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Renewable energies in Africa

Current knowledge

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Executive Summary

This report summarizes current knowledge at the Joint Research Centre regarding Renewable Energy in Africa. It assesses current energy consumption and the share of renewables in African states, and attempts to estimate the technical potential of available resources of solar, wind, biomass and hydropower which could be economically used to provide energy for the increasing population.

Existing Statistical data on energy supply and demand have a large uncertainty, both in terms of quantity and costs or price. The available data which were used for this report indicate a wide range both of per capita energy consumption (100 to 2000 kgoe/cap/y) and per capita electricity consumption (50 to 4000 kWh/cap/y). Relative to the average of the European Union, this corresponds to up to 35 times less regarding all energy, and up to 100 times less regarding electricity. Even though electrification made considerable progress in the past 10 years, 600 Mio of rural population has no access to electricity at all.

This report assesses in detail the renewable energy options for electricity production in rural areas, where the de-centralised feature of these technologies allow an economically viable competition with conventional grid extension. It is particularly true in remote areas where the nearest grid infrastructure is already unreliable and overloaded. In areas where household density is low (<50 cap/km2), any investment in larger grid infrastructure would never be cost competitive. This report enhances also insight in the transport costs of conventional fuel, taking a population density to be served and transport infrastructure into account.

Regarding renewable resources, geographical data on solar radiation, wind weather patterns, biomass resources of forests, agriculture and residues as well as water resource data have been assembled. Such an approach allows for each region of Africa to estimate the best choice or mix of renewable resources, taking fully into account sustainability and environmental criteria. It is hoped that these data can be referenced by African states involving in setting up a national renewable energy action plan.

A detailed analysis is given regarding one of the currently major energy vectors, biomass combustion and charcoal, as it is not only supplying almost 60% of current energy needs, but a major target to improve efficiency by modern technologies. Such improvement is of key importance, as it would avoid the negative health effects, reduce specific greenhouse gas emissions and contribute to sustainable forest management.

Finally, current costs of technology are compared to existing energy costs, assuming also "willingness-to-pay" estimates. This comparison also reveals the influence of existing energy subsidies in the slow deployment of renewable resources.

The report was compiled in relatively short time, and it shows the remarkable capability of the JRC to pool instantaneously available expertise. However, a range of important items should be studied better in a follow-up:

- More precise energy data, in particular current energy prices and in general more consistent and harmonized data. Large parts of this report's Energy data miss at least 10 countries, including some with considerable population.
- The potential of smaller scale (<50 kW) wind-energy systems within hybrid solar/(bio-)diesel-generator/wind electricity systems has not yet been studied
- A systematic biomass resource assessment has still to be developed, in particular regarding yield-increase, competition of resources along food, fuel, feed and fibre, the distribution vectors and human resources.

- On a longer perspective, the effect of climate change on the rural environment should be studied, both regarding floods, draughts and solar radiation changes.
- More socioeconomic studies regarding the estimated growth of rural and urban area population. Renewable energy as de-centralised source has the potential to limit the excessive growth towards mega-cities.

Renewable Energy in Africa is a huge opportunity to allow for a better standard of living for a large part of current and future population in Africa. However, it should be pointed out here that much of the knowledge, - including that which is also presented in this report -, should be transferred swiftly to research and technology partners in Africa, in collaboration and co-operation with the wide range of existing research and university infrastructure. Only if much of the research, prototyping, demonstration and large scale deployment are done by African people, one can accelerate the uptake of renewable energy in Africa.

1. Introduction.

1.1 Access to energy in African countries

Compared to the rest of the world, there is a general shortage of energy related information in Africa (on potential of energy resources, actual installed systems and current energy use).
This lack of information is even more apparent for renewable energies (REN-21,2010). It is indeed difficult to compare the potential for the different energy options due to the scattered validated information. Nevertheless, available data sources are in agreement in describing a difficult situation as far as access to energy is concerned.

Figure 1.1 shows the energy (left) and electricity (right) consumption per capita, in 2006 (UN-WB, 2011), to be compared with an International Energy Agency definition of an individual in "electricity poverty" when not having access to at least 120 kWh of electricity per year for lighting and other basic households needs.

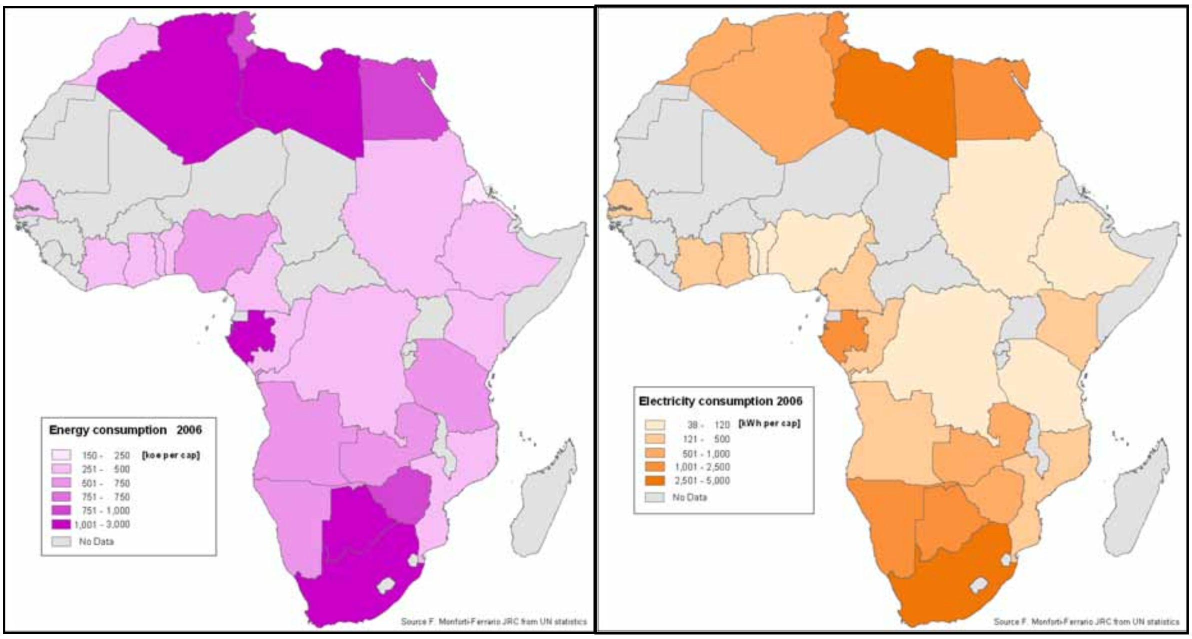


Figure 1.1 *Energy consumption (left – kgoe per capita) and electricity consumption (right – kWh per capita) in 2006 in several African countries. For comparison, the 2008 average EU-27 corresponding figures amounted to 3510 kgoe per capita and 6384 kWh percapita, respectively. (UN-WB, 2011)*

According to 2010 estimates, approximately 3 billion people worldwide rely on traditional biomass for cooking and heating, and about 20% of the world's population, 1.4 billion people, have no access to electricity (OECD/IEA, 2010) with 85% of those people living in rural areas. Up to a billion more have access only to unreliable electricity networks (UN-AGECC, 2010).

In the African continent, according to Alliance for Rural Electrification elaboration of IEA data (ARE, 2011), the overall amount of people without access to electricity has reached 589 millions in 2008, with additional 9 millions of people with no access to electricity every year since 2002. Nevertheless, the electrification rate increased from 35.5% in 2002 to 40% in 2008. More in detail, the urban electrification rate has reached 66.8% in 2008 while the rural electrification rate was stuck to 22.7% in 2008 showing a very small increase from the 2002 figure of 19%. Considering that around 59.6% of people are estimated to live in sparsely populated rural areas (UN, 2011), access to energy and especially electricity remains a major issue for most of the continent.

1.2 The current state of renewable energies in Africa

The high share of rural population, coupled with the low ability and willingness to pay (affordability), the low per capita energy consumption and the high rate of non-electrified rural areas, has traditionally pushed rural communities to make use of locally available energy sources, mostly biomass from agriculture residues and forest ad savannah wood for their daily cooking and heating needs.

Figure 1.2 shows the share of total energy use coming from biomass and organic waste combustion (BOWC) in some African countries in 2006-2008 (top), and the longer 1990-2010 trend making more evident the deeply different use of mostly local biomass resources between Sub-Saharan Africa (SSA) (with the exception of South Africa) and northern Africa, with SSA using these energy sources for an average share of 57.6% of total energy needs in 2008 (IEA, 2011).

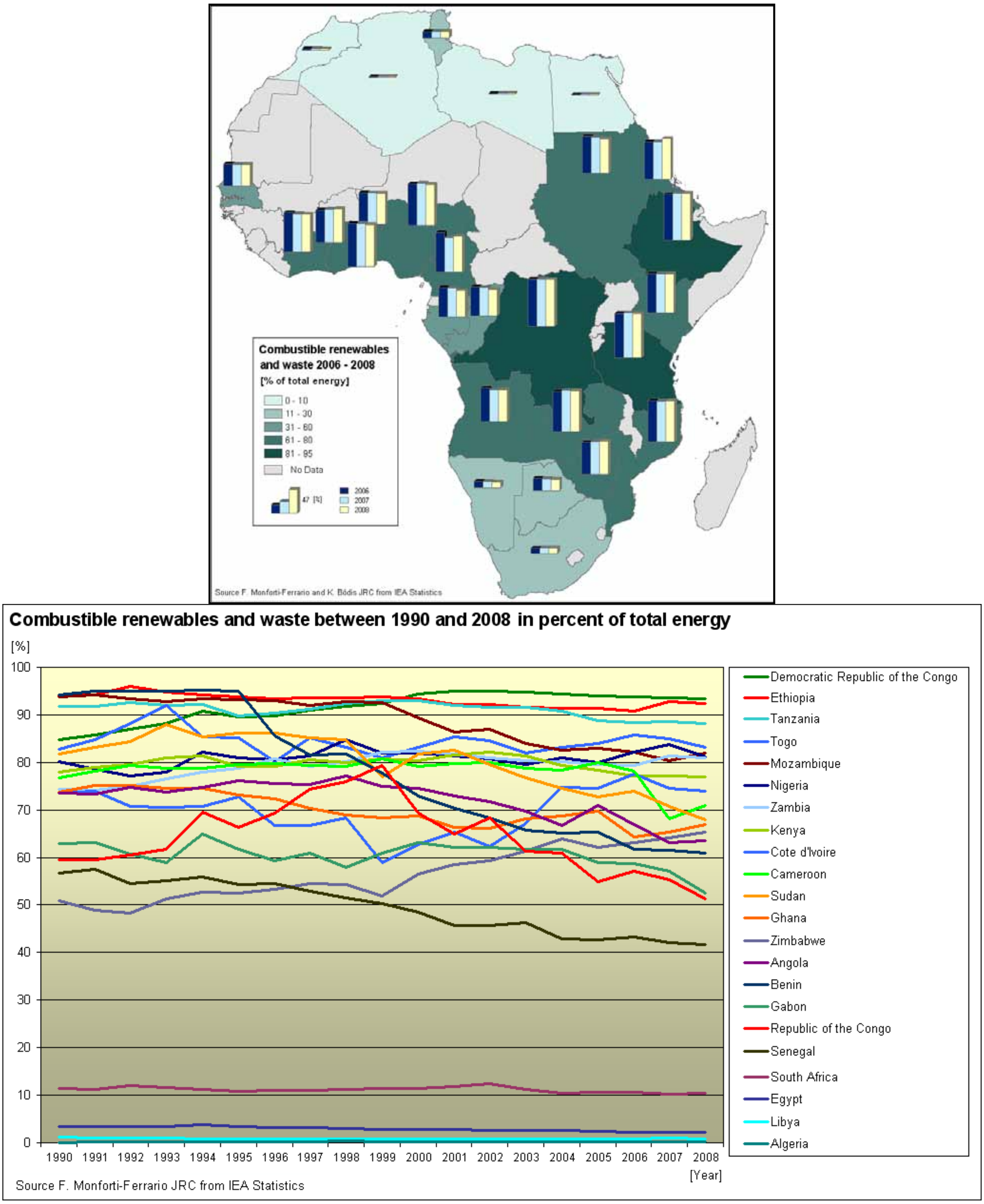
The following table 1.1 shows how in 2008 biomass and organic waste combustion in SSA are mainly used in residential sector and, conversely, how the residential sector is often almost totally dependent on these resources (IEA, 2011).

Table 1.1: Dependence of residential energy needs from BOWC in five SSA countries

Country	**Share of BOWC used for residential needs - 2008**	**Share of residential energy needs covered by BOWC -2008**
Dem. Rep. of the Congo	80%	99%
Ethiopia	100%	99%
Tanzania	85%	98%
Togo	90%	91%
Mozambique	90%	99%

Unfortunately local biomass and organic waste sources are often exploited in a non sustainable way and burnt into non appropriate stoves and oven, causing a diffuse problem of indoor air quality (see chapter 4 for details).

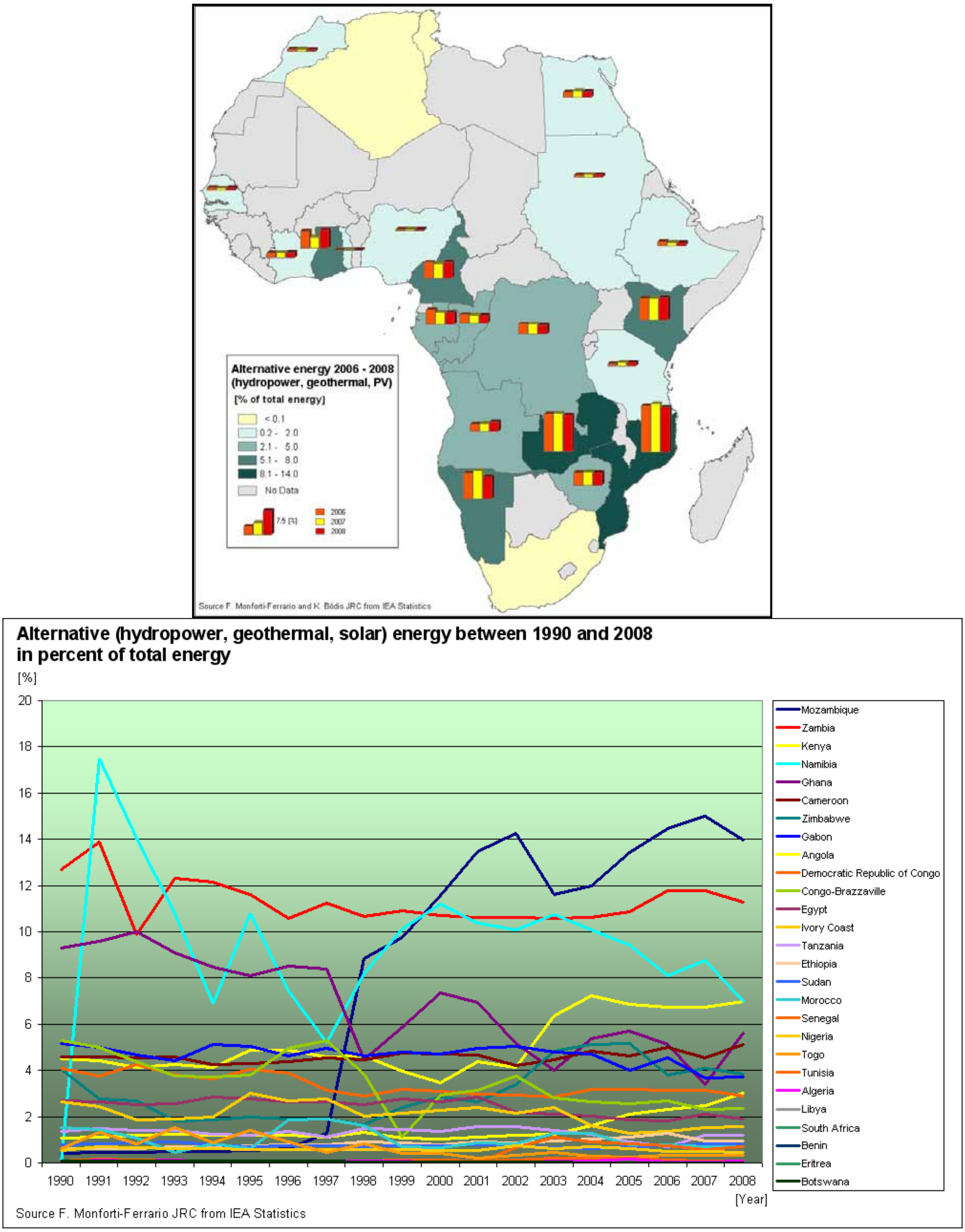
Figure 1.3 shows the amount of renewable energy produced from solar, hydro, wind and geothermal sources in 2006-2008 and the similar 1990-2010 trends. It is worth noticing that among the six leading countries (Mozambique, Zambia, Namibia, Kenya, Ghana and Cameroon), five derive almost all their renewable energy from some large hydro plants while only one (Kenya) shows a relevant non-hydro renewable energy production coming from geothermal (IEA, 2011).



Source F. Monforti-Ferrario and K. Bódis JRC from IEA Statistics

Source F. Monforti-Ferrario JRC from IEA Statistics

Figure 1.2 *Share of total energy use coming from biomass and organic waste combustion. 2006-2008 data (top) and 1990-2010 trends (bottom).*



Source F. Monforti-Ferrario and K. Bódis JRC from IEA Statistics

Source F. Monforti-Ferrario JRC from IEA Statistics

Figure 1.3 *Share of total energy use coming from wind, solar, hydro and geothermal sources. 2006-2008 data (top) and 1990-2010 trends (bottom).*

1.3 Renewable energy exploitability and infrastructure availability in Africa

Renewable energy resources are diffuse in the territory and mapping their physical availability can only be the first step in understanding their exploitability especially for people without modern forms of energy in Africa. A deep knowledge of the existing and feasible energy infrastructures is fundamental for moving towards the assessment of the economically utilizable renewable energy.

Indeed, according to IEA data, 99.6% of the African population without electricity access is concentrated in Sub-Saharan Africa (SSA) countries, reflecting the great disparities in the different African regions caused also by the still unbalanced development of the energy production and transport infrastructures in the continent.

Figure 1.4 shows the JRC elaboration of available data of the electricity grid in all African countries (AICD, 2009) and the location and type of the main power plants in Sub-Saharan Africa, as collected by JRC in the frame of the AFRETEP project (left) together with the population density of the African continent (Balk et al.,2004). The comparison of the two maps makes it evident how several areas of the continent are still well far away from relevant energy infrastructures even with non-negligible population density.

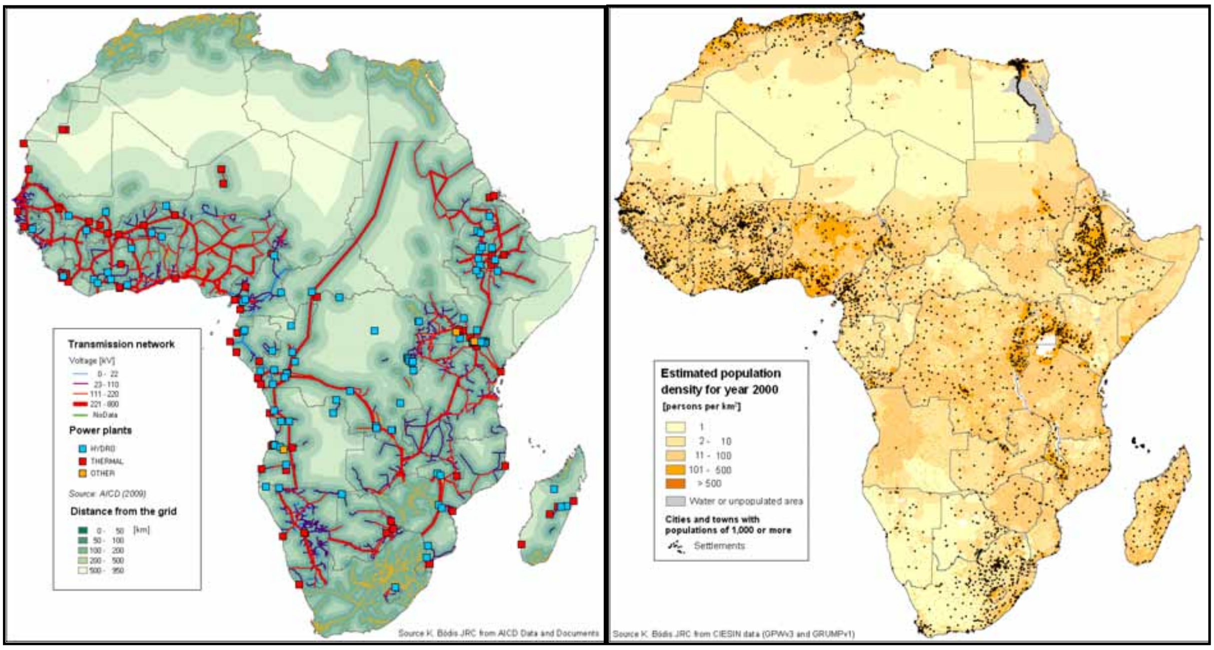
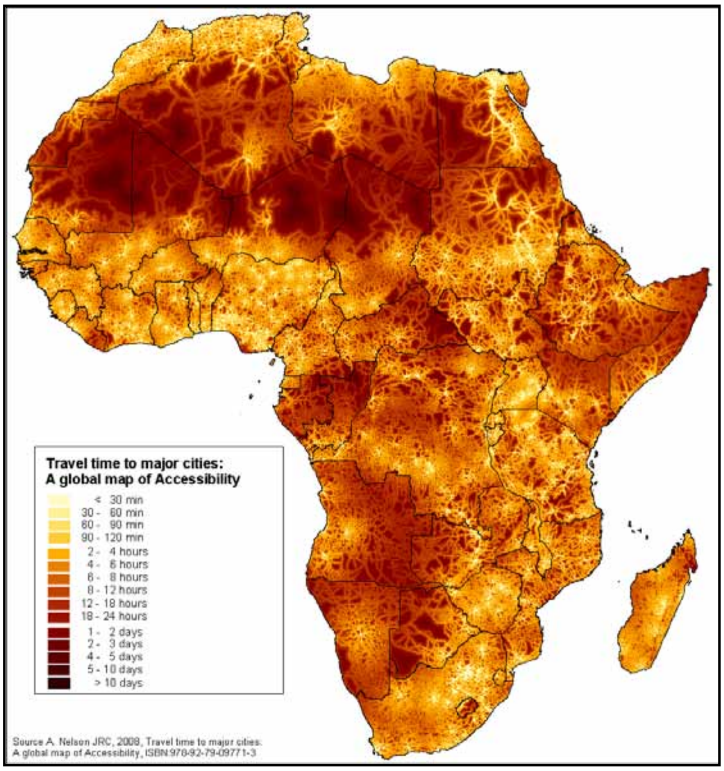


Figure 1.4 *The geographical deployment and voltage capacity of electricity grid in African continent (yellow lines mean transmission/distribution grid existing but no data on capacity are available) and power plants in Sub-Saharan countries (left) and population density estimated in year 2000 in the African continent (right).*

Moreover, one has also to notice that in Africa the population access to fossil energy sources too is not always easy. Figure 1.5 shows the accessibility map elaborated by JRC on the basis of available transport infrastructure data, showing the time needed to reach every area of the continent from the nearest town with more than 50,000 inhabitants. This map provides an overview of how long goods, including fossil fuels, need to travel from mid-size towns to reach dispersed rural areas: in case of fuels travelling by trucks the longer the travel time the higher the price of fuel and the smaller the total availability.



Source A. Nelson JRC, 2008, Travel time to major cities: A global map of Accessibility, ISBN 978-92-79-09771-3

Figure 1.5 *Travel time from the nearest 50,000+ town in Africa. (Nelson, 2008)*

In summary, if properly exploited, renewable energies are a big opportunity for improving the currently very poor access to energy for rural communities.

In the following chapters the resources and deployment potentials of the most relevant renewable energy sources in Africa will be discussed in more detail, mostly on the basis of relevant data and analysis recently developed in the JRC.

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2. Solar energy: resources and possible penetration.

2.1 Solar resources in Africa . The PVGIS tool.

Photovoltaic Geographical Information System – PVGIS (Huld *et al.*, 2005) has been developed in the JRC during the last 10 years and provides a map-based inventory of **solar energy resource** and assessment of the **electricity generation from photovoltaic systems** in Europe, Africa, and South-West Asia. PVGIS is a well known, widely employed and robustly validated tool also suitable for further analysis on solar energy deployment.

In figure 2.1 one of the maps developed specifically for the African continent in the framework of the AFRETEP project is reported. The figure shows the yearly average of daily total of global irradiation on a horizontal and/or optimally inclined surface. The data are derived by resolution enhancement of the HelioClim-1 database, representing 20-years average of the period 1985-2004 [kWh/m^2].

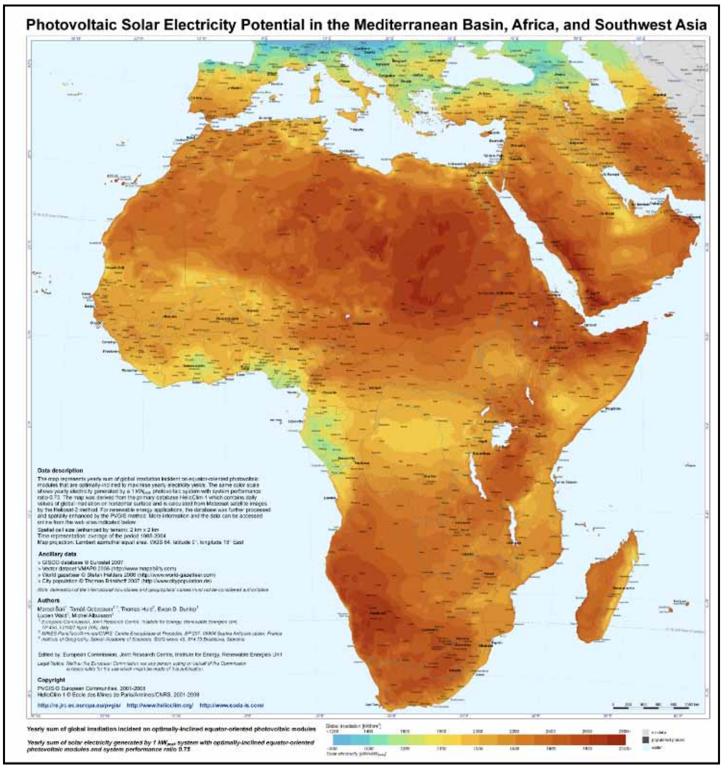

Figure 2.1 *Photo Voltaic Solar electricity potential as computed by PVGIS (PVGIS, 2011)*

It is interesting to notice that there are areas in Africa where solar potential can be considered very interesting, with the same photovoltaic panel ready to produce twice as much electricity in Africa as in Central Europe on average. Nevertheless, to be considered as a suitable energy solution for providing electricity to rural areas, photo voltaic has to prove to be more economically convenient once compared with at least two main competitors: grid extension and traditional diesel generators. In the following paragraph a "case study" data and methodology basis of such a comparison study are summarized.

2.2 Assessing economically feasible rural electrification strategies in Africa. The case study of PhotoVoltaic in comparison to diesel and grid extension[1].

While local biomass resources have been traditionally the main energy sources for rural households heat needs, from the 1950s onwards, diesel stand alone systems and grid extension have been the dominant solutions for the electrification of rural areas in Africa.

In certain cases, grid extension may prove to be the most economic solution to bring electric power to rural communities. Nevertheless, a mini-grid or stand alone system could be the least-cost option, especially given the overall underdevelopment of the grid infrastructure and the excessive cost of grid building when the expected electricity load is relatively low

In such a situation, mini-grids based on local renewable resources may prove to be more affordable in specific regions than grid extension. It is also relevant that some of the renewable energy technologies (e.g. PV itself) are much more productive in Africa than in regions where renewable energies are highly present in the national energy mix. Furthermore, the fact that the transport cost of diesel is higher in remote areas with a sparsely developed road structure helps to increase the competitiveness of diesel– renewable hybrid systems with a higher share of renewable energy technologies.

2.2.1 Off-grid PV and diesel cost analysis

Starting the cost analysis from photovoltaic, Figure 2.2 (left) shows the calculated electricity production cost calculated for local minigrid PV systems in Africa. Computations are primarily based on solar radiation data (see Figure 2.1) and a set of assumptions on costs and efficiency of "typical" off grid PV systems suitable for the African environment. (see Szabó *et al*, 2011 for details). Large geographical differences can be observed: some of the most favourable regions with low costs have very low population density (e.g. Sahara with 0–15 persons per square kilometre), while other regions are relatively densely populated (e.g. Tanzania, South Africa with 30– 100 persons per square kilometre).

For costs of diesel produced electricity in rural areas, to estimate the location specific operating costs for diesel gensets, the country-based diesel prices have been combined with the travel time data (derived from the accessibility map shown in Figure 1.3) integrating the transport costs. The database of international diesel market prices for 2008 in African countries was used, including national taxes/subsidies. Diesel transport cost is the other relevant variable. The transport infrastructure underdevelopment has severe consequences, the transport costs faced by African countries being almost twice as high as the world average.

Information regarding the travel time to major cities was used as a proxy to establish the diesel price for various locations differentiated from the countries' average. Thus, the farthest villages would probably be the most favoured for renewable energy installations. The overall results of the analysis are shown again in Figure 2.2 (right side) where the both effects of different country diesel market prices and proximity to the main roads are evident.

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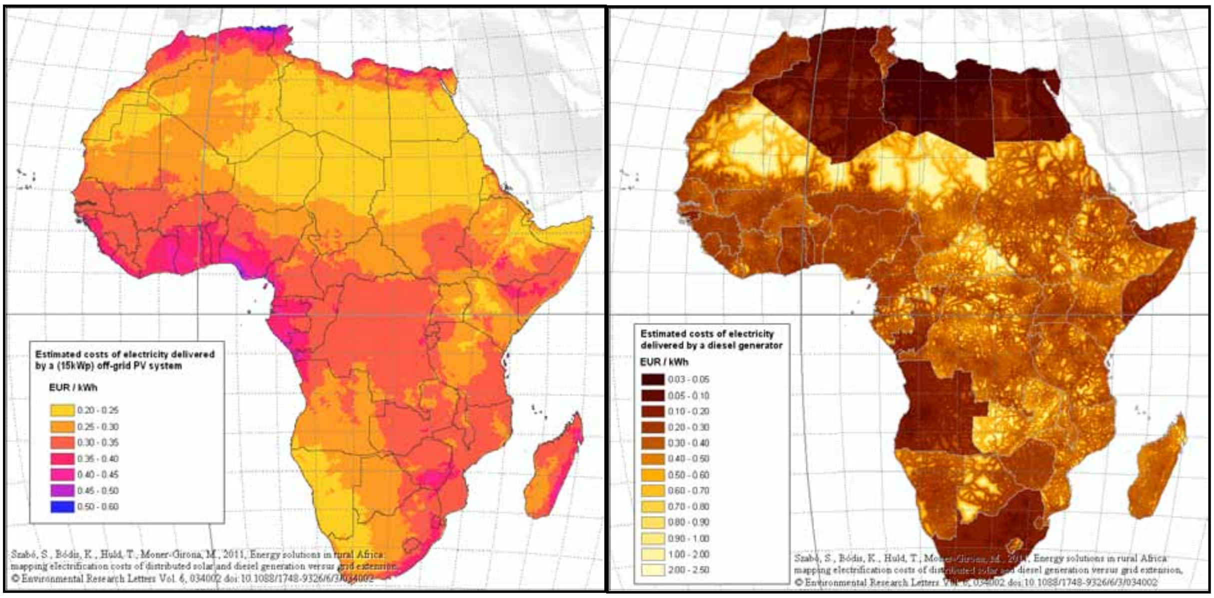
[1] Chapters 2.2 and 2.3 summarize the main findings of the research paper Szabo *et al.* (2011).
Full details, references and actual values of parameters employed are available in the published paper.



Szabó, S., Bódis, K., Huld, T., Moner-Girona, M., 2011, Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension, © Environmental Research Letters Vol. 6, 034002 doi:10.1088/1748-9326/6/3/034002

Figure 2.2 *Cost of production of a kWh of electricity delivered by an off-grid photovoltaic (left) and diesel generator (right) system.*

Comparing the PV and diesel options leads to the map in Figure 2.3: regions where diesel results the most convenient option are shown in scale of blue, while PV is more suitable for yellow-to-red areas. Even in this map the important effect of diesel prices and the related subsidies or taxation policies is evident.

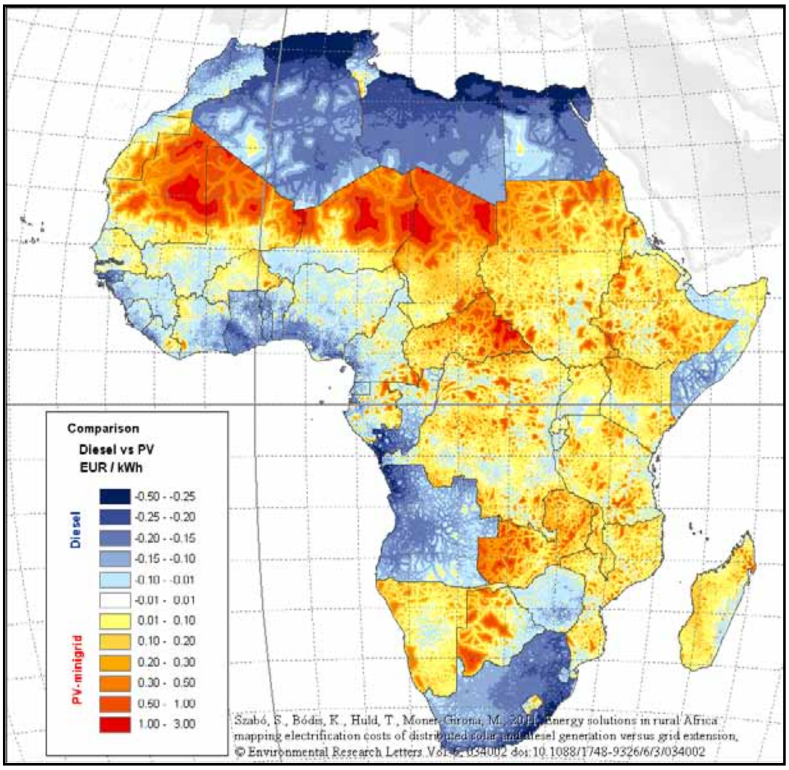


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Figure 2.3 *Graphical comparison of electricity generated with PV and diesel systems*

2.2.2 Comparing grid extension with PV and diesel off-grid options with grid extension.

Finally, PV and diesel off-grid options for rural electrification can be compared with the completely different option of extending the electricity grid to reach a larger number of villages and a higher share of rural population. Nevertheless, the costs of electricity, when considering grid extension, are determined by the load density (measured in households per square kilometre), the number of households connected and line length among others. For most of the Sub-Saharan African rural areas, this information is still available unevenly.

For this reason, reference prices of grid-delivered ad off-grid electricity were considered.

In Figure 2.4 the electricity reference price has been fixed to 0.30 EURO/ kWh on the basis of willingness to pay approach.

The yellow areas indicate the regions where PV is the most competitive option, while the dark brown ones show where diesel gensets are the competitive options.

The red regions are those where both rural electrification options (PV and diesel) are cheaper than the electricity cost threshold while the orange regions show where the extension of the grid is the most economical option. In contrast, the different blue coloured parts of the buffer zone indicate the regions where, depending on grid-extension cost, the other rural electrification options might be viable despite the closeness of the existing grid.

Finally, green areas represent the territory where the cost of electricity delivered by both PV and diesel technologies is higher than the electricity cost threshold and grid is too far to consider its extension as a feasible option. In these area the analysis should be extended to other energy options not assessed here (e.g. biomass, hydro, wind energy) have to be further considered and evaluated.

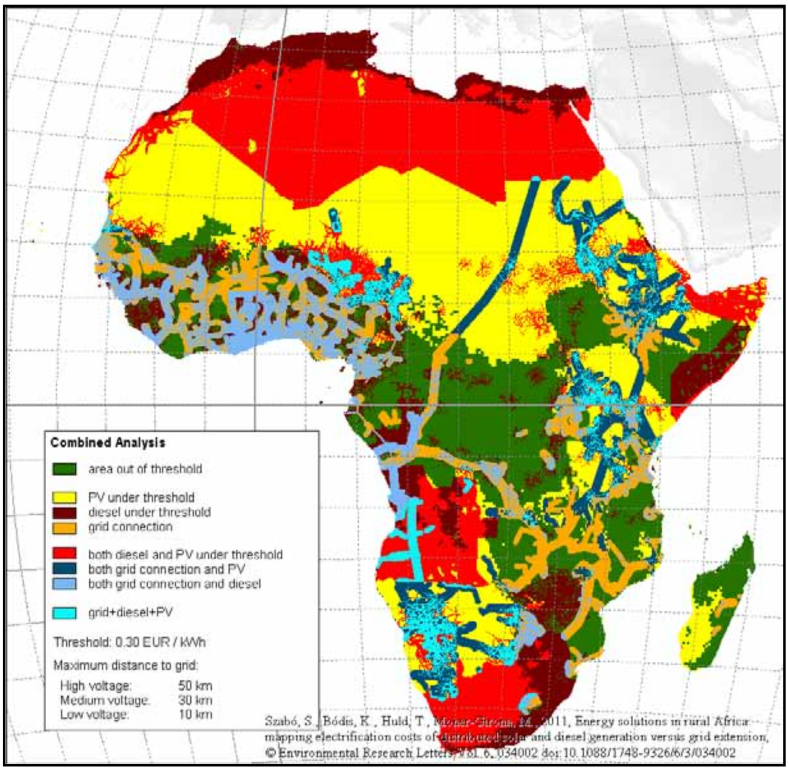

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Figure 2.4 *Overall distribution of PV, diesel and grid extension electricity options compared with an average assumed willingness to pay of 0.3 EUR/kWh*

2.3 Outlook

From the point of view of actual results of the previously summarized study, one can notice how Over large regions, neither diesel genset nor PV shown by green colour in Figure 2.4 offers affordable solutions for rural areas if a willingness to pay threshold of 0.3 EUR/kWh is set. These are the places where the various (sustainable) biomass production, micro hydro, wind and efficient fuel use options have to be analysed in order to determine whether these can serve as potentially viable answers to the challenges of rural energy services in Africa. Moreover, the analysis also revealed how sensitive the rural electrification costs are to diesel prices. As certain African governments have decided to subsidize diesel due to other social factors, it could also be considered to support PV (for example in the form of feed-in-tariff) in order not to distort the emerging rural electrification market.

From a more general methodological point of view, the study has shown evidence that different electrification options have to be studied simultaneously. Taking the above described information and analyses into account and using a combination of already available optimization tools (renewable energy datasets, empirical and analytical resource mapping methods, satellite and terrestrial measurements, and numerical models), it is possible to design the optimal generation scheme for small off-grid systems and for achieving a better integration of renewable energy into the African countries energy mix. However, the model would only be applicable in local country-specific situations when all layers of data here employed (e.g., geographical, socio-economic, data) become available in more detail.

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3. Wind energy

While in the past wind energy was considered to be a renewable energy source primarily for developed countries, this is slowly changing. Since 2004, wind energy production has risen steadily worldwide and the actively installed global capacity increased from 40000 MW at the end of 2003 to 94000 MW at the end of 2007 (European Wind Energy Association 2009).
According to the Global Wind Energy Council (GWEC, 2011), more wind power capacity was newly installed in developing countries and emerging economies than in the traditional wind markets of the Organisation for Economic Co-operation and Development (OECD) in 2010.

Also in Africa, the potential of wind energy has started to be recognized and in Egypt, Morocco and Tunisia wind farms have already been installed. Currently, by far the largest share in wind energy production in Africa is held by Egypt where 97% of all wind power installations are located with total capacities of 550 MW (GWEC, 2011). In Morocco wind energy capacity of around 290 MW exists and in Tunisia the annual wind production amounts to about 120 MW. While wind farms currently exist predominantly in Northern Africa mostly along the Mediterranean coast, wind farm projects are now also under discussion for other areas. Currently planned are the establishment of wind production farms for Nigeria with capacities of about 10 MW, in Ethiopia for about 120 MW, and for Kenya with capacity of 300 MW (Afrique Avenir, 2010).

3.1. Estimate of mean winds across Africa

Wind energy production depends primarily on wind speed and how the winds are changing during the day, a season, a year or even over decades. In order to estimate the actual available wind power, wind observations over several decades from dense station networks or high resolution wind modelling would be required. Both are not available for Africa for this study, and therefore the *potential wind power energy* has been estimated instead. It is based on re-analysis data provided by the European Centre of Medium-Range Weather Forecast (ECMWF). Re-analysis data incorporate observations and numerical weather prediction output to provide a continually updated best estimate of the state of the Earth's atmosphere. It has the advantage that it is available for every grid point distributed equally across entire Africa. The data set has been validated with observations as reported by a study from the German Weather Service (Duensing et al., 1985) and it appears that the data are sufficiently suitable to provide a reasonable estimate of potential wind power on continental scale.

This study is based on the mean winds at 100 m above ground for a period from 1979 to 2010. 6 hourly re-analysis model output data on grid cells with roughly a size of 75x75 km^2 have been used. Figure 3.1 illustrates that mean winds above 5 m/s are largely found north of the Equator, at the Horn of Africa and in the South of the Continent. In Central Africa there are extended areas with average winds of less than 3.5 m/s.

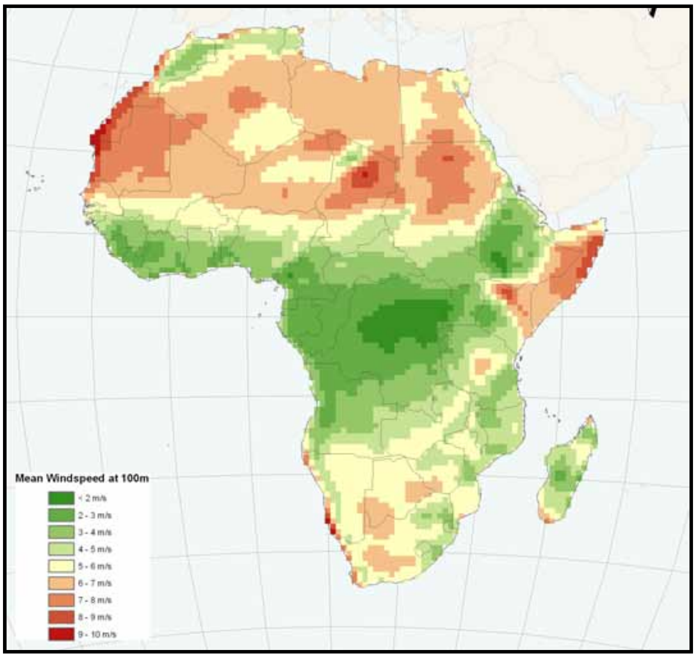

Figure 3.1: *Geographical distribution of average wind speed over Africa at 100 m height derived from 6-hourly ECMWF re-analysis data for a period from 1979 to 2010.*

3.2 Potential availability of wind energy resources

While the distribution of mean winds is a first good indicator where wind energy production might be profitable, the potential energy production cannot be extrapolated from it without a number of important assumptions with regard to the wind turbines, their size, efficiency, density as well as landuse.

For this study we assume modern technology wind turbines with a diameter of rotor blades of 80 m and full working hours in a year (8760 h). Following literature, the maximum wind power that can be converted into energy has been set to 59.3% (Betz, 1926), a coefficient that is likely to be lower in reality. In order to calculate the average wind energy production potential per square kilometre, it is assumed that five wind turbines can be sited per square kilometre (European Environment Agency, 2009).

Furthermore, there is a minimum and maximum speed in which wind turbines operate. Following guidance from the "*WindPower program (online)*", these limits have been set to 3.5 m/s for the so-called *cut-in* speed and to 25 m/s for the upper *cut-out* speed. Full productivity is assumed from a rated output speed of 15 m/s onwards, meaning that higher winds will not yield more energy production than the one at 15 m/s. A cut-in speed of 3.5 m/s is considered the minimum speed for wind turbines to start operating, but for larger commercial wind turbines, a cut-in speed of 5 m/s may be more appropriate. Therefore, here all maps are based on the assumption of a cut-in speed of 3.5 m/s, but are provided for both *cut-in* speeds for comparison in tabular form.

The potential wind energy has been calculated as

$$E(v) = \frac{1}{2}\rho A v^3 C_p t$$

where • = air density (kg/m^3), A = the area swept by the rotorblades (m^2), C_p = power coefficient (Betz, 1926), t = hours, v = wind speed at 100m (m/s) if $3.5 < v < 25$. Else, for $v < 3.5$ and for $v > 25$, the wind energy E = E(0) = 0. For v > 15 m/s, the wind energy is set to the one of 15 m/s: E = E(15).

Figure 3.2 illustrates the potential wind energy production for Africa excluding areas with water bodies, cities, deep forest and nature reserve areas which are shown in white. Perhaps desert areas should also be excluded but has not been done for this study. There is obviously a high degree of uncertainty associated with the absolute values because of the quality of the underlying input data and assumptions made, and should be seen as indicative values only.

The available data on the currently existing power grid is also drawn in figure 3.2. It is quite obvious, that for those regions with the highest values of potential wind energy production, there is little infrastructure with regard to existing power grids. This would mean that many of the countries potentially most benefiting from wind energy would not only have to invest in the wind farms themselves but also into an extension of the grid (see Chapter 5 for a detailed discussion on power grid extension).

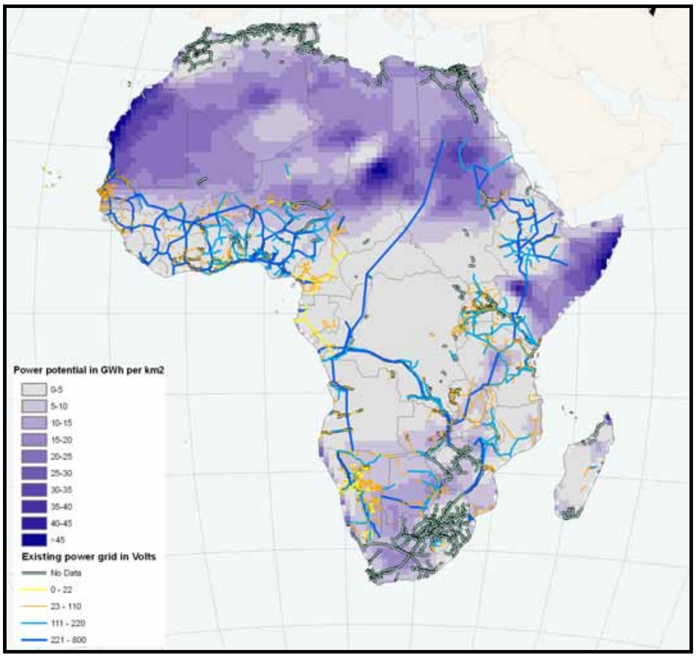

Figure 3.2: *Potential wind power production in GWh per km^2 excluding regions with water bodies, forest, cities and protected areas and assuming 5 turbines per km^2. Overlaid is the position of available data on existing power grid with capacity in kVolt.*

<u>3.3 Different scenarios of potential availability of wind energy resources</u>

It is of interest to calculate the total potential energy that can be produced per country, taking into account the current distribution of the grid and by excluding obvious areas where wind farms cannot be established such as cities, water bodies and forest areas. Assuming that wind farms are only installed within +/- 35 km of range to the power grid, the geographical distribution of national potential wind energy is shown in Figure 3.3.

Clearly, the absence of power grids limits the potential wind energy in some regions, like for example at the Horn of Africa.

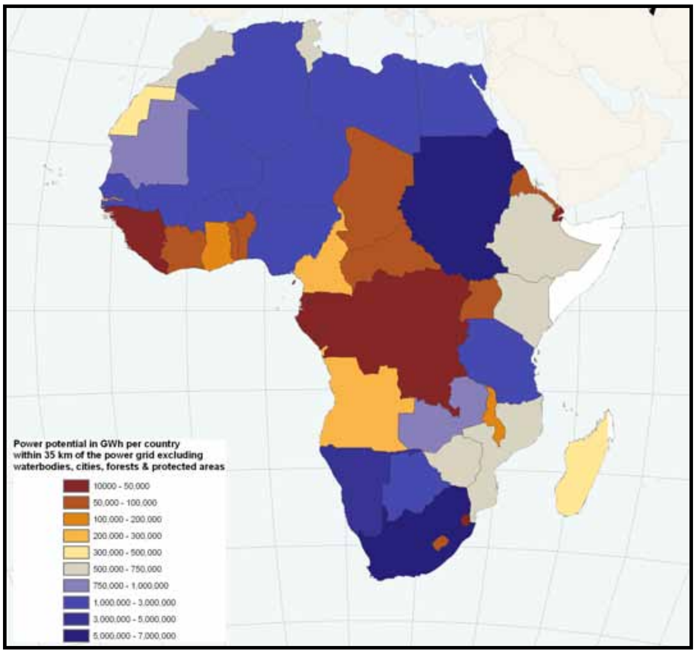

Figure 3.3 *Potential National annual wind energy production in GWh/year excluding areas with water bodies, cities, forest, nature reserves and pixels further than +/- 35 km from the current power grid and assuming 5 turbines per* km^2.

Potential wind energy power for different scenarios for entire Africa is given in Table 3.1.

Table 3.1: *Values of total potential wind energy in TWh*[2] *over entire Africa taking into account different scenarios of areas to be excluded and distance to the power grid and assuming a cut-in value of 3.5 m/s and 5 m/s and 5 turbines per* km^2.

		Distance from current power grid				
I: Reference		+/- 35 km*		+/- 50 km	+/- 100 km	unlimited
Cut-in speed in m/s		3.5	5**	3.5	3.5	3.5
I	Total potential wind energy without restrictions on landuse	52432	35992	67325	103656	293731
II. Total potential wind energy excluding areas with						
II a	- water bodies and cities	51542	32024	66289	102233	291982
II b	- water bodies, cities, forests	45739	29278	59024	92070	278517
II c	- water bodies, cities, forests, and nature reserves	41012	26418	52332	80201	251937

* *only values on the grid are considered*; ** *cut-in speed for larger commercial turbines*

Thus, under the assumption that on every square kilometre within +/- 35 km in range of the existing power grid, 5 turbines are installed and excluding areas with water bodies, cities, forest and nature reserves, the total potential wind production energy amounts to ca 40000 TW per year when considering a cut-in value of 3.5 m/s. Using a higher cut-off value of 5 m/s instead of 3.5 m/s reduces the overall potential wind energy by 35%. For comparison, the currently actual available wind energy power in Africa is estimated at about 9 TW (GWEC, 2011), and the projections for the next decades are 166 TW for 2020 and 587 TW to 2030.

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[2] TeraWatts hour

3.4 Outlook

For this first study a number of rather coarse assumptions needed to be made with regard to the wind field, parameters for converting wind into wind energy, landuse and distribution of the power grid. Therefore the results of this study are to be interpreted rather qualitatively than quantitatively.

In order to have a more detailed and quantified study, research would be needed into a more accurate representation of the wind fields taking also into account local effects such as orographically induced winds or land-sea wind circulations. More detail on technical specification of wind farms would be required.

Finally, with more reliable information on cost for constructing wind mills, expansion of the power grid, and value of energy, a cost-benefit study could be performed.

Acknowledgements

The meteorological data for this study has been provided by the *European Centre for Medium-Range Weather Forecast.* Data layers have been extracted from the *African Renewable Energy Technology Platform* and the *World Database on Protected Areas*.

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4. Biomass contribution to Sub-Saharan Africa’s energy needs

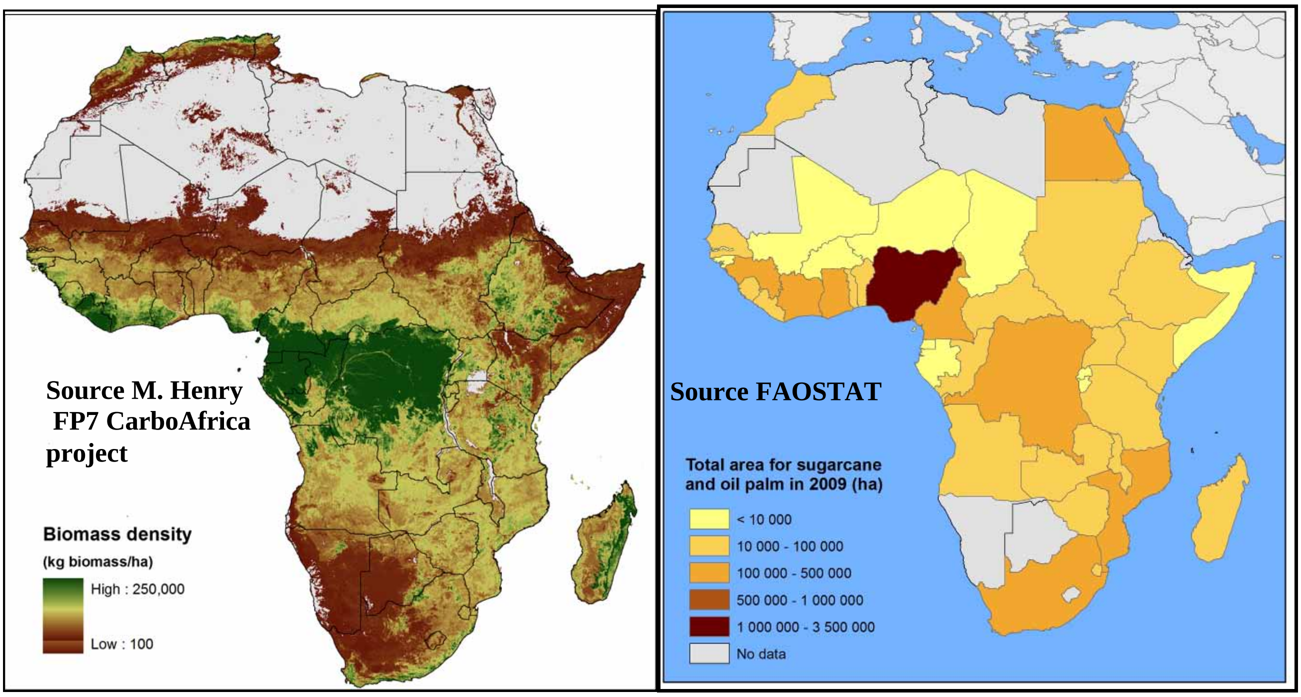
4.1 Towards a biomass resource assessment for Africa - Methodological issues

Agriculture is traditionally related to the 4 Fs (Food, Feed, Fiber, Fuel) with in addition an ongoing growth of green chemistry and bio-materials. Bioenergy is based on the use of biomass from three main categories: forest, agriculture and waste. For Africa as well as for Europe or at worldwide level, bioenergy is the category of renewable energy which, compared to solar, wind and geothermal, provides presently and will continue to provide the greatest part of primary energy. In order to reach the EU targets of the Renewable Energy Directive (RED) Directive (20% of renewables and 10% of renewables in transport in 2020), some EU Member States are considering to import biofuels for transport, biomass feedstock or biomass products. The EU RED targets are based on the respect of some environmental constraints related for example to biodiversity, tropical deforestation, peat soils. There is now a global trade of biomass or bioenergy products (e.g.; pellets, bioethanol, biodiesel, biomass) with players all over the world, in tropical countries but also in Russia and Canada.

In the case of Africa, as in the case of other continents or specific countries, bioenergy policies, are thus related to agriculture, forestry, energy supply and security, environment, rural development, research. In terms of available land, in the future, independently of the final use of biomass, the greatest share of available land could come from Latin America, Africa and Asia.

Brazil is presently world leader for bioethanol from sugar cane (about 1% of agricultural land used for sugar cane, both for food and ethanol, substituting about 40% of gasoline consumption). Argentina is the third country for biodiesel from soya, Indonesia and Malaysia are world leaders for palm oil production.

Africa has abundant biomass, sometimes called "the green gold" of Africa, but its distribution varies considerably, with the grassland regions of the Sahel and the dry land savannas being particularly low and the humid tropical forest regions having very high biomass values. The access and infrastructure varies enormously too and biomass is presently used to a large extent in an inefficient way. Figure 4.1 shows as in some tropical regions exists a potential for increased production or mobilization of biomass, both for domestic use and exports. Total cropland used for sugarcane and oil palm in Africa in 2009 was 6 million hectares whereas only Brazil cultivated sugarcane on 8.5 million hectares. Bioenergy for Africa is an opportunity but sustainability must be ensured, both for environmental and social issues, for example through certification.



Source M. Henry FP7 CarboAfrica project

Source FAOSTAT

Figure 4.1 *Biomass density in the Africa continent (left) and total area used to produce sugarcane and oil palm in Africa in 2009*

One of the first steps to define bioenergy policies is a realistic assessment of the biomass natural capital. Many studies exist at global, national, regional or local level and address bio-energy potential assessment. These studies are based on different definitions, parameters and data, time frame, and thus provide very different estimates.

Generally speaking, however, there is broad agreement about the most important factors affecting the contribution bio-energy might make to the future primary energy supply. These are: i) the availability of land; ii) the productivity of the biomass grown upon it; and, iii) competition for alternate uses of the land (or the biomass), and for the waste materials derived from the biomass (including crop residues, forest residues and Municipal Waste).

The discussion of bio-energy potentials inevitably involves comparing figures for the quantity of energy produced and the amount of land occupied. To put these figures in context, it is useful to have an appreciation of current land and energy use at the global level. Some of the key points to be addressed are:

- Definitions of resource potential (theoretical, geographical, technical, economic, implementation aspects).
- Selection of biomass categories, terminology and nomenclature.
- Selection of data on (current) biomass production and land or forest productivity.
- Methods for estimating (future) biomass production and availability.
- Assumptions used to estimate factors external to the modeled system (such as land use and biomass production for food and fiber purposes) that might influence potentials.

The assumptions that underpin the descriptions of future land availability, biomass productivity, and competing uses are particularly important:

- Global population
- Per capita food consumption and diet.

- Potential to increase crop yields (and to close the gap between optimal yields and those achieved by farmers).
- Impacts of climate change (interactions with land, water availability, and crop yields).
- Availability of water.
- Areas required for nature conservation (e.g. for biodiversity).
- Soil degradation and nutrient availability.
- Use of marginal lands.

Most global agricultural scenarios assume that increases in food demand will primarily be met through increases in crop yields. Nevertheless, the FAO estimate that at least ~120Mha of additional arable land will be required in developing countries by 2050 under a business as usual scenario. This is equivalent to the 2009 arable area in South America. Thus, due to the pressure on land and water resources, resource assessment is essential in order to meet our future needs in a sustainable way.

Table 4.1: *Alternative definitions in the hierarchy of biomass resource potentials (Slade et al., 2011)*

Name	**Definition**
Theoretical potential / Ultimate potential	Describes the amount of biomass that could grow annually, limited by fundamental physical and biological barriers. The Theoretical potential may change if conditions change, for example, due to climate change. (This category is not useful for analysing biomass production, except as a comparator of biomass production vs. total global primary production.)
Geographical potential	All you can collect from the theoretical potential (taking into account ecological constraints, land area constraints, agro technological restraints, topographic problems etc. An alternative definition is the proportion of the theoretical potential that is not limited by the demand for land for food, housing, etc. The geographic potential may change as technology advances.
Technical potential	The geographic potential, reduced by losses due to conversion to energy in useable form. (primary to secondary). Technical advances may also be assumed.
Economic potential	All biomass available up to a specified price level (taking into account the price elasticity of competitors on the market). I.e. the potential at a given price is determined by where the supply and demand curves intersect. This is highly variable as economic conditions may change dramatically over time. Moreover, markets may not exist for many biomass feedstocks, or they may be imperfect.
Realistic potential / Implementation potential	All biomass available without inducing negative social or social economic impacts and respecting technology and market development issues. May be estimated using *recoverability fraction* or *accessibility factor* multipliers, reflecting what is considered the realistic maximum rates of energy use of biomass residues. Deciding what is the most appropriate multiplier to use in any particular instance is often a matter of expert judgement.

Table 4. 2: *Sources and categories of biomass feedstocks (From Slade et al., 2011)*

Classification			**Biomass source**
Energy crops [a]	Conventional crops		Annual crops: cereals, oil seed rape, sugar beet…..
	Perennial energy crops		Short rotation coppice (willow or poplar); plantation tree crops e.g. eucalyptus; energy grasses: miscanthus, switch grass….
	Forestry [f] and forestry residues		Short rotation forestry [h]
Primary residues [b, c]			Wood chips from branches, tips and poor quality stemwood
	Agricultural crop residues		Straw from cereals, rape seed, and other crop….s
Wastes	Secondary residues [b,d]	Sawmill co-product	Wood chips, sawdust and bark from sawmill operations
		Arboricultural arisings	Stemwood, wood chips, branches and foliage from municipal tree surgery operations
	Tertiary residues [b,e]	Waste wood [g]	Clean and contaminated waste wood
		Organic waste	Paper/card, food/kitchen, garden/plant and textiles wastes….
		Sewage sludge	From Waste Water Treatment Works
		Animal manures	Manures and slurries from cattle, pigs, sheep and poultry….
		Landfill gas	Captured gases from decomposing biodegradable waste in landfill sites…

[a] Availability depends on the amount of land dedicated to the crop, and the crop yield

[b] Availability depends on activity in other economic sectors.

[c] Harvest residues: typically available 'in the field' and need to be collected to be available for further use.

[d] Processing residues: produced during production of food or biomass materials; typically available in the food and beverage industry.

[e] Post consumption residues: materials that become available after a biomass derived commodity has been used.

[f] Timber from mature forests is generally considered to be too valuable to use for energy purposes

[g] This category may, or may not, be taken to include a fraction of municipal solid waste (MSW)

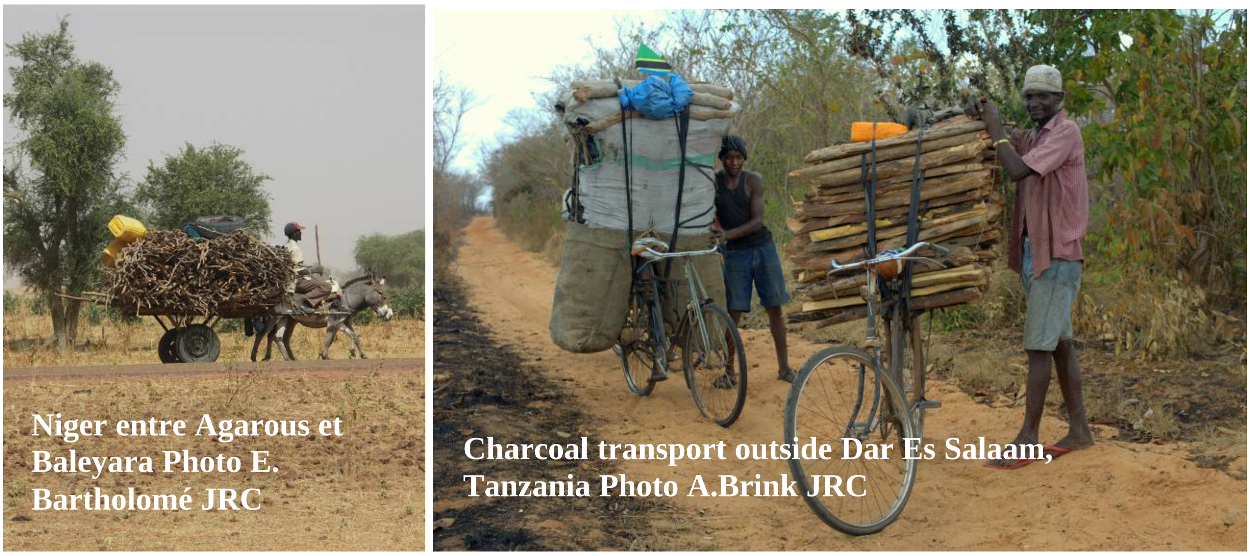
[h] short rotation forestry may also be considered an energy crop in some schemes.

4.2 Wood and charcoal as the major biomass energy sources for Africa

While endowed with a huge diversity of energy sources such as oil, gas, coal, uranium and hydropower, the local infrastructure and use of these commercial energy sources is very limited. Non-woody biomass - animal waste, crop residue, grass- meets a small percentage of household energy needs and the use of liquid fuels from biomass, bio-gas and sawmill and paper pulp waste (black liquor) are extremely rare at present.

Traditional sources of energy in the form of firewood and charcoal account for over 80% of the total energy use in sub-Saharan Africa. Charcoal meets most of the gap and more than 95% of the urban demand. Africa has the highest birth-rate of any continent and also the world's highest urbanization rates with an average urban growth rate of 4% per year. The growth in urban population is directly linked to a growth in charcoal demand. Every 1% increase in the level of urbanization is estimated to result in a 14% increase in the consumption of charcoal.

The use of charcoal in rural areas is growing too. Firewood and charcoal are mainly used to meet household cooking requirements, but also in the agriculture and rural industry sector for brick-making, food processing, bakeries, tobacco-curing, etc.



Niger entre Agarous et Baleyara Photo E. Bartholomé JRC

Charcoal transport outside Dar Es Salaam, Tanzania Photo A.Brink JRC

Picture 4.1 *Transport of Biomass for energy production in Sub-Saharan Africa*

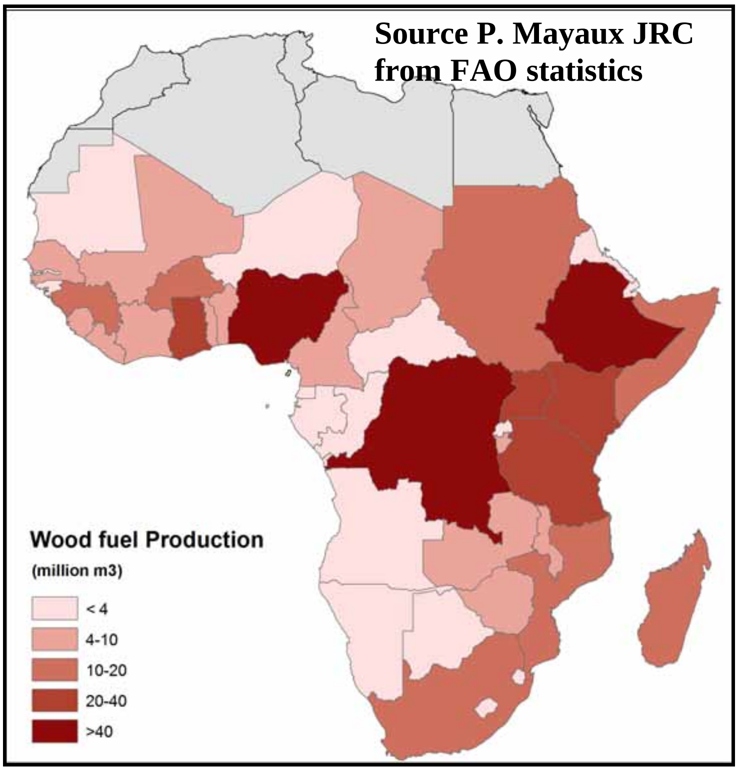


Figure 4.2 *Wood fuel production per country for 2010*

Sub-Saharan Africa produces around 600m m^3 of wood fuel/yr, which covers 60% to 85% of the energy needs, depending on country and region.

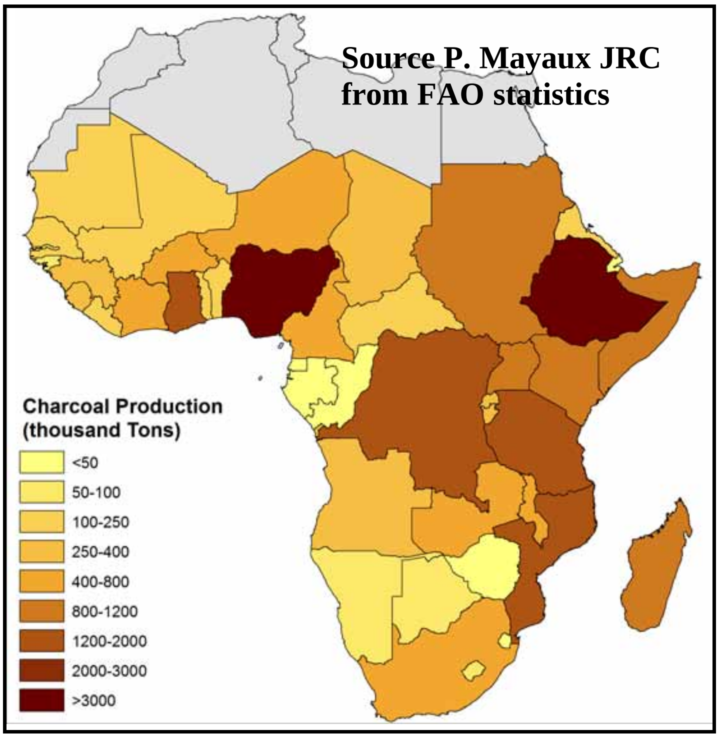
In comparison, the EU produces around 90m m^3 of wood fuel/yr, which covers less than 1% to 18% of the energy consumption, depending on country and region.

Nevertheless, the efficiency of production and use between the EU and Sub-Saharan Africa contrasts dramatically, as well as the sustainable patterns of production. The wood to charcoal conversion efficiency is dependent upon many factors (kiln type, wood moisture content, tree species, etc.). In the traditional earth-mound kiln used widely in Sub-Saharan Africa, 5-10 tonnes of wood are needed to make 1 tonne of charcoal (mass-based conversion efficiency of 10-20%). Hence, using the traditional kiln, 60-80% of the wood's energy is lost in the charcoal production process.

Traditional earth-mound kiln, Kenya Photo A. Brink JRC

Picture 4.2 *Traditional production of charcoal in Kenya*

Africa produces over 29 m tonnes of charcoal per year, but the undeclared production may far exceed this figure. In Tanzania for example, only 25% of the estimated 24,500 sacks of charcoal consumed daily in the city of Dar Es Salaam are accounted for at the road checkpoints.



Source P. Mayaux JRC
from FAO statistics

Figure 4.3 *Charcoal production per country for 2010*

High production levels in Nigeria and Ethiopia primarily satisfy internal needs. Indeed, Ethiopia is the third largest user in the world of traditional fuels for household energy use, with 96% of the population dependent on traditional biomass to meet their energy needs, mainly in form of fuelwood and charcoal, but also dung and other agricultural residues. In the late 1990ies of the total energy demand approximately 89% was consumed by households, while only 4.6% was due to industry.

4.3 Charcoal as a valuable trading commodity

Charcoal use has socio-economic benefits along the trade chain, from the producers in rural areas to the consumers in urban areas. In many countries, charcoal is the main cash income source for rural households. FAO statistics report more than US$ 1 billion per year of licit charcoal trade – illicit trade figures are unavailable, but for example Virunga National Park (DR Congo) alone is estimated to produce US$ 30 million a yr. The charcoal industry is a competitive market with large numbers of producers, transporters and sellers with little government regulation. Kenya’s charcoal industry for example, employs about 30,000 full-time producers, 4000 transporters and 800 sellers; the annual business is around US$ 213 million. In the early 1990ies in Zambia the charcoal industry contributed 2.3% to the country’s GDP.

While local and national trade figures for charcoal are high, FAO statistics show that charcoal import and export is relatively low with few exceptions such as South Africa and Somalia. International trade in charcoal is discouraged in many countries, because of its impact on forests and woodlands. For example, Kenya has banned charcoal exports to countries in the Middle East already in the 1970ies. But illegal charcoal production and export is high in many countries as reported mainly by news and unofficial sources. Examples include “Congo Gorilla Killings Fueled by Illegal Charcoal Trade” as reported by National Geographic News and The Independent, the “Illegal charcoal trade on the rise” in Tanzania as reported by the Tanzania Daily News, “Somalia’s al-Shabaab Islamist militant movement razes Somali forests to finance Jihad” as reported by the Jamestown Foundation.

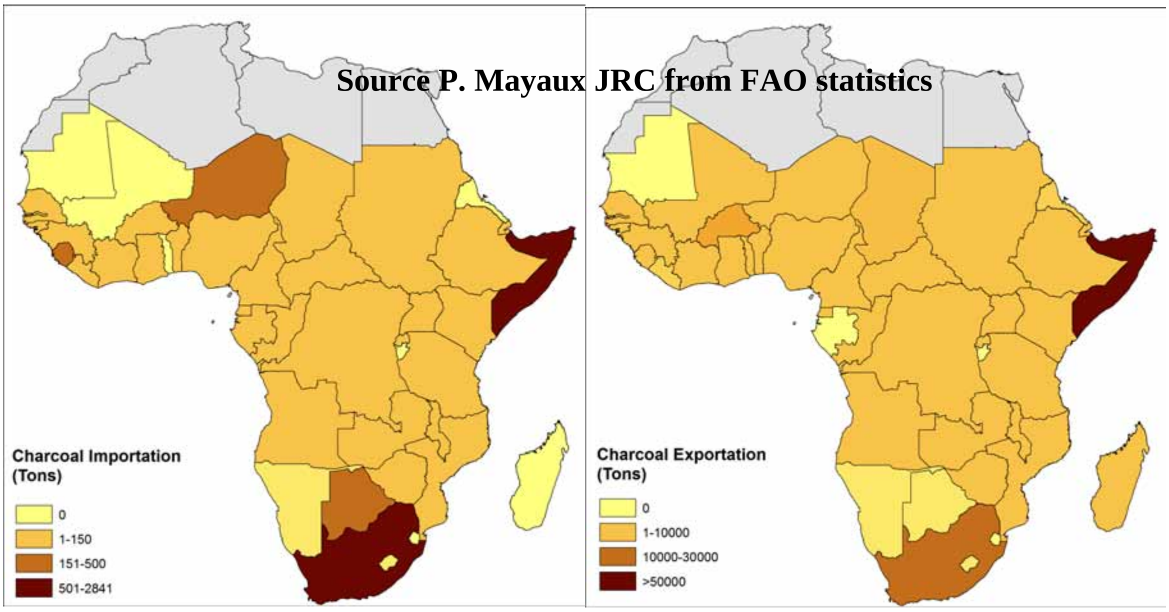

Source P. Mayaux JRC from FAO statistics

Figure 4.4 *Charcoal imports (left) and exports (right) in 2010*

4.4 Forest and savanna; the wood energy resource base

The forest area of Africa exceeds 235 million ha. Other wooded land and shrub savanna cover over 830 million ha. The dry forests and woodlands are the main source of wood fuel. The potentially available stocks for energy purposes in sub-Saharan dry forests and wood lands range from 11.7 tonnes per hectare in semi-arid dry forest of the East Africa Somali-Masai region to 136.3 tonnes per hectare in the sub-humid dry forests in the Congo-Zambezian region. FAO estimates the economic value of wood energy across Africa at around US$6bn per year.

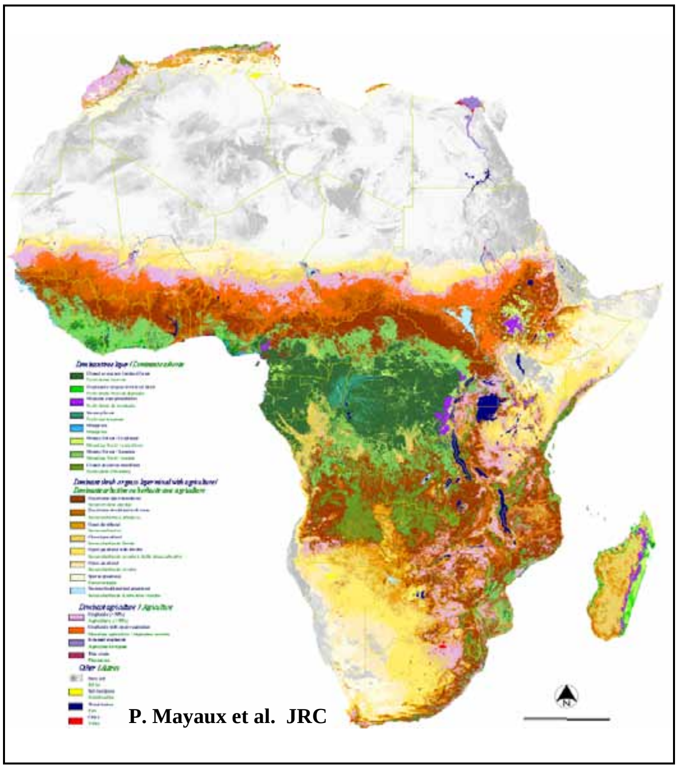


Figure 4.5 *Land cover map for Africa.*

Wood fuel consumption far outweighs other uses in sub-Saharan Africa. The driving force behind deforestation in sub-Saharan can be attributed mainly to clearing of trees for new agriculture land and wood extraction and harvesting for firewood and charcoal production.

FAO statistics show much higher wood fuel consumption versus timber consumption for Africa. This means that forest and woodland clearing and degradation for firewood and charcoal production is not just a by-product of bigger forces such as logging for timber and agriculture expansion, but a specific need to satisfy energy demand.

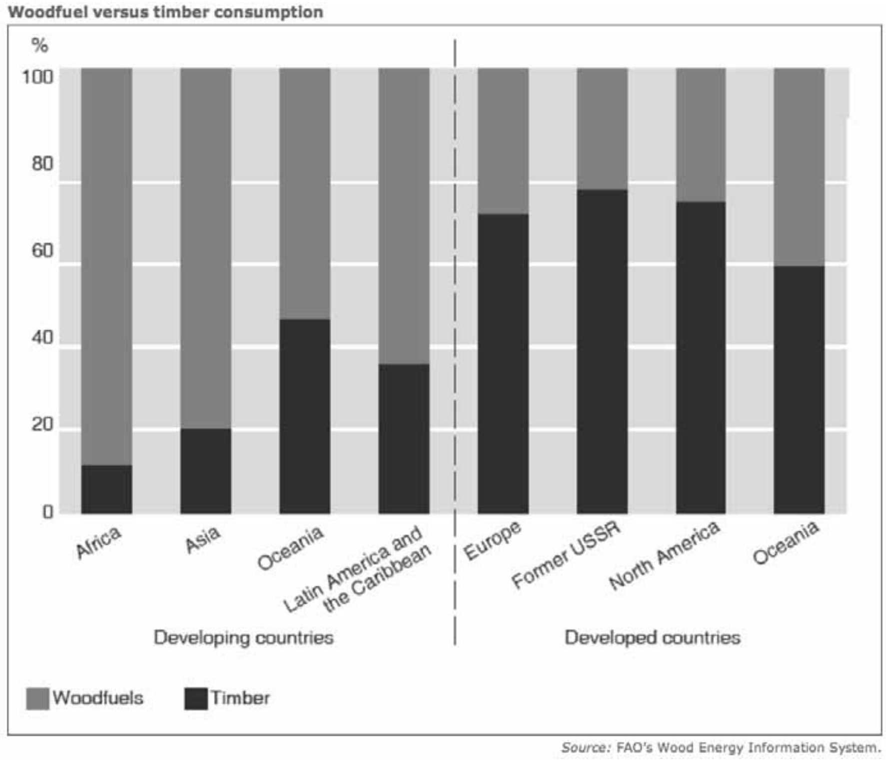


Figure 4.6 *Energy wood uses versus timber exploitation in different world regions.*

<u>*4.5 A threatened resource base – changes in natural vegetation measured by JRC using satellite time-series*</u>

The JRC measures changes in forest and natural vegetation over time as observed from satellite images. JRC figures highlight patterns of deforestation and desavannisation as well as areas of regrowth in some cases. The resource base is strongly exploited and particularly threatened in West Africa, in some East African countries such as Tanzania, Zambia, Mozambique and Zimbabwe and also in DR Congo. But, deforestation rates - at 0.16% per year - in the African humid tropics, are the lowest in the humid tropics. On the other hand, dry forests and other wooded land are disappearing twice as quickly in sub-Saharan Africa. Dry forests and woodlands are the main source of woodfuel and JRC evidence shows that the hot spots of change are closely allied to important fuelwood and charcoal markets.

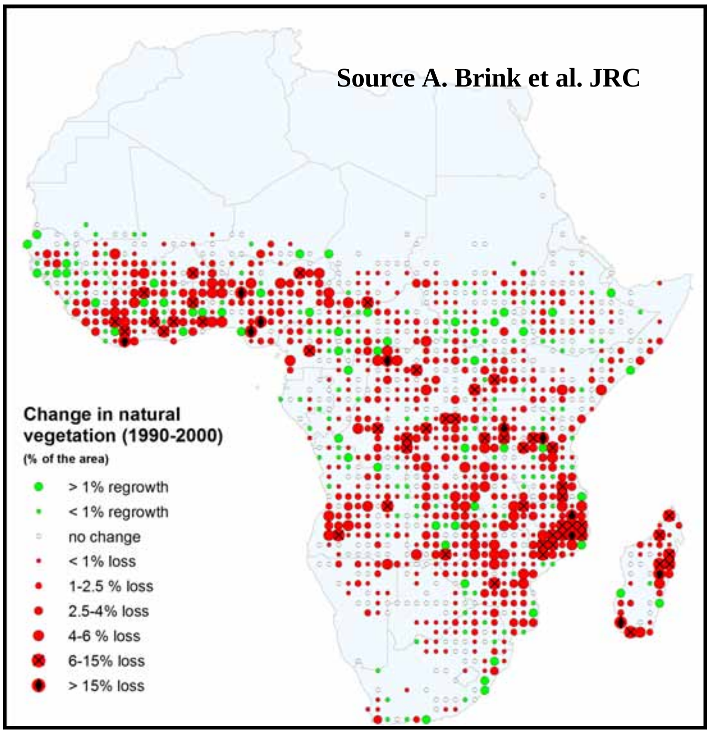


Figure 4.7 *Change in natural vegetation (1990-2000)*

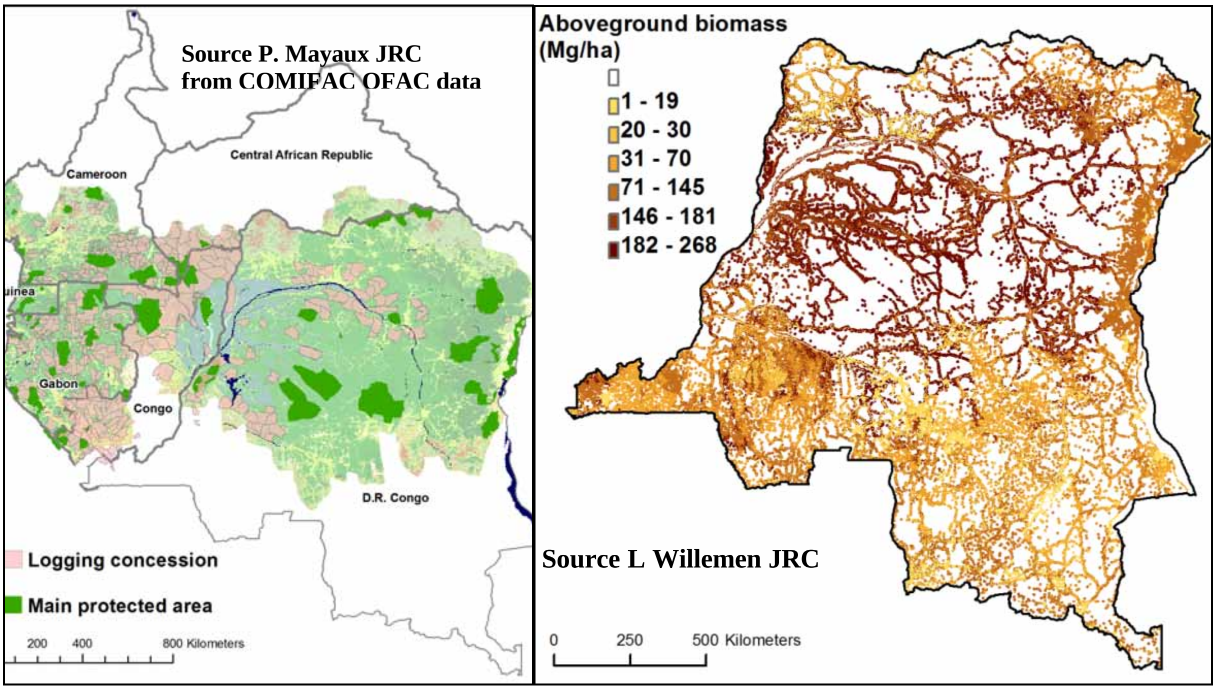
Population pressure is also highest in these regions, mainly due to biological and ecological reasons (better climate for people and livestock, smaller trees which are easier to clear for agriculture, often more fertile soils, etc.). Afforestation/reforestation is evident mainly in the drier regions, reflecting the typical agricultural system of shifting cultivation including wood extraction for fire-wood or charcoal production employed by the majority of farmers in Africa, but the net loss of natural vegetation by far outreaches the regrowth of forest and woodland. The regeneration and expansion potential is high – though conflicting demands for land is an issue.

4.6 JRC Monitoring, reporting and verification activities in partnership

The European Commission funds many forest protection schemes. DG DEVCO and JRC directly support the Comission des Forêts d'Afrique Centrale hosting forest management database and supporting regional technology centres in Yaounde and Kinshasa.

- *Fuel wood assessment in the Democratic Republic of Congo (DRC).*

Geospatial data analysis can be used to produce regional assessments of fuel wood availability.



Source P. Mayaux JRC from COMIFAC OFAC data

Source L Willemen JRC

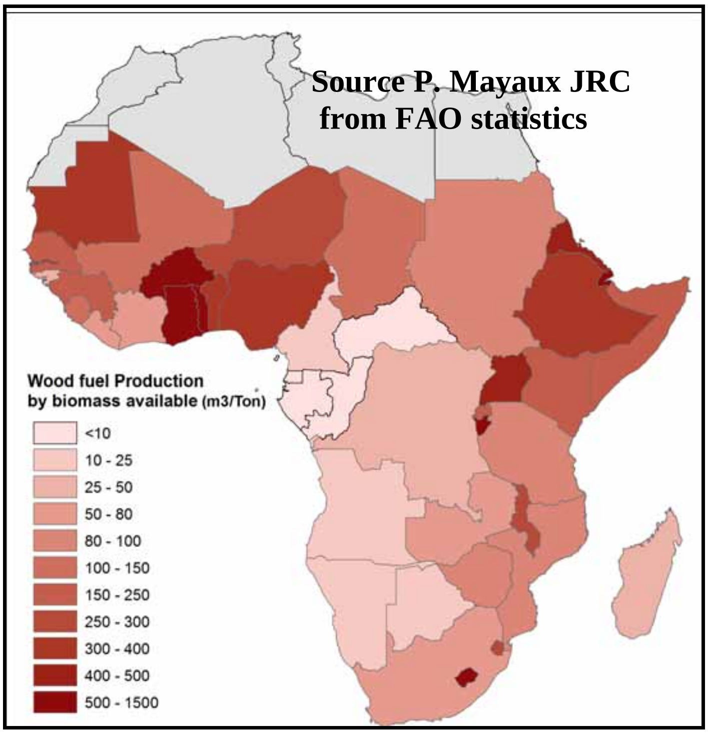
Figure 4.8 *Protected areas and logging concessions in 5 Central Africa countries (left) and biomass density in accessible area of Democratic Republic of Congo (right)*

To assess the available biomass that could be used for fuel wood in the Democratic Republic of Congo accessible vegetation was mapped (locations within 5 km of a populated area, a road or a navigable river are considered fuel wood locations). Secondly, the aboveground biomass was estimated for each land cover class. Based on the vegetation type and estimates from literature, biomass values in Mg per hectare were assigned to each class. Combining the accessibility assumptions with the biomass estimations resulted in a “fuel food availability” map (Figure 4.8 – right side). From this map we can clearly observe that most of the accessible areas have low biomass stocks (in yellow). Only the in central region of the country high level of biomass can be found (in brown).

In a next step the *spatial distribution of the current biomass could support a sustainable harvest of fuel wood* step could be assessed. Estimates for the DRC indicate an average use of 1 m^3 per person per year. These fuel wood use figures could be combined with the population map, and our ‘fuel wood availability’ map together with a mean annual increment.

4.7 Developing a wood fuel sustainability index

Balancing biomass available in a country with the wood fuel production in a country reveals stark contrasts. Some countries clearly harvest far more wood than they can sustainably replace. The continent-wide map in Figure 4.9 is not yet an index of sustainability, but this provides an overview – the darker the colours the less sustainable the use currently is. Detailed models, such as the FAO Woodfuel Integrated Supply/Demand Overview Mapping methodology (WISDOM) provide detailed localized assessments.



Source P. Mayaux JRC from FAO statistics

Figure 4.9 *Wood fuel production by biomass available (m3/tonne)*

4.8 Outlook

Wood-fuel supply and demand management are essential for energy planning in Africa.

Well-managed wood-fuel sources can be sustainable, but growing demand for fuelwood and charcoal in particular due to high urbanization rate, currently cause a net loss of wood resources. Possible alternative sources of energy for most Sub-Saharan Africa countries are hydroelectricity, kerosene, solar, coal, wind and biogas, but a large number of the renewable energy technology projects are beyond the financial reach of their target groups – the rural and urban poor.

Moreover, because wood-fuel use drives deforestation and desavannisation, it contributes significantly to greenhouse gas emissions, biodiversity loss and land degradation. For this reason, the European Commission should take more account of wood-fuel management issues in forestry planning and environmental protection strategies, including interaction with the three Rio Conventions.

Baseline information is scarce and of poor quality – FAO reporting is the de facto benchmark, but this is dependent on National submissions and many nations lack the capacity for such reporting while official reporting does not deal well with ‘out of market’ fuelwood consumption or illegal activities

Monitoring Reporting and Verification (MRV) systems are essential, building on the JRC FAO collaboration on Global Forest Resource Assessments for example. JRC has some key regional networks in Africa (especially through the partnership with COMIFAC) but this is not continent-wide The EC already has some projects in place that could address some key aspects of fuelwood consumption MRV –area change, degradation-) e.g the Monitoring of the Environment and Security in Africa.

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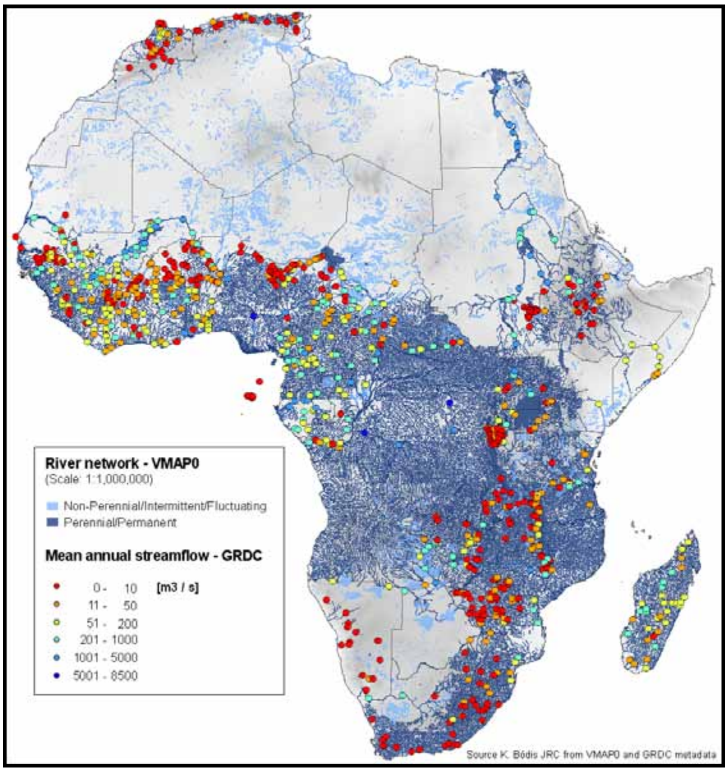
5. Pico and mini-hydro resource based energy potential[3]

5.1. Physical availability of hydro power resources

As for most of the renewable energy based power generation the geographic information on the distribution of adequate hydro resources for power generation has been proved to be an important factor when the potential of renewable energy sources is assessed in an optimal energy portfolio for Africa. The distribution of hydro resource shows much higher geographical diversity within the African continent than any of the other types of analysed renewable sources. Huge part of the continent is deprived from this resource while it is abundant in other vast regions.

From an energy production point of view, the temporal feature of the river flow is also very important: when the hydro-resource availability is assessed the permanent and temporal or fluctuating water flows have to be distinguished. In this respect the annual distribution of the precipitation, the surface relief and the size of river basins are the most important factors among other climatic and geographic parameters.

The Local Drain Direction map of African River Basins has been derived from the SRTM global elevation dataset (Bódis 2009). The Vector Map Level 0 (VMAP0) data provides worldwide coverage of geo-spatial data and is equivalent to a small scale (1:1,000,000). This data forms the current basis of map of river courses and shows their most important descriptive hydrographical information (Figure 5.1). The source of more detailed information on river regime is the publicly available international archive of river discharge data from the Global Runoff Data Centre (GRDC).



Source K. Bódis JRC from VMAP0 and GRDC metadata

Figure 5.1 *Geographical distribution of permanent and non-permanent river network in Africa and mean annual streamflow [m^3/s]*

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[3] This chapter summarizes a study developed in 2010 and 2011 in the framework of the Renewable Energy Unit activities related to non-European areas. A scientific paper with a detailed description of the methodology and parameters employed has been submitted for peer-reviewed publication.

5.2. Mapping of the economically viable mini-hydro resources for rural electrification

As already stated in chapter 2, Africa suffers of a very serious lack of electricity access in most of the Sub-Saharan rural areas. In order to assess the interest of mini hydro as a potential solution to this problem, the methodology that was worked out in chapter 2 for the economic comparison of the solar based and the diesel generation with the grid connected electricity has been further elaborated in order to include the hydro generation in the same analytical framework.

Compared to the diesel generator option and to the small (15kW) PV generation, the hydro electricity has two important characteristics that require the modification of the comparative methodology. First the generator has to be placed right on the available resource, and the produced electricity has to be transported to the settlement(s) relatively distant from the production site, at least when compared to the locally produced PV or the diesel electricity where it is the fossil fuel that needs transport.

For this reason a deep study of small scale grid extension has been carried also on the basis an extensive literature overview to find an approximate cost value that can be used in the assessment how the distance increase the lifetime cost of electricity in the grid extension planning in the rural areas of the developing world.
As most experiences have been accumulated in India and in South America in rural electrification, the work has focused on literature from these regions.

The incremental cost due to the network extension cost depends on many factors, but the most important are the population density and load parameters: how many household can be found in a compact location and how far the are from the existing grid. The projected consumption per new consumer is also as important as it gives the proportion how the overall extension cost can be spread over each kWh of electricity consumed. As this load projection is quite variable, in India the government planning uses the figure that each kWh of electricity costs 2 $cent more if the grid has to be extended by a kilometre (Danny Harvey, 2010; MNRE, 2011) Such a figure has been chosen as a proxy value determine if the grid extension or the off-grid solution could be more economic in the different rural locations.

On summary, the following approach was applied. The already planned grid extensions in the various African countries are taken as implemented (reaching the most populous regions that are not yet covered) and the 2 $cent/kWh/km extension cost figure was used for both the hydro power plants and for the grid extension option.
For the hydro resource the lifetime production costs has been calculated taken into account the average life time, the investment and operation cost of the hydro power from the information accumulated for German projects in Africa (Energypedia, 2011). A similar generator size has been used that can produce the same energy output as the 15kW PV array (with the additional advantage of continuous production).

Then the cost of electricity delivered was computed for all the four options: extending the grid from the closest network, extend a local grid from the closest permanent river with an average water flow larger than a feasibility threshold, the PV generator and the diesel genset) for each pixel of the African continent.

Figure 5.2 summarizes the areas where the hydro resource based electricity gives in theory the cheapest energy among the four options analysed.

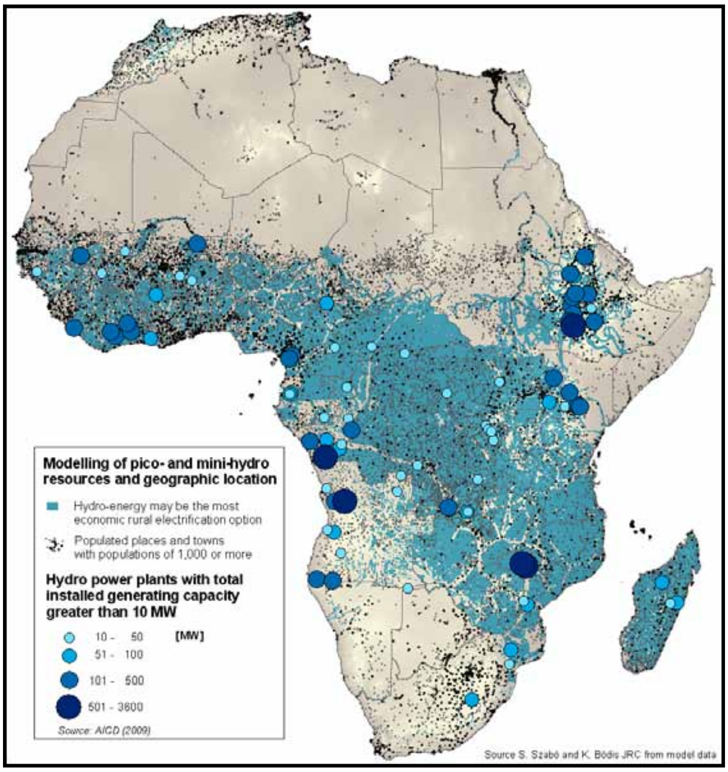

Figure 5.2 *The geographical area where mini- hydro may be the most economic rural electrification option*

5.3. Outlook

It is evident as huge areas have very good potential for mini-hydro electricity sources in Africa. As some of the areas indicated on the map tend to be less populated than average, when the population density is also considered, it results that nearly 30% of the population lives in areas, where the small hydro-energy options promise the cheapest source for electricity.

Most of the Central and Eastern African countries fall into this category. As the grid is near to areas of high population density, grid extension would cover the highest proportion of population according to the applied methodology, while PV and diesel based distributed generation would cover roughly a quarter of the remaining population in electricity supply.

It is also worth noticing again that one of the mini-hydro competitors, the diesel electricity generation, would depend deeply on the fossil fuel subsidies (see also Figure 2.2). With the present subsidy level diesel dominates as a cheapest potential technology almost exclusively in the rural areas of the North African countries, as well as in Angola, and partly in Nigeria and South Africa. Nevertheless changes in subsidies policy could produce a further relevant shift on the ranking of the most economical energy sources in favour of renewable ones, including mini-hydro.

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6. Conclusions and outlook

A few facts can summarize the context in which renewable energies deployment has to be considered in Africa:

- Regardless the increasing urban drift, the population in Africa is still mostly rural (59.6% in 2011) and the access of population to electricity is still limited to 22.7% (2008 data).
  Sub-Saharan Africa is in an especially difficult situation, with 99.6% of population without access to electricity living in this group of countries.
  Network infrastructures (electricity grid and roads), in Sub-Saharan Africa especially, are still under-developed and there is a general lack of detailed data on their deployment and expansion plans.
- In such a situation, renewable energies, some of which show a very interesting potential are requested to play different roles in Northern Africa and in Sub-Saharan regions. In Northern Africa, renewable energies have to compete with cheap and sometimes heavily subsidized fossil fuel predominance in a usually mature infrastructure context. On the contrary, in Sub-Saharan areas, the main challenge faced by renewable energies in this last context then consists in pushing energy production towards an increased sustainability. Well-managed wood-fuel sources can be sustainable, but growing demand for fuelwood and charcoal in particular due to urbanization, currently cause a net loss of wood resources.
- Finally, the fact that compared to the rest of the world, there is a general shortage of energy related information in Africa has to be reminded.This lack of information is even more apparent for renewable energies and the large uncertainties caused by such a scattered validated information availability should be kept in mind whenever compare the potential for the different energy options are compared.

In this context future research lines could focus on the following issues:

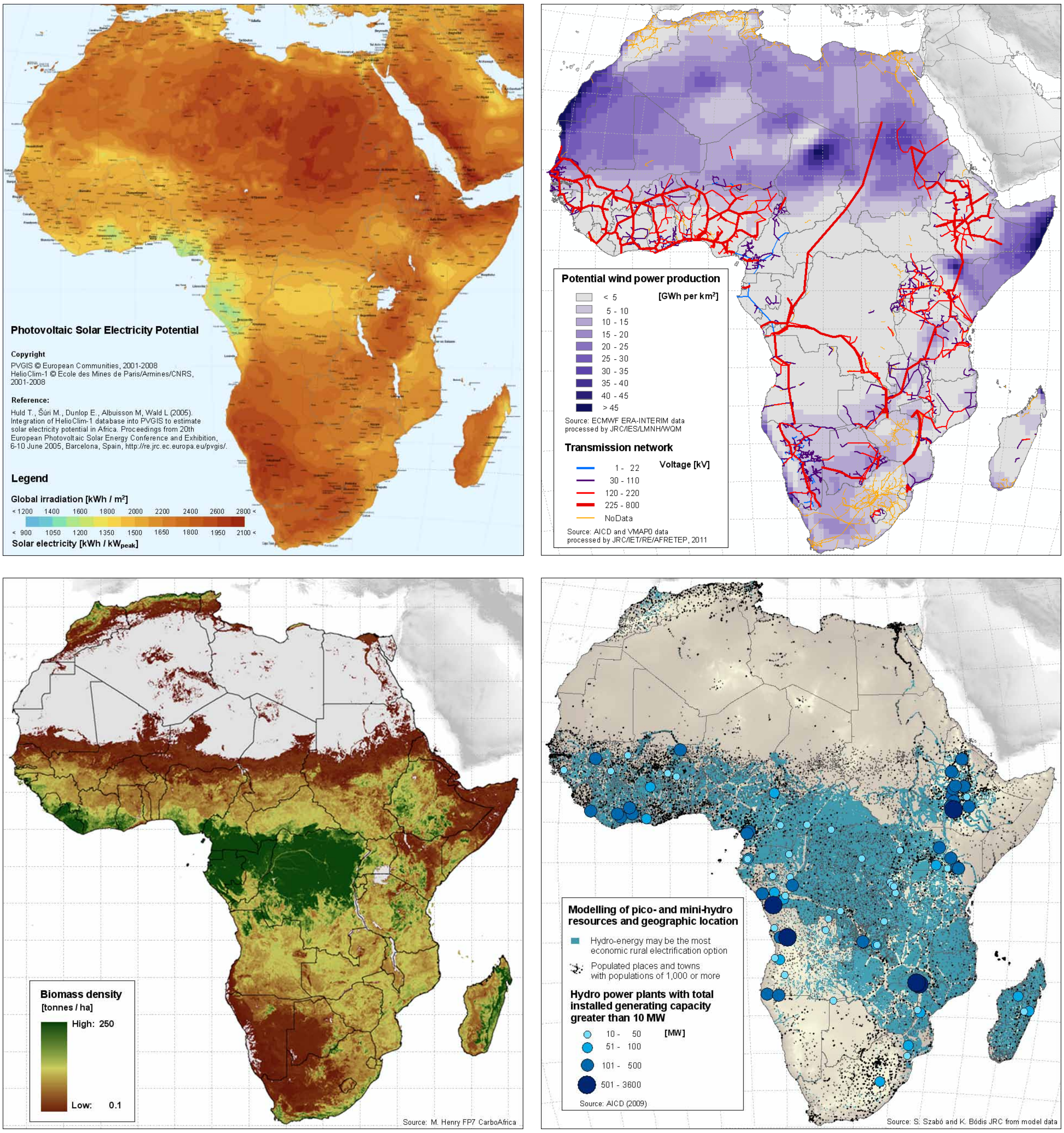
- Data gaps coverage: further investigation and analysis is needed to obtain harmonized and consistent data and statistics for the African continent.

- Resource assessment: for some energy sources (e.g. biomass) a systematic resource assessment taking into consideration availability, exploitability and sustainability of the potential energy has not been developed. In the case of biomass, such an assessment should consider the traditional 4 Fs (Food, Feed, Fiber, Fuel) approach to competing uses with in addition an ongoing growth of green chemistry and bio-materials, also considering biomass from the three main categories of forest, agriculture and waste.

- Climate change: Climate change is known to have mid and long term effects on renewable energy resources availability as it is expected to effect directly or indirectly (e.g., through changing precipitation patterns) most of the physical variable at the basis of renewable energy availability. JRC is currently involved in CORDEX (Coordinated Regional Downscaling Experiment) in which Arica was selected as the main focus. The project aims to produce an improved generation of regional high resolution climate change scenarios. Following the methodologies mentioned in the present report, it could be possible to read the results of such a research effort could be read in terms of modified renewable energy availability patterns.

Appendix. Resource maps

A.1 Overview



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HelioClim-1 © Ecole des Mines de Paris/Armines/CNRS, 2001-2008

Reference:
Huld T., Šúri M., Dunlop E., Albuisson M, Wald L (2005). Integration of HelioClim-1 database into PVGIS to estimate solar electricity potential in Africa. Proceedings from 20th European Photovoltaic Solar Energy Conference and Exhibition, 6-10 June 2005, Barcelona, Spain, http://re.jrc.ec.europa.eu/pvgis/.

Source: ECMWF ERA-INTERIM data processed by JRC/IES/LMNH/WQM

Source: AICD and VMAP0 data processed by JRC/IET/RE/AFRETEP, 2011

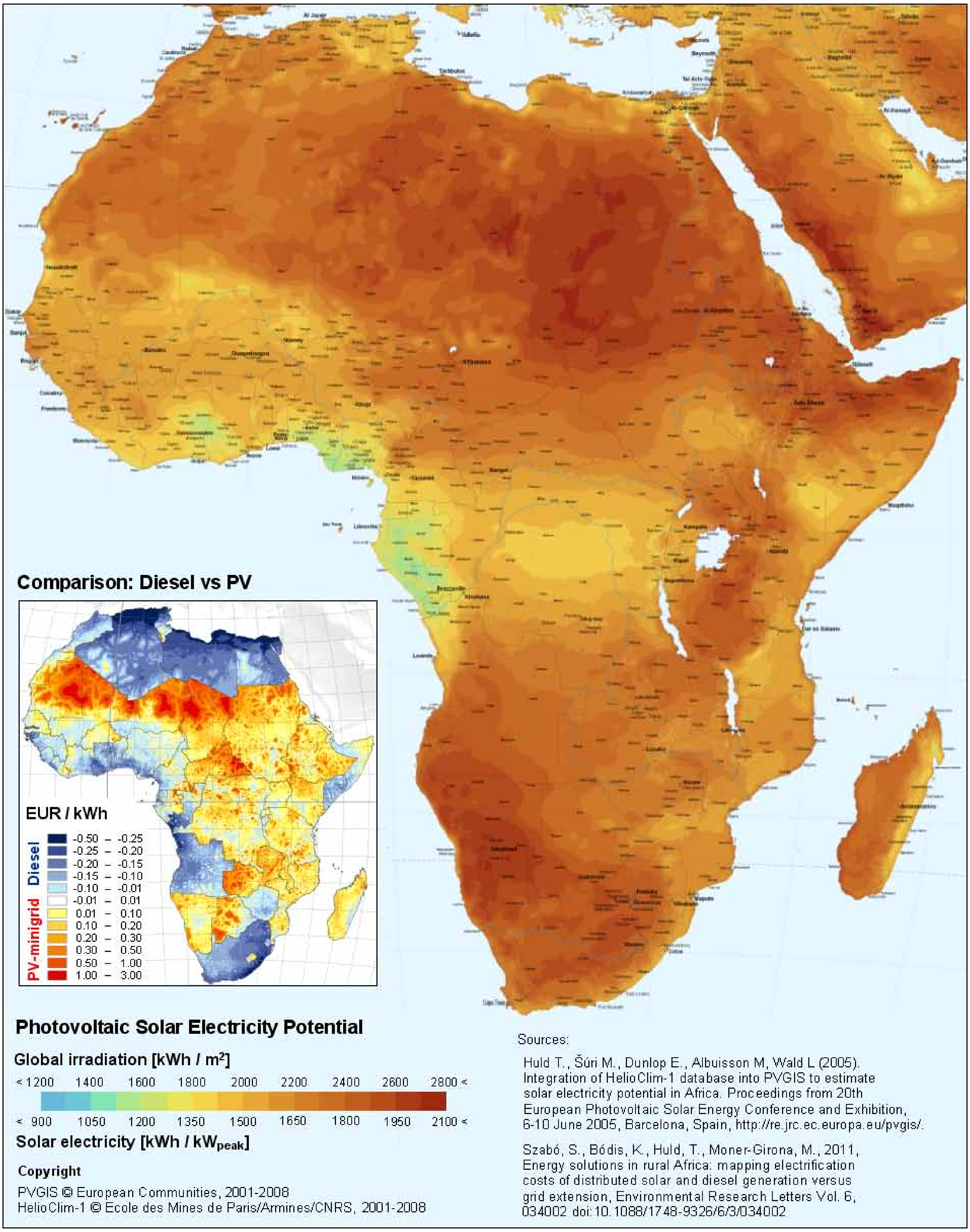
Source: M. Henry FP7 CarboAfrica

Source: AICD (2009)

Source: S. Szabó and K. Bódis JRC from model data

Figure A.1 *Renewable energy resource mapping for Africa. Top left: solar radiation [kWh/m*$^{2]}$*; top right: wind energy density [GWh/km*$^{2]}$*; bottom left: biomass density [tonnes/ha]; bottom right: mini hydro area suitability and hydro capacity installed [MW].*

A.2 Solar energy



Comparison: Diesel vs PV

Photovoltaic Solar Electricity Potential

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Sources:

Huld T., Šúri M., Dunlop E., Albuisson M, Wald L (2005). Integration of HelioClim-1 database into PVGIS to estimate solar electricity potential in Africa. Proceedings from 20th European Photovoltaic Solar Energy Conference and Exhibition, 6-10 June 2005, Barcelona, Spain, http://re.jrc.ec.europa.eu/pvgis/.

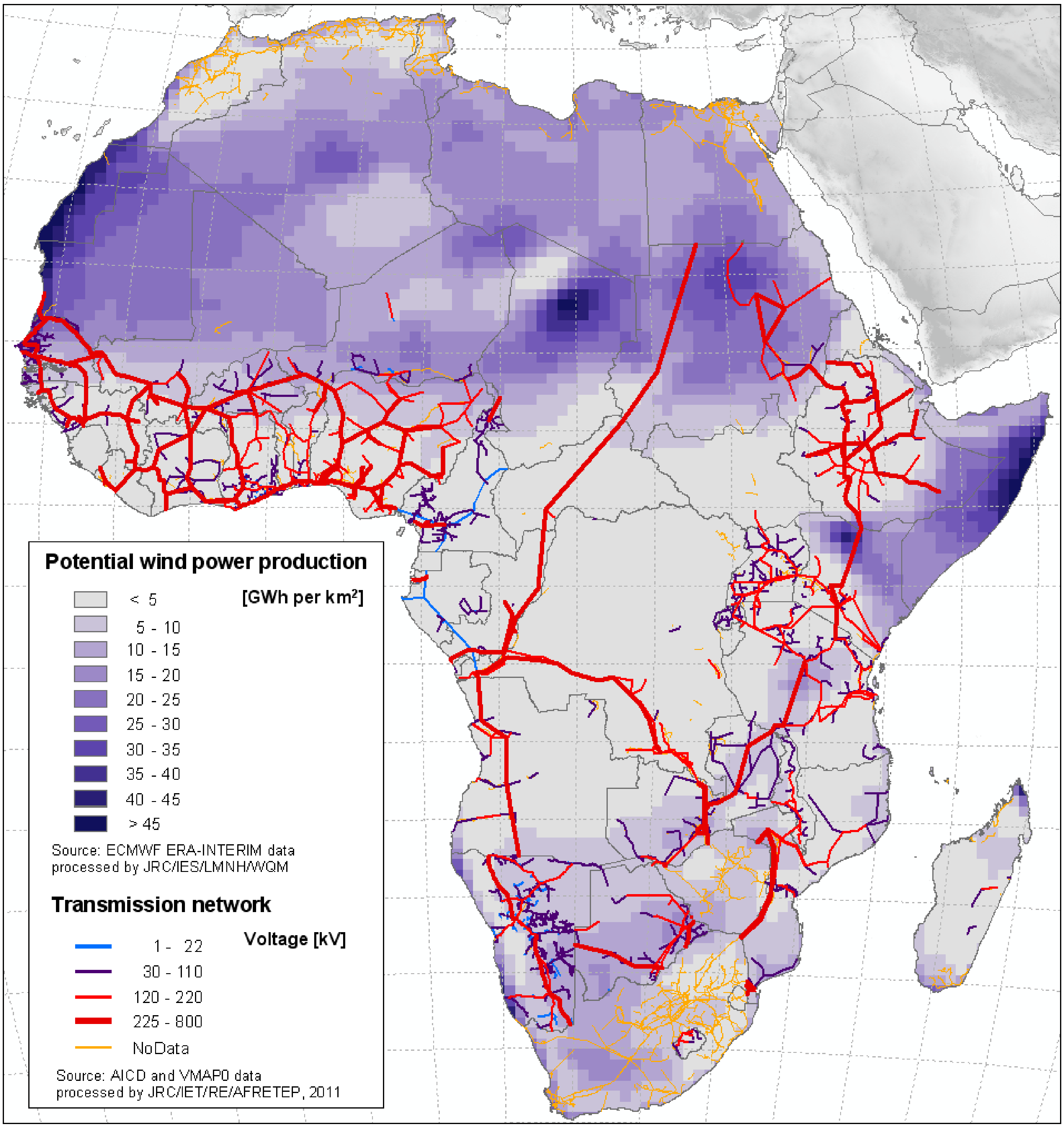
Szabó, S., Bódis, K., Huld, T., Moner-Girona, M., 2011, Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension, Environmental Research Letters Vol. 6, 034002 doi:10.1088/1748-9326/6/3/034002

Figure A.2: *Photo Voltaic Solar electricity potential as computed by PVGIS [kWh/m^2] and comparison of costs between diesel and photovoltaic electricity generation (detail).*

The large map represents the yearly sum of global irradiation on equator-oriented photovoltaic module optimally oriented [kWh/m^2] computed on the basis of Helio-Clim 1 database for years 1985-2004. The same scale represents also the potential production of solar electricity for each kW$_{peak}$ installed for photovoltaic system with system performance ratio of 0.75.

The small map shows a comparison between diesel generated and PV generated electricity in a rural (off-grid) context. Blue colour identifies area where diesel production is less expensive, considering the current (2009) diesel process and subsidies. On the contrary, PV electricity production is more convenient in red-orange-yellow areas.

A.3 Wind energy



Source: ECMWF ERA-INTERIM data processed by JRC/IES/LMNH/WQM

Source: AICD and VMAP0 data processed by JRC/IET/RE/AFRETEP, 2011

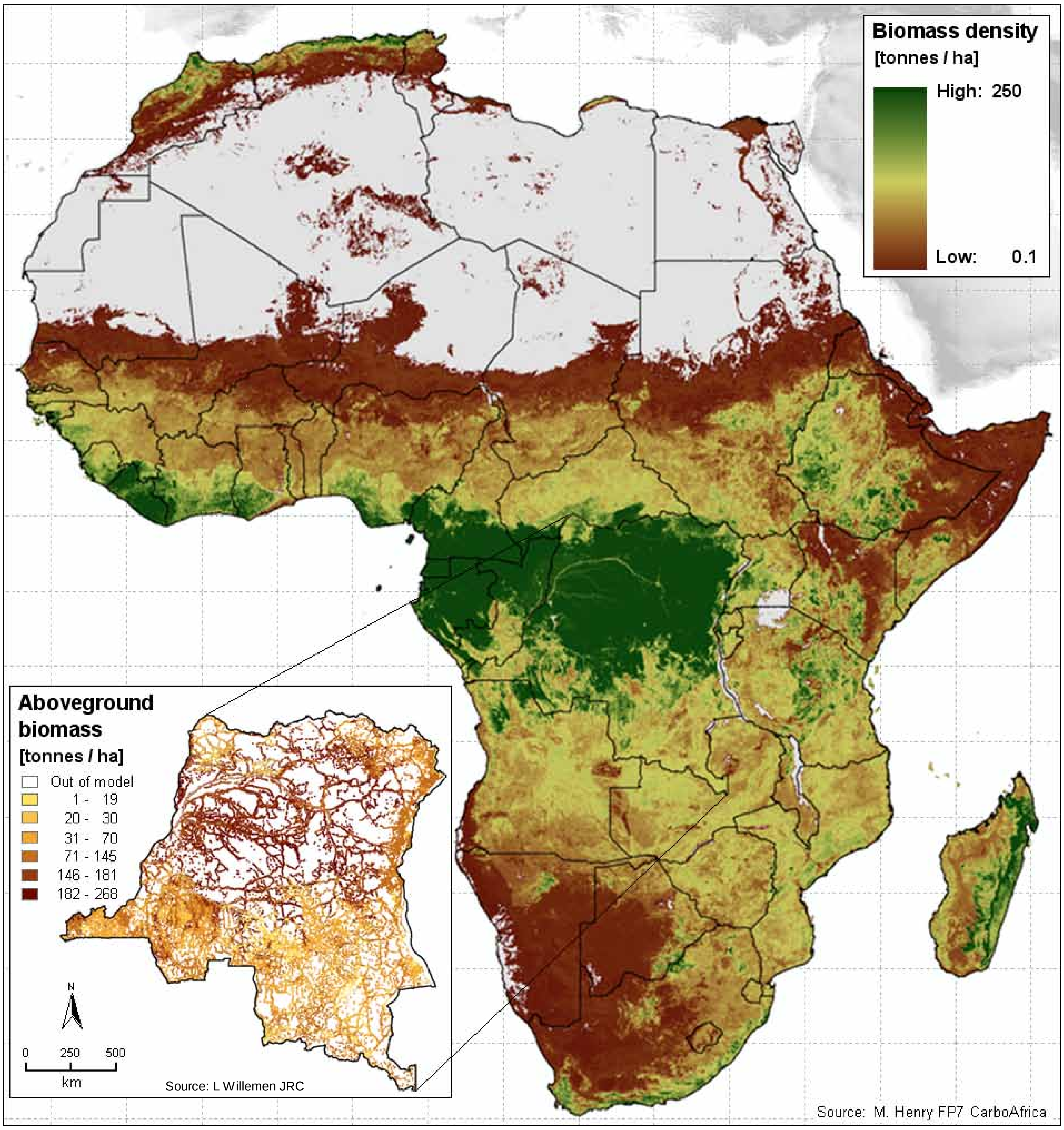
Figure A.3: *Potential wind power production in GWh per km^2 excluding regions with water bodies, forest, cities and protected areas and assuming 5 turbines per km^2. Overlaid is the position of the available data on the existing power grid with capacity in kVolt. Data on the grid are not available for all countries.*

The map shows the potential wind power production on the basis of the available wind energy density (Figure 3.1) and the efficiency of transformation of a "typical" 100m tall wind tower. For assessing wind energy density, winds at 100 m above ground for a period from 1979 to 2010 have been derived from 6 hourly re-analysis ECMWF model output data on grid cells with roughly a size of 75x75 km^2.

For this study we assume modern technology wind turbines with a diameter of rotor blades of 80 m and full working hours in a year (8760 h) and an "ideal" conversion coefficient of 59.3%. In order to calculate the average wind energy production potential per square kilometre, it is assumed that five wind turbines can be sited per square kilometre.
Minimum *(cut-in)* and maximum *(cut-off)* speed in which wind turbines operate have been set to 3.5 m/s and to 25 m/s respectively. Full productivity is assumed from a rated output speed of 15 m/s onwards, meaning that higher winds will not yield more energy production than the one at 15 m/s.

Water bodies, forest, cities and protected areas were excluded from the analysis.

A.4 Energy from biomass



Source: L Willemen JRC

Source: M. Henry FP7 CarboAfrica

Figure A.4 *Biomass density in the African continent [tonnes/ha] and biomass density in the area closest than 5 km from a road in Democratic Republic of Congo - detail [tonnes/ha]*

The overview map shows the density of all the kinds of biomass (woody and agricultural) in the African continent.

As the efficient transformation of biomass into energy strongly relies on the accessibility and the efficient mobilization of the raw material, the detail of "accessible" biomass density, here defined as the biomass lying not farer than 5 km from a road, is also shown in the case of Democratic Republic of Congo. The methodology for assessing bioenergy resources, considering also sustainability and protection of biodiversity issues is detailed in Chapter 4.

A.5 Hydro and mini-hydro

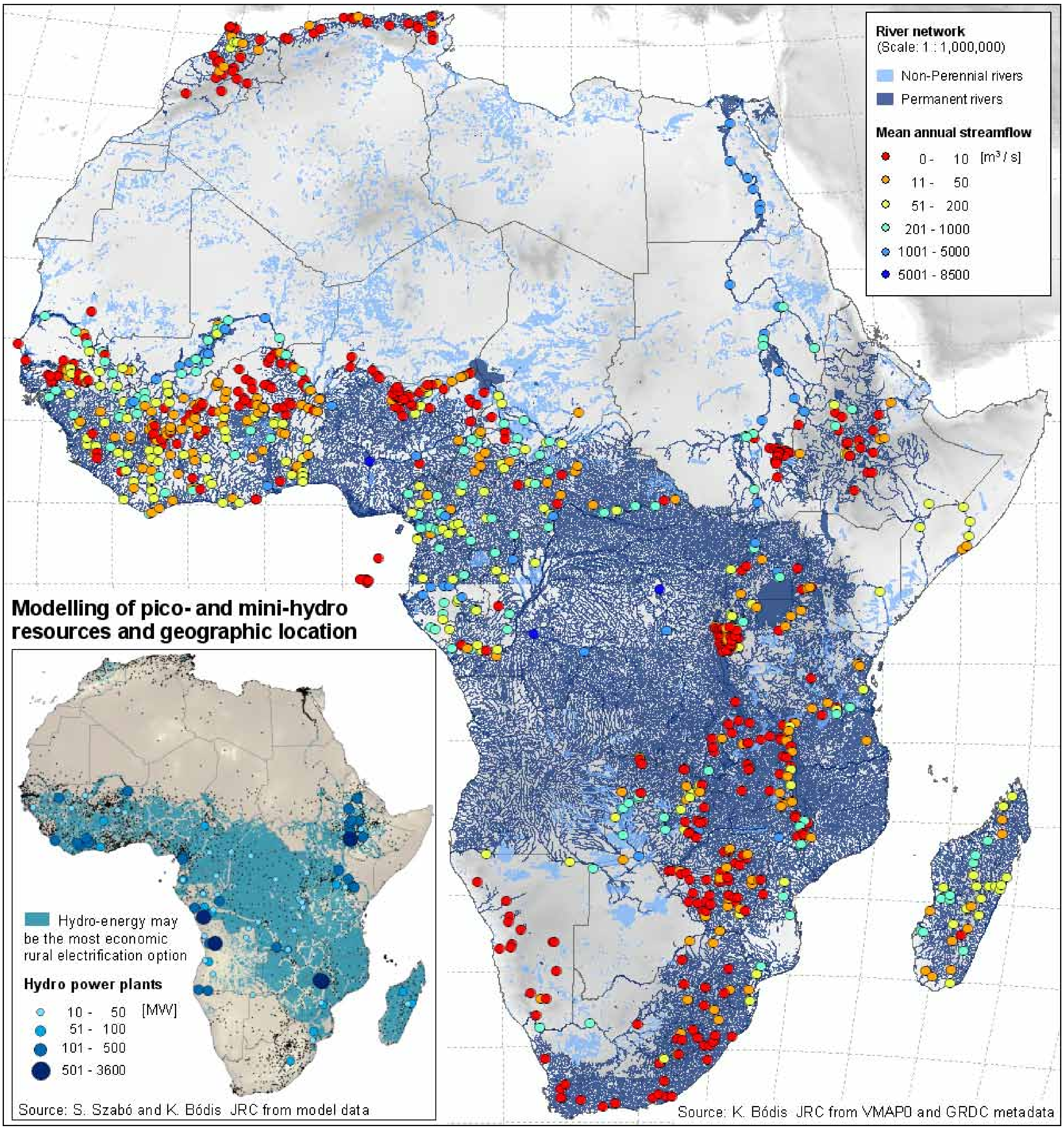


Figure A.5 *Permanent (dark blue) and non permanent (light blue) river network in the African continent with annual mean discharge data [m^2/s] and areas where mini-hydro results the most convenient rural electrification option (detail)*

The large map shows the African river network and the available public data on annual typical discharge (flows) of water.

Permanent rivers with flow higher than a feasibility threshold have been considered suitable for mini-hydro installation whose cost was compared with diesel and photovoltaic options for rural electrification. Detail map shows areas where mini-hydro has been shown to be the most economically convenient option (see chapter 5 for details).

European Commission

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Abstract

This report summarizes current knowledge at the Joint Research Centre regarding Renewable Energy in Africa. It assesses current energy consumption and the share of renewables in African states, and attempts to estimate the technical potential of available resources of solar, wind, biomass and hydropower which could be economically used to provide energy for the increasing population.

Existing Statistical data on energy supply and demand have a large uncertainty, both in terms of quantity and costs or price. The available data which were used for this report indicate a wide range both of per capita energy consumption (100 to 2000 kgoe/cap/y) and per capita electricity consumption (50 to 4000 kWh/cap/y). Relative to the average of the European Union, this corresponds to up to 35 times less regarding all energy, and up to 100 times less regarding electricity. Even though electrification made considerable progress in the past 10 years, 600 Mio of rural population has no access to electricity at all.

This report assesses in detail the renewable energy options for electricity production in rural areas, where the de-centralised feature of these technologies allow an economically viable competition with conventional grid extension. It is particularly true in remote areas where the nearest grid infrastructure is already unreliable and overloaded. In areas where household density is low (<50 cap/km2), any investment in larger grid infrastructure would never be cost competitive. This report enhances also insight in the transport costs of conventional fuel, taking a population density to be served and transport infrastructure into account.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

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