MASTER THESIS

within the scope of the university course
„Geographical Information Science & Systems“ (UNIGIS MSc)
at the Centre for Geoinformatics (Z_GIS) of the Paris Lodron University Salzburg
on the subject of:

EnerKey – Renewable Energies for Gauteng

submitted by
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In fulfillment of the requirements for the degree
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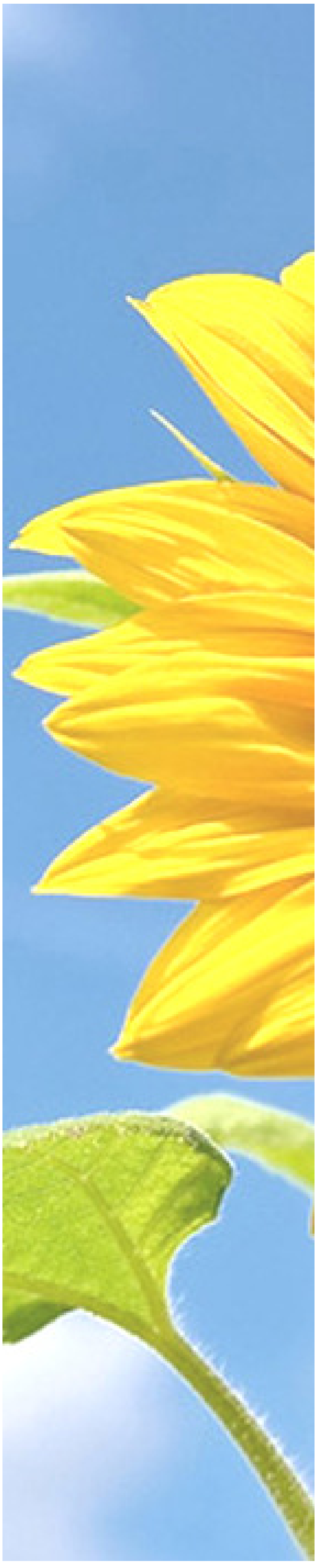
Reviewer:
Ao. Univ. Prof. Dr. Josef Strobl

Stuttgart, 18th April 2014



DEDICATION

To my sons Georg and Hagen,
wishing to leave them a world worth living in.

ACKNOWLEDGEMENT

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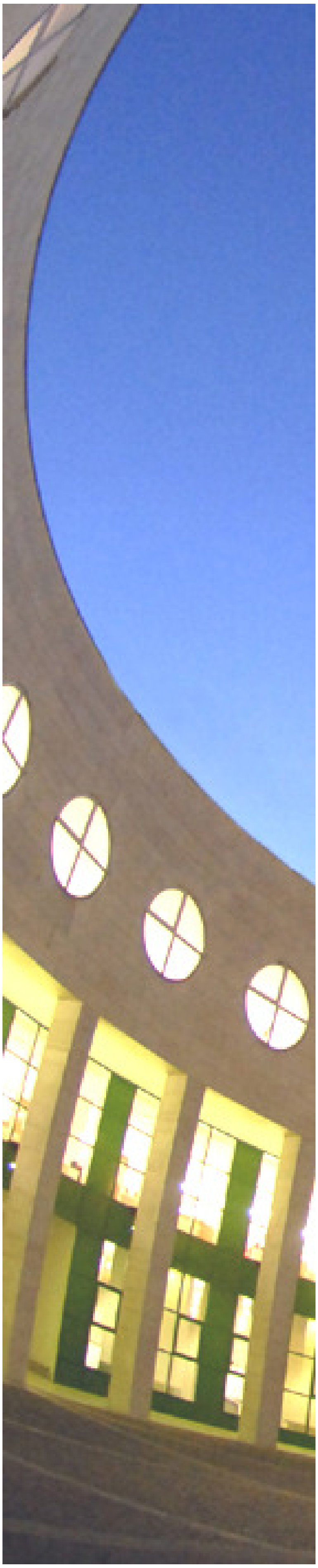

Statement of Originality

I hereby certify that the content of this thesis is the result of my own work. This thesis has not been submitted for any degree or other purposes, neither in whole nor in part.

To the best of my knowledge and belief, it contains no ideas, techniques, quotations or any other material from the work of other people unless acknowledged in accordance with standard referencing practices.

Stuttgart, 18th April 2014

Matthias Wörner

ABSTRACT

There is a broad consensus, that the use of renewable energy sources is indispensable for a viable sustainable energy management. This thesis takes its place in the plurality of potential analyses for various regions and constraints.

Within the framework of the EnerKey project, run by the universities of Stuttgart, Germany and Johannesburg, South Africa, in GIS analyses the energy production potential out of wind power, solar power and biomass in the province of Gauteng, South Africa is determined. Essentially two questions are answered in this context:

1. How much energy can be produced in which locations and by which renewable sources?
2. How can such analyses be done most effectively with the available data?

The first question is divided into the aspects WHERE and HOW MUCH. The major focusses in the second question are on the analysis methods and the preparation and modifying of data.

The main challenge results from the insufficiency of many datasets for the emerging country South Africa. It is described in detail which inaccuracies unfold from that and how the results could be improved. Thus e.g. different approaches for the generation of a base data for urban areas as precisely as possible are presented, the framework conditions on the digitalisation of roof areas are discussed and the difficulty of the forest area data structure is explained.

The outcome of the analysis results is a surprisingly significant potential for energy production out of renewable sources in the province of Gauteng. But this is relativised by the fact that doubtlessly not the entire determined theoretical potential can be used. The restricting reasons are presented.

Although in other regions of South Africa there are better conditions especially for the use of wind and solar power, a considerable proportion of the energy demand can be covered out of renewable sources.

Keywords: Renewable energies, potential analysis, emerging country, data mining

KURZZUSAMMENFASSUNG

Es ist breiter Konsens, dass die Nutzung erneuerbarer Energiequellen für eine zukunftsfähige, nachhaltige Energiewirtschaft unumgänglich ist. Diese Master Thesis reiht sich ein in die Vielzahl von Potentialanalysen für verschiedenste Regionen und Rahmenbedingungen.

Im Rahmen des Projekts EnerKey, betrieben von den Universitäten Stuttgart und Johannesburg, wird in GIS Analysen das Potential zur Energiegewinnung aus Wind, Sonne und Biomasse in der Provinz Gauteng (Südafrika) ermittelt. Dabei werden im Wesentlichen zwei Fragen beantwortet:

1. Wo kann wieviel Energie aus welchen erneuerbaren Quellen gewonnen werden?
2. Wie können die Analysen mit den verfügbaren Daten möglichst effektiv durchgeführt werden?

Dabei gliedert sich die erste Frage wiederum in den Aspekt WO und in den Aspekt WIEVIEL. Bei der zweiten Frage liegen die Schwerpunkte auf den Analysemethoden und der Aufbereitung der Daten.

Die größte Schwierigkeit erfolgt aus der Unzulänglichkeit vieler Datensätze für das Schwellenland Südafrika. Es wird ausführlich beschrieben, welche Ungenauigkeiten sich dadurch ergeben und wodurch dies verbessert werden könnte. So werden z.B. verschiedene Ansätze zu Gewinnung einer möglichst präzisen Datengrundlage für Ortsflächen vorgestellt, die Rahmenbedingungen bei der eigenen Digitalisierung von Dachflächen diskutiert oder die Problematik der Datenstruktur der Waldflächen erläutert.

Im Ergebnis zeigt sich ein überraschend großes Potential zur Energiegewinnung aus erneuerbaren Quellen in der Provinz Gauteng. Jedoch relativiert sich dies dadurch, dass zweifellos nicht das gesamte ermittelte theoretische Potential genutzt werden kann. Die einschränkenden Gründe werden vorgestellt.

Auch wenn in anderen Regionen Südafrikas speziell für die Nutzung der Wind- und Sonnenenergie bessere Bedingungen herrschen, kann doch ein beträchtlicher Anteil des Energiebedarfs aus erneuerbaren Quellen gedeckt werden.

Stichworte: Erneuerbare Energien, Potentialanalyse, Schwellenland, Datengewinnung

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We are like tenant farmers chopping down the fence around our house for fuel when we should be using Nature's inexhaustible sources of energy — sun, wind and tide. ...
I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that.

Thomas Alva Edison

„If there is no more planet, then there is no more economy"

Al Gore

1 INTRODUCTION

1.1 ESSENTIALS

1.1.1 Motivation

It is not alone the passion for the conservation of our natural environment that inspired me for this work. It is as well the fascination for the technological and economical capabilities to maintain our standard of living without exhausting the resources of this planet.

The generation of renewable energy does not only enable us to meet some of the most urgent challenges in the industrial nations, resulting from the enormously risen demand for energy. It can particularly avoid the appearance of such problems in emerging and developing countries.

1.1.2 Challenge and Scientific Question

Within the EnerKey project framework, as specified by the Institute of Energy Economics and the Rational Use of Energy (IER), University of Stuttgart, the energy generation potentials of wind power, solar power and biomass have to be examined in GIS analyses for the province of Gauteng, South Africa.

In this thesis two questions shall be answered, both relating to the Gauteng region. One is given by the renewable energies background:

- Where can how much energy be produced from which renewable sources?

The other one is given by the geoinformatics background:

- How can such analyses be done most effectively with the available data?

The first question is concretely, practically and pragmatically aligned with the requirements of the EnerKey project. It is answered along the specific project framework and according to the input of the IER supervisors.

The answer to the second question is primarily adapted to the found data. Moreover, the technical means of the used software play a part.

1.1.3 Approaches

Renewable Energies in the EnerKey Project

The following renewable energy sources can be considered for the EnerKey project:

Renewable Energy Sources:

1. Wind Power
2. Biomass – Wood
3. Biomass – Energy Crops
4. Concentrated Solar Power (CSP)
5. Photovoltaics – Industrial (PV)
6. Photovoltaics – Residential (PV)
7. Solar Water Heaters (SWH)

Figure 1: List of considered energy sources

Wind power, biomass (wood and energy crops) and solar power (CSP, PV und SWH). The outcome of this is the detailed order of analyses as listed in figure 1. The coloured marks represent the affiliation to the three subject areas wind power, biomass and solar power.

Energy production out of water power will not be analysed since there are no sources of water power of relevant dimension in Gauteng. Geothermal energy is not relevant in Gauteng either.

For all these analyses two components of a question have to be answered:

- The WHERE component identifies suitable locations and determines the suitability of areas for the energy production from renewable sources.
- The HOW MUCH component identifies the particular potential for the energy production from renewable sources.

Methodology – Data Mining

Since there was no budget available, generally cost-free data have been used. Whenever this lead to unsatisfactory results, it is commented.

Due to imperfect land use data in an experiment from OSM road data residential areas have been constructed.

In some cases data from several sources have been merged to gain datasets as complete as possible.

To meet analysis needs, multiple buffer zones to roads and transmission lines are required. In an iterative process the buffer distances are defined according to the spatial conditions and the analysis framework.

Methodology – Analysis

In the selection of suitable areas for power plant sites different aspects have an effect:

- Exclusion areas of no suitability
- Several criteria of particular suitability
- Proximity to infrastructure (analyses 1 to 5)

For areas determined as generally suitable, their specific suitability is evaluated by these criteria.

For the calculation of the energy production potential the values of actual hardware have been used in combination with the determined spatial results. Sometimes as initial data in fact a range of values is possible. Then in some cases alternative calculations have been made.

In contrast to the other examinations for the analyses 6 (PV Residential) and 7 (SWH) a different approach is chosen. Here the whole area of Gauteng cannot be explored. This would be by far too time-consuming. For that reason exemplary cutouts are analysed and the results are projected to the whole of Gauteng.

The two analyses 6 and 7 have to be regarded in context, since both refer to the same areas. Due to the higher efficiency of SWH these are given a higher priority in this examination. Therefore, the available area for PV installations on residential buildings is generally calculated less the area required for SWH.

1.1.4 Objectives and Expected Results

The data preparation for the analyses will be presented and the failures of the existing data will be regarded. The results of the several analyses form the answers to the two question components mentioned above. The weaknesses of the base material lead to imperfect analysis results that will be reviewed in detail. A validation will be carried out as well. Furthermore, the data quality, that would be necessary for an optimal result, will be discussed. And finally in a synopsis the potential of a combined use of renewable energy sources will be evaluated.

1.1.5 Excluded Topics

Due to the limited time available for a master’s thesis some aspects could not be elaborated. These are:

- Analysis of the current energy use in the single administration units of Gauteng as well as the potential development of the energy demand.
- Extracting a model that displays the relation of energy production and energy demand and hence illustrate the required energy transportation routes.
- Evaluating the applicability of open GIS software – particularly QuantumGIS or gvSIG – in processing the analyses in the required quality and with full interoperability to ArcGIS.

1.1.6 Target Audience and Thesis Structure

As a matter of course this work is part of the EnerKey project documentation. It reflects the methods and background of the GIS analyses within the potential evaluation on renewable energies in Gauteng.

Beyond that the thesis mainly addresses people involved in renewable energy production analyses. It is meant to be a support for decision makers in judging the framework of the use of different renewables. It especially sheds light on the combination of several renewable energy forms to achieve an expedient whole.

The thesis is subdivided in 6 chapters with several sections as depicted in figure 2.

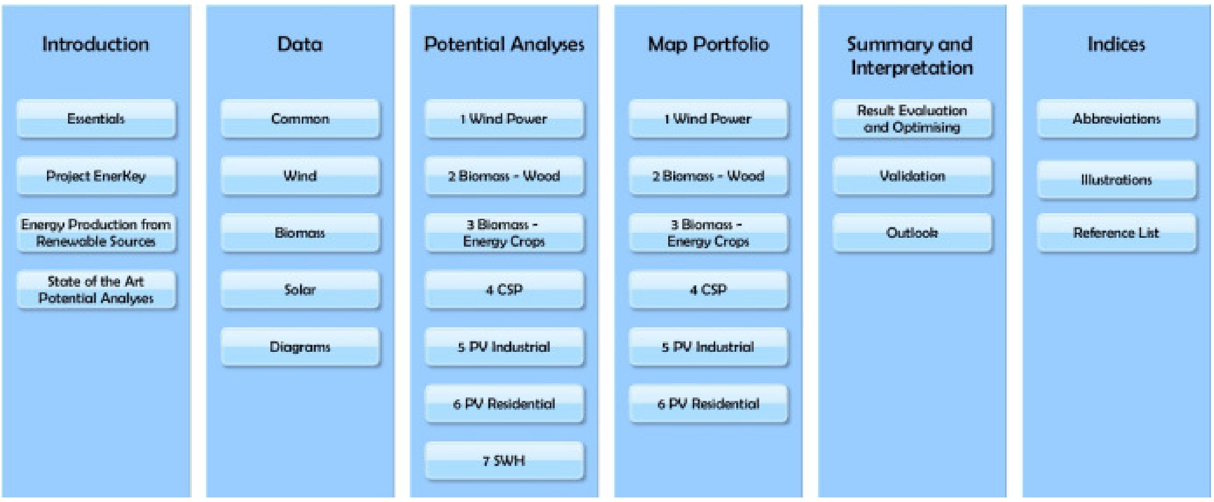

Figure 2: Thesis structure

1.2 THE ENERKEY PROJECT

This thesis is part of the EnerKey project, a South African - German collaboration. Along with several municipalities and companies the university of Johannesburg, South Africa and the university of Stuttgart, Germany are stakeholders of this project.

Figure 3: EnerKey Project Logo

The aim of the project is to develop and implement innovative pathways in urban energy supply and use in order to improve the sustainability in the region of Gauteng, South Africa. Gauteng is an urban agglomeration, consisting of the three municipalities Johannesburg, Ekurhuleni and Tshwane with a total of more than 10 million inhabitants. EnerKey stands for the focus of the project on energy as a key element of sustainable transformation.

The EnerKey project is about to assist the Gauteng municipalities to manage these energy challenges and develop measures to improve and optimise the sustainable development of megacities while meeting economic, social and environmental objectives. The project objectives are:

- To investigate the potentials of innovative technologies for climate protection and sustainability.
- To show the feasibility of an integrated approach through the development and use of integrated model tools and instruments.
- To develop and implement energy projects as pilot studies, e.g. mass SWH implementation, schools retrofit and education campaign, and a cooking and heating energy needs test site.[1]

Figure 4: Randburg, Gauteng, © Seeff

Since the project working language is English this thesis is written in English as well.

1.3 ENERGY PRODUCTION FROM RENEWABLE SOURCES

1.3.1 Generalities

Energy production out of renewable sources is of minor significance in this thesis. The main focus here is the question, where to use them. Therefore only a brief summary of the state of the art use in the use of renewable energies shall be given here. The explanation report on the geographical analysis follows in chapter "Potential Analysis".

1.3.2 Wind Power

In the process of finding suitable areas for wind turbine generators (WTG) the total examination area is taken as a basis and then exclusion areas are calculated by the following criteria:

As of an average wind speed of 5.8 m/s at hub height of the planned facilities the operation of WTG is reasonable[2]. Normally areas with lower wind speed values form exclusion areas. Since the existing figures for Gauteng are completely below this value, they are only used for the evaluation of a gradual suitability.

Figure 5: WTG Vestas V-90 2.0 MW, © RES Americas photo

WTG should not be built on areas with a gradient of more than 8 %. For that reason, from a terrain model, areas with a higher gradient are taken and added to the exclusion areas.

[1] o.V., 2009
[2] o.V., 2012: 14

Minimum distances to the following objects have to be observed: Residential areas, roads, railway lines, transmission lines, waters, protected areas, sights, areas used by armed forces.

There are various regulations for the respective distances in different countries. Since the governmental directions for South Africa are unclear, the German regulations are taken as a basis here.

From land use data, the respective areas are taken and buffer zones of the desired width are constructed. These areas as well are added to the exclusion areas.

It has to be clarified for the remaining areas determined as suitable for wind power use, on which areas wind power can be used parallel to the previous usage and which areas have to be rededicated.

1.3.3 Biomass

Biomass is not only a source of energy, it is even more: Biomass is particularly appropriate to replace fossil fuels and thus it can make a significant contribution to the reduction of CO^2 emissions.

Another aspect is that energy can be gained from biomass in the form of heat and electricity.[3] Combined biomass heat and power plants can generate not only electricity but also useful heat by burning solid biomass. Such power-heat cogeneration processes are even more efficient than biofuels.[4]

For reasons of simplicity in this thesis biomass shall only be regarded as an energy supplier by way of a resource for biomass power plants. Of the several forms of biomass – wood, energy crops and residual materials – only wood, maize and sunflower are regarded here. They may serve as examples for other materials.

Biomass is the most controversial form of renewable energy and is the subject of many political conflicts. Particularly in regions with a strained food supply situation an area, which would be in competition with food and pasture production, will be viewed critically. In this context the increased demand for maize in order to gain fuel ethanol is disputed as a possible cause of the food prize crisis 2007/2008.[5] [6] [7]

Figure 6: Maize cob, © pixelio.de

An important contribution nevertheless biomass can make as balancing energy, because it is easily storable and continuously producible.

[3] FAULSTICH, 2005
[4] EKARD, 2009
[5] BÜHLER, 2009: 73 ff
[6] OECD, 2007
[7] OECD/FAO, 2007

The criteria and methods regarding the evaluation of suitable areas for biomass power plants are widely the same as for the use of wind power. A particular criterion, however, is the amount of the available resources around the power plant sites. This is based on the rule, that raw materials should not be transported more than 50 km.[8]

1.3.4 Solar Power

Concentrated Solar Power (CSP)

A CSP system works exactly like a coal steam power plant, with the difference that concentrated solar power is used for the steam production, instead of coal. For this reason large mirrors track the sun orbit in order to bundle the sunlight just like in a burning glass. A major advantage of this technology is, that a part of the solar heat can be collected over the day in big heat accumulators while it can be fed into the steam cycle at night or specifically in periods of peak demands. This way renewable balanced and controlled energy can be provided in the power grid as required.[9]

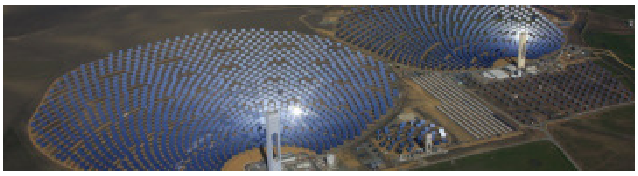

Figure 7: PS20 and PS10 CSP, Seville, Spain, © www.abengoasolar.com

In comparison to other renewable energy technologies CSP excels by low land requirements in terms of efficiency.[10] On the other hand a large contiguous area is required, since each shadow effects constrain the power generation. CSP need direct solar irradiation. This is most constantly granted in desert areas far away from coasts and waters.

In this thesis the parabolic trough technology as used in the Andasol solar power station in Guadix, Spain, is taken as a standard.[11] Parabolic troughs are linearly arranged reflectors that concentrate sunlight onto a tube positioned directly above the middle of the parabolic mirror along the reflector's focal line. It is filled with a working fluid. The reflector tracks the sun orbit during the daylight hours. While flowing through the receiver the working fluid is heated to 150 to 350 °C and is then used as a heat source for a power generation system. Amongst the different CSP technologies trough systems are the most developed CSP technology.[12]

Photovoltaics (PV)

With photovoltaics luminous energy in the form of sunlight is converted by means of solar cells into electrical energy. This technology is used in power plants as well as in individual installations on residential building roofs.

8 Özdemir, 2012
9 Alt, 2014
10 Weilharter, 2013: 3
11 o.V., 2011a
12 Martin, 2005

Figure 8: Lieberose PV park, Germany, © www.solarserver.de

Apart from fixed mounted open-site systems there are solar trackers which permanently adjust the solar modules according to the sun position. These systems achieve a higher return but are more expensive regarding installation and maintenance. Mono-axial tracking systems can reach an increment of about 30 % comparing to fixed mounted facilities, while dual axis tracking systems can generate an extra output up to about 45 %.[13] As an example one of the world's largest solar power plants the Lieberose photovoltaic park produces 52 GWh/a with an efficiency of 10 % on an area of 162 ha.

Figure 9: Solar cells on roof, © Köbernik Energietechnik

In terms of a decentralised energy production just where it is consumed, solar cells are mounted on residential roofs. In Germany 10 m^2 are sufficient to cover a quarter of the average household energy demand.[14] Due to climatical and geographical criteria these values vary widely from country to country.

Solar Water Heaters (SWH)

Figure 10: SWH, © www.sunflower-solar.com

With solar panels the solar power is collected and used for heating, cooling or other purposes. In this study hot water preparation with SWH is regarded. With this technology a solar absorber converts luminous energy of the sunlight into heat and supplies it to a heat carrier, mostly water. This heated water is used directly, but could be stored as well and indirectly be used for heating. The major advantage of solar thermal collectors is the high efficiency of 62 to 77 %.[15]

1.4 STATE OF THE ART POTENTIAL ANALYSES

Exemplary for up to date potential analyses in the field of renewable energies here the studies of Lisa Schwarz on wind power[16] and Prof. Dr.-Ing. Wolfgang Ruck et al. on all renewable energy sources in combination[17] are regarded.

[13] DAA, 2014
[14] AEE, 2010: 19
[15] EICKER, 2011: 6
[16] SCHWARZ, 2011
[17] RUCK et al., 2012

1.4.1 Example: Wind Power

In 2011 Lisa Schwarz examined the potential of South Africa to produce energy out of wind power in a student research project. Here the present paper is compared with the study of Schwarz to point out the advantages and disadvantages.

Due to the lack of knowledge about the exact legal situation in South Africa both examinations follow the regulations of Baden-Württemberg, Germany. This applies to both, exclusion areas as well as distance regulations for wind parks.

Table 1 compares the exclusion areas used in both examinations.[18] In contrast to Schwarz in the present paper some more data could be used: Industrial areas, small roads and forest areas. Furthermore, areas defined as too small for wind parks are excluded as well.

Wind Power Analysis - Exclusion Areas	
Schwarz	Wörner
Urban Areas	Urban Areas
-	Industrial Areas
Main roads	Main roads
-	Small Roads
Railways	Railways
Transmission Lines	Transmission Lines
Water Bodies	Water Bodies
Nature Protection Areas	Nature Protection Areas
-	Forest Areas
Slope > 8 %	Slope > 8 %
-	Areas smaller than 25 ha

Table 1: Exclusion Areas in different studies

In both studies the proximity to roads and transmission lines is used as basis for the evaluation of suitability. Schwarz considers all areas more than 5 km away from these infrastructure axes as not suitable.[19] In the present paper this method is improved in such a way, that the suitability is evaluated in steps of 2, 4 and 6 km away from roads and transmission lines.

Table 2 compares the distances used in both examinations.[20] In the examination of Schwarz only main roads are considered. In the present paper with much more detailed data small roads are considered as well. This applies to both, exclusion areas as well as evaluation of suitability.

Wind Power Analysis - Distances			
Schwarz		Wörner	
700 m	Urban Areas	700 m	Urban Areas
450 m	Single Buildings	700 m	
-	-	300 m	Industrial Areas
40 m	Main Roads	200 m	Main Roads
15 m	Small Roads	200 m	Small Roads
50 m	Railway Lines	200 m	Railway Lines
240 m	Transmission Lines	200 m	Transmission Lines
10 m	Water Bodies	10 m	Water Bodies
200 m	Nature Protection Areas	200 m	Nature Protection Areas
-	-	100 m	Forest Areas

Table 2: Distances in different studies

As the investigation area of Schwarz covered South Africa on the whole, there is a wider range of wind speed values than in the present paper, which covers only the province of Gauteng.[21] This results in different categories of suitability.[22]

Regarding the potential determination Schwarz works with a more detailed calculation[23], as this study concentrates on wind power, while the present paper offers an overview on different kinds of renewable energies.

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18 SCHWARZ, 2011: 25 ff
19 SCHWARZ, 2011: 27
20 SCHWARZ, 2011: 26
21 SCHWARZ, 2011: 28 f
22 SCHWARZ, 2011: 36 f
23 SCHWARZ, 2011: 39 ff

1.4.2 Example: Photovoltaics

In a pilot study Ruck et al. examine the potential of the renewable energy sources photovoltaics, wind power, solar heat, biomass, biogas and geothermal energy. The study was established in order to determine, if the Lüneburg region can cover 100 % of its energy demand out of renewable sources. On the part of the energy use the study operates with assumed scenarios. Deviations in reality can falsify the results considerably.[24]

The study distinguishes theoretical and technical potential. The latter is the portion of the former, which can be used with up to date technology. Further constraints are depicted with the economic, social and ecological potential. These limitations are considered in the examination as far as possible.[25] In the present study, however, such considerations remain disregarded, since it can be excluded for South Africa or there are no findings on that.

Here the photovoltaics analysis shall be discussed as an example. In this examination Ruck et al. implicate roof orientation and slope as well as shadowings and roof constructions.[26] All these factors are generalised in the present study, since an exact investigation would not have been possible with a justifiable effort.

For the determination of suitable roof tops on public buildings Ruck et al. had access to detailed and complete map data of the responsible authorities[27], which was not available for Gauteng.

For the investigation of suitable roof areas, such as the identification of supermarkets, Ruck et al. made use of earth viewers like Google Maps.[28] In the present examination satellite images in Bing Maps have been evaluated as well, for example to determine the number of plots in an example cutout.

In the field of residential buildings Ruck et al. resort to generalising approximations, since the evaluation of all residential buildings would have taken too much time.[29] In the present study values from several example cutouts are projected to the total area as well.

[24] RUCK et al., 2012: 1 ff
[25] RUCK et al., 2012: 12
[26] RUCK et al., 2012: 60
[27] RUCK et al., 2012: 62
[28] RUCK et al., 2012: 65
[29] RUCK et al., 2012: 66

2 DATA

2.1 GENERALITIES

Here the data used for the analyses is described as well as the data sources and the methods to prepare it for the work. Additionally, some remarks are made regarding the quality and possible alternatives. The notes on the data quality in general refer to completeness and accuracy.

The chapter is divided in the subsections “Common”, “Wind”, “Biomass” and “Solar”. The latter three contain data used especially for the referring analyses, the first is about data used for several analyses.

2.2 COMMON

2.2.1 Project EnerKey

Some datasets were available from the project framework data pool and could be used directly or with minor changes.

From the existing province boundary of Gauteng the area of the province can be derived. The outcome are the layers *GautengBoundary* and *GautengArea*. The polygon in the first layer is used for the analyses, the line in the second one is just used as a visual orientation.

The available data with transmission lines and transformer stations have a sufficient quality. By buffering the transmission lines with different widths some layer for several purposes are generated. The point features of the transformer stations data are buffered as well and merged with the other buffers.

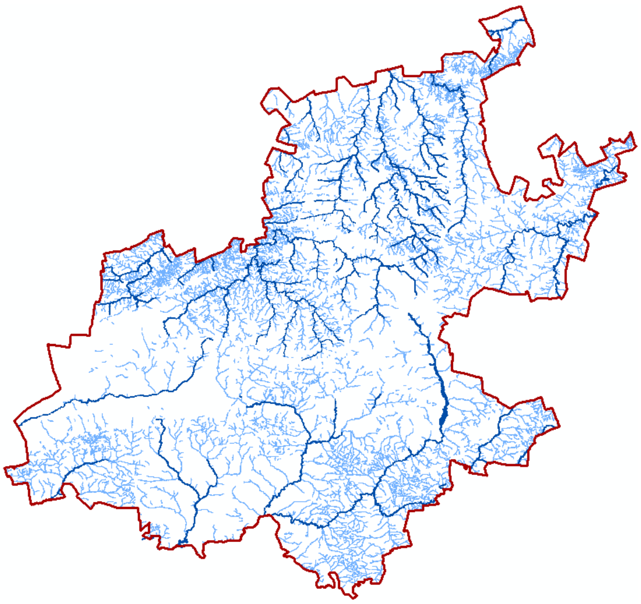


Figure 11: River data

In spite of thoroughly searching no satisfying river data could be found. So the EnerKey dataset *RiverPolygons* has been used here although the quality is disputable. It contains permanent and periodical rivers as buffer areas with different width.

There are datasets of water bodies in acceptable quality. These features are combined with those from OSM and saved as layer *Waters*.

From several vegetation data with acceptable quality features with different attributes are selected and the layers *Forest*, *Cultivation*, *Maize* and *Sunflower* are derived. Layer *Forest* is merged with OSM features.

From data on livestock breeding areas the layer *Livestock* is derived.

Out of a land-cover dataset some attributed areas are useable for different layers. These features are merged into the layers *Waters* and *Industry*.

A layer *UrbanArea* is derived as well. The quality of this original dataset is poor since the single areas are widespread in very small pixels. For further efforts regarding the generation of land-cover layers see the sections "OSM Infrastructure" and "Others".

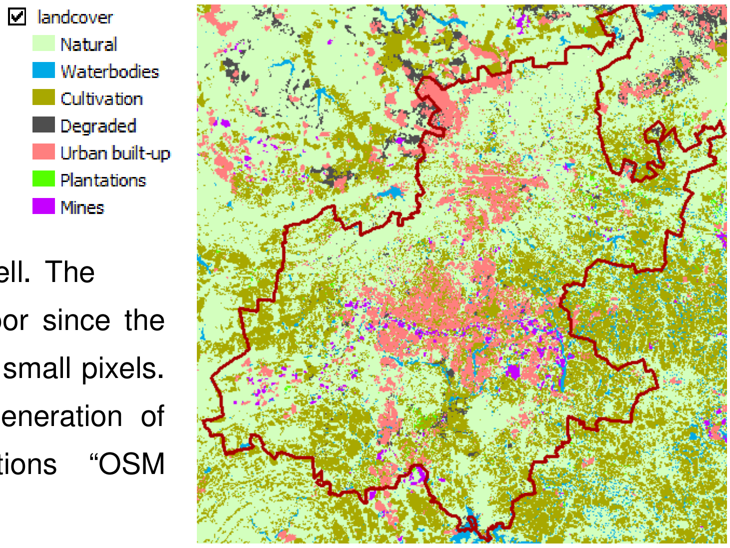


Figure 12: Land use data

Gradient

The provided data contain values from 0 to 342.86. Appropriate to the requirements of the analyses these values are grouped into three classes with certain gradient thresholds.

The outcome is the layers *Slope21*, *Slope50* and *Slope80* with areas of a gradient as of 2.1 %, 5.0 % and 8.0 %.

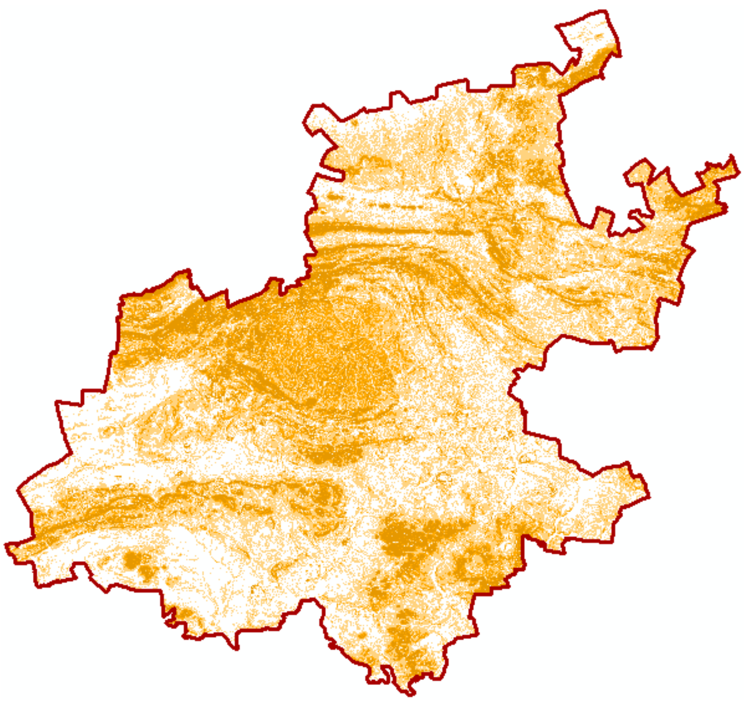


Figure 13: Gradient data

2.2.2 OSM Infrastructure

Obviously the available data in OpenStreetMap (OSM) are not absolutely perfect. But regarding accuracy and completeness in the area of Gauteng, for some object categories OSM offers by far more than all other available datasets.

The data of South Africa, downloaded from the Geofabrik website[30], consist of several layers with different relevance for this work.

Roads

Table 3 shows the process of extracting the relevant datasets.

Roads (OSM)							
Type	Number	Width	Buffer	Main	Urban	Built	Notes
motorway	2.244	50 m	25 m	x	-	-	
motorway link	2.729	10 m	5 m	x	-	-	
trunk	1.830	25 m	13 m	x	-	-	
trunk link	445	10 m	5 m	x	-	-	
primary	5.009	20 m	10 m	x	-	-	
primary link	850	8 m	4 m	x	-	-	
secondary	8.163	15 m	8 m	x	-	-	
secondary link	295	8 m	4 m	x	-	-	
tertiary	8.580	15 m	8 m	-	-	-	not tarred in the countryside
tertiary link	62	8 m	4 m	-	-	-	
residential	152.632	12 m	6 m	-	x	x	
living street	1.049	6 m	3 m	-	x	x	to **residential**
track	10.529	5 m	3 m	-	-	-	
cycleway	136	3 m	2 m	-	x	-	
footway	3.395	3 m	2 m	-	-	-	
pedestrian	222	3 m	2 m	-	x	x	to **footway**
path	3.922	5 m	3 m	-	-	-	to **footway**
steps	475	3 m	2 m	-	x	x	to **footway**
service	25.863	5 m	3 m	-	x	-	e.g. parking site
racetrack	1	15 m	8 m	-	-	-	
raceway	17	15 m	8 m	-	-	-	to **racetrack**
bridleway	47	5 m	3 m	-	-	-	
platform	3	10 m	5 m	-	x	-	
construction	204	15 m	8 m	-	-	-	
road	2.227	15 m	8 m	?	?	?	Reclassification has to be clarified
unclassified	74.705	15 m	8 m	?	?	?	Reclassification has to be clarified
unclassified re	1	?		?	?	?	to **residential**
unclassified lin	2	?		?	?	?	to **primary_link**
abandoned	1	-		-	-	-	deleted, as it is no more road
access	1	-		-	-	-	not in Gauteng
byway	1	-		-	-	-	not in Gauteng
disused	1	-		-	-	-	not in Gauteng
ford	1	-		-	-	-	not in Gauteng
motorway junction	2	-		-	-	-	not in Gauteng
proposed	5	-		-	-	-	not in Gauteng
residential unc	1	-		-	-	-	not in Gauteng
residential uncl	1	-		-	-	-	not in Gauteng
traffic signals	1	-		-	-	-	not in Gauteng
turning circle	2	-		-	-	-	not in Gauteng
SUM total	305.654						
SUM reduced	305.637						

Table 3: OSM road data - original

Some do not appear in Gauteng, others can be grouped. Some are listed in rather general named classes (highlighted pink in the table). Such generalisation marks a weakness of OSM data. For exact data the affiliation of these features should be clarified. Due to the big number of features here they have been categorised into an additional class between tertiary and residential roads.

The crowdsourcing concept of OSM is the reason that in general there are mistakes in the mapping of features to the particular classes. For an increased accuracy and correctness of the data at least the features in the classes “road” and “unclassified” should be analysed and assigned to the other classes. This could be carried out by means of Google Maps, including StreetView and integrated photos. Due to time constraints this remains undone here.

[30] GEOFABRIK, 2012

Table 4 shows the classification after adjustment.

The marks in the columns “Main”, “Urban” and “Built” display the assignment to the future layers *RoadsMain*, *RoadsUrban* and *RoadsBuilt*. Additionally, a layer *RoadsAll* with all road classes is generated. These layers are meant to answer different purposes:

Roads (OSM)							
Type	Number	Width	Buffer	Main	Urban	Built	Notes
motorway	2.244	50 m		x	-	-	
motorway link	2.729	10 m		x	-	-	
trunk	1.830	25 m		x	-	-	
trunk link	445	10 m		x	-	-	
primary	5.009	20 m		x	-	-	
primary link	852	8 m		x	-	-	
secondary	8.163	15 m		x	-	-	
secondary link	295	8 m		x	-	-	
tertiary	8.580	15 m		-	-	-	not tarred in the countryside
tertiary link	62	8 m		-	-	-	not tarred in the countryside
road	2.227	15 m		-	-	-	Classification unclear
unclassified	74.705	15 m		-	-	-	Classification unclear
residential	152.633	12 m		-	x	x	
living street	1.049	6 m		-	x	x	to residential
track	10.529	5 m		-	-	-	
footway	3.395	3 m		-	-	-	
pedestrian	222	3 m		-	x	x	to footway
path	3.922	5 m		-	-	-	to footway
steps	475	3 m		-	x	x	to footway
service	25.863	5 m		-	x	-	e.g. parking site
racetrack	1	15 m		-	-	-	
raceway	17	15 m		-	-	-	to racetrack
cycleway	136	3 m		-	x	-	
bridleway	47	5 m		-	-	-	
platform	3	10 m		-	x	-	
construction	204	20 m		-	-	-	
Layer RoadsAll	305.637	s.o.					
Layer RoadsMain	21.567	s.o.		x			
Layer RoadsUrban	180.381				x		
Layer RoadsBuilt	154.379					x	

Table 4: OSM road data - adjusted

- *RoadsAll*: Forming exclusion areas by individual buffering of each road class.
- *RoadsMain*: Forming preference areas by buffering the main roads.
- *RoadsUrban*: Forming urban areas by buffering the urban road classes.
- *RoadsBuilt*: Forming built-up areas by buffering the residential road classes.

Urban Area and Built-up Area

Since there were not a lot of suitable data found for urban area and built-up area an experiment has been started to generate such layers by buffering residential roads. In fact, better suitable data have been found and used later on.

As a reference for the buffering, the average widths of different road classes are measured in Google Maps. The final choice of the buffer widths then depicts a compromise between the real environment of roads within built-up areas and the coverage of built-up areas where there are no roads contained in OSM.

Due to the incompleteness of the original data a most possible coherent mean value has to be found. The focus is on the approximate size of the built-up area, whereas a certain inaccuracy regarding the real location of the built-up area is accepted.

Based on this built-up area in Roodeport (see figure 14), northwest of Johannesburg, the residential roads are buffered with a buffer width of 50 m, 100 m, 150 m and 200 m.

Figure 14: Satellite image of Roodeport, © Bing Maps

The roads buffered with 100 m buffer width (green, upper right picture in figure 15) give the best depiction of the built-up area. Based on this test for layer *RoadsBuilt* a buffer width of 100 m is chosen and for layer *RoadsUrban* a buffer width of 200 m.

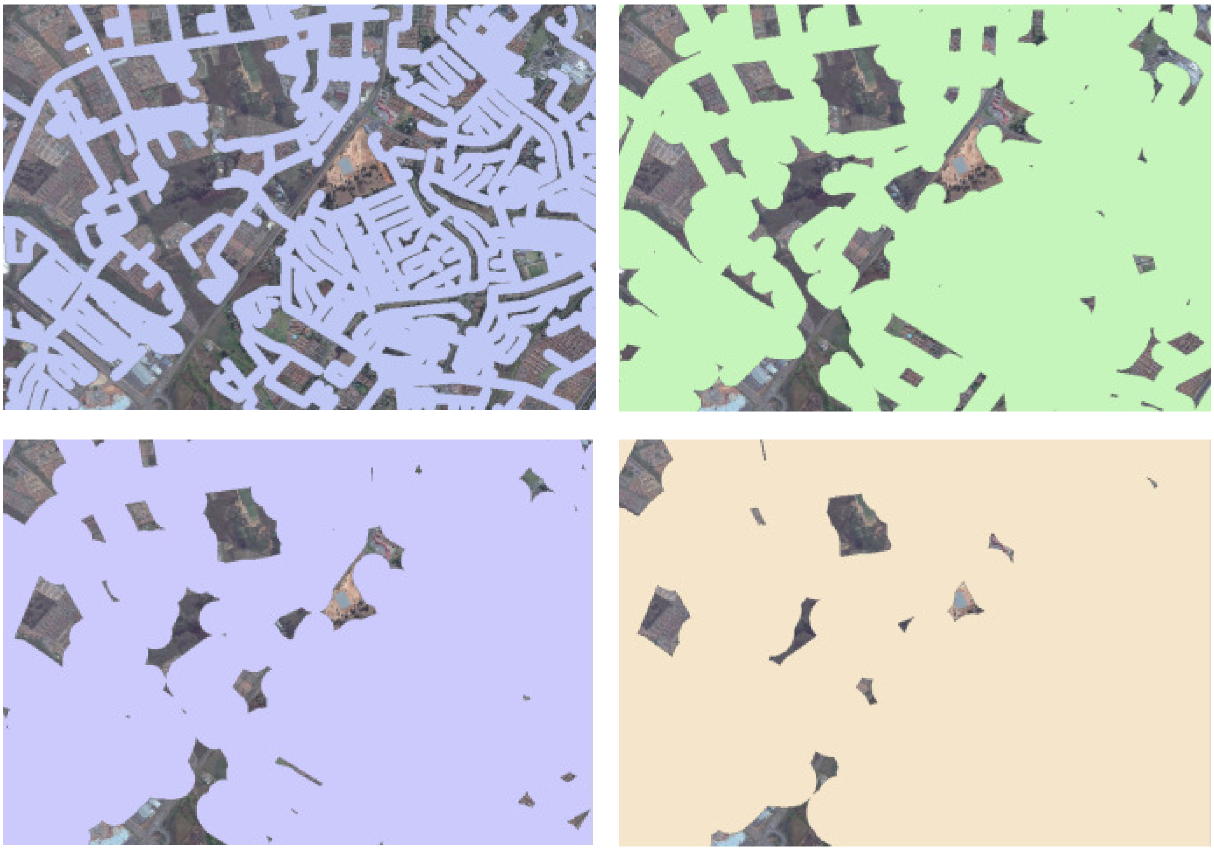


Figure 15: Different buffer widths on roads over satellite image, © Bing Maps

Railways

The completeness and accuracy of the OSM layer *railway* is sufficient. As visible in table 5, some features are not relevant for Gauteng and are deleted for this reason. The stations exist of closed polylines, the platforms are just simple lines. To get useful data the station polylines are converted to polygons, the platform lines are buffered.

Railway (OSM)						
Type	Number	Colour	Colour Value	Size	Symbolization	Notes
rail	9.191	Black	100k	1,0	Line	
subway	100	Dark Grey	60k	1,0	Line	
station	3	Dark Grey	60k	-	Polygon	convert into Polygon
platform	272	Dark Grey	60k	-	Polygon	convert into Polygon globally with buffer
construction	5	Light Grey	30k	0,5	dashed line	
abandoned	826	Dark Grey	60k	0,5	dotted line	
disused	566	Dark Grey	60k	0,5	dotted line	
funicular	4	-	-	-	-	not in Gauteng
historical_plann	1	-	-	-	-	not in Gauteng
light_rail	4	-	-	-	-	not in Gauteng
monorail	1	-	-	-	-	not in Gauteng
narrow_gauge	147	-	-	-	-	not in Gauteng
preserved	6	-	-	-	-	not in Gauteng
SUM total	11.126					
SUM reduced	10.963					
Layer RailwayLines	10.688					
Layer RailwayStations	275					

Table 5: OSM railway data

Other OSM Layers

Layer *Natural* contains forest areas, park areas, riverbanks and water bodies. These areas are integrated into the future layers *Forest*, *Protected* and *WaterAreas*.

Layer *Buildings* is unusable, since only a few buildings are digitised. Layer *Waterways* contains several categories of rivers and hydraulic structures, but is too incomplete and for that reason not useful.

2.2.3 Others

Land-cover

The first and the second solution for urban area and built-up area data have been described above. Just after the first analyses a more suitable dataset from SANBI[31] has been found. It is from 2009 as well as the EnerKey data, but has a much better quality regarding the compactness of the single areas. The new *UrbanArea* layer, which replaces the previous layer of the same name, has been derived directly from these data. The former layer has been generated out of OSM road data. In the same way the previous layer *Industry* is replaced by features with related attributes from the new dataset. By comparison with satellite images in Google Maps the new data look more up-to-date and correct.

Degree Squares

An extract of the grid of parallels and meridians has been constructed manually in Quantum GIS. The outcome is layer *LatLon* with polygons of the whole-number degree squares. In the same way a layer *LatLonFifth* with the fifth part of the degree squares has been constructed.

[31] SANBI, 2013

Protected Areas

Nearly all protected areas worldwide are visible and can be downloaded from the WDPA website[32]. The datasets mostly have a surprisingly good quality, but in some cases they do not. Beyond that, by comparison with the official IUCN list[33] a few areas are missing.

All individually downloaded features are combined in a layer *ProtectedAreas*. Areas located immediately outside of the Gauteng province boundary are considered as well as they might impact the adjacent areas inside of Gauteng. With the Groenklof Nature Reserve one missing area has been digitised.

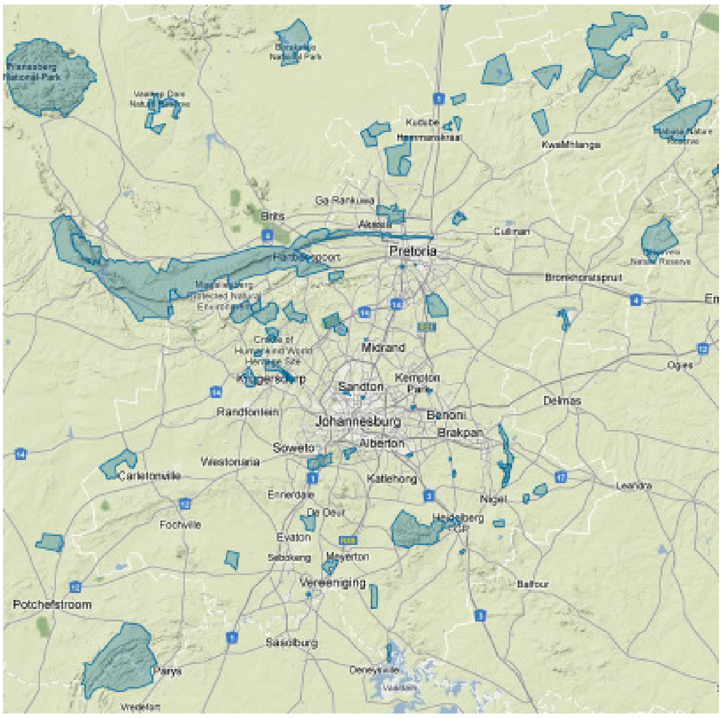


Figure 16: Protected areas in Gauteng

It could not be clarified, if the UNESCO world heritage site “Cradle of Humankind” is a protected area insofar as it is not allowed to build there. Since there are several protected areas located within this zone only these are considered as protected areas here.

Background Maps

ArcMap features the display of background maps. Several of these free offered basemaps have been tested and finally Bing Maps Aerial has been chosen. These satellite images with high resolution in urban areas are a great help whenever situations in datasets are unclear and have to be validated.

2.2.4 Missing Data

Information on public and private land ownership is missing, which would be a critical factor on the construction of energy production plants.

From the field of land-cover, no data on swamps, sand dunes and salt deserts are available. Furthermore, data on restricted areas, e.g. areas used by armed forces, are missing as well as airports with entry lanes and radio-relay systems of telecommunication organisations.

For that reason only a theoretical potential can be determined in the analyses.

[32] WDPA, 2012
[33] IUCN, 1993: 169-174

2.3 WIND

2.3.1 Wind Speed

Wind speed data are available from a NASA website[34]. These datasets provide average wind speed values for each whole-number grid field at a height of 50 m over ground. With the logarithmic elevation profile (see figure 17) they are converted to a height of 120 m over ground.

v(z2) = v(z1) * [ln(z2 / z0) / ln(z1 / z0)

v = wind speed	z1 = 50 m
z0 = 0,03 m (roughness length)	z2 = 120

Figure 17: Logarithmic elevation profile

Then out of layer *LatLon* a new layer *WindSpeed* is generated and the polygons are provided with the related values as calculated above.

In fact these data are quite inaccurate. The resolution of one degree is by far too inaccurate for a serious analysis. Due to the lack of better alternatives these data still have been used. Single values for arbitrarily exact coordinates can be downloaded from the mentioned NASA website. But this does not result in more precise data. Effectively the intermediate area is filled with the values of the full degrees.

Alternatives

Wind data for South Africa are available from the WASA[35] website, but they only refer to areas with better wind conditions along the South African coast, not to the northern part of the country with Gauteng.

Wind and solar data (and other useful data) can be viewed on the IRENA[36] website but cannot be downloaded from there.

A lot of useful data on wind, solar and other topics can be downloaded from the Natural Earth[37] website, nevertheless, the respective data for Gauteng is of poor quality.

2.3.2 Separation Zones

Since no regulations could be found for South Africa, the separation zones in these analyses have been defined as per the regulations valid in Baden-Württemberg, Germany[38].

Due to the different conditions in Gauteng and the data characteristics in contrary to the German

Separation Zone Definition	
Urban area	700 m
Roads and Railway lines	200 m
Transmission Lines	200 m
Industrial areas	300 m
Water bodies	10 m
Protected areas	200 m
Forest areas	100 m

Figure 18: Width of separation zones

34 NASA, 2012
35 WASA, 2013
36 IRENA, 2013
37 NATURAL EARTH, 2012
38 O.V., 2012

regulations the distances have been defined as shown in figure 18.

The available data contain no detached houses, so this class is not applicable.

The industrial areas cover mining areas, too. The shorter distance has been applied to all industrial areas.

The distance for water bodies has been used for buffering lakes and wetlands, but not for rivers, since these data are already buffered river lines.

The protected area data contain no further specification so the shortest distance has been used. Water preserves and bird sanctuaries have not been considered in particular.

Airports are contained in urban areas and industrial areas. Radio links have not been considered here and would be subject of particular determination on a case-by-case basis.

Forest areas globally have been considered as excluded areas. Due to the dimensions of present-day wind turbines a distance of 100 m has been defined.

Proximity to Roads and Transmission Lines

For most analyses multiple buffer zones to roads and transmission lines are required. After tests with different distances three buffer zones are generated with a distance of 2, 4 and 6 km from the infrastructure objects. The outcome is layer *RoadsProx6*.

In this layer in the attribute “RoadsProx” for each buffer zone the proximity values are calculated on the basis of the distance values and the formula **8 - [distance]**.

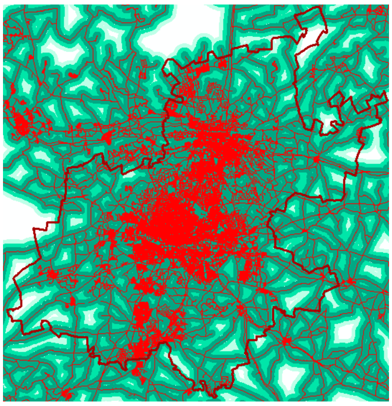


Figure 19: Road Proximity Buffer

The proceeding regarding the proximity to transmission lines is exactly the same as for the roads. While generating the multiple buffer zones the outcome is layer *TransmissionLinesProx6*. In this layer in the attribute “TransProx” for each buffer zone the proximity values are calculated as seen above.

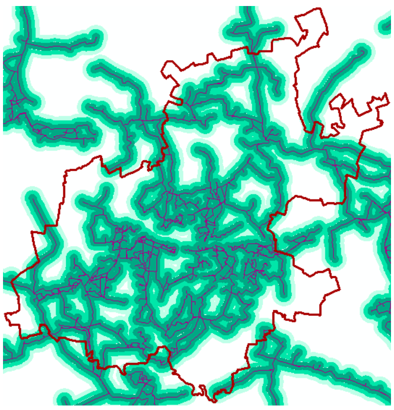


Figure 20: Transmission Lines Proximity Buffer

The distances of 2, 4 and 6 km have turned out to be the best choice for both infrastructure objects. Longer distances result in almost the whole area of Gauteng being covered by the buffer zones. And smaller distances are not reasonable in the context of determining location quality levels.

2.4 BIOMASS

According to the approach in the analysis “Wind Power” and appropriate to the requirements of the analysis “Wood” separation zones have been defined for transmission lines, railway lines and roads.

Some datasets were available from the EnerKey project framework again. For the analysis “Energy Crops” an available yield capacity dataset can directly be used. Out of different land-cover data attributed features have been merged to the layers *Maize* and *Sunflower*.

2.5 SOLAR

Solar radiation data are available from a NASA website[39]. These datasets provide average solar radiation values for each whole-number grid field.

From layer *LatLon* a new layer *SolarRadiation* is generated and the polygons are provided with the related solar radiation values.

According to the approach in the analysis “Wind” and appropriate to the requirements of the solar analyses separation zones have been defined for urban areas, industrial areas and forest areas.

For alternatives on solar radiation data see section “Wind Speed”. Alternative data sources listed there partially provide solar data as well.

2.5.1 Administrative Units

South Africa’s provinces are subdivided in local administrative units, so-called wards. For the analyses “PV Residential” and “SWH” a classification of the settlement areas according to income groups is required. The GCRO Priority Wards Project[40] offers such data, but they cannot be downloaded. Another interesting data compilation is available on the Planet GIS website[41], where there is a link leading to the Municipal Demarcation Board website[42]. The boundaries of the South African administrative units, the Gauteng wards included, can be downloaded here.

[39] NASA, 2012
[40] GCRO, 2013
[41] PLANET GIS, 2013
[42] MUNICIPAL DEMARCATION BOARD, 2013

2.6 DIAGRAMS

Table 6 lists all layers used in the analyses along with their source and the analyses, they are used in.

The diagrams in figure 21 and 22 list the layers along with their source, the original datasets and intermediate steps where applicable.

DATASETS for the Master Thesis		Analyses							
Layer	Remarks	1	2	3	4	5	6	7	Source
Cultivation	Cultivated areas	-	x	x	x	x	-	-	EnerKey
Cutouts	25 ha cutouts of four settlement examples	-	-	-	-	-	x	x	own Digitising
Forest	Forest areas	-	x	-	-	-	-	-	EnerKey / OSM
Forest_d100	Buffer zone 100m Forest areas	x	-	-	-	-	-	-	EnerKey / OSM
Forest_d60	Buffer zone 60m Forest areas	-	-	-	x	x	-	-	EnerKey / OSM
GautengArea	Province area	x	-	-	x	x	x	-	EnerKey
GautengBoundary	Province boundary	x	x	x	x	x	x	x	EnerKey
Income	Income data table referring to the Gauteng Wards	-	-	-	-	-	x	-	GCRO
Industry	Industrial areas (also oil fields, gas fields, mines, quarries)	-	x	x	-	-	-	-	EnerKey
Industry_d25	Buffer zone 25m Industrial areas	-	-	-	x	x	-	-	EnerKey
Industry_d300	Buffer zone 300m Industrial areas	x	-	-	-	-	-	-	EnerKey
LatLonFifth	Fifth part graticule fields	-	x	x	-	-	-	-	own Creation
Livestock	Livestock breeding areas	-	x	x	x	x	-	-	EnerKey
Maize	Maize growing areas	-	-	x	-	-	-	-	EnerKey
ProtectedAreas	Protected areas: WDPA, Parks (OSM), Others	-	x	x	x	x	-	-	WDPA / OSM
ProtectedAreas_d200	Buffer zone 200m Protected areas	x	-	-	-	-	-	-	WDPA / OSM
Railway_d10	Buffer zone 10m Railway lines	-	x	x	x	x	-	-	OSM
RailwayLines	Railway lines	-	-	-	-	-	-	-	OSM
RailwayStations	Railway stations	-	-	-	-	-	-	-	OSM
RiverPolygons	Rivers as Polygons	-	-	-	-	-	-	-	EnerKey
Roads_dist	Buffer zone variable Roads	-	x	x	x	x	-	-	OSM
RoadsAll	All Roads	-	-	-	-	-	-	-	OSM
RoadsProx6	Roads with multi buffers	x	x	x	x	x	-	x	OSM
Roofs	digitized roof areas	-	-	-	-	-	x	x	own Digitising
Slope21	Gradient from 2,1 %	-	-	-	x	-	-	-	EnerKey
Slope50	Gradient from 5 %	-	-	-	-	x	-	-	EnerKey
Slope80	Gradient from 8 %	x	-	-	-	-	-	-	EnerKey
SlopeK1	Gradient class 1 (0-13%)	-	x	-	-	-	-	-	EnerKey
SlopeK2	Gradient class 2 (13-36%)	-	x	-	-	-	-	-	EnerKey
SlopeK3	Gradient class 3 (36-62%)	-	x	-	-	-	-	-	EnerKey
SlopeK4	Gradient class 4 (62-93%)	-	x	-	-	-	-	-	EnerKey
SlopeK5	Gradient class 5 (93-100%)	-	x	-	-	-	-	-	EnerKey
SolarRadiation	Solar radiation classes	-	-	-	x	x	-	x	NASA
Sunflower	Sunflower growing areas	-	-	x	-	-	-	-	EnerKey
Traffic_d200	Buffer zone 200m Traffic infrastructure	x	-	-	-	-	-	-	OSM
Transmission_d200	Buffer zone 200m Transmission lines	x	-	-	-	-	-	-	EnerKey
Transmission_d50	Buffer zone 50m Transmission lines	-	x	x	x	x	-	-	EnerKey
TransmissionLines	Transmission lines	-	x	x	-	-	-	-	EnerKey
TransmissionLinesProx6	Transmission line with multi buffers	x	x	x	x	x	-	x	EnerKey
TransmissionStations	Transmission stations	-	-	-	-	-	-	-	EnerKey
UrbanArea	Urban areas	-	x	x	-	-	x	-	SANBI
UrbanArea_d25	Buffer zone 25m Urban areas	-	-	-	x	x	-	-	SANBI
UrbanArea_d700	Buffer zone 700m Urban areas	x	-	-	-	-	-	-	SANBI
WardsGauteng	Adminstrative units	-	-	-	-	-	x	-	Municipal Demarcation Board
Waters	Gewässerflächen	-	-	-	-	-	-	-	EnerKey / OSM
Waters_d10	Buffer zone 10m Waters (Rivers, Lakes, Wetlands)	x	x	x	x	x	-	-	EnerKey / OSM
Wetlands	Wetlands, Swamps	-	-	-	-	-	-	-	EnerKey
WindSpeed	Wind speed classes	x	-	-	-	-	-	-	NASA
YieldCapacity	Yield classes	-	-	x	-	-	-	-	EnerKey

Table 6: Dataset list

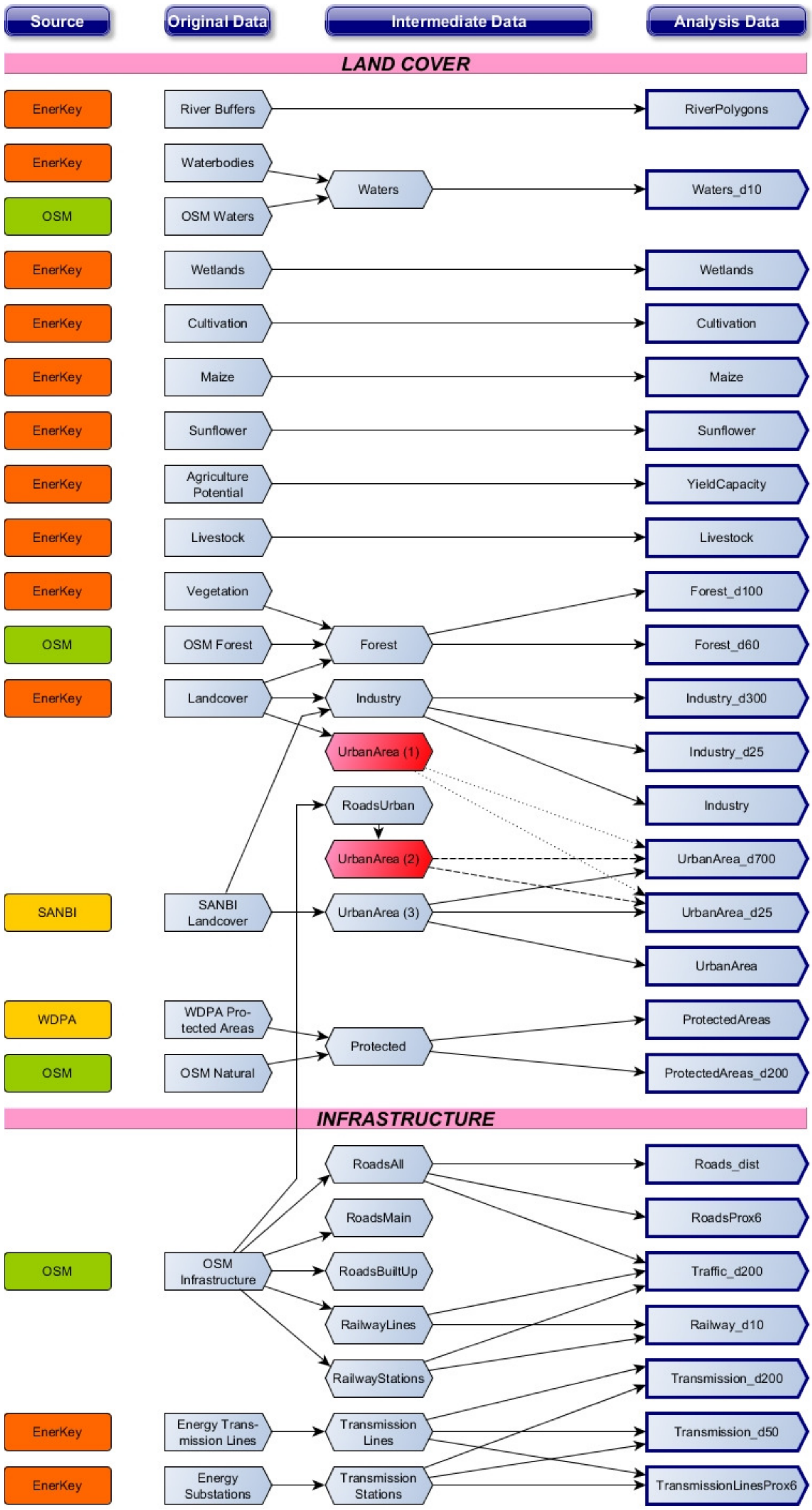


Figure 21: Data sources, Part 1

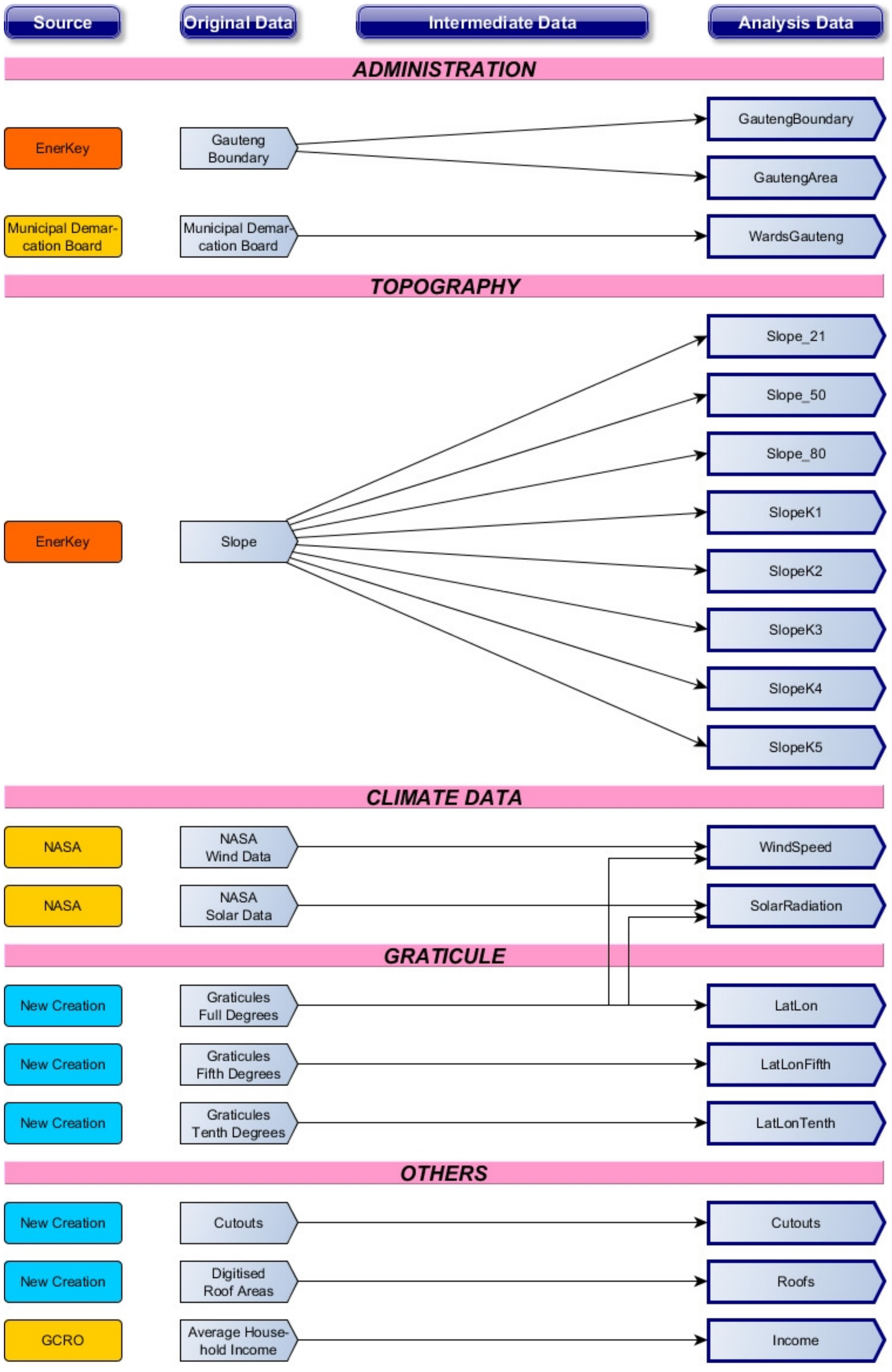


Figure 22: Data sources, Part 2

3 POTENTIAL ANALYSES

3.1 ANALYSIS 1 – WIND POWER

3.1.1 Data

These layers are required for this analysis and are loaded in an ArcMap file:

- *Forest_d100* Buffer zone 100 m around forest areas
- *GautengArea* Polygon of the province area
- *Industry_d300* Buffer zone 300 m around industrial areas
- *ProtectedAreas_d200* Buffer zone 200 m around protected areas
- *RoadsProx6* Multiple buffer zone around roads
- *Slope80* Areas with a gradient of 8 % or higher[43]
- *Traffic_d200* Buffer zone 200 m around traffic infrastructure
- *Transmission_d200* Buffer zone 200 m around transmission lines
- *TransmissionLinesProx6* Multiple buffer zone around transmission lines
- *UrbanArea_d700* Buffer zone 700 m around urban areas
- *Waters_d10* Buffer zone 10 m around water bodies
- *WindSpeed* Zones of different wind speeds
- *GautengBoundary* Boundary of the Gauteng Province

Bing Maps Aerial is loaded as background map for plausibility checks. Layer *GautengBoundary* is loaded as orientation.

3.1.2 Approach

Suitable Areas

Starting with the entire area of the Gauteng province, all areas not suitable as a wind park site are excluded step by step.

Areas excluded due to the type of use:

- Topografic: Water bodies and forest (data on swamps, sand dunes and salt deserts are not available).
- Anthropogenic: Traffic infrastructure (roads, railway lines), transmission lines, urban areas, industrial areas (including Oil- and gas fields, mines, quarries, according to

[43] SCHWARZ, 2011: 27

availability), protected areas. Data on restricted areas and airports with entry lanes are not available.

Wind power use in Gauteng Province has a rather poor profitability comparing to coastal areas and is therefore only reasonable with low outlay. For that reason forest areas that would have to be cleared before, shall be considered as exclusion areas.

Agricultural areas in contrast are not generally exclusion areas. A parallel use as a wind park site has to be examined in individual cases.

There are no specific distances that have to be kept from the exclusion areas. As there are no distance rules available for South Africa the regulations of Baden-Württemberg, Germany shall be used here as a substitute.[44]

Areas excluded due to technical reasons:

- Areas with a gradient of 8 % or higher.
- Areas that are too small (wind parks are profitable from a size of 25 ha).[45]

Potential

For the determined suitable areas the highest possible number of wind turbine generators (WTG) has to be evaluated. In fact this is a complex calculation. Since a lot of necessary variables are not known here, for reasons of simplicity a formula from another study is used.[46]

The weighting of the wind speed for the whole of the suitable areas is calculated based on the local measured wind speed values and the surface area of each single polygon. Both of these factors are set in relation to each other.

Finally, the possible annual yield is calculated by multiplying the evaluated number of WTG with the estimated mean wind speed value.

3.1.3 Exclusion Areas

All exclusion areas are cut out of the province area. For this purpose, all exclusion areas are first merged in a layer *WindClip*. These areas of layer *WindClip* are then cut out from layer *GautengArea*, resulting in the layer *WindArea*.

3.1.4 Size of the Polygon areas

In order to exclude areas that are too small for wind parks as per the definition above, the sizes of all 13,635 single polygons are calculated in square meters. After that all polygons smaller than 250,000 m^2 are deleted. The outcome is layer *WindArea25*.

[44] KRUCK, 2013
[45] KRUCK, 2013
[46] KRUCK, 2013

In fact some smaller objects could come into consideration as well, if:

- several of them together form an area of at least 25 ha, AND
- they are located close together, AND
- they can be connected with transmission lines without difficulties, OR
- there exist local wind speeds that make the installation of one single WTG profitable.

3.1.5 Evaluation of Suitable Areas

All areas where the use of wind power is possible in general, shall be evaluated regarding their proximity to existing infrastructure (roads and transmission lines) as well as the local existing wind speed. For this purpose the multiple buffer zone layers *RoadsProx6* and *TransmissionLinesProx6* are intersected with each other and with the wind speed zones.

The following values are applied for these three factors: There are wind speed values between 4.49 und 4.62. For the proximity to roads and transmission lines 6 points are assigned for areas with a maximum distance of 2 km, 4 points for a maximum distance of 4 km and 2 points for a maximum distance of 6 km.

The values for the local wind speeds are contained in the polygons of layer *WindSpeed*.

Intersection

The outcome of the intersection of the layers *RoadsProx6*, *TransmissionLinesProx6* and *WindSpeed* is the layer *WindZones* with all subareas and all attributes of the original layers. In this layer in the attribute “WindValue” for each single subarea polygon the suitability values are calculated with the formula **[RoadProx] * [TransProx] * [WindSpeed]^3**.

This calculation formula with the parameters as explained in figure 23, considers the fact, that the wind power is proportional to the third power of the wind speed.[47]

The wind power is given by the formula: $P = 0.5 * \rho * A * V^3$

where: P: power in watt (W) A: rotor circular area in m^2
ρ: air density in kg/m^3 V: wind speed in m/s

Figure 23: Wind power formula

Then the generally suitable areas (Layer *WindArea25*) are clipped out of layer *WindZones*. The outcome is layer *WindResult*, the final result of this analysis. In this layer all polygons with value are deleted. This means that only areas within at most 6 km distance from roads or transmission lines come into consideration as wind park site. Finally 32 polygons with values from 369.382 to the theoretical maximum of 3,550 remain.

[47] KRUCK, 2013

The map in figure 24 shows all areas that are suitable as wind park sites in the sense of this analysis. The darker the colour, the more suitable based on the proximity to roads and transmission lines as well as the level of the local wind speed.

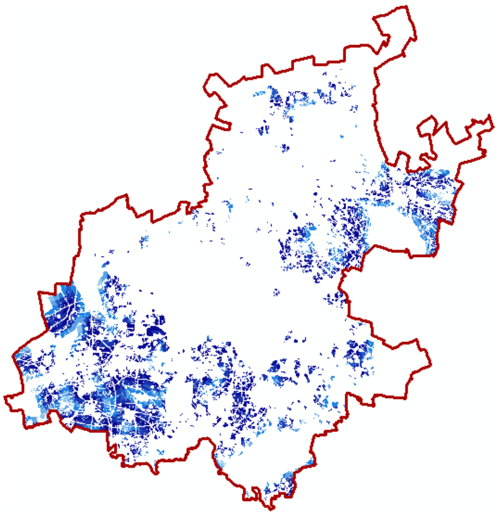


Figure 24: Wind analysis result

Further Evaluation

All these single areas have to undergo a separate examination, so that possibly further areas are excluded.

Still included are e.g. the agricultural areas for which a parallel use as wind park sites has to be examined individually. Furthermore, radio-relay systems of telecommunication organisations or areas used by armed forces are criteria for exclusion disregarded so far.

Type and quality of the original data cause errors as well. The pictures in figure 25 shall exemplify this: In the left picture the suitable areas overlie the airport of Johannesburg (O.R. Tambo International Airport). For airports as such no data were on hand.

The middle picture shows suitability areas overlying an industrial plant. Obviously in the land use data this was neither identified as such nor as other urban area.

The holes in the right picture are buffered single pixels of the land use forest located here by mistake.

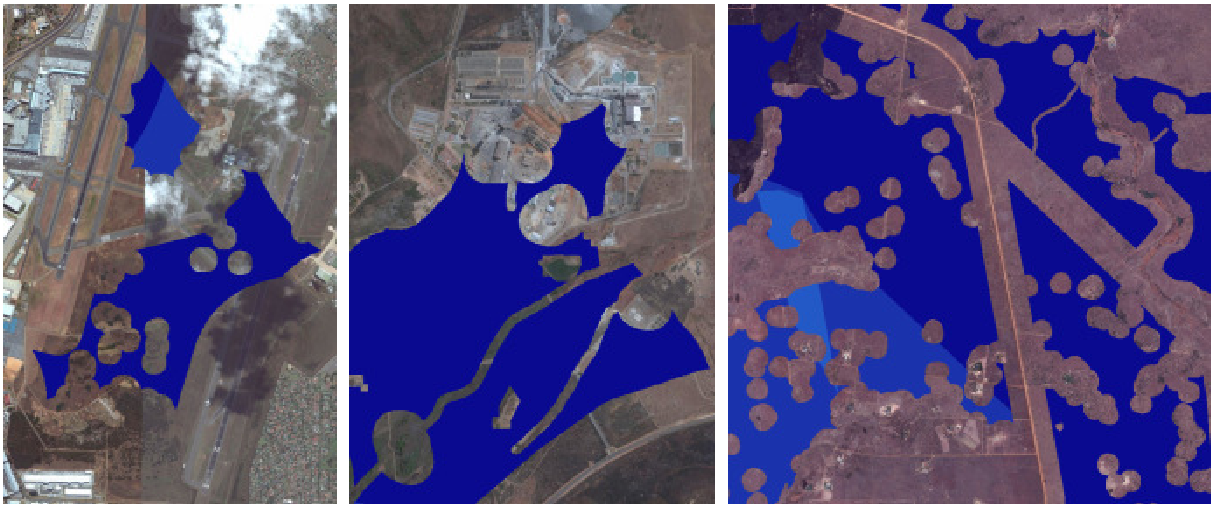


Figure 25: Insufficient result due to poor data quality

3.1.6 Potential Calculation

The identified areas of suitability cover a total area of 251,288 ha.

The number of WTG that in fact can be placed on these areas cannot be calculated by a single division. Depending on the local prevailing wind direction on an area with a specific shape more or less WTG can be placed. As well not all areas are located adjacently, which results in a lot of residual areas.

In a study the designation of wind power priority areas in the Neckar-Alb region (Baden-Württemberg, Germany) has been regarded. In this context, for the purpose of estimating the possible number of WTG in bigger wind parks, the following empirical formula[48] has been derived: **Number of WTG = 0.0443 * Area in ha + 2.59**

The possible number of WTG has been estimated with this formula for the identified wind power priority areas. Afterwards a regression analysis for these pairs of values has been performed. The formula enables for other wind parks as well a rough estimation of the possible number of WTG. For Gauteng this results in the following calculation: **0.0443 * 251,288 ha + 2.59 = 11,135 WTG**

Mean Wind Speed

For the calculation of the mean wind speed for each polygon in layer *WindResult* the area is calculated in ha. Then based on the wind speed and the area of each polygon a value for a new attribute “MidWind” is calculated.

According to the attribute table the total area of all polygons amounts to 251,287.73 ha. The total sum of the “MidWind” values adds up to 1,149,354.587. The mean wind speed is calculated by dividing the last amount by the total area. Here the outcome for the relevant areas is 4.57 m/s.

At this wind speed in a height of 120 m and with an assumed technical availability of 97 %, which is a common value, with a representative WTG (Vestas V-90, nominal power 2.0 MW) an annual power generation of 2.47 GWh is possible.[49]

Possible Annual Yield

For the calculation of the possible annual yield in all identified areas in Gauteng, regardless of the inaccuracy described above, the calculated 11,135 WTG are assumed. As the wind speed values in Gauteng range within a narrow bandwidth, the mean value of 4.57 m/s calculated above is used here.

With 2.47 GWh/a per WTG in total the outcome is 27,502.58 GWh/a or 27.5 TWh/a, respectively.

[48] KRUCK, 2013
[49] KRUCK, 2013

Figure 26 shows the original layers (with blue border line) used in this analysis along with the working steps, inter-mediate data and result layers (with red border line).

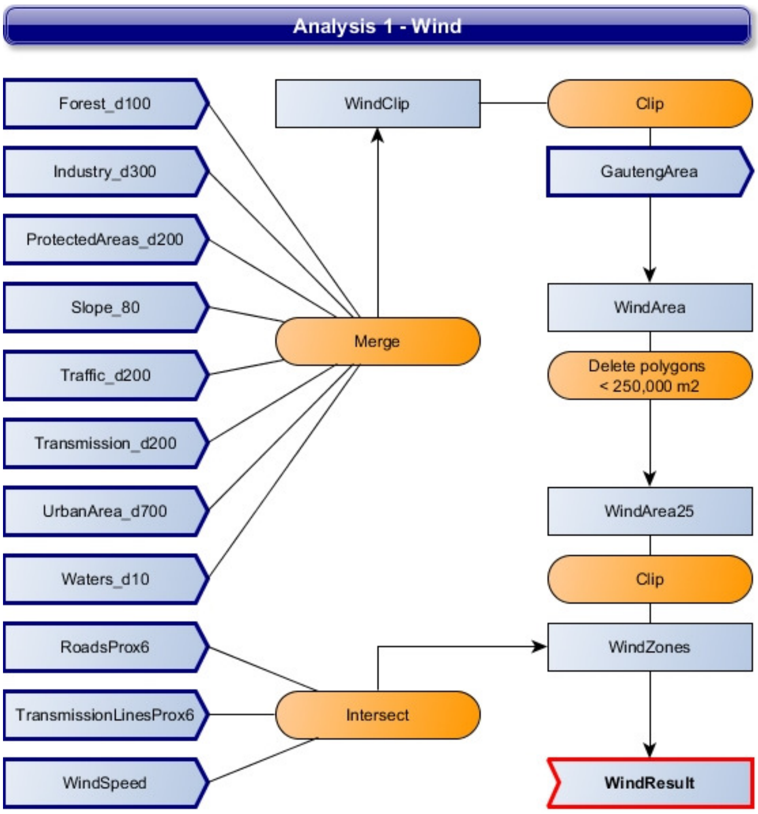


Figure 26: Data in Wind analysis

3.2 ANALYSIS 2 – BIOMASS / WOOD

3.2.1 Data

These layers are required for this analysis and are loaded in an ArcMap file:

- *Cultivation* Agricultural cultivation areas
- *Forest* Forest areas
- *Industry* industrial areas
- *LatLonFifth* Square Array of fifth degrees
- *Livestock* Agricultural pasture areas
- *ProtectedAreas* Protected areas
- *Railway_d10* Buffer zone 10 m around railway lines
- *Roads_dist* Roads with variable widths
- *RoadsProx6* Multiple buffer zone around roads
- *SlopeK1* to *SlopeK5* Areas with different slope limit
- *Transmission_d50* Buffer zone 50 m around transmission lines
- *TransmissionLinesProx6* Multiple buffer zone around transmission lines
- *UrbanArea* Urban areas
- *Waters_d10* Buffer zone 10 m around water bodies

Bing Maps Aerial is loaded as background map for plausibility checks. Layer *GautengBoundary* is loaded as orientation.

3.2.2 Approach

Subject of this analysis is the potential calculation for energy production out of wood and the search for suitable locations for wood-fired power plants. This contains the following steps:

- Determining the available forest area by calculating the surface area of the polygons in layer forest.
- Calculating the potential of these forest areas. This calculation is based on the available forest area, a given volume yield for forest residues per ha, and a given heat value.
- Estimating the number of wood-fired power plants for the processing of the determined wood amount. This is calculated based on the available wood amount and the power of actual plants. Several calculations with different assumptions lead to a range of comparative values.

- Determining the areas suitable and available for wood-fired power plants. For this purpose all areas not suitable for power plants are excluded from the Gauteng province area. Additionally, areas below a minimum size and a defined compactness ratio are excluded.
- Evaluation of these areas based on the proximity to roads, transmission lines and forest areas.

3.2.3 Forest Areas

First the available forest areas are determined. The whole forest area of Gauteng is defined as available (see figure 27), because wood used for the power plants can be harvested parallel to other usage of the forests.

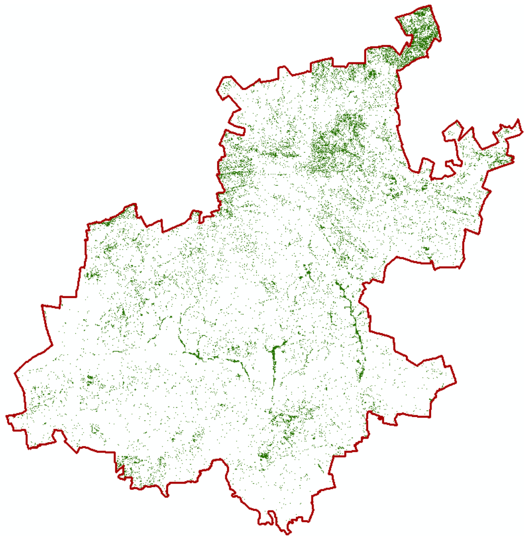


Figure 27: Available forest areas

As per layer *Forest* the total area of all polygons amounts to 1,283,263,966.51 m^2 or 128,326 ha, respectively.

The definition of a minimum size for useable forest areas is based on several factors. Basically the expected yield has to be set in relation to the efforts for logging. The effort in turn is calculated from labour cost and material cost and is partially depending on distance and accessibility of the forest sector. Growth conditions based on climatic factors as well take effect, since for a sustainable use only a wood amount below the accrescence is allowed to be harvested[50]. Since in this context neither for yield nor for effort any sums are known, a breakeven point cannot seriously be calculated. Beyond that, due to the unfavourable data structure of the forest data, the areas below a somehow defined threshold cannot be filtered reliably. For that reason no minimum size for forest areas has been defined.

According to the slope the forest areas are divided in five classes, defining the accessibility for the wood harvest.[51] These classes form a quality criterion for the potential power plant locations. Regarding the use of the forest areas class 5 is an exclusion area.

Slope		
Class		Grade
1	Slightly	0 % to < 13 %
2	Possible	13 % to < 36 %
3	Hard	36 % to < 62 %
4	Extreme	62 % to < 93 %
5	Impossible	93 % to 100 %

Table 7: Slope classes

Potential

The volume yield for forest residues is 1.0 t/(ha*a)[52]. This wood has a heat value of 15.6 MJ/kg. An alternative calculation with 0.5 t/(ha*a) shows the difference to a more conservative estimation.

[50] REICHLE, 2013
[51] KAPPLER, 2007: A131
[52] FNR, 2012: 18

With 1.0 t/(ha*a) from 128,326 ha forest area there can be harvested 128,326 t forest residues per year, which again have a heat value of 2,001,885,600 MJ. The formula to convert Joule into watt-hours is: **1 Wh = [J] * 0.00027778** or **1 kWh = [MJ] * 0.27778**, respectively.[53]

With this formula the calculation for Gauteng is: 2,001,885,600 MJ * 0.277781 = 556,083,782 kWh, which means that there is an existing potential of 556,084 MWh/a or 556.1 GWh/a. Table 8 additionally shows the values for the conservative calculation with a volume yield of 0,5 t/(ha*a).

Total Potential of Gauteng		
Area	128.326 ha	128.326 ha
Volume Yield	1,0 t/(ha*a)	0,5 t/(ha*a)
Annual Yield	128.326 t	64.163 t
Heat Value	15,6 MJ/kg	15,6 MJ/kg
Heat Value/Yield	2.001.885.600 MJ	1.000.942.800 MJ
Heat Value (kWh)	556.083.782 kWh	278.041.891 kWh
Heat Value (MWh)	556.084 MWh	278.042 MWh
Heat Value (GWh)	556 GWh	278 GWh

Table 8: Wood analysis – Total potential

3.2.4 Power Plants

Number of Power Plants

The number of power plants that have to be built is calculated based on the available amount of wood and the assumed power of common current plants. The energy that can be produced with the available amount of wood has been calculated above. As plant sizes 800 kW, 2 MW and 5 MW shall be assumed here, as average annual runtime 8,000 h and as efficiency value 30 % (see table 9).

Annual Performance of Power Plants			
Power	0,8 MW	2,0 MW	5,0 MW
Runtime	8.000 h/a	8.000 h/a	8.000 h/a
Efficiency	30%	30%	30%
Annual Performance	21.333 MWh	53.333 MWh	133.333 MWh

Table 9: Wood analysis – Annual performance of power plants

The energy that can be produced with a power plant is calculated with the formula:

Energy per Year = [Power in kW] * [Runtime in h] / [Efficiency as Proportional Value][54]

This results in: 0.8 MW * 8,000 h / 0.3 = 21,333 MWh/a

2 MW * 8,000 h / 0.3 = 53,333 MWh/a

5 MW * 8,000 h / 0.3 = 133,333 MWh/a

Based on this, the number of required power plants is calculated with this formula:

Power Plants = [Energy of Wood in MWh/a] / [Power of Power Plants in MWh/a]

This leads to the following results:

[556,084 MWh/a] / [21,333 MWh/a] = 26.1 (rounded: 26 power plants)

[556,084 MWh/a] / [53,333 MWh/a] = 10.4 (rounded: 10 power plants)

[556,084 MWh/a] / [133,333 MWh/a] = 4.2 (rounded: 4 power plants)

[278,042 MWh/a] / [21,333 MWh/a] = 13.0 (rounded: 13 power plants)

[278,042 MWh/a] / [53,333 MWh/a] = 5.2 (rounded: 5 power plants)

[278,042 MWh/a] / [133,333 MWh/a] = 2.1 (rounded: 2 power plants)

[53] FNR, 2007: 353
[54] FNR, 2012

Table 10 shows the results for a 800 kW power plant as well as for a 2 MW facility and for the volume yields 1.0 t/(ha*a) and 0.5 t/(ha*a).

Number of Power Plants						
Volume Yield	1,0 t/(ha*a)	1,0 t/(ha*a)	1,0 t/(ha*a)	0,5 t/(ha*a)	0,5 t/(ha*a)	0,5 t/(ha*a)
Total Potential	556.084 MWh	556.084 MWh	556.084 MWh	278.042 MWh	278.042 MWh	278.042 MWh
Power	0,8 MW	2,0 MW	5,0 MW	0,8 MW	2,0 MW	5,0 MW
Annual Performance	21.333 MWh	53.333 MWh	133.333 MWh	21.333 MWh	53.333 MWh	133.333 MWh
Number of Power Plants	**26,1**	**10,4**	**4,2**	**13,0**	**5,2**	**2,1**

Table 10: Wood analysis – Number of power plants

Proceeding the opposite way, it can be calculated how capable one power plant has to be, that processes the total available wood in Gauteng. This is calculated with the formula:

Power in MW = [Energy of Wood in MWh/a] * [Efficiency as Proportion Value] / [Runtime in h]

This results in: 556,084 MWh/a * 0.3 / 8,000 h = 20.85 MW
or alternatively: 278,042 MWh/a * 0.3 / 8,000 h = 10.43 MW

Due to the rule that raw materials should not be transported more than 50 km to power plants, in view of the size of the Gauteng province this calculation does not have to be taken into account.[55]

Areas suitable for Power Plants

Areas suitable for power plants are in general all areas apart from: Urban areas, roads, railway lines, transmission lines, water bodies, swamps, protected areas, forests, agricultural areas (cultivation and livestock, industrial areas.

An area of 400 m^2 is defined as the minimum size for a power plant site. This is more than the 300 m^2 for a 800 kW plant and excludes approximate areas as well, which have the required size, but no suitable shape for the location of a power plant. On a 400 m^2 site even a 2 MW plant could be built.[56]

Exclusion Areas

All exclusion areas are clipped out of the area of Gauteng (layer *GautengArea*). These are the layers *Waters_d10*, *UrbanArea*, *ProtectedAreas*, *Cultivation*, *Livestock*, *Industry*, *Roads_dist*, *Railway_d10*, *Transmission_d50*. The outcome is layer *WoodArea* with 79,948 Polygons.

Minimum Size and Compactness

In layer *WoodArea* all polygons smaller than 400 m^2 are deleted.

$$CompactRatio = \frac{P}{2\pi\sqrt{\frac{A}{\pi}}}$$

Figure 28: Compactness ratio formula

With the formula shown in figure 28 the compactness of polygons can be calculated. The smaller the compact ratio value, the better the compactness of the polygon.

[55] ÖZDEMIR, 2012
[56] FNR, 2007: 147

Figure 29 shows the polygons with the best (brown) and the poorest (light blue) compactness. The latter are artifacts, occurring due to small data inaccuracies.

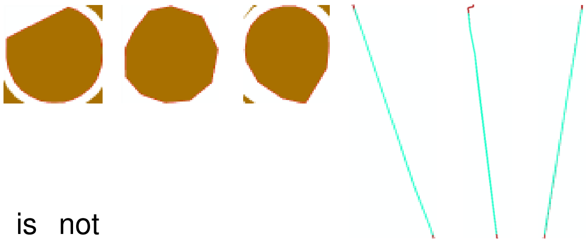


Figure 29: Compactness ratio formula

To filter artifacts from the other objects it is not sufficient to pick those polygons with the highest compact ratio values. This could imply big delicate areas with a compact part, which in fact could serve as power plant site. For that reason, additionally small areas have to be filtered. After an iterative process with modified values of size and compactness ratio finally a minimum size of 10,000 m^2 and a maximum compactness ratio of 7.0 is defined as filter limit.

Then the artifacts are detected and deleted. As well polygons with a shape that disqualifies them for power plants are deleted. After this layer *WoodArea* contains 54,074 polygons.

3.2.5 Evaluation of Areas

The areas are evaluated based on the available wood in the surrounding as well as the proximity to roads and transmission lines. The slopes are a quality criterion for these areas as well.

Distribution of Forest Areas

The evaluation of the available forest areas is based on fields with an edge length of a fifth degree. In Gauteng this equals an edge length of about 20 km.

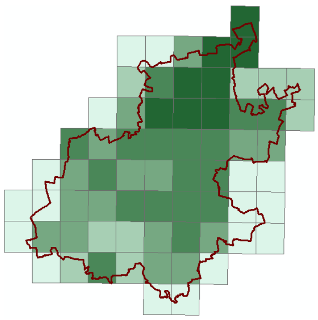


Figure 30: Local amounts of forest area

The forest areas are merged with layer *LatLonFifth*, which contains this square array. The symbolisation of the new layer *ForestAmount* shows the amount of forest area located in each square field. The attribute “ForestAmount” contains the added up area values for each square field.

Evaluation of potential Power Plant Sites

In order to evaluate suitable areas, the multiple buffer zones around roads and transmission lines are merged with the wood amount values from layer *ForestAmount* and the slope zones *SlopeK1* to *SlopeK5*. The values of these quality criteria are set as given in table 11.

Values of Location Criterions					
Wood Amount			Roads	Transmission	Slope
Maximum	103.295.571	5,020	6	6	5
	10.000.000	3,749			4
	1.000.000	2,812	4	4	3
	100.000	2,108			2
Minimum	27.252	1,792	2	2	1

Table 11: Location criteria

The outcome is layer *WoodZones* with all subareas and attributes of the original layers.

Relationship of the Criteria

After trying several quantifications of the different criteria this formula is used: **([RoadProx]+2)*([RoadProx]+2)*([TransProx]+2)*([TransProx]+2)*[WoodValue^3]*[Slope Value^2]**

For symbolisation purposes the values are arranged in seven classes with the same interval. Values equaling 0 are excluded. The result makes the zones of suitability for the placement of wood-fired power plants visible. The darker the colour, the better the suitability.

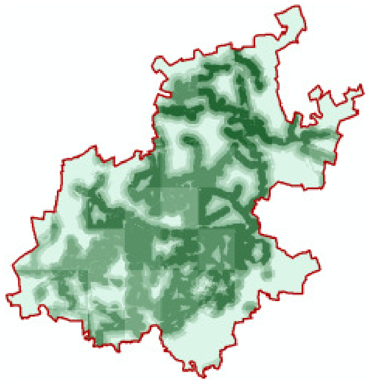


Figure 31: Wood analysis – Zones of suitability for power plants

Locations by Quality

From these zones of suitability the generally suitable areas (layer *WoodArea*) are clipped. The outcome is layer *WoodResult*, the final result of this analysis.

The map in figure 32 shows all areas that are suitable as wood-fired power plant sites in the sense of this analysis. The darker the colour, the more suitable based on the proximity to roads and transmission lines as well as on the available wood in the surrounding and the local slope.

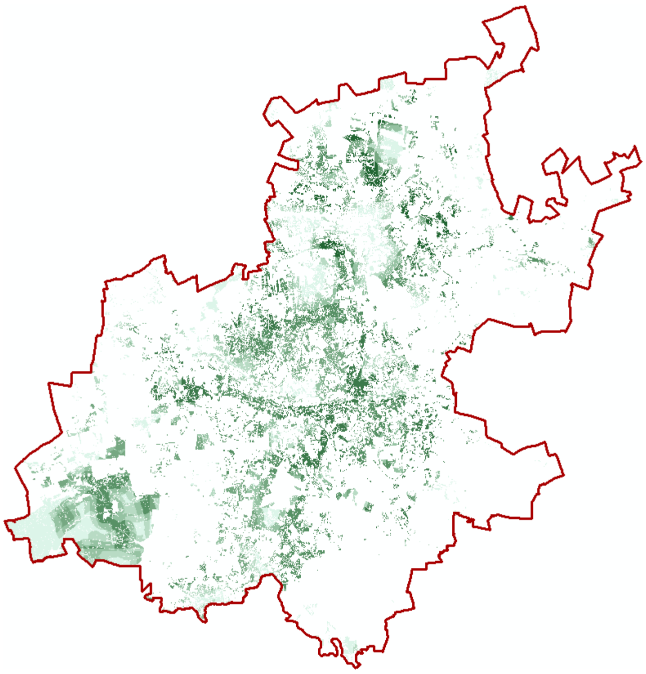


Figure 32: Wood analysis result

Most Suitable Locations

With the formula used here, the available wood in the surrounding area dominates against the other evaluation criteria. Marking only the best values – in several steps from the left to the right picture in figure 33 – makes clear, that the most suitable areas are located along the infra-structure lines in Gauteng. The top sites can be localised in the central north of the province.

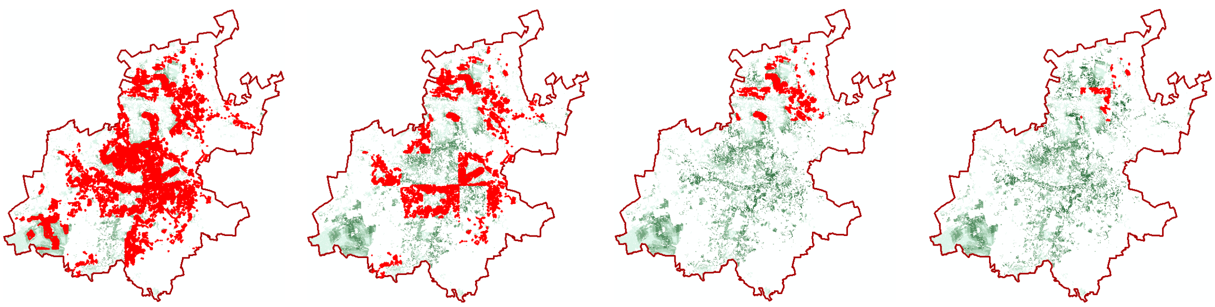


Figure 33: Wood analysis – Most suitable locations

Figure 34 shows the layers used in this analysis along with the working steps, inter-mediate data and result layers.

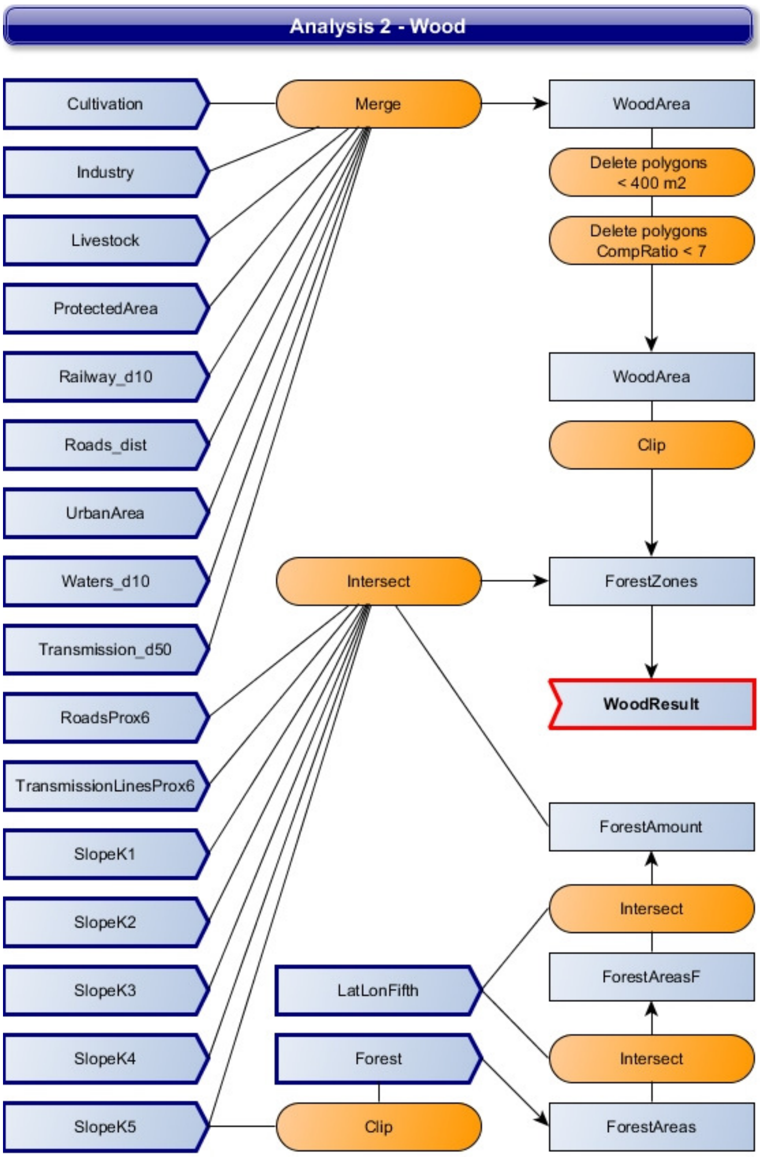


Figure 34: Data in Wood analysis

3.3 ANALYSIS 3 – BIOMASS / ENERGY CROPS

3.3.1 Data

These layers are required for this analysis and are loaded in an ArcMap file:

- *Cultivation* Agricultural cultivation areas
- *Industry* industrial areas
- *LatLonFifth* Square Array of fifth degrees
- *Livestock* Agricultural pasture areas
- *Maize* Cultivation areas of maize
- *ProtectedAreas* Protected areas
- *Railway_d10* Buffer zone 10 m around railway lines
- *Roads_dist* Roads with variable widths
- *RoadsProx6* All roads with multiple buffers
- *Sunflower* Cultivation areas of sunflowers
- *Transmission_d50* Buffer zone 50 m around transmission lines
- *TransmissionLinesProx6* Multiple buffer zone around transmission lines
- *UrbanArea* Urban areas
- *Waters_d10* Buffer zone 10 m around water bodies
- *YieldCapacity* Yield capacities of the cultivation areas

As background map for plausibility checks *Bing Maps Aerial* is loaded. Layer *GautengBoundary* is loaded as orientation.

3.3.2 Approach

Subject of this analysis is the potential for energy production out of energy crops and suitable locations for related power plants. This contains the following steps:

- Determining the available cultivation areas.
- Calculating the potential of these cultivation areas.
- Determining the areas suitable and available for related power plants.
- Evaluation of these areas based on the proximity to roads, transmission lines and cultivation areas.

Maize, rapeseed, soy, sunflower, sugar cane and sugar beet come into consideration as energy crops. But since there are only data for maize and sunflower on hand only these crops are regarded here. For sugar cane and sugar beet there are better conditions in other provinces, they are not relevant in Gauteng.

All areas that are used for these crops so far, are regarded as cultivation area. Certainly not all of these areas can be used for energy production, but the proportion that shall be used for this purpose is subject to a political discussion.

3.3.3 Cultivation Areas

Layer *Maize* (brown in the map in figure 35) contains 15,210 polygons, layer *Sunflower* (green) 1,217 polygons.

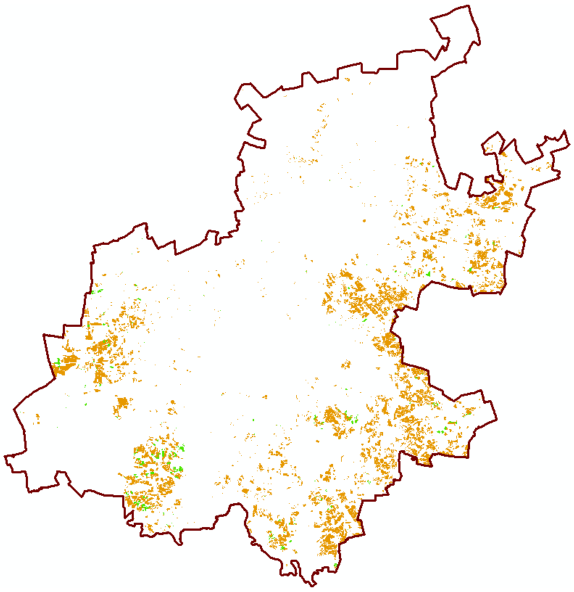


Figure 35: cultivated area – Maize (Brown) and Sunflower (Green)

The maize areas cover a total of 2,003,534,136.368 m^2, which is 200,353 ha.

The sunflower areas cover a total of 149,010,437.978 m^2, which is 14,901 ha.

For the energy production usage a minimum size for profitable cultivation areas should be defined. This will be around 2 to 5 ha. The minimum size in the political process of the participation of the HDI (Historically Disadvantaged Individuals) could be valid as an indication value. The Subdivision Act on Minimum Farm Sizes does not give a specific value for that.[57]. There is just the predetermined principle, that the minimum size of a farm has to be an economic unit.[58]

Figure 36: Cutout of cultivated areas (Maize)

If the minimum size is assumed to be 3 ha and all smaller areas are deleted, then certainly a lot of areas are dispensed of, that in fact are part of an associated economic unit (farm). Thus most probable, working with all areas, even the smallest, makes the result a more realistic picture.

Potential

Approximately 10,000 m^3 biogas can be produced from energy maize with 30 % dry substance on one ha cultivation area. This equals a theoretical (gross) heat value of 60,000 kWh. In practice about 70 % of the energy dissipates as heat waste during the operation of the gas motor. About net 18,000 kWh net remain.

60,000 kWh * 0.3 = 18,000 kWh
18,000 kWh / 7,000 h = 2.5 kW
(with 0.3 for 30 %)

Figure 37: Heat value calculation formula

[57] BERRISFORD et al., 2008: 19
[58] FRANTZ, 2010: 23

With an annual gas turbine runtime of 7,000 h and an efficiency of about 30 % a 2.5 kW installation facility is operated at full capacity. For a biogas heating plant with a gas turbine per kW an area of 0.4 ha is required, with 1 ha cultivation area a 6.25 kW facility could be operated at full capacity. For a power plant with a gas turbine that can generate 250 kW/h about 100 ha cultivation area are required.[59]

From 1 ha cultivation area of sunflower about 30,000 kWh can be generated.[60]

The cultivation area of maize covers 200,353 ha. From one ha cultivation area of maize 18,000 kWh/a can be generated. This results in a total potential for maize in Gauteng of 3,606,354 MWh/a or 3,606 GWh/a.

Potential of Gauteng		
	Maize	Sunflower
Area	200.353 ha	14.901 ha
Volume Yield	18.000 kWh/a	30.000 kWh/a
Potential	3.606.354 MWh/a	447.030 MWh/a
Potential	3.606 GWh/a	447 GWh/a

Table 12: Crop analysis – Total potential

The cultivation area of sunflower covers 14,901 ha. From one ha cultivation area of sunflower 30,000 kWh/a can be generated. This results in a total potential for sunflower in Gauteng of 447,030 MWh/a or 447 GWh/a (see table 12).

The combined total potential amounts to 4,053,348 MWh/a or 4,053 GWh/a.

Of course not all of these areas can be used for energy production, but the proportion that shall be used for this purpose requires a political decision. However, table 13 shows the potential at different proportional usage.

Level of Potential Utilisation			
	Maize	Sunflower	Total
100%	3.606 GWh/a	447 GWh/a	4.053 GWh/a
90%	3.246 GWh/a	402 GWh/a	3.648 GWh/a
80%	2.885 GWh/a	358 GWh/a	3.243 GWh/a
70%	2.524 GWh/a	313 GWh/a	2.837 GWh/a
60%	2.164 GWh/a	268 GWh/a	2.432 GWh/a
50%	1.803 GWh/a	224 GWh/a	2.027 GWh/a
40%	1.443 GWh/a	179 GWh/a	1.621 GWh/a
30%	1.082 GWh/a	134 GWh/a	1.216 GWh/a
20%	721 GWh/a	89 GWh/a	811 GWh/a
10%	361 GWh/a	45 GWh/a	405 GWh/a

Table 13: Crop analysis – Utilisation level

3.3.4 Power Plants

Number of Power Plants

The number of power plants that have to be built is calculated based on the available amount of crops and the assumed power of usual actual plants. The energy that can be produced with the available amount of crops has been calculated above. It is 4,053,348 MWh/a. Same as in the analysis "Wood" as plant size 800 kW, 2 MW and 5 MW shall be assumed here, as average annual runtime 8,000 h and as efficiency value 30 % (see table 14).

Annual Performance of Power Plants			
Power	0,8 MW	2,0 MW	5,0 MW
Runtime	8.000 h/a	8.000 h/a	8.000 h/a
Efficiency	30%	30%	30%
Annual Performance	21.333 MWh	53.333 MWh	133.333 MWh

Table 14: Crop analysis – Annual performance of power plants

The energy that can be produced with a power plant is calculated with this formula[61]:
Energy per Year = [Power in kW] * [Runtime in h] / [Efficiency as Proportional Value]

This results in: 0.8 MW * 8,000 h / 0.3 = 21,333 MWh/a
2 MW * 8,000 h / 0.3 = 53,333 MWh/a
5 MW * 8,000 h / 0.3 = 133,333 MWh/a

59 LEL, 2013
60 O.V., 2011b: 9
61 FNR, 2012

Based on this the number of required power plants is calculated with this formula: **Power Plants = [Energy of Crops in MWh/a] / [Power of Power Plants in MWh/a]**

The results of this calculation can be taken from table 15.

Number of Power Plants						
Volume Yield	1,0 t/(ha*a)	1,0 t/(ha*a)	1,0 t/(ha*a)	0,5 t/(ha*a)	0,5 t/(ha*a)	0,5 t/(ha*a)
Total Potential	4.053.384 MWh	4.053.384 MWh	4.053.384 MWh	4.053.384 MWh	4.053.384 MWh	4.053.384 MWh
Power	0,8 MW	2,0 MW	5,0 MW	0,8 MW	2,0 MW	5,0 MW
Annual Performance	21.333 MWh	53.333 MWh	133.333 MWh	21.333 MWh	53.333 MWh	133.333 MWh
Number of Power Plants	190,0	76,0	30,4	95,0	38,0	15,2

Table 15: Crop analysis – Number of power plants

Depending on the parameters the number of power plants ranges from 15 to 190.

The opposite way it can be calculated how capable one power plant has to be, that processes the total available crops in Gauteng. This is calculated with the formula:

Power in MW =
[Energy of Crops in MWh/a] * [Efficiency as Proportion Value] / [Runtime in h]

This results in: 4,053,384 MWh/a * 0.3 / 8,000 h = 152 MW
or alternatively: 2,026,692 MWh/a * 0.3 / 8,000 h = 76 MW

Raw materials should not be transported more than 50 km to the power plants. However, regarding the size of the Gauteng province this calculation does not have to be taken into account.[62]

Areas suitable for Power Plants

The exclusion areas and the minimum sizes are equal to those of the analysis "Wood". From this it follows that layer *CropArea* is identical to layer *WoodArea*.

3.3.5 Evaluation of Areas

The areas are evaluated based on the available crops in the surrounding area and the quality of the cultivation areas as well as the proximity to roads and transmission lines. Since it is assumed that all crops shall be used in common power plants, both cultivation areas are combined in layer *EnergyCrops*. The different potential values calculated above are considered as attribute values in the referring polygons.

Quality of the Cultivation Areas

The zones of soil quality (layer *YieldCapacity*) are merged with the cultivation ares (layer *EnergyCrops*). The outcome is layer *EnergyCropsY*. Then in a new attribute "CropPot" for each polygon the potential is calculated based on the soil quality value.

[62] Özdemir, 2012

Distribution of Crop Cultivation Areas

The evaluation of the available crop cultivation areas is based on fields with an edge length of a fifth degree. In Gauteng this equals an edge length of about 20 km.

The crop cultivation areas (layer *EnergyCropsY*) are merged with layer *LatLonFifth*, which contains this square array. The symbolisation of the new layer *CropAmount* in figure 38 shows the amount of crop cultivation area located in each square field. The attribute "CropAmount" contains the added up area values for each square field.

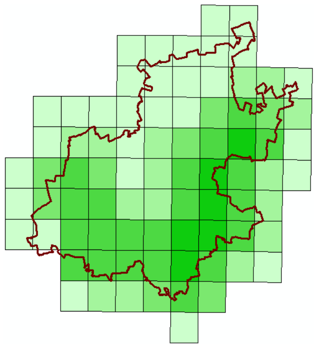


Figure 38: Local amounts of crop cultivation area

The procedure is widely the same as in the analysis "Wood". But in contrast here the fields extend beyond the provincial area of Gauteng and at the provincial boundary the values do not sink explicitly. The reason for that is the inclusion of the 15 km buffer. This enhances the result considerably.

Evaluation of potential Power Plant Sites

In order to evaluate suitable areas the multiple buffer zones around roads and transmission lines are merged with the crop cultivation areas. The values of the different criteria are converted in a way that none of them dominates the others.

The result is layer *CropZones* with all subareas and attributes of the original layers (see figure 39). For the symbolisation the values are arranged in six classes with the same interval. Values equaling 0 are excluded. The result makes the zones of suitability for the placement of crop-fired power plants visible. The darker the colour, the better the suitability

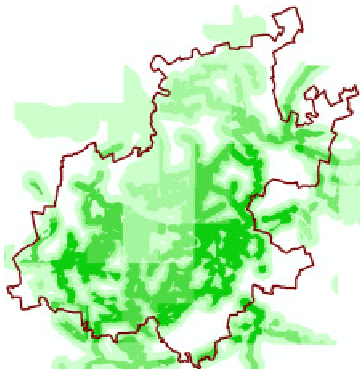


Figure 39: Crop analysis – Zones of suitability for power plants

Locations by Quality

From these zones of suitability the generally suitable areas (layer *CropArea*) are clipped. The outcome is layer *CropResult*, the final result of this analysis

The map in figure 40 shows all areas that are suitable as biomass power plant sites in the sense of this analysis. The darker the colour, the more suitable based on the proximity to roads and transmission lines as well as on the available crops in the surrounding.

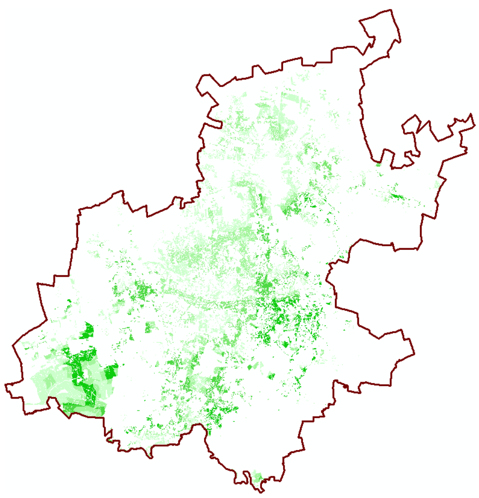


Figure 40: Crop analysis result

Most Suitable Locations

With the formula used here the available crops in the surrounding area have the same weight as the other evaluation criteria. Marking only the best values – in several steps – makes clear, that the most suitable areas are located in the south east of Gauteng Province.

In figure 41 in addition to the potential power plant sites (brown) the cultivation areas are displayed (green). This makes the suitability of the top locations visible by the abundance of cultivation areas.

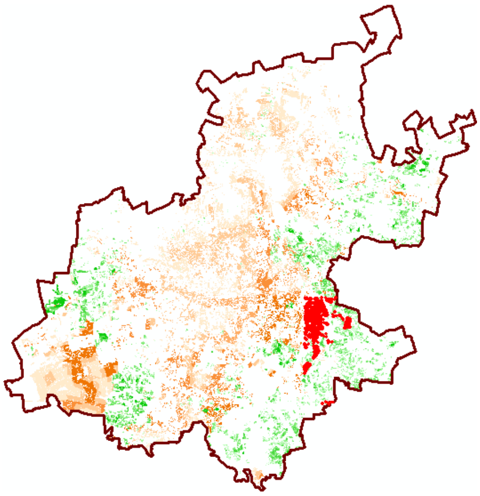


Figure 41: Wood analysis – Most suitable locations

Figure 42 shows the layers used in this analysis along with the working steps, inter-mediate data and result layers.

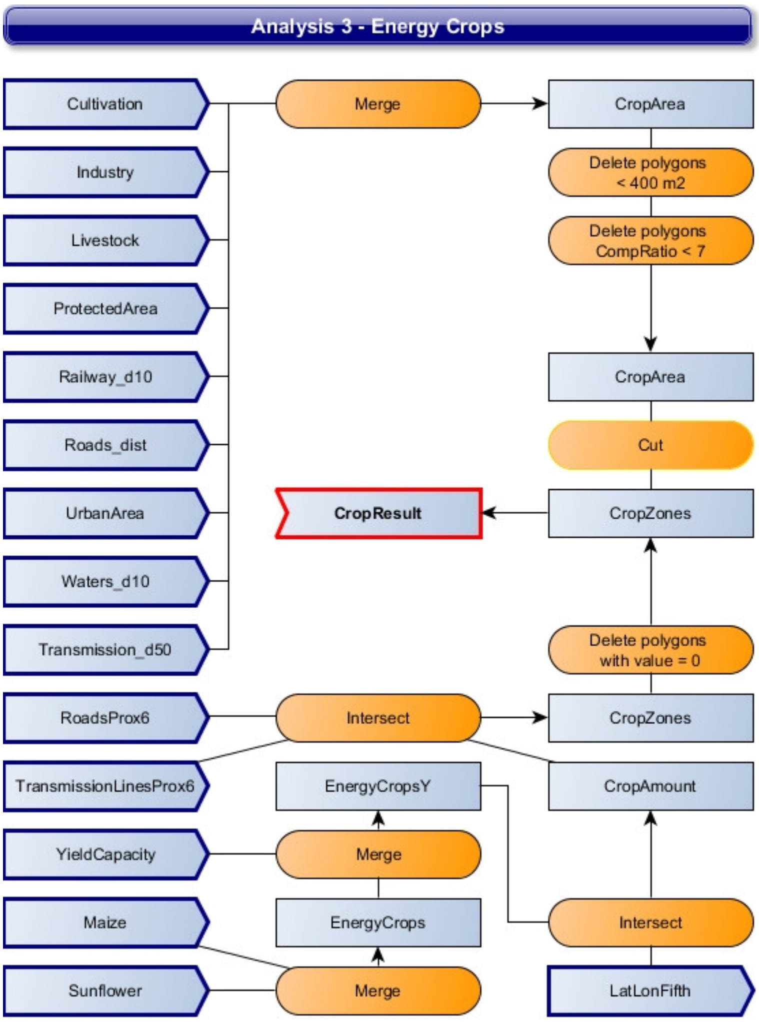


Figure 42: Data in Crop analysis

3.4 ANALYSIS 4 – CONCENTRATED SOLAR POWER

3.4.1 Data

These layers are required for this analysis and are loaded in an ArcMap file:

- *Cultivation* Agricultural cultivation areas
- *GautengArea* Polygon of the province area
- *Industry_d25* Buffer zone 25 m around industrial areas
- *Livestock* Agricultural pasture areas
- *ProtectedAreas* Protected areas
- *Railway_d10* Buffer zone 10 m around railway lines
- *Roads_dist* Roads with variable widths
- *RoadsProx6* All roads with multiple buffer zones
- *SolarRadiation* Zones of solar radiation
- *Transmission_d50* Buffer zone 50 m around transmission lines
- *TransmissionLinesProx6* Transmission lines with multiple buffer zones
- *UrbanArea_d25* Buffer zone 25 m around urban areas
- *Waters_d10* Buffer zone 10 m around water bodies

These layers were planned to be used, but were rejected later on.

- *Forest_d60* Buffer zone 60 m around forest areas
- *Slope21* Areas with a gradient of 2.1 % or higher

Bing Maps Aerial is loaded as background map for plausibility checks. Layer *GautengBoundary* is loaded as orientation.

3.4.2 Approach

Subject of this analysis is the potential for energy production with concentrated solar power (CSP) and suitable locations for CSP. This contains the following steps:

- Determining the areas suitable and available for CSP. Three different methods are tested to find an adequate result.
- Evaluation of these areas based on the local existing solar radiation as well as the proximity to roads and transmission lines.
- Statement on the potential of these areas.

Concept of the Analysis

Starting with the entire area of the Gauteng province, all areas not suitable for CSP are excluded step by step. Then the remaining areas are evaluated based on the local existing solar radiation as well as the proximity to roads and transmission lines.

3.4.3 Exclusion Areas

Definition of Exclusion Areas

Areas excluded due to the type of use:

- Following a thesis on the use of solar energy in North Africa: Urban area, industrial area, water bodies, protected area, unsuitable land cover, unsuitable geomorphology, too high slope values.[63]
- Following a DLR report in the framework of the EU project REACCESS: Sea, other water bodies, swamp, sand dunes, glacier (mandatory), forest, agricultural area, rice cultivation, salt plain, urban area, airport, oil or gas field, mine, quarry, desalination plant, protected area, restricted area (optional).[64]

In light of the fact, that the use of solar energy is much less profitable in Gauteng than for example in Upington (which means that it can only be ran reasonably with low efforts) the separation between mandatory and optional should not be applied. Thus the optional areas shall be observed as exclusion areas here as well. For Gauteng these exclusion areas are suggested:

- Topographic: Water bodies, swamp, sand dunes, salt plain, forest.
- Layers: *Waters_d10*, *Forest_d60*. Swamps are contained in *Waters_d10*. There are no data on sand dunes and salt plains on hand.
- Anthropogenic: Traffic infrastructure (roads, railway lines, airports with entry lines), transmission lines, urban areas, industrial areas (with oil and gas fields, mines, quarries, desalination plants…), protected areas, restricted areas, agricultural areas.
- Layers: *Roads_dist*, *Railway_d10*, *Transmission_d50*, *ProtectedAreas*, *UrbanArea_d25*, *Industry_d25*, *Cultivation*, *Livestock*. There are no data on airports and restricted areas on hand.

Regarding the interference by CSP there are no specific distance rules known for South Africa. Contrariwise an adequate distance has to be observed to objects that cast shadows (mountain ridges, forest, high buildings) as well as to sand dunes and salt plains.

There are no data on sand dunes and salt plains on hand. Same as with biomass power plants a distance of 50 m from transmission lines is defined here. The calculation of the distances from forest and urban areas is discussed below.

[63] MAY, 2005: 165
[64] TRIEB et al., 2009: 41

Areas excluded due to technical reasons:

- Areas with a gradient of 2.1 % or higher (layer *Slope_21*).[65]
- Too small areas (at least 195 ha).[66]
- Areas with too poor compactness. A contiguous area of about 1500 m * 1300 m would be optimal.[67]

Distance to Forest and Urban Area

With the formula **b = a / tan α** the distance values have been calculated. For forests an obstacle height of 50 m has been assumed[68] and for built-up areas 20 m. The minimal solar incident angle for June 21st (midwinter on the southern hemisphere) at 26° South and 28° East (Johannesburg in the centre of Gauteng) has been calculated with 40.52°.[69] In this process it has to be considered, that there is no daylight saving time in South Africa.

Height	Distance	
50 m	58,50 m	Distance to forest areas
20 m	23,40 m	Distance to urban areas

Table 16: Distance calculation

To forest areas a distance of 58.50 m has been determined, to urban areas and industrial areas 23.40 m. In the further process rounded distance values of 50 m to forest and 20 m to urban areas shall be used.

This calculation is valid at 12 o'clock on the mentioned day. The solar incident angle at other times of day are not considered. The direction of forest areas in relation to the CSP sites shall not be considered as well.

Exclusion Area Layers

All exclusion areas are cut out of the province area. These are the layers *Roads_dist*, *Railway_d10*, *Transmission_d50*, *UrbanArea_d25*, *Industry_d25*, *ProtectedAreas*, *Cultivation*, *Livestock*, *Waters_d10*, *Forest_d60* and *Slope_21*. The outcome is layer *CSPArea*.

Minimum Size

Areas of a too small size are excluded from this analysis. As minimum size the 195 ha estimated in the "Andasol" project are assumed.[70] In layer *CSPArea* all polygons with an area of less than 195 ha are deleted.

Compactness

Areas with a too poor compactness are not suitable for CSP sites. For the compactness as well the values of the "Andasol" project are assumed. Suitable are

$$CompactRatio = \frac{P}{2\pi\sqrt{\frac{A}{\pi}}}$$

Figure 43: Compactness ratio formula

[65] TRIEB et al., 2009: 41
[66] O.V., 2011a: 8
[67] O.V., 2011a: 8
[68] NABU, 2013
[69] QUASCHNING, 2013
[70] O.V., 2011a: 8

areas with an approximately rectangular shape and with about 1,500 m * 1,300 m edge length.[71] The compactness of areas is calculated with the formula shown in figure 43.

The smaller the compactness ratio, the more compact the shape. In figure 44 the three polygons with the biggest compactness ratio are depicted, in figure 45 the three with the lowest compactness ratio.

Figure 44: Areas with good compactness

The big number of holes in these polygons is conspicuous. This is due to the data structure of the forest areas, which are divided into many very small sections. This phenomenon falsifies the compactness values of the areas considerably and makes it difficult, to make a statement on the suitability of the areas regarding the available sizes. Some areas might have an adequate size, if it can be assumed, that these holes are obsolete.

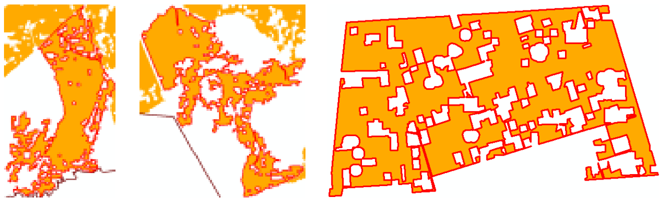


Figure 45: Areas with poor compactness

Calculation of Areas suitable for CSP

In order to find areas of the required size and shape a manipulation is used. A polygon that can contain a rectangle of the mentioned size has to contain a circular area with at least the diagonal of this rectangle as diameter. To calculate this, the polygons are buffered negatively with half of the diagonal of the rectangles.

From the formula $\mathbf{c^2 = a^2 + b^2}$ for the orthogonal triangle the calculation of the diagonal can be derived: $\mathbf{c = \sqrt{a^2 + b^2}}$. With the assumed values this results in: $\mathbf{\sqrt{(1{,}500\ m)^2 + (1{,}300\ m)^2} = 992\ m}$

When buffering with -992 m buffer distance as a result no polygon has the required size or compactness, respectively. In a repetitive process it is determined that with a buffer distance of -740 m there are two remaining polygons (see figure 46). They are small, but point out, that the original polygons, from which they have been generated, can contain rectangles of about 110 ha.

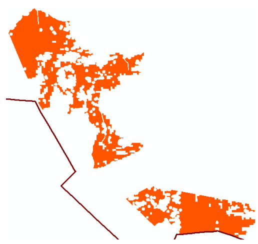


Figure 46: Result with buffer distance -740 m

Conclusion

With this method only two polygons have been found and both of them are not big enough for a 195 ha CSP site. An accurate suitability statement on these and other areas is difficult and is among other things depending on the following criteria:

[71] O.V., 2011a: 8

- If the holes caused by forest pixels are invalid, the suitable areas increase by a multiple.
- It has to be clarified, how the land use is in the found areas. Is it fallow land or can the areas be acquired and rededicated easily?

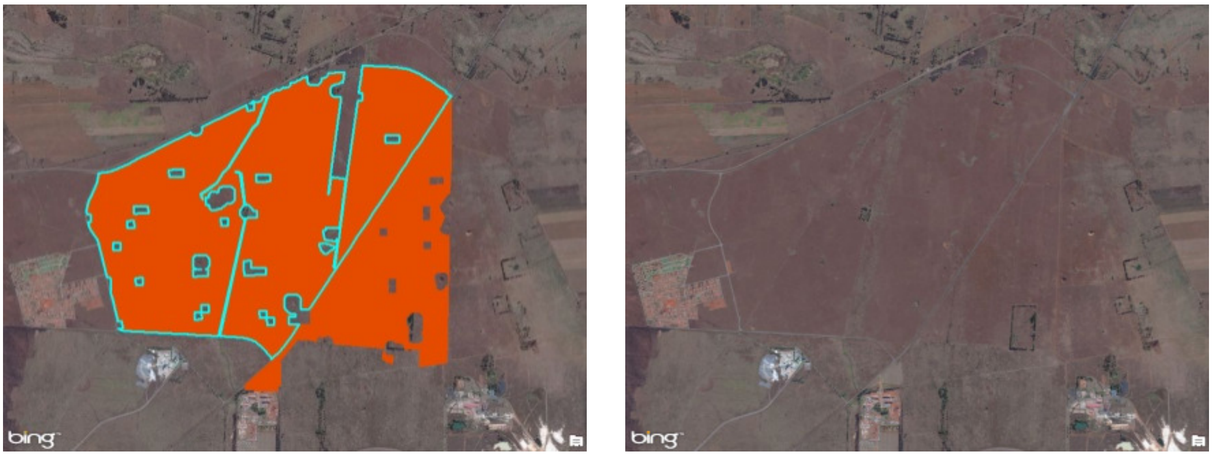


Figure 47: CSP analysis – Suitable area over satellite image, © Bing Maps

The example of this area with 921 ha, which is shown in figure 47, displays, that there are probably much more areas of the required minimum size, than determined by the analysis. In the first instance the holes caused by forest pixels falsify the result. For that reason in an alternative calculation the forest data shall not be used as exclusion area and the results shall explicitly be checked for the existence of forest.

3.4.4 Exclusion Areas – Alternative 1 – without Forest

In the process of clipping the exclusion areas the forest data are left out. The outcome is layer *CSPAreaA1*. In this layer all polygons with an area less than 195 ha are deleted.

Compactness

The compactness ratio is calculated the in the same way as before.

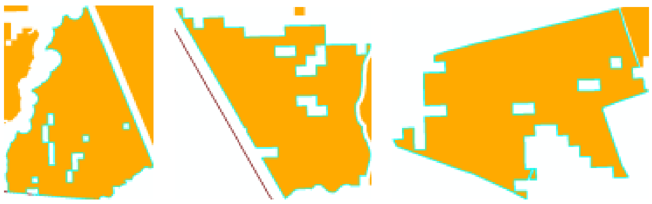


Figure 48: Areas with good compactness

In figure 48 the three polygons with the biggest compactness ratio are depicted, in figure 49 the three with the lowest compactness ratio.

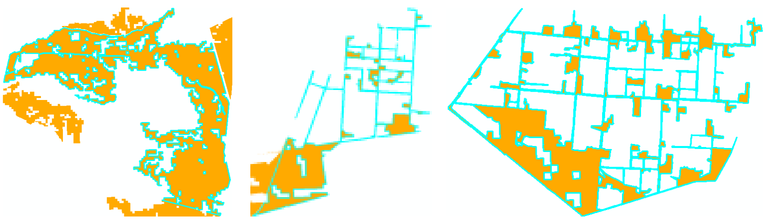


Figure 49: Areas with poor compactness

The typical holes can still be observed, but considerably less than before. These holes are due to the slope data. The data structure of these files is similar to the forest data, but in contrast it probably reflects the real conditions. Both of the polygons with the lowest compactness get their shape by missing roads in layer *Roads*.

Calculation of Areas suitable for CSP

The same method mentioned above is used. This time buffering negatively with a buffer distance of -992 m is possible and results in layer *CSPAreaA1P1* with one remaining polygon (see figure 50).

Figure 50: Result with buffer distance -992 m

Conclusion

With this method only one polygon has been found but this is big enough for a 195 ha CSP site. An accurate suitability statement on this and other areas is still difficult. Probably there are still more areas of the required minimum size, than determined by the analysis. At least by a check with the aerial images it can be told that there is no forest in the determined area, which means that it is suitable for a CSP site (see figure 51).

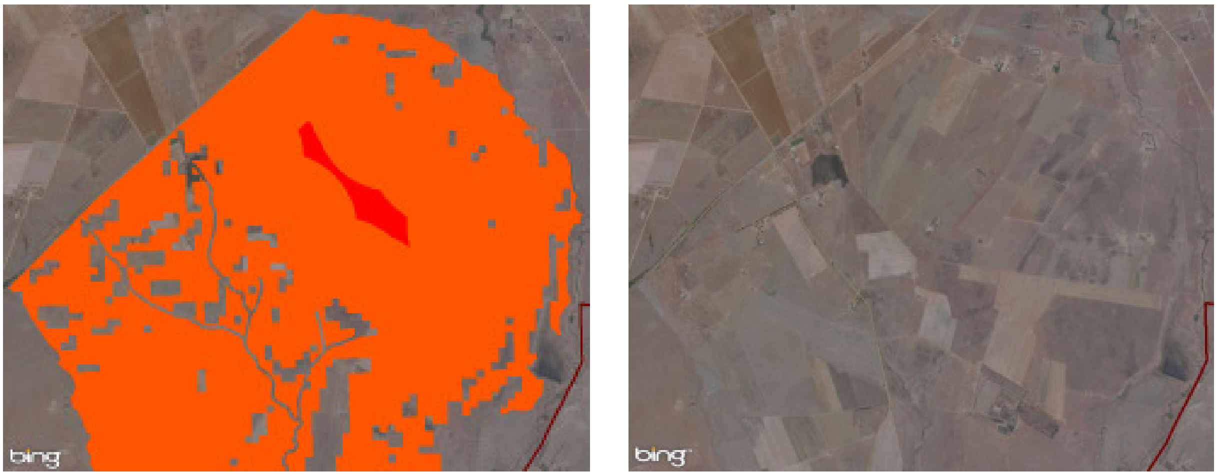


Figure 51: CSP analysis – Alternative 1: Suitable area / satellite image, © Bing Maps

In a second alternative calculation the forest and slope data shall not be used as exclusion area and the results shall explicitly be checked for the existence of forest and be evaluated by the local existing slope.

3.4.5 Exclusion Areas – Alternative 2 – without Forest and Slope

In the process of clipping the exclusion areas the forest and slope data are left out. The outcome is layer *CSPAreaA2*. In this layer all polygons with less than 195 ha are deleted.

Compactness

The compactness ratio is calculated in the same way as before. The three polygons with the biggest compactness ratio are depicted in figure 52, the three with the lowest compactness ratio in figure 53.

Figure 52: Areas with good compactness

In this result almost all of the holes have disappeared. The both polygons with the lowest compactness get their shape by missing roads in layer *Roads*.

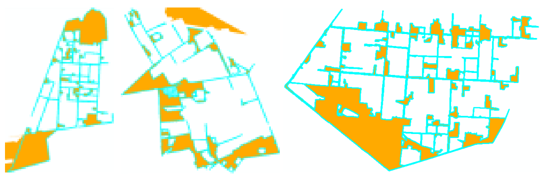


Figure 53: Areas with poor compactness

Calculation of Areas suitable for CSP

The same method mentioned before is used. Buffering negatively with a buffer distance of -992 m is possible and results in layer *CSPAreaA2P* with 18 remaining polygons that could contain a 195 ha CSP site (see figure 54).

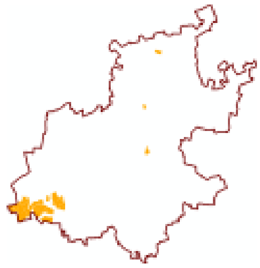


Figure 54: CSP analysis result

Evaluation of the remaining Polygons

These 18 suitable areas shall be checked for the appearance of forest and for local slope values. In the pictures in figure 55 slope values as of 2.1 % are depicted in dark blue, the relevant suitable polygons in half transparent orange and with light blue frame lines. The red half transparent polygons are the areas generated by buffering negatively with a buffer distance of -922 m. The suitable polygons are depicted by their size, beginning with the biggest.

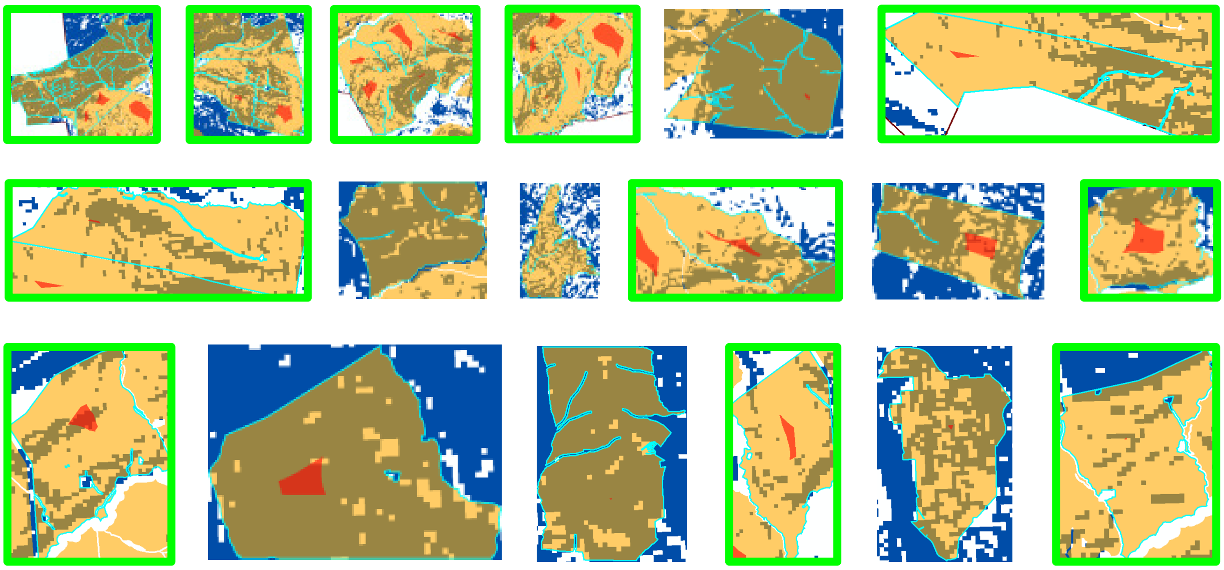


Figure 55: Evaluation of remaining polygons (Slope)

This depiction makes clear that some polygons are located widely in the zone of at least 2.1 % slope and thus are not suitable. Suitable in a sense that they do not contain too much high slope, are the green framed polygons 1, 2, 3, 4, 6, 7, 10, 12, 13, 16, 18 (marked with green frame line).

These eleven suitable areas shall now be examined regarding the appearance of forest (see figure 56a and b):

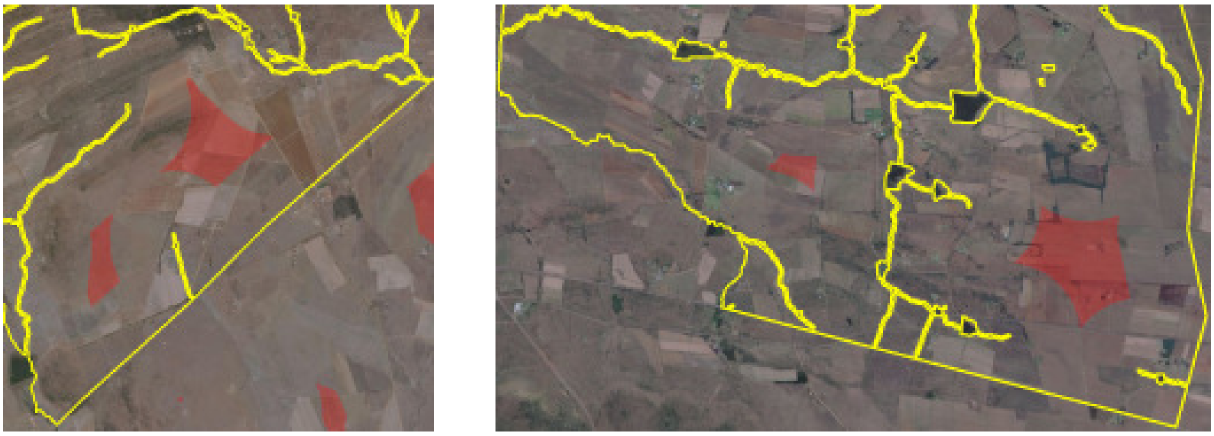


Figure 56a: Evaluation of remaining polygons (Forest)

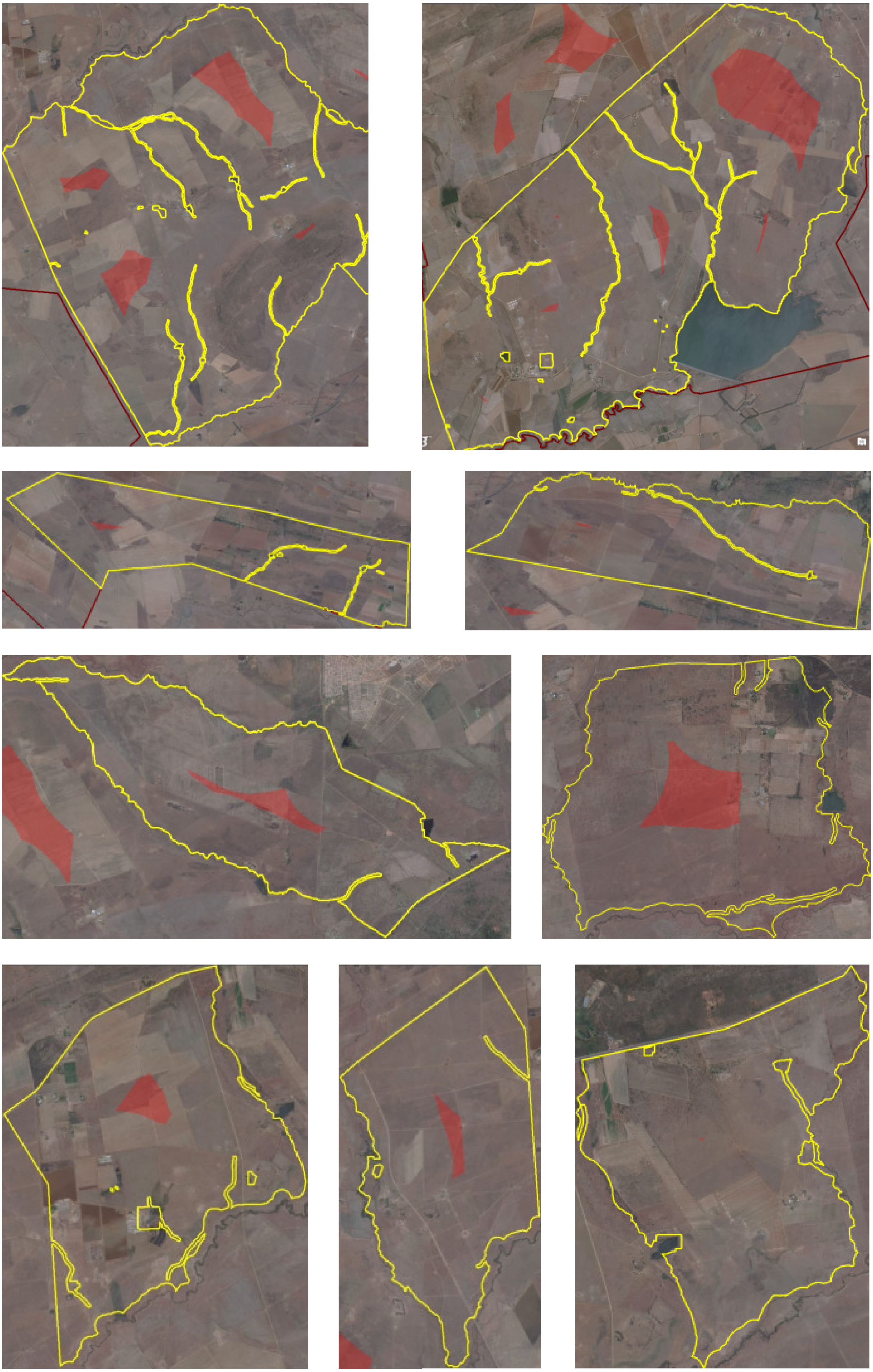


Figure 56b: Evaluation of remaining polygons (Forest)

By the aerial images it can be told that in the relevant compact zones of the remaining eleven polygons none or only little forest areas (observable as dark areas in the aerial images) exist, which means, that these areas really are suitable.

Conclusion

With the first method no polygon of the required size has been found. With the first alternative calculation one polygon has been found and with the second alternative calculation eleven polygons that have been proven to be suitable. In the further steps this last result shall be used. These data are saved as layer *CSPAreaFit*.

3.4.6 Evaluation of Areas

The remaining areas (layer *CSPAreaFit*) shall be evaluated using these criteria:

- Average solar radiation
- Distance from roads and transmission lines, same as in the analysis "Wind Power"

Average Solar Radiation

The NASA[72] data on solar radiation in South Africa are a table of values for each full degree field in the network of parallels and meridians.

For Gauteng the values in the white fields in table 17 are valid. The dimension of the figures is the average solar radiation in kWh/m²/day.

NASA Data about Solar Radiation					
	26°	27°	28°	29°	30°
-24°	5,74	5,71	5,68	5,52	5,08
-25°	5,70	5,74	5,60	5,58	5,40
-26°	5,70	5,65	5,65	5,62	5,30
-27°	5,61	5,60	5,53	5,46	5,25
-28°	5,56	5,56	5,52	5,41	5,15

Table 17: NASA solar radiation data

Distance to Roads and Transmission Lines

For the proximity to roads and transmission lines the same method is implemented as in the analyses before.

Evaluation of Locations

In order to evaluate suitable areas, the multiple buffer zones around roads (layer *RoadsAllProx6*) and transmission lines (layer *TransmissionLinesProx6*) are intersected with the zones of solar radiation (layer *SolarRadiation*). The values of these quality criteria are set as follows:

- The values of solar radiation range between 5.53 und 5.65.
- For the proximity to roads and transmission lines 6 points are assigned for areas with a maximum distance of 2 km, 4 points for a maximum distance of 4 km and 2 points for a maximum distance of 6 km.

[72] NASA, 2012

The outcome is layer *CSPZones* as visible in figure 57. The darker the colour in this picture, the more suitable the area. The focus of the suitable areas is on the infrastructure lines in Gauteng Province. Due to the little deviation of the values the solar radiation has a subordinate meaning.

From this layer the polygons of the suitable areas (layer *CSPAreaFit*) are clipped. The outcome is layer *CSPResult*, the final result of this analysis.

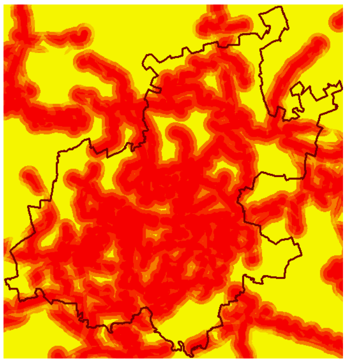


Figure 57: CSP analysis – Zones of suitability for power plants

Most Suitable Locations

In the map in figure 58 and 59 the eleven areas of general suitability as CSP sites are visible. The darker the colour, the better the suitability of the area as per the local existing solar radiation and the proximity to roads and transmission lines.

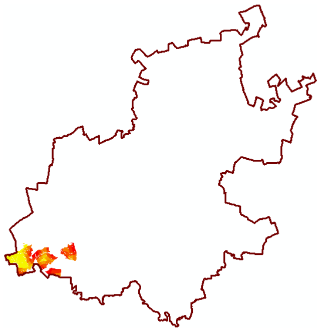


Figure 58: CSP analysis result

All these areas are located in a zone of Gauteng, which has not the highest solar radiation values. But as the values do not vary so much this has a subordinate meaning.

Substantial, however, is the question, to what extent big efforts in the usage of solar energy are really worth it. The spatial proximity on the other hand is a big advantage. In respect thereof, there could be developed a central location for solar energy use in Gauteng Province.

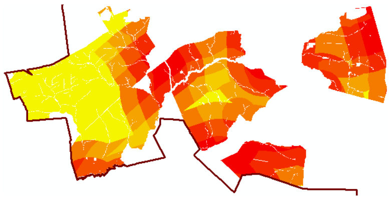


Figure 59: CSP analysis result in detail

3.4.7 Potential

In order to determine the potential of these areas, the real entirety of the available areas would have to be calculated. Beyond that, for a reliable calculation of the energy output of CSP, hourly radiation values over a whole year have to be used and the appearing loss in the solar field or in the thermic process, respectively, have to be considered.

Due to the complexity of this calculation it is not possible here. In an approximation it shall be assumed that on each area one 195 ha CSP site can be built.

The values of the existing CSP in Spain (see figure 60) shall be a reference for the determination of the potential:[73]

Figure 60: CSP near Guadix, Spain, © Bing Maps

[73] O.V. 2011a: 8

With an annual solar radiation of 2,136 kWh/m^{2}a (this equals 5.85 kWh/m^2 per day, not much more than the values of Gauteng) and a top efficiency factor of the solar installation of about 70 % (about 50 % as annual mean) in about 3,500 full load hours per year a net electricity of 150 GWh can be achieved. In this process the total installation reaches an efficiency factor of 28 % (about 15 % as annual mean).[74]

Based on these values, in the eleven suitable areas with eleven CSP plants of the discussed size and power there could be produced 150 GWh with each, thus 1,650 GWh/a in total.

In the framework of the *EnerKey* project, based on hourly measuring data, for a 50 MW power plant with a storage option in Pretoria the possible yield has been calculated. For this the solar radiation values of the best and the worst year have been used and the possible annual full load hours have been calculated:[75]

- For the best year (1997) at 4,389 full load hours it is:
  50 MW * 4,389 h/a = 219,450 MWh/a
- For the worst year (1990) at 3,463 full load hours it is:
  50 MW * 3,463 h/a = 173,150 MWh/a

An amount of 196,300 MWh/a could be assumed as a mean value here. Based on this value on the eleven suitable areas with eleven CSP plants of the discussed size and power there could be produced 196 GWh with each, thus 2,159 GWh/a in total.

Figure 61 shows the layers used in this analysis along with the working steps, inter-mediate data and result layers.

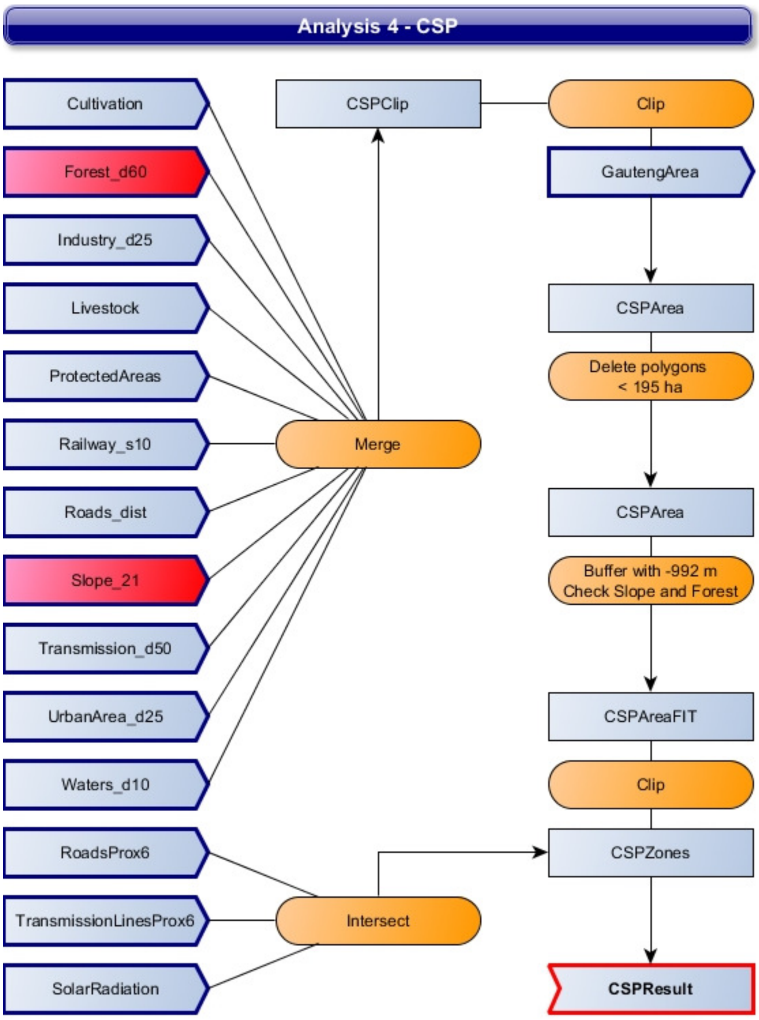


Figure 61: Data in CSP analysis

[74] O.V. 2011a: 8
[75] TELSNIG et al., 2013: 5

3.5 ANALYSIS 5 – PHOTOVOLTAICS / INDUSTRIAL

3.5.1 Data

These layers are required for this analysis and are loaded in an ArcMap file:

- *Cultivation* — Agricultural cultivation areas
- *Forest_d60* — Buffer zone 60 m around forest areas
- *GautengArea* — Polygon of the province area
- *Industry_d25* — Buffer zone 25 m around industrial areas
- *Livestock* — Agricultural pasture areas
- *ProtectedAreas* — Protected areas
- *Railway_d10* — Buffer zone 10 m around railway lines
- *Roads_dist* — Roads with variable widths
- *RoadsProx6* — All roads with multiple buffer zones
- *Slope50* — Areas with a gradient of 5 % or higher
- *SolarRadiation* — Zones of solar radiation
- *Transmission_d50* — Buffer zone 50 m around transmission lines
- *TransmissionLinesProx6* — Transmission lines with multiple buffer zones
- *UrbanArea_d25* — Buffer zone 25 m around urban areas
- *Waters_d10* — Buffer zone 10 m around water bodies

Bing Maps Aerial is loaded as background map for plausibility checks. Layer *GautengBoundary* is loaded as orientation.

3.5.2 Approach

Subject of this analysis is the potential for energy production out of solar radiation with PV power plants and the suitable locations for such plants. This contains the following steps:

- Determining the areas suitable and available for PV power plants.
- Evaluation of these areas based on the local existing solar radiation as well as the proximity to roads and transmission lines.
- Statement on the potential of these areas.

Concept of the Analysis

Starting with the entire area of the Gauteng province, all areas not suitable as a PV power plant are excluded step by step. Then the remaining areas are evaluated based on the local existing solar radiation as well as the proximity to roads and transmission lines. Finally, the energy production potential of the remaining areas is calculated depending on the local existing solar radiation.

Concept and course of this analysis are widely identical with the analysis "CSP" and shall not be described here detailed again. Only the determined values and results as well as the differences to the previous analysis shall be explicated here.

With regards to content the results of the analyses "CSP" and "PV Industrial" compete with each other directly. Since CSP and PV power plants perform different supply tasks it is reasonable to observe each technology separately.

3.5.3 Exclusion Areas

Definition of Exclusion Areas

The areas excluded due to the type of use are widely the same as in the analysis "CSP". These layers are used: *Waters_d10*, *Forest_d60*, *Roads_dist*, *Railway_d10*, *Transmission_d50*, *ProtectedAreas*, *UrbanArea_d25*, *Industry_d25*, *Cultivation*, *Livestock*.

For PV power plants there are no specific distance rules known to any objects, which is the same as for CSP sites. The distances observed to forests, urban areas and transmission lines are the same as in the analysis "CSP".

Areas excluded due to technical reasons:

- Areas with a slope of more than 5 % (layer *Slope_50*, see comments below).
- Areas of too small size (at least 9.4 ha or 94 ha, respectively, see comments below).
- Areas of too poor compactness (aspect ratio between 1:1 and 1:4, see measurements below).

Area Requirement

In this analysis two installation sizes are examined: Power plants with 5 MW and an area requirement of 9.4 ha as well as power plants with 50 MW and an area requirement of 94 ha (see table 18).[76]

Area Requirement		
Base Area	9,4 ha	94,0 ha
Aspect Ratio 1:1		
Short Side	307 m	970 m
Long Side	307 m	970 m
Aspect Ratio 1:4		
Short Side	153 m	485 m
Long Side	614 m	1940 m

Table 18: PV-I analysis – Area requirement

The aspect ratio should range between 1:1 and a maximum of 1:4, because the cabling of the modules takes considerably less effort for compact shapes. For a base area of 9.4 ha this means areas of 307 m * 307 m to 153 m * 614 m, for a base area of 94 ha areas of 970 m * 970 m to 485 m * 1,940 m.[77]

[76] TELSNIG, 2012
[77] TELSNIG, 2012

Slopes

The slope limit to be used is different to the analysis “CSP”. In order to include the slope into the evaluation of the suitable areas a digital terrain model of sufficient accuracy would have to be used, since on the sun-facing sides even bigger slope values – up to 30° (57.7 %)[78] – can be used without difficulties, on the sides orientated away from the sun a reasonable usage quickly becomes impossible. Since Gauteng is located completely to the south of the tropic of Capricorn, the sun-facing side is generally in the north. But in summer the sun stands in the zenith, which makes flat surfaces nearly optimal.

In a study for Mecklenburg-Vorpommern, Germany, the hillsides are divided in three classes:

- South-facing slope (135° to 225° orientation south – 0° is direct orientation south),
- None-south-facing slope with < 5° (8.8 %) gradient,
- None-south-facing with > 5° (8.8 %) gradient.[79]

Since there is no digital terrain model available, the slopes shall not be used explicitly. Instead of this as an approximative compromise it can be assumed, that areas with a slope value of less than 5 % are suitable for PV power plant sites.

Exclusion Area Layers

The layers that have to be clipped out of the province area as exclusion area are widely the same as in the analysis “CSP”. Only instead of layer *Slope_21* now *Slope_50* is used. For this reason an intermediate result of the analysis “CSP” can be used here as original data. From this forest and slope data have to be clipped.

Minimum Size

Areas of a too small size are excluded from this analysis. As mentioned above, 9.4 ha and 94 ha are assumed as minimum size here. Layer *PVIArea* is copied to *PVIArea9k4* and *PVIArea94*.

In layer *PVIArea9k4* all polygons with less than 9.4 ha are deleted. As well in layer *PVIArea94* all polygons with less than 94 ha are deleted.

Compactness – Plant Size 5 MW / 9.4 ha

$$CompactRatio = \frac{P}{2\pi\sqrt{\frac{A}{\pi}}}$$

Figure 62: Compactness ratio formula

Areas with a too poor compactness are not suitable for PV power plants. Suitable for a plant size of 5 MW and 9.4 ha are areas with an aspect ratio between 1:1 and 1:4, that means areas with an approximately rectangular shape and with about 307 m * 307 m to 153 m * 614 m edge length. The compactness of areas is calculated with the formula in figure 62.

[78] ZOLITSCHKA, 2010
[79] GRENZDÖRFFER, 2012: 16

The smaller the compactness ratio, the more compact the shape. In figure 63 on the left hand side the three polygons with the biggest compactness ratio and on the right hand side the three with the lowest compactness ratio are depicted.

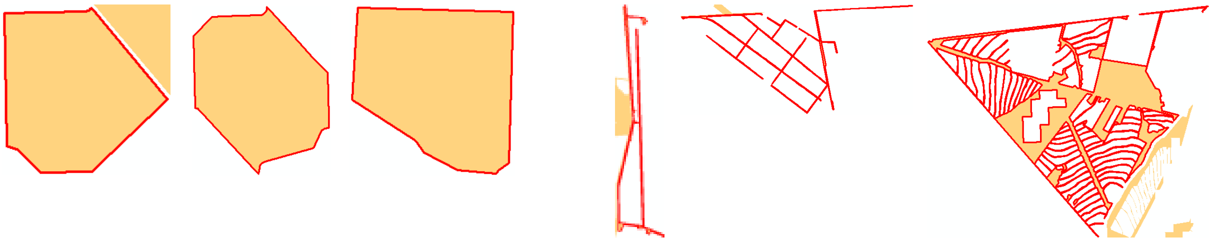


Figure 63: Areas with extremely good and extremely poor compactness

For the compact areas it has to be considered, that they do not necessarily conform to the ideal of a north-faced rectangle. If 9.4 ha rectangles shall be placed inside of these areas, they have to be bigger in total. The least compact areas are artifacts or do contain artifact-like parts. In an iterative process suitable limit values for size and compact ratio are found to filter these unsuitable areas. Then these areas are deleted, 2,394 polygons are remaining.

Compactness – Plant Size 50 MW / 94 ha

Suitable for a plant size of 50 MW and 94 ha are areas with an aspect ratio between 1:1 and 1:4, that means areas with an approximately rectangular shape and with about 970 m * 970 m to 485 m * 1,940 m edge length.

In layer *PVIArea94* as well suitable limit values for size and compact ratio have to be found to filter these unsuitable areas. Then these areas are deleted, 109 polygons are remaining.

3.5.4 Evaluation of Areas

The remaining areas (layer *PVIArea9k4* and *PVIArea94*) shall be evaluated using these criteria:

- Average solar radiation
- Distance from roads and transmission lines, same as in the analysis “Wind Power”

Average Solar Radiation

The NASA[80] data on solar radiation in South Africa are a table of values for each full degree field in the network of parallels and meridians.

For Gauteng the values in the white fields in table 19 are valid. The dimension of the figures is the average solar radiation in kWh/m²/day.

NASA Data about Solar Radiation					
	26°	27°	28°	29°	30°
-24°	5,74	5,71	5,68	5,52	5,08
-25°	5,70	5,74	5,60	5,58	5,40
-26°	5,70	5,65	5,65	5,62	5,30
-27°	5,61	5,60	5,53	5,46	5,25
-28°	5,56	5,56	5,52	5,41	5,15

Table 19: NASA solar radiation data

[80] NASA, 2012

Evaluation of Locations

The evaluation based on the distance to roads and transmission lines is executed in the same way as the analyses that have been described above.

A study regarding the suitability of buildable areas has shown, that the profitableness of a solar power plant exclusively depends on the solar radiation. Improved geographical conditions governing location have no significant impact.[81] Due to this reason the solar radiation values shall be weighted higher compared to the proximity to infrastructure.

In order to evaluate suitable areas, the multiple buffer zones around roads (layer *RoadsAllProx6*) and transmission lines (layer *TransmissionLinesProx6*) are merged with the zones of solar radiation (layer *SolarRadiation*). The values of these quality criteria are set as follows:

- The values of solar radiation range between 5.53 und 5.65. In order to prioritise these values they are multiplied with themselves once.
- For the proximity to roads and transmission lines 6 points are assigned for areas with a maximum distance of 2 km, 4 points for a maximum distance of 4 km and 2 points for a maximum distance of 6 km.

Layer *CSPZones* from the previous analysis can be used here, too. It is renamed as *PVIZones*. Then in this layer the values are calculated with the parameters above.

The result is visible in figure 64. The darker the colour in this picture, the more suitable the area. Although the numeric prioritisation of the solar radiation values, the focus of the suitable areas is still on the infrastructure lines in Gauteng Province. This is due to the visual division in the classes. Within these classes the values of solar radiation make a difference, but this cannot be visualised here.

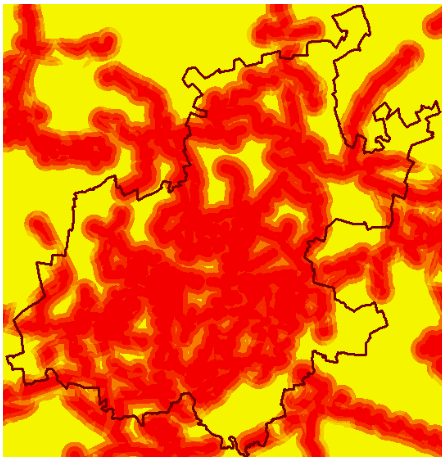


Figure 64: PV-I analysis – Zones of suitability for power plants

Evaluation of Location – Plant Size 5 MW / 9.4 ha

From layer *PVIZones* the polygons of the suitable areas (layer *PVIArea9k4*) is clipped. The outcome is layer *PVIResult9k4*, the final result of this analysis.

In the map in figure 65 the areas of general suitability for 5 MW PV power plants are visible. The darker the colour, the more suitable the area as per the local existing solar radiation and the proximity to roads and transmission lines.

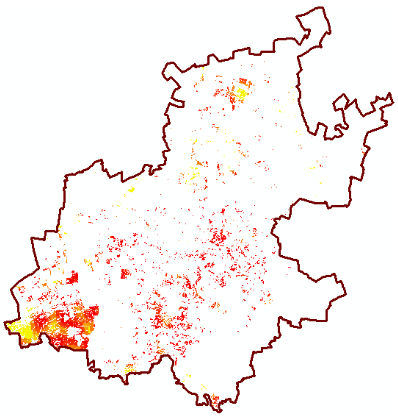


Figure 65: PV-I analysis result (5 MW plants)

[81] ZOLITSCHKA, 2010

Evaluation of Location – Plant Size 50 MW / 94 ha

From layer *PVIZones* the polygons of the suitable areas (layer *PVIArea94*) is clipped. The outcome is layer *PVIResult94*, the final result of this analysis.

In the map in figure 66 the areas of general suitability for 50 MW PV power plants are visible. The darker the colour, the more suitable the area, based on the local existing solar radiation and the proximity to roads and transmission lines.

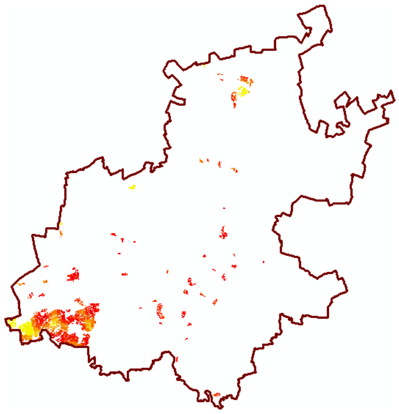


Figure 66: PV-I analysis result (50 MW plants)

3.5.5 Potential

The calculation of the potential is based on different assumptions. It shall not be assumed, that the determined suitable areas can be used completely. Instead, as many 5 MW plants or 50 MW plants as possible shall be built in the suitable areas.

The layers *PVIResult9k4* and *PVIResult94* cannot be used for this calculation, since often the suitable areas in these layers are divided in several subareas. On the other hand, sometimes they are combined to multipart features. Instead, the layers *PVIArea9k4* and *PVIArea94* are used.

Plant Size 5 MW / 9.4 ha

Layer *PVIArea9k4* contains 3,024 polygons. In the bigger areas there could be built either bigger or several smaller plants. Here only the installation of 5 MW plants shall be assumed. As well it is clear, that practically never the whole available area can be equipped with solar modules. Thus a residual area will remain, which here is assumed with 30 %.

The total area of the polygons adds up to 151,981.9 ha. This means that 106,387.4 ha are really available as suitable area. On this area the installation of 11,318 power plants with a power of 5 MW and an area requirement of 9.4 ha is possible.

Plant Size 50 MW / 94 ha

Layer *PVIArea9k4* contains 251 polygons. Here as well only the installation of 50 MW plants shall be assumed. And also the residual area is assumed with 30 %.

The total area of the polygons adds up to 72,099.2 ha. This means that 50,469.4 ha are really available as suitable area. On this area the installation of 537 power plants with a power of 50 MW and an area requirement of 94 ha is possible.

Calculation of the Potential

The production of electricity can be calculated as a function of the solar radiation with the following formula and the parameters as listed in figure 67:[82]

E_{el}	= Electricity generation
P_N	= Module power in [kW]
S_{STC}	= Standard test conditions [kW/m^2] (1 kW/m^2)
E_{glob}	= Global radiation at location [kWh/(m^{2}*a)]
Q	= Performance ratio [without dimension]

Figure 67: PV-I analysis – Potential calculation parameters

$$\mathbf{E_{el} = P_N / S_{STC} * E_{glob} * Q}$$

This could be calculated for a PV installation with a module power of 200 kW, with the maximum solar radiation value in Gauteng (5.65 kWh/m^2/day, which equals 2,062.25 kWh/m^2/a), standardised test conditions of 1 kWh/m^2 and a performance ratio of 0.76 like this:

$$\mathbf{E_{el} = (200\ kW / 1\ kW/m^2) * 2{,}062.25\ kWh/m^2/a * 1 = 313.46\ MWh/a}$$

For the further solar radiation values and for a 50 MW PV installation the results are as shown in table 20.

Calculation of Potential per m2/a	
Solar Radiation	Annual Yield
5,53 kWh/m2/day	306,80 MWh/a
5,60 kWh/m2/day	310,69 MWh/a
5,62 kWh/m2/day	311,80 MWh/a
5,65 kWh/m2/day	313,46 MWh/a
Mean Values	
5,60 kWh/m2/day	310,69 MWh/a

Table 20: PV-I analysis – Potential per m²/a

In order to calculate the potential of all available areas out of these general values, several aspects have to be generalised. For the calculation those areas are used, which can contain the smaller installations, since they contain the areas for the bigger installations as well. Beyond that the total available area is considered, despite the fact that not all of these areas really can be used.

In layer *PVIResult9k4* the area values of all polygons with a solar radiation value of *5.53* add up to 8,021.09 ha. The same way the other area values are determined. Out of this by multiplication with the values per m^2 the potential values are calculated as shown in table 21.

Calculation of Potential		
Solar Radiation	Area	Annual Yield
5,53 kWh/m2/day	8.021,09 ha	24.609,06 TWh
5,60 kWh/m2/day	44.808,20 ha	139.213,70 TWh
5,62 kWh/m2/day	19,11 ha	59,58 TWh
5,65 kWh/m2/day	19.515,36 ha	61.173,24 TWh
Sum:	72.363,76 ha	225.055,58 TWh

Table 21: PV-I analysis – Potential calculation

[82] SCHMID, 2007

Figure 68 shows the layers used in this analysis along with the working steps, inter-mediate data and result layers.

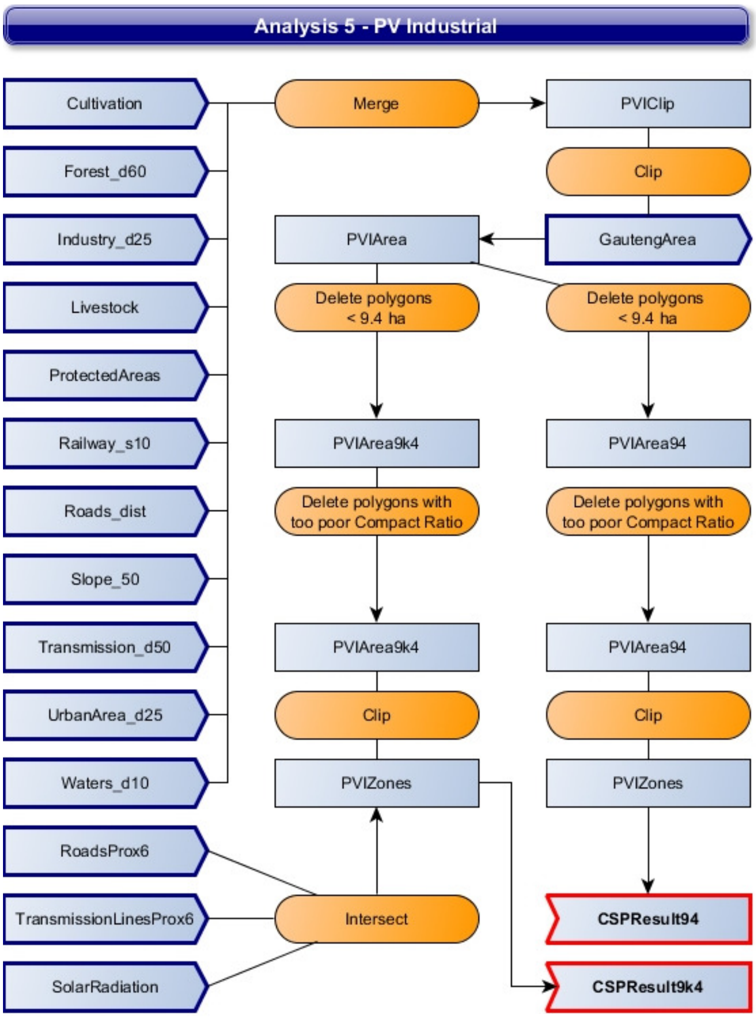


Figure 68: Data in PV-I analysis

3.6 ANALYSIS 6 – PHOTOVOLTAICS / RESIDENTIAL

3.6.1 Data

These layers are required for this analysis and are loaded in an ArcMap file:

- *GautengArea* Polygon of the province area
- *UrbanArea* Contiguous built-up area
- *WardsGauteng* Polygons of the administrative units in Gauteng
- *Income* Income data table referring to the Gauteng Wards

These layers are newly created in the course of this analysis:

- *Cutouts* The 25 ha cutouts of the four settlement examples
- *Roofs* The digitised roof areas

Bing Maps Aerial is loaded as background map for plausibility checks. Layer *GautengBoundary* is loaded as orientation.

3.6.2 Approach

Subject of this analysis is the suitability of the existing roof areas in Gauteng for individual PV installations. Beyond that, the potential for energy production out of solar radiation with PV installations on rooftops is determined. This contains the following steps:

- Identifying the roof area proportion of the total area in different settlement types.
- Statement on the potential of these areas.

Concept of the Analysis

For all existing roof areas in Gauteng the suitability for energy production with PV installations is determined. There are different types of exclusion areas:

- Roof areas with a too poor stability. Thus all quarters identified as informal settlements are exclusion areas.
- Too small roof areas. Individual PV installations are reasonable as of the following sizes: 5 kW with 49 m^2 on residential buildings and 100 kW with 1,063 m^2 on industrial buildings.

In this analysis different settlement types shall be examined globally. Example areas in the following categories are analysed:

- High priced residential area (e.g. Melville, Johannesburg)
- Middle priced residential area (e.g. Orange Farm)
- Downtown (e.g. Central Business District (CBD), Johannesburg)
- Industrial area (e.g. Vereeniging)

In these example cutouts of 25 ha each the available roof areas are determined exactly. These values can then be extrapolated to the total area of the respective settlement types in Gauteng.

The ulterior usage of roof areas has to be observed:

- According to the need of warm water in Gauteng 8,257.7 m^2 of the roof areas have to remain reserved for Solar Water Heaters (SWH). The use of SWH, however, is here only assumed for residential buildings, not for industrial plants or public buildings.[83]
- In general only 15.5 % of the roof areas on residential buildings are available.[84]

The alignment and slope of roofs would be relevant in this analysis as well. But there are no such data on hand and so these parameters shall not be considered here.

Informal settlements are not considered due to the fact that the roofs there are probably not stable enough and due to the lack of capital investment of the inhabitants for PV installations.

In the evaluation of the remaining areas the distance from roads and transmission lines is not relevant, since the produced energy shall be used in the respective buildings itself. The single remaining evaluation criterion is the solar radiation for which no really detailed values are available.

The analyses “PV Residential” and ”SWH” have a nearly identical course and with regards to content they compete with each other directly. Since energy production with SWH is considerably more efficient than with PV installations, each disposable residential rooftop shall be provided with a SWH and only if there is any more space available with PV installations.

[83] TELSNIG, 2012
[84] TELSNIG, 2012

3.6.3 Roof Areas

Digitalisation

In example cutouts of four typical settlement types with 25 ha each the roof areas are digitised. These examples are:

- High priced residential area (Melville, Johannesburg, see figure 69)
- Middle priced residential area (Orange Farm, see figure 70, left)
- Downtown (Johannesburg CBD, see figure 70, center)
- Industrial area (Vereeniging, see figure 70, right)

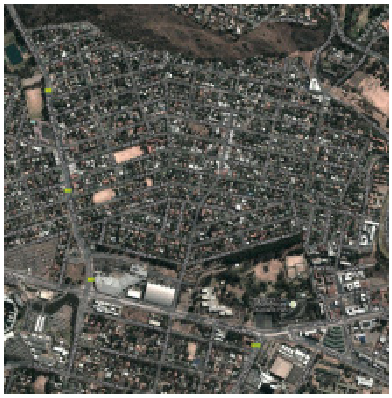


Figure 69: satellite image of Melville, © Bing Maps

Figure 70: Orange Farm, Johannesburg CBD, Vereeniging, © Bing Maps

In a new layer *Cutouts* four squares with an edge length of 500 m – which results in areas of 25 ha – are digitised and placed at the locations defined above. Then in a new layer *Roofs* the rooftops in these cutouts are digitised.

The pictures in figure 71 show the cutouts without and in figure 72 with digitised rooftops, from left to right: Melville, Orange Farm, Johannesburg CBD, Vereeniging.

Figure 71: satellite images of the four example cutouts, © Bing Maps

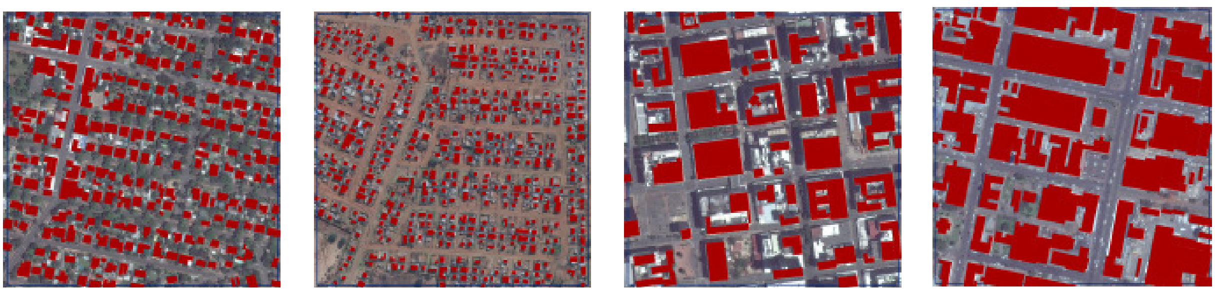


Figure 72: digitised roof tops of the four example cutouts, © Bing Maps

Comments on Digitalisation

In the aerial images of Bing Maps Aerial, which the digitalisation was based on, it was partly difficult to identify solid rooftops from tent roofs, awnings or other surfaces. In this connection the digitalisation was made in all conscience.

Not all rooftops are suitable for the usage of PV installations. Some are located in the cast shadow of other buildings, trees or other barricades. In general this fact is not considered here. For the multi-story buildings in Johannesburg CBD in particular, however, this is relevant. For this reason only those rooftops have been digitised, for which it can be assumed, based on the aerial images, that they are not located immediately in the cast shadow of adjacent buildings.

Partly rooftops are used otherwise in a way that they are not available for the use of photovoltaics. This is not considered individually here, but only globally.

For the sake of convenience the shapes of the rooftops have been generalised slightly and are generally depicted as rectangles. In doing so buildings can be combined of several rectangles and oblique or round shapes are balanced.

Minimum Sizes

Roof areas that are too small shall be excluded here, since PV installations are only reasonable from a certain size.

- For residential buildings installations with 5 kW and a required space of 49 m^2 are assumed. This applies to the cutouts “Melville” and “Orange Farm”.
- For industrial buildings installations with 100 kW and a required space of 1,063 m^2 are assumed. This applies to the cutouts “Johannesburg CBD” and “Vereeniging”.

In order to exclude the undersized areas the data first have to be revised in a way that afterwards all contiguous polygons are merged together. The outcome of this step is layer *RoofsBuf*. In this layer all areas with less than 49 m^2 are deleted. In the cutouts “Johannesburg CBD” and “Vereeniging” all areas with less than 1,063 m^2 are deleted as well.

Calculation of Roof Areas

The remaining roof areas are clipped from the cutout areas. The outcome is layer *RoofArea2*. In a plausibility check it can be found out that about 27 % of the cutout areas is covered with roof areas, which appears realistic.

The resulting values are listed in detail in table 22. The proportion ranges between 13.6 % in middle priced residential areas and 45.6 % in industrial areas. The values in column *Available* result from the fact that only 15.5 % of the roof areas

Calculation of Roof Areas					
Example	Settlement Type	Roof Area	Proportion	Available	Available/ha
Melville	High priced residential area	63.368,42 m2	25,3%	9.822,11 m2	392,88 m2
Orange Farm	Middle priced residential area	34.122,61 m2	13,6%	5.289,00 m2	211,56 m2
Johannesburg CBD	Downtown	57.753,32 m2	23,1%	8.951,76 m2	358,07 m2
Vereeniging	Industrial area	113.896,07 m2	45,6%	17.653,89 m2	706,16 m2

Table 22: Roof area calculation

really can be used for PV installations. In the last column these values are calculated per ha. This quantity of roof area is available for each ha of the respective kind of residential area.

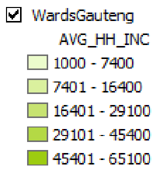
Urban Area

As per layer *UrbanAreaGT* the total urban area in Gauteng Province amounts to 2,499,457,840.76 m^2 which is 249,945.78 ha.

Residential Area Categories

In order to distinguish between residential areas of higher and lower income the earning capacity of the population as used in the *50 Priority Wards* project in 2011 have to be connected with the polygons of the Wards of Gauteng Province.

The Ward boundaries as polygons are downloaded from the internet page of the Municipal Demarcation Board.[85] From the GCRO GIS Viewer the earning capacity table of all Wards can be downloaded as CSV file.[86] The income data from this table are transferred into layer *WardsGauteng* and are there available as attribute "AVG_HH_INC". By symbolising these values the following becomes apparent for the chosen example cutouts of the residential areas:



The cutout "Melville" (left picture in figure 73) is spread over two Wards with an average income of *24,400 ZAR* and *61,400 ZAR*.

The cutout "Orange Farm" (right picture in figure 73) is spread over two Wards with an average income of 1,800 ZAR and 2,400 ZAR.

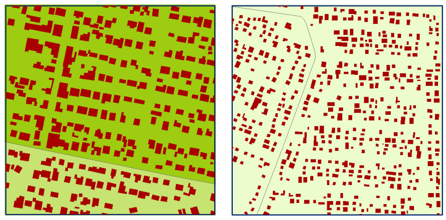


Figure 73: Income class visualisation of wards

The average income values are classified into three classes:

A: 30,000 ZAR and more (corresponding to high priced residential area, e.g. Melville)

B: 10,000 ZAR up to 29,999 ZAR (corresponding to middle priced residential area, e.g. Orange Farm)

C: less than 10,000 ZAR (corresponding to informal settlement)

The areas of the Ward polygons are calculated. On the basis of the income limits defined above, for all Wards the areas in the three classes are added up. In doing this the outcome is the values as shown in table 23. Due to the reasons mentioned at the beginning the areas of category "Residential Area C" are not further considered in this analysis.

Residential Area Classes		
Settlement Type	**Area**	**Proportion**
Residential Area A	225.953,6 ha	10 %
Residential Area B	932.763,7 ha	41 %
Residential Area C	1.105.071,7 ha	49 %
Total Area:	**2.263.789,0 ha**	

Table 23: Residential area classes

[85] MUNICIPAL DEMARCATION BOARD, 2013
[86] GCRO, 2013

Deduction of Roof Areas for SWH

For the calculation of the PV potential in this analysis a certain proportion of the rooftops shall remain excluded for the use with SWH. This applies to residential buildings only, not to downtown and industrial areas. The proportion is defined according to the warm water need of Gauteng. This is estimated with 188 Gl. With an annual warm water production of 22,766.7 l/m^2 a roof area of 8,257.7 m^2 in total has to be reserved for SWH.[87]

SWH Deduction by Residential Area Classes		
Settlement Type	Area	Proportion
Residential Area A	824,2 m2	10 %
Residential Area B	3.402,5 m2	41 %
Residential Area C	4.031,0 m2	49 %
Total Area:	8.257,7 m2	

Table 24: Deduction of roof areas for SWH

By distributing this area on the three residential area classes as per the calculation above, the outcome is the earning capacity values as shown in table 24.

3.6.4 Potential

General Potential

As per "Photovoltaiko" the annual yield on residential rooftops are calculated according to their orientation and slope as shown in table 25. These amounts of energy can be produced with 100 m^2 of available roof area.[88]

PV Yield per 100 m2					
Slope	West	S/W	South	S/E	East
< 20°	9.956 kWh	10.480 kWh	10.480 kWh	10.480 kWh	9.956 kWh
20-39°	9.432 kWh	10.480 kWh	10.480 kWh	10.480 kWh	9.432 kWh
40-60°	8.908 kWh	9.956 kWh	10.480 kWh	9.956 kWh	8.908 kWh
> 60°	8.384 kWh	9.432 kWh	9.956 kWh	9.432 kWh	8.384 kWh

Table 25: PV yield per 100 m²

These values are a rough point of reference and are valid for Germany. For Gauteng the orientation (from West over South to East) has to be turned around to West-North-East. Since Gauteng is located closer to the equator than Germany, the slope values will be different to those in the table, too. The local climate conditions and the average sunshine continuity will have a different impact as well.

For this analysis the orientation and slope of rooftops shall not be considered. For that reason this calculation is made with a mean value of 9,773 kWh per 100 m^2. Referred to the available roof areas calculated above and applied to one ha, this results in the potential values as shown in table 26.

Potential per ha	
Settlement Type	Potential/ha
Residential Area A	1.536 kWh
Residential Area B	827 kWh
Downtown	1.400 kWh
Industrial Area	2.760 kWh

Table 26: PV-R analysis – Potential per ha

Potential of Urban Area in Total

Layer *UrbanArea* contains all urban areas of Gauteng. For an evaluation of the real potential in total, the roof area values calculated above have to be distributed to this total area, based on the distribution of the different settlement types as shown above.

Since there are no data on hand that differentiate between residential, downtown and industrial areas in the space of urban areas, no exact calculation can be carried out. In order

[87] TELSNIG, 2012
[88] HOFFMANN, 2013

to calculate the potential to produce electricity out of solar radiation by the use of PV installations, at least approximately, an average of the values determined above shall be used for the different settlement types.

Potential Calculation					
Settlement Type	Proportion	Settlement area	Available	Available without SWH	Potential
Residential Area A	7 %	18.710,7 ha	7.351.144,3 m2	7.350.320,1 m2	71.840 GWh
Residential Area B	31 %	77.240,1 ha	16.340.927,0 m2	16.337.524,6 m2	159.693 GWh
Residential Area C	37 %	91.508,5 ha	0,0 m2	0,0 m2	0 GWh
Downtown	13 %	31.243,2 ha	11.187.278,9 m2	11.187.278,9 m2	109.329 GWh
Industrial Area	13 %	31.243,2 ha	22.062.577,6 m2	22.062.577,6 m2	215.609 GWh
SUMME:		249.945,8 ha	56.941.927,9 m2	56.937.701,2 m2	556.471 GWh

Table 27: PV-R analysis – Potential calculation

Assuming that the residential areas amount to 75 % of the total urban area (with the distribution to the categories A, B and C as determined above) and distributing the rest equally to downtown and industrial areas, then the outcome is as given in table 27. Within this calculation, the roof areas reserved for SWH as calculated above are excluded from the residential area categories A and B. The residential areas with low income are not applicable due to the reasons mentioned at the beginning of this analysis.

Potential Calculation by Solar Radiation

The general potential to produce energy as a function of the solar radiation has already been shown in the analysis “PV Industrial”. In order to calculate the potential of the available areas with this formula, the subareas of the different settlement types as calculated above would have to be distributed to the four existing solar radiation values in Gauteng. But since there are no data available, showing which proportion of the different settlement types is located in the diverse zones of solar radiation, this calculation can not be carried out here.

Figure 74 shows the layers used in this analysis along with the working steps, inter-mediate data and result layers.

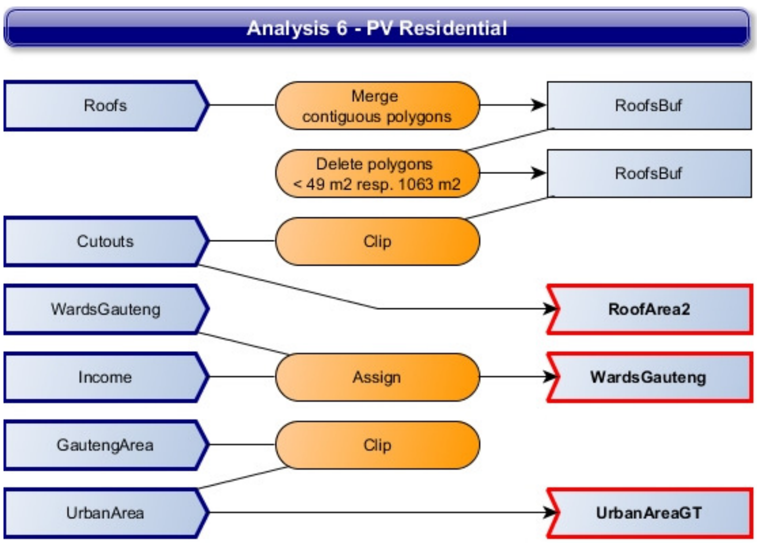


Figure 74: Data in PV-R analysis

3.7 ANALYSIS 7 – SOLAR WATER HEATERS

3.7.1 Data

These layers, newly created for the previous analysis, are required here again and are loaded in an ArcMap file:

- *Cutouts* The 25 ha cutouts of the four settlement examples
- *Roofs* The digitised roof areas

Bing Maps Aerial is loaded as background map for plausibility checks. Layer *GautengBoundary* is loaded as orientation.

3.7.2 Approach

Subject of the analysis is the suitability for SWH of the existing roof areas in Gauteng. Beyond that the energy saving potential of water heating with SWH is determined.

Concept of the Analysis

For all existing roof areas in Gauteng the suitability for water heating with SWH is determined. There are different types of exclusion areas:

- Roof areas outside of residential areas. In this analysis the usage of SWH is considered only for residential buildings.[89]
- Roof areas whose stability is too poor. Thus all quarters identified as informal settlements are exclusion areas.
- Roof areas that are too small. SWH are reasonable from the following sizes: 300 l storage tank with 4 to 5 m^2 collector area. The next size, common in Germany, is a 400 l storage tank with 6 to 8 m^2 collector area. As minimum size an area of 5 m^2 shall be assumed here.

The rooftops already digitised for several settlement types in the analysis “PV Residential” are applied here again, but only these example areas:

- High priced residential area (e.g. Melville, Johannesburg)
- Middle priced residential area (e.g. Orange Farm)

In these example cutouts of 25 ha each, the available roof areas are determined exactly. These values can then be extrapolated to the total area of the respective settlement types in Gauteng.

[89] TELSNIG, 2012

Informal settlements are not considered due to the fact that the roofs there are probably not stable enough and due to the lack of capital investment of the inhabitants for SWH. As well industrial and public buildings are not considered as SWH are normally not applied there.

The otherwise usage of roof areas has to be observed. In general only 15.5 % of the roof areas on residential buildings are available.[90]

3.7.3 Minimum Areas

An area of 5 m^2 shall be assumed as minimum area for SWH here. The layer *Roofs* from the analysis "PV Residential" can be used. It contains the digitised roof areas, thus the small subareas, the buildings are composed of. The smallest contained polygon has an area of 8.96 m^2, which is still over the minimum size. Even though more area is required for bigger or several SWH on bigger buildings, it can be assumed, that there is enough space for SWH on all rooftops. Beyond that in the analysis "PV Residential" it has been defined, that SWH always should have priority over PV installations on rooftops. For these reasons in this analysis no rooftops have to be excluded.

3.7.4 Potential Savings

SWH do not produce energy, but use solar energy for water heating. For the determination of the energy saving the costs – in CO^2 or in South African Rand (ZAR) and Euro, respectively – of the conventional water heating have to be compared with that by SWH.

Savings with SWH compared to Reference Technology per Household				
	Electric Geyser	SWH (HH Mid)	Saving	
Emissions in kg CO2eq/a	6.457,14 kg	2.582,86 kg	3.874,28 kg	40,0%
Costs in ZAR	5.541,01 ZAR	3.853,83 ZAR	1.687,19 ZAR	69,6%
Costs in Euro	490,36 €	341,05 €	149,31 €	69,6%

Table 28: SWH savings per household

Compared to the reference technology, an electric geyser, with a SWH savings of 3,874.28 kg CO^2eq/HH/a or 149.31 Euro, respectively, per household can be achieved in one year (see table 28). This calculation is taken from the EnerKey Technology Handbook.[91] The values are valid for 2007.

For the calculation of the potential savings in CO^2 or in South African Rand (ZAR) and Euro, respectively, in comparison with the conventional water heating it has to be clarified, how many households there exist on the example cutout. There are no data on this, but for both cutouts the number of households can be estimated in the aerial images.

[90] TELSNIG, 2012
[91] TELSNIG et al., 2012

In the left cutout in figure 75 (Melville) 206 plots are identifiable, on which a different number of buildings are placed. In the right cutout (Orange Farm) there are 512 plots of land.

Figure 75: satellite image with 25 ha cutout of Melville and Orange Farm, © Bing Maps

With 5 m^2 per SWH in the cutout "Melville" 1,030 m^2 would have to be used for SWH, in the cutout "Orange Farm" 2,560 m^2. In the available roof area calculated for these cutouts, the proportion in both examples is clearly less than 15.5 %, which was defined as the proportion of the roof areas, that can be assumed as available for the use of solar energy.

Calculation

According to the census of 2011 in Gauteng there are 3,909,022 households with 12,272,263 persons.[92] Thus each household consists of an average of 3.14 persons. From the calculation above it follows, that by the usage of SWH instead of electric geysers 3,874.28 kg CO^2eq or 149.31 Euro, respectively, per household in one year can be saved. With 3,909,022 households this amounts to 15,144,662 t CO^2eq or 6,595 Mio ZAR or 583 Mio Euro, respectively, per year for Gauteng in total (see table 29).

Savings with SWH compared to Reference Technology		
	Saving/HH	Saving total
Emissions in kg CO2eq/a	3.874,28 kg	15.144.662.923,22 kg
Costs in ZAR	1.687,19 ZAR	6.595.248.748 ZAR
Costs in Euro	149,31 €	583.650.332 €

Table 29: SWH savings

Figure 76 shows the layers used in this analysis along with the working steps, inter-mediate data and result layers.

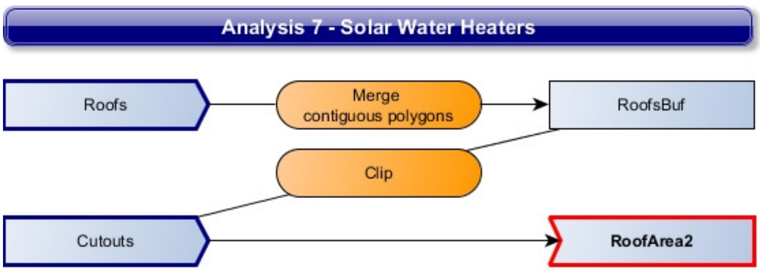


Figure 76: Data in SWH analysis

92 STATISTICS SOUTH AFRICA, 2012

4 MAP PORTFOLIO

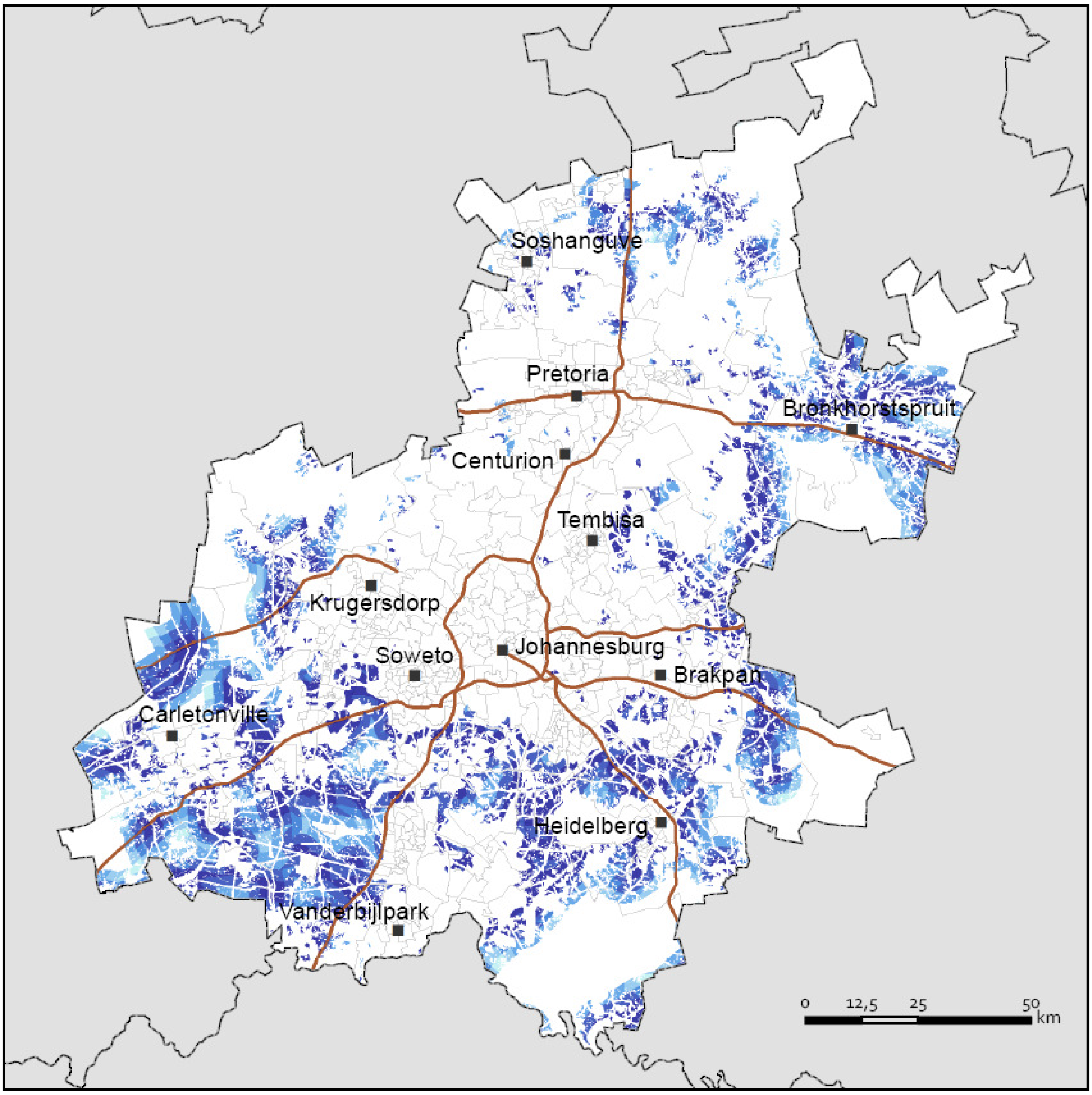
On the following pages the analysis results are depicted as maps. Each map is provided with a scale bar and a legend, which explains the result values and their representing colours. If there are no units indicated, the values are unspecified and result from the multiplication of several other values.

As an orientation, in addition to the Gauteng province boundary, the major cities, major roads and the ward boundaries are depicted in the maps.

A short text explains the content and the determined result of the analysis in a nutshell. The sources of the map contents are given as well.

Apart from analysis 6 (PV Residential) the maps always refer to the province of Gauteng. The result of analysis 5 (PV Industrial) is represented in two maps. In analysis 6 as an exception four maps show the different settlement type cutouts with the roof areas and an additional map illustrates the location of these cutouts. For analysis 7 (SWH) a map would be pointless.

Figure 77 to 87: Analysis results as maps with legends (following pages)

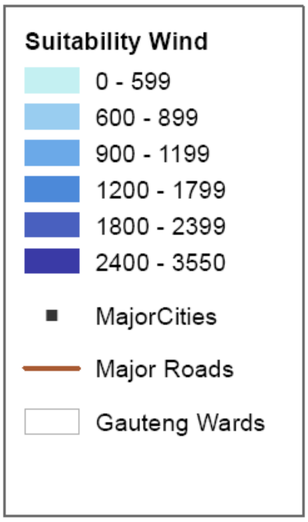


Analysis 1 – Wind Power

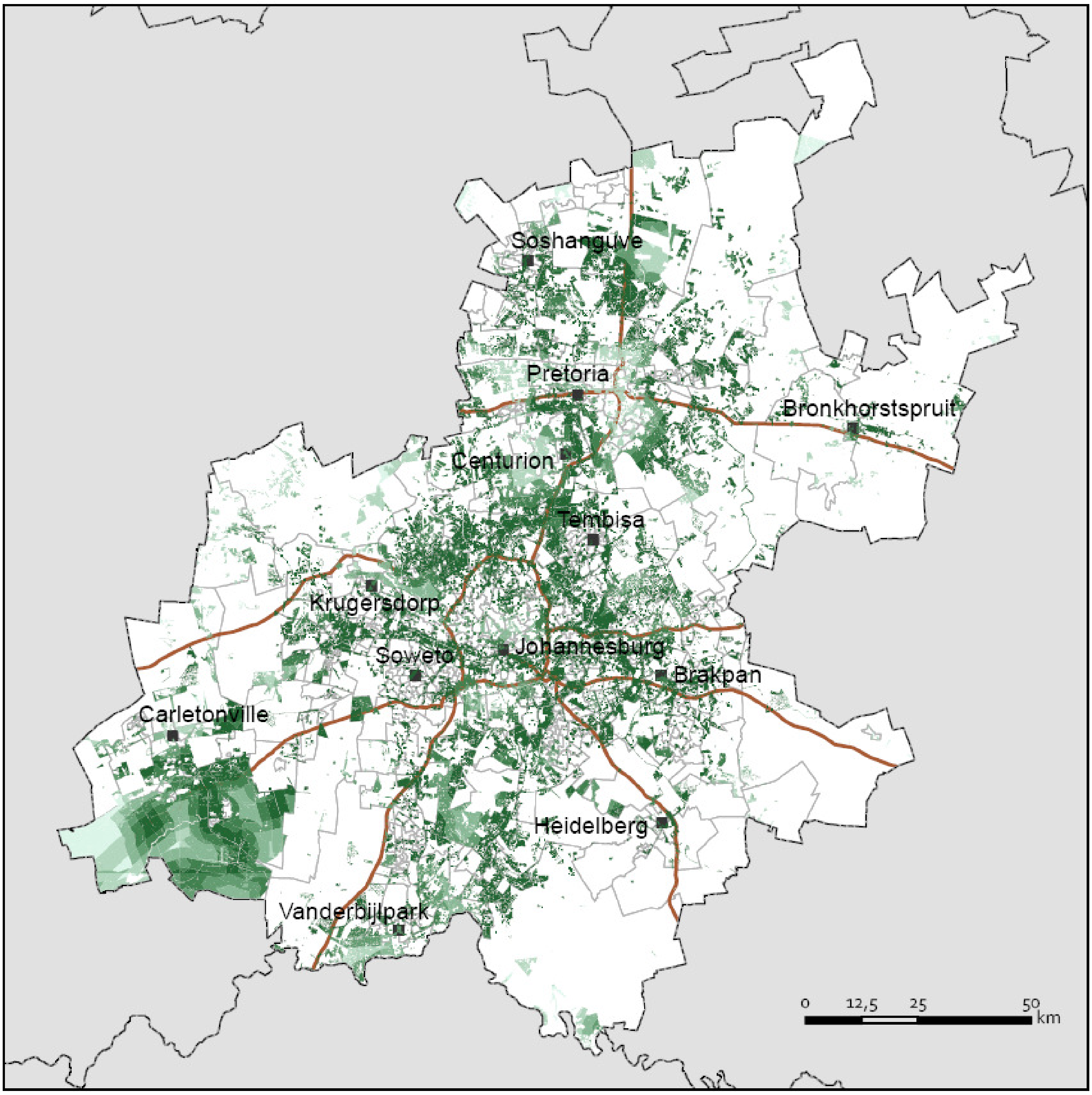
Areas where energy can be produced with wind power are depicted in blue colour. The darker the colour, the better the suitability based on the existing local wind speed as well as the proximity to roads and transmission lines.

The figures in layer *Suitability Wind* result from different coefficients and do not have a dimension.

Depending on the assumed parameters in total an annual yield of 27.5 TWh is possible as a maximum.



Sources: Municipal Demarcation Board (Wards),
NASA (wind speed), Own calculation (Suitability Wind)

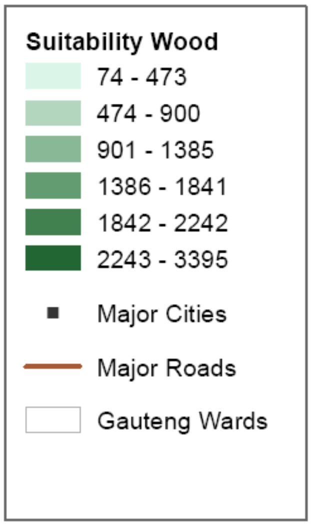


Analysis 2 – Biomass / Wood

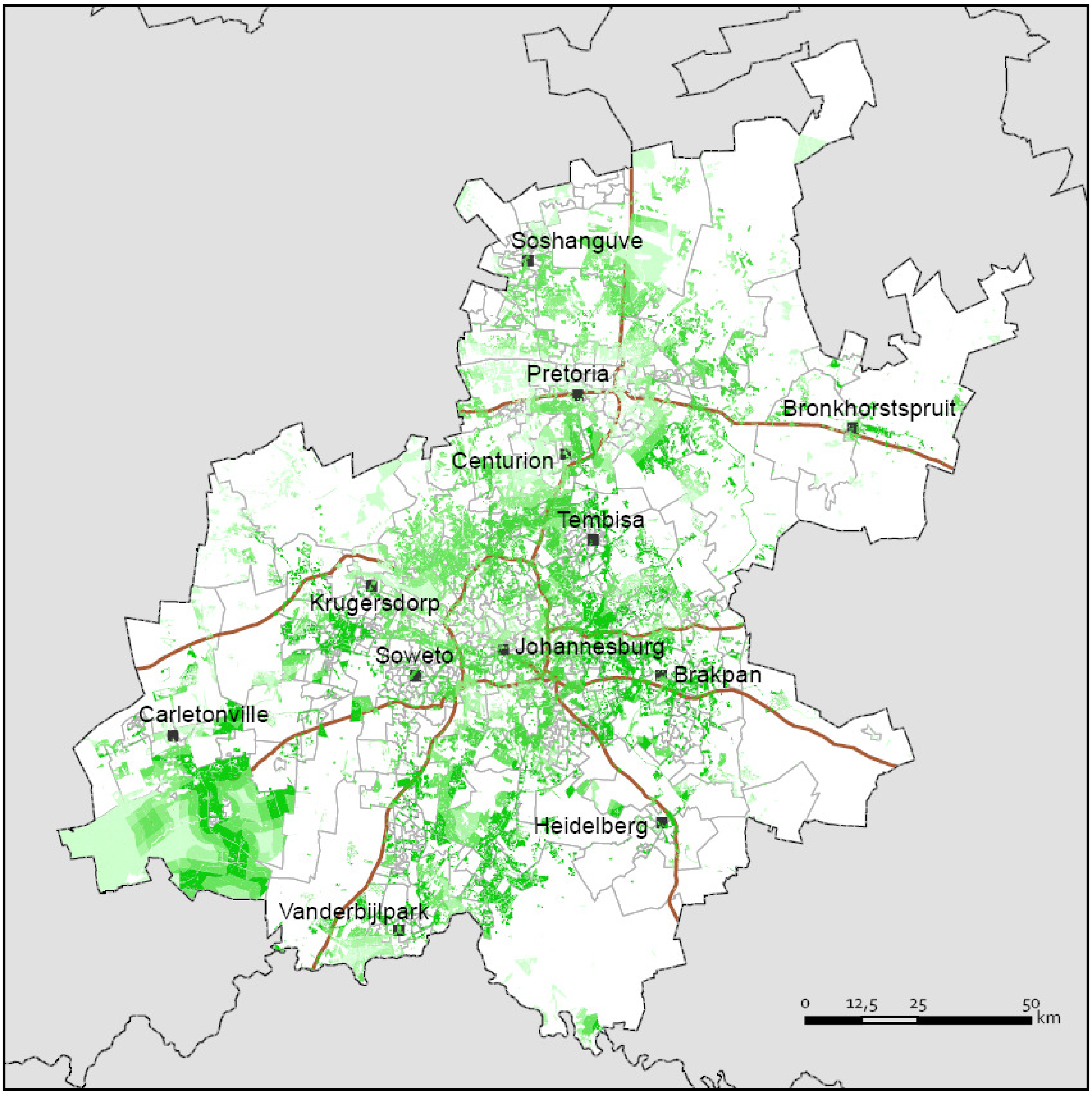
Areas where energy can be produced with power plants operated with wood are depicted in green colour. The darker the colour, the better the suitability based on the available quantity of wood in the surrounding area as well as the proximity to roads and transmission lines.

The figures in layer *Suitability Wood* result from different coefficients and do not have a dimension.

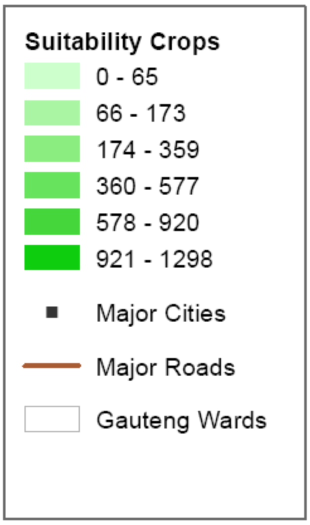
Depending on the assumed parameters in total an annual yield of 556 TWh is possible as a maximum.



Sources: Municipal Demarcation Board (wards), EnerKey (forest areas), Own calculation (Suitability Wood)



Analysis 3 – Biomass / Energy Crops

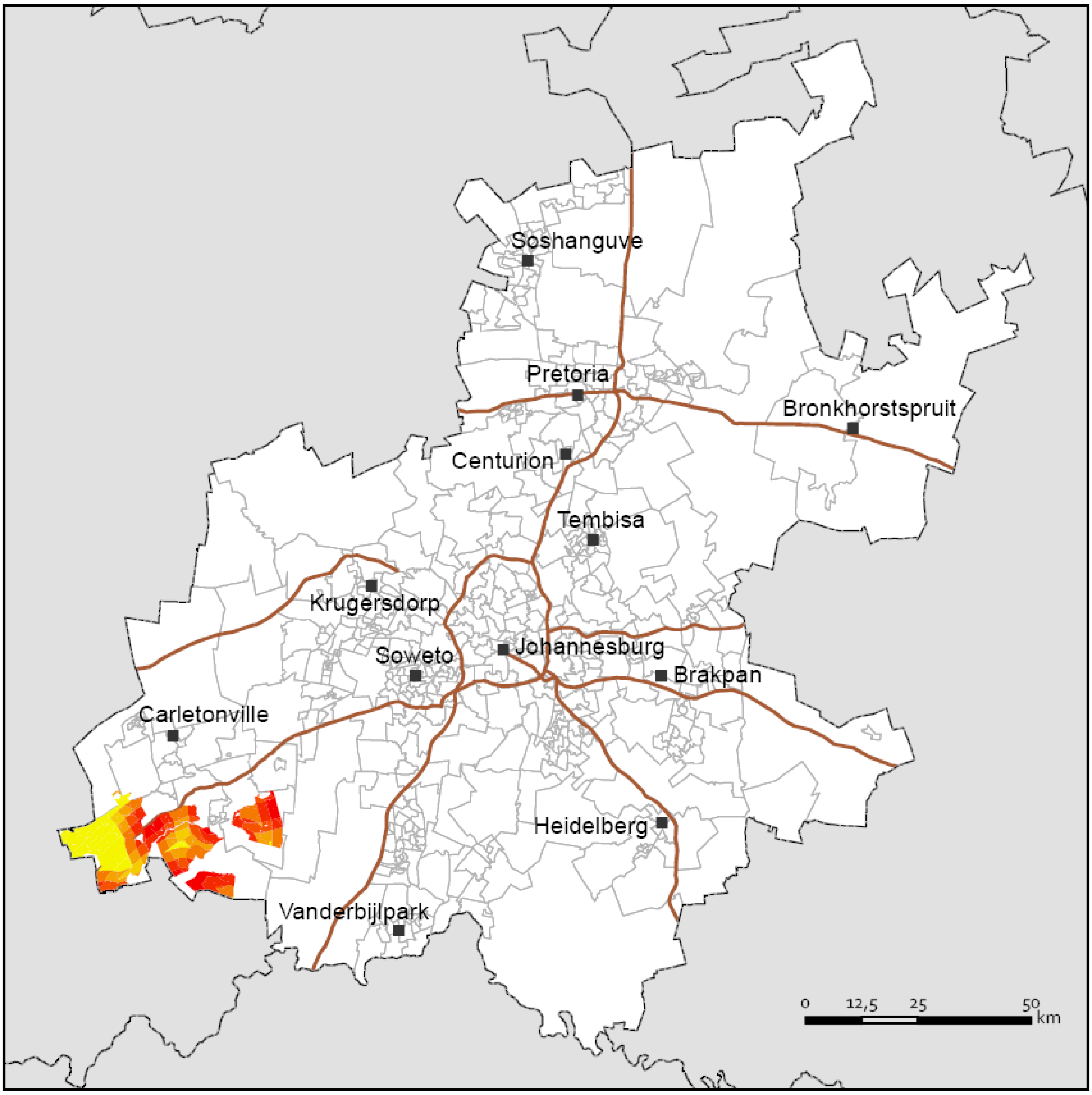


Areas where energy can be produced with power plants operated with energy crops are depicted in green colour. The darker the colour, the better the suitability based on the available quantity of energy crops in the surrounding area as well as the proximity to roads and transmission lines.

The figures in layer *Suitability Crops* result from different coefficients and do not have a dimension.

Depending on the assumed parameters in total an annual yield of 4.05 TWh is possible as a maximum.

Sources: Municipal Demarcation Board (wards), EnerKey (agricultural areas), Own calculation (Suitability Crops)

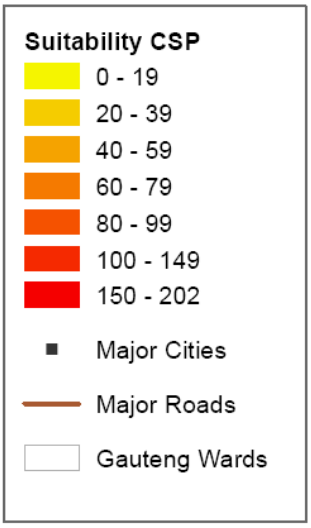


Analysis 4 – Concentrated Solar Power

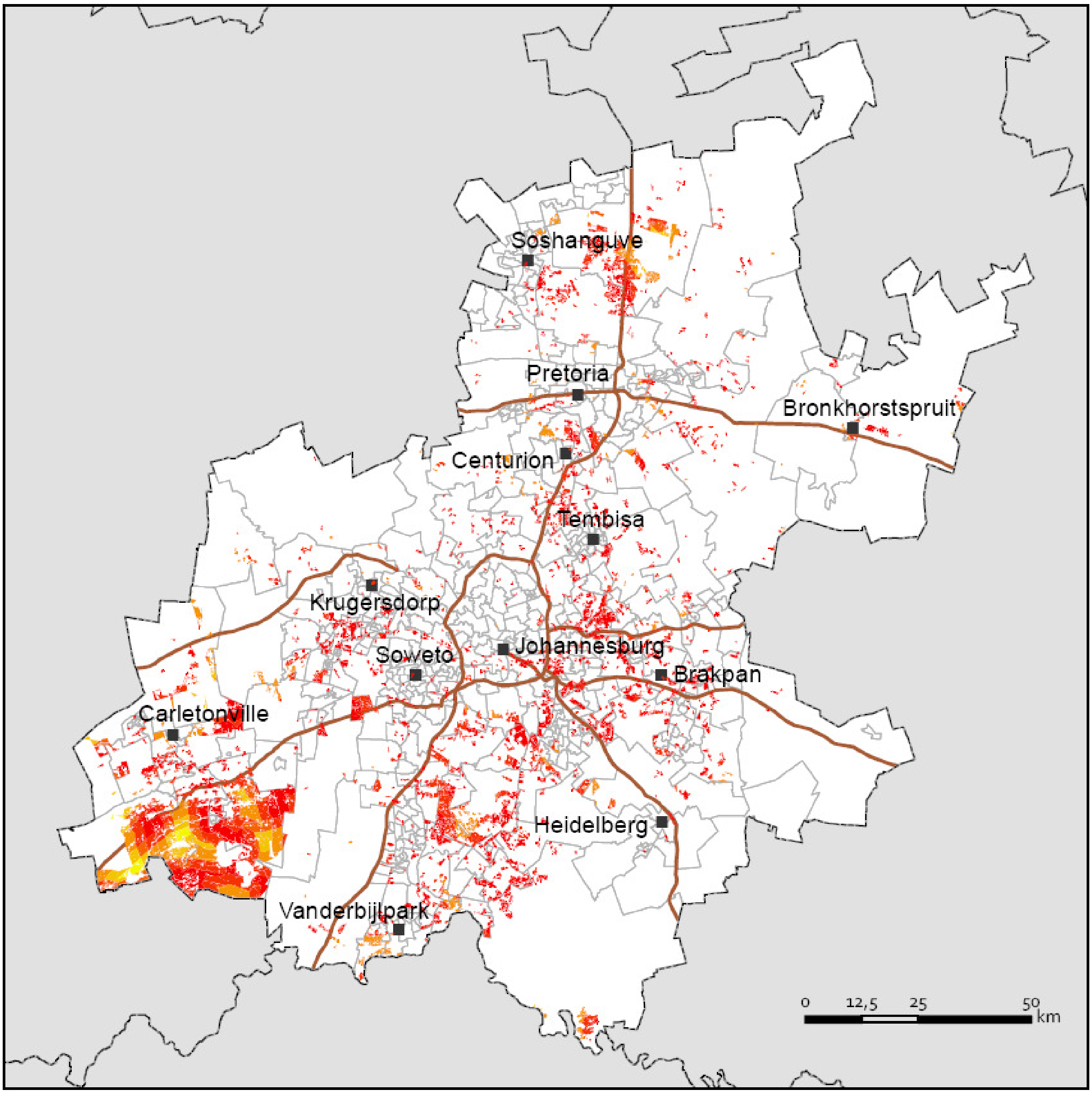
Areas where energy can be produced with CSP are depicted in yellow and red colour. The darker the colour, the better the suitability based on the existing local solar radiation as well as the proximity to roads and transmission lines.

The figures in layer *Suitability CSP* result from different coefficients and do not have a dimension.

Depending on the assumed parameters in total an annual yield of 2.16 TWh is possible as a maximum.



Sources: Municipal Demarcation Board (wards), NASA (solar radiation), Own calculation (Suitability CSP)



Analysis 5 – PV Industrial / 5 MW

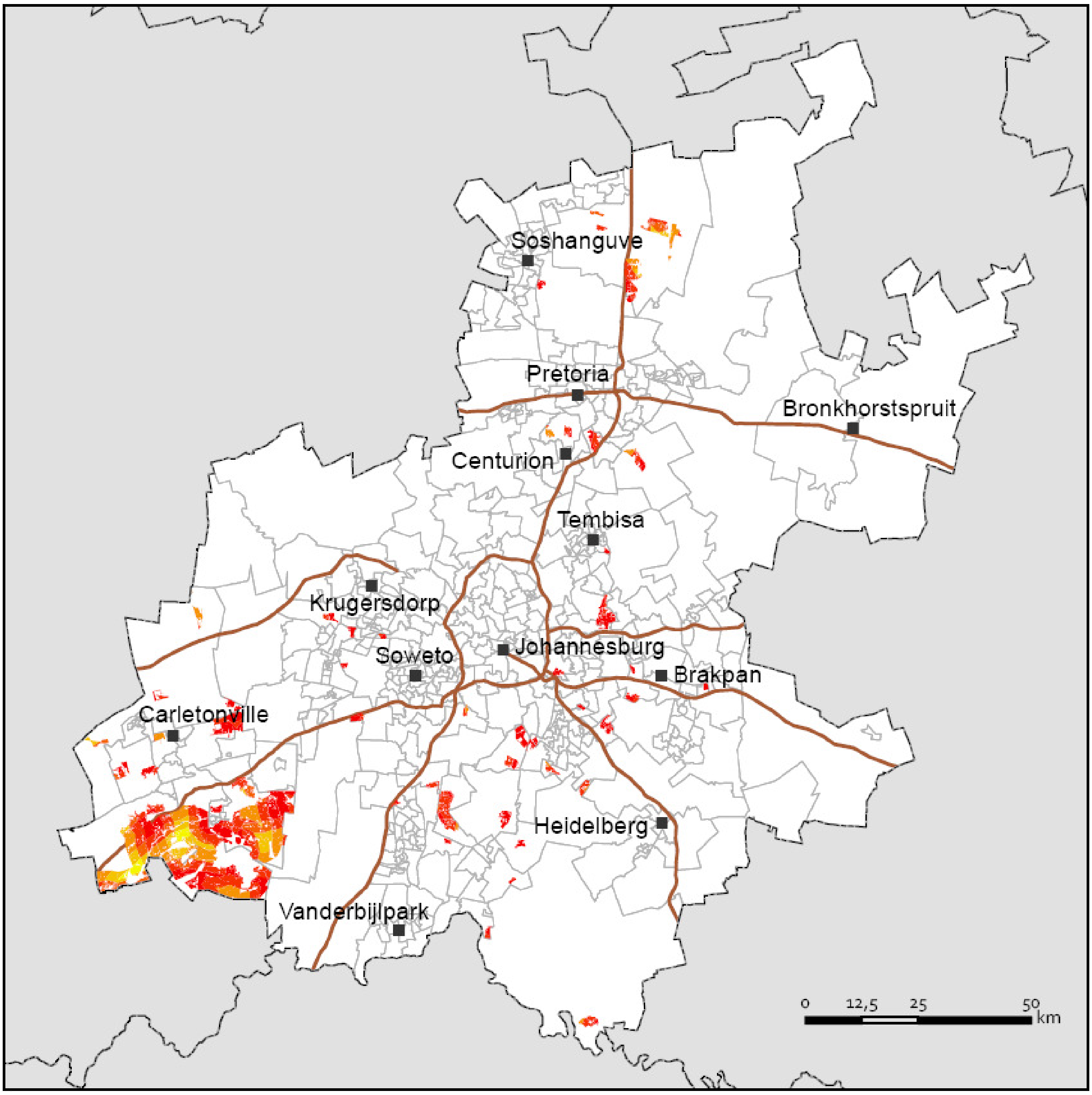
Areas where energy can be produced with 5 MW PV power plants are depicted in yellow and red colour. The darker the colour, the better the suitability based on the existing local solar radiation as well as the proximity to roads and transmission lines.

The figures in layer *Suitability PVI* result from different coefficients and do not have a dimension.

Depending on the assumed parameters in total an annual yield of 225,055 TWh is possible as a maximum.

Suitability PVI
- 0 - 149
- 150 - 299
- 300 - 449
- 450 - 599
- 600 - 899
- 900 - 1150
- Major Cities
- Major Roads
- Gauteng Wards

Sources: Municipal Demarcation Board (wards), NASA (solar radiation), Own calculation (Suitability PVI)



Analysis 5 – PV Industrial / 50 MW

Areas where energy can be produced with 50 MW PV power plants are depicted in yellow and red colour. The darker the colour, the better the suitability based on the existing local solar radiation as well as the proximity to roads and transmission lines.

The figures in layer *Suitability PVI* result from different coefficients and do not have a dimension.

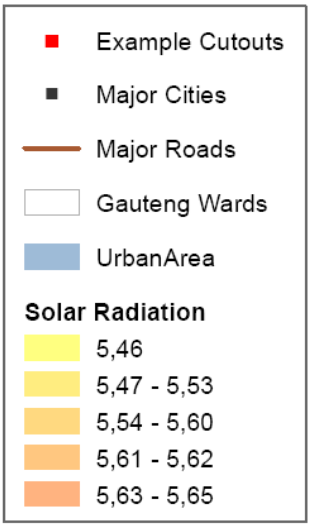
Depending on the assumed parameters in total an annual yield of 225,055 TWh is possible as a maximum.

Suitability PVI

- 0 - 149
- 150 - 299
- 300 - 449
- 450 - 599
- 600 - 899
- 900 - 1150
- Major Cities
- Major Roads
- Gauteng Wards

Sources: Municipal Demarcation Board (wards),
NASA (solar radiation), Own calculation (Suitability PVI)

Analysis 6 – PV Residential



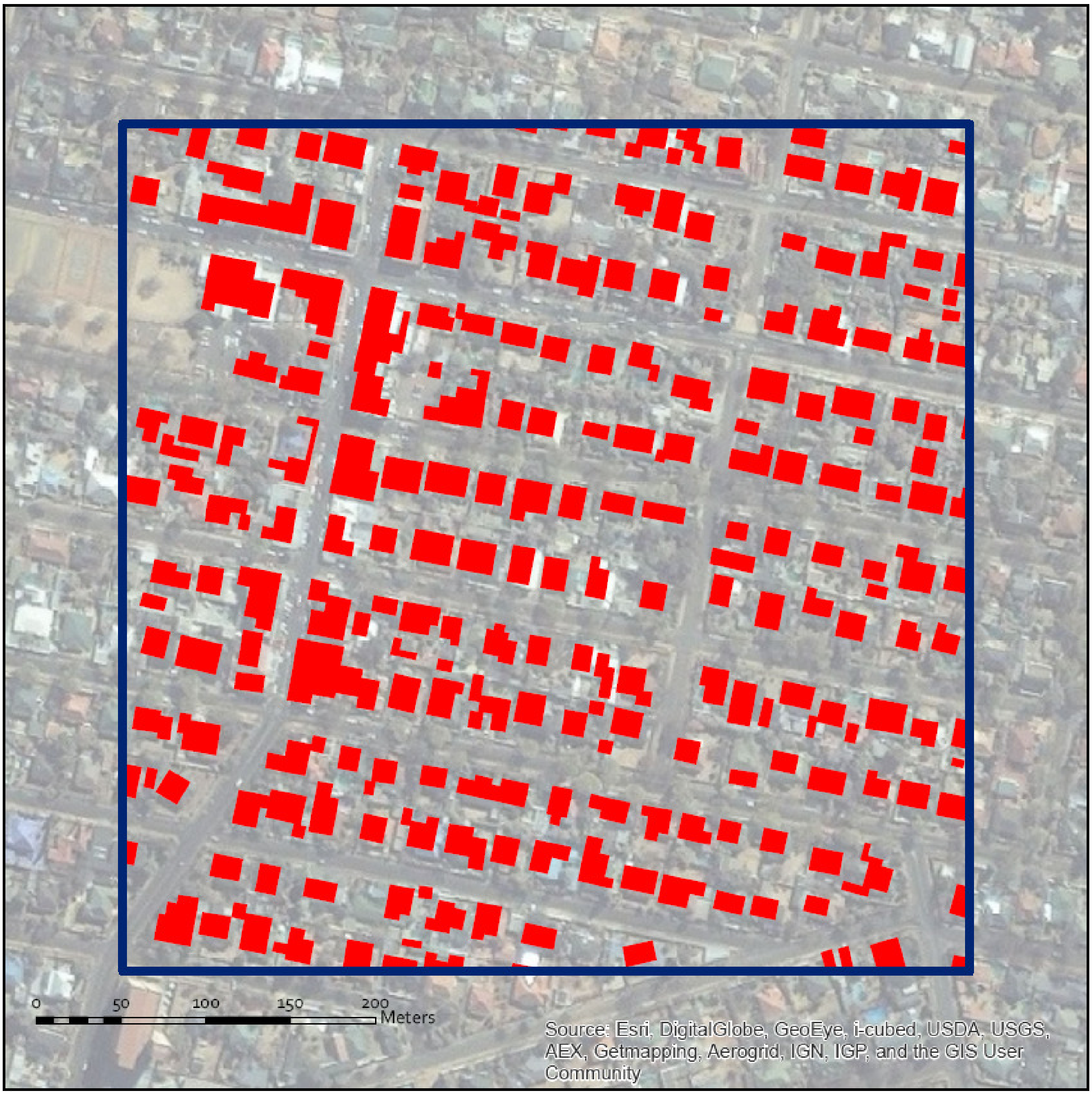
There are four example cutouts of the analysed settlement types:

- Residential area with high income (Melville)
- Residential area with middle income (Orange Farm)
- Downtown (Johannesburg CBD)
- Industrial area (Vereeniging)

The colour fields in the background display the existing local solar radiation. The darker the colour, the higher the average solar radiation. The values are given in kWh/m^2/d.

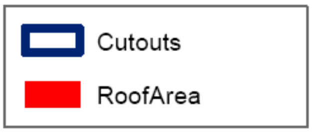
Depending on the assumed parameters in total an annual yield of 619 TWh is possible as a maximum.

Sources: Municipal Demarcation Board (wards), NASA (solar radiation), Own calculation (Suitability PVR)



Analysis 6 – PV Residential / Melville

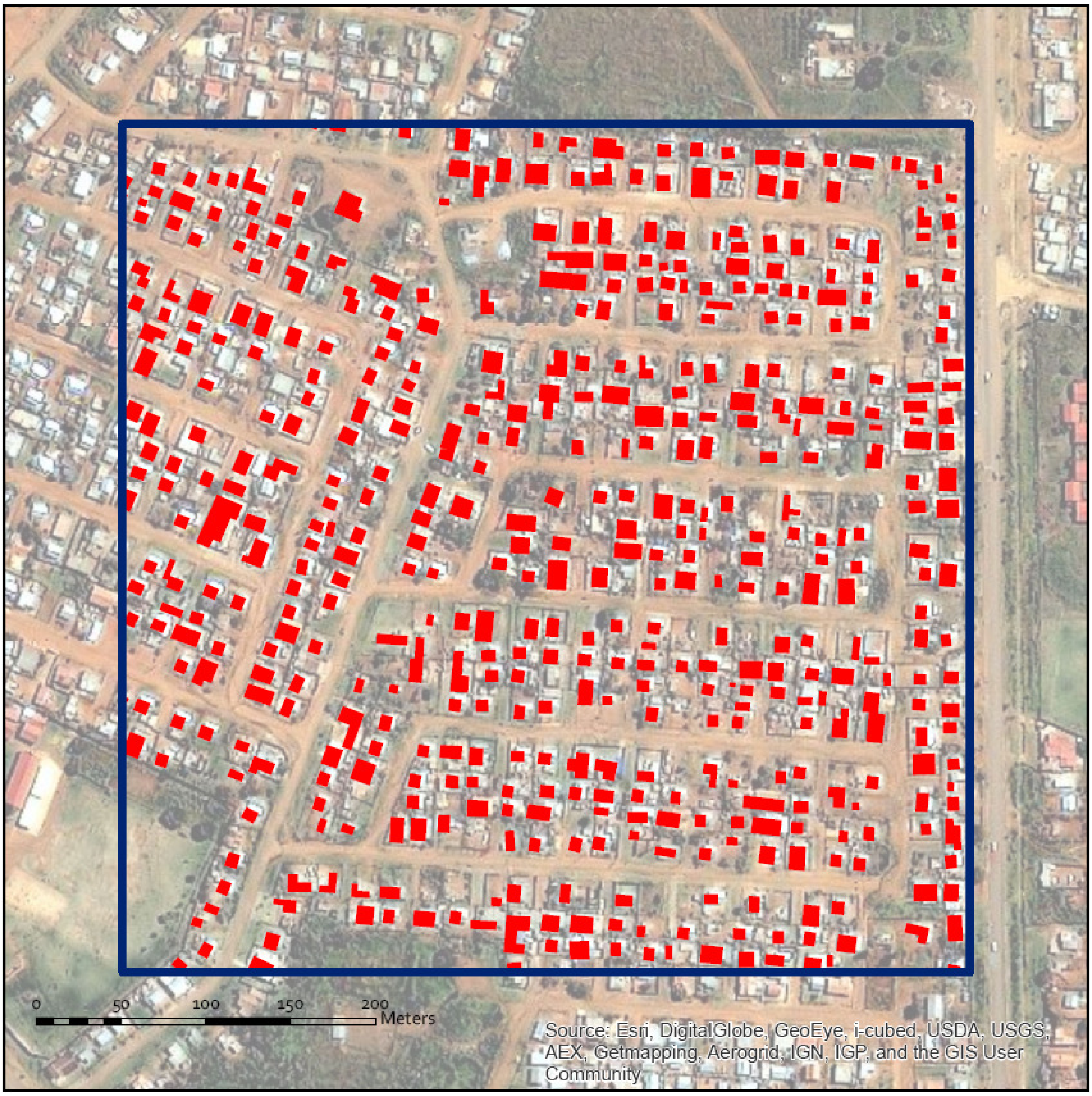
For this 25 ha cutout of Melville - an example for a residential area with high income - the potential of photovoltaic power generation with rooftop PV installations has been calculated.



Depending on the assumed parameters in total an annual yield of 38.4 MWh is possible as a maximum.

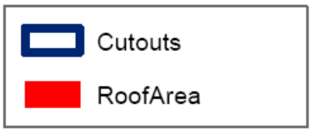
This equals a maximal annual yield of 1,536 kWh per ha.

Sources: See above (aerial image), Own digitalisation (roof areas)



Analysis 6 – PV Residential / Orange Farm

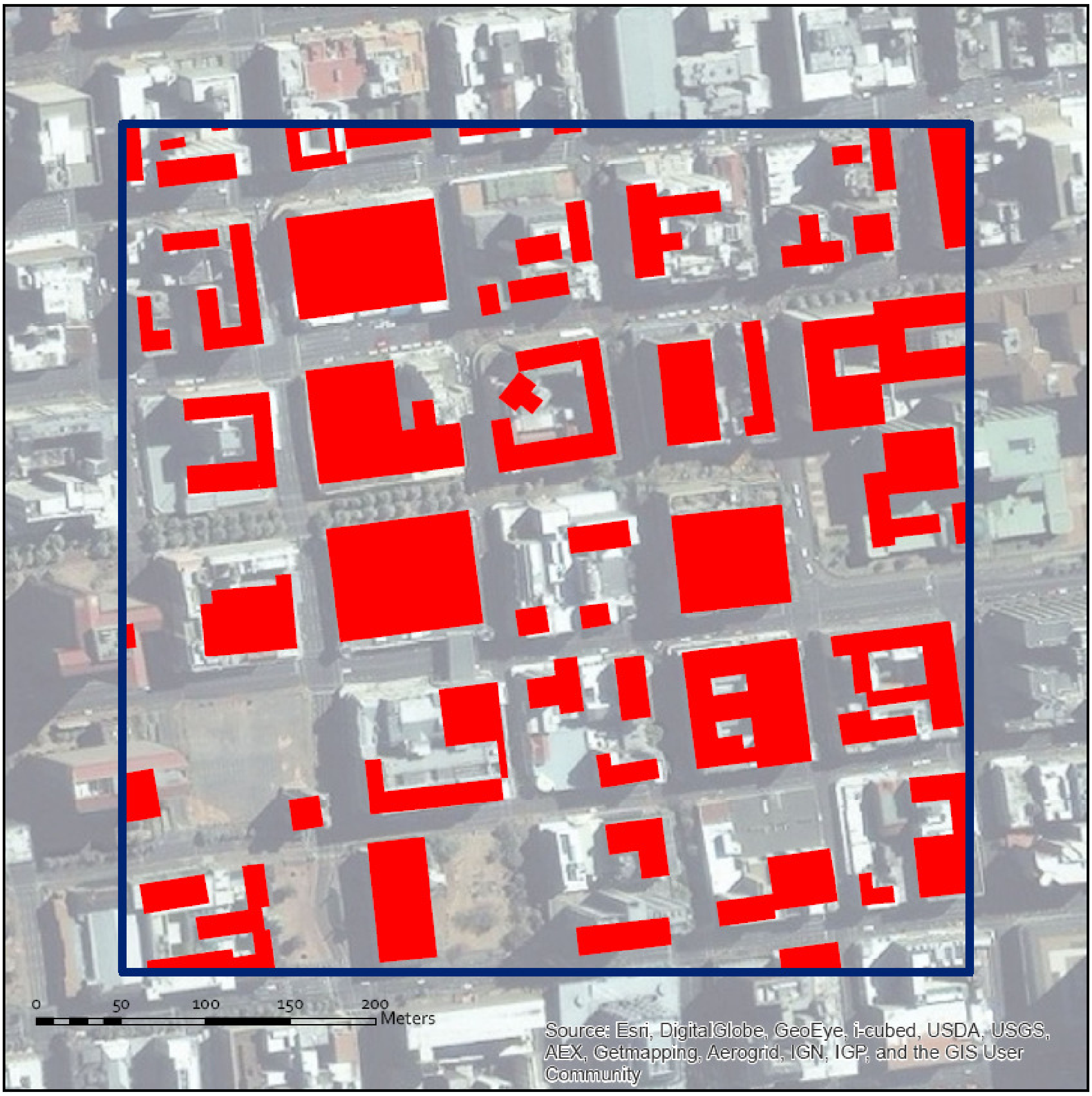
For this 25 ha cutout of Orange Farm - an example for a residential area with middle income - the potential of photovoltaic power generation with rooftop PV installations has been calculated.



Depending on the assumed parameters in total an annual yield of 20.7 MWh is possible as a maximum.

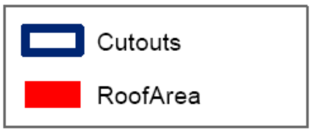
This equals a maximal annual yield of 827 kWh per ha.

Sources: See above (aerial image), Own digitalisation (roof areas)



Analysis 6 – PV Residential / Johannesburg CBD

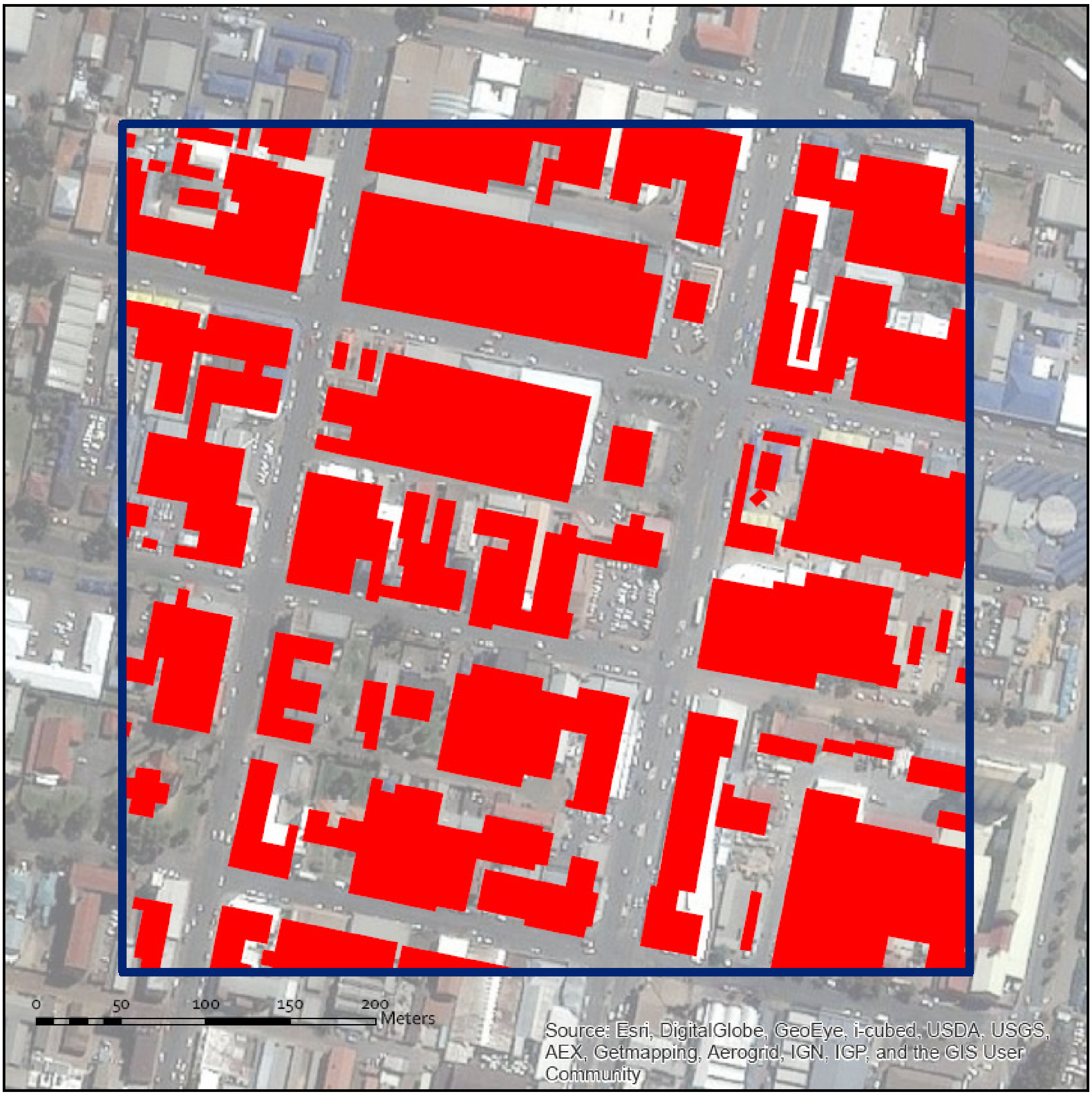
For this 25 ha cutout of Johannesburg CBD - an example for a downtown area - the potential of photovoltaic power generation with rooftop PV installations has been calculated.



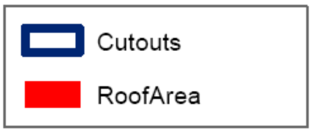
Depending on the assumed parameters in total an annual yield of 35.0 MWh is possible as a maximum.

This equals a maximal annual yield of 1,400 kWh per ha.

Sources: See above (aerial image), Own digitalisation (roof areas)



Analysis 6 – PV Residential / Vereeniging



For this 25 ha cutout of Vereeniging - an example for an industrial area - the potential of photovoltaic power generation with rooftop PV installations has been calculated.

Depending on the assumed parameters in total an annual yield of 69.0 MWh is possible. As a maximum

This equals a maximal annual yield of 2,760 kWh per ha.

Sources: See above (aerial image), Own digitalisation (roof areas)

5 SUMMARY AND INTERPRETATION

5.1 RESULT EVALUATION AND OPTIMISING

In the following segment the achieved result, and possible ways for improving the result, are illustrated and discussed for each analysis.

5.1.1 Analysis 1 – Wind Power

The average wind speed values in Gauteng are generally rather poor and hence the resulting energy production. Although as well wind power should be considered in the total energy production complex wherever applicable.

Taking these facts into consideration, the approach and the outcome quality of this analysis meet the requirements of the EnerKey project. The accuracy, however, could be enhanced by the following steps:

- Usage of more precise and more actual data on urban areas, traffic infrastructure, industrial plants, agricultural land use, restricted areas, protected areas, water bodies, forest areas, other land use.
- Usage of distance rules for WTG valid in South Africa or in the province of Gauteng, respectively.
- Usage of detailed data on local wind speeds.
- Usage of data on local prevailing wind directions.
- Calculating the number of WTG for all contiguous areas separately and considering the local existing wind speed.
- Clearing of artefacts and single pixels in raster data to avoid error areas.
- Checking the combination of areas separated only by narrow barriers and connectable by transmission lines with little effort.
- Checking of the parallel use of agricultural areas for energy production.
- Usage of data on areas used by armed forces.
- Checking for radio-relay systems of telecommunication organisations in the suitable areas.
- The calculation of the potential by usage of different levels of suitability – thus not all but only the most suitable areas, would be an interesting enhancement. This consideration follows the fact, that in reality not all generally suitable areas are really used for energy production with wind power, too. Partly they are used for other purposes. This way with lower effort a higher rate of return can be achieved. Thus by comparing several levels the optimal rate can be determined.

5.1.2 Analysis 2 – Biomass / Wood

Possible steps to enhance the outcome quality:

- The biggest drawback in this analysis is the imperfect forest data. It does not reflect the real distribution and size of the existing forest areas. This downgrades the result quality in several aspects as described in the following.
- Due to the forest data problem the slope data could not be considered for the evaluation of the forest distribution around the potential power plant sites, which would mean a further enhancement of the result.
- Furthermore, no minimum size for forest areas has been defined due to the forest data problem.
- In the heat value calculation formula 1.0 t/(ha*a) for the volume yield and 15 % for the water content have been assumed. For a more accurate calculation the real values referring to growth and climate conditions in South Africa would have to be implemented.
- A slope limit for the construction of power plants should be implemented.
- Here a global minimum size of 400 m^2 for power plant sites has been defined. For an exacter result there could be differed between several plant sizes (e.g. 800 kW, 2 MW und 5 MW).
- The usage of smaller units – to the point of pixels – for the evaluation of the available forest areas in the surrounding would be a considerable enhancement. But this depends on the available computer processing power.

5.1.3 Analysis 3 – Biomass / Energy Crops

Possible steps to enhance the outcome quality:

- Data on rapeseed, soy, sugar cane and sugar beet are not on hand. These crops are missing in the calculation of the total potential.
- The soil capacity data are only approximately. With more exact data the potential could be calculated much more accurate.
- A slope limit for the construction of power plants should be implemented.
- The usage of smaller units – to the point of pixels – for the evaluation of the available cultivation areas in the surrounding would be a considerable enhancement.
- In order to clarify the number of power plants required in total, the level of utilisation of the total potential has to be defined in a political decision.

5.1.4 Analysis 4 – Concentrated Solar Power

Possible steps to enhance the outcome quality:

- The NASA data on solar radiation have a resolution of 1 ° (about 20 km in this area) which is quite inaccurate. With a higher resolution a much better result would be achievable.
- Due to the partly very inaccurate original data – particularly layer *UrbanArea* – the buffer zones (in this case 25 m) relating to these data are not very significant.
- The described difficulties with the holes, caused by the forest data could be avoided with better original forest data.
- For the remaining suitable areas an evaluation regarding the possible rededication has to be made. Due to missing information on the actual land use and the land tenure this was not possible here.
- Due to the following reasons the potential of the suitable areas could not be calculated exactly.
  - In order to calculate the potential of the determined suitable areas, the real entirety of the available areas would have to be considered (see difficulties regarding urban area and forest data).
  - For a reliable CSP energy output calculation the hourly radiation values over a whole year have to be used and the appearing loss in the solar field or in the thermic process, respectively, have to be considered.
  - To judge about the suitability of areas a digital terrain model (DTM) would have to be used. In particular attention must be paid to the gradients.

5.1.5 Analysis 5 – Photovoltaics / Industrial

Possible steps to enhance the outcome quality:

- The NASA data on solar radiation have a resolution of 1 ° (about 20 km in this area) which is quite inaccurate. With a higher resolution a better result would be achievable.
- Due to the partly very inaccurate original data – particularly layer *UrbanArea* – the buffer zones (in this case 25 m) relating to these data are not very significant.
- Building PV power plants in the areas determined as suitable in this analysis will be subject to case-by-case-review. This covers not only the geometrical dimension but a lot of further criteria. The results given here can only be an approximation.
- In particular the suitable areas have to be investigated for the possibility of rededication. Due to missing information on the actual land use and land tenure this is not possible here.
- The difficulties with the urban area data and with the holes, caused by the forest data and described in the analysis “CSP”, could be avoided with better original data.
- Areas located adjacently and only separated by narrow paths or trenches have been determined as too small, but could possibly be suitable areas. In order to consider this

possibility, the areas could be buffered with a buffer distance of 15 m – first positively, then negatively. It has to be examined for all these areas in a case-by-case-review, if such combination of subareas is possible and reasonable.[93]

- To judge about the suitability of areas a digital terrain model (DTM) would have to be used. In particular attention must be paid to the gradients.

5.1.6 Analysis 6 – Photovoltaics / Residential

Possible steps to enhance the outcome quality:

- For better outcome values there would have to be digitised more example cutouts for each settlement category.
- Roof areas with less than 49 m^2 in residential areas and less than 1,063 m^2 in public and industrial buildings are excluded from this analysis. In fact it should be considered, that normally not the complete roof areas are available and thus bigger roof areas sometimes could have to be excluded as well.
- In this analysis roof areas have been merged by the mentioned buffering procedure. This way single roof areas have been combined as well that in fact do not belong together. For a more exact result the cadastral units would have to be used to separate contiguous but not belonging together roof areas.
- For an improved result the roof gradients and orientation would have to be considered.
- In the potential calculation within this analysis the solar radiation values have not been used. The reason was the missing data on the distribution of the different settlement types to the varying solar radiation values in Gauteng. Only with this information a reliable calculation is possible.

5.1.7 Analysis 7 – Solar Water Heaters

Possible steps to enhance the outcome quality:

- The accuracy is limited by the small area of the example cutouts. Bigger or more cutouts in different settlement types would result in a more precise picture. Densely populated areas with multi-family buildings and apartment blocks in particular would be subject of further examinations.
- Same as in the analysis “PV Residential” the cadastral units would have to be used for a more exact result concerning contiguous but not belonging together roof areas.
- In this calculation residential areas with a low income (informal settlements) are excluded due to the mentioned reasons. The water heating for these areas has to be discussed separately.

[93] GRENZDÖRFFER, 2012: 9

5.2 VALIDATION

Within a quality control process by means of validation it has to be checked if the analysis results generally meet the expectations. Usually in a quality management framework validation is combined with verification, which is similar but not the same. The following questions, extracted from B.W. Boehms "Software Risk Management" illustrate the difference[94]:

- Validation: „Are we building the right product"?
- Verification: „Are we building the product right"?

In the PMBOK, another benchmark publication a different definition is given[95]:

- Validation: The assurance that a result meets the specified needs.
- Verification: The evaluation of whether or not a result complies with a regulation, requirement, specification, or imposed condition.

In summary a verification process examines, if the result meets the specifications previously agreed on. In contrast a validation process ensures that a result meets the real requirements, implying a check whether the specifications previously agreed on are proved to be reliable.

In the analyses executed and discussed here, abstractions, assumptions and simplifications were necessary as in every model. Due to these reasons the analysis results have a considerable lack of accuracy and reliability. The reasons have been described to detail in the related sections. In the following some validation methods are presented along with possible examples of use in this thesis.

5.2.1 Methodology

It is only natural that results vary. But there should be objective criteria regarding variations that cannot be accepted and procedures to deal with such cases. Only as per defined criteria their observance can be checked.[96]

Sensitivity Analysis

The sensitivity analysis method examines, how variations in the output of a model can be apportioned to different sources of variation in the input of a model[97]. Namely the effect of input parameter changes on the output is tested.

Sensitivity Analysis ArcGIS Tool

With *Geostatistical Tools / Utilities / Semivariogram Sensitivity* ArcMap provides a tool for sensitivity analysis. It compares an analysis outcome with a temporarily calculated result,

94 BOEHM, 1989
95 O.V., 2013
96 KROMIDAS, 2011
97 SALTELLI, 2008

generated with slightly different input parameters. A percentage for this variance can be entered. If both of the results differ considerably with marginally different input parameters underlying, the result cannot be regarded as reliable.

Plausibility Check

In some cases, none of the other methods can be applied or at least not with a justifiable effort. Then the correctness can be judged on the basis of plausibility.[98]

5.2.2 Example: Analysis 1 – Wind

As an example for all analyses the lack of data required for a complete and reliable result is the first drawback here: In fact, data on swamps, sand dunes, salt deserts, oil-fields and mining areas, restricted areas, airports with entry lanes and radio-relay systems of telecommunication organisations are not available. Beyond that the land use data namely regarding urban area and forest are of poor quality.

Comparing the achieved analysis result with an outcome calculated on the basis of more complete or accurate data would give a picture of the result quality. It would furthermore allow a statement, whether the model is plausible or not.

- The holes in the suitable areas caused by single forest area pixels for instance (see Figure 25) are an example for small mistakes causing big outcome changes. Corrected forest data would effect a completely different result.

The same applies to the calculation of the highest possible number of WTG. For simplicity reasons here a formula was used, that was developed especially for another study.

- The used formula **Number of WTG = 0.0443 * Area in ha + 2.59** makes clear, that with an evaluated area of 251,288 ha even small parameter modifications could effect big result changes.

Already within the data preparation of the multiple buffer zones around roads and transmission lines the effect of changed buffer widths has become visible.

- A test with different values quickly made clear, that rather small buffer widths have to be chosen (see Figures 19 and 20). Otherwise the buffer zones would cover a portion of the Gauteng province area which is too big. This would defeat the purpose of this step.

The most significant fault in this analysis is the poor resolution of the wind speed data. In reality without more exact datasets such an analysis is of disputable value.

- Effectively real wind speed data with a resolution of about 1 km instead of the used 20 km would result in a completely different output picture. Here more than anywhere else the sense of this calculation can be called into question.

[98] KROMIDAS, 2011

Only in form of plausibility checks in a case-by-case review it could be determined, if areas with a size below the lower limit could anyway be used (see criteria in the related section).

5.2.3 Example: Analysis 4 – CSP

The problem regarding the lack of data has been described above. As well the statement on the wind speed data applies in the same way to the solar radiation data used in the analysis "CSP".

The calculation of the compactness of areas opens a wide field for modifications regarding input parameters.

- The details to the decision making process regarding the compactness ratio and size limit values have been described for the analysis "Wood", but apply to the analysis "CSP" as well. Even small changes of the compactness ratio limit or the size limit would result in a considerably different choice of polygons.

By means of a plausibility check, namely the comparison of determined areas with satellite images of the region it could be clarified, that often the size and compactness of polygons has been limited by data faults. With some manipulations that are described in detail in the analysis chapter an attempt has been made to achieve a result which represents an approximation to the expected result related to the actual circumstances.

- The calculation of suitable areas has been done three times with a different composition of excluding area datasets. First the process has been done with the complete composition of datasets, then without forest data and finally without forest and slope data.

Within the validation process, taking into account the imperfect solar radiation values in Gauteng, the question that inevitably comes to mind is, which efforts in the usage of solar energy is worth it. But the spatial proximity of the determined suitable areas can be considered as an advantage for the development of a central location for solar energy use with CSP in the province.

5.3 OUTLOOK

From the analyses prepared here various conclusions can be drawn for the different forms of renewable energies and their use.

Potential of Gauteng		
Analysis		Potential per year
Wind Energy		27.503 GWh/a
Wood (1)		556 GWh/a
Wood (2)		278 GWh/a
Energy Crops (1)		4.053 GWh/a
Energy Crops (2)		2.027 GWh/a
CSP		1.650 GWh/a
PV Industrial		225.055.580 GWh/a
PV Residential		556.471 GWh/a

Table 30: Total Energy Production Potential

Table 30 illustrates the determined theoretical energy production potential with the presented methods in an overall view. As mentioned before, these values will not be feasible, but there must be established a local discussion on how much energy shall be produced from which renewable source. Beyond that, the areas of suitability, determined in each case, overlap each other partially, which makes the various usage types exclude each other to some extent. For that reason no total sum of the single values has been calculated.

As we have seen, there are different approaches for the allocation of facilities for wind, biomass and solar energy – according to the requirements of number and capacity. In view of the distribution of energy needs, the production facilities should be positioned as decentralised as possible. Regarding biomass, however, a focus on areas with an increased incidence of the related resources seems appropriate. Due to the circumstances regarding space requirement and local solar radiation this also applies to CSP sites.

5.3.1 Conclusions and Discussion

Wind Energy

Due to the moderate wind speed values in Gauteng the use of wind energy will always play a minor role there. In other South African provinces, particularly in the southern coastal regions much more advantage can be taken of wind energy.

Nevertheless, at particular locations wind energy surely can be used in Gauteng. Single WTG or small wind parks can be established with low space requirement. This is easily possible at isolated profitable spots as a supplement to other forms of renewable energies.

Biomass

The two values recorded in table 30 for the energy production potential of wood refer to both of the assumed annual volume yield values, 1.0 t/(ha*a) and 0.5 t/(ha*a).

For the energy production potential of energy crops, two values are given in the table as well. They represent exemplarily the usage of 100 % or 50 %, respectively, of the calculated potential. It has already been pointed out that the desired quota in reality has to be defined in a political discussion.

Solar Energy

Particularly notable are the considerably higher values for the potential of solar energy. Table 31 illustrates the proportions for the different forms of renewable sources. In comparison with wind energy and biomass the solar radiation conditions in Gauteng provide the best options for the gain of renewable energies. Here the best prospects seem to be offered. But the following aspects have to be observed:

Potential of Gauteng			
Analysis		Potential per year	Proportion
Wind Energy		27.503 GWh/a	0,012 %
Biomass		6.914 GWh/a	0,003 %
Solar Energy		225.613.701 GWh/a	99,985 %

Table 31: Potential per Renewable Source

The potential calculated for the use of PV power plants clearly stands out from the other values. The reason for that is the relatively few land requirement for the single sites in comparison with CSP sites. Hence significantly more single areas have been defined as suitable. However, it has to be expected that only a fraction of the entire potential will be exploited, since a lot of these areas have to be excluded due to criteria described above.

The value for individual PV installations, likewise far above average, has to be regarded with caution. Of course this theoretically maximum amount of the possible potential cannot be exploited in reality. The limitations are the same as in Europe. The decision on the use of PV installations on residential property is made by the respective owners and not by the governmental administration. Politics itself can only create incentives to promote the usage. The financial options of the decision makers have to be measured on the basis of the national Human Development Index (HDI)[99] value of this emerging country.

Table 31 contains no values for the use of SWH, since this is not actually a method of energy production. Only the energy saving potential in comparison to conventional water heating could be determined. But taking into account the local solar radiation conditions, the use of SWH is already widely disseminated.

5.3.2 Further Work

Further efforts in continuing the previous work will concentrate on refining the analysis results by the use of improved data. Two key aspects in particular will lead to expedient results:

Higher resolution data on wind speed and solar radiation have to be gained. In addition, it has to be clarified, which of the areas, defined as suitable, really can be used or have to be excluded on the basis of criteria disregarded so far. Furthermore, for the usage of individual PV installations it has to be examined which proportion of the available areas realistically can be used.

To face and solve the energy management problems, as discussed in the beginning within the EnerKey project framework, one important aspect goes beyond the field examined in this thesis. In addition to renewable energy production, an increased efficiency in energy use is essential. In Germany the overall efficiency of energy use is about 30 %, worldwide it is about 10 %[100].

An economical and efficient use of energy is essential, if we want to get our energy management under control in harmony with an intact environment. And all of us can exert our influence on energy use, even more than on energy production.

[99] UNDP, 2013
[100] GEITMANN, 2010

6 INDICES

6.1 ABBREVIATIONS

CBD	Central Business District
CSP	Concentrated Solar Power
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DTM	digital terrain model
EU	European Union
FNR	Fachagentur Nachwachsende Rohstoffe
GCRO	Gauteng City-Region Observatory
HDI	Historically Disadvantaged Individuals
HDI	Human Development Index
IER	Institute of Energy Economics and the Rational Use of Energy, University of Stuttgart
IRENA	International Renewable Energy Agency
IUCN	International Union for Conservation of Nature
LEL	Landesanstalt für Entwicklung der Landwirtschaft und der Ländlichen Räume
NABU	Naturschutzbund Deutschland
NASA	National Aeronautics and Space Administration
OSM	OpenStreetMap
PV	Photovoltaics
PV-I	Photovoltaics Industrial (Power Plants)
PV-R	Photovoltaics Installations on Residential Buildings
RE	Renewable Energies
REACCESS	Risk of Energy Availability: Common Corridors for Europe Supply Security
SANBI	South African National Biodiversity Institute
SAWEP	South Africa Wind Energy Programme
SWH	Solar Water Heaters
UNESCO	United Nations Educational, Scientific and Cultural Organization
WASA	Wind Atlas for South Africa
WDPA	World Database on Protected Areas
WTG	Wind Turbine Generator

6.2 ILLUSTRATIONS

6.2.1 Figures

6.2.2 Tables

6.3 REFERENCE LIST

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