22nd February 2018

Renewable Energy in East Africa:

Technical Potential and Policy Challenges

Giacomo Falchetta
FEEM, PhD student and ESP researcher

Co-authors:
Giovanni Occhiali, Manfred Hafner,
Simone Tagliapietra

Outline

1. **East Africa**
   - Overview
   - Energy mix and key issues
   - Electricity access
2. **RE: technical potential**
   - Overview, by country
   - RE resources mapping
3. **RE: deployment challenges**
   - Technological considerations
   - Cost profiles and energy sources rivalry
   - On/off-grid trade-off framework
   - Financial constraints: public and private issues
   - Role of transboundary cooperation
   - RE – natural gas interaction in East Africa
4. **Policy implications**
   - On-grid (urban) and off-grid (rural) policy
   - Conclusion

1. East Africa

1.1

EA, overview

	Burundi	Kenya	Malawi	Mozambique	Rwanda	Tanzania	Uganda	S. Africa
Population (million)	**10.524**	**48.461**	**18.091**	**28.829**	**11.917**	**55.572**	**41.487**	**55.908**
Population growth rate (2015-16)	**+3.1%**	**+2.6%**	**+2.9%**	**+2.9%**	**+2.4%**	**+3.1%**	**+3.3%**	**+1.6%**
Pop. urban share	**12%**	**26%**	**16%**	**33%**	**30%**	**32%**	**16%**	**65%**
Pop. rural share	**88%**	**74%**	**84%**	**67%**	**70%**	**68%**	**84%**	**35%**
PPP GDP (mil. int. 2011 $)	**8,187**	**153,000**	**21,155**	**35,089**	**22,803**	**150,336**	**76,702**	**739,419**
PPP GDP/ capita ($)	**778**	**3,156**	**1,169**	**1,217**	**1,913**	**2,787**	**1,849**	**13,225**
IHDI	**0.276**	**0.391**	**0.328**	**0.280**	**0.339**	**0.396**	**0.341**	**0.435**

World Bank (2017), UN (2017), World Bank (2017)

- 271 million: **3.6%** of world's **total population** (2.9% excluding South Africa)
- Expected to reach **569 million** by 2050 (UN Population Division 2017, medium fertility scenario)
- **1.5%** of global **primary energy consumption** (0.2% excluding South Africa**)**
- 261 TWh **electricity consumption** in 2015 (**310 TWh** in Italy, 1/5th population)

1.2 EA, energy situation

Figure 1: Primary energy mix in EA countries

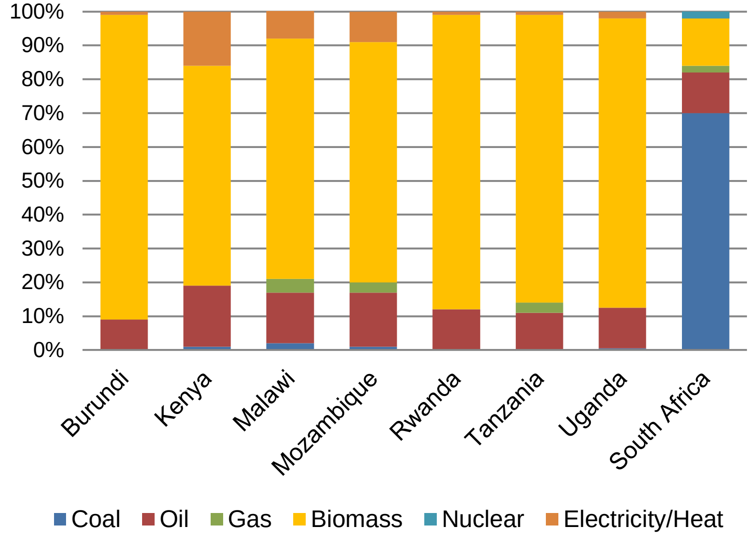
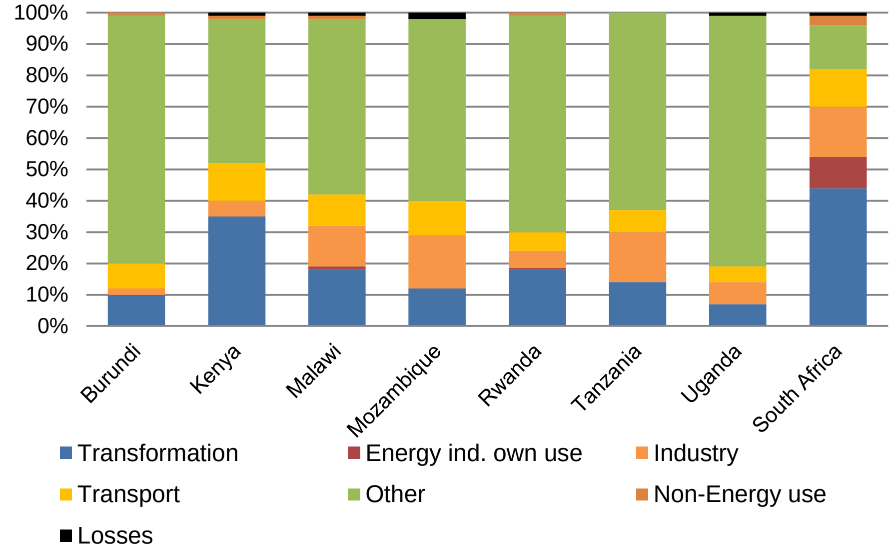


Figure 2: Energy demand by sector in EA countries

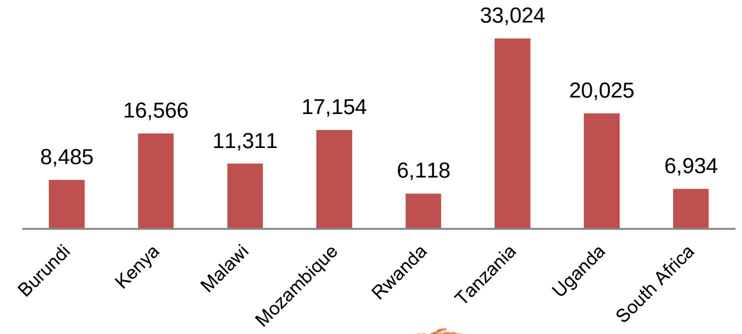


- **Solid biomass:** dominant in primary energy mixes (except SA) → **health and socio-economic externalities, scarce productive use.**

- **20%** mean **share of power transform. on TPES**. Negligible share of elecricity in the mix.

- Vast majority of demand from residential level **(65% average excluding SA)**, with industry and transport sectors lagging behind.

Figure 3: Number of premature deaths due to indoor air pollution from the use of solid fuels in 2016



Data sources: UNDATA (2015) and IHME (2017)

1.3.1. EA, electricity access (i)

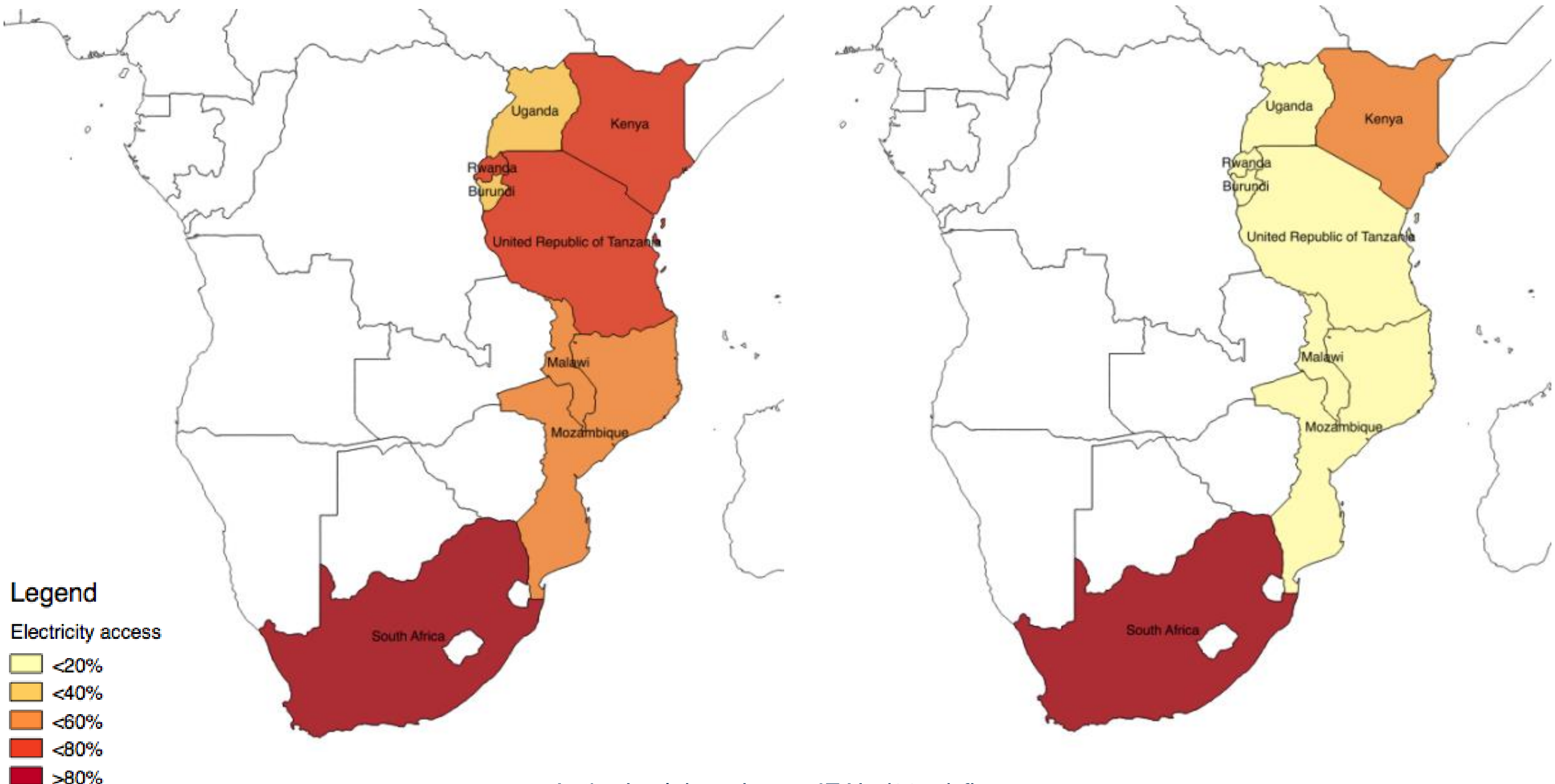
Country	Burundi	Kenya	Malawi	Mozambique	Rwanda	Tanzania	Uganda	S. Africa
Installed capacity (MW)	**68**	**2,269**	**353**	**2,556**	**211**	**1,187**	**922**	**46,963**
Electrification rate (2017)	**10%**	**65%**	**11%**	**29%**	**30%**	**33%**	**19%**	**86%**
Urban	***35%***	***78%***	***49%***	***57%***	***72%***	***65%***	***23%***	***87%***
Rural	***6%***	***60%***	***3%***	***15%***	***12%***	***17%***	***19%***	***83%***
Target (Year)	**25% (2025)**	**100% (2020)**	**30% (2020)**	**100% (2025)**	**70% (2018)**	**50% (2025)**	**26% (2022)**	**100% (2020)**

IEA (2017), World Bank (2017), CIA (2015), various governmental energy strategies and visions

- Share of EA **population without access: 90% in 2000, 61% in 2016** (IEA 2017), but **absolute number** **increased by 8 million units (same interval).**
- Persistent **urban-rural imbalance**
- Limited **grid** extent and intercconections.
- Even in urban areas, **access not guaranteed** and productive uses undermined by **outages.**
- Ambitious targets, still unclear how to reach them.

1.3.2. EA, electricity access (ii)

Figure 4: Electricity access rates in urban (left) and rural (right) East Africa



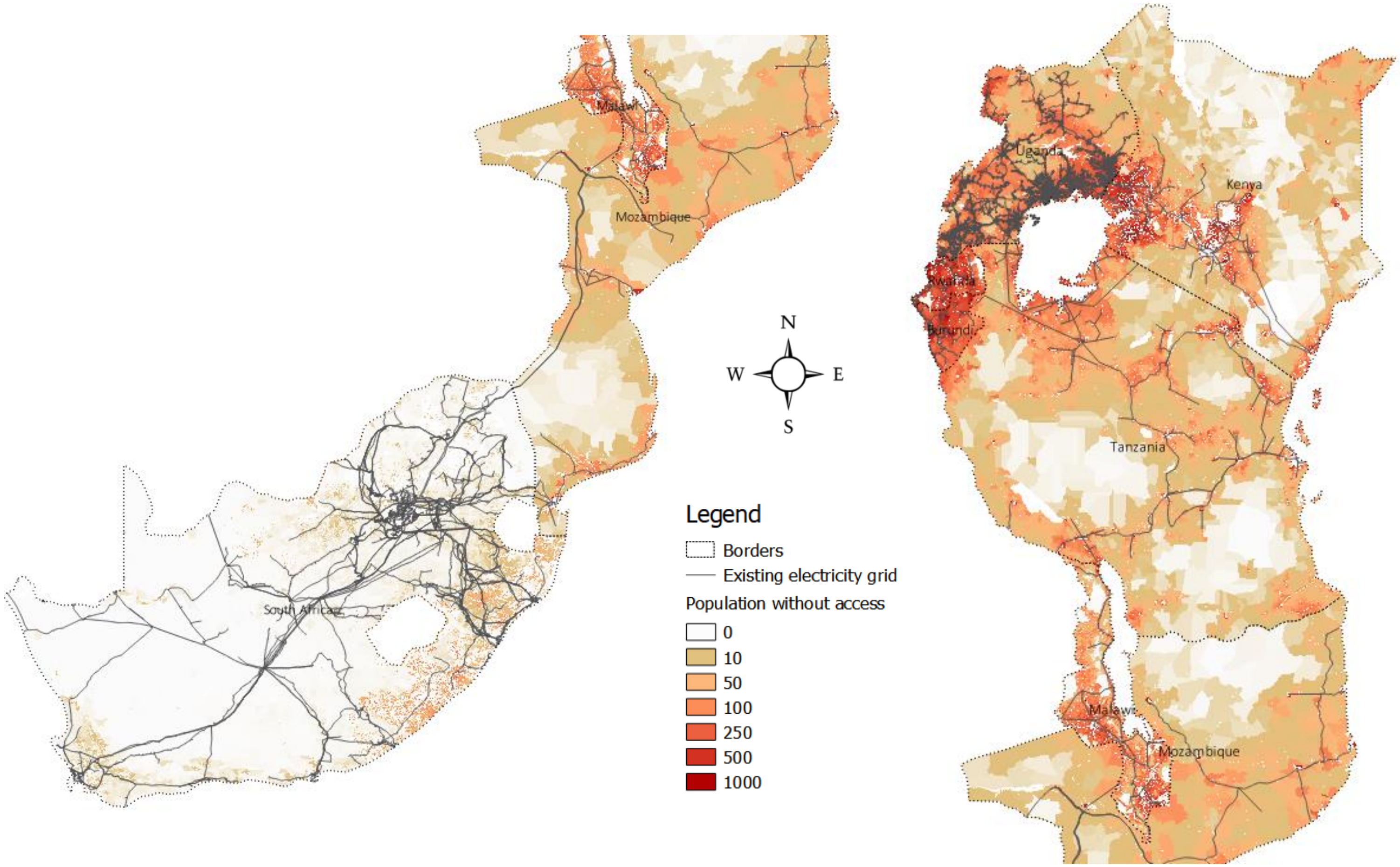
Author's elaboration on IEA's (2017) figures

VIIRS DNB night lights, 2015 composite

Elaboration on NOAA (2017)

1.3.3. GIS: Spatial determination of population without access against grid

Figure 5: Existing electricity transmission and distribution grid in EA and population without access



Author's elaboration on Ardene-World Bank (2017), NOAA (2017), SEDAC (2016)

2. RE in EA:
Technical potential

2.1. Renewable energy in EA: technical potential

Energy endowments/potential of EA countries, by source

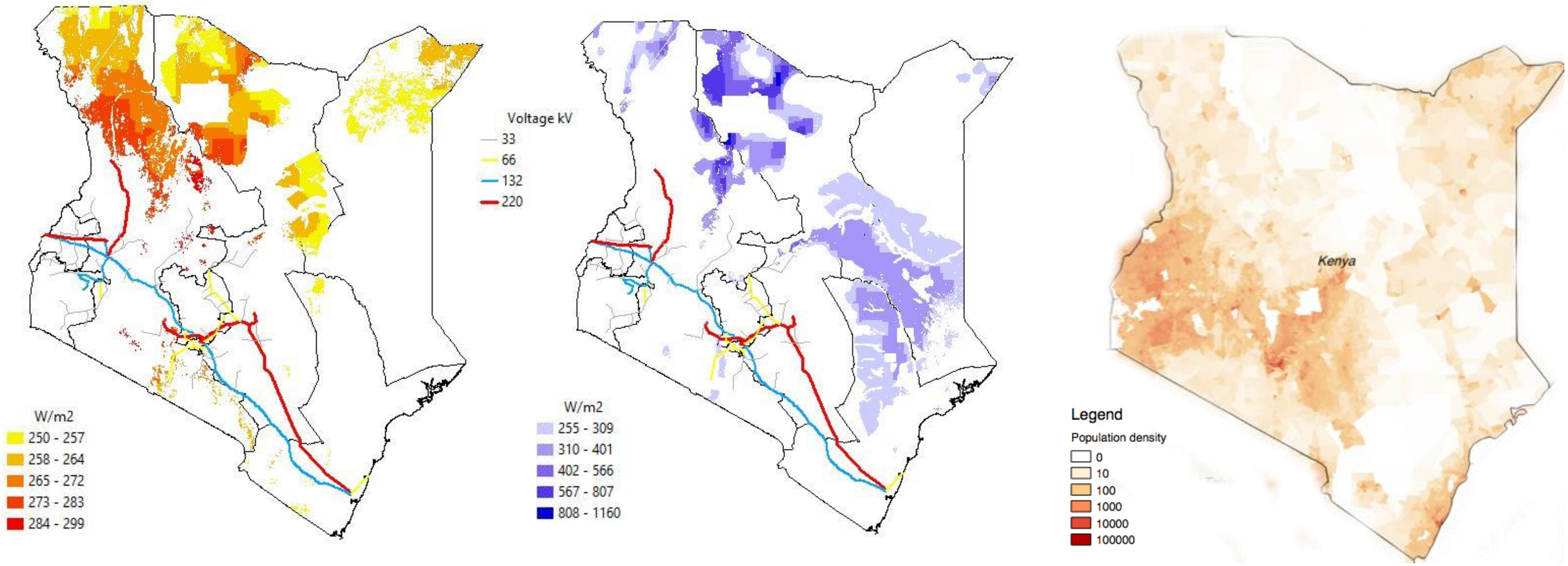
Country/Source	PV	CSP	Wind	Small hydro	Large hydro	Geoth	Oil	N. gas	Coal
Burundi	Green	Red	Yellow	Green	Red	Yellow	Red	Red	Red
Kenya	Green	Green	Green	Green	Green	Green	Yellow	Red	Red
Malawi	Green	Red	Green	Green	Green	Green	Red	Red	Yellow
Mozambique	Green	Green	Green	Green	Green	Green	Red	Green	Yellow
Rwanda	Green	Green	Red	Green	Red	Green	Red	Yellow	Red
Tanzania	Green	Green	Green	Green	Green	Green	Red	Green	Yellow
Uganda	Green	Red	Red	Green	Green	Green	Green	Red	Red
South Africa	Green	Green	Green	Red	Red	Red	Yellow	Yellow	Green

Red: unavailable/unviable; yellow: partially viable; green: abundant and viable

- **Energy resources endowment:** heterogeneous
- Renewables more **evenly distributed** than fossil fuels.
- Overall **abundance of untapped potential** → technically sufficient to satisfy growing regional demand and promote exports.

2.2. Example of resources mapping: Kenya

Figure 6: Kenya electricity grid over most relevant areas for solar and wind potential; pop. density



Author's elaboration on Ardene-World Bank (2017), IRENA – MapRE (2017)

- GIS plots: **areas with technically feasible solar and wind potential** vs. **grid** and its **bearing** provide interesting insights on the **economics of RE.**
- Especially overlaid to **population density** data.

3. RE in EA:
Deployment challenges

3. RE deployment: challenges

- Widespread **abundance of untapped resources,** heterogeneous mixes
- Common challenges and objectives across countries in the region.

→ Which are the main issues for RE deployment and how can governments intervene?

Technology	Economics	Transboundary cooperation	Main policy challenges
Path dependency of infrastructure and energy mix	On-grid/off-grid efficiency trade-off	Infrastructure development	Investment attractiveness and the role of IPPs
Off-grid technology and storage	Subsidies, public debt, and willingness-to-pay for electrification	Energy resources sharing	Subsidies, FiTs, and policy instruments
Threats posed by large-scale projects	Uncertainty over future costs and developments	Cooperation spillovers	Payment schemes and behavioural considerations

3.

RE deployment: challenges

- Widespread **abundance of untapped resources,** heterogeneous mixes
- Common challenges and objectives across countries in the region.

→ Which are the main issues for RE deployment and how can governments intervene?

Technology	Economics	Transboundary cooperation	Main policy challenges
Path dependency of infrastructure and energy mix	On-grid/off-grid efficiency trade-off	Infrastructure development	Investment attractiveness and the role of IPPs
Off-grid technology and storage	Subsidies, public debt, and willingness-to-pay for electrification	Energy resources sharing	Subsidies, FiTs, and policy instruments
Threats posed by large-scale projects	Uncertainty over future costs and developments	Cooperation spillovers	Payment schemes and behavioural considerations

3.1 Technological considerations

- Fouquet (2017): **Energy systems** subject to **strong and long-lived path dependence:**
  - → technological, infrastructural, institutional and behavioural lock-ins.

- During industrialisation/development, **large flexibility** → threat of **energy-intensive pathways** take-up**, detrimental to long-run prosperity despite tackling short-run issues.**
- Trade-off **large grid-connected projects** *vis-à-vis* **small and localised ones** in investment decisions. Also consider:
  - **scale and network dynamics**
  - expected **changing costs profiles and technological advances** (not only upfront costs)
  - ways to **complement** limitations of modern renewables.

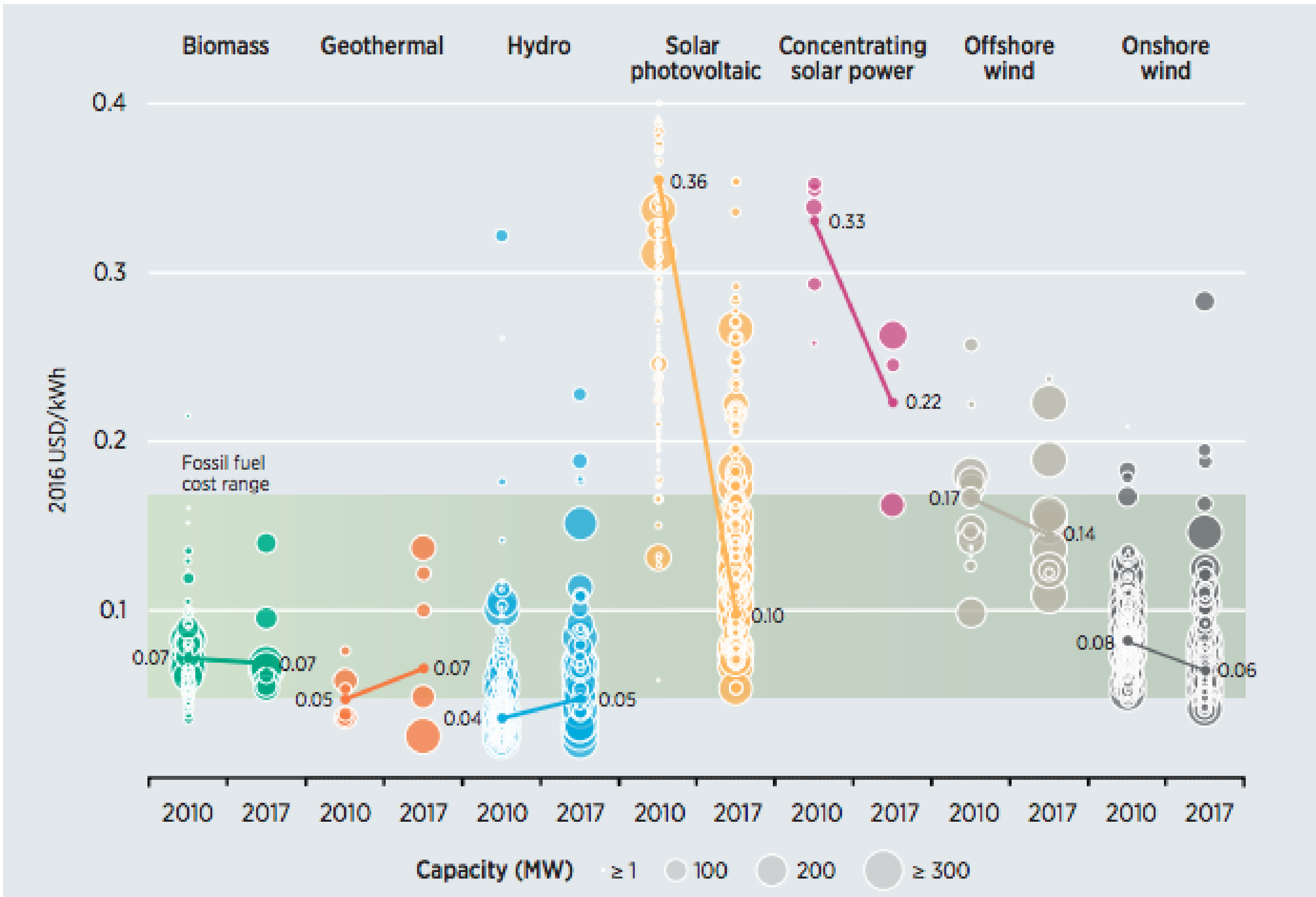
→ **RES: long-term benefits (energy independency) and steep learning curves** (Creutzig et al. 2017).

→ **Spatially optimal locations** to locate large infrastructure projects: not only **expected capacity**, but also **distribution basin.**

3.2 Cost profiles and energy sources rivalry

Levelised cost of electricity (LCOE) allows comparing different technologies on the basis of the minimum unit price a user must pay for each system to break even.

Figure 7: LCOE 2010-2017

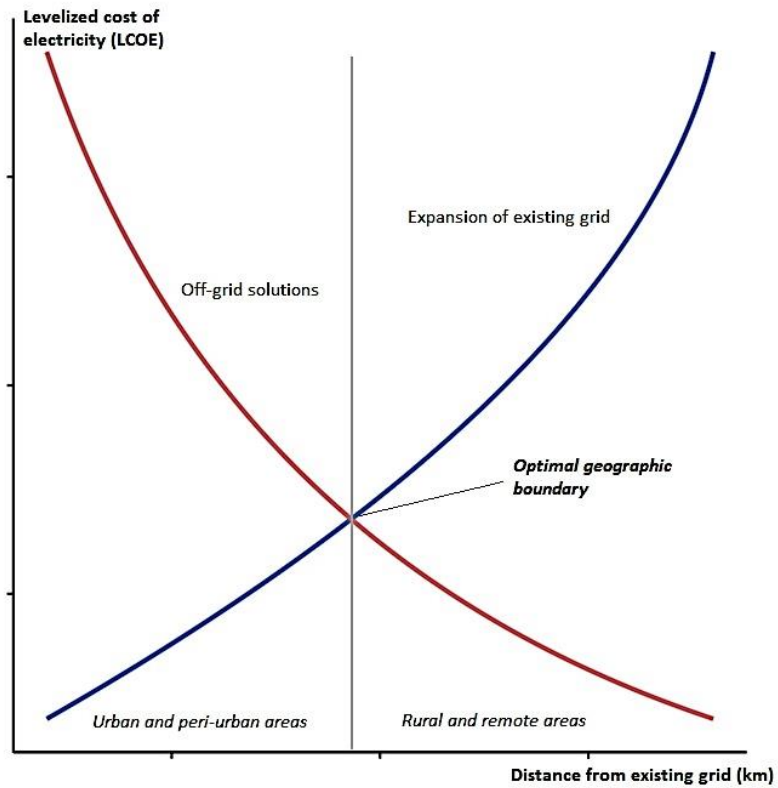


Source: IRENA Renewable Cost Database.
Note: Size of the diameter of the circle represents the size of the project.

Fondazione Eni Enrico Mattei

3.3.1. On/off-grid trade-off framework (i)

Figure 8: On/off-grid economic framework



Author's elaboration

The optimisation problem faced by public decision-makers

○ Off/mini-grid solutions only competitive where distance such that **expanding the grid is inefficient** (beyond optimal geographic boundary).

○ **MC** of grid expansion upward-sloped

→ Hard infrastructure fixed costs imply **progressively fewer consumers reached as system expands in remote areas (population, geography, institutions).**

○ Least-cost mix of centralized and decentralized power depends on:

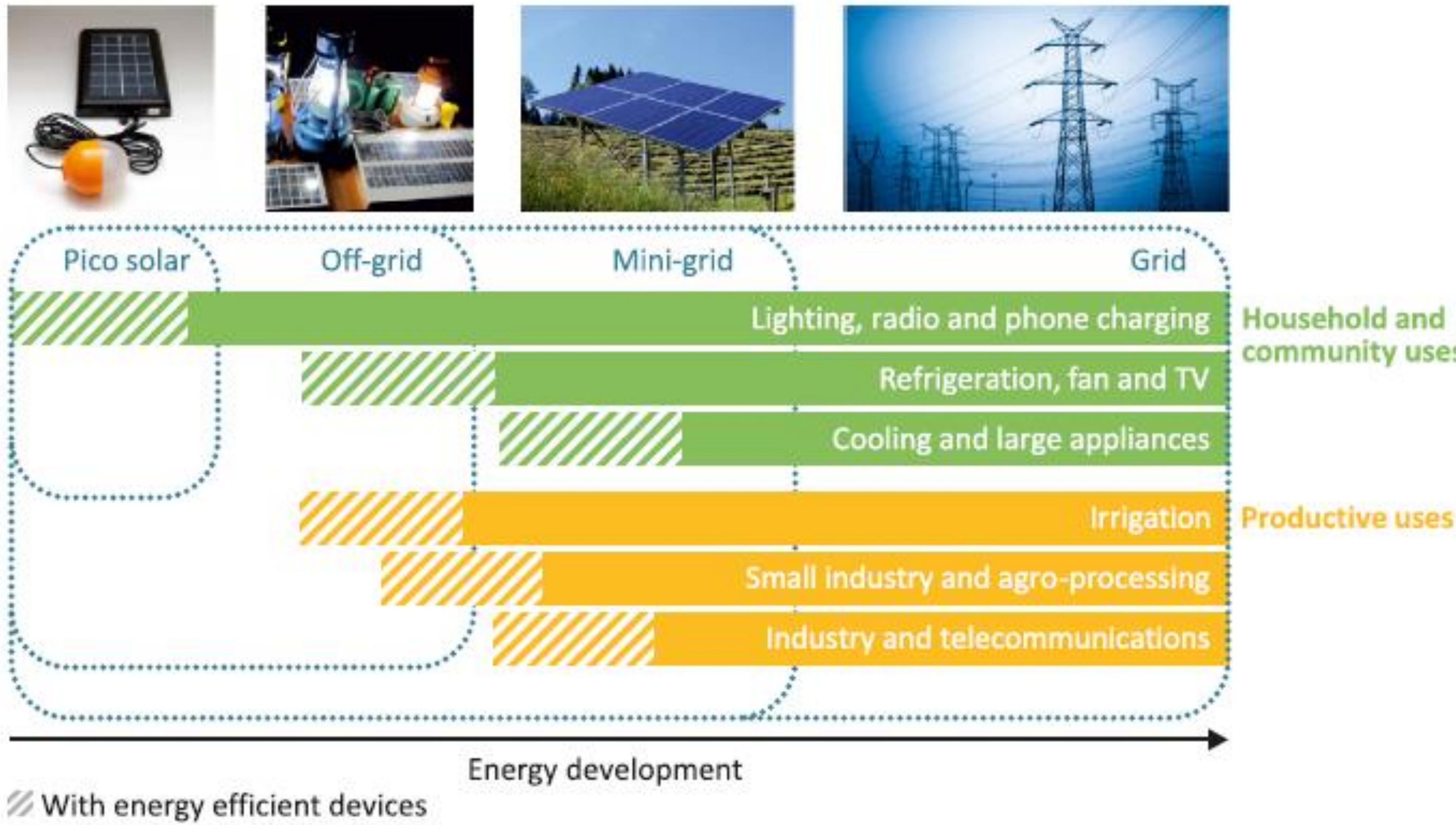
a) **cost of grid expansion (remoteness, geography, population)**;

b) **relative costs of locally available energy sources.**

Fondazione Eni Enrico Mattei

3.3.2. Excursus: on-grid/off-grid uses

Figure 9: Illustrative technology options for electricity access



IEA (2017)

3.3.3. On/off-grid trade-off: Evidence from models

1) *New Policies Scenario* (IEA 2017)

○ **Main grid extension** serves **half** of newly connected households by 2030.

○ In **rural** areas, **decentralised power systems** most cost-effective solution for more than **65%** of HHs, with 20% off-grid solar PV and 11% mini-grid networks.

2) Multi-scenario spatial-economic analysis (Deichmann et al. 2011; Mentis et al. 2017)

○ Decentralised off-grid solutions lowest cost option only for a **minority** of households in EA

○ **Optimal geographic boundary** rather **remote** from main grid (future cost reductions accounted).

○ From the household perspective, on/off-grid potentially **complements** rather than substitutes (outages, budget constaints).

3.4. Household financial constraints

Grimm et al. (2017): RCT-based experiment for off-grid PV appliances in rural Rwanda

→ Estimated **willingness-to-pay (WTP)** for different typologies of PV appliances in villages with no grid: **elicited values in 38% - 52% range of market prices.**

Result: Approach based on the private market alone unlikely to reach broader population!

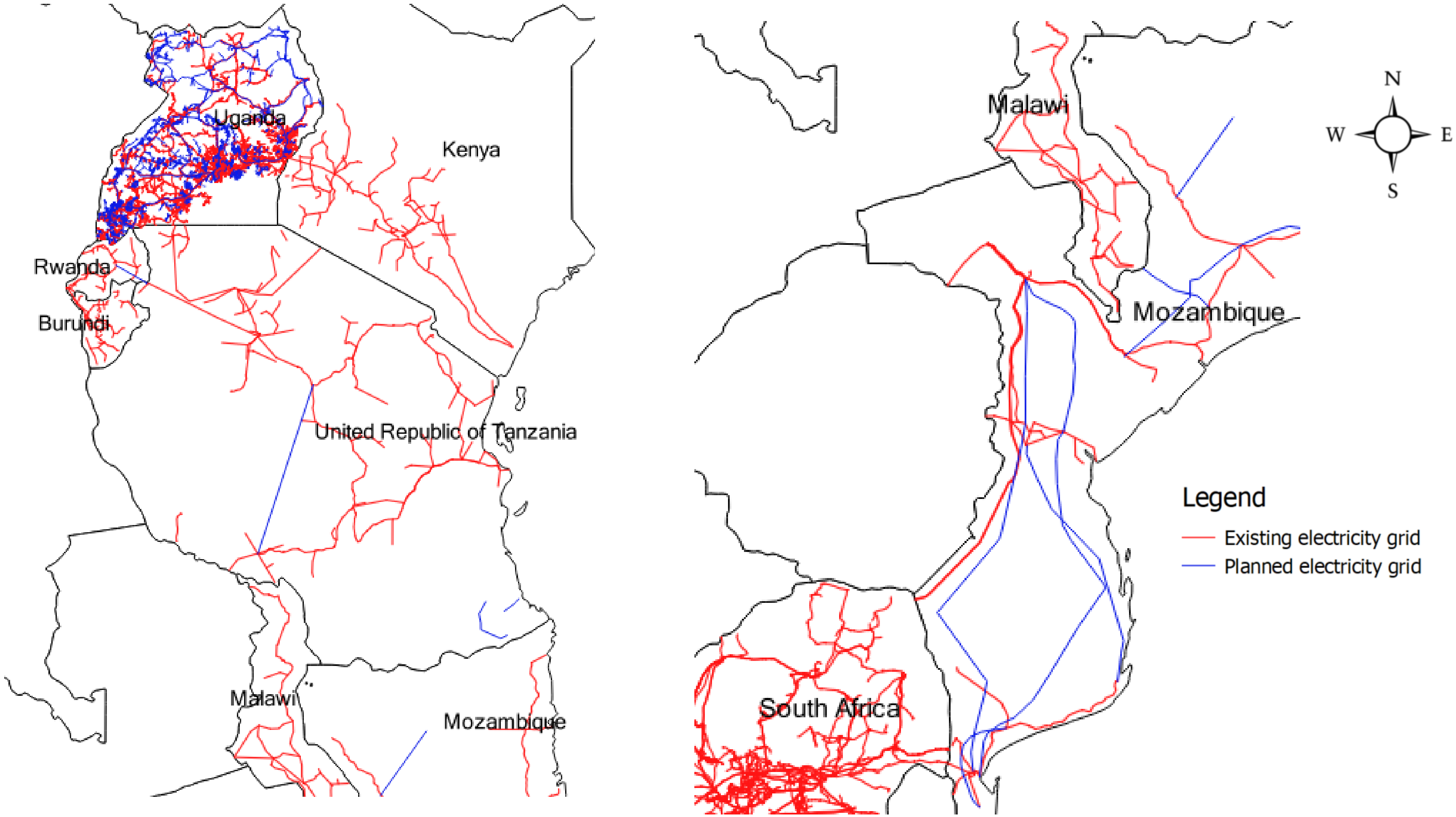
Implication: Off-grid technology requires **public subsidies/'pay-as-you-go' plans**, otherwise **lack of demand at market prices**.

NB: traditional biomass - **no explicit price or opportunity cost** to anchor on.

→**Publicly-subsidised but privately-purchased** alternative to:
(i) deliver off-grid electricity at the household level
(ii) render biomass collection and the related social costs at least more visible and reduce energy-derived externalities.

3.5. Transboundary cooperation (i)

Figure 10: Existing and planned grids in EA: zoom near borders



Author's elaboration on World Bank (2017) – DIVA GIS (2017)

3.6. Transboundary cooperation (ii)

- **Scarcity of interconnectors to transfer power across borders** determines low access levels in EA (besides insufficient power generation).

→ Interconnected high-voltage grid to **fix country-level imbalances and shortages.**

- Bilateral agreements for power exchange **already in place** between neighbouring countries in EA, but **regional interconnections not optimised and failure to meet contractual obligations.**
  - Also, in previous plans no **coordinated planning for the expansion of generation capacity** (Expogroup, 2017).

- Cooperation **necessary condition** for realisation of large projects involving transboundary resources, e.g. **river basins and large hydro dams.**

- W/ coordinated + interconnected grid systems, **cheapest power always consumed first**. Under **excess capacity**, complement others by selling excess supply beyond borders and trigger **win-win scenario** (WU et al. 2017).

3.7.1. NG reserves in EA: risk or opportunity for renewables deployment?

Substantial natural gas reserves in EA, estimated at:

2,832 bcm (Mozambique)

1,614 bcm (Tanzania)

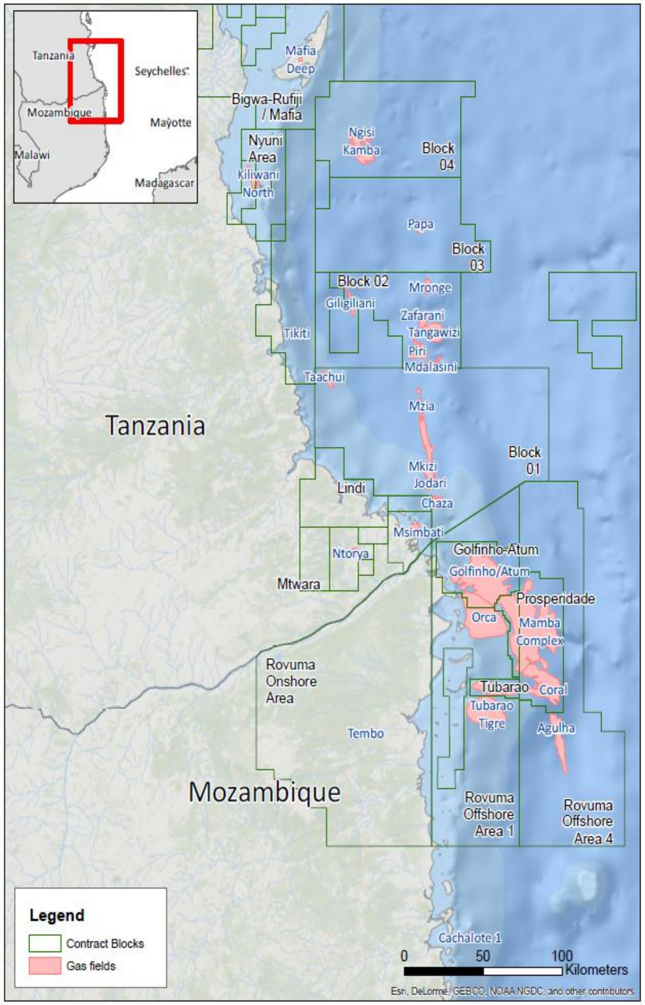
Contracts signed with international majors mainly for **LNG exporting (Asian market)** → Potentially **higher netback prices** than domestic prices (but strong competition)

- 2004 (M & T): production start
- 2016: **190,000 TJ** (M.); **34,000 TJ** (T.)
- Increasing trends

➢ What could be the implications for domestic renewable energy deployment?

➢ Is there a **'rivalry' risk** between NG and RE domestically, or room for a complementarity?

Figure 11: Gas fields in EA



USGS (2017)

FONDAZIONE ENI ENRICO MATTEI

3.7.2. A RE – NG complementarity?

- **Solar + wind:** abundance in most countries; intermittency (storage) issues.

- **Hydropower:** large untapped potential, but risk of climate-induced disruptions; competition for water resources.

NB: Overreliance on hydro in electricity mix of the region: Burundi (91.2%), Malawi (88%), Mozambique (100%), and Uganda (94%). (Figures from RISE 2017)

- ○ Turner et al. (2017); IPCC (2015): potential long-term/short-lived climate change impacts on hydro availability.
- ○ Electricity output fluctuations and short-lived extreme events (Conway et al. 2015; Occhiali 2016) economic impact.

- **Geothermal:** reliable baseload power; heterogeneous availability in the region; large site identification costs raise LCOE.

3.7.3. A RE – NG complementarity?

NG can play a fundamental role, but it is unlikely that it will displace renewables:

- **Diversification** of the energy mix likely to have a positive role in guaranteeing energy security in EA.
- NG resources: baseload/complement to cope with
  - **intermittency and storage issues** of solar and wind power
  - **Hydropower issues.**
- NG in **urban centres and their industry** to:
  - foster development of **the transport, fertilizers and manufacturing sectors**,
  - serve **non-electric needs in rural areas** (e.g. LPG tanks distribution).
- However, **capital intensive gas pipelines.**
- NG **distribution constraints to domestic consumption** in EA **- rural regions** particularly - where distance from grid is long and population scattered in villages with low density.

Renewables cheapest option in most areas if electrification is massive and diffuse!

4. Policy implications

4.1. Policy (urban and on-grid)

- Suitable **investment environment** and tackling of macroeconomic and political instability, weak protection of contract and property rights to attract investment (**funding** and **IPPs**).

- Incentives to enter the market with **competitive tendering processes** following principles of **efficiency and cost-effectiveness**

  (rather than direct negotiation with govern. actors).

- **Renewable energy feed-in-tariffs** (REFITs) to foster investment in infrastructure and provide **guaranteed return** into the future

  NB: In the case of IPPs procuring large power plants, FiTs provide **price certainty and long-term contracts.**

- **Complementarity** RE/NG (net of current + future external costs) to achieve least-cost electrification scenario, and serve major urban centres and industry + transport and agricultural sectors.

4.2.1. Policy (rural and off-grid) (i)

Issue: upfront costs higher than most consumers are willing/able to pay.

- **Subsidies schemes** for grid connection / off-grid infrastructure installation to **complement the low ability-to-pay.**
- **Context: comprehensive electrification and development plans** looking at specificities of regions (role of **Independent Energy Authorities).**

- Implementation of **institutional conditions**: **Renewable Energy Authorities**, w/ sufficient discretion and autonomy to:
  - Regularly update national **electrification plans**
  - Lobby national governments for **means** of implementation
  - Encourage **private actors** to invest offering **long-term standardised PPAs and transparent rules** (including for future interconnections)
  - Offer connection grants, subsidies, and incentives to potential customers.

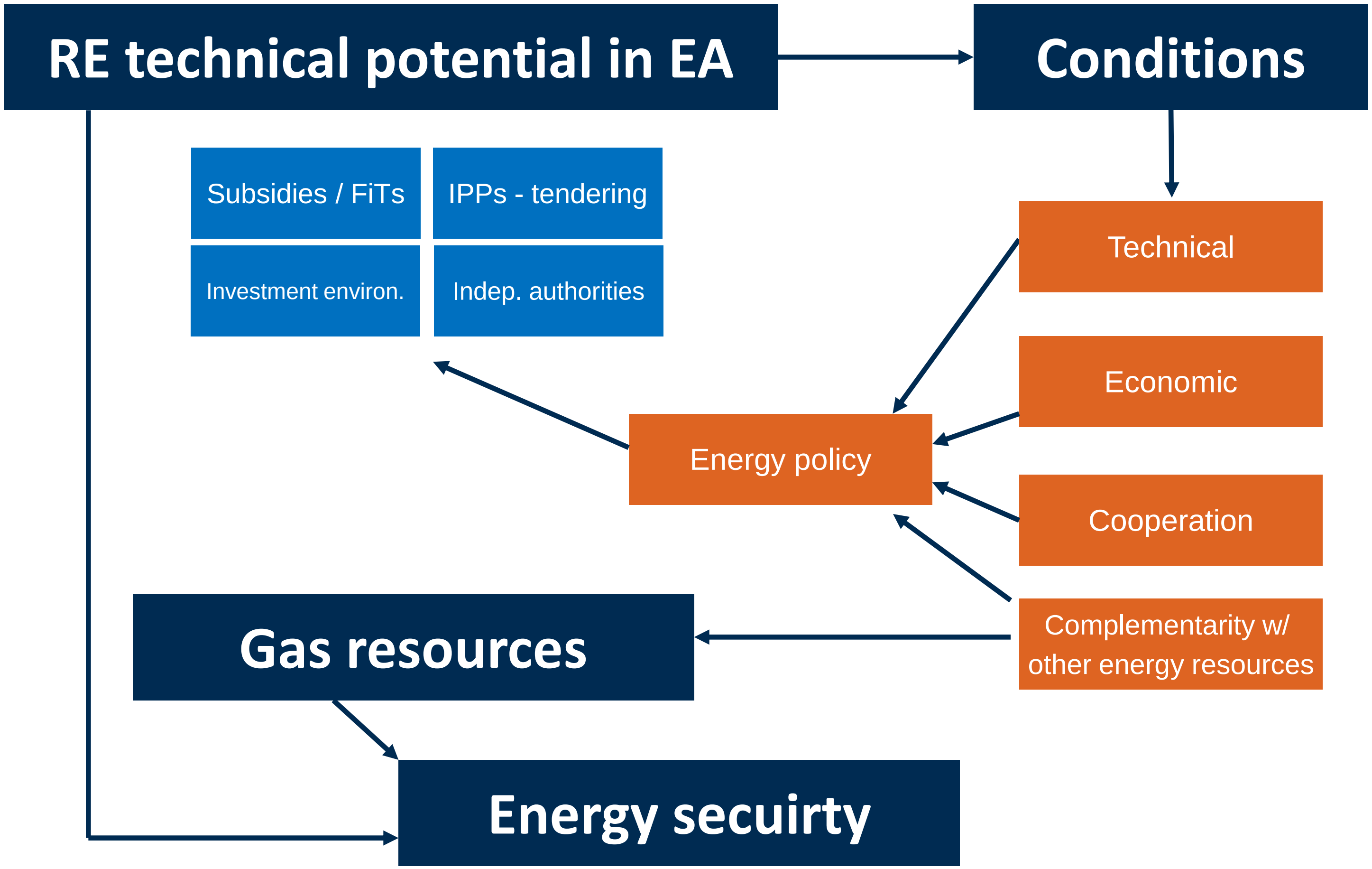
4.2.2. Policy (rural and off-grid) (ii)

- **Feed-in-tariffs (FiTs)** beneficial for small RE projects: communities relying on "free" biomass unwilling to invest relevant proportion of their incomes to achieve electrification **without a predictable economic return**.
- **NB** design caveats:
  - Avoid market distorsion
  - Be flexible to different technologies + changing costs and conditions.

- Electricity providers' **billing schemes** to accommodate needs of credit-constrained households and **nudge to gain access → trigger win-win scenario for both provider and consumer**.
- **Behavioural considerations** e.g. information and the default contract type

- Small energy firms cooperation w/ state-owned electricity companies to create **integrated business-to-business arrangements and increase access to potential markets and funding**. → **special & context-specific focus on projects** (business models and financial solutions).

Conclusion


RE technical potential in EA
Conditions
Subsidies / FiTs
IPPs - tendering
Investment environ.
Indep. authorities
Technical
Economic
Energy policy
Cooperation
Complementarity w/ other energy resources
Gas resources
Energy security

References

•Arderne, C., & World Bank. (2017). Africa - Electricity Transmission and Distribution Grid Map. Retrieved from https://energydata.info/dataset/africa-electricity-transmission-and-distribution-2017

•CIA, Central Intelligence Agency. (2017). The World Factbook 2017. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/index.html

•Conway, D., van Garderen, E. A., Deryng, D., Dorling, S., Krueger, T., Landman, W., … Dalin, C. (2015). Climate and southern Africa's water–energy–food nexus. Nature Climate Change, 5(9), 837–846. https://doi.org/10.1038/nclimate2735

•Creutzig, F., Nemet, G., Luderer, G., Goldschmidt, J. C., Agoston, P., & Pietzcker, R. C. (2017). The underestimated potential of solar energy to mitigate climate change. Nature Energy, 2(9), 17140. https://doi.org/10.1038/nenergy.2017.140

•Deichmann, U., Meisner, C., Murray, S., & Wheeler, D. (2011). The economics of renewable energy expansion in rural Sub-Saharan Africa. Energy Policy, 39(1), 215–227.

•Expogroup. (2017, August 9). EAST AFRICA: LIGHTING EAST AFRICA. Retrieved from http://expogr.com/rwanda/lightexpo/detail_news.php?newsid=5019&pageid=2

•Fouquet, R. (2016). Path dependence in energy systems and economic development. Nature Energy, 1, 16098.

•Grimm, M., Lenz, L., Peters, J., & Sievert, M. (2017). Demand for off-grid solar electricity–Experimental evidence from Rwanda.

•IEA. (2017a). WEO 2017 Special Report: Energy Access Outlook. International Energy Agency. Retrieved from https://www.iea.org/publications/freepublications/publication/weo-2017-special-report-energy-access-outlook.html

•IEA. (2017b). World Energy Outlook 2017. Retrieved from https://www.iea.org/weo2017/

•Ikejemba, E. C. X., Mpuan, P. B., Schuur, P. C., & Van Hillegersberg, J. (2017). The empirical reality & sustainable management failures of renewable energy projects in Sub-Saharan Africa (part 1 of 2). Renewable Energy, 102(Part A), 234–240. https://doi.org/10.1016/j.renene.2016.10.037

•Institute for Health Metrics and Evaluation (IHME. (2017). Global Burden of Disease from Household Air Pollution.

•IPCC. (2015). Fifth Assessment Report - The Physical Science Basis. Retrieved 17 January 2018, from http://www.ipcc.ch/report/ar5/wg1/

•IRENA. (2017). Data and Statistics. Retrieved 15 February 2018, from http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=16

•Mentis, D., Howells, M., Rogner, H., Korkovelos, A., Arderne, C., Eduardo Zepeda, … Scholtz, E. (2017). Lighting the World: the first application of an open source, spatial electrification tool (OnSSET) on Sub-Saharan Africa. Environmental Research Letters, 12(8), 085003. https://doi.org/10.1088/1748-9326/aa7b29

•NOAA/NGDC - Earth Observation Group - Defense Meteorological Satellite Progam, Boulder. (n.d.). Retrieved 17 January 2018, from https://ngdc.noaa.gov/eog/viirs/download_dnb_composites.html

•Occhiali, G. (2016). Power Outages, Hydropower and Economic Activity in Sub-Saharan Africa (PhD thesis). University of Birmingham. Retrieved from Power Outages, Hydropower and Economic Activity in Sub-Saharan Africa

•RISE. (2017). RISE Renewable Indicators for Sustainable Energy. Retrieved from http://rise.esmap.org/

•SEDAC - NASA. (2015). Gridded Population of the World (GPW) v4. Retrieved 15 January 2018, from http://sedac.ciesin.columbia.edu/data/collection/gpw-v4

•Turner, S. W. D., Ng, J. Y., & Galelli, S. (2017). Examining global electricity supply vulnerability to climate change using a high-fidelity hydropower dam model. The Science of the Total Environment, 590–591, 663–675. https://doi.org/10.1016/j.scitotenv.2017.03.022

•United Nations Population Division. (2017). World Population Prospects: The 2017 Revision. Retrieved from https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf

•United Nations. (2015). Energy Statistics Yearbook 2014. United Nations Publications.

•World Bank. (n.d.-b). World Bank Data. Retrieved 20 November 2017, from https://data.worldbank.org/