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Introducing MOZLEAP: an integrated long-run scenario model of the emerging energy sector of Mozambique

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Abstract

Since recently Mozambique is actively developing its large reserves of coal, natural gas and hydropower. Against this background, we present in this paper the first integrated long-run scenario model of the Mozambican energy sector. Our model makes use of the LEAP framework and is calibrated on the basis of recently developed local energy statistics, demographic and urbanization trends as well as cross-country based GDP elasticities for biomass consumption, sector structure and vehicle ownership. We develop four scenarios to evaluate the impact of the anticipated surge in natural resources exploration on aggregate trends in energy supply and demand, the energy infrastructure and economic growth in Mozambique. Our analysis shows that until 2030, primary energy production is likely to increase at least six-fold, and probably much more. This is roughly 10 times the expected increase in energy demand; most of the increase in energy production is destined for export. As a result, Mozambique is rapidly developing into an important player at international energy markets. Therefore, a major challenge for energy policy in Mozambique is to strike a balance in meeting domestic and international demand for energy, such that energy production benefits the entire Mozambican population.

Keywords:

Mozambique, Energy Sector, Energy Modeling, LEAP, Scenarios

1. Introduction

Since recently Mozambique is actively developing its large reserves of coal, natural gas and hydropower. Once developed, this could make Mozambique an important player in regional and global energy markets. The recent IEA Africa Energy Outlook refers to Mozambique as an emerging large energy producer (together with Tanzania), that soon will join the group of leading energy producers in Africa, including Nigeria, South Africa and Angola (IEA 2014). Against this background, we present in this paper a new integrated long-run scenario model of the Mozambican energy sector.

Our scenario model is based on newly developed and locally collected energy statistics for the recent past as well as information about the latest developments and future plans as regards the production and transformation of energy in Mozambique. These data are supplemented with demographic and urbanization trends as well as cross-country based GDP elasticities with respect to biomass consumption, sector structure and vehicle ownership. The analysis makes use of LEAP, the Long range Energy Alternatives Planning System – an integrated modeling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy (Heaps, 2012). Hence, we name the model MOZLEAP.

To the best of our knowledge, MOZLEAP is the first integrated energy modeling and future planning model for Mozambique in the energy studies literature.[1] Our analysis fits in the literature of LEAP-based studies presenting energy planning scenarios at the country level. Recent examples include studies on China (Wang and Zhang 2011), Greece (Argiro et al. 2012), Japan (Takase and Suzuki 2011) and Taiwan (Huang et al. 2011, Yophi et. al. 2011). In addition, and more often, LEAP has been used for sector-level analysis in a country or region, often focusing on the power sector (Bautista 2012, Dagher and Ruble 2011, Kale and Pohekar 2014, McPherson and Karney 2014), but also on renewable energy planning (Jun et al. 2010).

Our modelling period starts with historical trends since 2000 and subsequently covers the anticipated surge in natural resources exploration until 2030. We model energy demand by households, transport and extractive industries, as well as the sectors agriculture, manufacturing, services, government and other. Also we specify electricity demand from neighboring countries in the region, given their essential role in developing the Mozambican electricity market. As regards the supply side, we model electricity

[1] It should be noted that, in an unpublished ministerial report, Mulder (2007) used the LEAP framework to draft a rudimentary first version of an energy scenario study for Mozambique, based on data for the period 2000-2005. Other (consultancy) energy planning studies for Mozambique, using different frameworks, typically consider one dimension or subsector of the energy system, like for example the electricity sector (Ministry of Energy /Norconsult 2009, Norconsult, 2011).

production on a project by project basis, as well as gas exploration, coal mining, mineral (heavy) sands mining and charcoal production. We use the model to explore the potential impact of the expected surge in natural source exploration on aggregate trends in energy supply and demand, the energy infrastructure and economic growth in Mozambique. Because of space constraints, we present in a separate paper a more detailed energy outlook for Mozambique based on our scenario model, including the underlying shifts in energy mix and economic structure that drive the aggregate trends presented and discussed in this paper.

The structure of the paper is as follows. In section 2 we present our methods: the database that we developed in order to build our scenario model as well as the modelling framework and our scenarios. In Section 3 we present and discuss the main results of our modelling exercise. Section 4 concludes and discusses key policy implications.

2. Methods

2.1 Modeling framework

As mentioned in the introduction, our model makes use of the LEAP framework. LEAP is intended as a medium to long-term modeling tool, designed around the concept of long-range scenario analysis[2]. Our model includes a historical period that comprises the period 2000-2010, in which the model is run to test its ability to replicate known statistical data. Subsequently, our model generates multiple forward looking scenarios for the period 2011–2030. LEAP supports a wide range of different modeling methodologies. On the supply side, we model electricity production, gas exploration, coal mining and mineral (heavy) sands mining on a project by project basis, using information that we collected about the latest developments and future plans as regards the production and transformation of energy in Mozambique (see below). In addition we develop and integrate into the LEAP framework a simple biomass model to calculate future paths of charcoal production and biomass consumption in Mozambique. On the demand side we adopt a mix of these methodologies to model energy demand by households, transport and extractive industries, as well as the sectors agriculture, manufacturing, services, government and other. Also we specify electricity demand from neighboring countries in the region, given their essential role in developing the Mozambican electricity market.

In essence, the LEAP accounting framework calculates (future) energy demand as the product of activity levels (such as GDP, population, physical production levels) and energy intensity per unit of

[2] For more information see www.energycommunity.org

activity. Our energy demand modeling is based on a combination of historical energy and activity level data that we collected and information on demographic and urbanization trends supplied by external sources, locally collected bottom-up information as regards future electricity distribution and cross-country econometric modeling of GDP elasticities with respect to biomass consumption, sector structure and vehicle ownership. Figure 1 and Table 1 summarize, respectively, the structure of the MOZLEAP modelling framework and the MOZLEAP model itself. In the next section we describe this approach and its results in more detail.

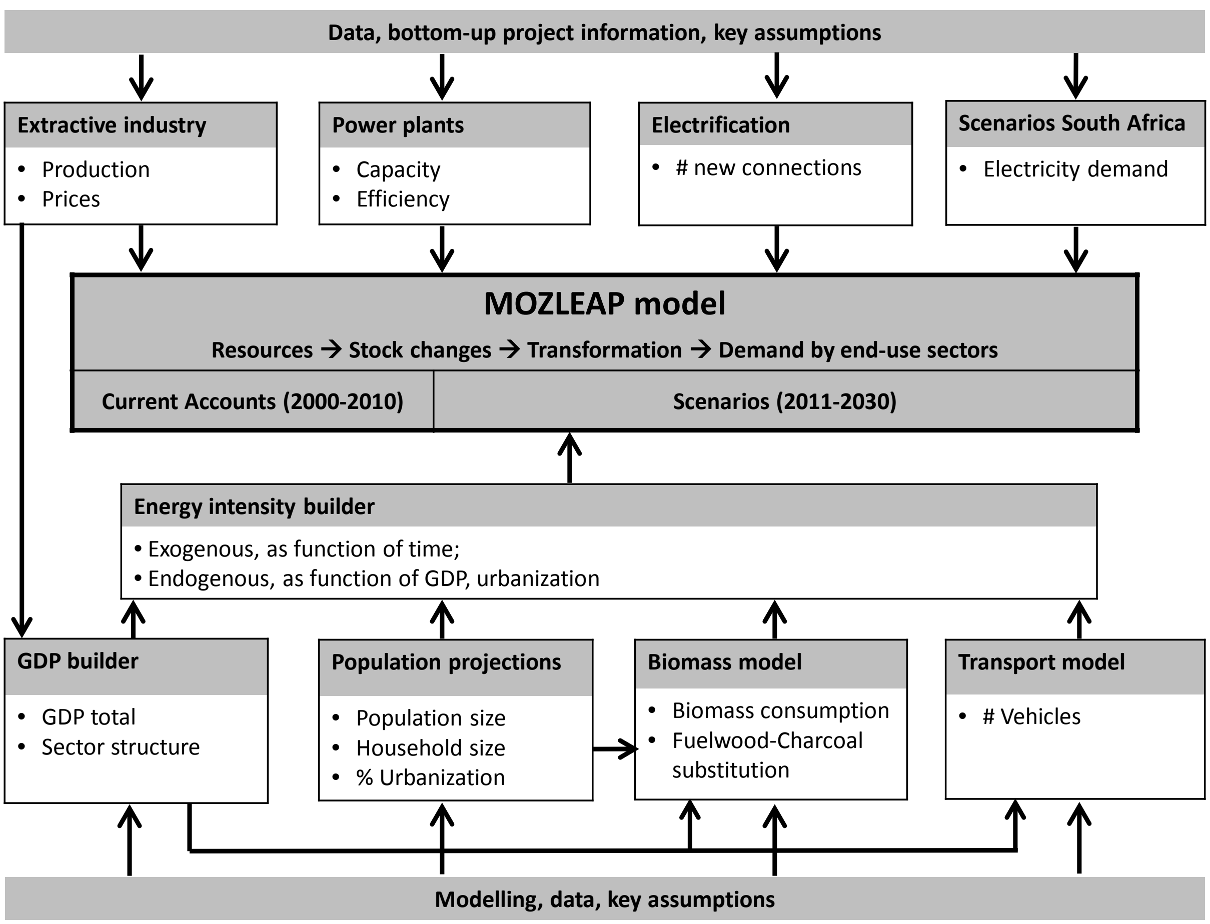

Figure 1. Structure of the MOZLEAP modelling framework

Table 1. The structure of the MOZLEAP modeling framework.

Category, Sector	Subsector	Activity	Energy type
DEMAND			
Residential	Electrified	# Households	Electricity, LPG, Kerosene, Charcoal, Fuelwood
	Non Electrified	# Households	Kerosene, Charcoal, Fuelwood
Agriculture			Electricity, Diesel
Manufacturing	MOZAL	Metric Tonne	Fuel Oil, Natural Gas, Electricity
	Other Industry	GDP	Fuel Oil, Natural Gas, Electricity, Diesel
Services	Commercial Services	GDP	Electricity, LPG, Fuelwood, Charcoal
	Public Lighting	Not applicable	Electricity
Government		GDP	Electricity
Extractive Industries	Coal Mining*	Metric Tonne	Electricity, Diesel
	Natural Gas Exploration	GDP	Natural Gas
	Heavy Sands Mining*	Metric Tonne	Electricity, Diesel
Other Sectors		GDP	Electricity
Transport Road	Passenger Cars	# Vehicles	Gasoline, Ethanol
	Trucks	# Vehicles	Diesel, Methanol
	Motorcycles	# Vehicles	Gasoline, Ethanol
	Tractors	# Vehicles	Diesel, Methanol
Regional Electricity Demand	South Africa	Not applicable	Electricity
	Zimbabwe	Not applicable	Electricity
	Other	Not applicable	Electricity
STATISTICAL DIFFERENCES			
	Primary		All primary
	Secondary		All secondary
TRANSFORMATION			
Transmission and Distribution			Electricity, Natural Gas
Electricity Generation	Solar PV		Electricity
	Hydro		Electricity
	Thermal Natural Gas		Electricity
	Thermal Coal		Electricity
Charcoal Making	Existing		Charcoal
	New Efficient		Charcoal
Coal Mining			Coal
Natural Gas Exploration			Natural Gas
STOCK CHANGES			
	Primary		All primary
	Secondary		All secondary
RESOURCES			
	Primary		All primary
	Secondary		All secondary

2.2 Data

Most of the energy statistics for Mozambique that we use in our analysis were collected and processed by the Directorate of Studies and Planning (DEP) of the Mozambican Ministry of Energy (ME, 2012). Underlying data have been provided by a range of local institutions, including National Institute of Petroleum (INP), National Company of Hydrocarbons (ENH), Mozambique Petroleum Company (PETROMOC), Cahora Bassa Hydroelectric (HCB), Mozambique power utility (EdM), Mozambique Transmission Company (MOTRACO), National Energy trust-Fund (FUNAE), South African multinational gas and Oil company (SASOL), Matola Gas Company (MGC), Portuguese Petroleum and Gas Company (GALP), VidaGas, National Institute of Statistics (INE), Mozambique Petroleum Import (IMOPETRO) and the Ministry of Planning and Development (MPD). Historical data on consumption of traditional biomass have been estimated on the basis of combined information from national survey data published by INE and international data published by the IEA and FAO.

Data on existing and future production of mineral resources (coal, natural gas and heavy sands) were compiled on the basis of information gathered from the Ministry of Mineral Resources (MIREME), KPMG International (2013), United States Geological Survey (Yager, 2012) and the US Energy Information Administration (EIA/DOE). In addition we collected information from press releases by private companies (in Bloomberg, Reuters, Mining Weekly, Mozambique Information Agency-AIM, and other national press), as well as from personal communications with local experts. Information on future electricity trade in the region is based on information published in the Integrated Resource Plan by the South African government (SA Department of Energy, 2011) and interviews with local experts. Finally, demographic and economic data on Mozambique were obtained from INE, the Ministry of Planning and Development and the Mozambique Central Bank (BM) as well as from the World Bank, the International Monetary Fund (IMF, 2013), the United Nations Department of Economic and Social Affairs (2011 Revision), and the African Development Bank (AfDB). All locally collected data, insofar possible, have been checked against data from international sources, including British Petroleum (BP Statistical Report 2012), International Energy Agency (IEA 2013a, 2014), United Nations Populations statistics and the World Development Indicators as published by the World Bank.

2.3 Scenarios

Energy scenarios are self-consistent storylines of how an energy system might evolve over time. Since this is, to the best of our knowledge, the first integrated energy modeling and future planning study for Mozambique in the energy studies literature, we chose to develop in this paper a limited number of scenarios that are intentionally fairly simple and straightforward. Our main goal is to introduce our newly developed scenario model MOZLEAP, and to use it for highlighting major trends in the transformation of the emerging Mozambican energy sector, including the expected consequences for both domestic and international energy markets. The development of richer scenarios, including more detail and variation in terms of energy policies, structure of energy demand, energy supply mix options and regional differences, is deliberately left for future work.

Energy outlooks usually give three basic scenarios – medium, high and low – that are often largely defined by GDP and population growth expectations. We follow this approach, but add a fourth scenario that assumes exploitation of Mozambique's natural resources exploration to its fullest potential. We label our three basic scenarios as Reference, Reference High and Reference Low. Reference is the *most likely* development path. Instead, development of GDP in the Reference scenario is based on baseline projections plus activities of new extractive industry and electricity generation projects that are (almost) sure to be realized, taking into account realistic and somewhat conservative estimates about the output price development in the extractive and aluminum industry. Furthermore, it adopts a medium variant of population growth scenarios, a modest decline in household size, a moderate speed of urbanization and somewhat conservative estimates as regards the development of energy intensity improvements across sectors. Reference High and Reference Low then refer, respectively, to the optimistic and pessimistic variant of Reference – thus assuming higher (lower) baseline economic growth, lower (higher) population growth, higher (lower) speed of urbanization, faster (slower) decline of household size and energy intensities across sectors and higher (lower) output price developments in the extractive and aluminum industry. We refer to Table 2 for a brief summary and overview or scenarios.

Finally, our Extractive scenario describes the expected evolution of the Mozambican energy system if all potential projects of extractive and aluminum industries as well as power generation are realized, including those projects that are yet (very) uncertain. In other words, this scenario tells the story of the Mozambican economy and energy sector becoming very much extractive industry driven. Because of this focus, we assume all other leading dimensions of the model (population growth, household size, speed of urbanization, energy intensity improvements and output price developments) to be equal to the Reference or Reference High scenario (see Table 2). This straightforward set-up, again, is motivated by our aim to show the potential impact of an extractive industry driven development path as caused by the mere expansion of this activity rather than by (optimistic) energy intensity changes or price developments. We leave it to future work to analyze the potential impact of price volatility on international natural resource and commodity markets on the Mozambican economy and energy sector, detailing the (future) evolution of international commodity price variation across markets and sectors.

Table 2. Scenarios for MOZLEAP

Scenario	**Variant**	**Description**	Annual growth Baseline GDP*	New projects extractive industry and power sector	Output price extractive and aluminum industry	Population growth	Household size	Speed of urbanization	Energy intensity improvements
Reference	Medium	The *most likely* development path.	Gradual decrease to 4.7% in 2030.	Including those that are (almost) sure to be realized	Realistic and somewhat conservative estimates	Medium growth scenario	Linear extrapolation of decreasing trend	Medium scenario	Realistic and somewhat conservative estimates
	Low	The *pessimistic* variant of Reference-medium.	Gradual decrease to 3.8% in 2030.	Same as Reference-medium	Low estimates	High growth scenario	Trend 50% slower than Reference-medium	Trend 50% slower than Reference-medium	Same as Reference-medium
	High	The *optimistic* variant of Reference-medium.	Gradual decrease to 5.9% in 2030.	Same as Reference-medium	High estimates	Low growth scenario	Trend 50% faster than Reference-medium	Trend 50% faster than Reference-medium	Same as Reference-medium
Extractive		The *extractive industry driven* development path.	Same as Reference-high.	Including all planned projects, including those that are uncertain	Same as Reference-high.	Same as Reference-high.	Same as Reference-high.	Same as Reference-high.	Same as Reference-medium.

* Baseline GDP means all sectors excluding extractive industry

3. Results and discussion

In this section we present the different parts of our scenario model (see also Figure 1) in more detail, and show how the expected surge in natural source exploration affects aggregate trends in energy supply and demand, the energy infrastructure and economic growth in Mozambique.

3.1 GDP builder

Together with population growth, per capita GDP is a key driving force in our model. Evidently, on the one hand energy is an essential production factor that fuels economic growth, while on the other hand increasing standards of living lead to growing demand for energy demand (GEA 2012). In accordance with this, our model structure assumes that across sectors growing GDP is associated with higher energy use. Also, we assume that total biomass consumption and fuel demand for road transport are determined by GDP per capita, either directly (in the case of biomass) or indirectly (in the case of road transport, assuming that vehicle ownership is determined by per capita GDP). Finally, we assume that in various sectors of our model the evolution of energy intensity is a function of GDP growth, reflecting the notion of increasing energy efficiency under economic development (Lescaroux 2011).

To model future development paths of GDP we developed a so-called GDP builder that is embedded in LEAP's overall accounting framework. We construct future GDP paths by combining a top-down and bottom-up approach, as follows. We start with historical data from existing sources (Mozambique Central Bank, National Statistics Institute, IMF, Worldbank) on Mozambique's total GDP and its sector structure for the period 2000–2010. From these data series we derive historical GDP growth rates, excluding the extractive industry – which was very small until 2010 (around 1% of total GDP; see Table 2). We call this baseline GDP growth. Subsequently, adopting a simple top-down approach, for the period 2011–2030 we assume that baseline GDP growth *Y* follows a declining trend as function of time *t*, according to the following straightforward logistic curve,

$$Y_t = Y_{t-1}\mathrm{e}^{-\delta t} \quad , \tag{1}$$

with δ a parameter that determines the speed of decline in the logistic curve. During the period 2000–2010 Mozambique experienced rapid economic growth, on average 7.3% per year for total GDP and 5.5% for per capita GDP. The value of δ in equation (1) is scenario-specific and chosen such that annual GDP growth gradually evolves towards 3.8% – 5.9% by 2030, depending on the scenario (see also Figure 2 and Table 3).

Next, using a bottom-up approach, we construct GDP separately for each extractive industry, including the aluminum industry, as follows. First, based on the information in our dataset (see section 2), we specify per existing and planned extractive industry project the expected future production in physical units. We include in our model electricity production, gas exploration, coal mining and mineral (heavy) sands mining. In section 3.7 we describe the considered extractive industry projects in more detail. Second, we calculate for each project the GDP value per physical unit of production. To do so, we start with historical data until 2012, which we subsequently extrapolate, assuming a simple but scenario-specific trend based on expected international market prices of the primary resources involved (LNG, heavy sands minerals, coal, aluminum). Third, we estimate future GDP of the extractive industry by combining these price trends with expected physical production patterns per project, and subsequently aggregating over all projects. Together with the baseline GDP this sums up to total GDP, including an implied total GDP growth rate.

As noted before, we calculate for each project the GDP value per physical unit of these production levels by extrapolating historic trends, based on data until 2012. Our extrapolation methodology assumes a simple, scenario-specific, trend based on expected international market prices of the primary resources involved (LNG, heavy sands minerals, coal, aluminum). These prices are partly based on expert judgments for the upcoming years, published in a variety of resources (IEA 2013b, KPMG 2013), while for the remaining years price trends are assumed to follow a straightforward but scenario-specific pattern, with annual price fluctuations varying between –2% and 4%. Given the expected large relative size of the extractive industry in the future economy of Mozambique, future price trends for primary resources are deliberately designed to be conservative, in order to avoid an upward bias in future GDP development paths. We refer to Table 3 for further details.

Finally, we construct a sectoral breakdown of aggregate GDP by calculating future sector shares of four main sectors (agriculture, services, manufacturing and government) as percentage of total GDP. The underlying idea is of course that economic development typically involves a change in the sectoral composition of economies, with the industrialization process inducing a shift from the agricultural sector towards industry, followed by a deindustrialization phase increasing the importance of the service sector (e.g., Baumol 1967; Maddison 1991, 1999). Again, our starting point is historical data for the period 2000-2011 from existing sources. Next, we assume that the respective sector shares *S* evolve over time as a function of per capita GDP *y*, according to the following logistic curve:

$$S_{(t)} = S_{t-1} * \left[1 + \frac{\Theta}{\mathrm{y}_t}\right]^{\Delta \mathrm{y}_t} \tag{2}$$

with parameter θ signifying the elasticity of the change in the sectoral composition of the economy under influence of economic development. The value of θ is sector-specific and is derived from cross-country regressions of the relation between per capita GDP and the respective sector share, using Worldbank data for 39 countries with per capita GDP values between US$700 and US$3000; estimated coefficients vary from -2.94 for agriculture to 4.86 for manufacturing. We refer to Table A.1 in the Annex for details.

The results of our GDP calculations are summarized in Figure 2. When we look at the last decade and a half, the data clearly illustrate that Mozambique is extremely poor but at the same time experienced rapid economic growth. In 2010 per capita GDP was just over $400, in 2015 this is expected to be over $600 (which equals to about $1300 in PPP terms). These levels roughly correspond with, respectively, 9% and 2% of the per capita GDP level in South Africa and the USA and imply that still about half of the Mozambican population lives below the local absolute poverty line (Boom 2011). Yet, the rapid increase in per capita GDP implies that the average annual growth rate of GDP is well over 7% during the period 2000-2015. In addition, Figure 2 shows that our modelling of Baseline GDP (see equation 1) leads to a gradual increase of Baseline GDP per capita to levels of $750–$1000 by 2030, depending on the scenario. Extractive GDP per capita is expected to increase dramatically over time, from almost zero in 2000 to $123–$235 by 2030 in the Reference scenarios and $528 in the Extractive scenario. Our assumptions as regards the expansion of production levels in the extractive industry, as described above, imply that Extractive GDP growth is expected to peak in this decade, and will smooth after 2020. Depending on the scenario, together these developments cause total per capita GDP to be in the range of $900–1400 by 2030, which equals a 115–243% increase from 2010 levels.

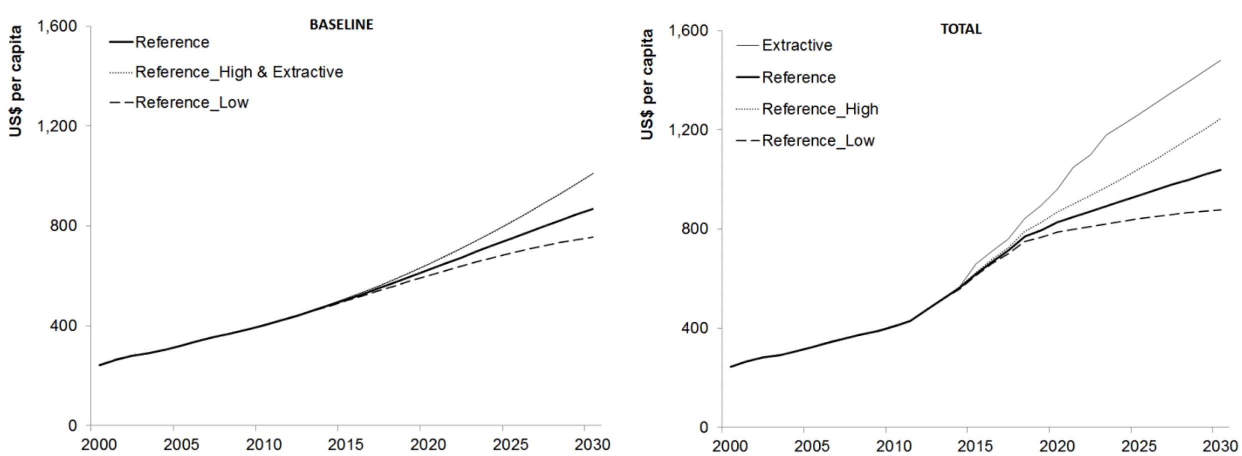

Figure 2. Per capita GDP across scenarios; Baseline GDP (left) and Total GDP (right).

3.2 Population projections

Size and growth of the population helps define critical indicators in our model, such as per capita GDP, the electrification rate, total residential energy consumption, and fuel consumption by passenger cars. In addition, these indicators are influenced by the composition of the population in terms of the urban-rural divide and whether or not households have access to electricity. Growth of population has been calculated as the product of birth, mortality and net migration statistics, based information from the National Statistics Institute (INE) that is derived from national censuses 1997 and 2007, supplemented with data obtained from local surveys on, amongst others, infant mortality and HIV prevalence. Future projections of these various demographic statistics have been obtained by INE through a combination of extrapolating historical trends, collecting new data from local surveys (after 2007) and the use of demographic modelling software developed by the UN and the US Census Bureau. Figure 3 and Table 3 summarize our key demographic indicators across the various scenarios.

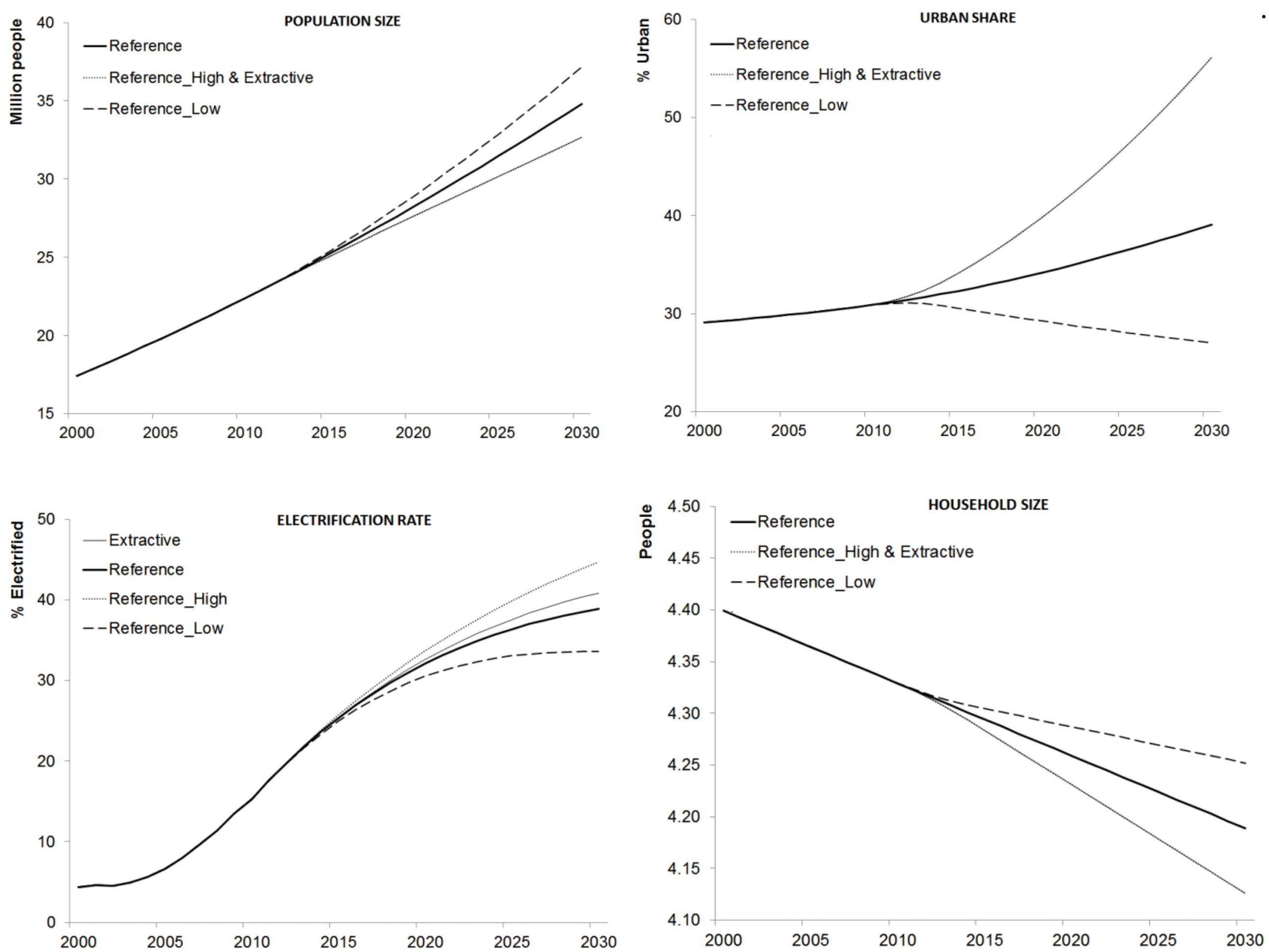

Figure 3. Model results for population size, urbanization, electrification and household size

As regards population growth, all our scenarios for the period 2011–2030 take as their starting point historic data for the year 2010. In 2010 Mozambique's population was some 22.4 million in total, of which almost 31% lived in urban areas; average household size was 4.3, average annual population growth was 2.5%, with urban population growing 3.2% per year. Subsequently, all scenarios assume population growth to gradually decrease over time. In our Reference scenario we expect average annual population growth to decrease to 2.0% in 2030. In our Reference Low and High scenarios, we assume this numbers to be 0.4 percentage point higher and lower, respectively; the Extractive scenario is identical to the Reference High for all demographic indicators (see Table 3). As a result, by 2030 total population size is expected to be 32.7–37.1 million people, with 34.8 million people in the Reference Medium scenario (see Figure 3). Growth of urban population is expected to increase to 3.5% per year in 2030 in the Medium scenario; in the Low and High scenarios we assume this percentage to be 50% lower and higher, respectively (see Table 3). As a result, by 2030 the percentage of urban population is expected to be 30.8 – 49.4, with 39.1% of urban people in the Medium scenario (see Figure 3). This implies that in the Medium scenario the number of people living in cities in Mozambique by 2030 is as large as 60% of the entire population in 2010, which obviously will reshape the urban landscape in Mozambique over the next 25 years, and, hence, transform (residential) energy demand. Finally, in all scenarios we assume the average household size to gradually decrease under influence of income growth and urbanization, from 4.3 persons in 2010 to 4.13 – 4.25 persons in 2030 (see Table 3 and Figure 3).

The extent to which the Mozambican population has access to electricity is expected to change rapidly as a result of intensive (rural) electrification programs and growing income levels. In our model the electrification rate is endogenously determined by combining information on electricity network expansion (number of new connections realized) with population growth dynamics as described above. In 2010 the national utility EdM realized 100.000 new connections. In our Reference scenario we expect this number to increase to 135.000 in 2015, and subsequently decrease to 100.000 in 2030. In our Reference Low and High scenarios, we assume that in 2030 respectively 70.000 and 130.000 new connections will be realized (see Table 3). Given population growth, this implies that in our model the (household) electrification rate is expected to increase from 15% in 2010 to 34% – 45% in 2030, with 39% in the Reference scenario (see Figure 3). We assume transmission and distribution losses to remain at 5% as from 2011 (see Table 3).

Table 3. Key assumptions MOZLEAP model

			Reference												Extractive			
			Medium				Low				High							
	Unit	2010	2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
GDP																		
Parameter δ	1/100	--	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Unit price change																		
Natural Gas	%	--	0.0	2.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	0.0	4.0	4.0	4.0
Heavy Sands	%	--	0.0	0.0	0.0	0.0	-1.0	-1.0	-1.0	-1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Coal	%	--	-1.0	0.0	0.0	0.0	-1.0	-2.0	-2.0	-2.0	-1.0	2.0	2.0	2.0	-1.0	2.0	2.0	2.0
Aluminum	%	--	0.0	0.0	0.0	0.0	-1.0	-1.0	-1.0	-1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Population																		
Growth population	%	2,45	2,36	2,25	2,13	2,01	2,60	2,64	2,56	2,43	2,14	1,88	1,70	1,57	2,14	1,88	1,70	1,57
Growth urban population	%	3,23	3,39	3,50	3,50	3,45	1,69	1,75	1,75	1,73	5,08	5,25	5,26	5,18	5,08	5,25	5,26	5,18
Household size	#	4,33	4,29	4,26	4,22	4,19	4,30	4,29	4,27	4,25	4,28	4,23	4,18	4,13	4,28	4,23	4,18	4,13
Electricity distribution																		
# New connections / year	1000	110	135	123	112	100	129	109	90	70	141	137	134	130	135	123	112	100
Losses*	%	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

δ: Speed of decline logistic curve of baseline GDP growth.

** Transformation and distribution losses*

3.3 Biomass model

To model future demand for fuelwood and charcoal we developed a simple biomass model, embedded within LEAP's overall accounting framework. Following micro-based evidence of household energy consumption patterns in developing countries (Barnes and Floor 1999, Barnes et al. 2005), we adopt a nested model structure. First, we assume that total biomass consumption is merely determined by GDP per capita, thus considering substitution with modern energy forms (such as LPG and electricity) as function of relative prices a second-order effect (Leach 1992). Second, we assume that the choice for one of the two dominant forms of biomass (fuelwood and charcoal) is implicitly driven by their relative prices as well as the urbanization rate. More specifically, we first define the evolution of per capita biomass consumption *B* over time *t* according to a logarithmic S-shaped curve, as follows:

$$B_t = \alpha \left[1 + \beta \mathrm{e}^{-\gamma y_t}\right] \ , \qquad (3)$$

where α is the initial value of B (in the year 2000), β is a constant (vertical shift of the curve), and γ the elasticity of *B* with respect to GDP per capita *y*. The value for α is estimated on the basis of a combination of international data (IEA Energy Balances 2010) and local household survey data (Atanassov, *et. al.*, 2012; INE, 2009), and equals 10.5 GJ per capita. The values for β and γ are derived from a cross-country logarithmic panel data regression of biomass consumption on per capita GDP for the period 1971-2006, using IEA data for 74 countries with per capita values below US$3000; estimated coefficients for β and γ equal 0.0274 and 0.239, respectively. We refer to Table A.1 in the Annex for details.[3]

Next, we define the evolution of per capita consumption of charcoal *C* and fuelwood *F* as follows:

$$C_t = B_t \lambda_t \qquad \text{with} \quad \lambda_t = \lambda_{t-1}[(1+\rho)\gamma] \qquad (4)$$

$$F_t = B_t[1 - \lambda_t] \qquad (5)$$

where λ is the share of charcoal in total biomass consumption, ρ is the inter-fuel substitution elasticity (i.e. between charcoal and fuelwood) and γ is the annual growth rate urbanization. Historical values for γ were derived from census data (INE, 2010b), whereas values for λ in the initial year (2000) and ρ were derived from local household survey data (Atanassov et. al., 2012; INE, 2009), with ρ set at 0.03. Future values

[3] The US$3000 cut-off criterion is chosen to avoid a potential bias in the estimated coefficients: the share of biomass in total energy consumption becomes in general very low in countries where GDP per capita exceeds US$3000; in our scenarios per capita GDP increases from about US$ 400 in 2010 to around US$1000 by 2030.

for γ are taken from expected urbanization trends published by the UN in its World Urbanization Prospects (UN 2008).

Finally, to allocate charcoal and fuelwood consumption across electrified and non-electrified households, we implemented the following assumptions. First, we assume that in 2000 all electrified households lived in urban areas, and that in 2011 the urban and rural electrification rates were, respectively 55% and 5% (IEA 2013). Second, we assume that 5% of total fuelwood consumption and 85% of total charcoal consumption is consumed by urban households with the remainder being consumed by rural households (Atanassov, *et. al.,* 2012; Brouwer and Falcão, 2004; INE, 2009). Third, we assume that fuelwood and charcoal is consumed by, respectively, 33% and 80% of households in urban areas, while 10% of households in rural areas consume charcoal.[4] Finally, building on these assumptions we model future evolution of biomass consumption per electrified household b_t^{Elec} as a function of changes in the total biomass consumption (equations 3–5) as well as the change in urbanization rate *U* relative to the change in the electrification rate *E*, according to

$$b_t^{Elec} = \Delta b_{t-1}\left[1 + \frac{\Delta U}{\Delta E}\right] \ , \qquad (6)$$

with *b* representing either charcoal *C* or fuelwood *F* per electrified household. Biomass intensity per non-electrified household is subsequently derived from total biomass consumption not consumed by electrified households.

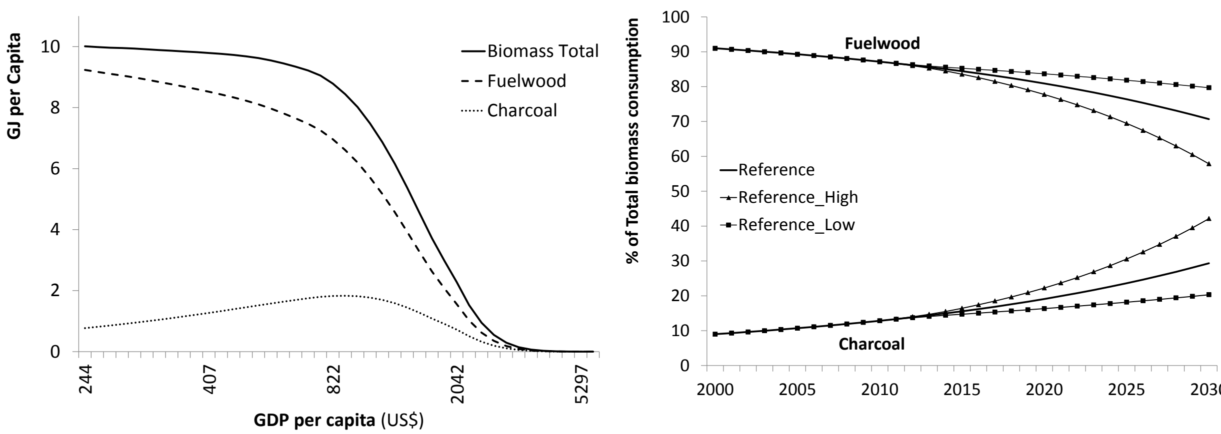

Figure 4. Biomass consumption across scenarios – as function of GDP per capita (left) and its composition over time (right).

[4]. Note that rural electrification has a minor impact on switching of cooking fuel while the opposite is true for urbanization, which is a major driving force for the choice of cooking fuel.

Figure 4 illustrates the working of our biomass model within the LEAP framework for Mozambique. The left-hand side of Figure 4 shows the evolution of per capita biomass consumption as function of per capita GDP, using actual values for Mozambique. Total biomass consumption declines with increasing GDP, following an inverted S-shaped patterns as defined by the logistic function of equation (3). As regards its composition, with rising GDP per capita consumption of charcoal increases at the expense of fuelwood consumption, under influence of rising income and urbanization – up to some income threshold level, after which is substituted for modern energy forms such as LPG and electricity. The right-hand side of Figure 4 demonstrates the substitution of fuelwood for charcoal across basic MOZLEAP model runs (see below for more detail on the scenarios). In our baseline scenario ("Reference") the percentage share of charcoal in total biomass consumption in Mozambique increases from about 10% in 2000 (historical data) to almost 30% in 2030, thus decreasing the percentage share of fuelwood from about 90% to 70% over the same period. In the optimistic (high economic growth) scenario the expected percentage charcoal by 2030 is over 40%, in the pessimistic scenario it still is expected to double from 10% in 2000 to 20% by 2030.

3.4 Fuel for road transport

We model fuel demand for road transport on the basis of the expected evolution of vehicle ownership over time, given the evolution of per capita GDP and population as described before. To this aim we developed again a simple logistic function that is embedded within LEAP's overall accounting framework. Following evidence from the top-down transport modeling literature in developing countries (Button et al. 1993, Medlock and Soligo 2002) we assume the number of vehicles per 1000 people to be merely determined by GDP per capita, thus considering (relative) fuel prices a second-order effect. More specifically, we define the number of vehicles *V* per 1000 people at time *t* according to:

$$V_t = V_{t-1} * \left[1 + \frac{\psi}{y_t}\right]^{\Delta y_t} \tag{7}$$

with parameter ψ denoting the elasticity of the change in vehicle ownership under influence of economic development. The value of ψ is derived from a cross-country logarithmic panel data regression of passenger car ownership on per capita GDP for the period 1971-2006, using data from the Worldbank Indicators database for 74 countries with per capita values below US$3000; the estimated coefficient for ψ equals 8.7. We refer to Table A.1 in the Annex for details. In the absence of more detailed data we assume this parameter to apply equally to the evolution of passenger cars as well as trucks, motorcycles and tractors.

Next we calibrate our model by combining this approach with data on the annual evolution of registered vehicles in Mozambique and fuel consumption in the recent past, supplied by, respectively, the Mozambican National Institute of Road Transport (INATTER, 2012) and the Ministry of Energy (ME, 2012). Figure 5 summarizes the results of our methodology for estimating future demand for transport fuels across the various scenarios. It shows that the number of vehicles per thousand people is expected to grow from just over 10 in 2010 to about 28–35 in 2030, depending on the scenario. With increasing per capita GDP, the implied GDP elasticity of vehicle ownership in our model is decreasing over time, from 2,5% in 2010 to about 1% in 2030. In short these numbers mean that the total number of vehicles in Mozambique is expected to increase four to five fold over the period 2010–2030, from just over 370.000 to about 1.6–2.0 million, depending on the scenario; of this total number of vehicles in 2030 in our model 63% consists of cars and 22% of trucks.

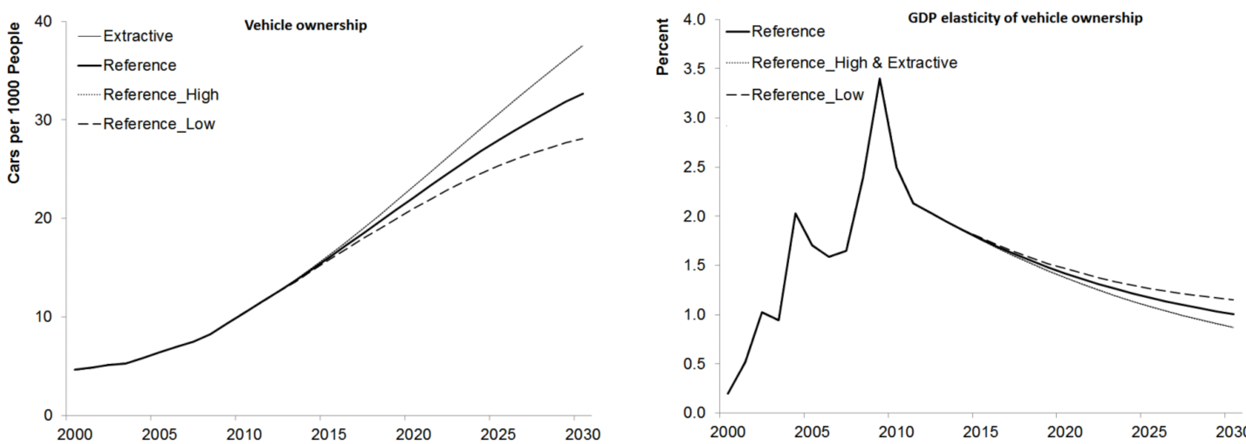

Figure 5. Model results for vehicle ownership (left) and GDP elasticity of vehicle ownership (right).

Mozambique has a large potential for the production of biofuel, given its climate and a vast amount of unused arable land. At this moment, biofuel production plays only a marginal role in the energy mix. However, the country has adopted a National Program for the Development of Biofuels to promote and use agro-energy resources for energy and food security. In doing so, the government also aims to encourage socioeconomic development and to reduce the country's dependence on fuel imports (IRENA, 2012; Ecoenergy, 2008). The program aims to progressively increase the proportion of biofuel in Mozambique’s domestic liquid fuel mix in three phases. The pilot phase (2012-2015) is currently being implemented with a fuel blending mandate of 10% for bioethanol and 3% for biodiesel. An operational phase (2016 to 2020) will follow, with 15% bioethanol and 7.5% biodiesel blending and conclude with an expansion phase (2021-onwards) of 20% bioethanol and 10% biodiesel blending. In our scenarios, we include these phases, but taking into account a 5-year delay to reflect the actual situation.

3.5 Demand scenarios from South Africa

South Africa's power utility (Eskom) has identified Mozambique as a potentially important supplier of electricity in its Integrated Resource Plan 2011 (SA Department of Energy, 2011) to help addressing its future supply-side challenges. Eskom is particularly interested in new hydropower from Mozambique, as the existing electricity generation mix in South Africa is carbon-intensive. Already, HCB represents 40% of Eskom's carbon-free generation. One of the scenarios in the IRP is to use 2600 MW of power from Mozambique, including 2135 MW from the new hydro projects. Electricity purchases from Natural Gas plants at the Mozambique-RSA border is not looked at in the IRP. As of date, South Africa gets 92 MW from Gigawatt plant in Ressano-Garcia, and could get an additional 150 MW from Sasol's plant in the same area. According to the IRP, South Africa needs an additional 90 GW of generating capacity by 2030, mostly from renewables. Therefore in our *Extractive Scenario,* we have modeled 3320 MW of capacity dedicated to Eskom, of which 1900 to 2100 MW would have to be firm.

3.6 Energy Intensity builder

As noted before, the LEAP accounting framework calculates (future) energy demand as the product of activity levels (such as GDP, population, physical production levels) and energy intensity per unit of activity. Therefore, the final building block of our model is an energy intensity builder that defines for each level of activity the corresponding energy intensity values over time. For the period 2000-2010 energy intensity values are calculated based on historical data regarding energy consumption and activity levels on a sector by sector basis. Subsequently, future energy intensity values for the period 2011-2030 are calculated on the basis of a variety of simple assumptions, again on a sector by sector basis. In this first integrated energy modeling and future planning study for Mozambique we deliberately apply simple and straightforward assumptions that do not vary in itself across scenarios. This choice is primarily motivated by our emphasis on exploring the potential impact of the expected unique surge in natural resources exploration in Mozambique on the country's energy supply and demand and economic growth prospects. Especially given Mozambique's current status as an extremely poor country with a rapidly expanding energy sector, this made us decide to leave a careful analysis of energy efficiency improvements in end-use sectors – although interesting and important – for future research.

Table 4. Key parameter values Energy Intensity Builder

Sector	Fuel type	Characterization	Value or formula
Residential	Electricity	Increase	$I_t = I_{t-1}*(1+(0,1*\Delta Y_t)$
	LPG	Increase	$I_t = I_{t-1}*(1+\Delta Y_t) *(1+\Delta U_t)$
	Kerosene	Decrease	-5% per year
	Charcoal	Increase	See Biomass model
	Fuelwood	Decrease	See Biomass model
Agriculture	Total	Increase	0.65 MJ/GDP (End year value 2030)
MOZAL	Total	Constant	55.1 GJ/MT
Other Industry	Total	Increase	2.4% / year in 2011, gradually towards 0% / year in 2030.
Commercial Services	Electricity	Increase	1% per year
	LPG	Increase	$I_t = I_{t-1}*(1+\Delta Y_t) *(1+\Delta U_t)$
	Fuelwood, Charcoal	Decrease	-3% per year
Public Lighting	Electricity	Increase	$I_t = I_{t-1}*(1+(0,5*\Delta Y_t)$
Government	Electricity	Increase	1% per year
Other sectors	Electricity	Increase	1% per year
Coal Mining	Electricity	Constant	27 kWh/MT
	Diesel	Constant	2 Liter/MT
Heavy Sands Mining	Electricity	Constant	600kWh/MT
	Diesel	Constant	2 Liter/MT
Tractors	Total	Increase	$I_t = I_{t-1}*(1+(0,05*\Delta Y_t)$
Other Vehicles	Total	Decrease	$I_t = I_{t-1}*(1+(-0,05*\Delta Y_t)$

A summary of our assumptions as regards future energy intensity trends across the various end-use sectors is presented in Table 4. We assume that in a poor country like Mozambique electricity consumption per household increases over time under influence of rising GDP, because growing household income leads to increasing demand for electric appliances such as refrigerators and air conditioning. We assume that LPG consumption per household increases over time under influence of rising GDP as well as the degree of urbanization, because growing household income leads to a shift towards modern cooking fuels, while in developing countries LPG is a typical urban fuel for logistic reasons. Furthermore, we assume that kerosene consumption per household decreases over time, because of a gradual ‘autonomous’ substitution towards more efficient and cleaner fuels like electricity and LPG. Finally, future charcoal and fuelwood intensities are derived from our biomass model. In short, we assume that total biomass consumption decreases under influence of increasing per capita GDP, while the share of charcoal in total biomass consumption increases with income and urbanization at the expense of fuelwood.

For the Agriculture sector we assume that energy intensity increases with about 20% over the course of 20 years, under influence of modernization and mechanization. We assume constant energy intensity values and fuel shares for MOZAL, based on historical data, because we do not expect changes in its production process. In the Other Industry sector we assume decreasing energy intensity growth, driven by the opposing forces of modernization and increasing energy efficiency. Under influence of increasing domestic natural gas production, we assume that the natural gas share in this sector increases to 33% by 2030 at the expense of electricity and diesel shares; fuel oil plays a minor role. In the sector Commercial Services we assume that electricity intensity increases with economic growth, while LPG consumption (in hotels and restaurants) again also positively depends on the degree of urbanization – following the same logic as in the residential sector. Consequently, we assume a gradual substitution away from biomass consumption. Finally, we assume that electricity intensity for Public Lighting increases with economic growth. Also, in the sectors Government and Other we assume that electricity intensity will rise under influence of economic growth.

Energy intensity in the extractive industry is determined by constant values of electricity and diesel consumption per physical unit of production. Actual values originate from a combination of indicative figures on open-cut coal mining and mineral sands explorations reported in the literature (Bleiwas 2011; SEE 2009) and from personal communications with local experts involved in mining activities in Mozambique. Finally, fuel efficiency in road transport is assumed to gradually increase over time under influence of economic development, which stimulates increasing import of newer and thus more fuel efficient vehicles. In contrast, we assume that fuel intensity for tractors increases because of the expected increasing use of heavy equipment as economic development proceeds. As regards the fuel mix, we assume a progressive use of biofuel in the domestic liquid fuel mix, adopting biofuel blending mandates from the government of Mozambique, taking into account a 5 year delay in accordance with the actual situation.

3.7 Aggregate energy supply and demand

As was described in section 3.1, we constructed extractive industry GDP on the basis of a bottom-up approach, based on information for individual projects in electricity production, gas exploration, coal mining and mineral (heavy) sands mining. Below, we describe these projects in more detail, since they constitute a key element in our scenario paths regarding future energy supply in Mozambique.

As regards electricity generation, we consider in total 37 projects with a total capacity of almost 11.000 MW. Hydro is and remains to be the main source for electricity generation in Mozambique. The existing capacity is around 2200 MW, of which 2075MW is provided by the Cahora Bassa (HCB) dam. In total we consider in our model 15 hydro projects over the entire period 2000-2030, with a total capacity of about 7579 MW. In addition, in the period 2011-2030 we consider the construction of 12 natural gas fired power plants with a total capacity of 1114 MW as well as 6 coal fired power plants with a total capacity of

2150 MW. Finally, we include 101 MW from diesel generations and 1.2MW solar power. Next to its capacity, for each project we define its transformation efficiency, expected first year of production and merit order. As regards the latter, we divide the modeling period into four intervals and attribute merit order by expected first year of production in the basis of 5-years intervals, such that the value one represents existing power plants. Furthermore, the Reference scenario includes existing and very likely future power projects whereas the Extractive scenario includes all 37 power projects, including those whose realization is still fairly uncertain. We refer to Table A.2 in the Annex for a detailed overview.

As regards the exploration of coal, our model includes in total 13 major coal mining projects with, in the Extractive scenario, a maximum total estimated annual production of 113 million ton by 2030. In the more moderate Reference scenario we consider 8 mining projects, which together account for 62 million ton per year by 2030. We refer to Table A.3 in the Annex for details. For each mining project we define it's expected first year of production, the expansion of capacity over time, and the destination of its production (export versus electricity production).

As regards Natural Gas production, we of course start by modeling the existing natural gas exploration project by the South African company Sasol in the Pande & Temane gasfields. As noted before, the vast majority of natural gas produced from these fields is exported to South Africa through a 865 km pipeline. In addition, following the recent gas discoveries in the Rovuma Basin, we include the future construction of 12 so-called LNG trains, of which 4 are included in the Reference scenario. Total gas production in the Reference scenario is then anticipated to reach over 1.200 million GJ per year as from 2018. In the Extractive scenario gas production could reach over 3.000 million GJ per year from 2023 onwards. A detailed list is provided in Table A.4 in the Annex.

Finally, on the demand side we model the evolution of several energy-intensive megaprojects, including five heavy sands mining projects and the MOZAL aluminum smelter. In the Reference scenario we assume that heavy sands mining only grows marginally from current levels to reach 1.2 million ton per year, with production confined to the existing Moma-Kenmare project. In the Extractive Scenario we include four new mining projects, with a total production level of 9.5 million ton by 2030. A detailed list is provided in Table A.5 in the Annex. As regards the aluminum company MOZAL, we assume a constant physical production of 547 thousand tons per year in the Reference scenario, and an expansion to 728 thousand tons per year as of 2019 (often referred to as MOZAL-III) in the Extractive scenario. In doing so, we implicitly assumed that by 2019, the Center-South "Backbone" transmission line (CESUL) will be accomplished, such that the major power plants from the Zambezi Basin in the North of Mozambique are connected with the dominant economic center of the Maputo area in the South of Mozambique.

Taken together, these assumptions as regards extractive industry evolution in Mozambique, in combination with the previously described future development paths of GDP and population, drive energy production scenarios in our modeling framework. As illustrated in the right-hand side of Figure 6, we expect in the reference scenario that total primary production increases from almost 14 million toe in 2011 to over 90 million toe in 2030. If Mozambique were to follow the extractive scenario development path, primary production could even increase to a level of 180 million toe in 2030. This equals a 6 to 13-fold increase in primary energy production in less than 20 years. Clearly, this means that Mozambique will undergo no less than a revolution at the supply side of its energy sector.

The left-hand side of Figure 6 pictures the evolution of aggregate final energy consumption across the various scenarios. It shows that in the Reference scenario total energy demand is expected to increase to over 11 thousand toe in 2030. This is a 60% increase from the 2011 level of energy demand, and equivalent to an average annual increase of 2.6% as from 2011. If Mozambique were to follow the Reference Low development path, total final energy consumption is expected to reach about 12 thousand toe in 2030, which equals an average annual increase of energy demand of 2.9% as from 2011. In contrast, the lowest level of energy consumption is to be expected if Mozambique were to follow the Extractive Scenario development path – with an estimated total final energy demand of more than 10 thousand toe in 2030, implying a 2.1% average annual increase over the period 2011-2030. The evolution of total final energy demand in the Reference High scenario is very similar to the Extractive scenario, notwithstanding differences in its composition.

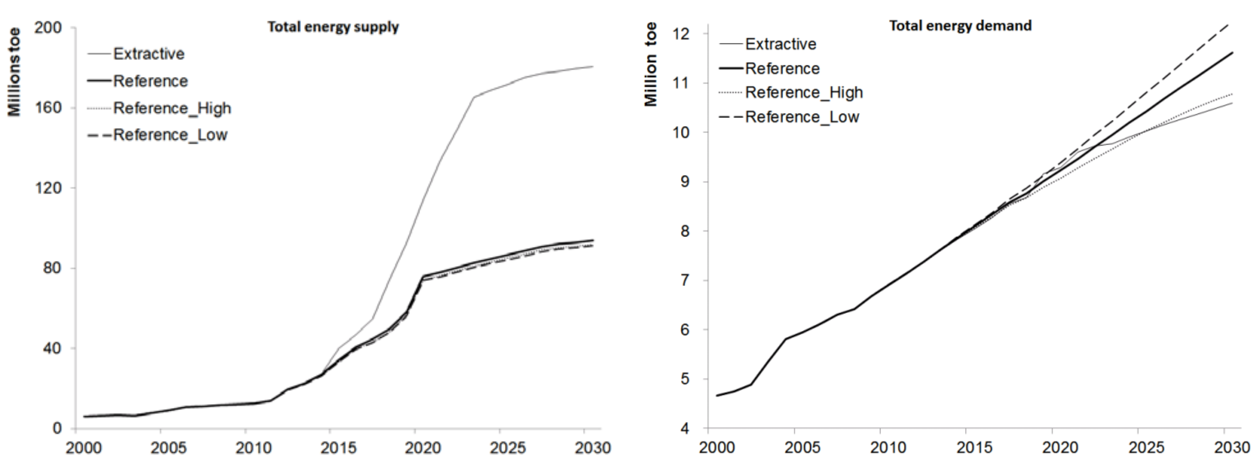

Figure 6. Total energy supply (left) and demand (right) across scenarios.

It may appear at first sight somewhat counterintuitive that in the long run the Reference Low scenario yields a considerably higher level of aggregate energy demand than the Extractive or Reference High scenario – surely the latter scenarios include high economic growth and extractive industry expansion. Underlying data, however, clearly reveal that this result is to be explained entirely by the evolution of energy demand from the household sector. Given the relatively small size of the underdeveloped Mozambican economy, the residential sector is and remains responsible for a large part of total energy consumption in Mozambique (over 90% in 2000 and 50-60% in 2030). Hence, the diverging energy demand patterns in the right-hand side of Figure 6 are mainly caused by a straightforward scale effect: over time the number of households becomes much smaller in the Extractive and Reference High scenario than in the Reference Low scenario. This feature of our model of course follows from our assumption that population growth is inversely related to GDP growth (see section 3.2). Consequently, it is in the high economic growth scenarios that the weight of the dominant households sector in driving total energy demand decreases most.

4. Conclusions and policy implications

In this paper we have presented MOZLEAP, the first comprehensive long-run scenario model of the emerging energy sector of Mozambique. The analysis made use of the integrated modeling tool LEAP, to track energy consumption, production and resource extraction in all sectors of the Mozambican economy. It was our aim to introduce the model, and show its potential as a tool for energy planning and forecasting in the context of the emerging energy sector in Mozambique. Because of space constraints, we will present a more detailed energy outlook for Mozambique, based on our model, in a separate publication. In this paper, we have described how the calibration of our model is based on recently developed local energy statistics and international data for the recent past, as well as on information about the latest developments and future plans as regards the production and transformation of energy in Mozambique. We have shown how future GDP paths were built from a combination of macro trends and bottom-up developments in the extractive industry. Moreover, we presented the key mechanisms that drive our model results, including demographic and urbanization trends and cross-country based GDP elasticities with respect to biomass consumption, sector structure and vehicle ownership. We have developed four scenarios to evaluate the impact of the anticipated surge in natural resources exploration on energy supply and demand in Mozambique.

Our analysis suggests that until 2030, primary energy production is likely to increase at least six-fold, and probably much more. This is roughly 10 times the expected increase in energy demand; most of the increase in energy production is destined for export. As a result, Mozambique is rapidly developing into an important player at international energy markets; it may well become one of the leading global producers of natural gas and coal.

This raises the question whether the current expansionary strategy for the energy sector is also the best strategy from a welfare point of view. Of course, large-scale extraction and export of natural resources contributes to economic growth and generates tax revenues that may help reduce the structural dependence of the Mozambican government on international aid to finance basic services and much needed investments in, among others, health, education and infrastructure. But, this strategy also makes the Mozambican economy vulnerable to volatility of resource prices on international energy markets, and energy sector planning highly dependent on foreign demand. For example, international coal prices have fallen dramatically over the last years, under influence of decreasing (US) demand, which in turn is (partly) driven by the shale gas revolution. Mozambique has good quality coking coal reserves that command a higher price than the steam coal prevalent in neighbouring countries (IEA 2014). Nevertheless, the major coal company operating in Mozambique (Vale) announced recently that is willing to sell at least a quarter of the Tete coal mine and half of its 70% share of the Moatize mine because of the huge losses it faces at today's low coal prices. In addition, the existing infrastructure to export coal has reached its limits; sufficient economies of scale and further export growth hinges crucially on the development of a new railway line and deepwater port (IEA 2014). As regards future electricity generation projects, these heavily depend on the willingness of the South African power utility ESKOM to reach long term agreements with Mozambique to meet its own future demand. Also, one may question the planned expansion of thermal electricity generation capacity on the basis of coal and natural gas from an environmental perspective, if the country's hydro capacity is more than enough to meet domestic demand for electricity in the long run.

In short, a major challenge for future energy policy in Mozambique is to strike a balance in meeting domestic and international demand for energy, such that energy production benefits the welfare of the Mozambican population and economy. By creating appropriate institutional frameworks and economic incentives, the Mozambican government can critically contribute to make exploration of its natural resource wealth beneficial to the entire economy and population. Of course, this is much more easily said than done, because the government in Mozambique is not a strong institutional player that can effectively manage and enforce change for the better (Mulder and Tembe, 2008). In contrast, the country is recently facing increasing local institutional and political instability, which even recently led to attacks by armed insurgents on newly developed mining and transport infrastructures. This underlines the importance to make sure that the entire population – across the country and across income levels – will share in the expected (windfall) gains from the large-scale natural resource exploration. Moreover, it emphasizes the need to invest in improving the quality of governance in Mozambique, in the energy sector and beyond.

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ANNEX

*Table A.1 Estimation results for coefficients MOZLEAP model**

	Sector shares				Biomass elasticity	Vehicle ownership
	θ SRV	θ MAN	θ AGR	θ GOV	γ	Ψ
Constant	46.554	-22.577	37.843	10.009	1.989	-42.752
Coefficient	0.834	4.861	-2.935	0.822	0.239	8.659
R^2	0.10	0.51	0.40	0.56	0.40	0.27
# observations	39	39	39	39	74	86

** Dep. variable = coefficient * ln(GDP per capita) + constant.*

Table A.2. Hydro Production Assumptions

#	Plant/Project Name	Full Capacity[1] (MW)	1st year Planned	Scenario [2]	Location (province)	Merit order	Process Efficiency (%)
I. Hydro		7579					
1	H. Cahora Bassa (HCB)	2075	2011	Reference	Tete	1	100
2	Majawa e Berua	100	2014	Extractive	Zambezia	1	100
3	Chicamba	19	2011	Reference	Manica	1	100
4	Mavúzi	37	2011	Reference	Manica	1	100
5	Various EdM[3]	16	2011	Reference	Niassa, Maputo	1	100
6	Pavue	300	2017	Extractive	Manica, Sofala	2	100
7	Cintura e Miracuene	100	2018	Extractive	Sofala	2	100
8	Massingir	27	2018	Extractive	Gaza	2	100
9	Projecto H. de Chemba	600	2020	Extractive	Tete, Sofala	2	100
10	Alto Malema	80	2020	Extractive	Zambezia	2	100
11	Cahora Bassa Norte (CBN)	1245	2021	Extractive	Tete	3	100
12	Lupata	600	2021	Extractive	Tete	3	100
13	Boroma	200	2022	Extractive	Tete	3	100
14	Mpanda Nkuwa (MNK)	2000	2022	Reference	Tete	3	100
15	Lurio	180	2022	Extractive	Cabo Delgado	4	100
II. Solar PV		1.2					
1	Solar PV	1.2	2011	Reference	All	1	100
III. Thermal_Diesel		101					
1	EdM	91	2011	Reference	Maputo, Sofala	1	33
2	Moatize Vale	10	2011	Reference	Tete	1	45
IV. Import_MOTRACO		900					
1	Imports from ESKOM	900	2000	Reference	Maputo	1	n.a.
V. Thermal_Gas		1114					
1	Temane & Mambone	6	2011	Reference	Inhambane	1	35
2	Aggreko	107	2012	Reference	Maputo	1	40
3	Gigawatt	109	2013	Reference	Maputo	1	40
4	CTRG (EDM/SASOL)	175	2014	Reference	Maputo	1	48
5	Kuvaninga	40	2015	Reference	Gaza	1	35
6	Chockwe (EDP)	32	2016	Extractive	Gaza	2	35
7	Electrotec	100	2017	Extractive	Maputo	2	48
8	C. Termica Maputo (CTM)	100	2018	Reference	Maputo	2	47
9	ENGECO	50	2018	Extractive	Gaza	2	35
10	Temane Sasol	300	2018	Extractive	Inhambane	2	40
11	Projecto ENI	75	2019	Extractive	Unknown	2	35
12	Central Buzi Power	20	2020	Extractive	Sofala	2	35
VI. Thermal_Coal		2150					
1	Projecto Elec. de Moatize	300	2016	Reference	Tete	2	37
2	Benga	300	2017	Reference	Tete	2	35
3	Chirondzi	350	2017	Extractive	Tete	2	35
4	Jindal	300	2018	Extractive	Tete	2	37
5	Kingho Investiment Co	600	2018	Extractive	Tete	2	35
6	Ncondezi	300	2018	Extractive	Tete	2	35

Source: Compiled based on reports from EdM (2012) and information from the Ministério de Energia (2013)

[1] Full capacity may be realized in phases; this is taken into account in the model.
[2] Extractive scenario includes all plants, while the Reference considers only those labelled as Reference
[3] Various EdM Hydro = Corumane + Linchinga & Cuamba + Pequenos Libombos

Table A.3. Mineral Coal Production Assumptions [Mtpy]

#	Project Name	2010	2015		2020		2025		2030	
			REF	EXT	REF	EXT	REF	EXT	REF	EXT
1	Moatize Vale	0	10	10	10	10	10	10	10	10
2	Moatize Phase 2 Vale	0	7	7	10	10	10	10	10	10
3	Benga Rio Tinto Tata Steel	0	3	3	8	8	8	8	8	8
4	Zambeze Rio Tinto	0	2	2	8	8	8	8	8	8
5	Moatize Jindal	0	0	0	8	8	8	8	8	8
6	Reveboe Talbot Nippon Steel	0	5	5	5	5	5	5	5	5
7	Moatize B Hill Resources	0	3	3	3	3	3	3	3	3
8	Ncondezi	0	2	2	10	10	10	10	10	10
9	Mucanha Vuzy Vale	0	0	0	0	11	0	11	0	11
10	Tete East Rio Tinto	0	0	0	0	0	0	10	0	10
11	Moatize ETA Star India	0	0	0	0	0	0	10	0	10
12	Moatize Coal India	0	0	10	0	10	0	10	0	10
13	Other 90 Licensed Projects	0	0	0	0	3	0	8	0	10
	Total Production	0	31	41	62	86	62	111	62	113

Source: Local data; press releases; KPMG, 2013; Callaghan, 2013; GBR, 2013; NWR, 2013; personal communications (see section 2).

Table A.4. Natural Gas Production Assumptions (10^6 GJ)

Project Name	2010	2015		2020		2025		2030	
		REF	EXTR	REF	EXTR	REF	EXTR	REF	EXTR
Sasol Pande/Temane	124	183	183	183	183	193	193	202	202
LNG Projects	0	0	0	1072	1608	1072	3216	1072	3216
Anadarko Train 1	0	0	0	268	268	268	268	268	268
Anadarko Train 2	0	0	0	268	268	268	268	268	268
Anadarko Train 3	0	0	0	0	268	0	268	0	268
Anadarko Train 4	0	0	0	0	268	0	268	0	268
Anadarko Train 5	0	0	0	0	0	0	268	0	268
Anadarko Train 6	0	0	0	0	0	268	268	268	268
ENI Train 1	0	0	0	268	268	268	268	268	268
ENI Train 2	0	0	0	268	268	0	268	0	268
ENI Train 3	0	0	0	0	0	0	268	0	268
ENI Train 4	0	0	0	0	0	0	268	0	268
ENI Train 5	0	0	0	0	0	0	268	0	268
ENI Train 6	0	0	0	0	0	0	268	0	268
Total LNG	0	0	0	1072	1608	1072	3216	1072	3216
TOTAL	124	183	183	1255	1791	1265	3409	1274	3418

Source: Local data; press releases; ICF, 2012; World Bank, 2014; personal communications (see section 2).

Table A.5. Heavy Sands Minerals. Capacity Production Assumptions (Mtpy)

#	Project Name	2010	2015		2020		2025		2030	
			REF	EXTR	REF	EXTR	REF	EXTR	REF	EXTR
1	Moma Kenmare	0.8	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
2	Corridor Sands BHP Billiton	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	5.0
3	Mutamba Rio Tinto	0.0	0.0	0.0	0.0	1.2	0.0	1.2	0.0	1.2
4	Moebase N. Pathfinder	0.0	0.0	0.0	0.0	1.3	0.0	1.3	0.0	1.3
5	Sangage Africa Great Wall	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.8
	Total Heavy Sands	0.8	1.2	1.2	1.2	3.7	1.2	9.5	1.2	9.5

Source: Local data, press releases; Callaghan, 2011; personal communications (see section 2).

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