Technical-economic evaluation of solar photovoltaic development in Botswana

Marco Stefanoni

ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Gaborone, 6th July 2017

Introduction

- ENEA provide to Italian Ministry of the Environment, Land and Sea (IMELS) technical support in cooperation international activities of climate changes mitigation and adaptation
- In the framework of the Memorandum of Understanding Italy-Botswana IMELS commissioned to ENEA a first study on solar photovoltaic development in Botswana
- The study identifies the technical-economical potential of solar photovoltaic considering the available database, the national context, the best technologies available on the market, utilizing a ENEA simulation model.

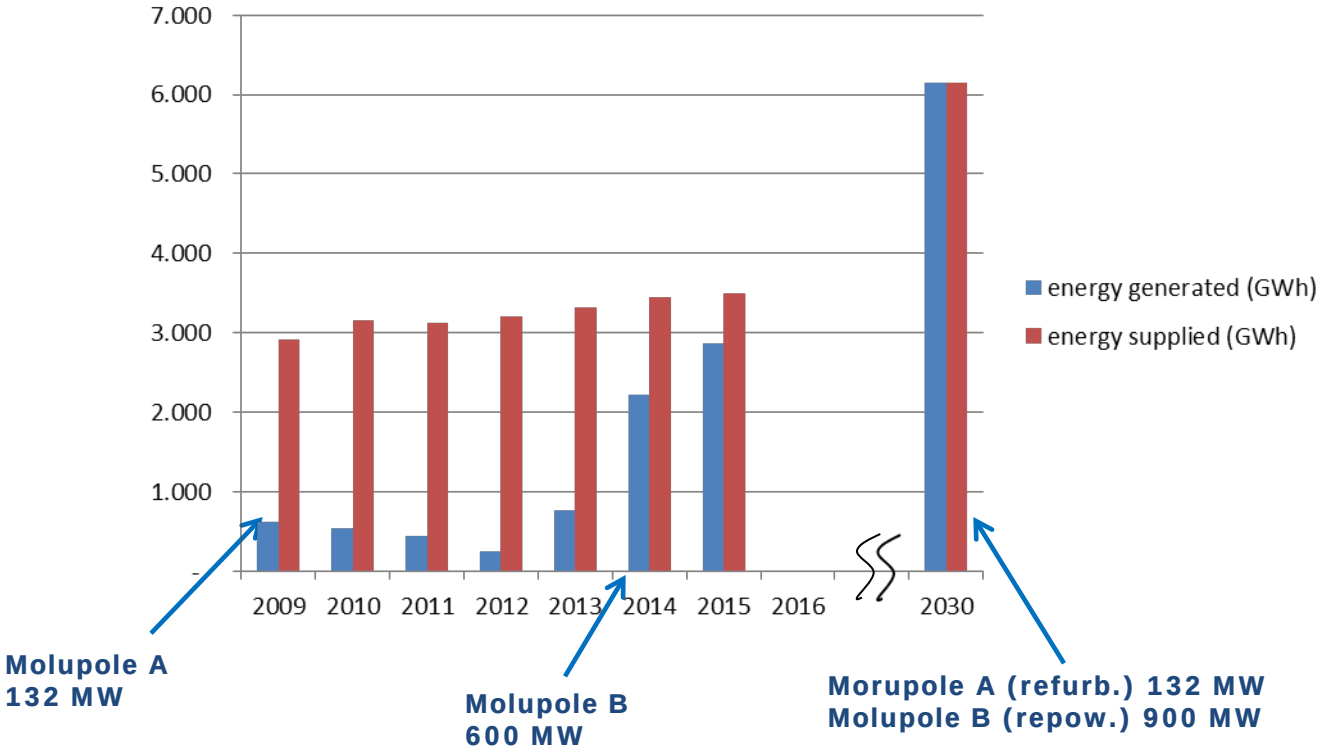
Electric system

- Access to electricity: 53%
- Production, transmission and distribution: Botswana Power Corporation (BPC) - government owned company
- Operating power station:
  - Morulupe B – 600 MW -coal fired
- Power stations under construction
  - Morulupe B (repow.) - 300 MW -coal fired
  - Morulupe A (refurb.) – 132 MW-coal fired
- Electricity mean cost: 65 €/MWh (with subsidies)
- Electricity mean cost: 115 €/MWh (without subsidies)

- Off-grid electricity cost (diesel gen.): 195€/MWh (fuel tax-free)

Electric system

Electrical energy generated and supplied - years 2009-2030



GHG emission

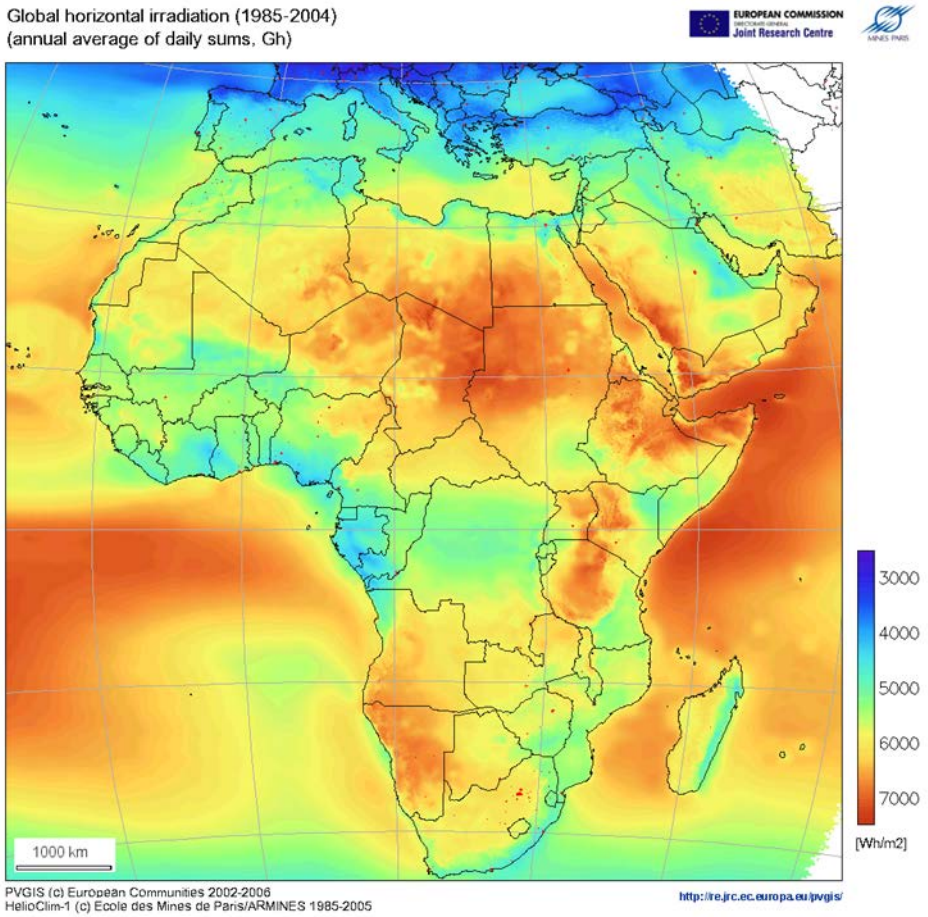
- GHG emission 2010: 8.3 $MtCO_2$
- GHG emission increase
  coal fired power plant (2010-2030): 5.3 $MtCO_2$
- National GHG reduction pledge (COP21): -15%

Solar photovoltaic potential

Available solar database:

- PVGIS
- Nasa Surface Meteorology and Solar Energy Data Subset

Only satellite database, without correlation with ground meteorological station



Solar photovoltaic input data

Site statistical weather data – Gaborone lat 24°29' Sud / 24° 54' Est

	Jan	Febr	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	annual total
H bh (direct horizontal radiation) (kWh/m2 day)	4.66	4.23	4.02	3.74	3.73	3.45	3.77	4.16	4.57	4.55	4.67	4.65	4.2
Hdh (diffuse horizontal radiation) (kWh/m2 day)	2.35	2.18	1.79	1.33	0.84	0.72	0.69	0.93	1.35	1.92	2.27	2.42	1.6
Htot (total horizontal radiation)(kWh/m2 day)	7.01	6.41	5.81	5.07	4.57	4.17	4.46	5.09	5.92	6.47	6.94	7.07	5.70
albedo of surface around the plant	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
max temperature - monthly average (°C)	28.9	29.8	29	26.9	23.5	19.3	20.1	23.8	28.1	29.5	29.6	28.7	26.4

Source: NASA database

Solar photovoltaic energy productivity

Photovoltaic electric production calculation - monthly average

Module peak nominal power (kW)	**1**
Modules slope (°)	**27**
Modules surface(m2)	6

month	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Total radiation on sloping surface (kWh/m2/day)	6.22	6.06	6.03	5.99	6.,22	6.07	6.,35	6.46	6.,51	6.29	6.,25	6.18	6.,22
Module average temperature (°C)	51.9	52.8	52	49.9	46.5	42.,3	43.1	46.,8	51.1	52.5	52.6	51.7	49.4
Efficiency corrected with temperature	13.5%	13.5%	13.5%	13.7%	13.9%	14.2%	14.1%	13.9%	13.6%	13.5%	13.5%	13.5%	13.7%
Specific net specific energy supplied (kWh/day/m2)	0.72	0.70	0.70	0.70	0.74	0.74	0.77	0.77	0.76	0.73	0.72	0.72	0.73
Supplied energy from PV (kWh/day)	4.67	4.53	4.52	4.54	4.80	4.78	4.98	4.97	4.91	4.71	4.67	4.64	**1702**

The energy produced by a PV system in Botswana is exceptionally stable during the year

Solar photovoltaic energy productivity

Photovoltaic electric production calculation in different sites

Site	District	Latitude	Slope	Capacity factor (specific energy production of 1 KW_p) (KWh/year)
Tsabong	Kgalagali	26° 01 S	27°	1719
Gaborone	South-East	24° 29' S	27°	1702
Orapa	Central	21° 18' S	24°	1701
Maun	Ngamiland	20° 00' S	23°	1725

In the main sites of higher energy demand, the PV capacity factor is about 1700 kWh/kW_p

Solar photovoltaic potential

The solar photovoltaic resource is almost unlimited
An area equal to a square of only 7 km of side could supply the entire Africa electricity demand

The factors limiting the use of photovoltaic potential are:

- economic (competition with fossil sources)
- technic (variability, need of energy storage)

A technical-economic evaluation for Botswana has been implemented considering following sectors:

1. Utility-scale installation (50-500 MW)
2. Residential and commercial installations (2-200 kW)
3. Off-grid installations for remote mining facilities, mini-grid for villages, agriculture pumping systems (2-2000 kW)
4. Small, diffused, domestic or portable electrification systems (5-500 W)

Solar photovoltaic economic evaluation

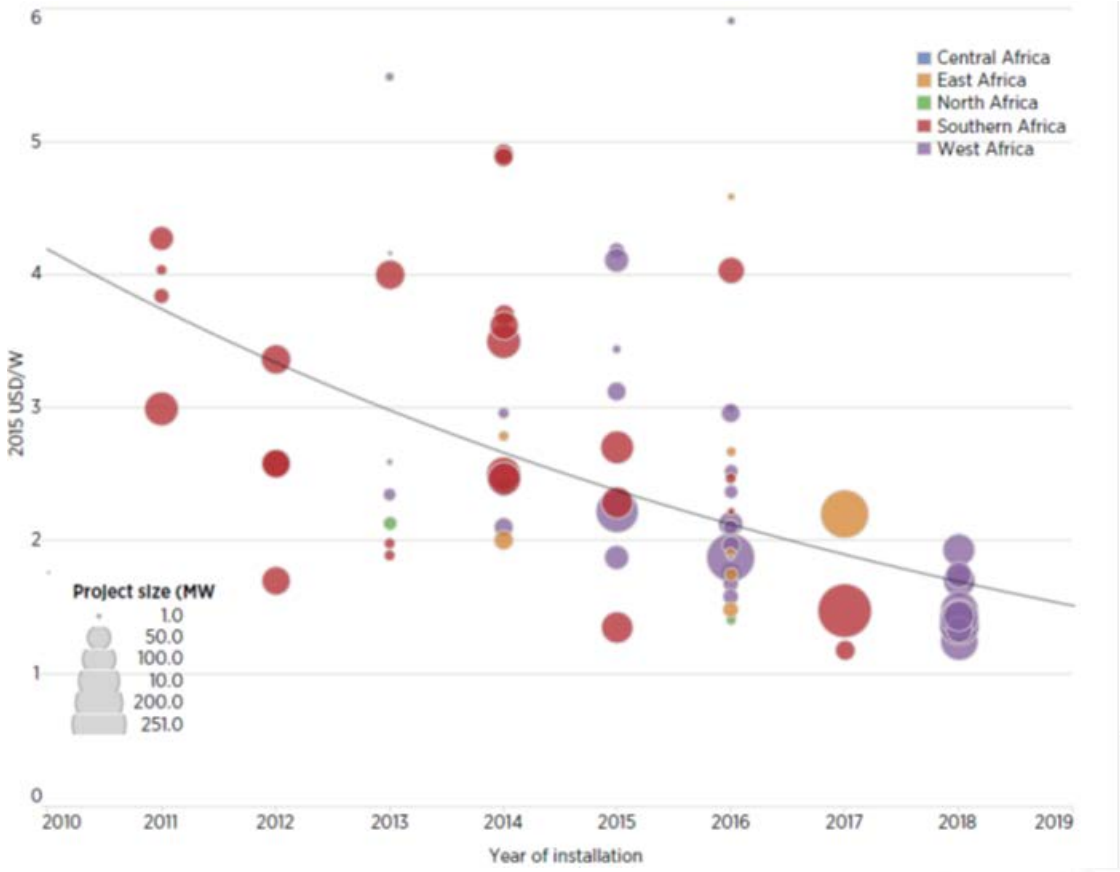
Levelized Cost of Energy (LCOE) is evaluated, utilizing a ENEA technical-economic simulation model and taking into account following parameters:

- investment costs
- operating and maintenance costs, including insurance
- extraordinary maintenance costs, scheduled every 10 years
- end-of-life decommissioning costs
- revenue from the sale of energy at a fixed cost, considering the yearly decrease of power of polycrystalline modules
- investment interest rate
- lifetime of the plant

Economic evaluation: investment cost

The African market is characterized by a considerable variability in PV installation costs

Investment cost of utility-scale PV plant in Africa – years 2010-2019



Source: IRENA

Economic evaluation: reference data - example

Economic parameters of utility scale plant – reference case

Disaggregated specific plant cost (€/kWp)

Polycrystalline photovoltaic modules	450	*44%*
Ground supports	150	*15%*
Inverters	80	*8%*
Cables, switchboards , transformers	100	*10%*
Installation and civil works	85,8	*8%*
Design, supervision, commissioning	52	*5%*
Transport	100	*10%*
Total	**1018**	*100%*

Economic parameters of PV plant

Investment return rate (IRR)	5%
Plant lifetime (years)	25
Guaranteed power at the end of lifetime	80%
Decreasing power per year	0,83%
Capacity factor (kWh/kWp)	1700

Operating & maintenance cost

Ordinary maintenance (€/kWp y)	10
All risk insurance (civil liability, theft, atmospheric events) (€/kWp y)	10
total	20

Extraordinary maintenance at 10 years (€/kWp)	106

Cost dismantling modules at the end of life (€/kWp)	7

Economic evaluation: results

	LCOE (€/MWh)	
Utility scale plant - reference	57	competitive with new coal-fired power station - not competitive with coal marginal cost
utility scale plant - min	42	competitive with new coal-fired power station - not competitive with coal marginal cost
utility scale plant - max	88	competitive with new coal-fired power station - not competitive with coal marginal cost
Residential plant	109	not competitive with the current energy subsidized price
Commercial plant	98	not competitive with the current energy subsidized price
Off-grid plant- hybrid diesel	98	competitive with diesel generation
Off-grid plant-irrigation pump	139	competitive with diesel generation
Off-grid plant-battery storage	408	not competitive with diesel generation
Small domestic appliances	-	competitive with fossil portable lighting system (paraffin, kerosene lamps)

Solar photovoltaic: technical constraints

The character interruptible and not dispatchable of solar PV systems imposes the following technical limitations:

- Off-grid hybrid systems PV-diesel without storage: maximum photovoltaic energy production rate **30%**
- Utility scale PV system: maximum power rate related to the total capacity (without any intervention on the grid) **30%**
- Utility scale PV system: maximum power rate related to the total capacity (with smart grid and small storage) **100%**

Solar photovoltaic: evaluation of possible actions

	Action	PV power (MW_p)	GHG emissions avoided ($MtCO_2$)	Investment (M€)	measures
1	Off-grid plants without storage (PV-diesel hybrid, agriculture pumping systems)	39	0,046	70	international funding (loan), ESCO
2	Off-grid plants with daily storage	233	0,278	583	international funding (grant, loan), ESCO, government subsidies
3	On-grid plants (utility scale + diffuse) without storage	350	0,565	390	feed in tariff, PPA, ESCO, international funding
4	On-grid plants (utility scale + diffuse) with storage	1000	1,615	1085	feed in tariff, PPA, ESCO, carbon tax, international funding
5	PV Lighting rural electrification	2	0,002	8	international funding (grant, loan), private fundraising, ESCO

Conclusion

- Solar photovoltaic in Botswana is, in principle, unlimited, clean, sustainable and, for most cases, a cost-effective source of energy
- PV-diesel hybrid systems, solar pumping and micro PV home lighting systems are already cost-effective in current legislative and market conditions
- Renewable energy support measures similar to those currently available for coal-fired power plants can also open up the market for utility scale and on-grid domestic and commercial PV systems
- International funding (grant and loan) and PPAs (Purchase Price Agreements) can accelerate PV penetration in the energy market
- Capacity building actions to the public and private stakeholders are important for a rapid technological transfer
- The contribution of PV source to the compliance to national GHG reduction pledges can be significant

Thanks for your attention

marco.stefanoni@enea.it