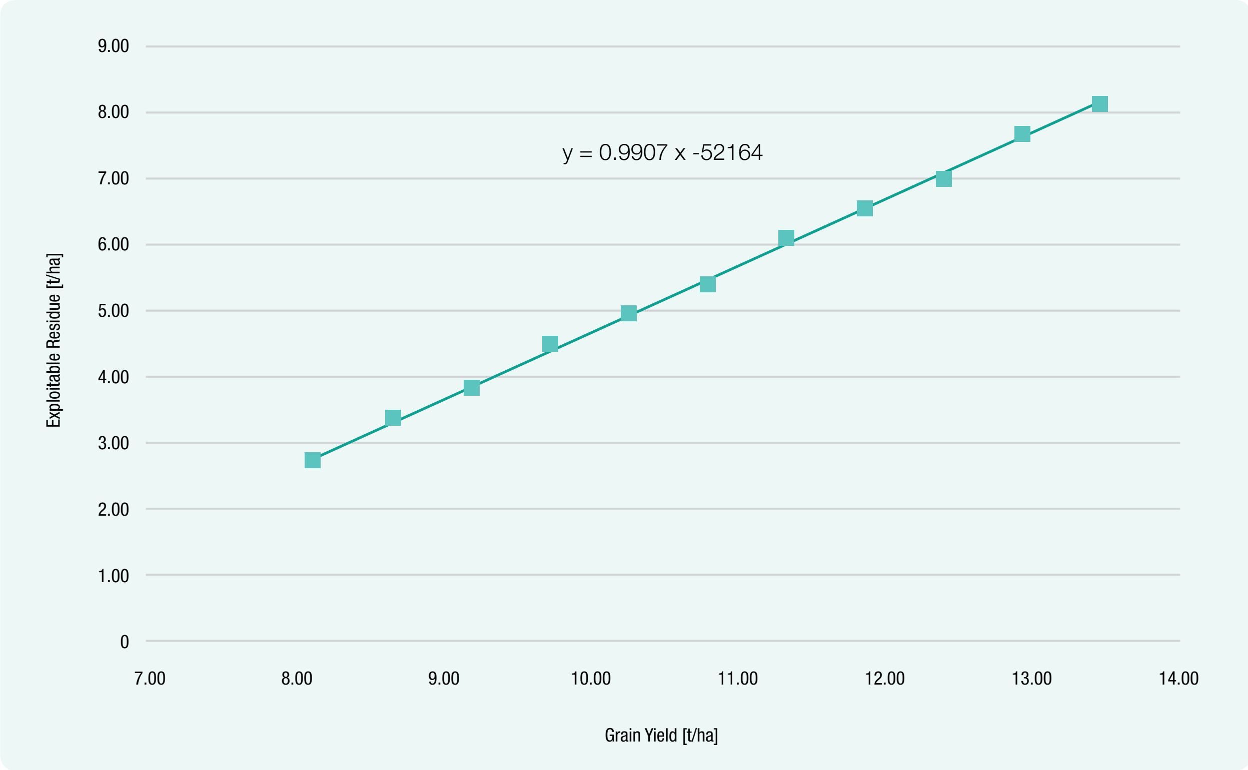
By combining crop field types allocated to maize (DAFF, 2014b) with data on maize potential and net primary productivity (Schulze and Walker, 2007), it is possible to calculate an exploitable residue for all of the intensively farmed areas. This distribution can then be used to determine feasibility that takes logistics into account, in addition to factors of economy of scale and conversion process choices.

Using data from Figure 18 (based on US conditions), it is unlikely that there will be any realistically exploitable residue at yields less than about 3-5 t/ha of grain. If residue is removed at lower yields, farmers run the risk of soil carbon loss, increased erosion and nutrient removal. Added to this is the relatively poorly understood fraction of residue that is used productively as animal feed. Applying this criterion in South African conditions results in very few maize-growing areas where sustainably exploitable residue can be found, given that the average yield in local conditions is in the order of 3.82 t/ha.

Research questions

- What is the proportion of sustainably harvestable residue in South African conditions, given requirements of soil preservation, animal feed and nutrient retention?
- Can grain-fed beef be reared using other sources of animal feed, thereby freeing grain for bioenergy production?

Figure 18: Exploitable maize residue (US conditions)



Case Study 5: Sweet Sorghum Production

This section evaluates sweet sorghum cultivation in more detail. Sweet sorghum has a number of apparent advantages as a bioenergy crop:

- It is drought-tolerant (more so than maize), which allows cultivation with less variability, as well as extending the climatically suitable areas of the country where it can be cultivated successfully.
- It is a native of the African subtropics, and recent work has seen the development of many high-yield varieties.
- It produces a triple product:
  - Grain (about 50% of comparable maize yield in similar conditions);
  - Sugar (extracted as juice from the stems); and
  - Leaf and fibre residues (similar in biomass to maize).
- It matures quickly, and in suitable areas it can yield two crops per season, can be intercropped with wheat, potatoes and beans, and can also yield a ratoon[7] crop.
- Allows the use of marginal/degraded land and conversion of rangelands.
- Unconstrained potential overlaps significantly with former homeland areas, and can serve as the basis for a rejuvenated, agriculture-based rural economy. This notion is aligned with the strategic positioning of the Department of Energy (DoE, 2014).

There are approximately 3.2m hectares of underutilised and subsistence farmland in South Africa, not all of which are suitable for crop cultivation or close enough to markets or centres of production.

Table 20: Cultivation of sweet sorghum

Climatic requirements for sweet sorghum		
Aspect	**Units**	
Temperature	°C	26 to 30
Minimum sowing temperature	°C	10 to 15
Rainfall	mm/a	500-600
Days to maturity	d	115 to 145
Drought tolerance	-	High
Moisture tolerance	-	Low
Cold tolerance	-	Low

Cultivation		
Per single crop		
Fertiliser	t/ha	0.16 to 0.275
Water use	m^3/ha	4 000 to 4 360
Water use	mm/a	400 to 436
NPK ratio	-	4:3:2
Intercropping		Legumes, potato, soybean, wheat

Yields per single crop		
Total yield (as harvested)	t/ha/a	35 to 55
Stalks (as harvested)	t/ha/a	17.5 to 35
Grain (dry mass)	t/ha/a	1.38 to 3.4
Juice	t/ha/a	17.5 to 42
Bagasse (dry mass)	t/ha/a	8.75 to 8.75
Sucrose content	%	2.62 to 5.2
Fermentable sugar content	%	6.06
Alcohol	l/ha/a	1250 to 2875
Residue (including bagasse)	t/ha/a	11.75 to 15

Based on Rajvanshi & Rimkar, 2008; NARI (2006), Reddy *et al.* (2006); Reddy *et al.* (2008)

7 Practice where the roots system and lower stem are not harvested, resulting in a second crop from the same planting.

Sweet sorghum produces both sugar and grain, and depending on the ratio of grain and sugar in the ethanol production feedstock, the bias can be towards ethanol production (most of the grain and all the sugar), or a balanced production that allows cash cropping and subsistence farming (using almost no grain and most of the sugar).

Sweet sorghum, by virtue of its triple product, lends itself to integrated farming initiatives, especially for rural subsistence farmers in South Africa. This view is based on case studies and pilot schemes conducted in India and China in recent years, in which a diversity of farming products and outputs, including bioenergy, are derived from sweet sorghum.

In the South African context, such an initiative may include:

- Collective farming, with sharing of the equipment required for processing of products;
- Availability of a 'cash crop' with a guaranteed market and income – as sugar delivered to ethanol-production facilities;
- Availability of grain as food, feed for livestock and other potential applications;
- Generation of small-scale local and regional electricity from residues;
- Availability of residue (stalks, leaves) as animal feed; and
- Biogas generation from integrated waste streams.

Figure 19: Sweet sorghum (grain) availability from subsistence and degraded cropland

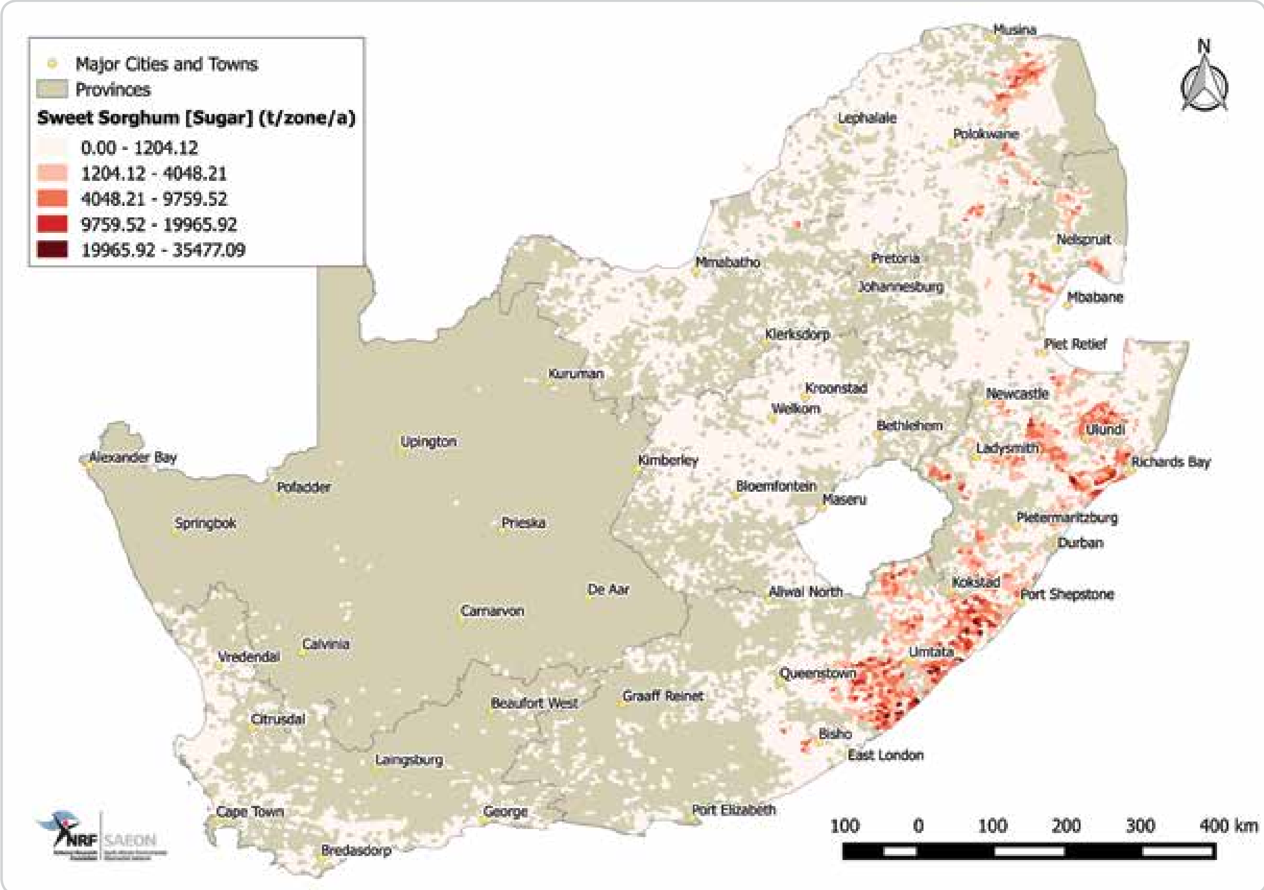
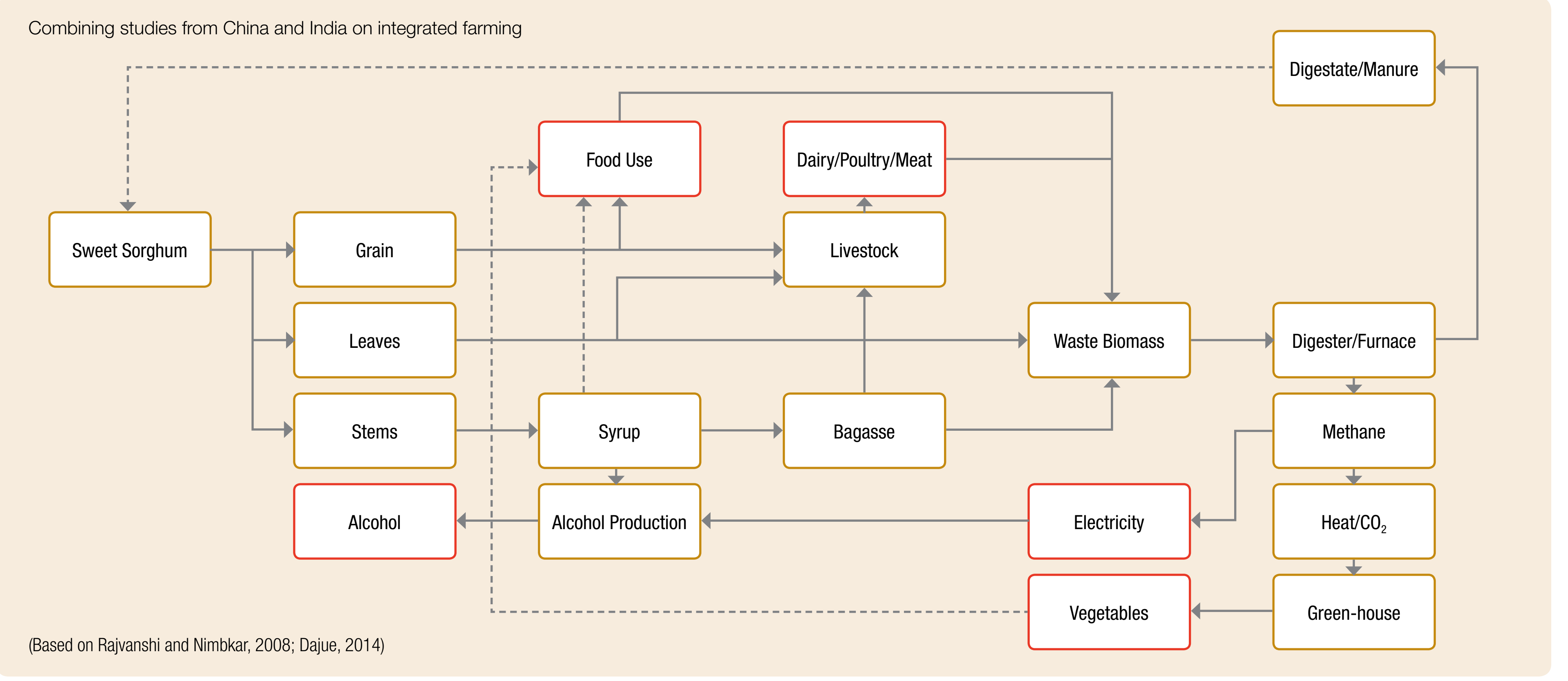


Figure 20 sketches a more elaborate integrated farming design investigated in both India and China, but due to local constraints on alcohol production, such a design will only be possible in a larger farming collective with industrialisation of the alcohol production. In essence, local adaptation will require a decision on the ideal mix of product to retain and apply in a farming context, with the balance going to industrial alcohol-production localities that are optimal in respect of economy of scale, but distributed widely enough to allow easy access to farming produce.

As indicated in the section on Feasibility – production of ethanol to anhydrous (E10) specification is expensive and will not be feasible without some form of subsidy. It may, however, be feasible to produce ethanol at 95% purity (suitable for E95 blending), but this will require a parallel distribution network for liquid fuel, or conversion of a dedicated fleet to E95 specification.

Figure 20: Integrated sweet sorghum farming



(Based on Rajvanshi and Nimbkar, 2008; Dajue, 2014)


ATLAS

Atlas Themes

Factors Determining Biomass Availability

The basic availability of biomass is determined by land cover, and by net primary productivity. This 'primary availability', together with broad-based exclusions such as conservation areas and inaccessible slopes, is shown in a series of maps and discussion boxes.

Agriculture and Forestry

Agriculture and Forestry provide potential for biomass – as field and plantation residues, as residues and waste streams from processing, and in respect of purposely cultivated energy crops. Due to food security and fuel price coupling concerns, only subsistence and degraded farmland was considered for purposely cultivated energy crops.

Biomass Availability

Biomass availability is estimated by planning zone for all of the feedstock streams under consideration: agricultural residues, plantation and sugar cane residues, sawmill and sugar mill residues and waste, organic fraction of municipal solid waste, organic component of waste water, fuelwood, invasive alien plants, and purposely cultivated crops – oil, sugar and grain-bearing.

Infrastructure

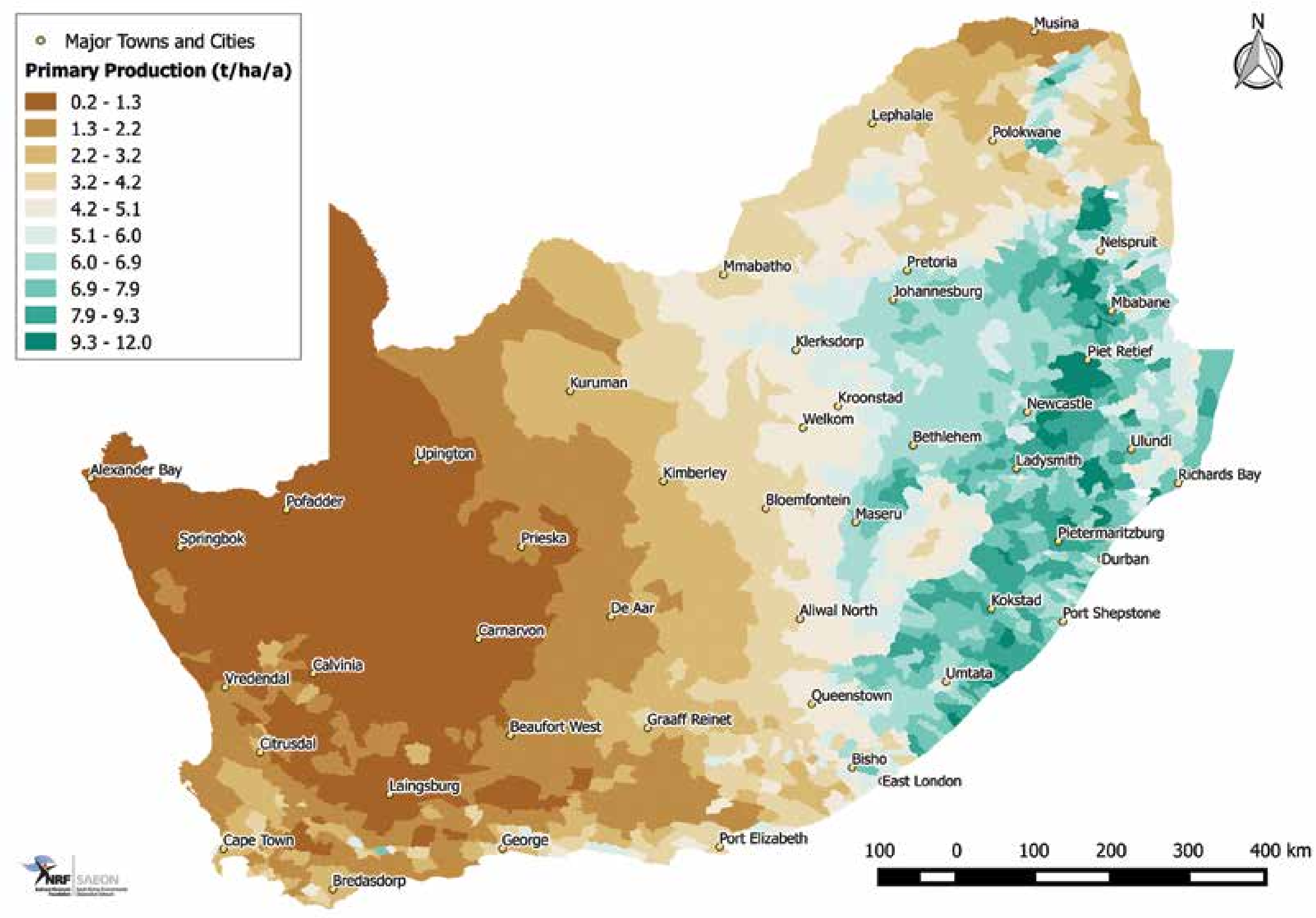
Maps depict the distribution of infrastructure for the energy, agriculture and waste processing industry, and evaluate the proximity of useful infrastructure to the population, to economic activity, and to availability of biomass.

Demand

Demand for energy is determined by economic activity, efficiency of application, and relative household income. Consumption has declined due to load-shedding impacts and slow economic growth. Increased economic growth and a rise in household income may lead to increases in demand.

Feasibility

Assessments are made of impacts of economy of scale, logistics, and placement on techno-economic feasibility of feedstock and processing combinations, leading to identification of a portfolio of feasible project options. These options are illustrative of areas where bioenergy is likely to be a competitive, sustainable alternative.



Based on Schulze (2007).

Measure of the net biomass productivity as dry matter in tons per hectare per annum.

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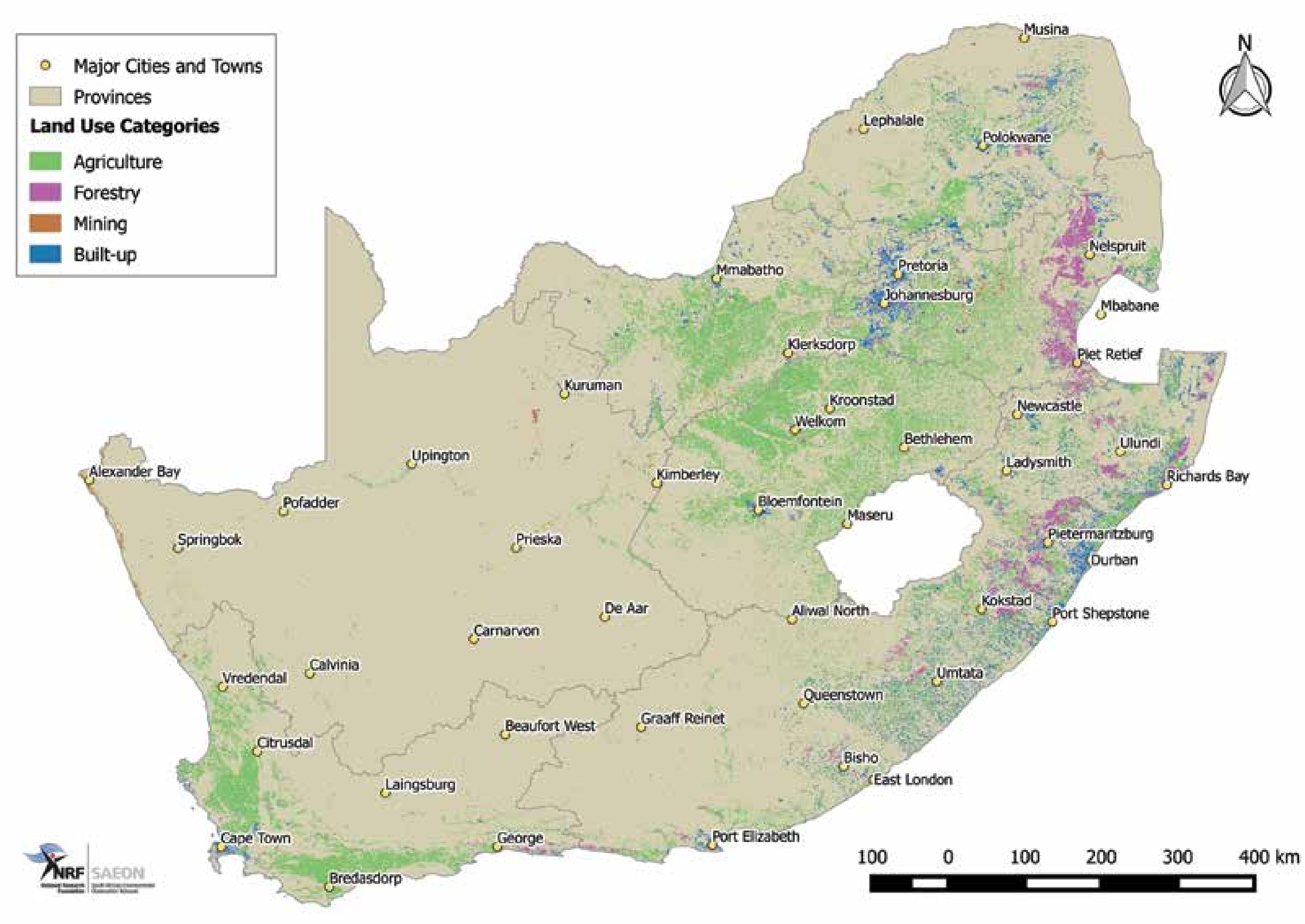


Based on Schoeman *et al.* (2013).

Main land-use categories.

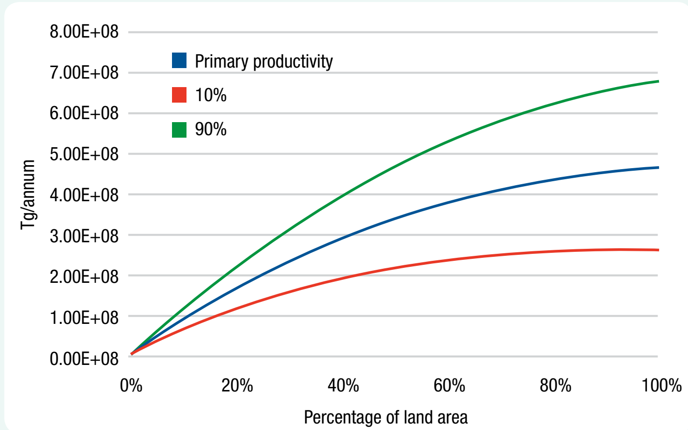
Metadata:
http://bea.dirisa.org/resources/atlas-maps/LANDUSE.PDF

Box A.1

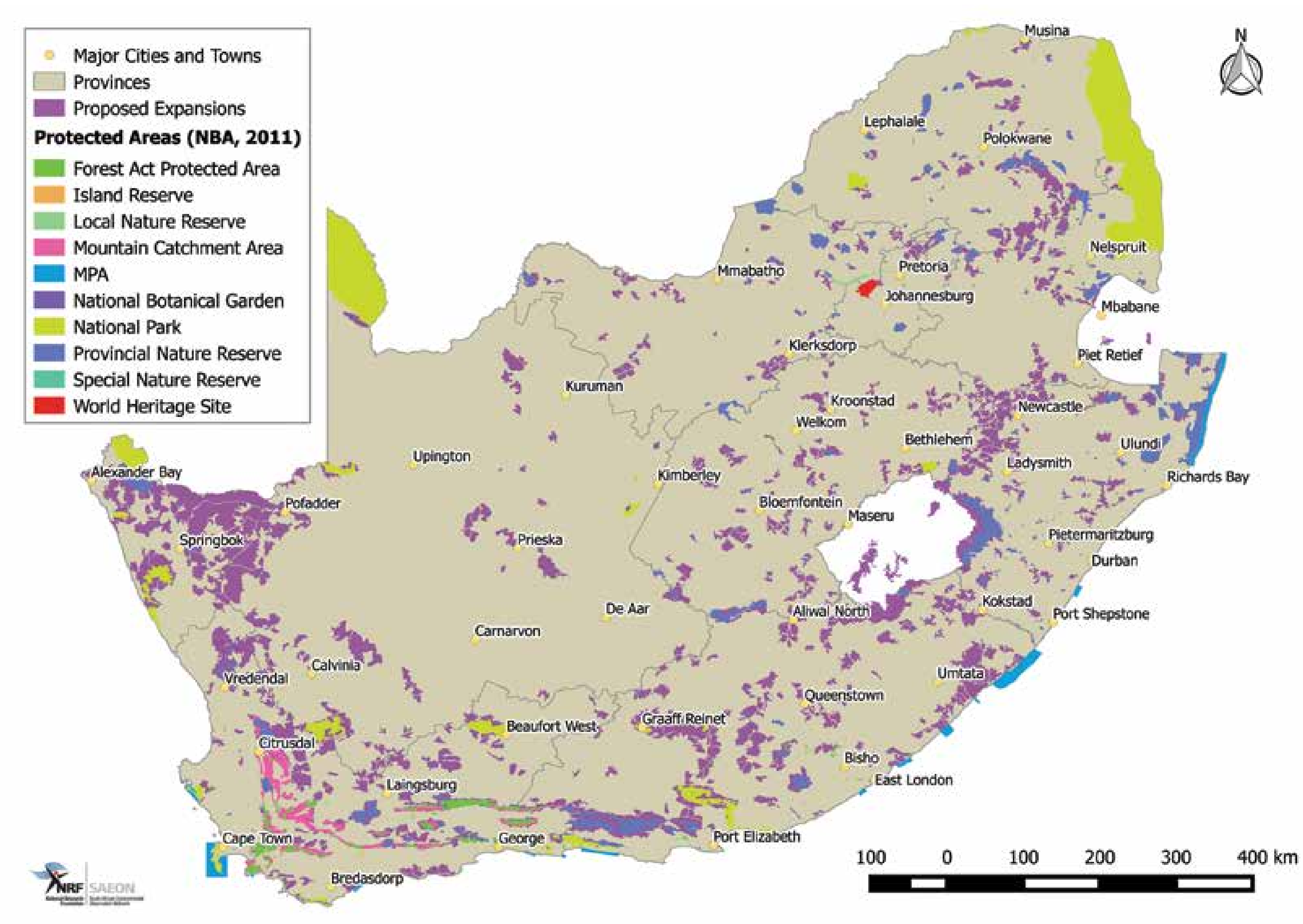
Source of biomass				Area (ha)
All biomass/All land area 125 025 996 ha 262.8 Tg/annum	**Habitation** 2 096 933 ha 1.7%	Organic solid waste	Serviced	N/A
			Unserviced	N/A
		Domestic wastewater	Serviced	N/A
			Unserviced	N/A
		Other waste	Cooking oil	N/A
	Mining 187 703 ha 0.1%	Not considered – small land area		N/A
	Forest 1 779 680 ha 1.4%	Indigenous/other	Fuelwood	506 680
			Sawmill waste	1 273 000
		Commercial	Plantation residue	
	Agriculture 12 905 375 ha 10.3%	Residues	Sugar cane	430 000
			Maize	2 859 000
			Other field crops	2 264 800
		Purposely cultivated	Food security/Commercial	5 123 800
			Subsistence/Degraded	3 119 409
		Livestock/Horticulture		4 232 166
	Other 108 071 722 ha 86.4%	Fuelwood gathering	Savanna	Unknown
		Invasive species	Acacia	44 000 000
			Eucalyptus	
			Pine	
			Prosopis, Willow	
	Excluded/Impacted	Protected areas		7 900 000
		Unsuitable slope		743 048
		Sensitive areas and future protection		10 800 000

Maximum available land areas and resulting biomass were estimated from information on net primary production (Schulze, 2007) and land cover data (Schoeman *et al.*, 2013). This estimate is significant for two reasons – it puts a maximum on the land-based production of biomass in the country, and it vividly illustrates the variability of biomass production. The variability is an important factor given that industrialisation of any kind generally relies on security of supply.

Figure A.1: Variability in net primary productivity



Biomass availability was categorised in the *BioEnergy Atlas* for purposes of analysis, reporting and modelling, using the schema in the adjacent table – representing maximum land availability for each biomass source without significant land-use change.



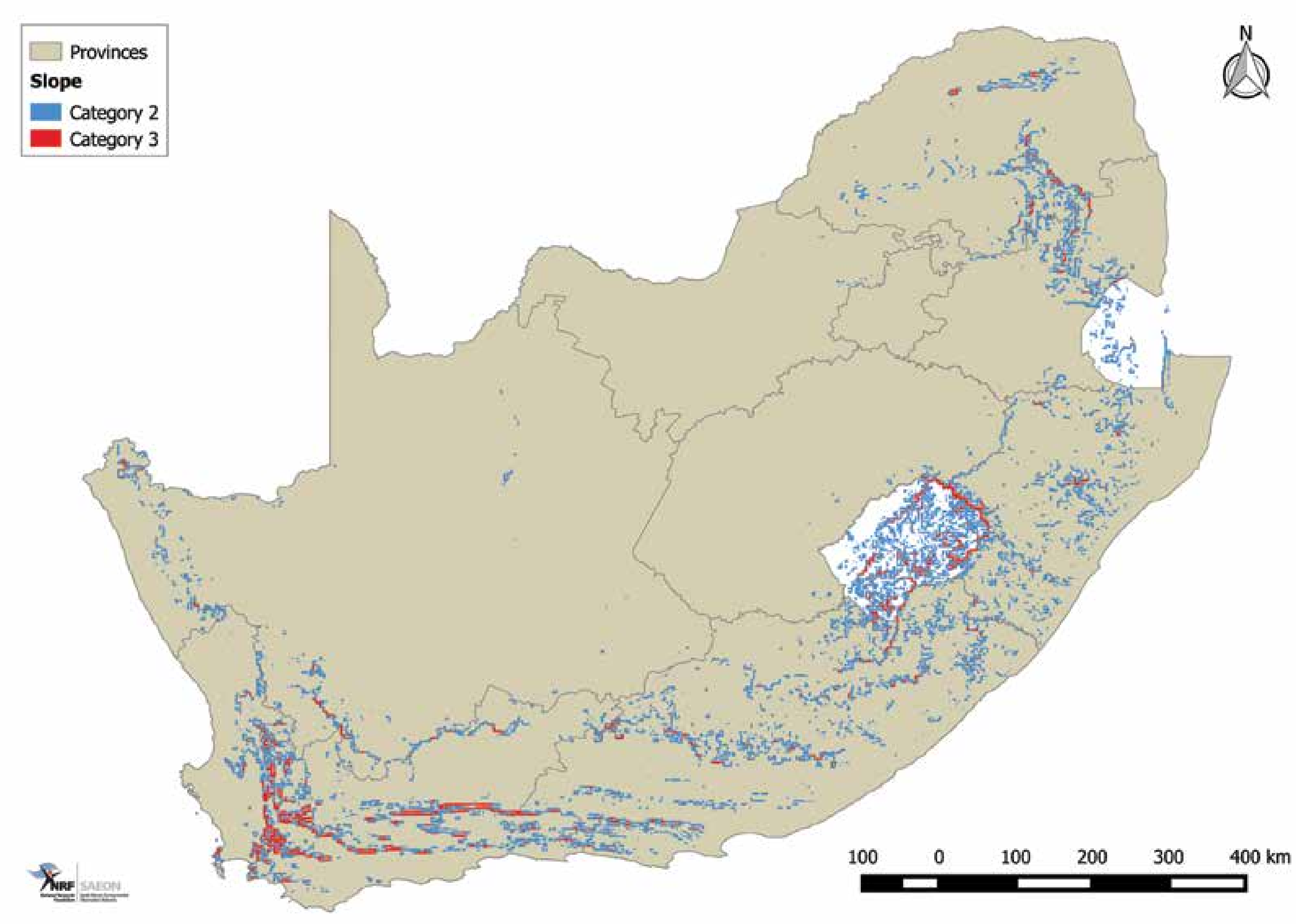
Derived from data published by SANBI (National Protected Areas, National Biodiversity Assessment, 2011) and the National Protected Areas Expansion Strategy (NPAES, 2011).

Metadata:

http://bea.dirisa.org/resources/atlas-maps/NPA.PDF

http://bea.dirisa.org/resources/atlas-maps/NPAES.PDF

Theme: Factors Determining Biomass Availability – Slope



Based on data published by Schulze and Horan (2007) and categorised by SAEON into extent of mechanisation that is possible.

Category 2:
Limited mechanisation possible.

Category 3:
No mechanisation possible.

Metadata:
http://bea.dirisa.org/resources/atlas-maps/SLOPE.PDF

Box A.2

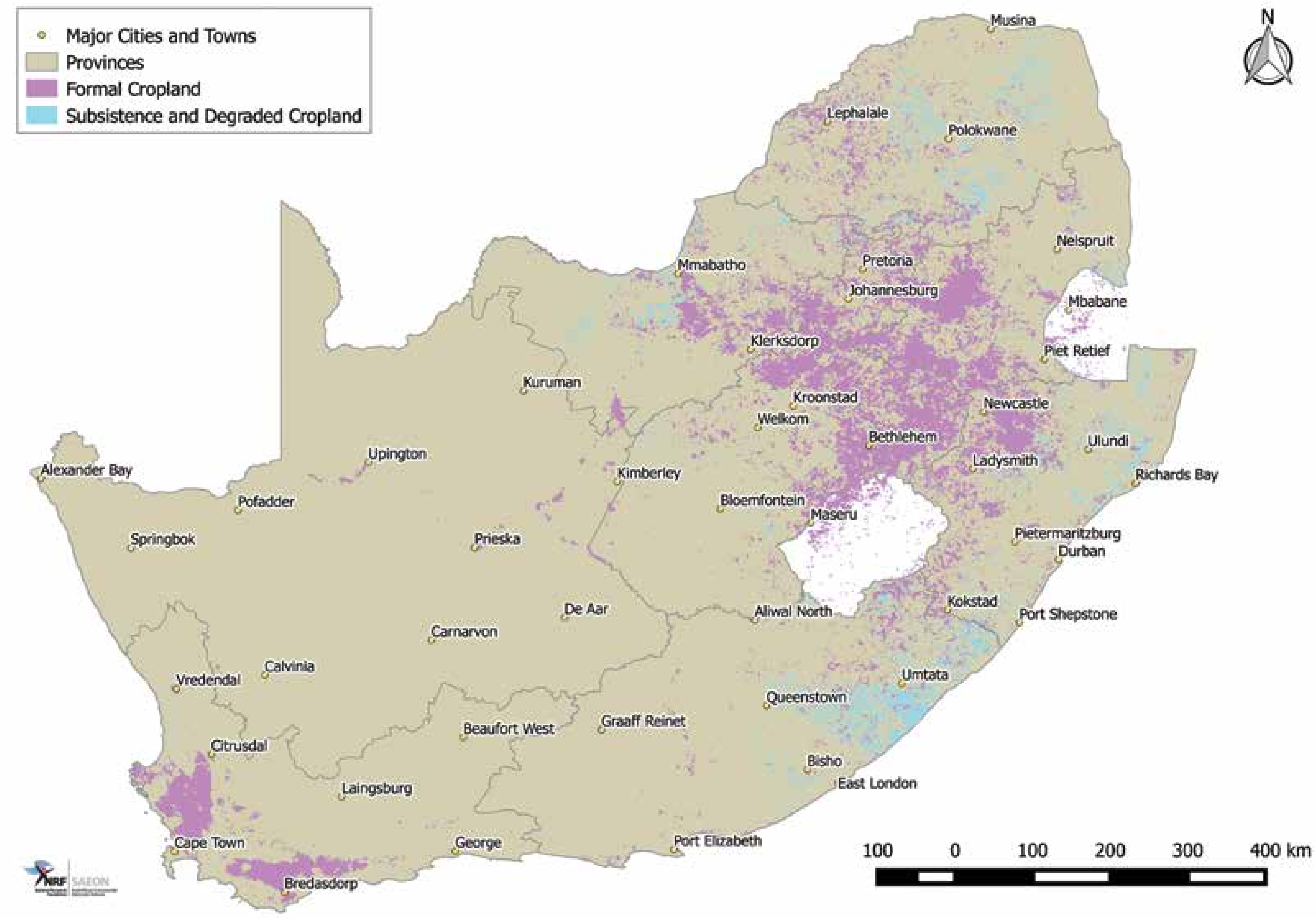
Gradient and soil-pattern limitations
Gradient (or slope) has a marked effect on mechanised farming

Gradient	Class	Category assigned	Problems
0-3	Gently sloping (1)	1	None.
3-7	Moderately sloping (2)		Difficulties with weeders, precision seeders and some mechanised root crop harvesters.
7-11	Strongly sloping (3)	2	Use of combine harvester restricted.
11-15	Moderately steep (4)		Limited use of combine harvester and of two-way ploughing (depending on field configuration).
15-25	Steep (5)	3	Not suitable for arable crops, with slopes over 20 being difficult to plough, lime or fertilise.
>25	Very steep (6)		Mass movement occurs, animal tracks across slope appear and mechanisation impossible without specialised equipment.

Protected areas data were obtained from the South African National Biodiversity Institute (SANBI), covering both protected areas defined by law (SANBI, 2011) and areas proposed for expansion (SANBI, 2008).

Categorisation of slope was based on the British Land Capability Classification (Bibby and Mackney, 1969), applied to South African topography. Slope was estimated from Schulze and Horan (2007).

The only biomass streams impacted by these considerations are invasive alien plants (due to inaccessibility) and subsistence farmland (due to slope and conservation planning). Only about 150 ha of subsistence farmland fall in either of these categories – negligible in the final analysis. Accessibility for harvesting was considered in detail for invasive alien plants.

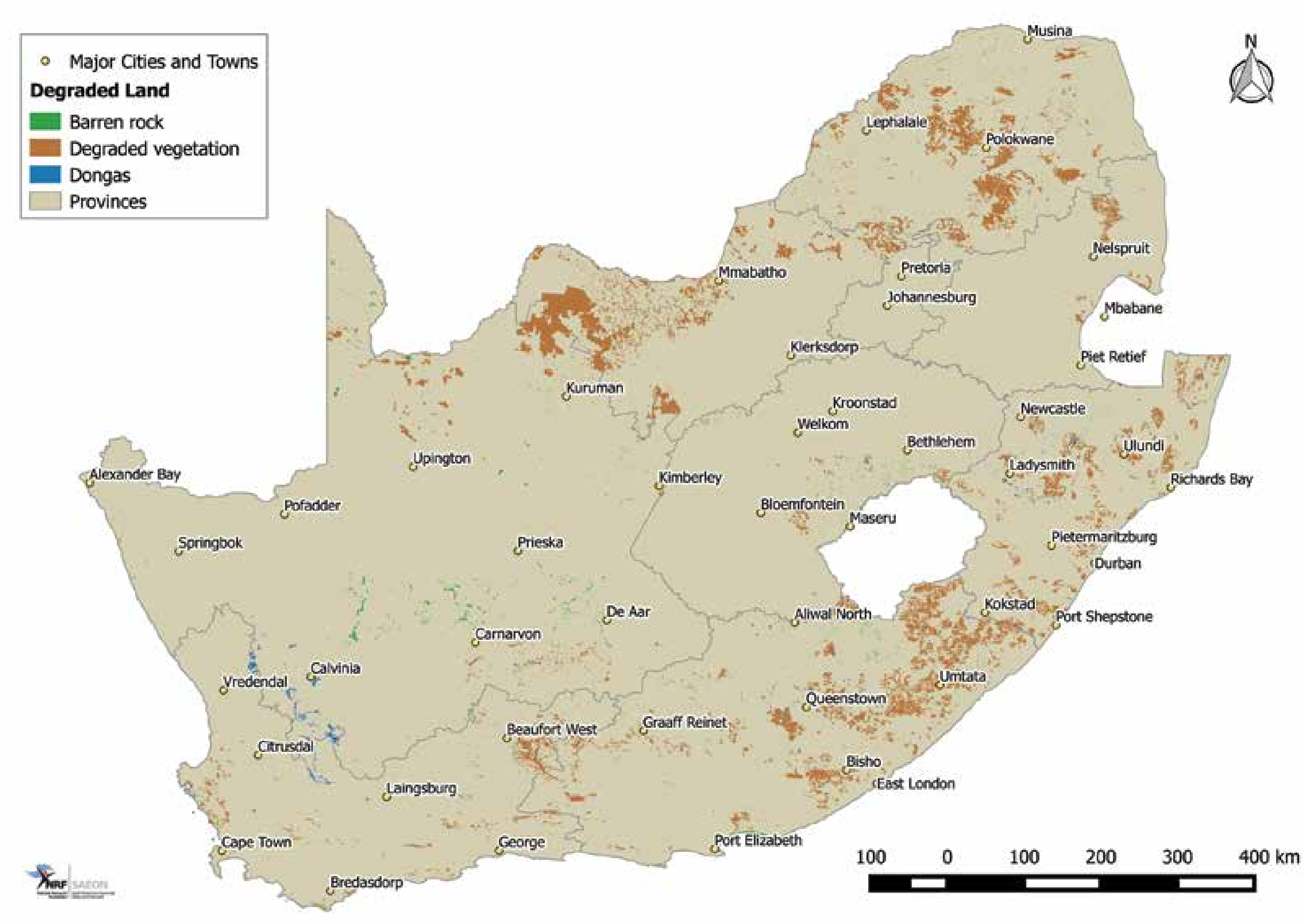


Based on data provided by DAFF (2014).

Metadata:

http://bea.dirisa.org/resources/atlas-maps/AGRCOMSUB.PDF

Theme: Agriculture and Forestry – Extent of degraded farmland



Based on data provided by DAFF (2014).

Metadata:

http://bea.dirisa.org/resources/atlas-maps/DEGRADED.PDF

	Production	Area	Residues	Soil Maintenance	Animal Feed	Available	Exploitable
Agricultural Production - Crops	Tg/annum	ha	%	%	%	Tg/annum	Tg/annum
Maize	10.924	2 859 000	74%	50%	35%	31.091	4.664
Wheat	1.858	605 000	57%	50%	35%	2.415	0.362
Grain Sorghum	0.178	69 000	57%	50%	35%	0.231	0.035
Groundnuts	0.055	55 000	81%	50%	35%	0.234	0.035
Sunflower	0.894	643 000	50%	50%	35%	0.894	0.134
Soya Beans	0.710	418 000	50%	50%	35%	0.710	0.107
Oats	0.057	22 000	57%	50%	35%	0.074	0.011
Barley	0.301	80 000	55%	50%	35%	0.361	0.054
Canola	0.059	44 000	50%	50%	35%	0.059	0.009
Dry Beans	0.046	42 000	50%	50%	35%	0.046	0.007
Sugar Cane Bagasse	16.800	272 000	38%	50%	35%	10.080	1.512
Sugar Cane Field Residues	21.500	272 000	22%	50%	0%	4.700	2.350
Chicory	0.028	9 800	50%	50%	35%	0.028	0.004
Cotton	0.073	5 000	50%	50%	35%	0.073	0.011

Sugar cane residues are calculated as a fraction for the total sugar case biomass

Assumptions based on data for maize

All other residue fractions are expressed relative to grain or final product (i.e. 60% implies a 60/40 split between dry residue and dry grain)

References:

BIOPACT, 2006

DAFF, 2014

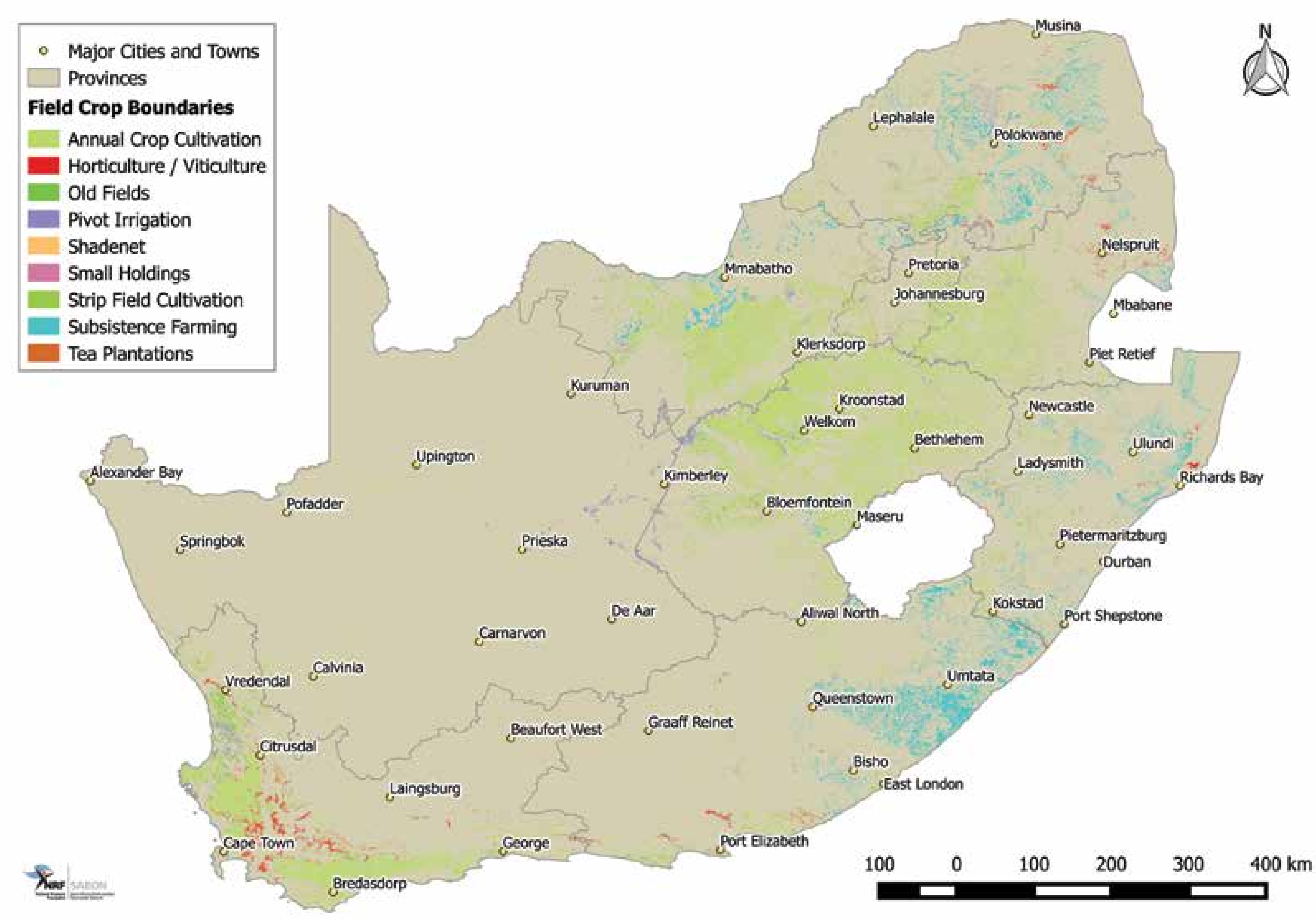
DAFF, 2014b

Jeschke & Heggenstaller, 2012

Kim & Dale, 2004

Smith, M 2008

UNEP, 2009

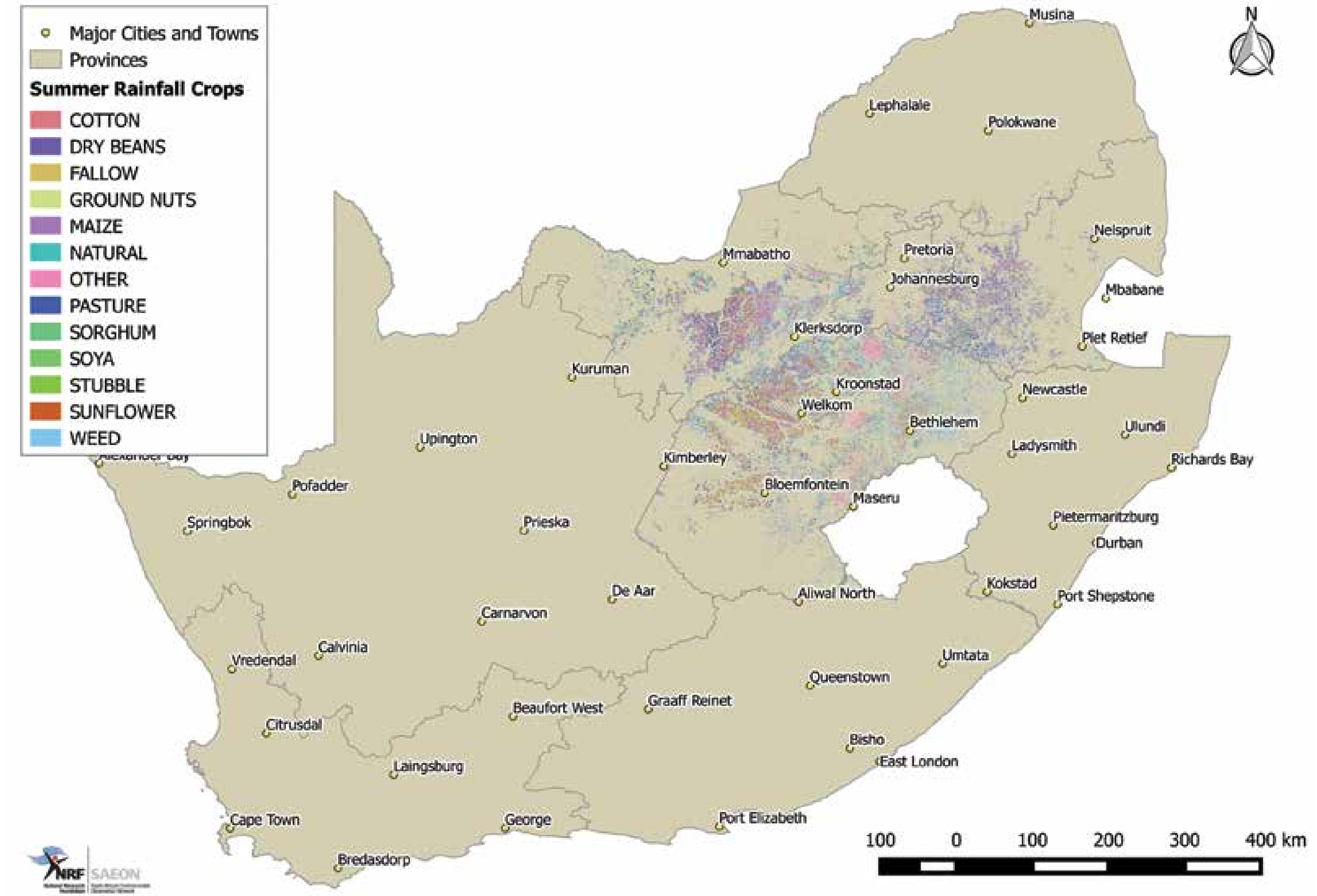


Based on data provided by DAFF (2014).

Metadata:

http://bea.dirisa.org/resources/atlas-maps/AGRTYPE.PDF

Theme: Agriculture and Forestry – Summer rainfall crops

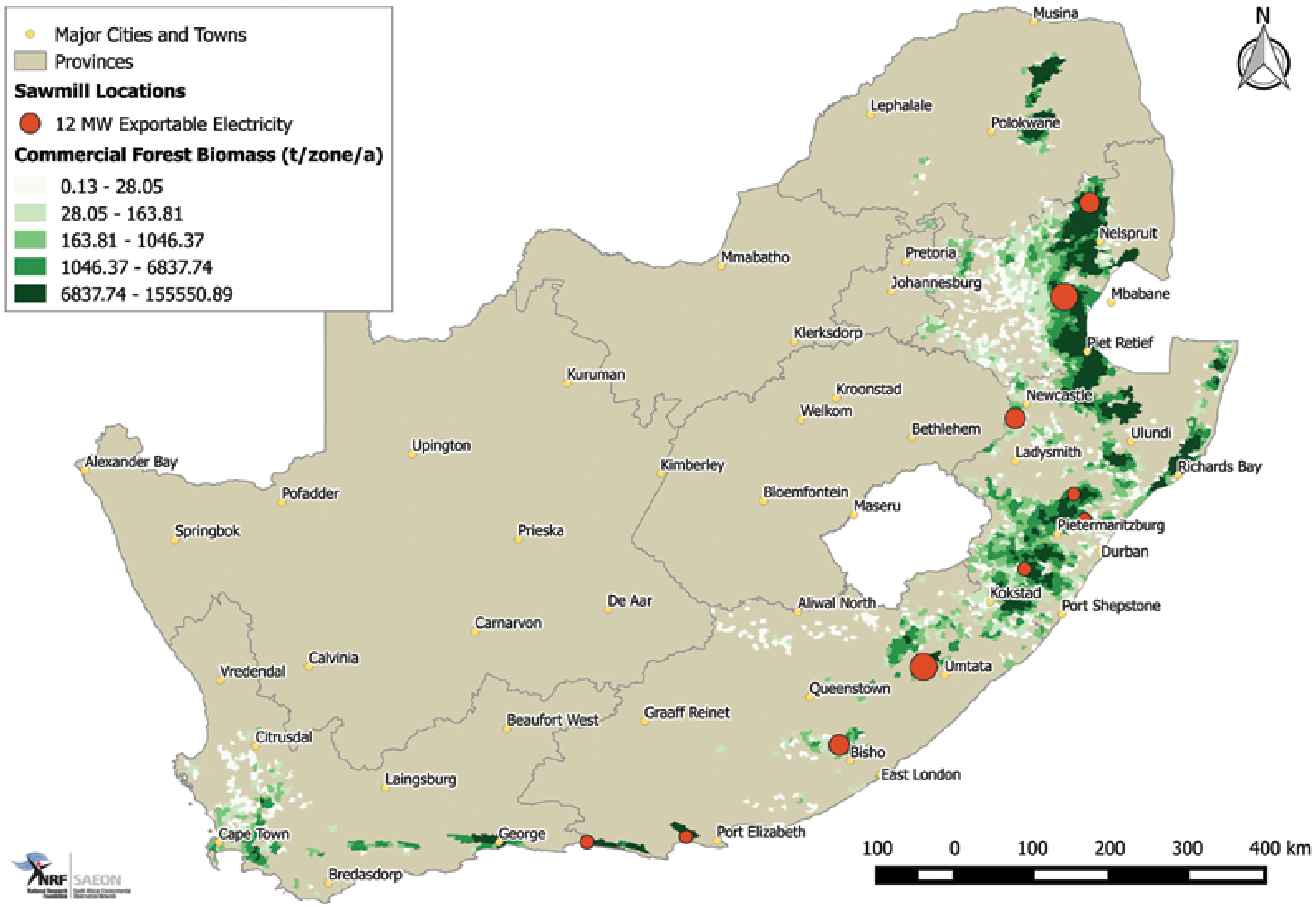


Based on data provided by DAFF (2014).

At the time of publication, data were not yet available for the Eastern Cape, KZN, Northern Cape and Limpopo.

Metadata:
http://bea.dirisa.org/resources/atlas-maps/AGRSUM.PDF

Theme: Agriculture and Forestry – Extent of commercial forestry

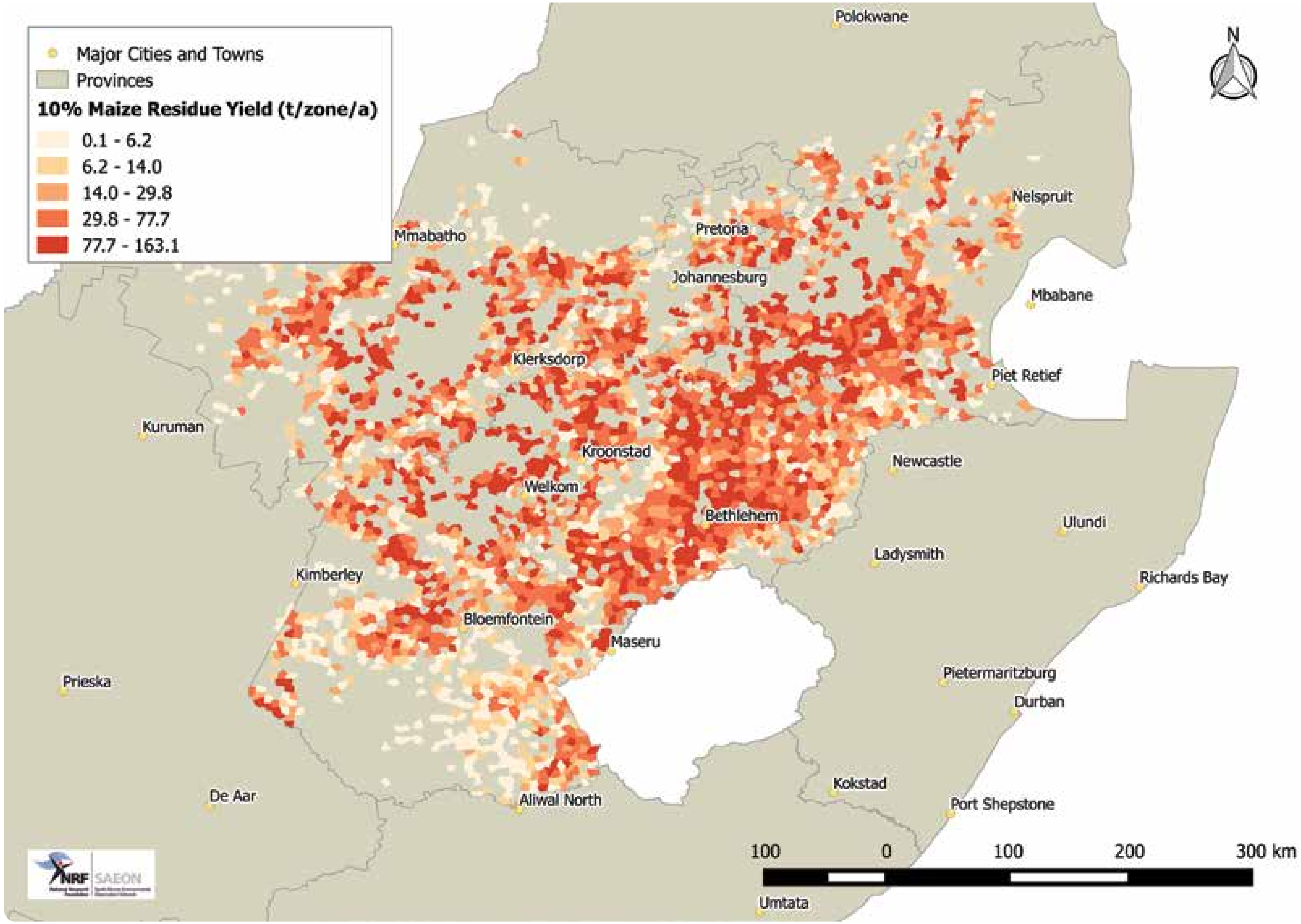


Data based on exportable electricity and location of sawmills gathered by CRSES (2014).

Forestry yields estimated from NPP (Schulze, 2007) and extent of forestry reported by Schoeman *et al.* (2013) as land use, scaled for annual production based on Naidoo (2014).

Metadata:
http://bea.dirisa.org/resources/atlas-maps/FOREST.PDF

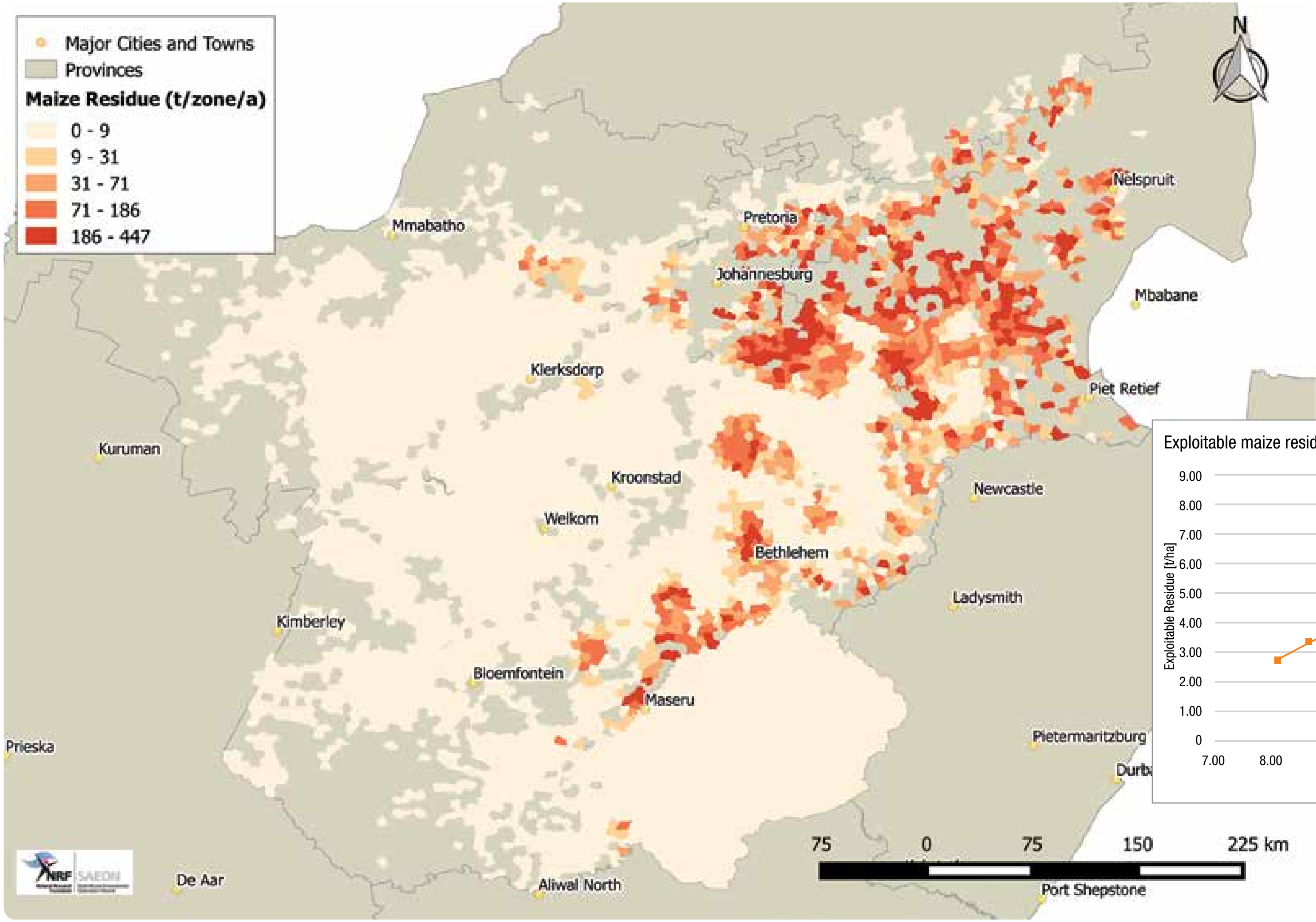
Theme: Biomass Availability – Maize residues at 10% of biomass yield



Based on maize production by province (DAFF 2014b), assigned to maize cropland (DAFF 2014) using Net Primary Productivity (Schulze 2007).

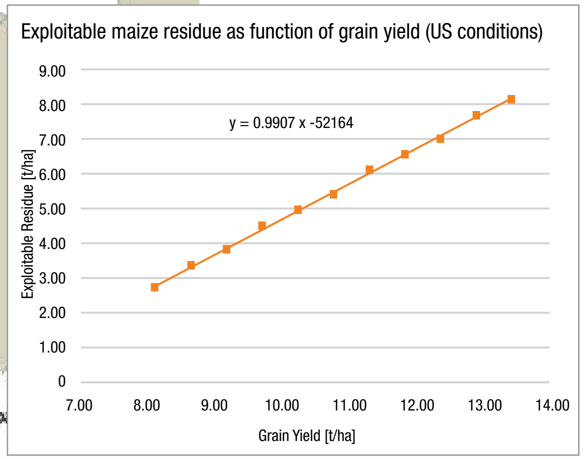
Metadata:

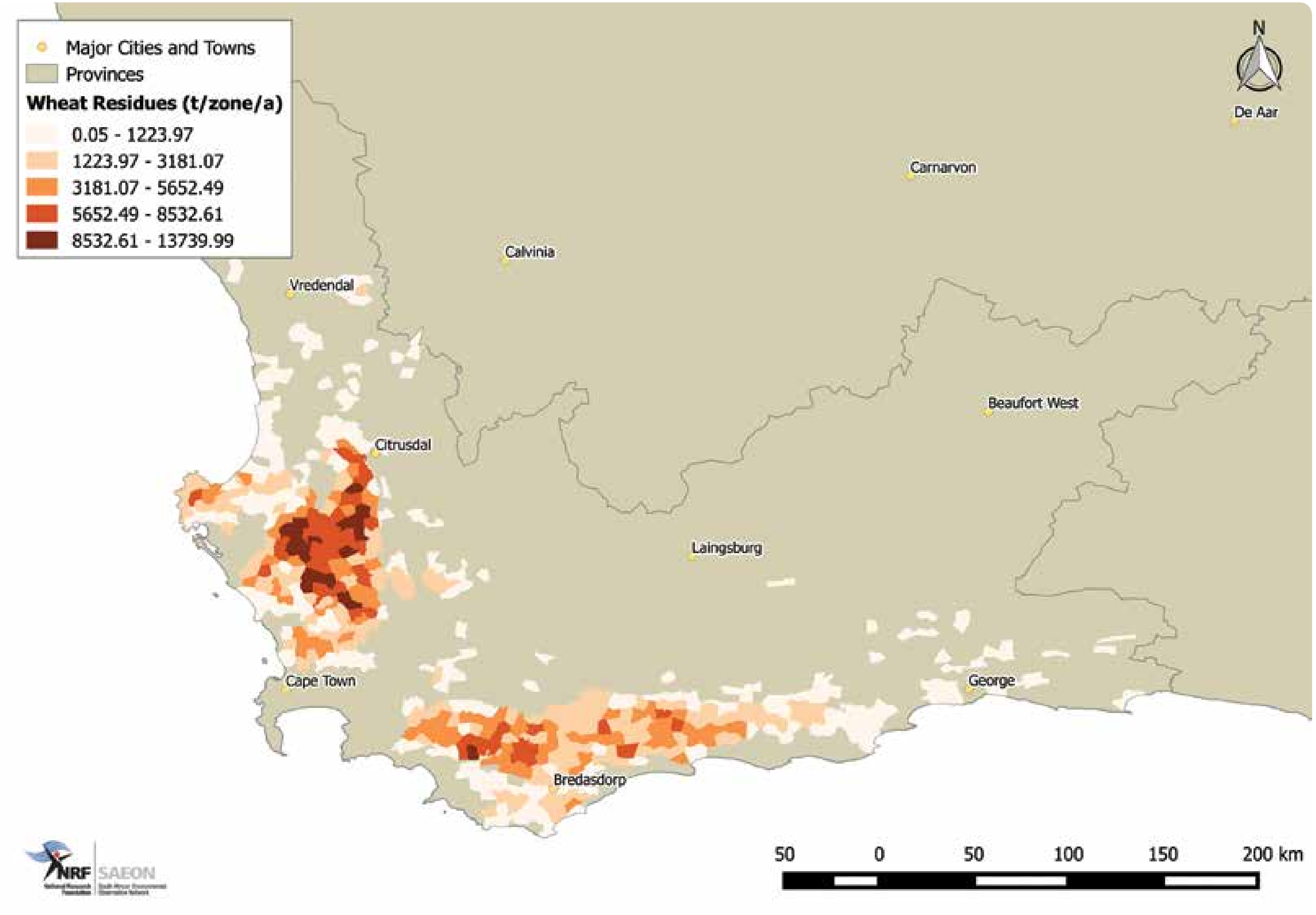
http://bea.dirisa.org/resources/atlas-maps/MRE10.PDF



Based on maize production by province (DAFF 2014b), assigned to maize cropland (DAFF 2014) using Net Primary Productivity (Schulze 2007) with yield-based excess residue potential.

Metadata:
http://bea.dirisa.org/resources/atlas-maps/MRE.PDF



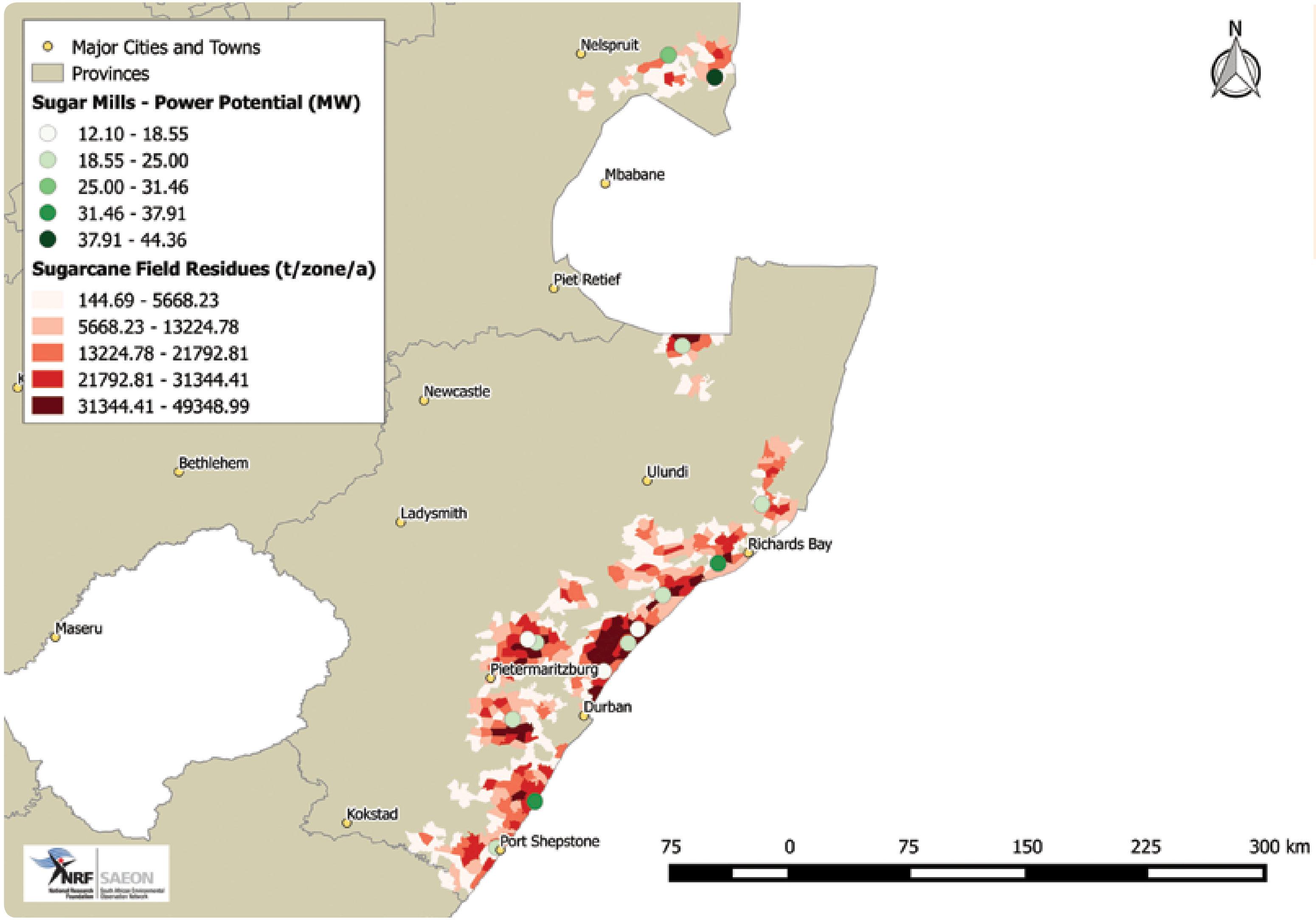


Extent of commercial wheat farming in the Western Cape was obtained from the Department of Agriculture of the Western Cape (2014).

Yield scaled using Schulze (2007), with totals from the Department of Agriculture Annual Statistics (DAFF, 2014b).

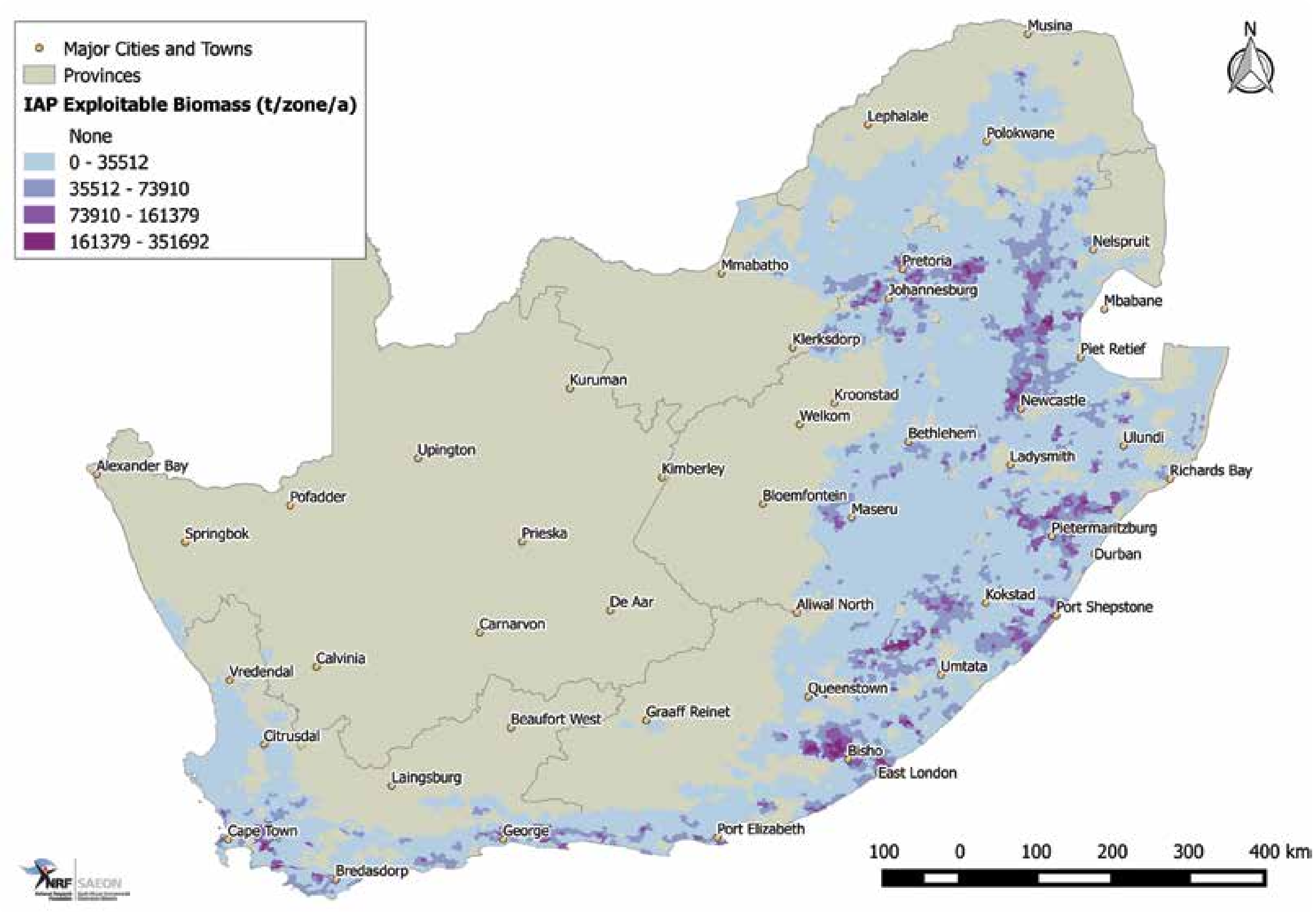
Residue extraction at 15%.

Metadata:
http://bea.dirisa.org/resources/atlas-maps/WRS.PDF



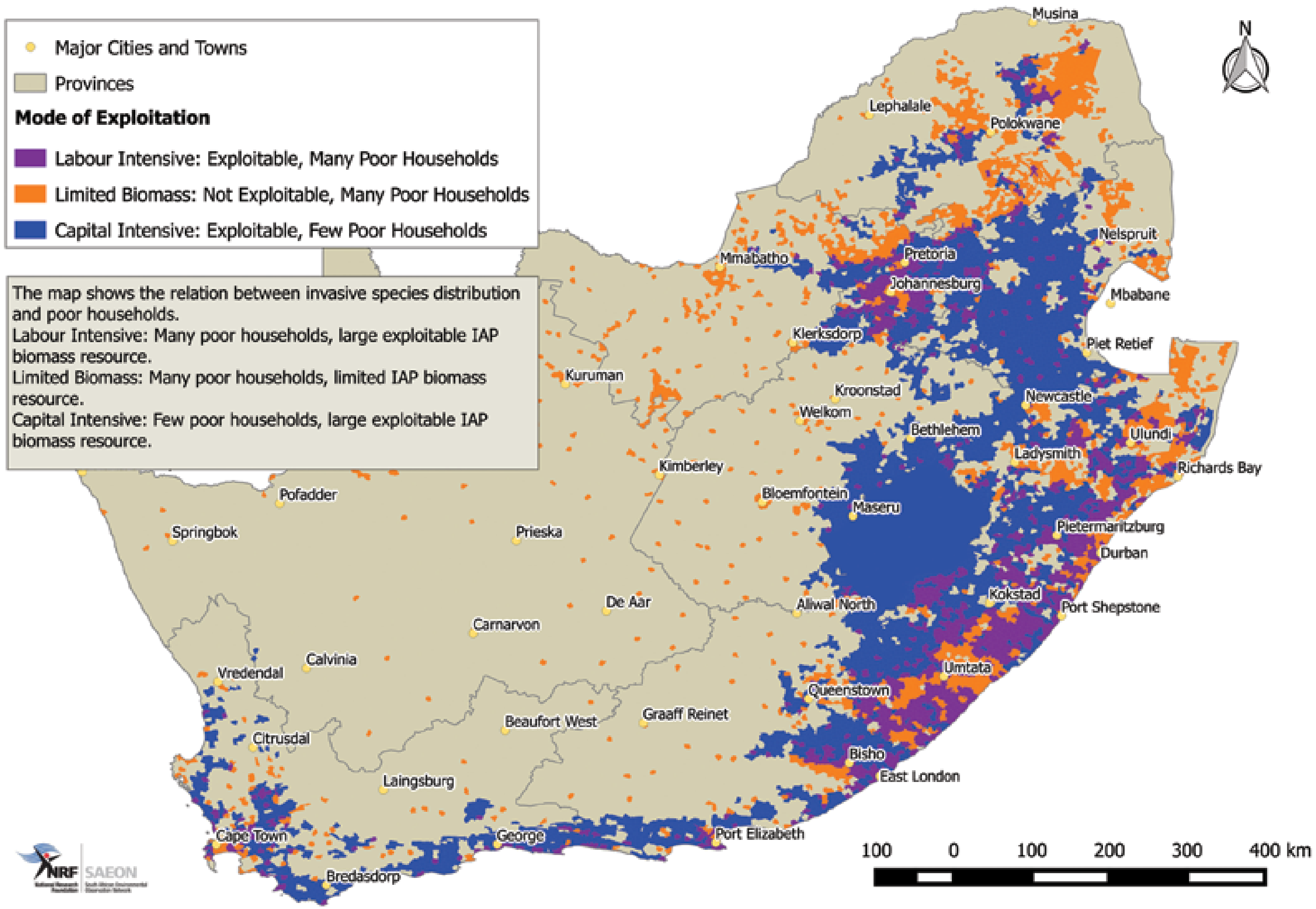
Based on data provided by CRSES (2014) from a study for Eskom.

Metadata:
http://bea.dirisa.org/resources/atlas-maps/BAGASSE.PDF



Based on data provided by the ARC (Kotze *et al*., 2010) and assessed for exploitable potential by Le Maitre *et al.* (2014) on behalf of SAEON.

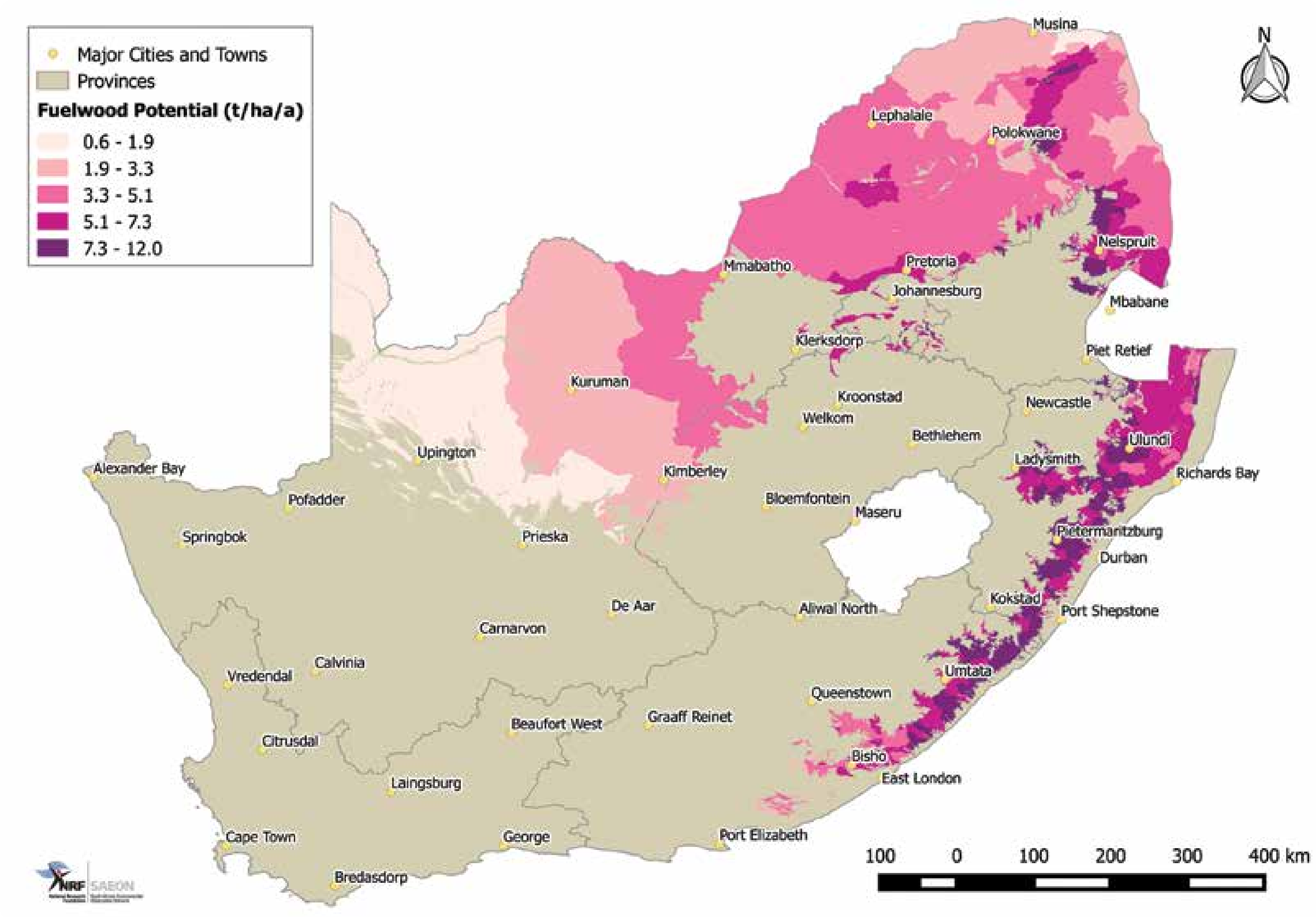
Metadata:
http://bea.dirisa.org/resources/atlas-maps/IAP.PDF



Based on data provided by the ARC (Kotze *et al.*, 2010) and assessed for exploitable potential by Le Maitre *et al.* (2014) on behalf of SAEON, as well as Population Profiles (StatsSA, 2011).

Metadata:

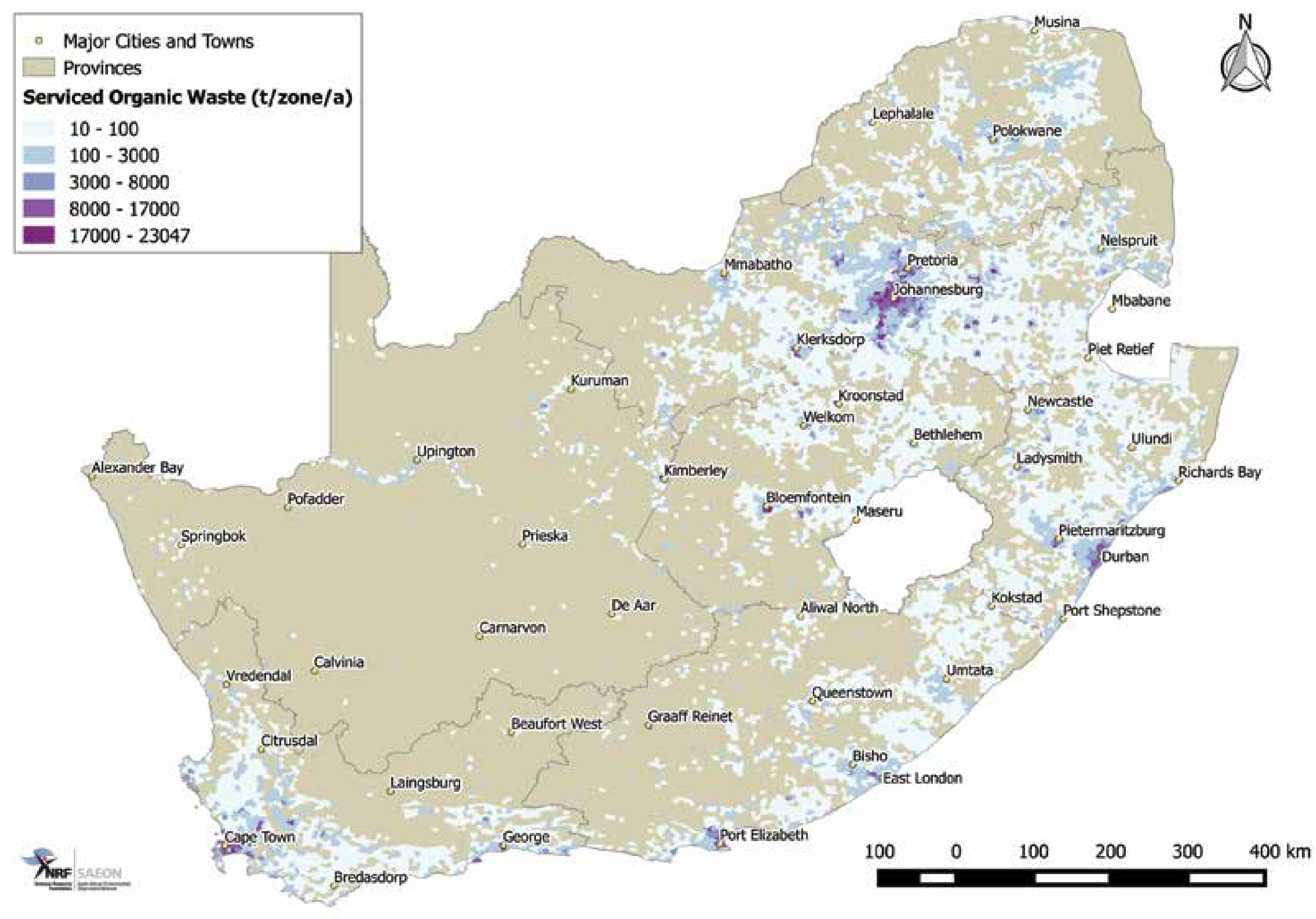
http://bea.dirisa.org/resources/atlas-maps/IAP_EXP.PDF



Based on data provided by SANBI (Vegetation Map, 2004) and Net Primary Productivity (Schulze, 2007).

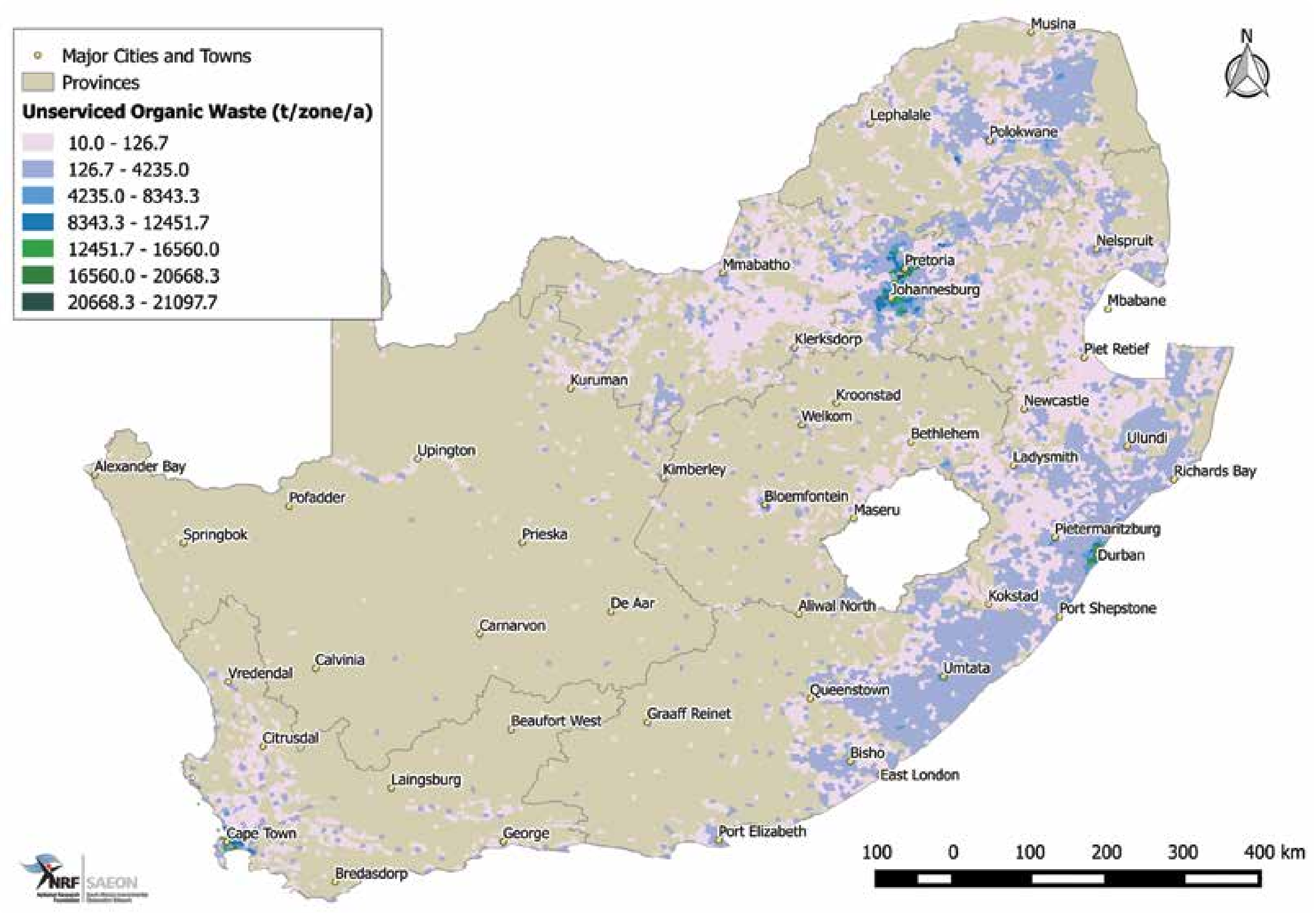
Unconstrained by species selection and lack of access. Savannah biome only.

Metadata:
http://bea.dirisa.org/resources/atlas-maps/FUELWOOD.PDF



Based on data provided by StatsSA (2011) on Population Incomes and Waste Services, combined with modelled production derived from DEA (2012). Adjusted for provincial totals and regional variations reported by DEA (2012).

Metadata:
http://bea.dirisa.org/resources/atlas-maps/ORGANIC_S.PDF



Based on data provided by StatsSA (2011) on Population Incomes and Waste Services, combined with modelled production derived from DEA (2012). Adjusted for provincial totals and regional variations reported by DEA (2012).

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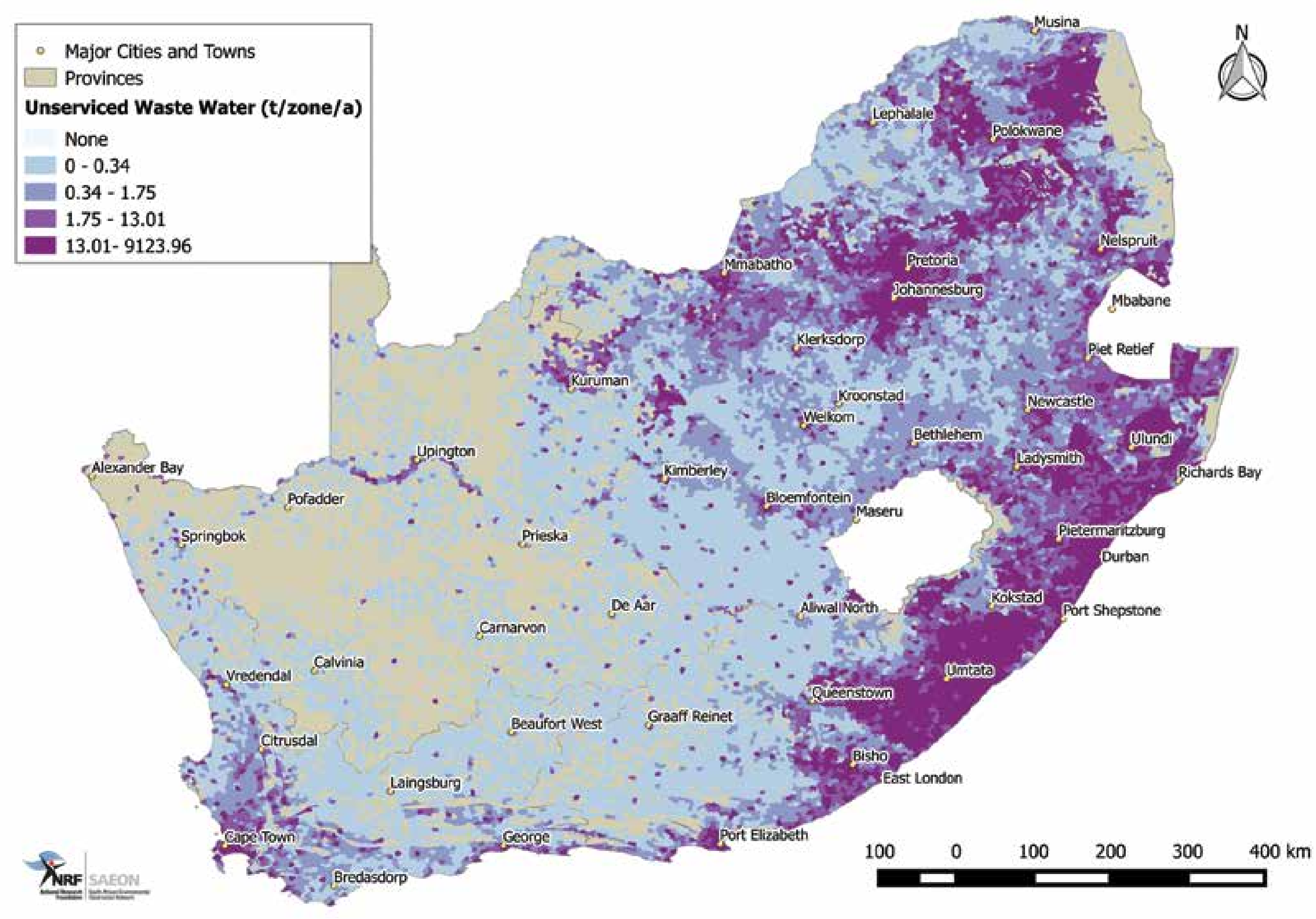

Based on data provided by StatsSA (2011) on Population Incomes and Waste Services, combined with modelled production derived from DEA (2012). Adjusted for provincial totals.

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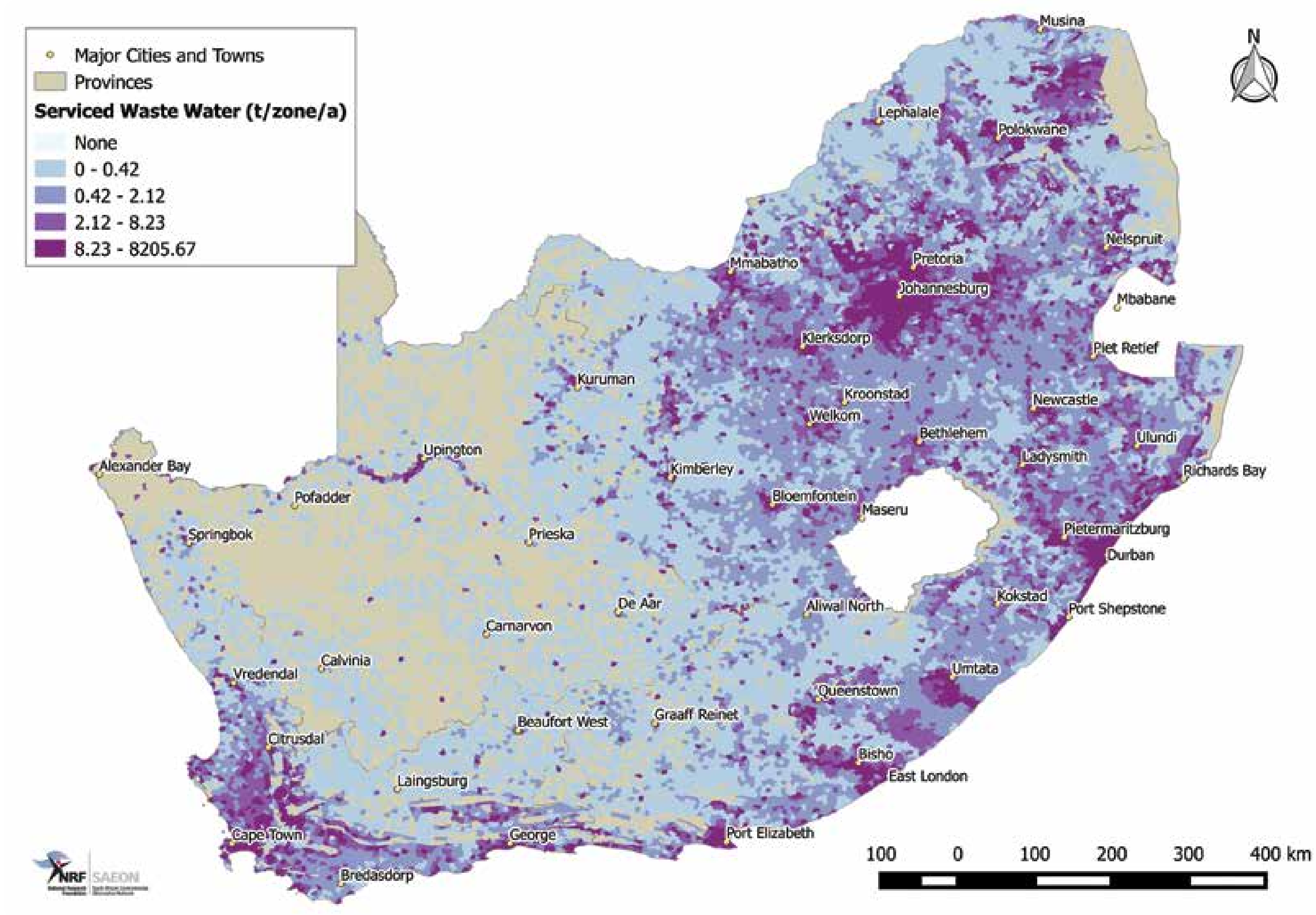
http://bea.dirisa.org/resources/atlas-maps/WASTEWATER_U.PDF



Based on data provided by StatsSA (2011) on Population Incomes and Waste Services, combined with modelled production derived from DEA (2012). Adjusted for provincial totals.

Metadata:

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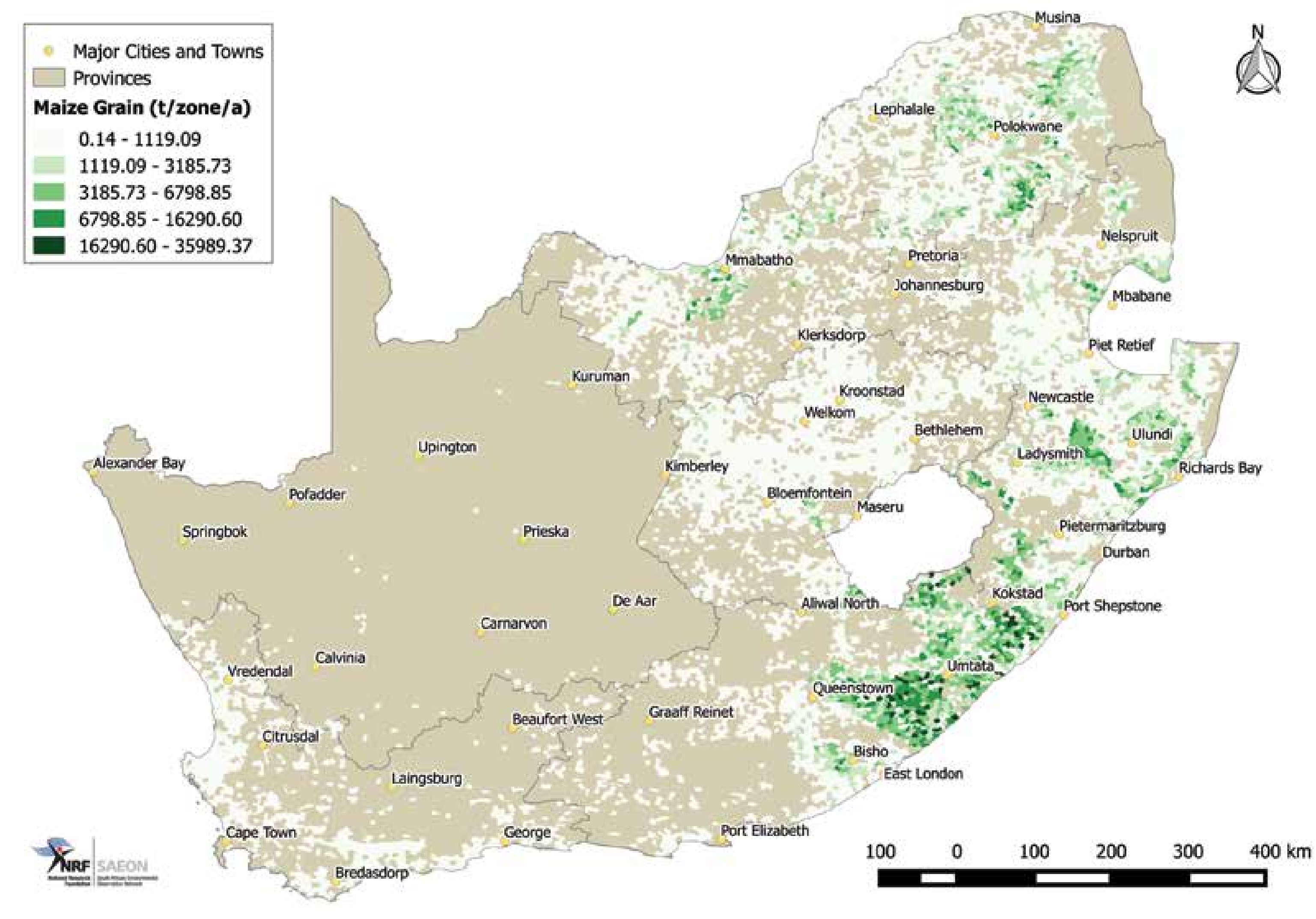
Theme: Biomass Availability – Maize production on subsistence and degraded farmland



Derived from data published by Schulze *et al.* (Maize Yields, National Agrohydrological Atlas, 2007) and DAFF (Cropland Distribution, 2014, and Abstract of National Agricultural Statistics, 2014).

Metadata:
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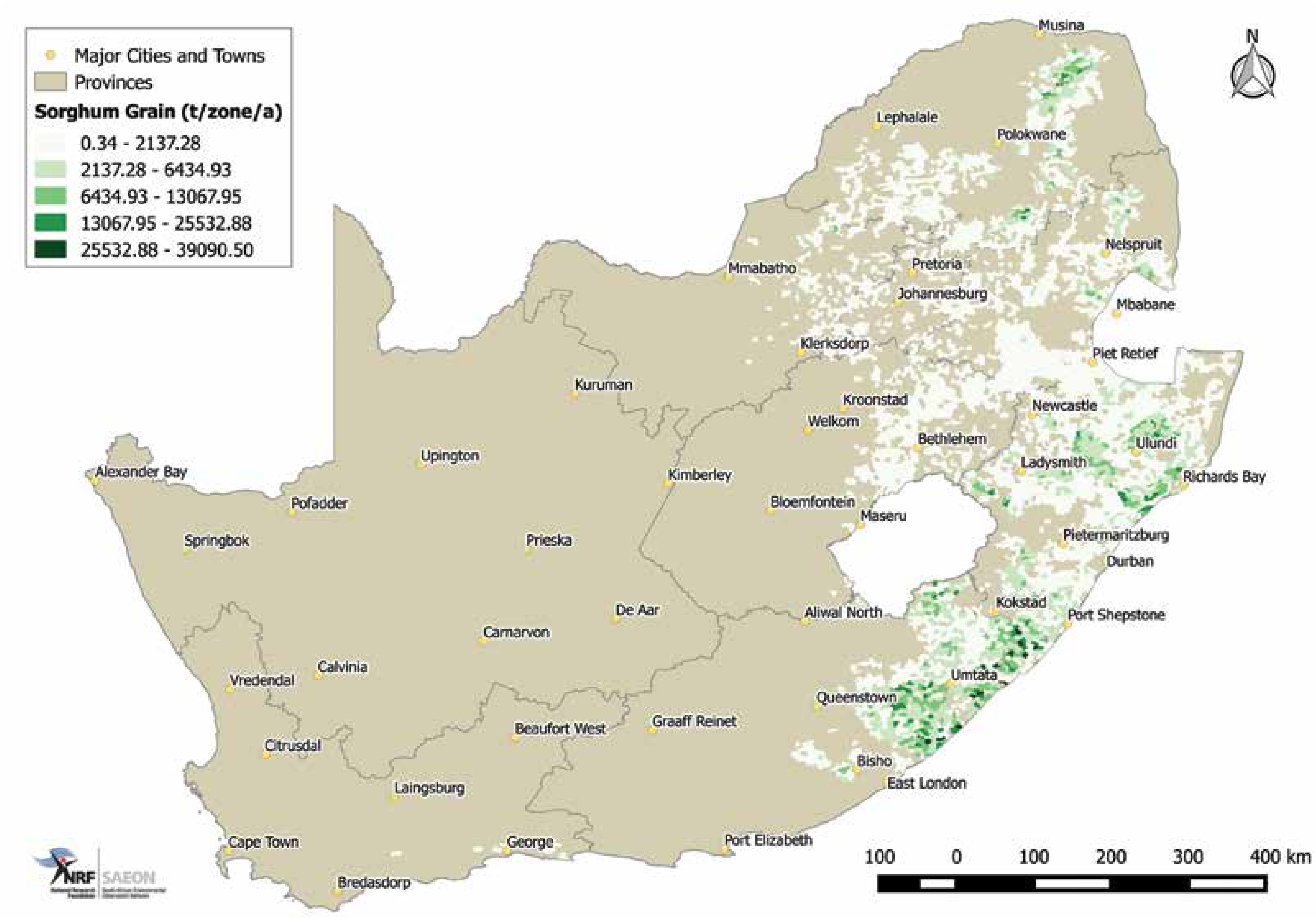
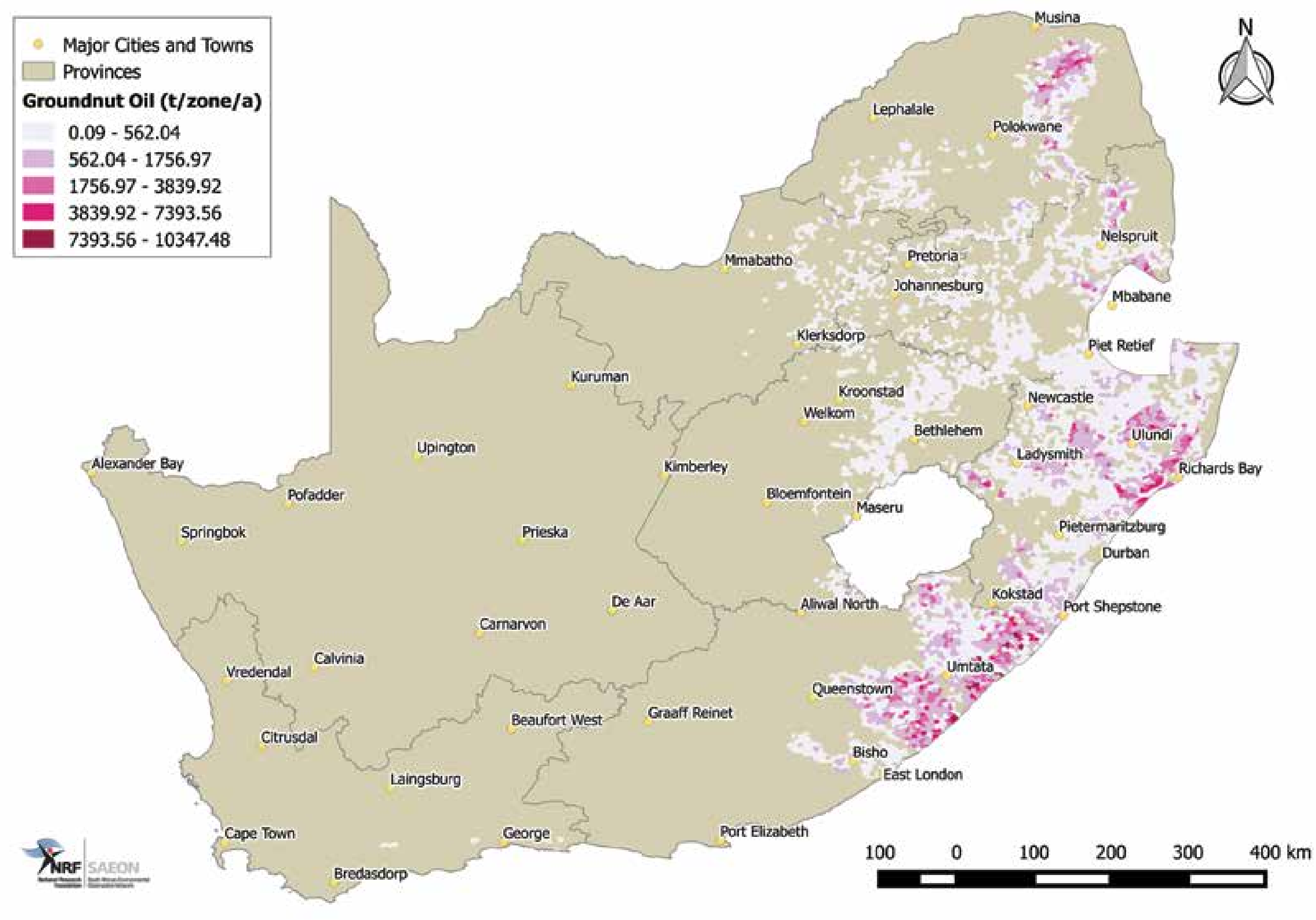


Derived from data published by Schulze *et al.* (Sorghum Yields, National Agrohydrological Atlas, 2007) and DAFF (Cropland Distribution, 2014, and Abstract of National Agricultural Statistics, 2014).

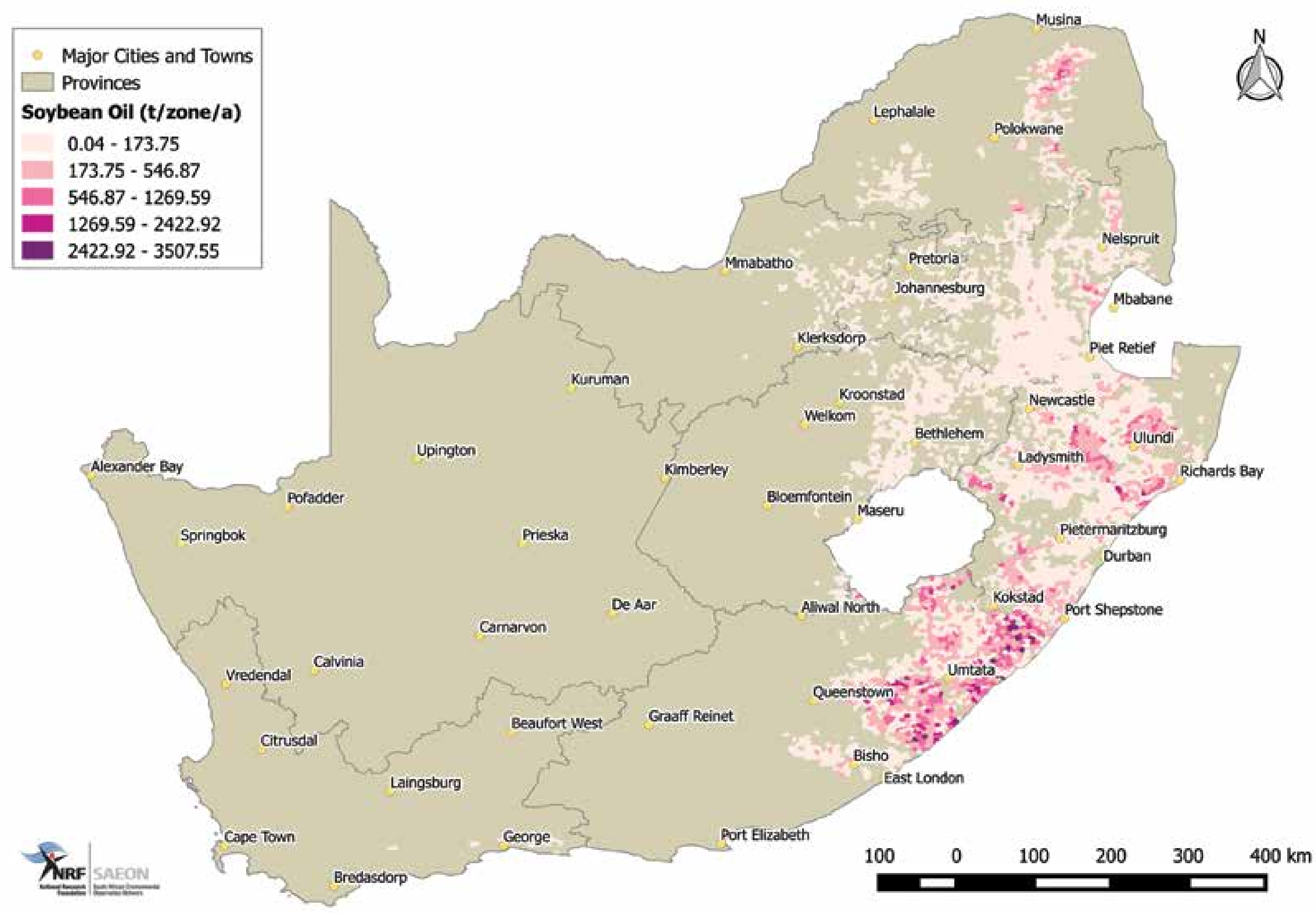
Metadata:

http://bea.dirisa.org/resources/atlas-maps/SOR.PDF



Derived from data published by Schulze *et al.* (Groundnut Yields, National Agrohydrological Atlas, 2007) and DAFF (Cropland Distribution, 2014, and Abstract of National Agricultural Statistics, 2014).

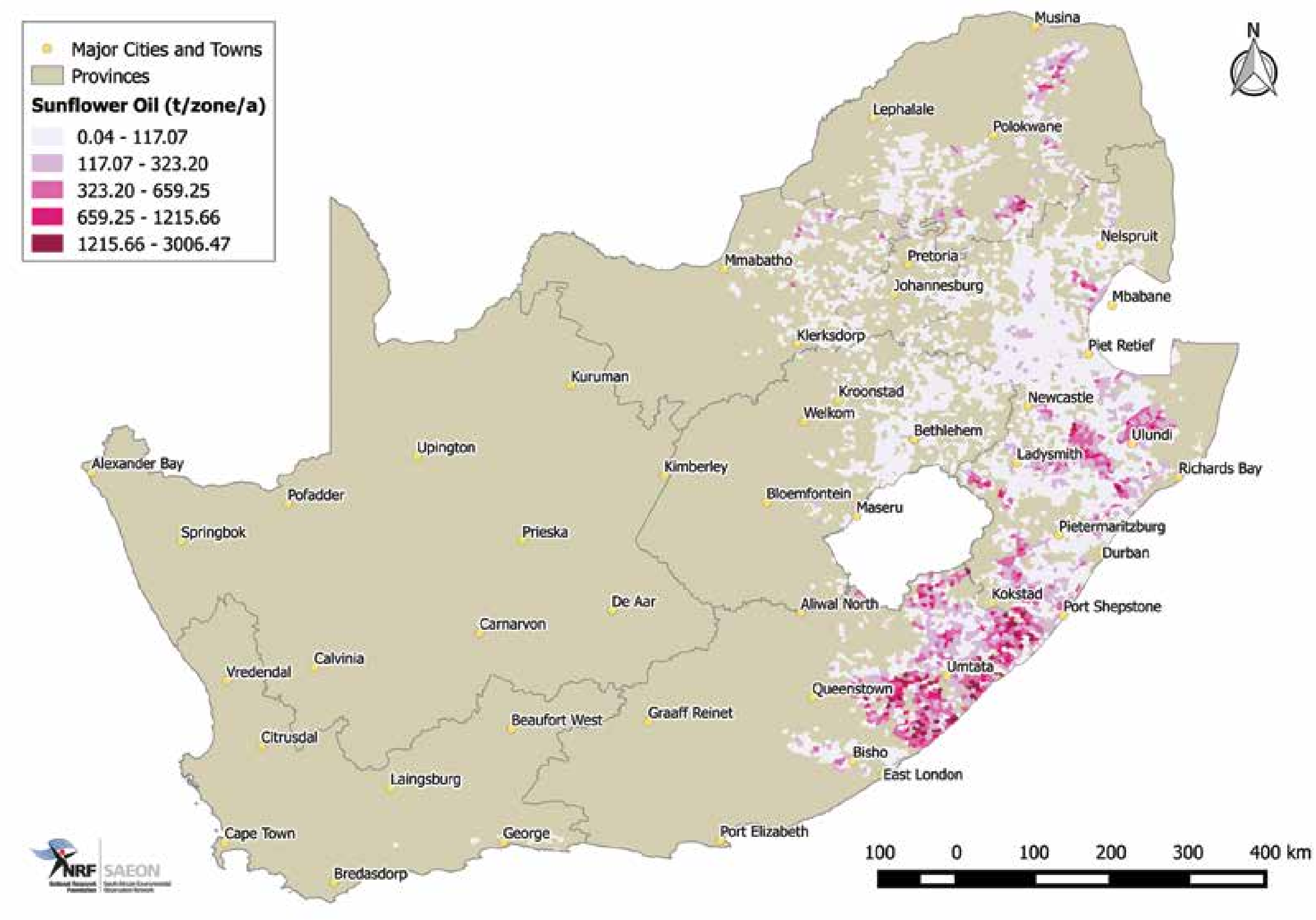
Metadata:
http://bea.dirisa.org/resources/atlas-maps/NUT.PDF



Derived from data published by Schulze *et al.* (Soybean Yields, National Agrohydrological Atlas, 2007) and DAFF (Cropland Distribution, 2014, and Abstract of National Agricultural Statistics, 2014).

Metadata:

http://bea.dirisa.org/resources/atlas-maps/SOY.PDF



Derived from data published by Schulze *et al.* (Sunflower Yields, National Agrohydrological Atlas, 2007) and DAFF (Cropland Distribution, 2014, and Abstract of National Agricultural Statistics, 2014).

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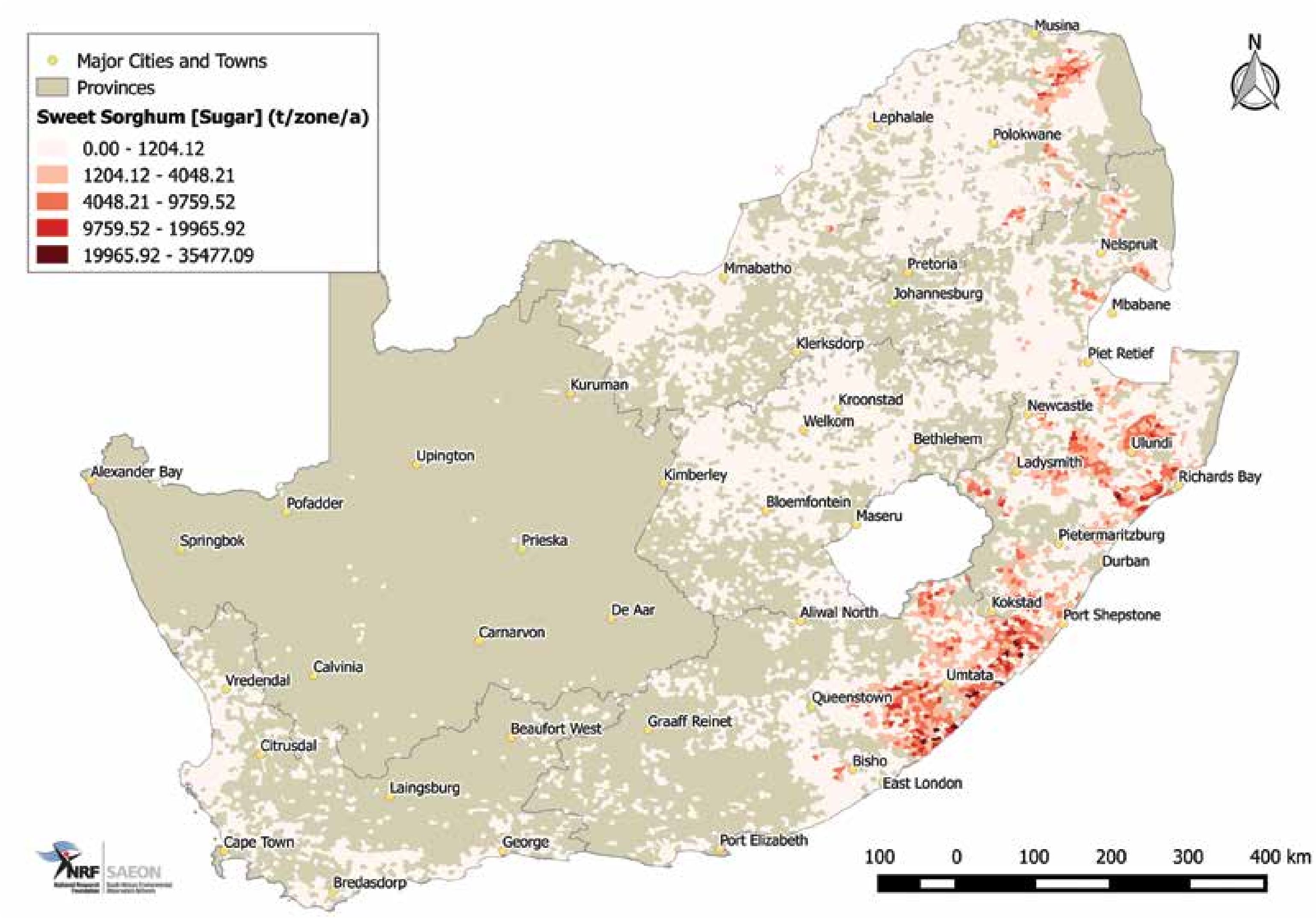
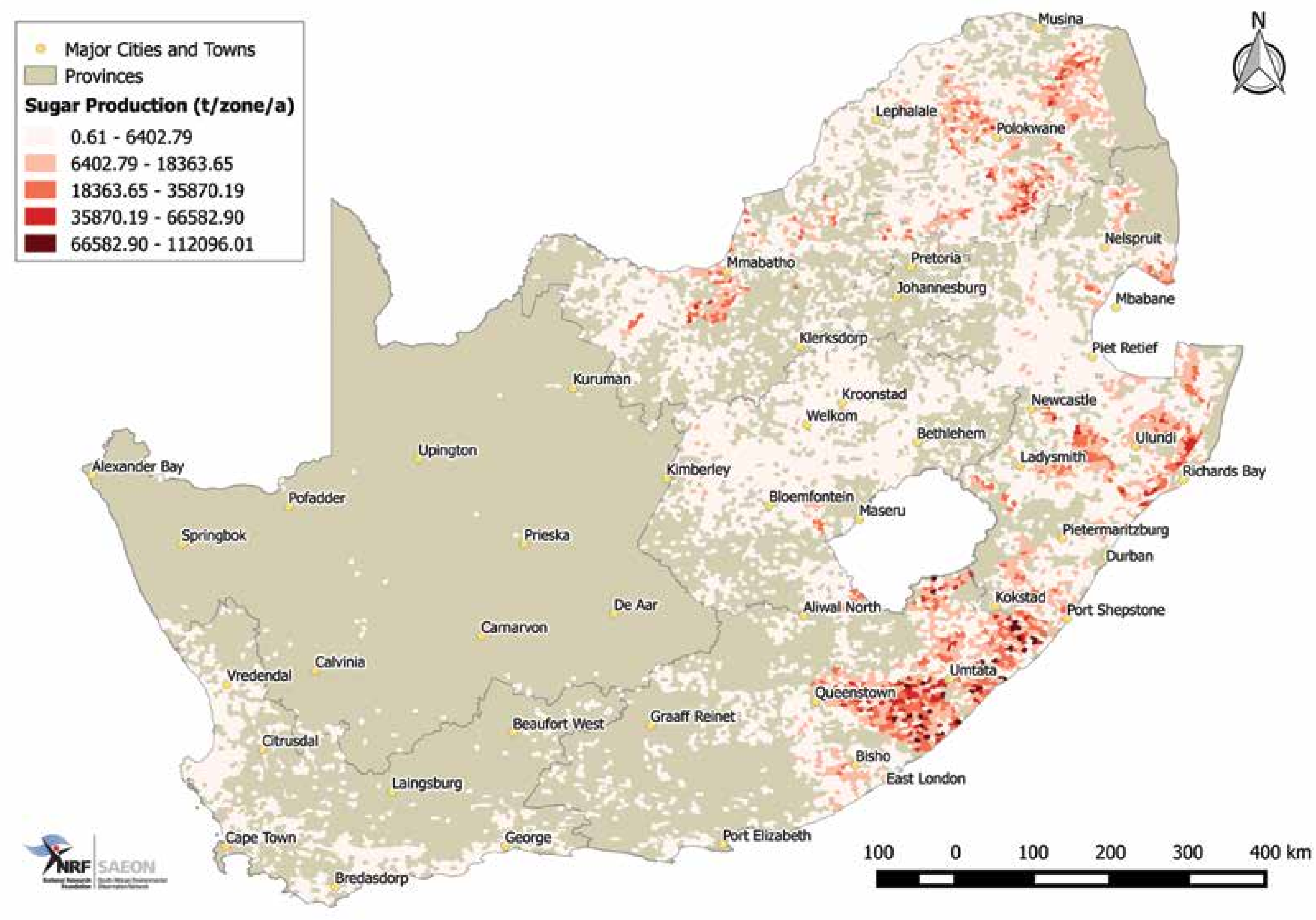
http://bea.dirisa.org/resources/atlas-maps/SUN.PDF



Derived from data published by Schulze *et al.* (Sorghum Yields, National Agrohydrological Atlas, 2007) and DAFF (Cropland Distribution, 2014, and Abstract of National Agricultural Statistics, 2014). Sorghum yields adjusted for sweet sorghum yields using a review of published data (Hugo, 2014).

Metadata:

http://bea.dirisa.org/resources/atlas-maps/SSO.PDF



Derived from data published by Schulze *et al.* (Sugar Cane Yields, National Agrohydrological Atlas, 2007) and DAFF (Cropland Distribution, 2014, and Abstract of National Agricultural Statistics, 2014).

Metadata:
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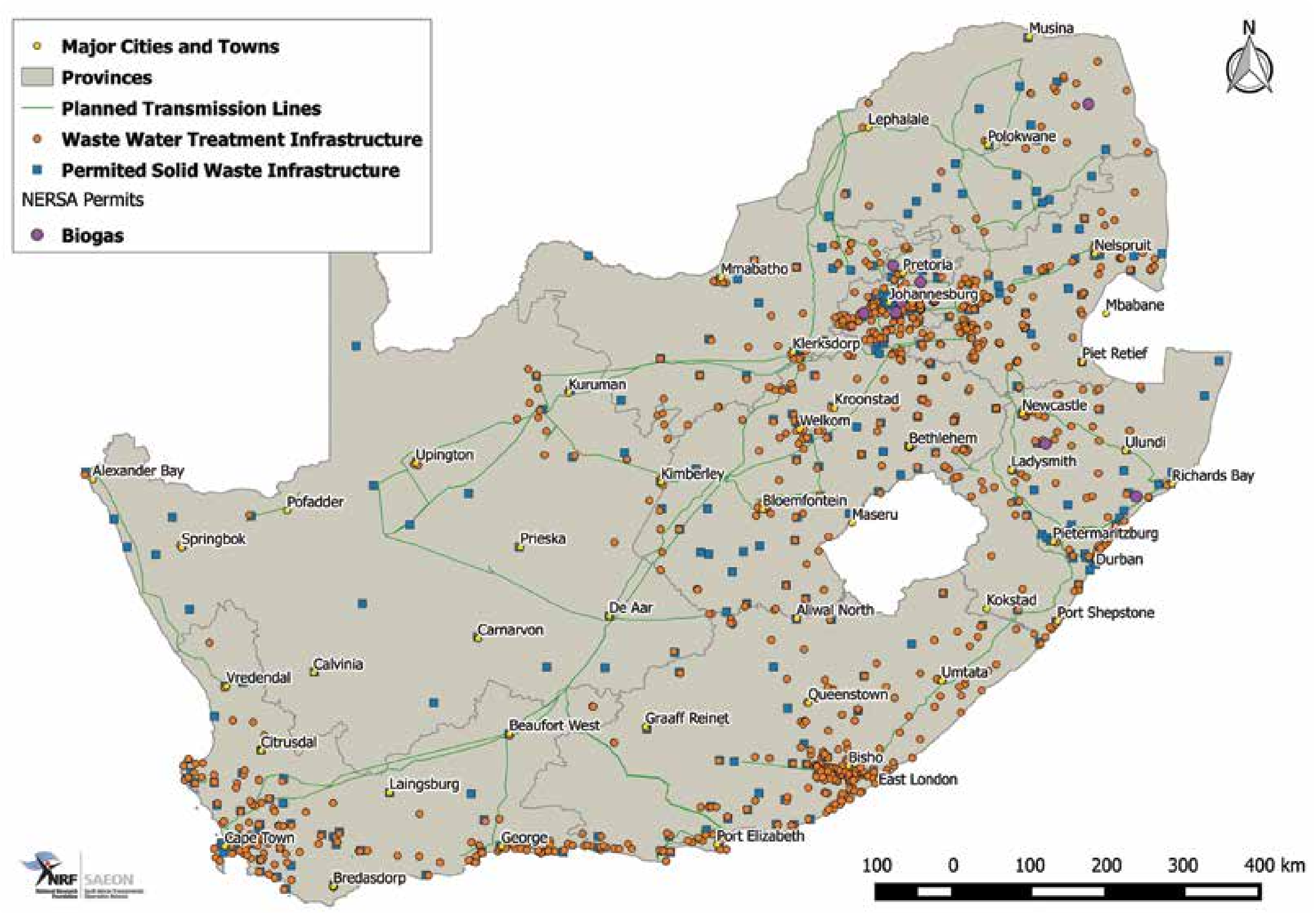

Derived from data published by DEA (2014) and NERSA (2014).

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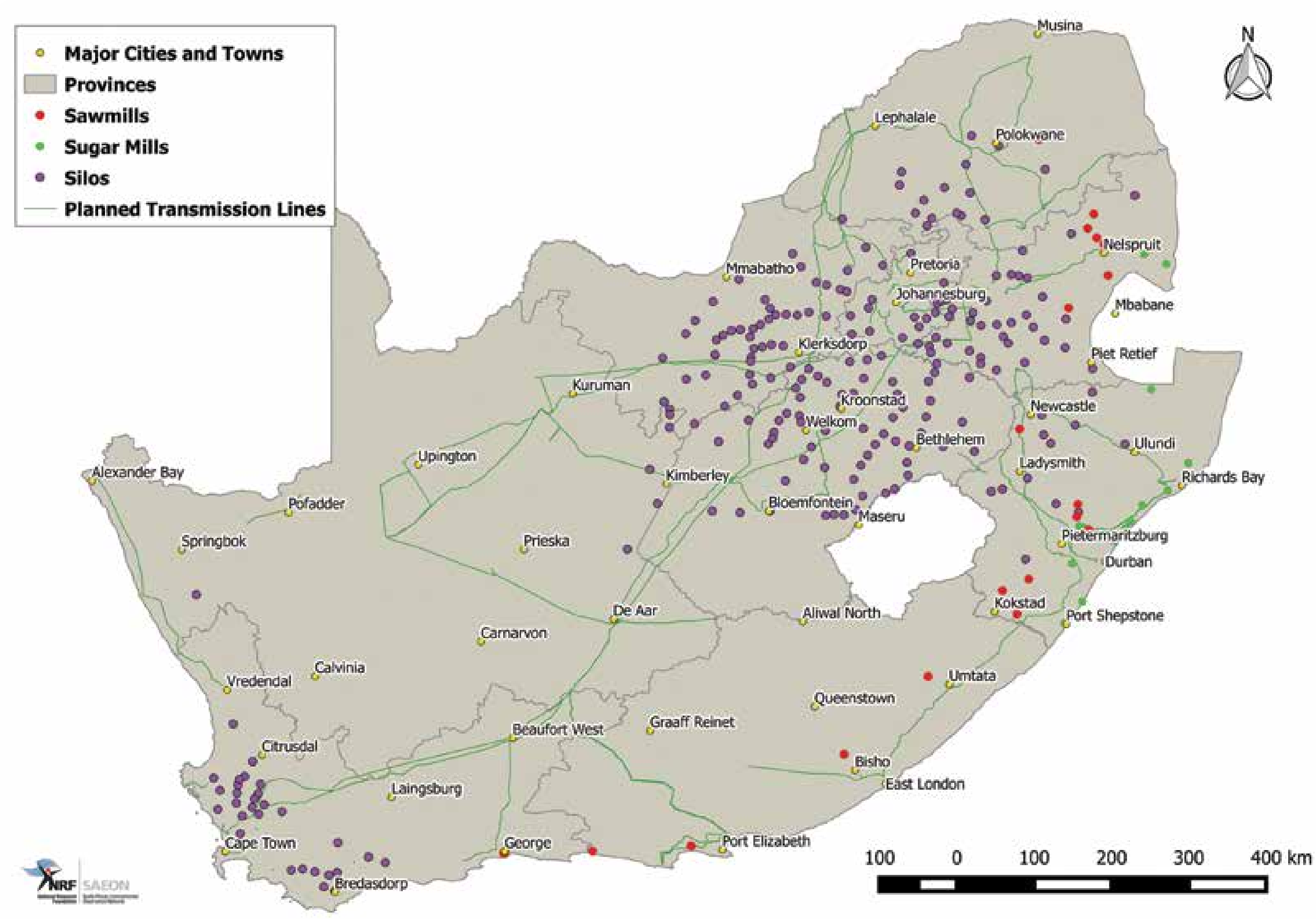
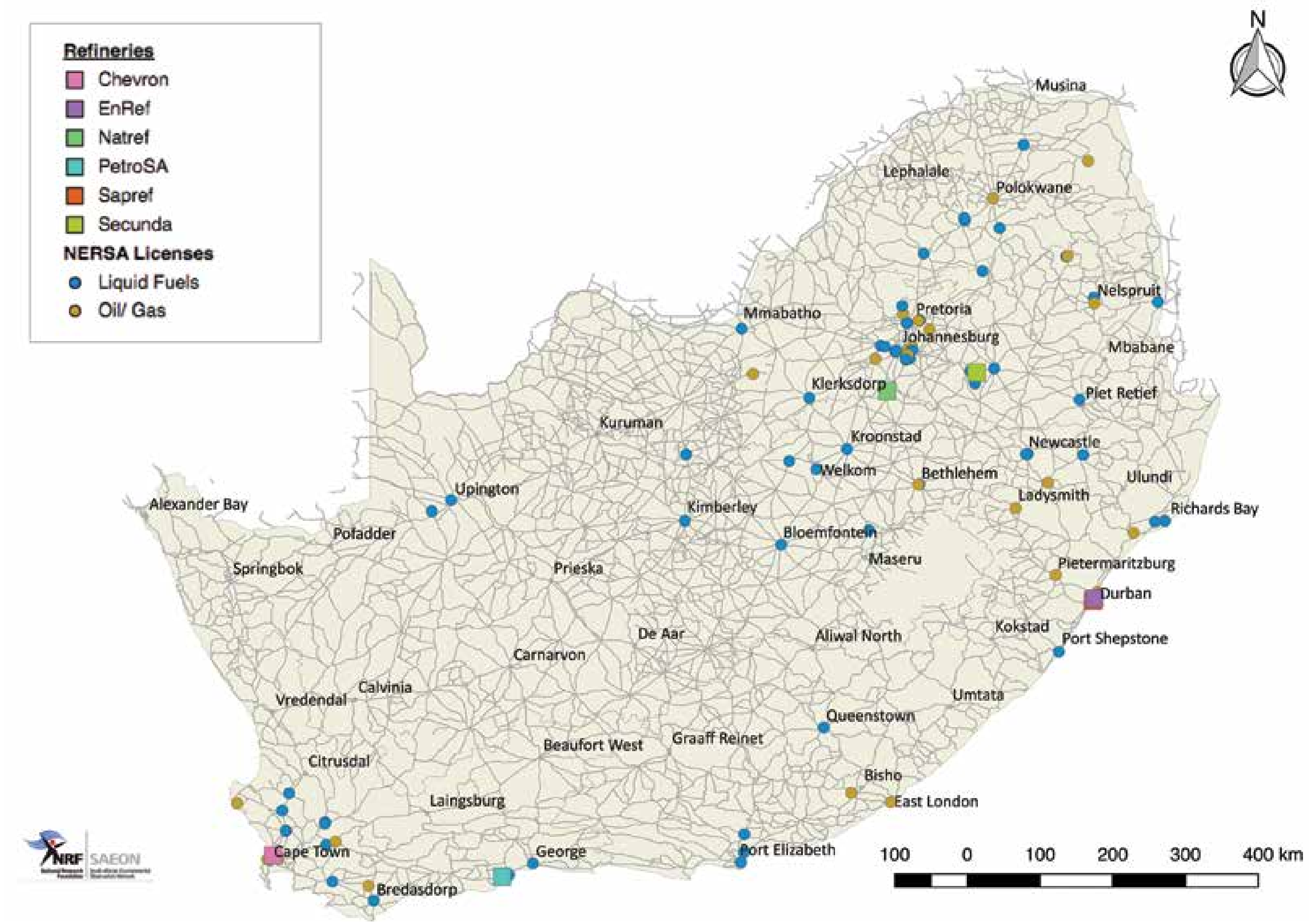
http://bea.dirisa.org/resources/atlas-maps/INF_WASTE.PDF



Derived from data published by the JSE (2014), and studies performed on behalf of Eskom by CRSES (2014).

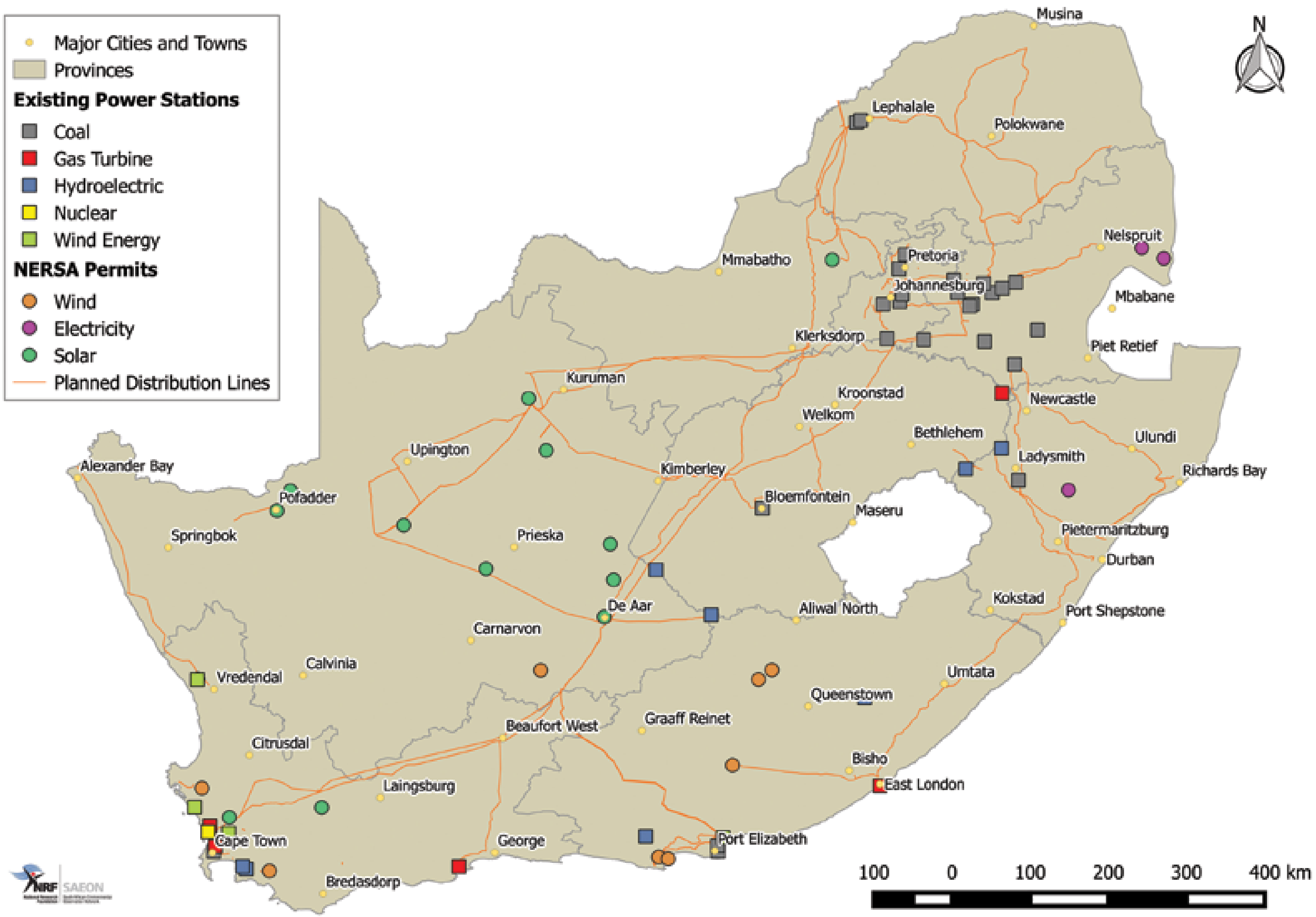
Metadata:

http://bea.dirisa.org/resources/atlas-maps/INF_AGRI.PDF



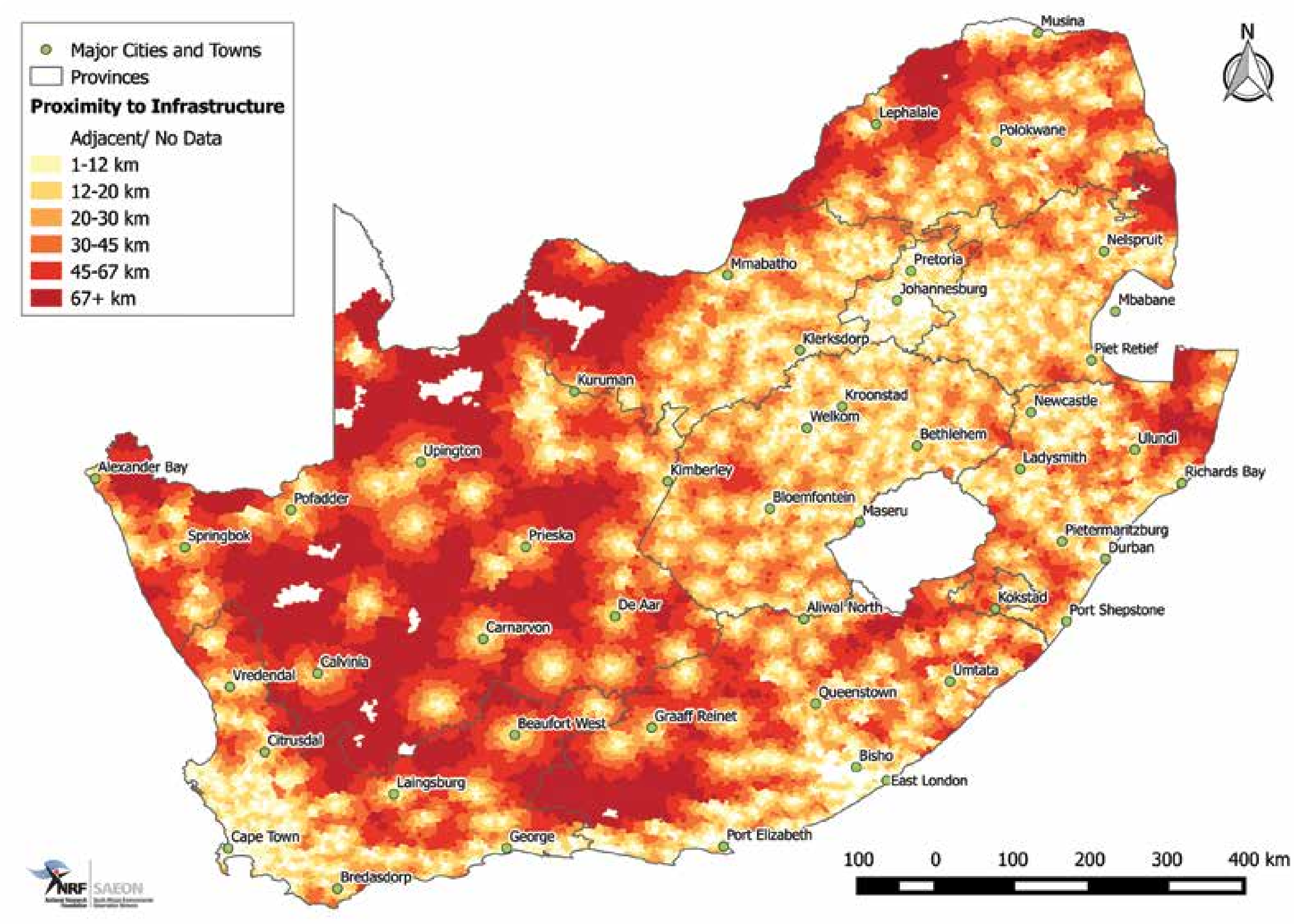
Derived from data published by NERSA (2014).

Metadata:
http://bea.dirisa.org/resources/atlas-maps/INF_FUEL.PDF



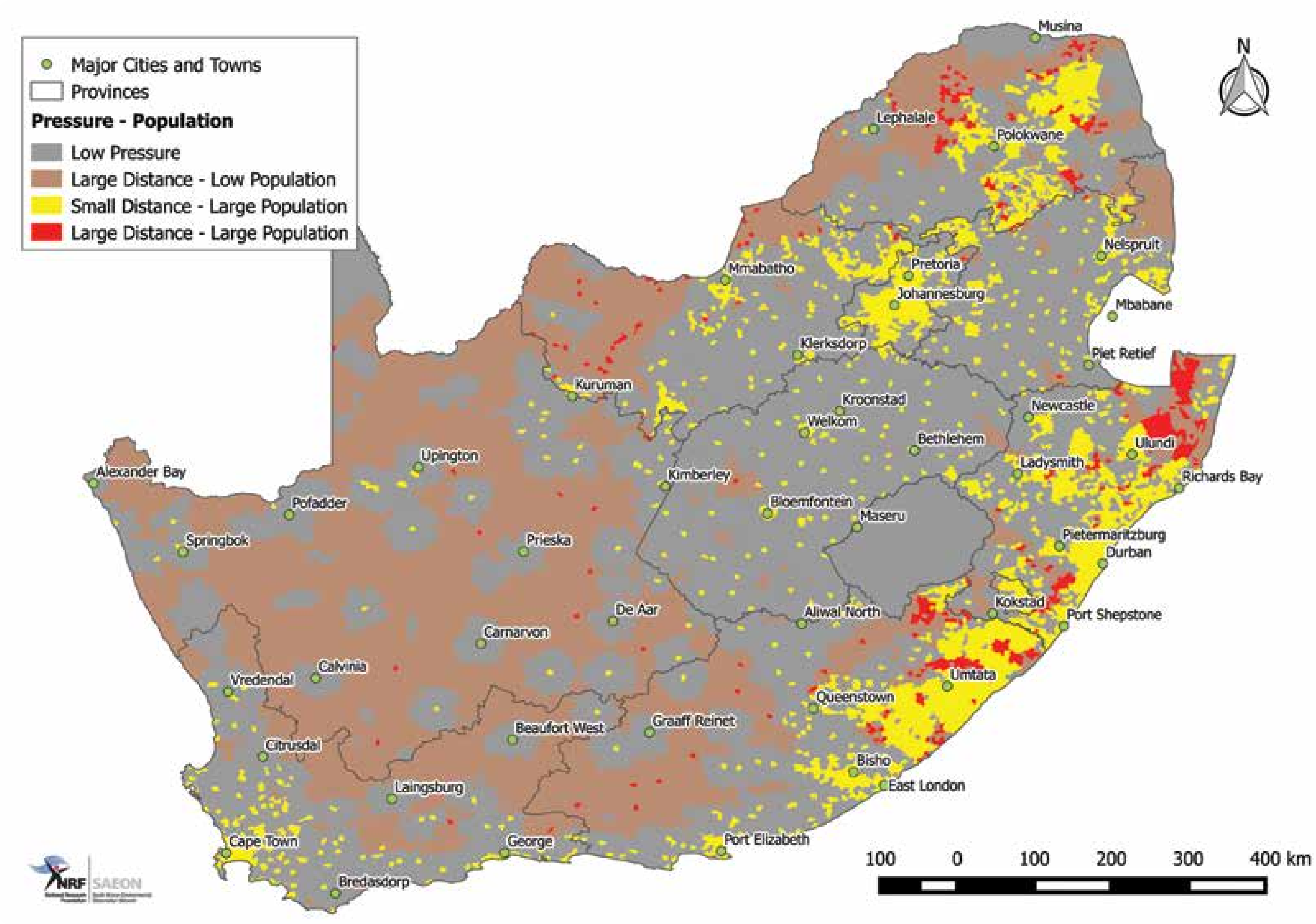
Derived from data published by NERSA (2014) and Eskom (2014).

Metadata:
http://bea.dirisa.org/resources/atlas-maps/INF_ELEC.PDF



Derived from data published by the CSIR (2009), CRSES (2014), Eskom (2014), the JSE (2014) and NERSA (2014).

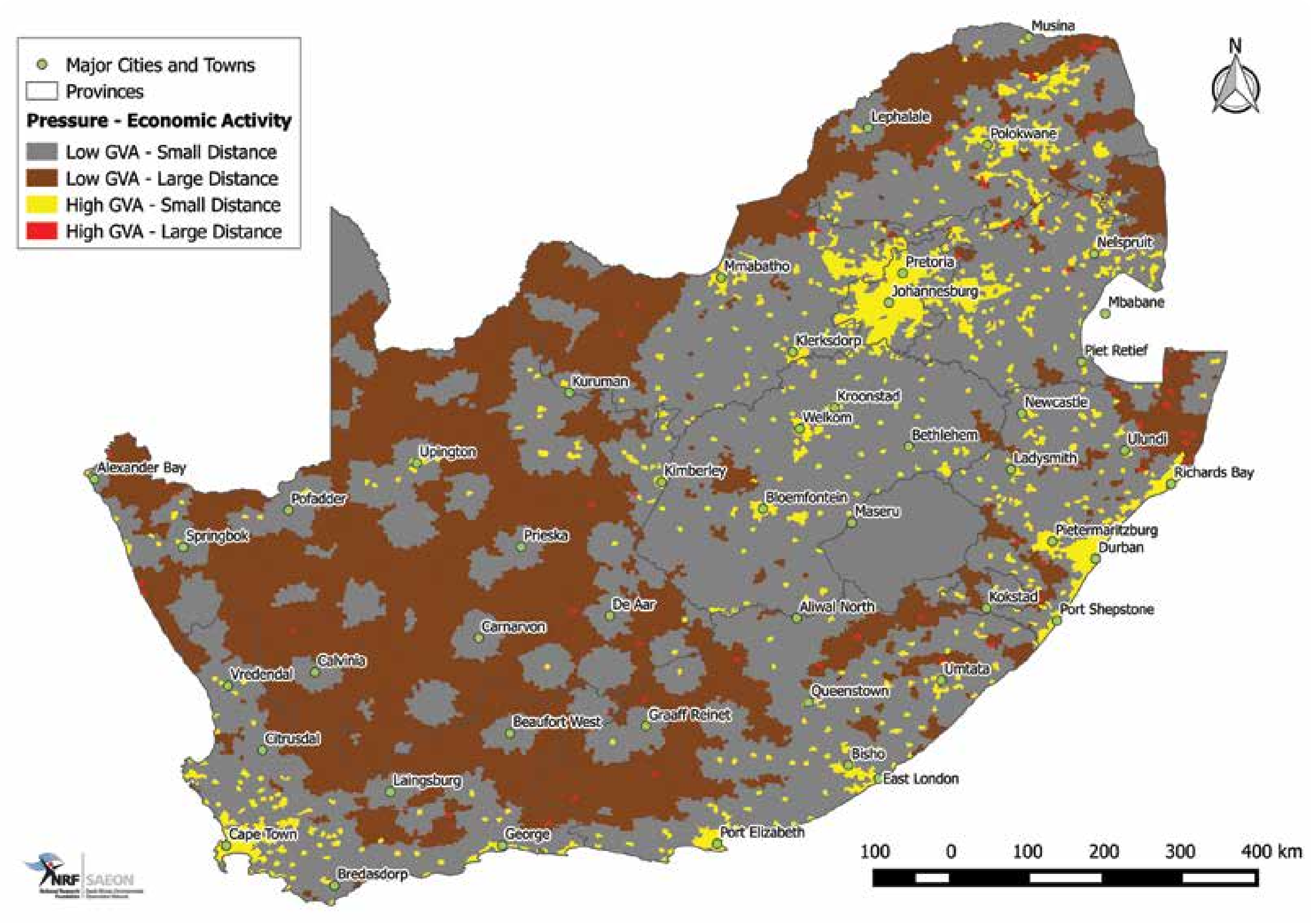
Metadata:
http://bea.dirisa.org/resources/atlas-maps/INF_PROX.PDF



Derived from data published by the CSIR (2009), CRSES (2014), Eskom (2014), the JSE (2014) and NERSA (2014).

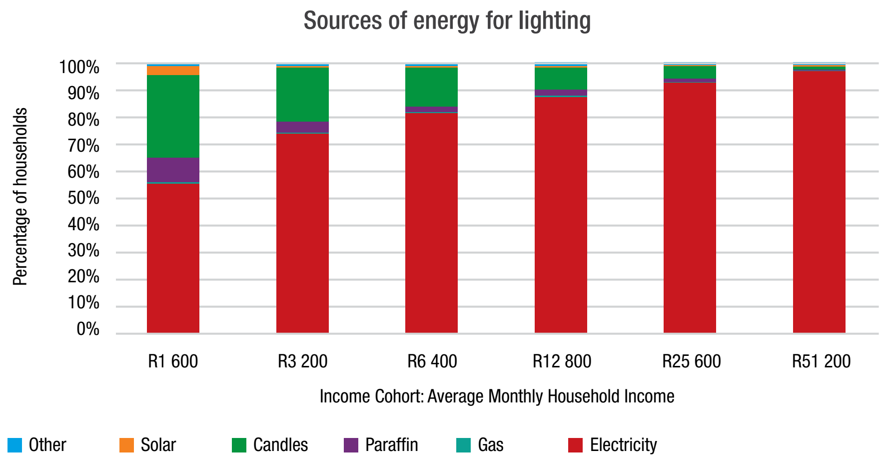
Metadata:

http://bea.dirisa.org/resources/atlas-maps/INF_POP.PDF

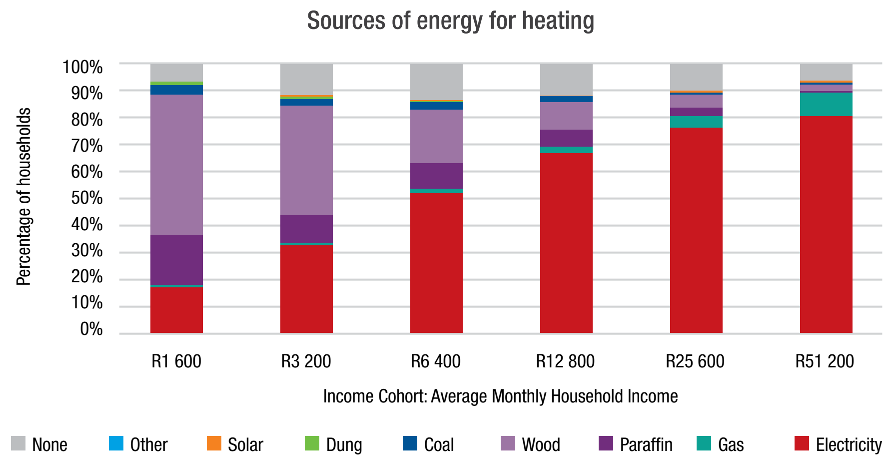


Derived from data published by the CSIR (2009), CRSES (2014), Eskom (2014), the JSE (2014) and NERSA (2014).

Metadata:
http://bea.dirisa.org/resources/atlas-maps/INF_GVA.PDF



Derived from data published by Statistics South Africa (2011)



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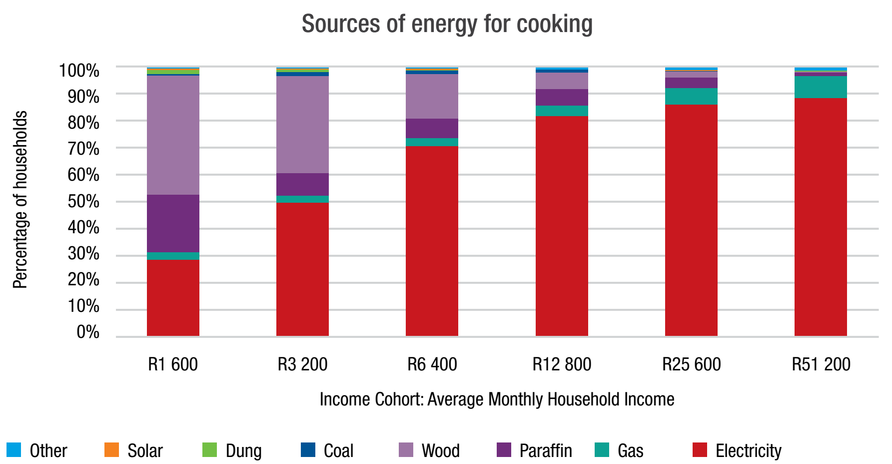

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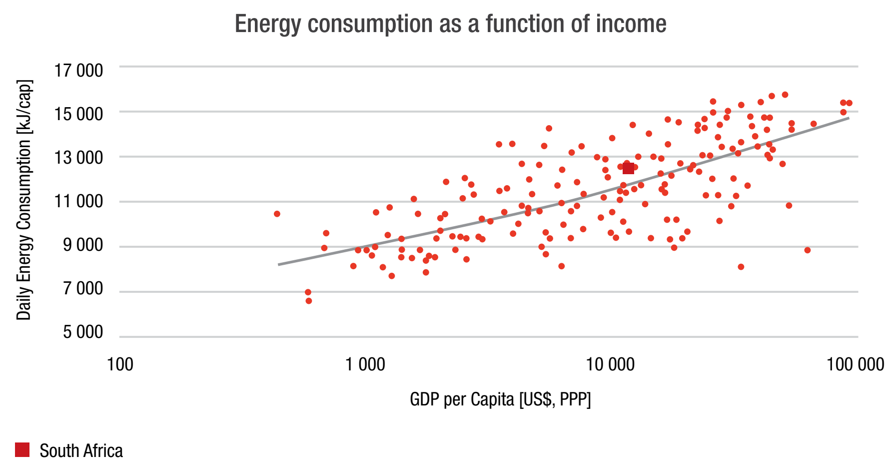
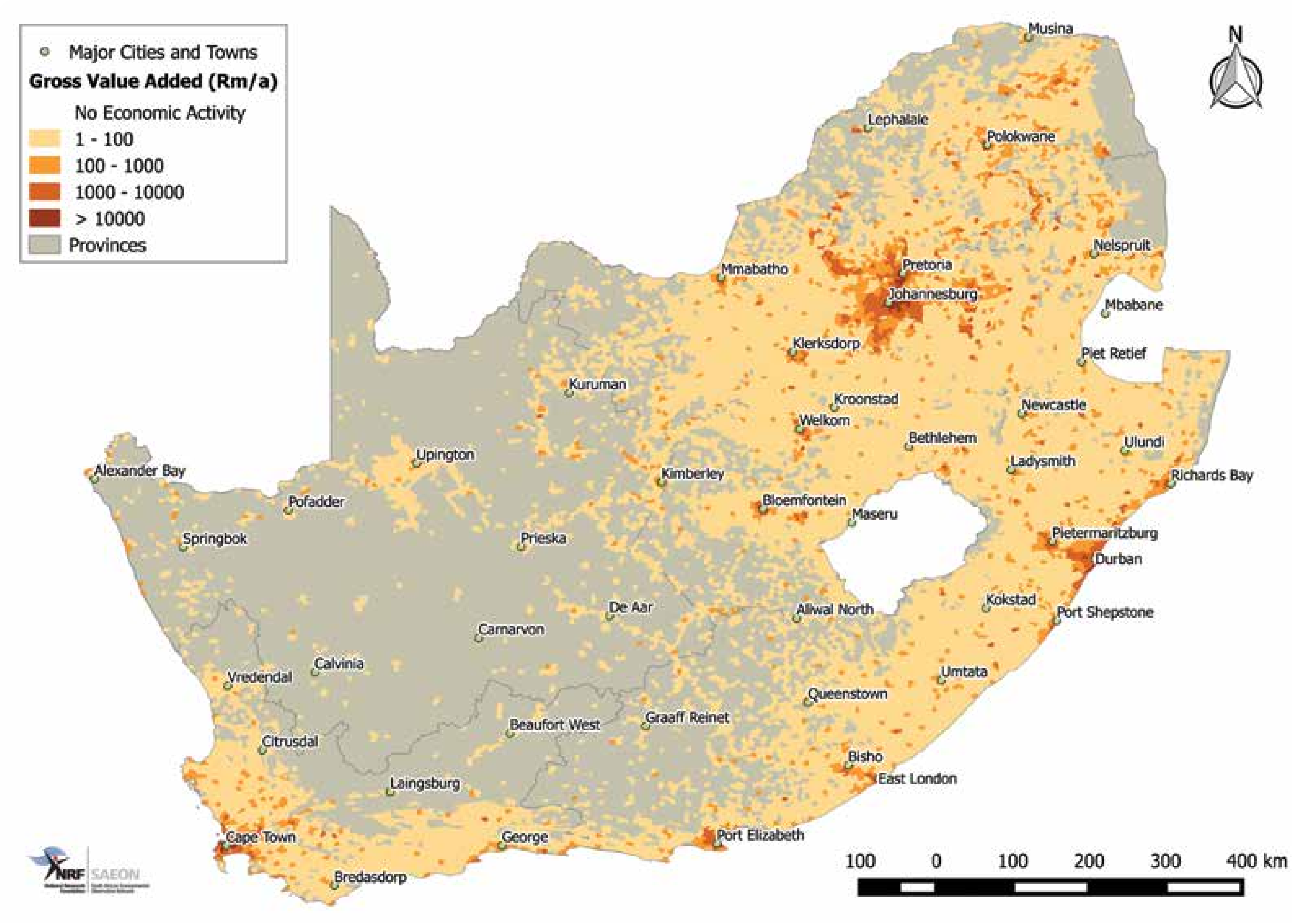


Derived from data published by the World Bank (2011)

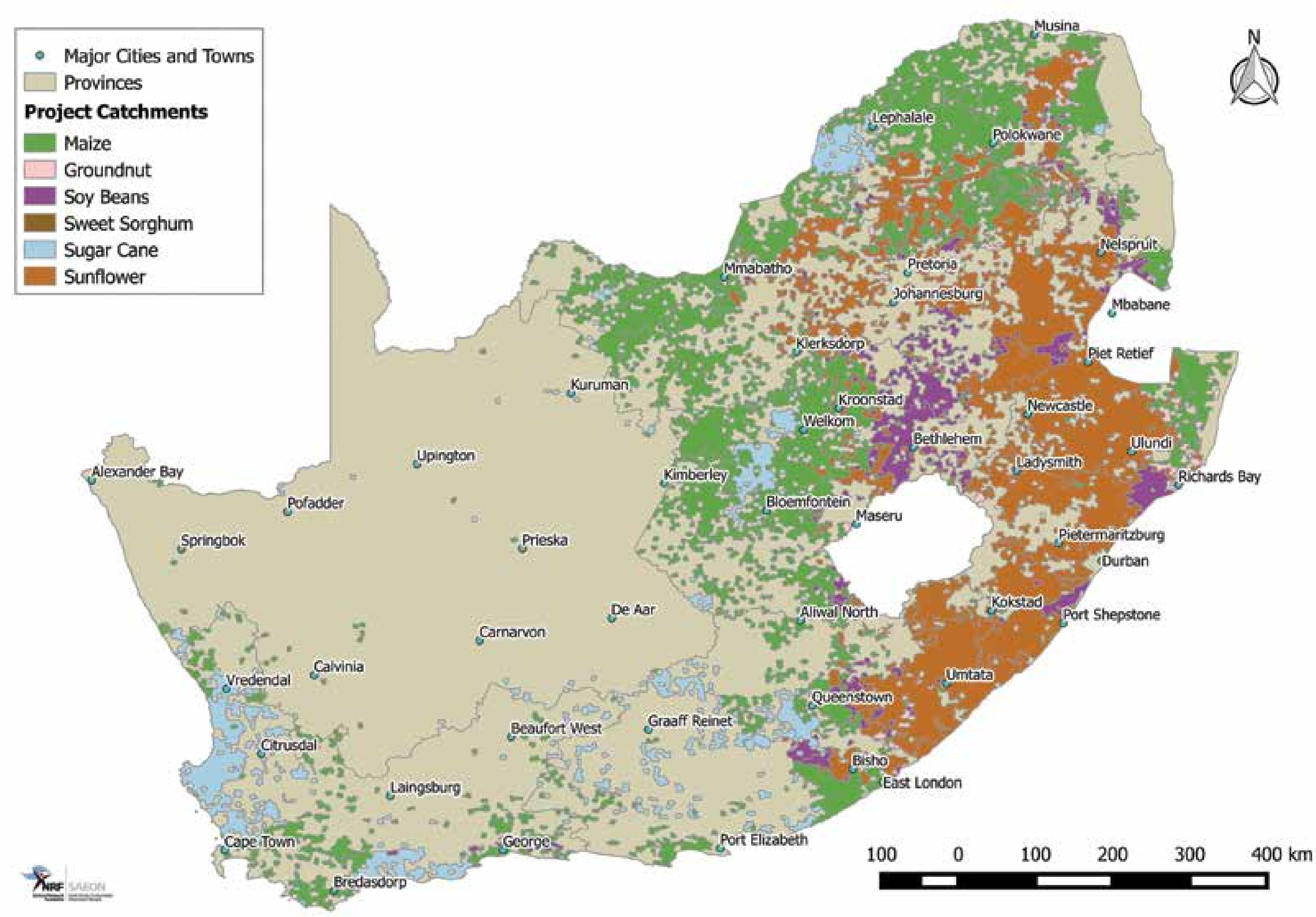
Theme: Demand – Economic activity in South Africa



Derived from data published by the CSIR (2009).

Metadata:
http://bea.dirisa.org/resources/atlas-maps/DMD_GVA.PDF

Theme: Feasibility – Most feasible cultivated crop (no subsidy)

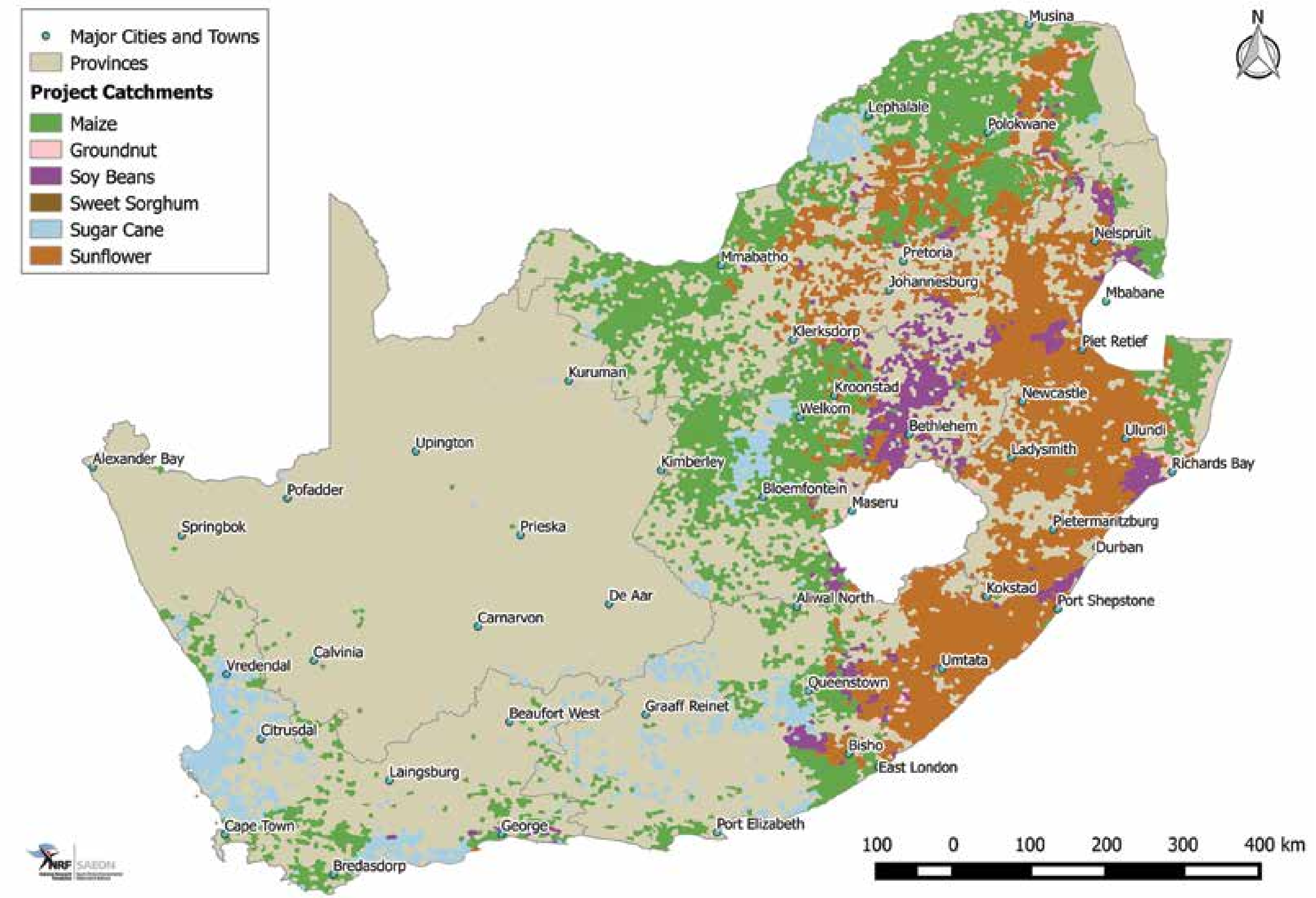


Derived from data published by Schulze *et al.* (2007), and process technology literature review performed by Stellenbosch University on behalf of SAEON (2014).

Map shows the most cost-effective crop to cultivate for conversion to liquid fuel in each specific area. The cost of doing so may not be feasible in comparison with current fuel prices, and the best alternative may be eliminated by food security concerns.

Metadata:
http://bea.dirisa.org/resources/atlas-maps/FEA_UNS.PDF

Theme: Feasibility – Most feasible cultivated crop (including cost offset from byproduct sales)

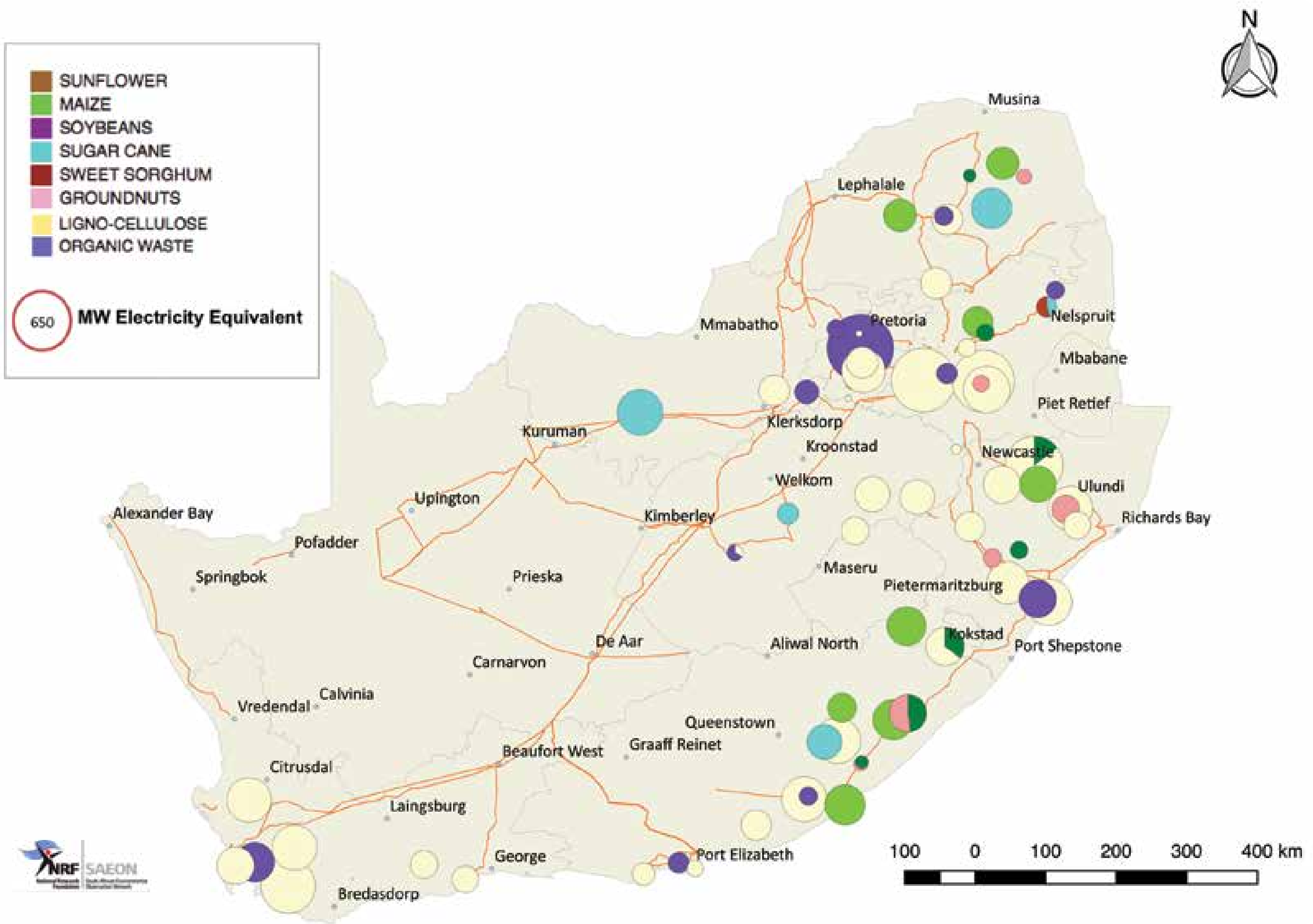


Derived from data published by Schulze *et al.* (2007), and process technology literature review performed by Stellenbosch University on behalf of SAEON (2014).

Map shows the most cost-effective crop to cultivate for conversion to liquid fuel in each specific area. The cost of doing so may not be feasible in comparison with current fuel prices, and the best alternative may be eliminated by food security concerns. For oil-bearing crops, a subsidy based on 50% of oil cake sales reduces the final cost.

Metadata:
http://bea.dirisa.org/resources/atlas-maps/FEA_SUB.PDF

Theme: Feasibility – No byproduct cost offset

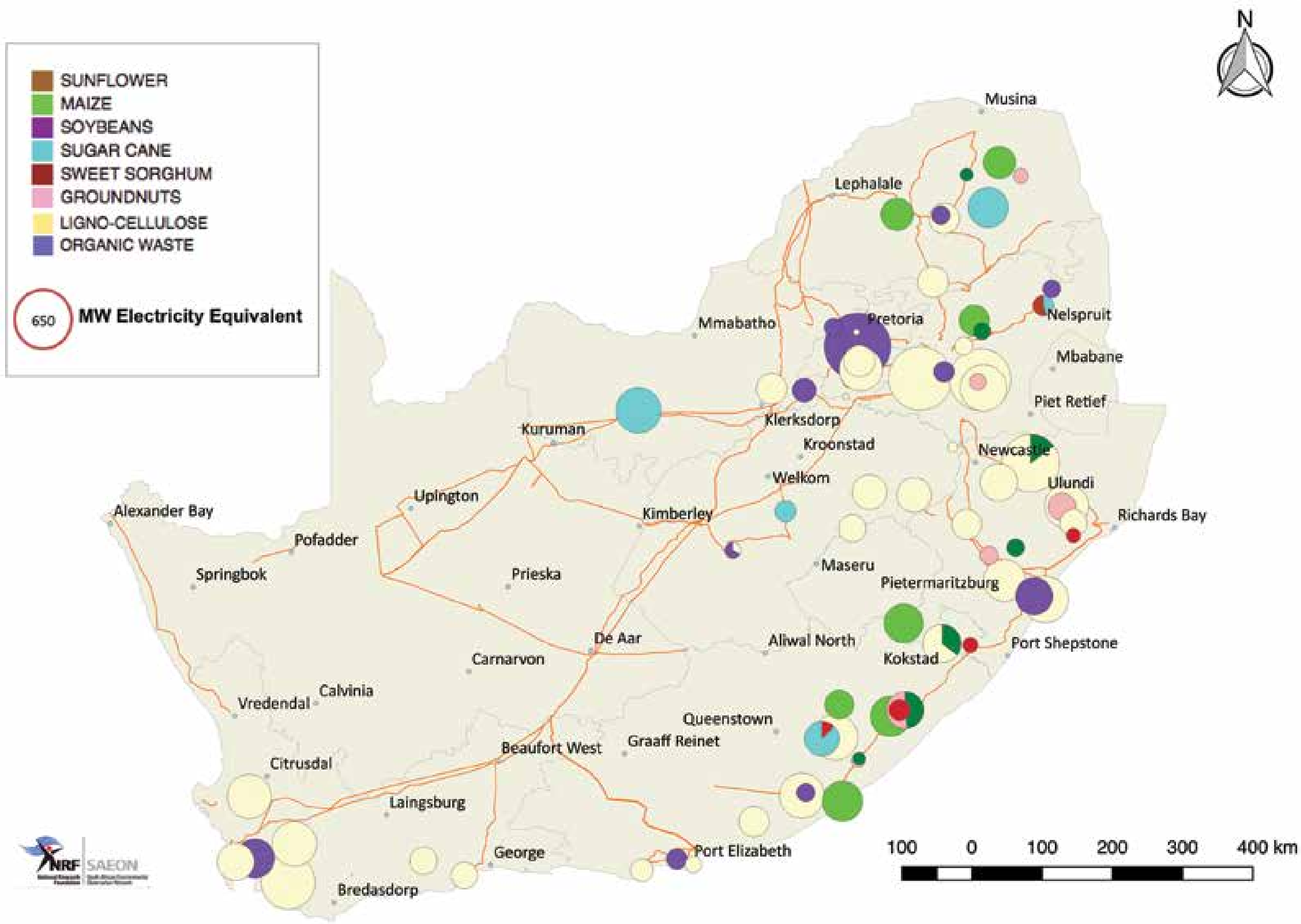


Derived from data published by Schulze *et al.* (2007), DAFF (2014), literature review performed by SAEON (2014) and literature review performed by Stellenbosch University on behalf of SAEON (2014). Shows the best option for each location, without subsidisation of the final energy product. Product costs may not be feasible compared with alternatives.

Metadata:
http://bea.dirisa.org/resources/atlas-maps/FEA_PRO_UNS.PDF

The map shows the largest feasible projects (up to 10) for each feedstock, aggregated per planning zone. Feasibility is determined as a bioenergy product cost equal to or less than the most common alternatives, either from fossil sources or renewable sources.

Project options in the more arid parts of the country are not reported because of small size, high costs, or both. There will be small, feasible options for biogas production in most larger towns.



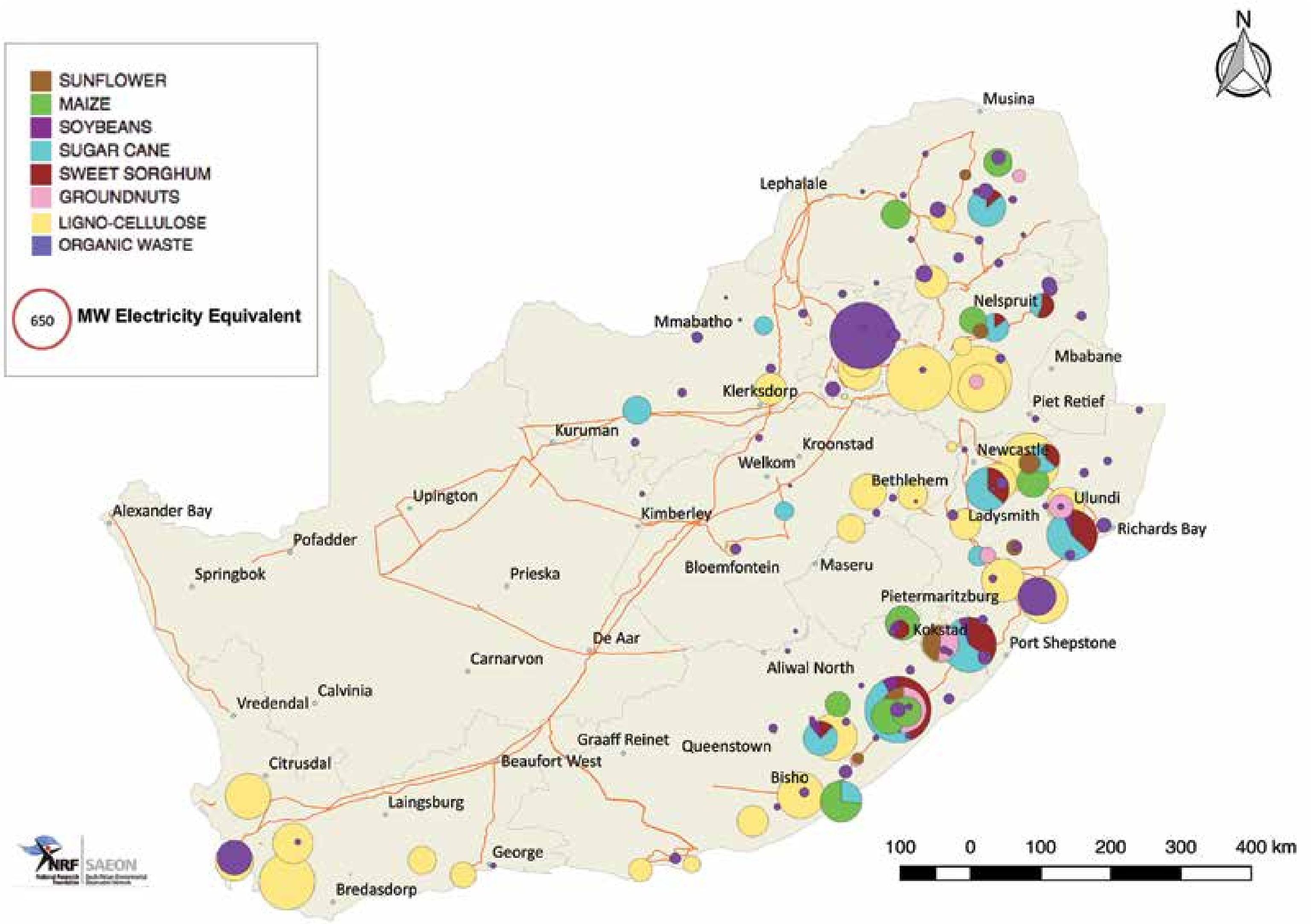
Derived from data published by Schulze *et al.* (2007), DAFF (2014), literature review performed by SAEON (2014) and literature review performed by Stellenbosch University on behalf of SAEON (2014). Shows the best option for each location, with subsidisation of bio-oil feedstock costs to 50% of byproduct oilcake value. Final product costs may not be feasible compared with alternatives.

Metadata:

http://bea.dirisa.org/resources/atlas-maps/FEA_PRO_SUB.PDF

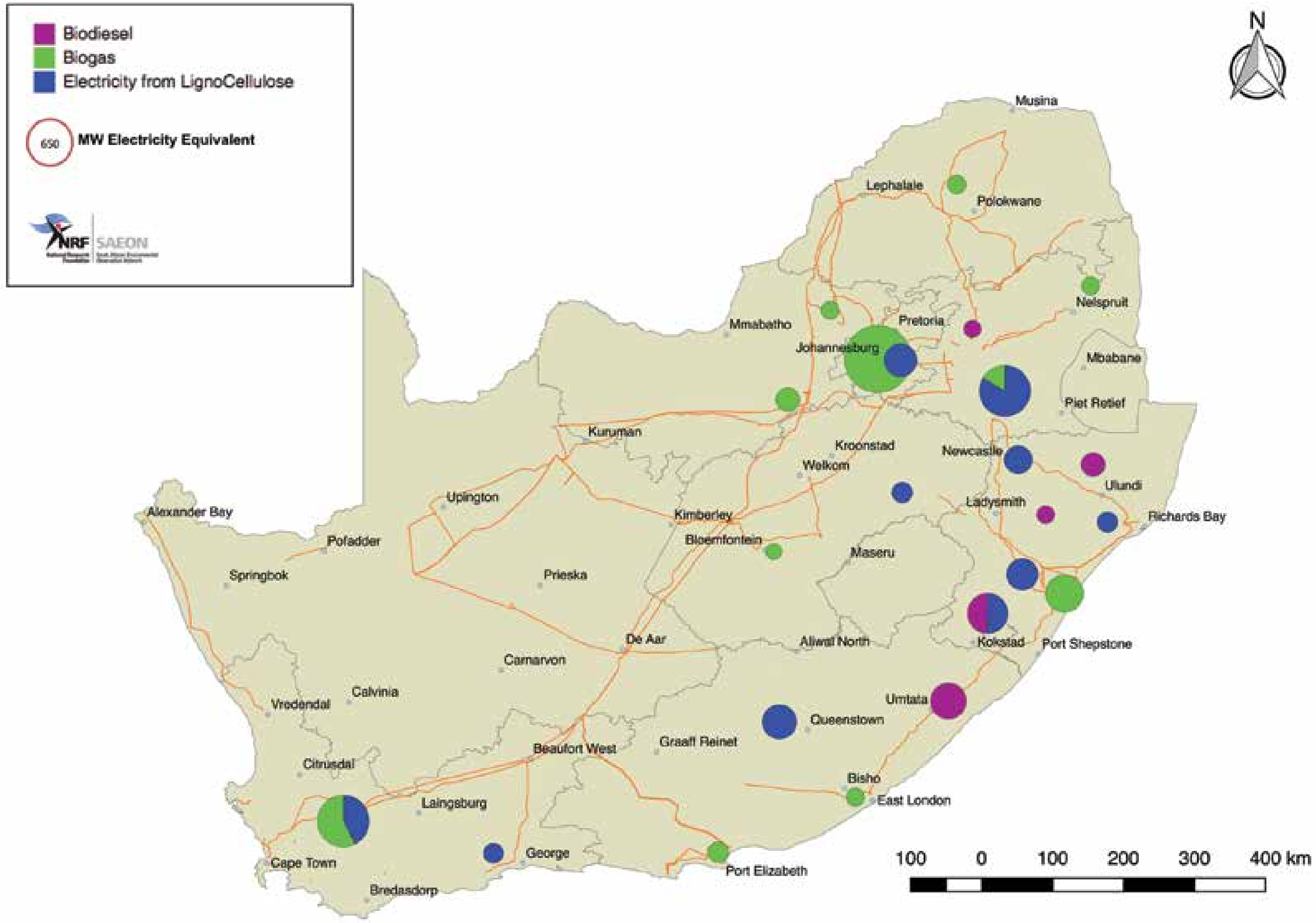
The map shows the largest feasible projects (up to 10) for each feedstock, aggregated per planning zone. Feasibility is determined as a bioenergy product cost equal to or less than the most common alternatives, either from fossil sources or renewable sources.

Theme: Feasibility – All identified projects



Derived from data published by Schulze *et al.* (2007), DAFF (2014), CRSES (2014), literature review performed by SAEON (2014), and literature review performed by the CSIR and Stellenbosch University on behalf of SAEON (2014). Shows all project options evaluated, irrespective of feasibility.

Metadata:
http://bea.dirisa.org/resources/atlas-maps/PROJ_ALL.PDF



Derived from data published by Schulze *et al.* (2007), DAFF (2014), CRSES (2014), literature review performed by SAEON (2014), and literature review performed by the CSIR and Stellenbosch University on behalf of SAEON (2014). Projects that have energy costs comparable to alternatives, aggregated to the closest district municipality.

Metadata:
http://bea.dirisa.org/resources/atlas-maps/PROJ_DIST.PDF

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1: Base layers – Productivity	SAEON/ARC
2: Base layers – Household demand and demography	CSIR-BE/SAEON/StatsSA
3: Agricultural residues	DAFF/SAEON ESKOM/CRSES
4: Organic waste – domestic, commercial and industrial	CSIR-NRE ESKOM/CRSES
5: Purposely cultivated biomass	DAFF/ARC/SAEON
6: Incidental woody biomass estimates	CSIR-NRE
7: Conversion processes and pathways	CRSES/SU
8: Infrastructure, markets and logistics	DoE/Eskom/SAEON/StatsSA
9: Impact assessment and ecosystem services	SAEON, CSIR-NRE
10: Energy alternatives	SAEON

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Acronyms and Abbreviations

ARC	Agricultural Research Council
BAPEPSA	Biomass Action Plan for Electricity Production in South Africa
BGTL	Biomass and natural gas to liquid
BICGC	Biomass integrated combined gas cycle
BTL	Biomass to liquid
CCC	Committee on Climate Change
CCGT	Combined Cycle Gas Turbines
CH_4	Methane
CO_2	Carbon dioxide
CSP	Concentrating Solar Power
CRSES	Centre for Renewable and Sustainable Energy Studies
CSIR	Council for Scientific and Industrial Research
CSIR-BE	Council for Scientific and Industrial Research – Built Environment
CSIR-NRE	Council for Scientific and Industrial Research – Natural Resources and the Environment
CTL	Coal-to-liquids
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DoE	Department of Energy
DST	Department of Science and Technology
DWA	Department of Water Affairs (now the Department of Water and Sanitation)
DWS	Department of Water and Sanitation
FT	Fischer-Tropsch
GAP	GeoSpatial Analysis Platform
GDP	Gross domestic product
GHG	Greenhouse gas
GTL	Gas-to- liquids
GVA	Gross value added
GW	Gigawatt
IAP	Invasive alien plant
IEEP	Institute for European Environmental Policy
iLUC	Indirect land-use change

IPP	Independent power producer
LCA	Life-cycle assessment
LCOE	Levelised cost of electricity
LPG	Liquefied Petroleum Gas
LUC	Land-use change
MAI	Mean annual increment
MW	Megawatt
NACI	National Advisory Council on Innovation
NERSA	National Energy Regulator of South Africa
N_2O	Nitrous Oxide
NPA	National Protected Areas
NPAES	National Protected Areas Expansion Strategy
NPK	Nitrogen, phosphorus and potassium
NPP	Net primary productivity
NRF	National Research Foundation
OGCT	Gas-fired open-cycle gas turbine
PFMA	Public Finance Management Act
PPP	Purchasing power parity
PV	Photovoltaic
REIPPP	Renewable Energy Independent Power Producer Procurement
RIRP	Revised Integrated Resource Plan
SAEON	South African Environmental Observation Network
SAEOSS	South African Earth Observation System of Systems
SANBI	South African National Biodiversity Institute
SANEDI	South African National Energy Development Institute
Stats SA	Statistics South Africa
SU	Stellenbosch University
UCT	University of Cape Town
UK	United Kingdom
UKZN	University of KwaZulu-Natal
VAT	Value-added tax
WRC	Water Research Commission

Glossary of Terms

Anaerobic digestion: is a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. One of the end products is biogas, which is combusted to generate electricity and heat, or can be processed into renewable natural gas and transportation fuels.

Bagasse: is the fibrous matter that remains after sugarcane or sorghum stalks are crushed to extract their juice. It is used as a biofuel and in the manufacture of pulp and building materials.

Biomethane: is a naturally occurring gas which is produced by the so-called anaerobic digestion of organic matter such as dead animal and plant material, manure, sewage, organic waste, etc.

Black liquor: is the waste product from the kraft process when digesting pulpwood into paper pulp removing lignin, hemicelluloses and other extractives from the wood to free the cellulose fibres.

Co-firing: refers to the burning of a solid or gas biofuel along with a more traditional fuel.

Coppicing: is the process of cutting trees down, allowing the stumps to regenerate for a number of years (usually 7 to 25) and then harvesting the resulting stems.

Digester: a container in which substances are treated with heat, enzymes, or a solvent in order to promote decomposition or extract essential components.

Fast pyrolysis: is a process in which organic materials are rapidly heated to 450-600 °C in the absence of air.

Fischer-Tropsch: is a collection of chemical reactions that converts a mixture of carbon monoxide and hydrogen into liquid hydrocarbons.

Hydrothermal liquefaction: also referred to as hydropyrolysis, is a thermochemical conversion process in which high temperatures and pressures are used to decompose complex organic material, including biomass.

Lignocellulose: refers to plant dry matter (biomass), so-called lignocellulosic biomass. It is the most abundantly available raw material on the Earth for the production of biofuels, mainly bio-ethanol. It is composed of carbohydrate polymers (cellulose, hemicellulose) and an aromatic polymer (lignin).

Mesozones: more or less equal-sized units which are similar in socio-economic character. On average, these zones are 50 km^2 (or roughly 7 km x 7 km) in size, and nested within administrative and physiographic boundaries.

Oilcake: is the solid residue remaining after any oilseed has been pressed to remove the vegetable oil.

Pelleting: is the process of compressing or molding a material into the shape of a pellet. Pellets can be made from any one of five general categories of biomass: industrial waste and co-products, food waste, agricultural residues, energy crops and virgin lumber. Wood pellets are the most common type of pellet fuel and are generally made from compacted sawdust and related industrial wastes from the milling of lumber, manufacture of wood products and furniture, and construction.

Pyrolysis: is a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen (or any halogen).

Residential Photovoltaic (PV): is a photovoltaic system that has its electricity-generating solar panels mounted on the rooftop of a residential or commercial building or structure.

Rootstock: is part of a plant, often an underground part, from which new above-ground growth can be produced. It can refer to a rhizome or underground stem.

South African Earth Observation System of Systems (SAEOSS) portal: offers the South African Earth observation community the opportunity to discover, access and eventually analyse Earth observations datasets. Access the SAEOSS portal on saeos.dirisa.org

Sludge: refers to the residual, semi-solid material that is produced as a by-product during sewage treatment of industrial or municipal wastewater.

Syngas (Synthesis gas): is a mixture comprising carbon monoxide, carbon dioxide and hydrogen. The syngas is produced by gasification of a carbon-containing fuel to a gaseous product that has some heating value.

Torrefaction: is a thermal process to convert biomass into a coal-like material, which has better fuel characteristics than the original biomass.

Transesterification: is the reaction of a triglyceride (fat/oil) with an alcohol to form esters and glycerol. The oil is transformed through a process called transesterification, which removes glycerine and adds methanol, leaving a thinner product that can power a diesel engine.

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The *BioEnergy Atlas* incorporates information on the basic factors involved in the production of biomass, potentials and yields for a variety of biomass resources, and assesses the techno-economic feasibility of energy products from these resources. It serves as an information resource on processes for energy production from biomass, and on the likely impacts of these value chains on social, economic and environmental indicators.

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