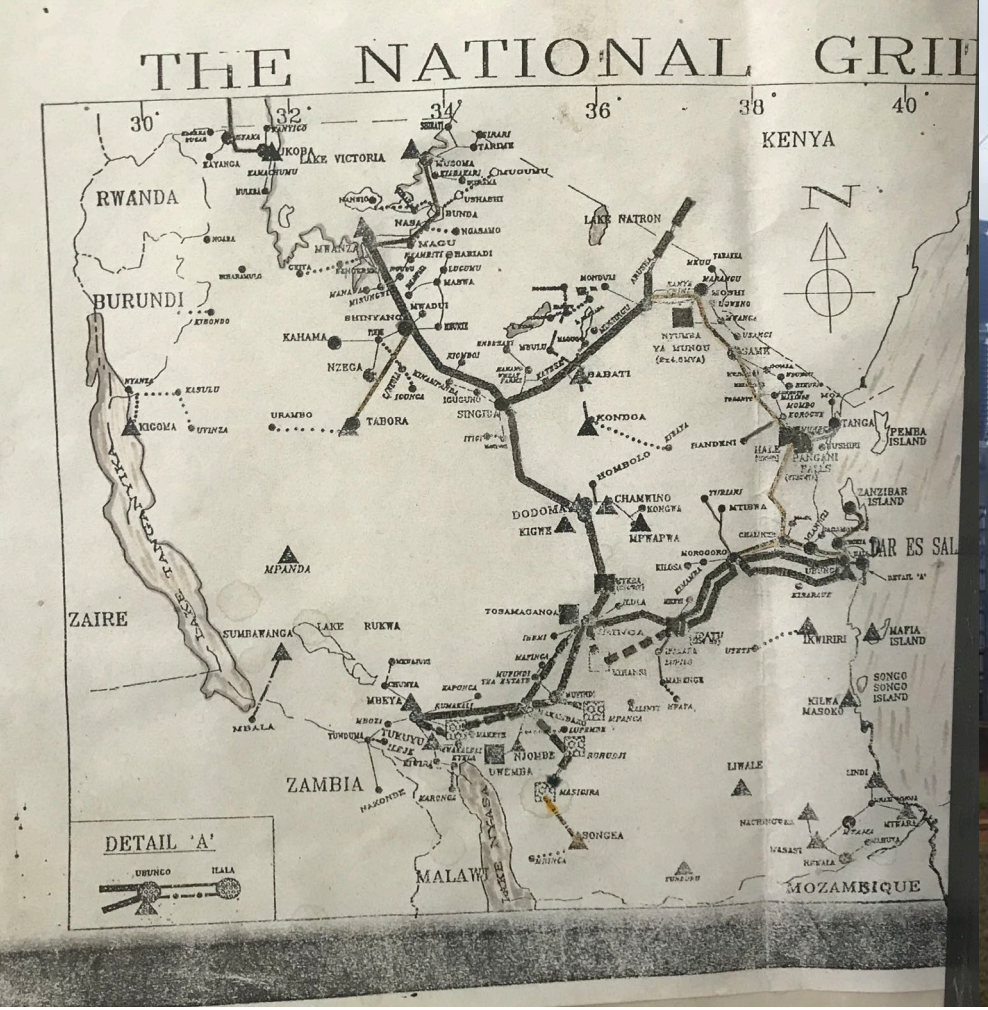

11/12/2019 | AIEE SYMPOSIUM 4TH AIEE ENERGY SYMPOSIUM CURRENT AND FUTURE CHALLENGES TO ENERGY SECURITY

Iliceto Shield Wire Scheme (ISWS): A Leap-Frog Technique For Low-Cost Rural Electrification, Micro-Grids Connection and RES Promotion in Developing Countries. A Precious Legacy from Professor Francesco Iliceto.

M.C. Falvo, S. Maccario, F. Santi, A. Iliceto

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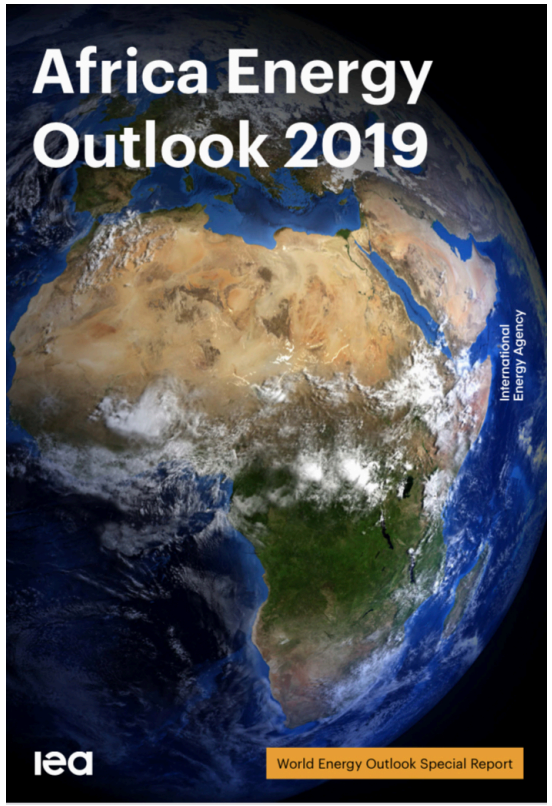
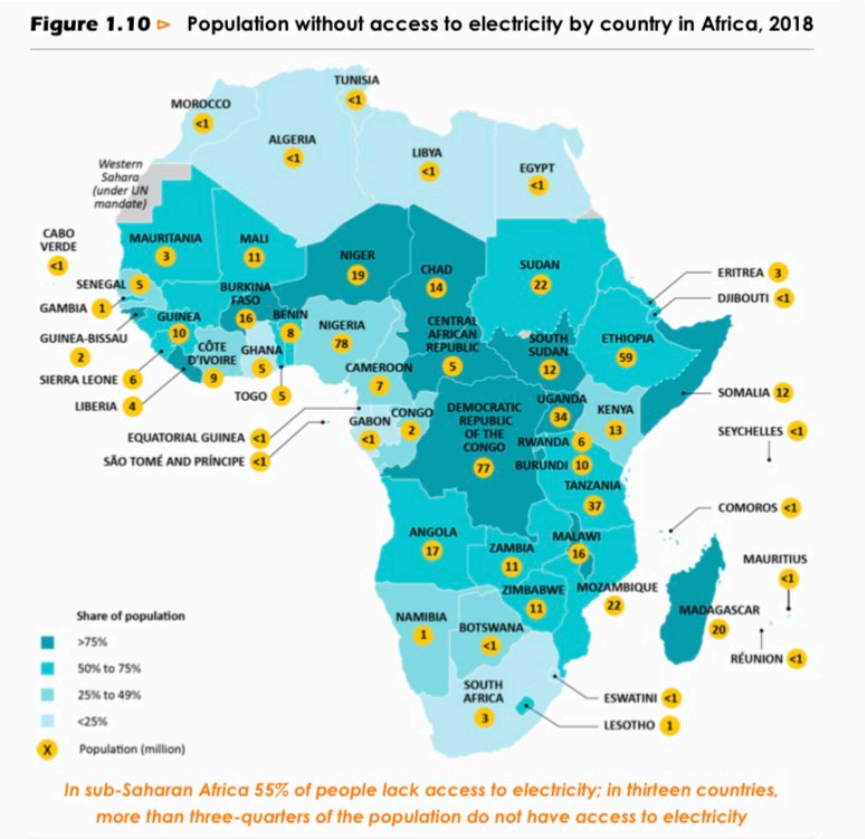
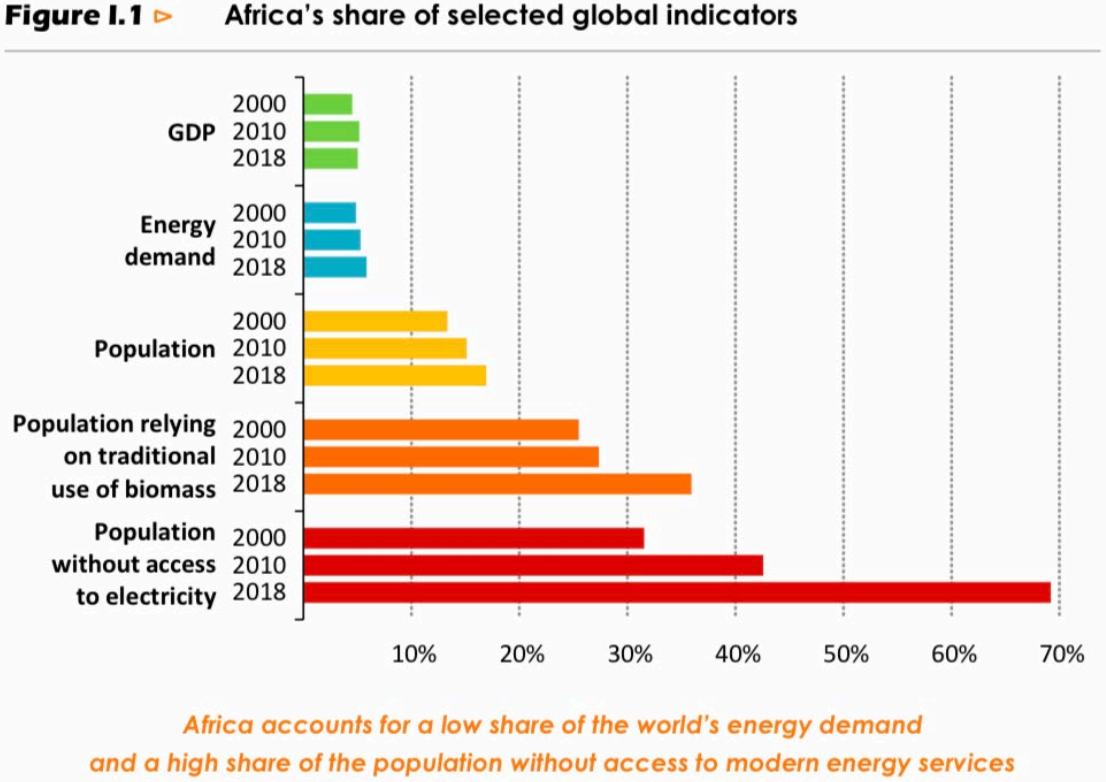
Access to electricity in Africa

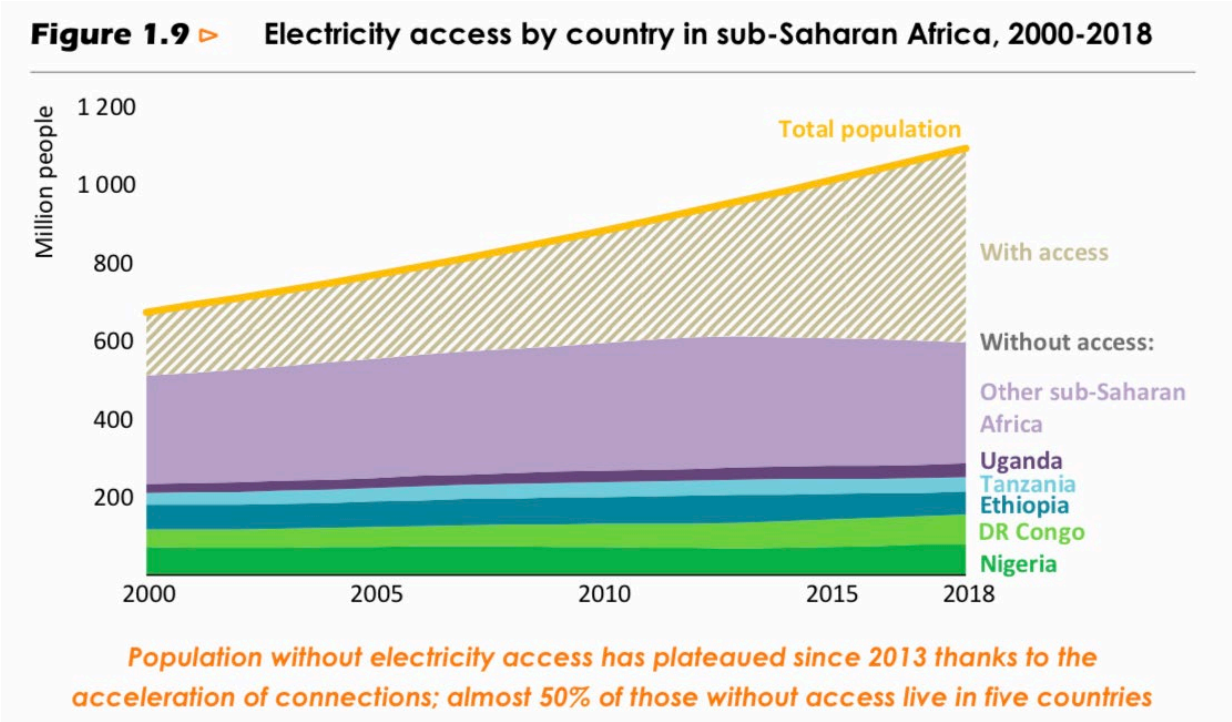


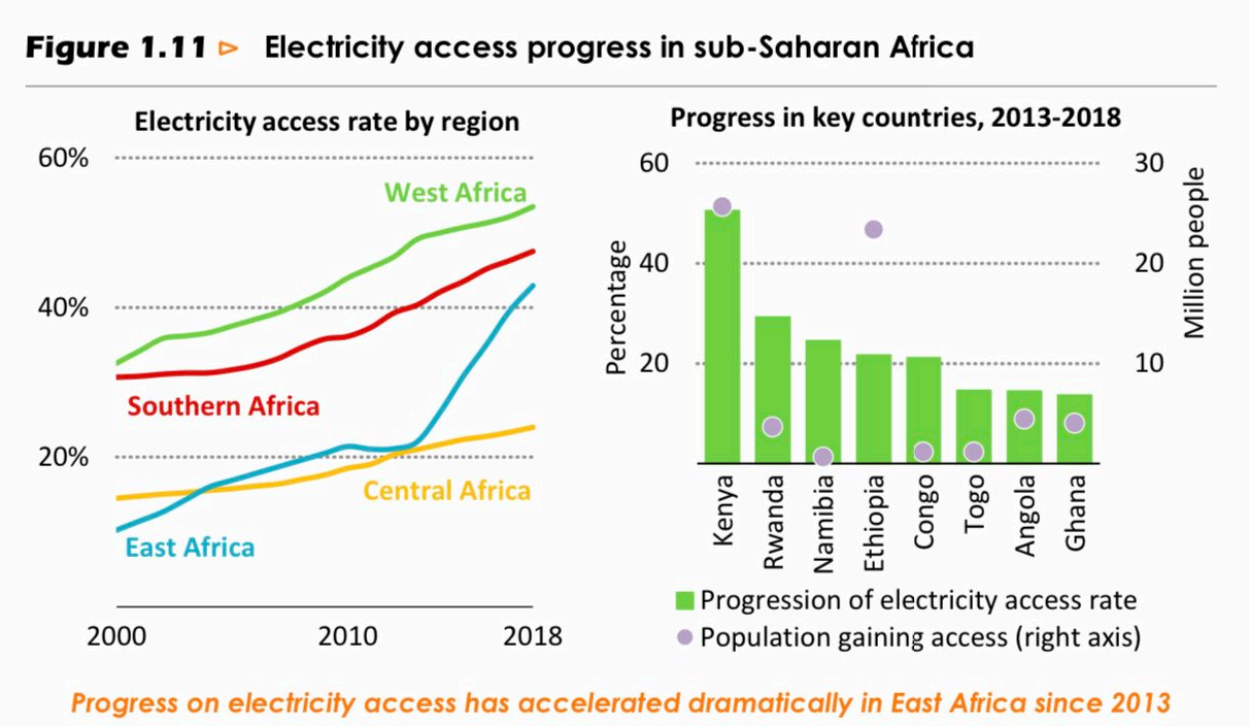




- Let us comment together some figures of African Energy Outlook 2019
- 55% of people in Sub-Saharian African lack the access to elecricity (in 13 Countries, 3/4)
- Increasing share of the population without access to modern electricity (almost 70% in 2018)

Electricity Access in Sub-Saharian Africa





- **Dramatic electricitity access progress in East Africa from 2013**
- **Still, about half of the population without electricity in Sub-Saharian Africa live in 5 Countries**

Sub-Saharian Africa Perspectives for Access to Electricity

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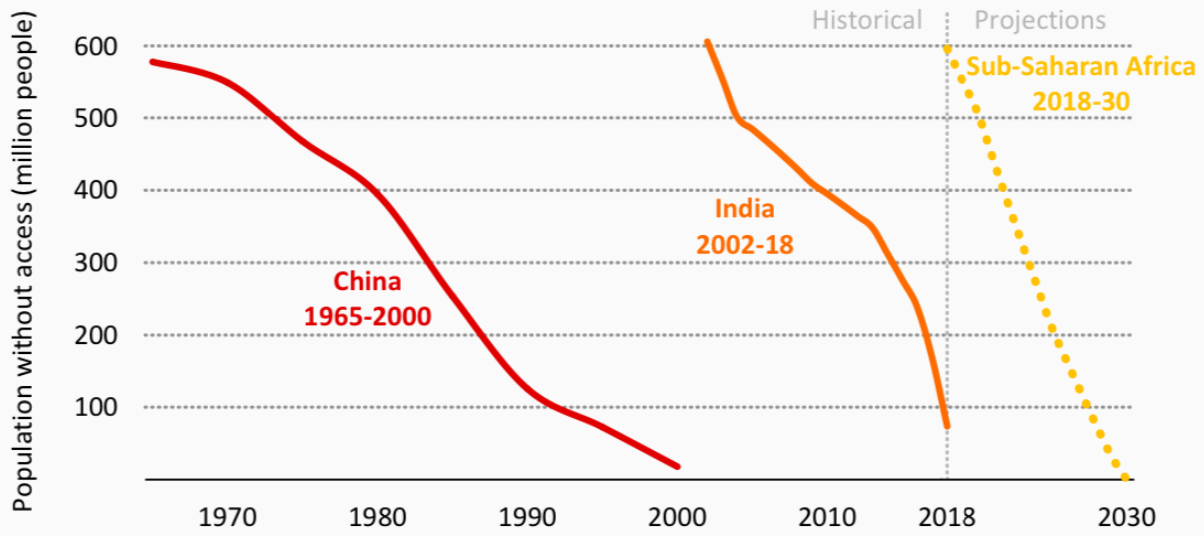
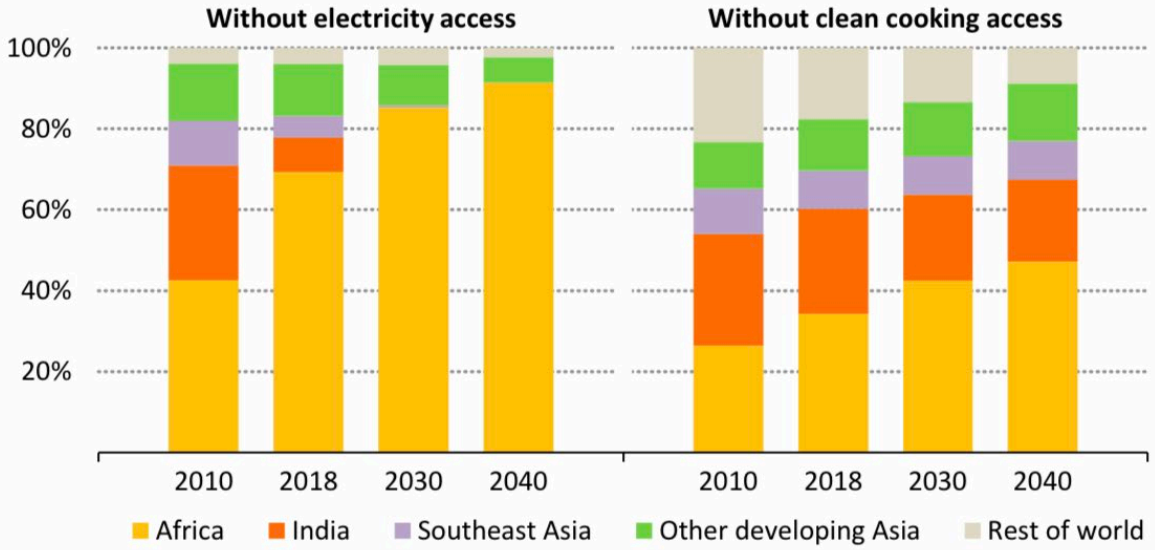
Figure 3.2 ▷ Reaching universal access to electricity in sub-Saharan Africa compared with achievements in China and India



Achieving access for all in sub-Saharan Africa in only twelve years will require an unprecedented effort

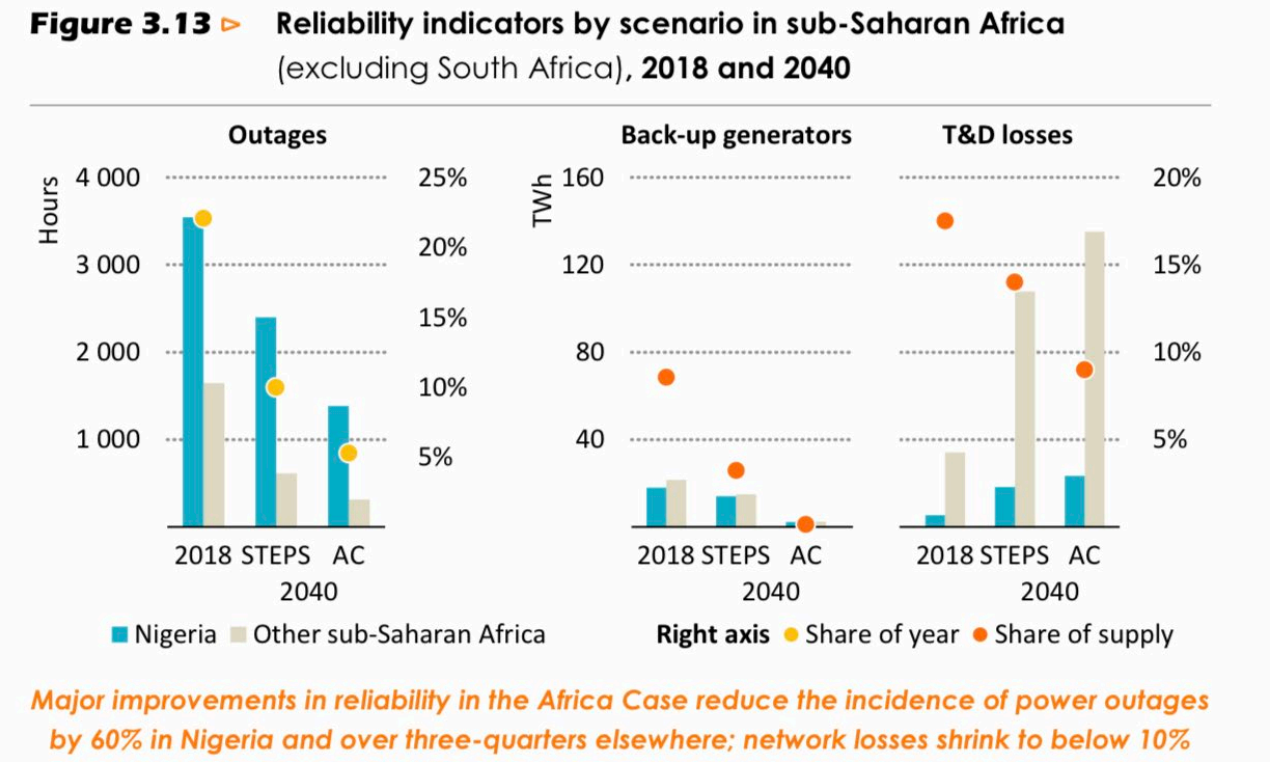
Figure 5.11 ▷ Share of population without access to electricity and clean cooking by region in the Stated Policies Scenario

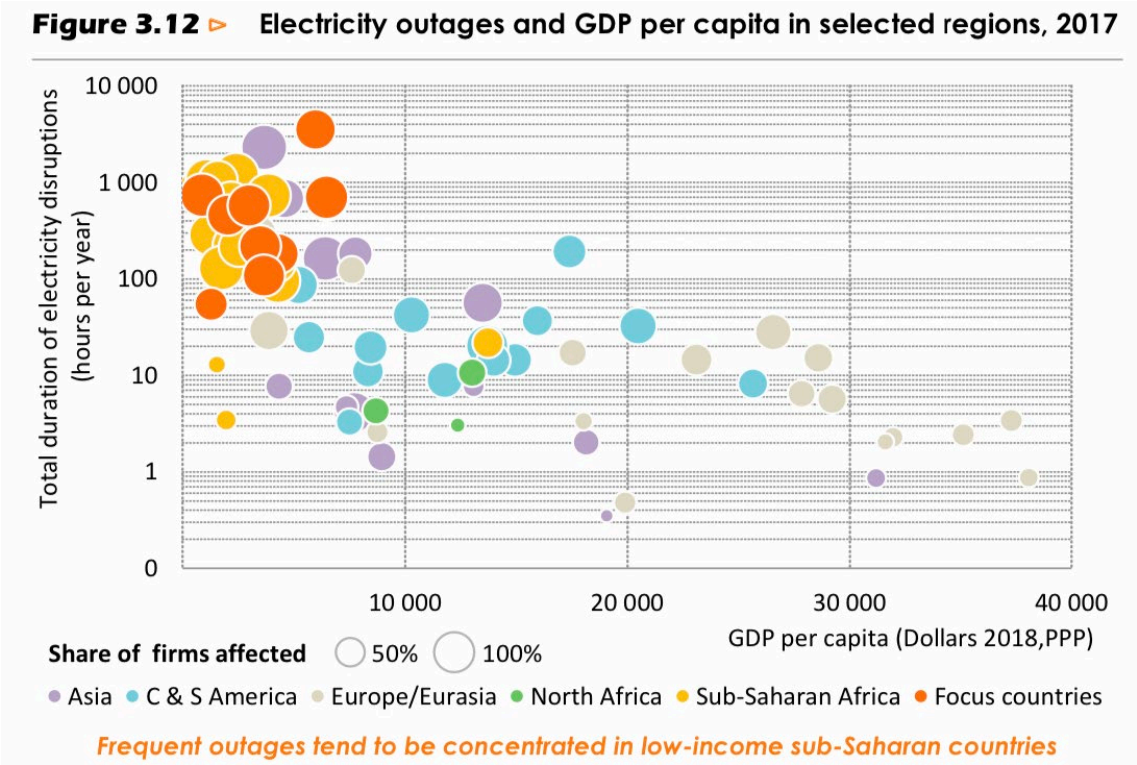


Those without access to electricity and clean cooking are increasingly concentrated on the African continent

- **To reach the goal of universal access to electricity in SSA within 2030 is a challenge without precedents in the human history**
- **IEA «Stated Policies» Scenario 2040: > 90% of the world population without electricity will live in Africa (now 70%)**

Reliability, Outages, T&D Losses, Back-up Generators

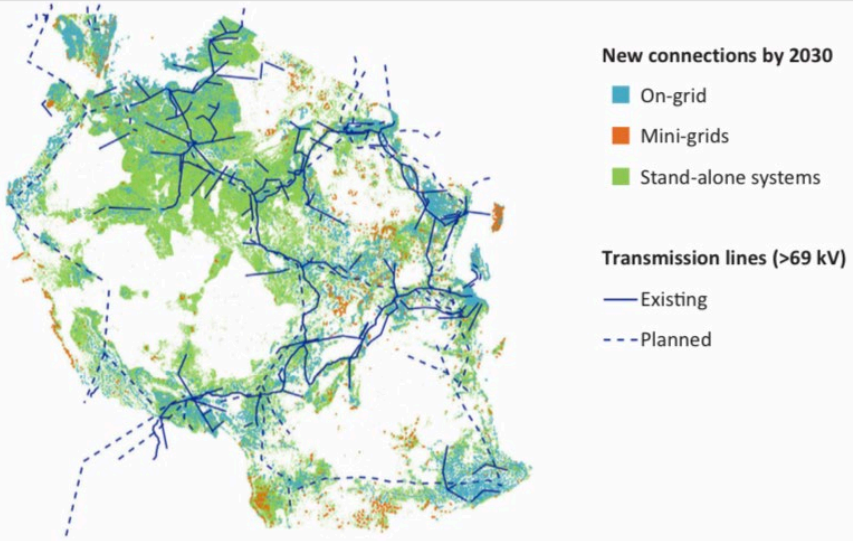




- **To develop a modern, adequate, reliable and resilient power system is a big challenge focusing on:**
  - **Outages / Power Quality**
  - **T&D losses**
  - **Use of back-up generators**

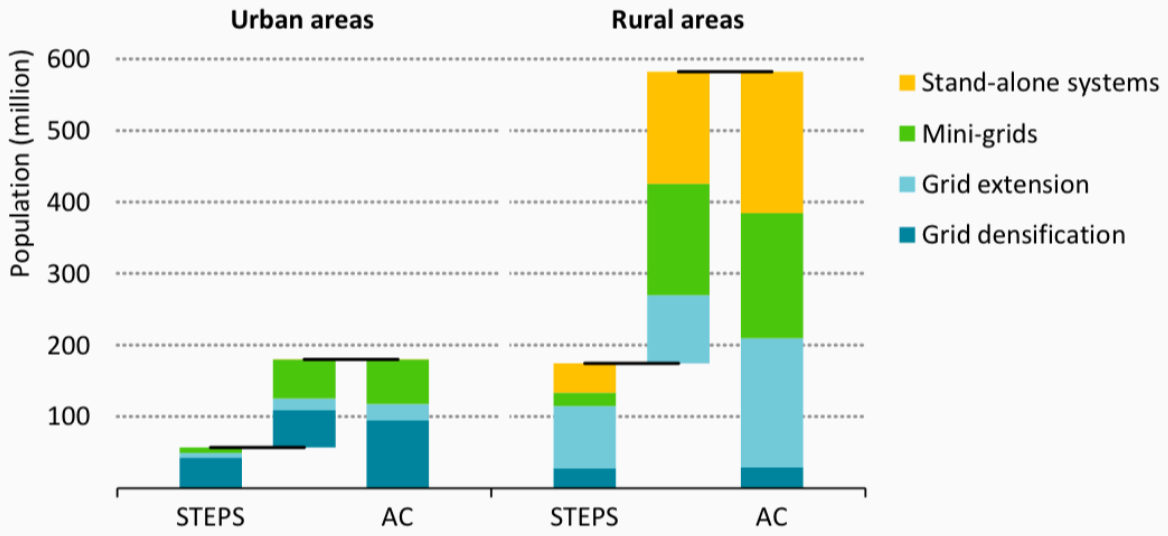
Electricity Access Solutions in Tanzania and SSA

Figure 6.12C ▷ Tanzania electricity access solutions by type in the Africa Case



- Despite the low access rate (37%) today, the grid represents more than half of new connections by 2030 in the AC given its existing and planned coverage.
- In the AC, around one-third of the remaining population, mainly located in sparsely populated areas far from the grid, would be best reached by stand-alone systems.

Figure 3.11 ▷ Solutions to provide electricity access by area and scenario in sub-Saharan Africa, 2019-2030



Access in urban areas will largely be via grid connections, while decentralised solutions are the least-cost option for about 370 million people in rural areas to reach full access

Sources: IEA analysis; KTH-dESA.

- **Decentralised solutions seems to be the least-cost option for about 370 million people in SSA by 2030**
- **In Tanzania, grid >50% of new connections by 2030, 1/3 of the population best reached by mini-grids and stand-alone systems**

Communities That Live «Under The Grid»

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SPOTLIGHT

What approaches can help communities that live "under-the-grid" but without electricity?

More than half of the urban population in African countries lives in informal settlements often lacking access to formal electrification services (Tusting et al., 2019). Furthermore, at least 110 million of Africa's 600 million people without electricity access live in informal urban settlements close to or directly under a grid (GTM Research, 2017). A 2017 World Bank study on infrastructure in Africa discovered that connection rates for populations living under-the-grid is lower than 50% in most countries in sub-Saharan Africa, with a few exceptions such as South Africa, Nigeria, Gabon and Cameroon. Depending on the data source, estimates for under-the-grid populations without access to legal electricity in other African countries range from 61% to 78% (World Bank, 2017a).

prices are frequently unaffordable. Before the Last Mile Connectivity Project, the price of a connection in Kenya was around $400 per household (Lee, Miguel and Wolfram, 2016), nearly one-third the annual average per capita income and over three-times the mean of the willingness to pay of surveyed Kenyans. In Nigeria, 62% of under-the-grid households cite high connection costs as the major reason for not being connected to the grid (GTM, 2017). The Centre for Global Development estimates that there may be up to 95 million people living in under-the-grid areas in Nigeria, Kenya, Tanzania, Ghana and Liberia.

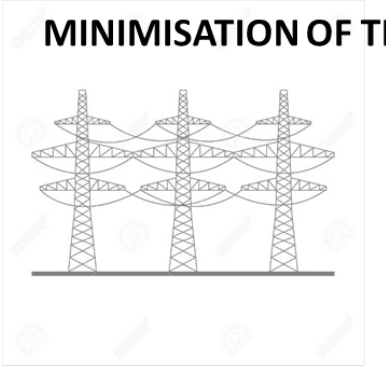
There is an urgent need for innovative approaches to provide affordable legal electricity to those living under-the-grid in African countries. A look at promising practices for

- **>110 million of Africa's 600 million people without electricity access live close or directly under a grid**
- **>50% of populations living under the grid in SSA lack a legal access to electricity**
- **Up to 95 million people living under-the-grid in Nigeria, Kenya, Tanzania, Ghana and Liberia**

What is ISWS

PURPOSE OF ISWS

MINIMISATION OF THE COST POWER SUPPLY



INNOVATIVE RURAL ELECTRIFICATION SOLUTION

IT IS PROPOSED TO REPLACE THE CONVENTIONAL CONNECTION TO THE GRID

IT IS COMPATIBLE WITH THE LONG DISTANCES INVOLVED AND THE SMALL POWER REQUIRED

CONCEPT OF ISWS

THE USE OF SHIELD WIRE LINES FOR MV POWER SUPPLY + THE USE OF THE EARTH RETURN CURRENT PATH =

- INSULATING THE SWs FOR MV OPERATION (20-34.5 kV) FROM THE TOWERS OF HV TL
- ENERGIZING THE SWs AT MV FROM THE HV/MV TRANSFORMER STATION AT ONE END OF THE HV TL
- USING THE EARTH RETURN OF CURRENT AS A MV DISTRIBUTION CONDUCTOR
- SUPPLYING LOADS BY MEANS OF MV/LV DISTRIBUTION TRANSFORMERS BRANCHED BETWEEN THE SWs AND THE GROUND

Shield Wires of High Voltage Trasmission Lines

High Voltage Transmission Line (HV TL) with **2** Shield Wires (SW)

High Voltage Transmission Line with **1** Shield Wire

ISWS Main Features

1) INSULATION OF THE SW(s)

COSTS ARE MINIMISED → 2 CASES:
1- HV TL already in operation
2- HV TL in construction (less expensive case)

ONLY COSTS OF THE ADDITIONAL MV INSULATORS AND ARCHING HORNS → They are incurred for most of the line lenght

👉 Sharp cost increase: insulators have to be attached retroactively (on TL in operation already present, involving live line working)

2) MV SUPPLY OF THE SW(s)

FROM WHERE? It is typically derived from an intermediate point of the HV TL

MV VALUE? 20~34.5 kV depending on the MV used in the country

PURPOSE? Using the physical infrastructure of the HV TLs, the MV power can be transported over long distances at minimal costs

BENEFIT? Rural areas where the load demand is very low and which are far away (more than 100 km) from the HV/MV transformer station, can be economically supplied by ISWSs (rather than MV conventional system)

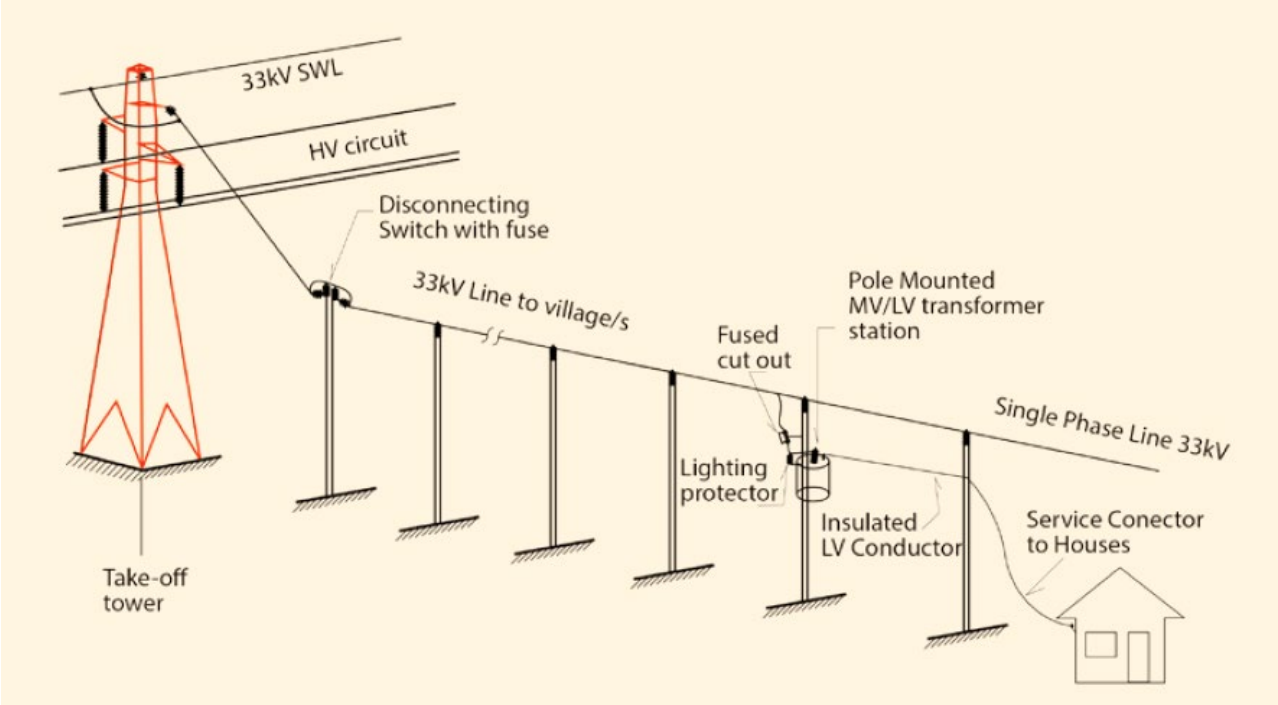
3) CONFIGURATIONS OF ISWS

3.1) With a single i-SW and earth return, providing a single-phase MV

3.2) With two i-SWs, providing a two wire single-phase MV

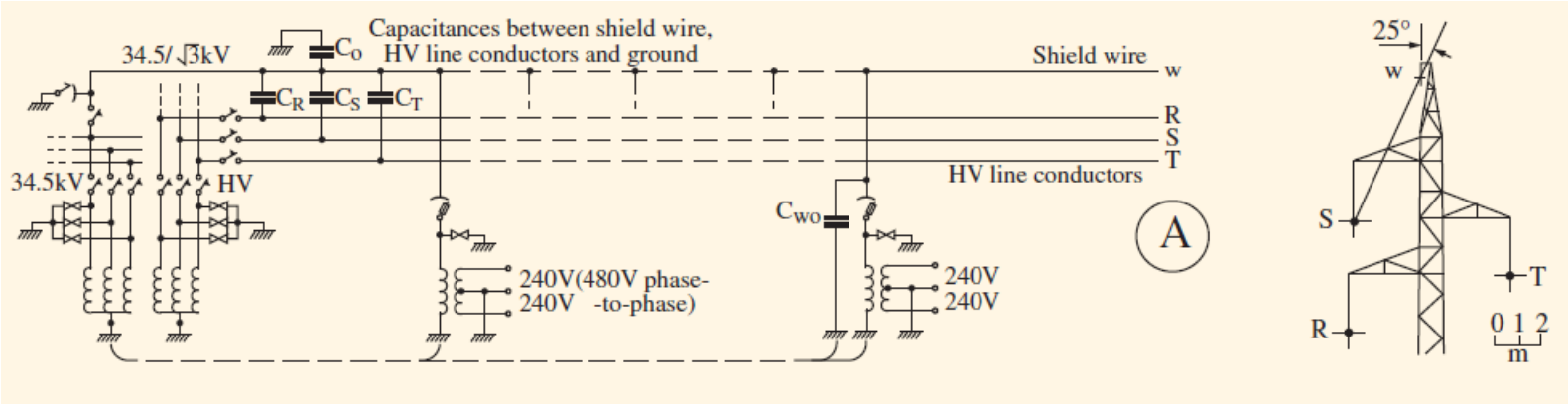
3.3) With two i-SWs and earth return, providing a three-phase MV

Single-Phase ISWS

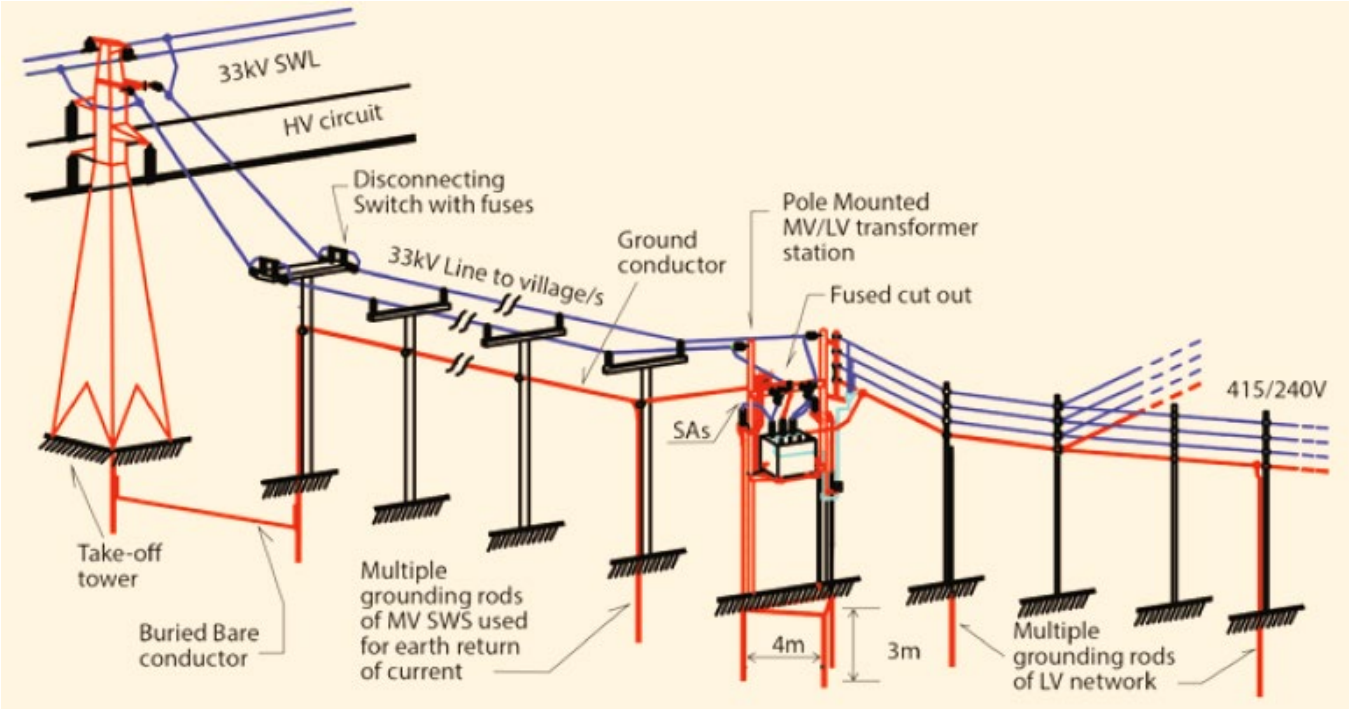


It is applicable in HV TLs protected by one SW
for single-phase MV distribution with earth return of current:

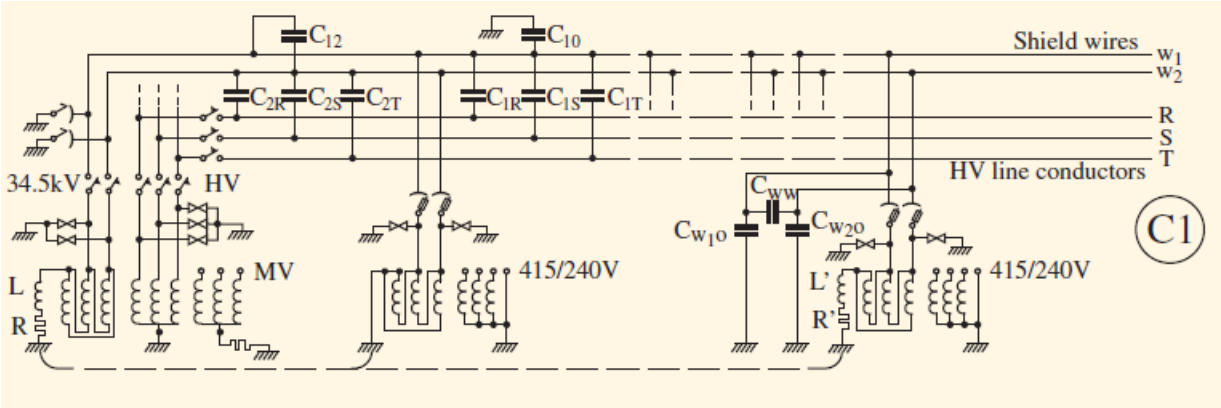
- if the HV/MV transformer station of origin of the SWL has a MV winding with the neutral solidly grounded, or if the neutral is grounded via a grounding transformer of low homopolar reactance, or via a reactor of low impedance the SWL can be directly supplied from one terminal of the MV winding
- if the neutral is high-impedance grounded or it has a rated voltage unsuitable for the long SWLs (too low), the SWL is supplied by an interposing transformer IT



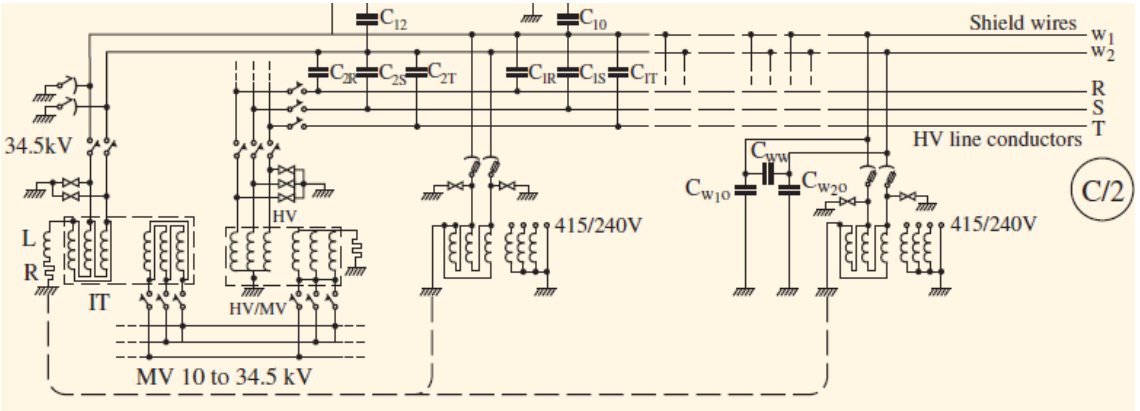
Three-Phase ISWS



- **3-phase more suitable for industrial / important loads**



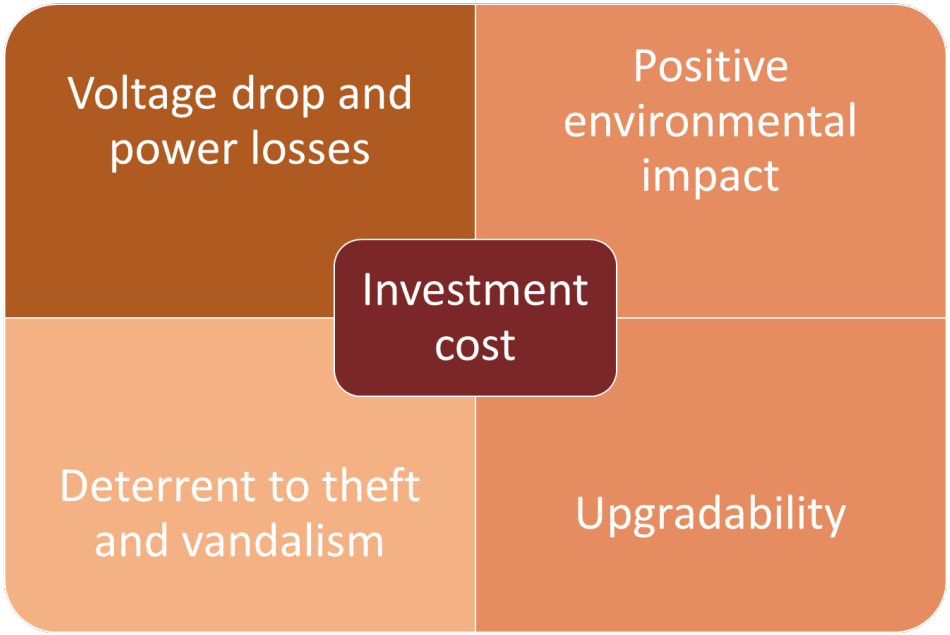
Three-phase SWS supplied by a dedicated tertiary winding of the HV/MV transformer



Three-phase SWS supplied by an interposing transformer, IT

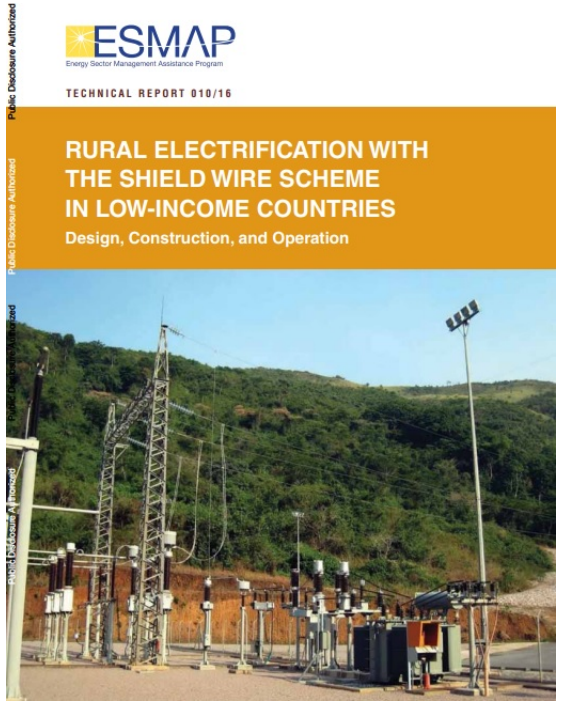
Main Benefits of ISWS Technique

WHY IT IS WORTH USING **ISWS?**



- **Low Cost** → investment cost to make the electricity available at MV with ISWS to rural areas «under the grid» is ***only 10~15%*** of the investment cost of conventional solution (that uses long independent MV lines of the same rated voltage)
- **Reduced Voltage Drop and Power Losses** → Larger cross section of the SWs, lower losses, lower voltage drop, larger power flow
- **Low Environmental Impact** → ISWS does not increase the impact of the HV TLs, shorter MV line
- **Deterrent to Vandalism and Theft of HV Lines** → communities along the line must protect them to ensure power supply to themselves («under the grid»)
- **Upgradability** → large increase of load can be served adding new HV/MV transformer station at intermediate point (the construction of them is justified)

Existing ISWS Plants and World Bank Technical Report



Location	SWs	Starting year	Lenght	HV - frequency
Ghana	Three-phase SWs	1980s	1000 km	161 kV – 50 Hz
Brazil	Three-phase SWs 34.5 kV	1995		230 kV – 60 Hz
Laos	Single-phase SWs	1996	190 km	115 kV – 50 Hz
	Three-phase SWs 34.5 kV	2002-2003	335 km	115 kV – 50 Hz
Sierra Leone	Three-phase SWs 34.5kV	2010		161 kV – 50 Hz
Togo	Three-phase SWs 34.5kV	-	265 km	161 kV – 50 Hz
Burkina Faso	Three-phase SWs 34.5kV	-	330 km	225 kV – 50 Hz
Ethiopia	Single-phase SWs	1990s	200 km	132 kV – 50 Hz

ESMAP-World Bank published ISWS Technical Manual, available on the website *esmap.org/node/57786*

ISWS Application in Tanzania

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- 2019 MoU TANESCO / UDSM / «Francesco Iliceto» Association
- 2019 M.Sc. Thesis Degree Energy Engineering: pre-feasibility study - ISWS application in Shinyanga rural areas
- 2019 Feasibility Study - ISWS Application in Tanga area (rural and industrial loads)
- 2020/2021 Tanga Demo Project implementation: engineering design, request for funding, construction
- Post Demo Project: if the low-cost will be effectively demonstrated, extension to the Country
- Next Steps: bidirectional approach to integrate local renewables / micro-grids in the grid
- Capacity building: «Francesco Iliceto» Association already financed two scholarships within this initiative
  University Sapienza will support capacity building activity and assign a M.Sc. Electrical Engineering scolarship to a UDSM graduate
  Professors Kihwele (UDSM) and Kyaruzi (UDSM; president of TANESCO) have been involved and already been in Italy to work on it – Advanced level courses at UDSM are foreseen

Survey of UDSM and Sapienza Graduates in Shinyanga Rural Area

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Figure 4 – «Lusu» Substation Public HV/MV step down transformer station; on the left the oil transformer 132 kV/33kV HV/MV, on the centre the control monitor for the tranformer, on the left the two Potential Transformers at HV side

Figure 6 – Chairperson's office; surveying team

Figure 7 – High-Voltage Transmission Line Route 132 kV

Figure 5 – Primary school in Ng'wamkanga village

Shinyanga ISWS Pre-Feasibility Study Assumptions

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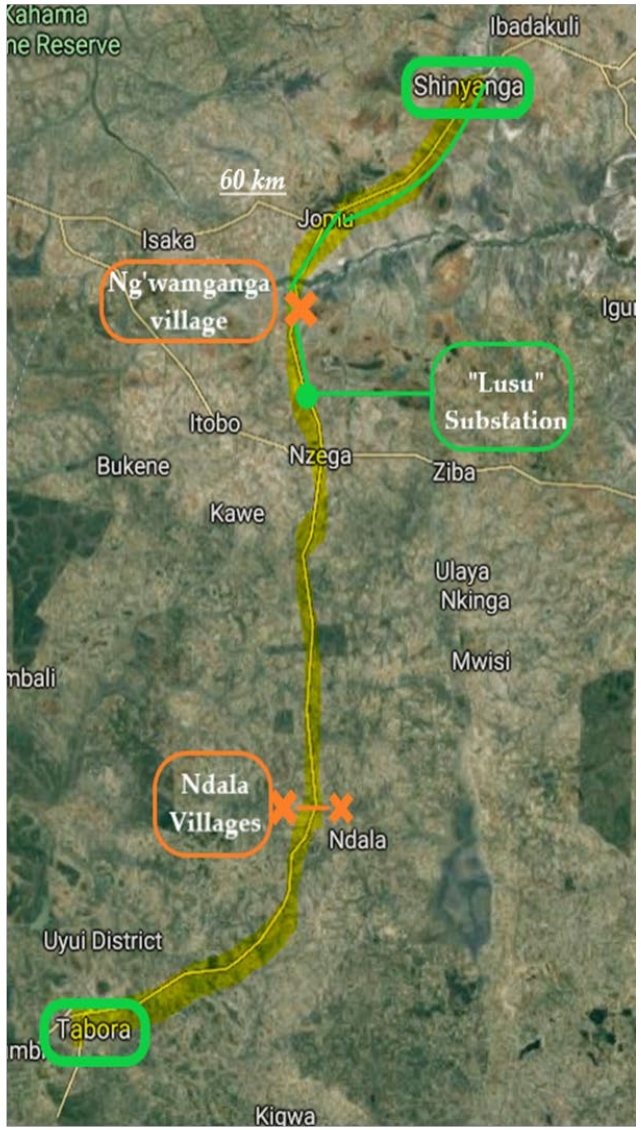
HIGH-VOLTAGE TRANSMISSION LINE: (S) Starting SS: **SHINYANGA SS** (I) Internal SS: **LUSU SS** (T) Terminal SS: **TABORA SS**		
Ur	132 kV	
Length	(S) To (T)	203 km
	(S) To (I)	60 km
Type	Single-circuit (S/C)	
	Two SWs Steel 50 mm^2	
Tower	587 HV horizontal S/C	
Conductor	Single; Wolf, 150 mm^2 ACSR	

LOADS TO BE SUPPLIED: 3 Villages	
Section	Distance km
LUSU-NG'WAMGANGA	15.58
LUSU-NDALAs	70
NG'WAMGANGA –HV TL route	1
NDALAs-HV TL route	2

HV/MV SS VISITED: **LUSU SS** **132kV/33kV; 15 MVA**	
Type	Public (Tanesco)
Estimated Power to be Transmitted	12 MW
Total Current Maximum Demand	1.240 MW
Current Maximum Demand for each feeder	1°Nzega 0.59 MW
	2°Igunga 0.65 MW
	3° Resolute 6 kW
Direction	Monodirectional

LOADS TO BE SUPPLIED: 3 Villages		
10 Years SCENARIO villages		
Ng'wamganga	Family growth	523 to 540
	Pd	0 to 2 MW
Ndala (x2)	Pd	0 to 2 MW



Shinyanga ISWS vs. Conventional Tech. Cost Comparison

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CASE STUDY COST COMPARISON

Implementation of a "Three-phase" ISWS to supply the unelectrified villages (4MW in tot) with: 1. ACSR SWs of 100 mm^2 and length 15.58 + 70 km 2. to be supplied by the tertiary winding of the HV/MV main transformer (6MVA) 3. including the R-L circuit 4. including the capacitor bank 5. INCLUDING MV SUPPLY BAY 6. INCLUDING 10 MV/LV POLE MOUNTED TRAFOS (630 KVA) 7. INCLUDING THE ADDITION OF 3 KM OF MV SPUR LINES		Implementation of a 30-34.5 kV three-phase independent line of 15.58 km + 70 km length to supply the unelectrified villages (4MW in tot) with: I. all aluminium alloy conductor of about the same cross-section (95 mm^2) supported by galvanized steel lattice poles and isolators II. including the capacitor bank III. including the MV supply bay IV. INCLUDING 10 MV/LV POLE MOUNTED TRAFOS (630 KVA)	
1	(0.3 + 0.6 + 0.25)€/M x 85.58x10^3 M = 98,417 €	I	18.505 €/m x 102 x 10^3 M = 1,583,658 €
2	37,500 €		/
3	13,400 €		/
4	10,000 €	II	8,400 €
5	45,000 €	III	30,000 €
6	11,937 € x 10= 119,370 €	IV	11,937 € x 10= 119,370 €
7	15.664 €/m x 3 x 10^3 M = 31,328 €		/
	370,679 €		**1,622,057 €**
	23%		**100%**

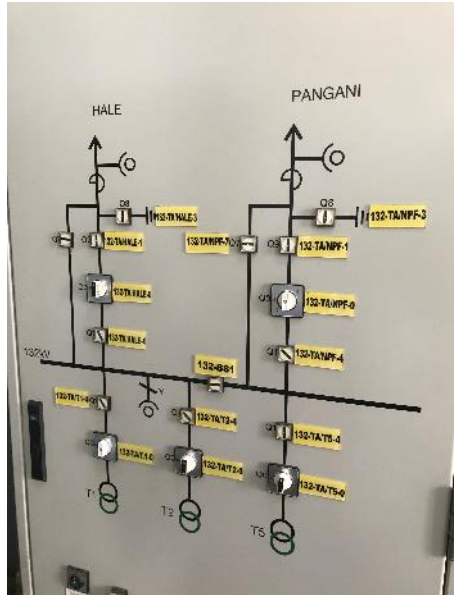
List of Sized Technical Components
MV convetional line - Overhead conductors - Support/Poles - Insulated supports
MV/LV pole mounted trafo
MV supply bay (involving SAs, CBs, Isolators, etc)
Capacitor Bank

Tanga ISWS Demo Project – Survey of Sapienza, UDSM, Tanesco

Chalinze – Hale – Tanga 132 kV (overloaded) Transmission Line

Very Low Expected Load in Shinyanga Region: TANESCO suggests a different demo project

Needs of power supply in Tanga Region (rural areas, industries, mining sites, hotels) along the route of the old 132 kV HV TL Chalinze-Hale-Tanga



Joint Survey of Tanesco, UDSM (prof. Kihwele) and Sapienza (prof. Santi): ensured pre-feasibility

Conclusions and Perspectives

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- **ISWS is a precious legacy from Professor Francesco Iliceto**, a giant in power system studies
  - He did not register any patent
  - He left a fund to promote power system studies in developing countries (capacity building) and to support poor electrical engineering students (*Francesco Iliceto Association*)

- ISWS is **the cheapest technology** to electrify the rural communities «*under the grid*» (along HV TLs, in a strip of about 100km around the line). The investment cost of ISWS is **10%-15%** of the conventional MV electrification techniques

- Compared to the conventional methods ISWS ensures:
  - the same **power quality**,
  - the same **safety**,
  - a reduced **environmental impact**,
  - a reduction in electrical **losses**,
  - a reduction in **voltage drop**.

- For developing countries / rural areas with low-density population (i.e. Sub-Saharian Africa) ISWS can be an important enabling factor of microgrids and renewables, a **«leap-frog»** towards a sustainable power system (SDG n.7)

«Lusu» substation - Day 11° of July - Prof. Santos Kiwhele with the 3 graduate students Ester (CoET-UDSM), Sara (Sapienza) and Heavenlight (CoET-UDSM)