Managing variability – key to a renewable energy future

Dr Bernard Bekker

7 June 2019

CENTRE FOR RENEWABLE AND SUSTAINABLE ENERGY STUDIES

Eskom

science & technology
Department: Science and Technology
REPUBLIC OF SOUTH AFRICA

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The Centre for Renewable and Sustainable Energy Studies was established in 2007 to facilitate and stimulate activities in renewable & sustainable energy study and research at Stellenbosch University.

The Department of Science and Technology has been funding the Energy Research Programme (ERP) at Stellenbosch University since its establishment in August 2006.

Stellenbosch University was designated as the Specialisation Centre in Renewable Energy as part of the Eskom Power Plant Engineering Institute (EPPEI), focusing primarily on the integration of renewable energy technologies into the national electricity grid, and includes the Eskom Chair in Power System Simulation.

TRAINING
Facilitate, coordinate and fund the training of students, interns and industry

RESEARCH
Influence research focus areas and unlock research funding opportunities

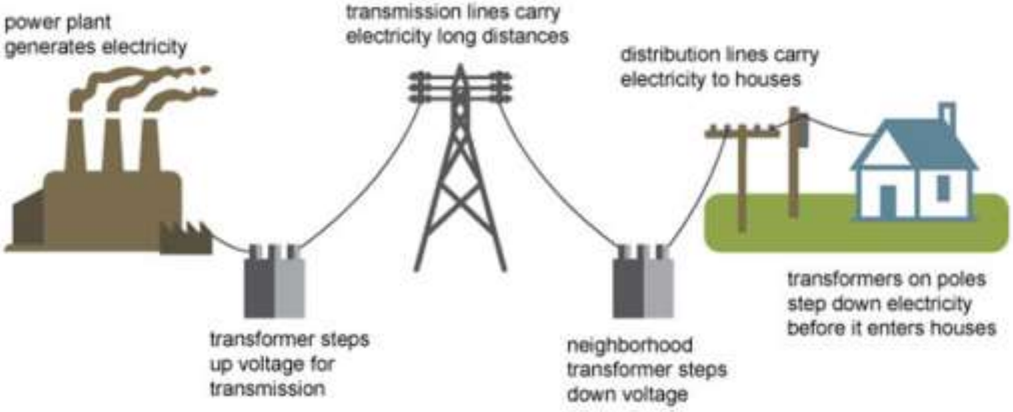
FLAGSHIP PROJECTS
Initiate and drive national flagship projects

AWARENESS
Increase public and institutional awareness and understanding

CONSULTING
Conduct contract research and specialist consulting projects

The traditional power system

- One of the largest and most complex machines ever built



Clark W. Gellings, “The Smart Grid: Enabling Energy Efficiency and Demand Response”, 2009
Adapted from National Education Development Project (public domain)

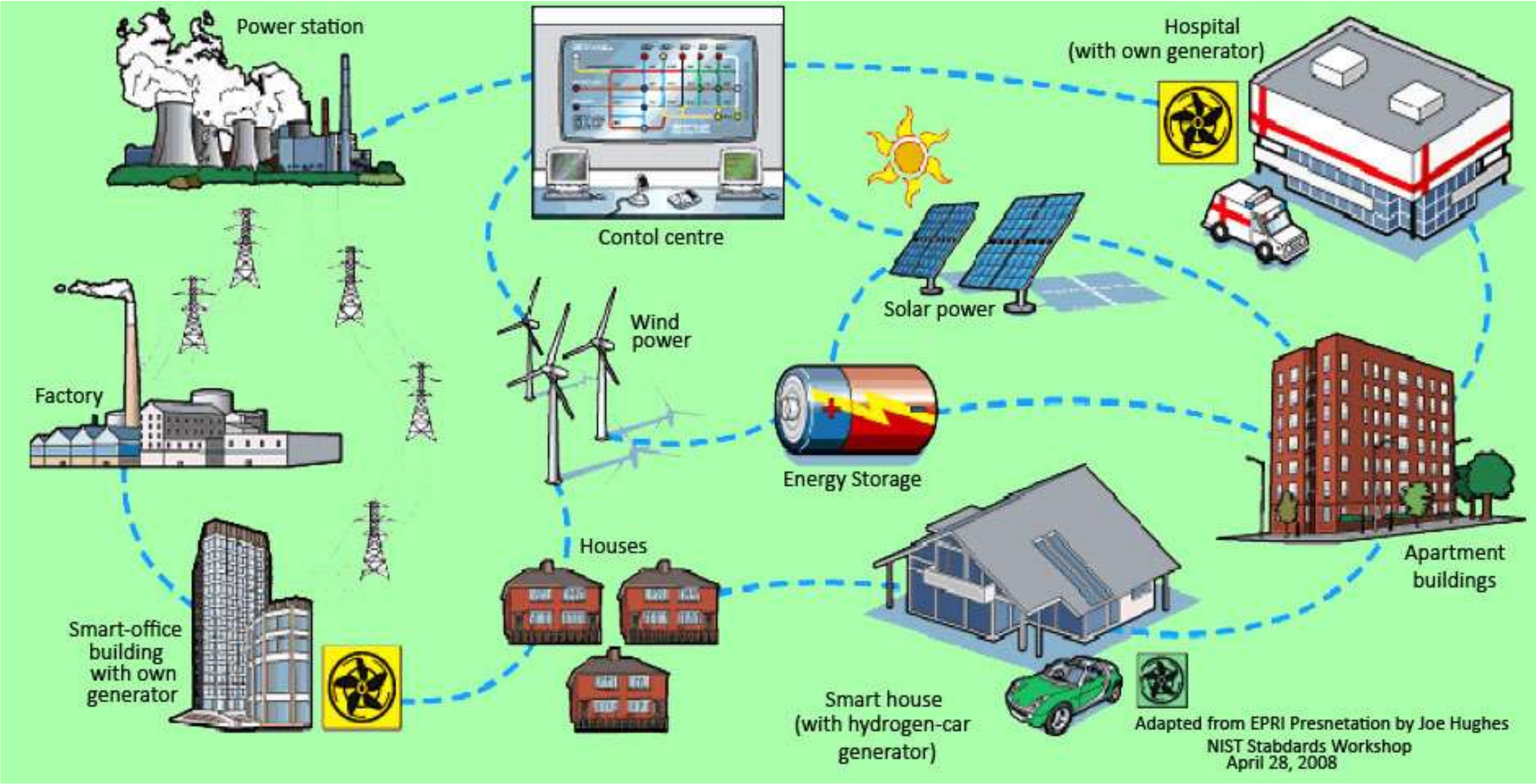
The future power system

variability

/vɛːrɪəˈbɪlɪti/

noun

1.lack of consistency or fixed pattern; liability to vary or change.



Google Dictionary

The future power system

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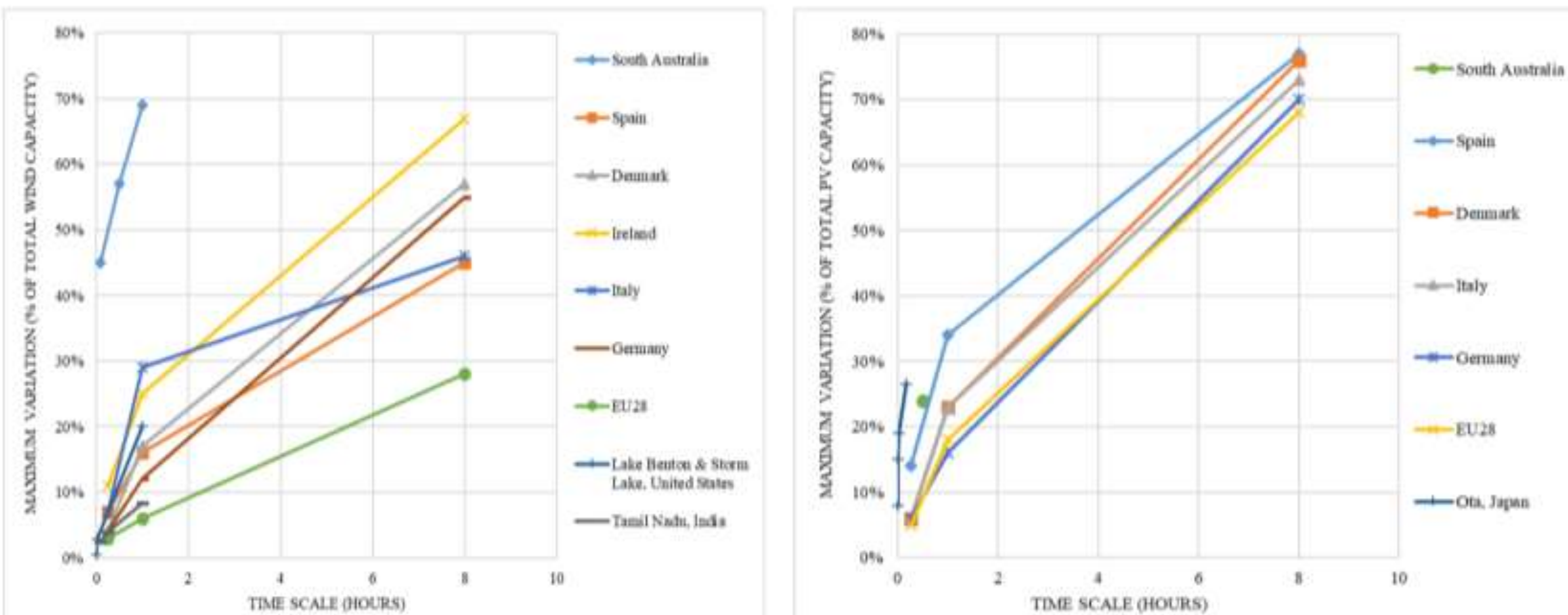
1.lack of consistency or fixed pattern; liability to vary or change.



a) Wind

b) Solar

Google Dictionary

Mararakanye & Bekker 2019 - A conceptual framework for assessing the impact of intermittent renewable energy systems on the grid, RSER journal

Roadmap

PERSPECTIVES

End-user (rooftop owner)

Distribution utility (e.g. municipality)

System operator (e.g. Eskom)

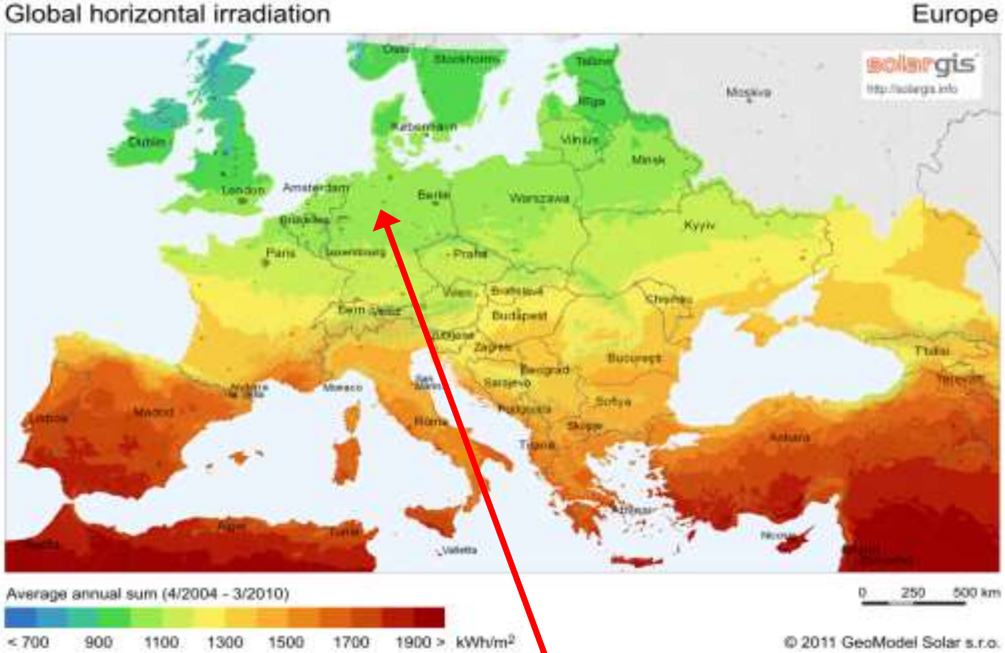
Return on investment

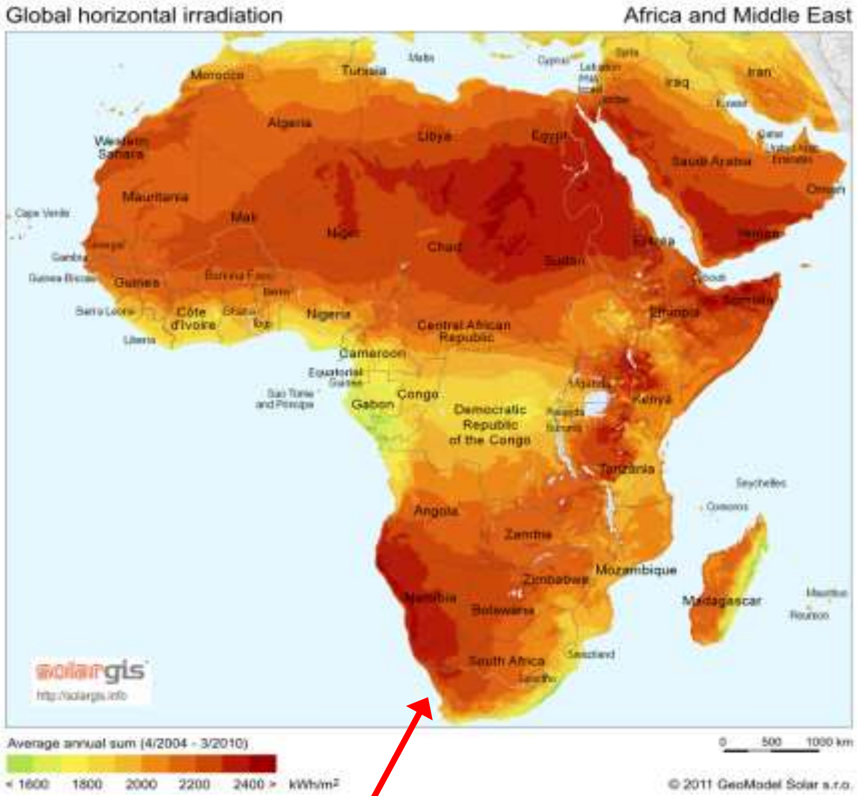
Safety & quality of supply

System stability

VARIABILITY’S IMPACT ON:

Solar resource



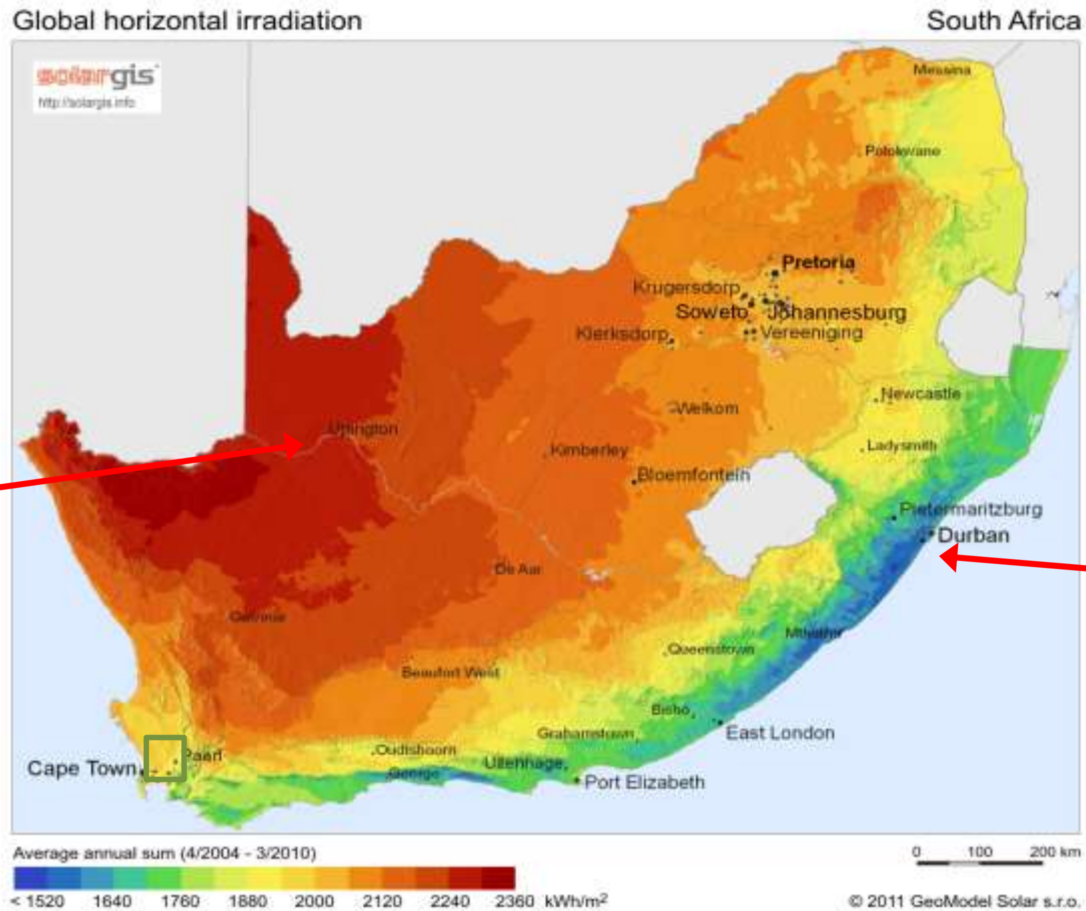


Germany total installed PV: ~40 GWp
Total electricity capacity: ~200 GW

South Africa total installed PV: ~2 (1.5+0.5) GWp
Total electricity capacity: ~50 GW

2018 Draft IRP PV by 2030: ~10.6 (8+3) GWp

Solar resource

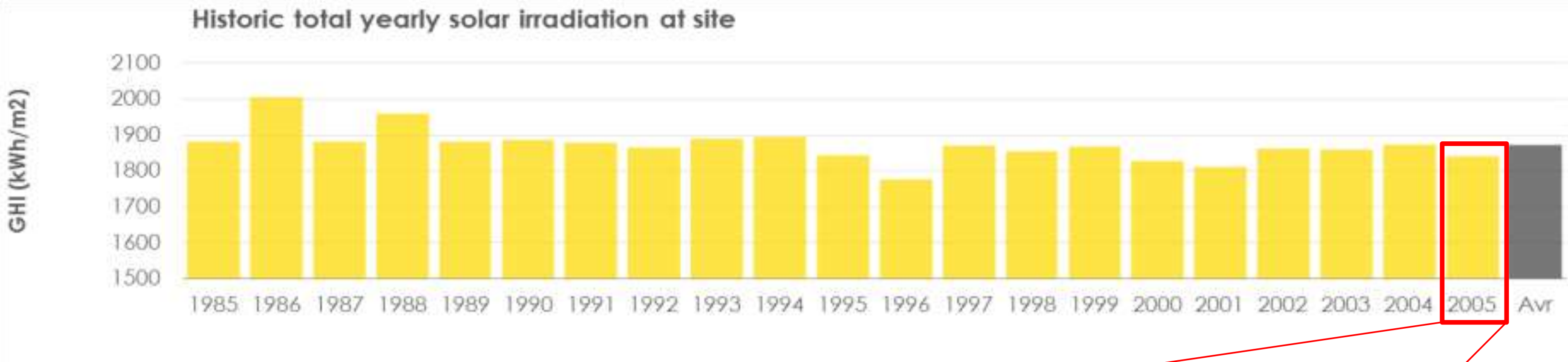


Upington:
2200 kWh/m2/a

Durban: 1600 kWh/m2/a

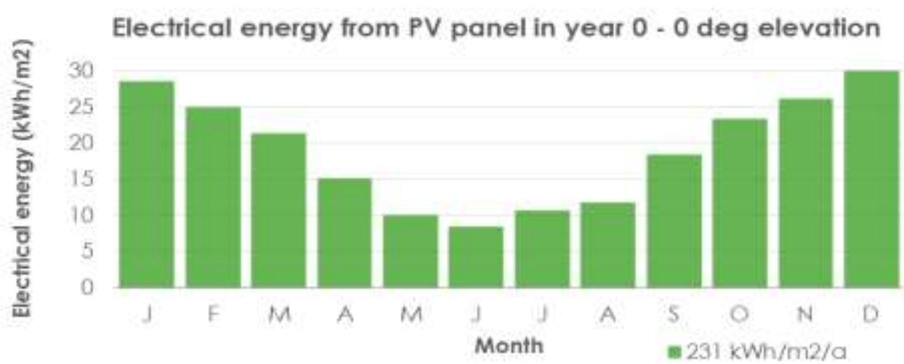
Cape Town: 1880 kWh/m2/a

Solar resource for Cape Town



PV basics

6% to 22% efficiency



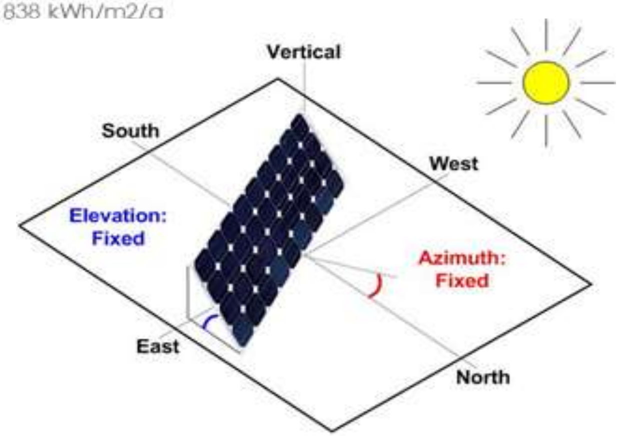
PV basics - materials

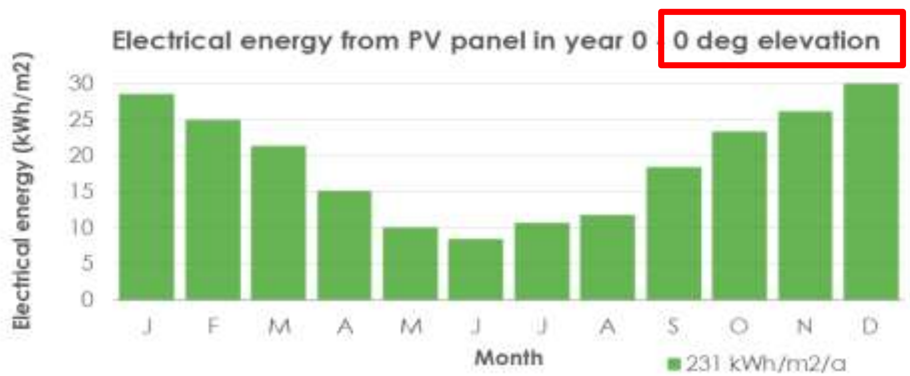
Mono-crystalline
13% - 22%

Poly-crystalline
11% - 18%

Amorphous thin-film
6% - 12%

PV basics - orientation





PV basics - orientation

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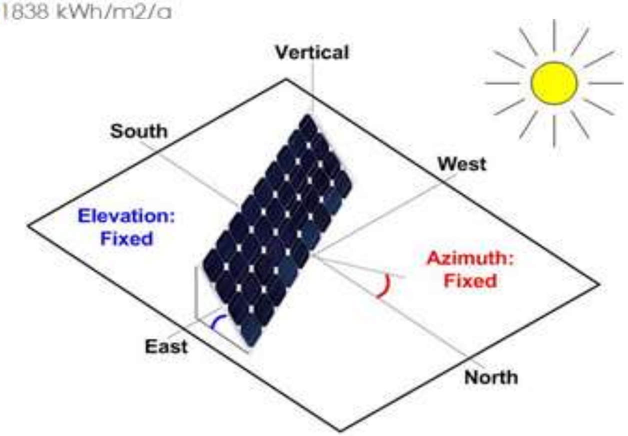
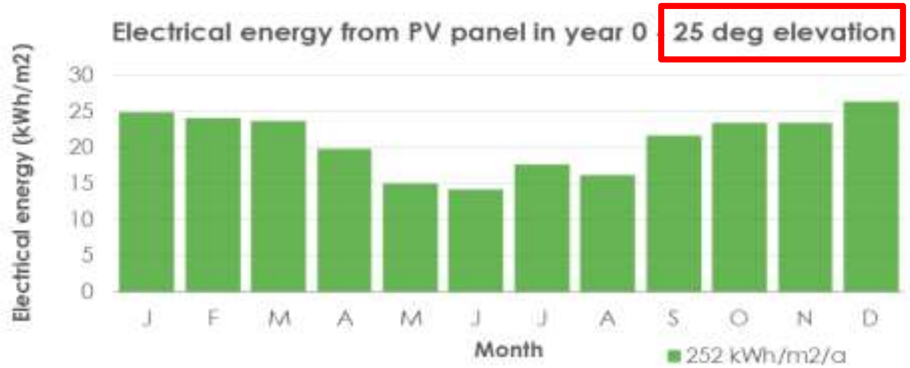
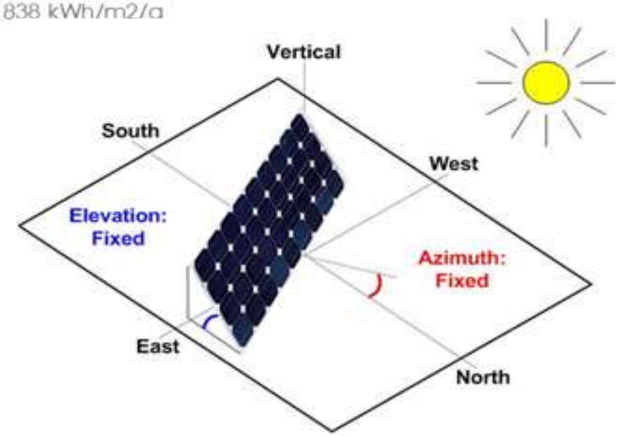
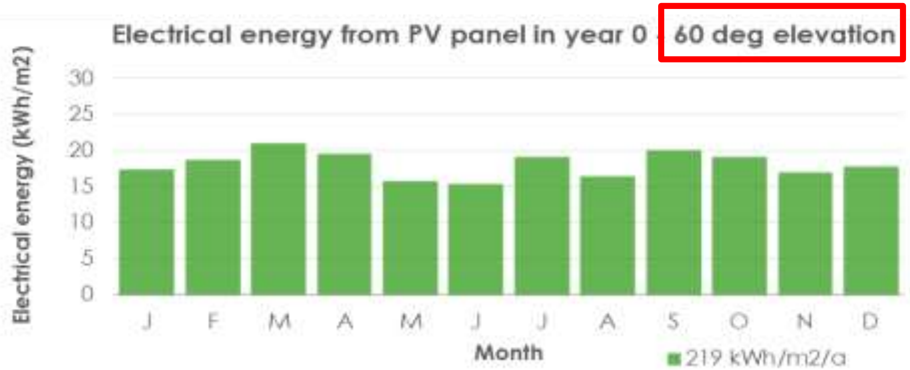


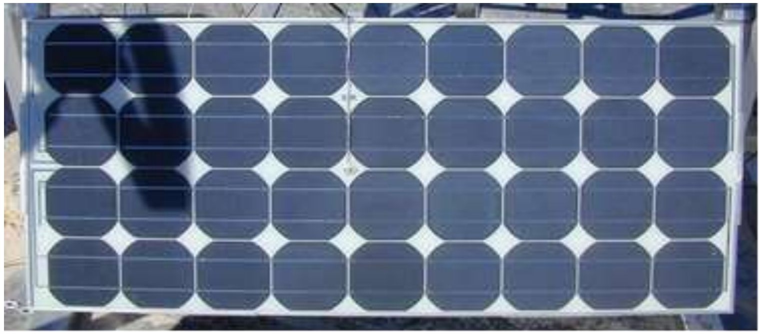


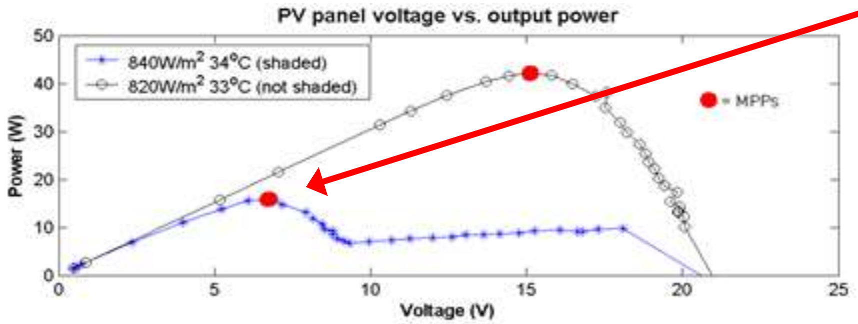
PV basics - orientation



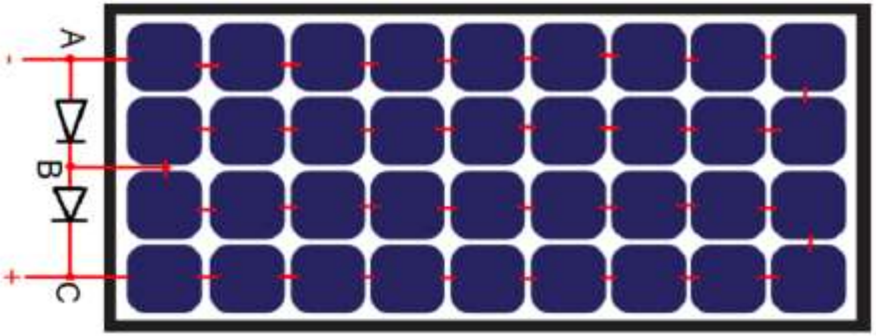


PV basics - shading



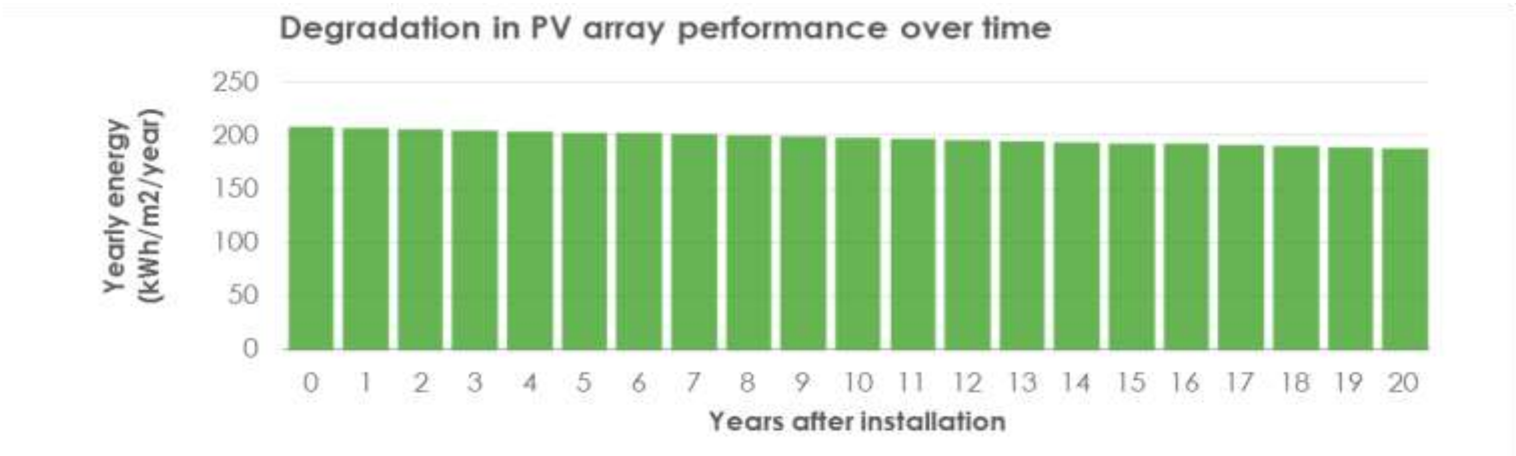


10% shade =
60% less power

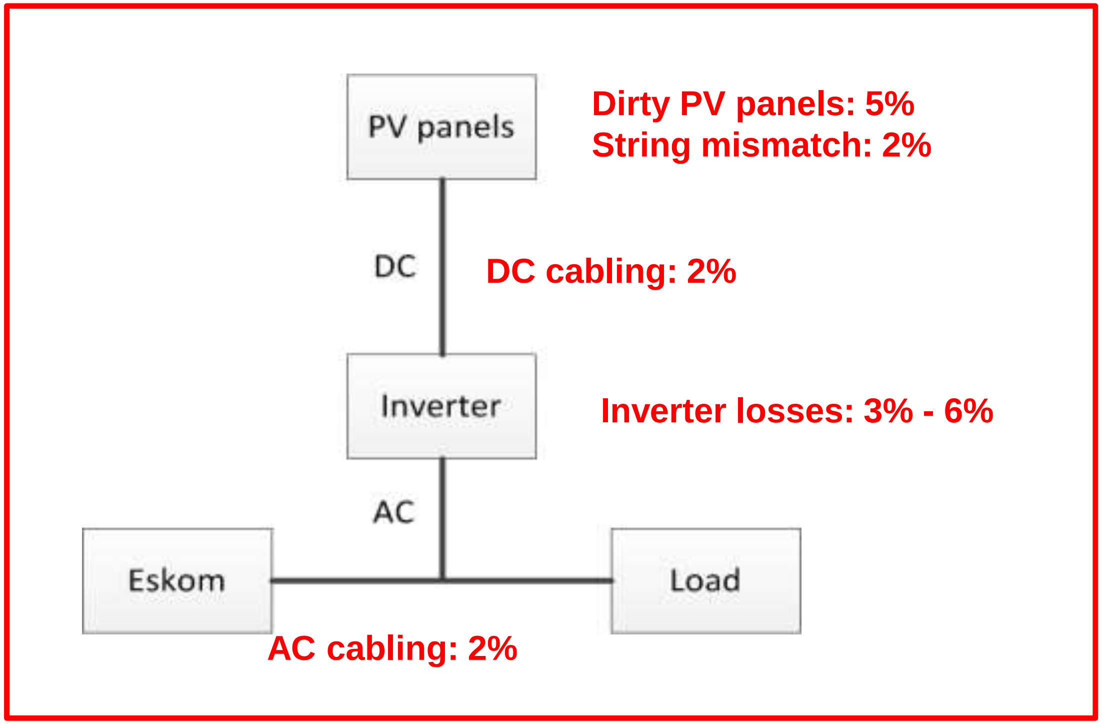


PV system configurations

Degradation: 0.5% per year



PV & hybrid system configurations



System availability: 98%

PV losses

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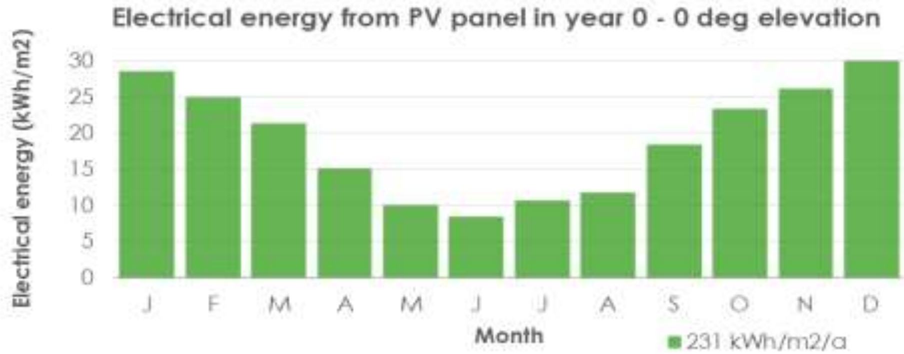
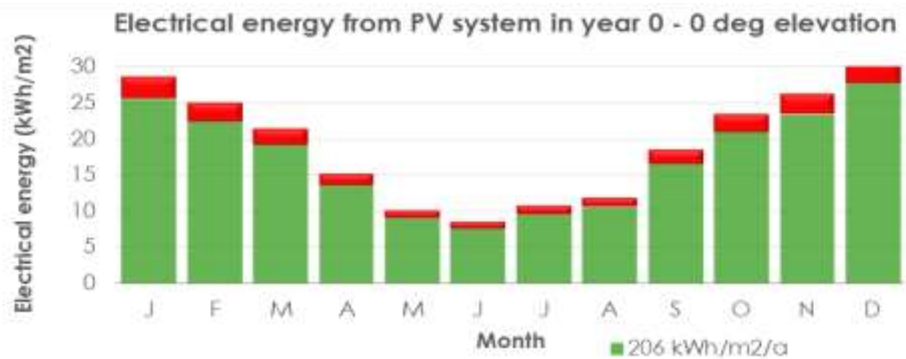
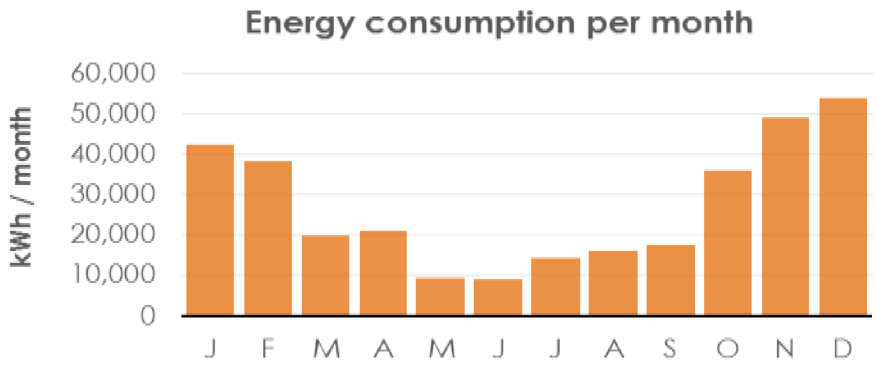


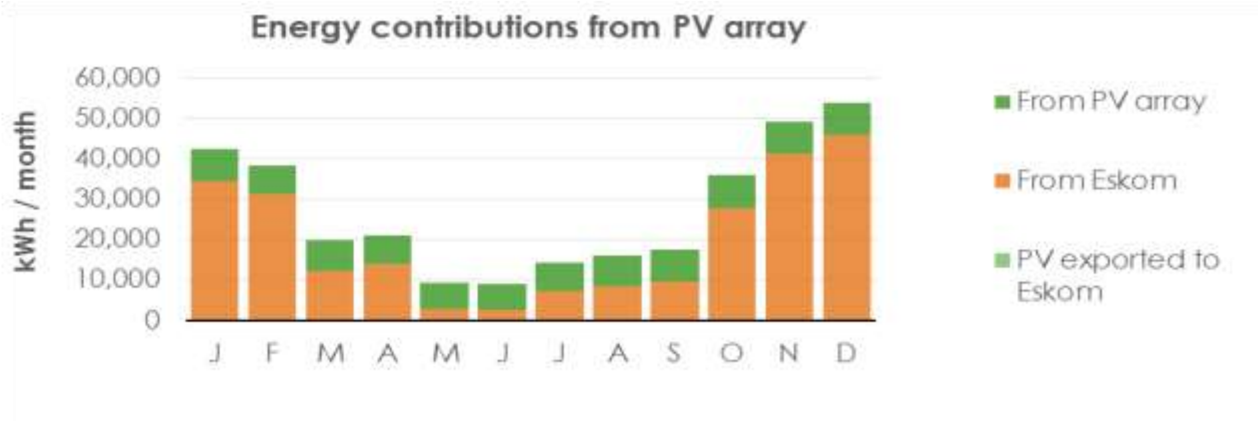


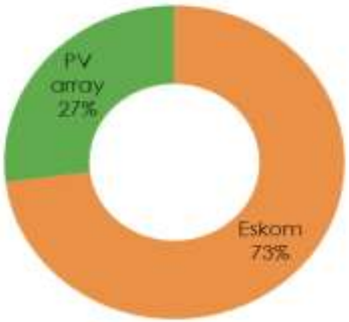
System sizing



System sizing

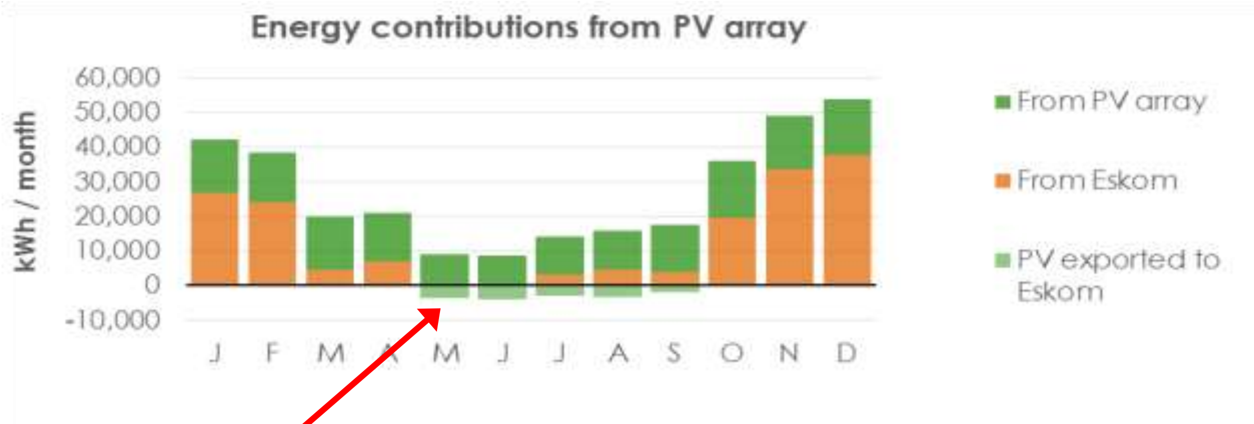
50 kWp solar PV:



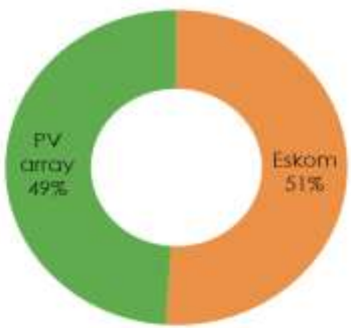


System sizing

100 kWp solar PV:

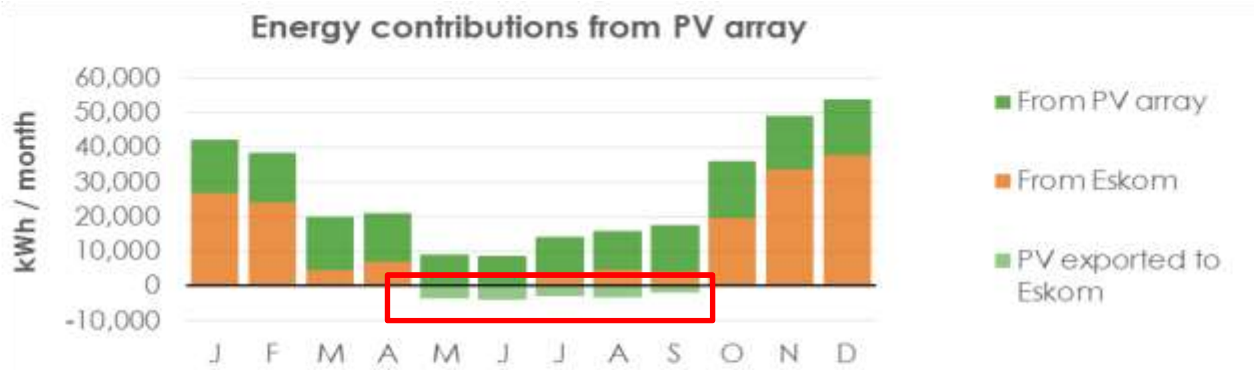


Limited financial benefit…

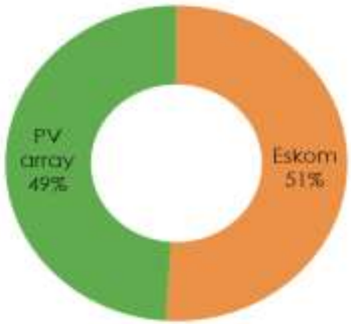


Batteries to increase self-consumption

100 kWp solar PV:

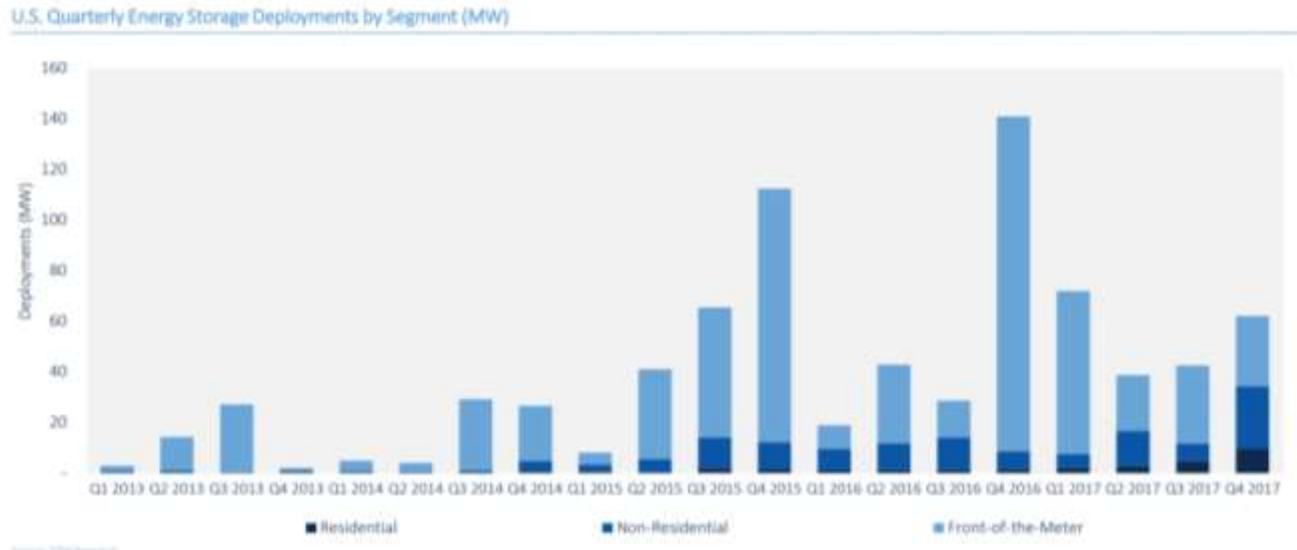


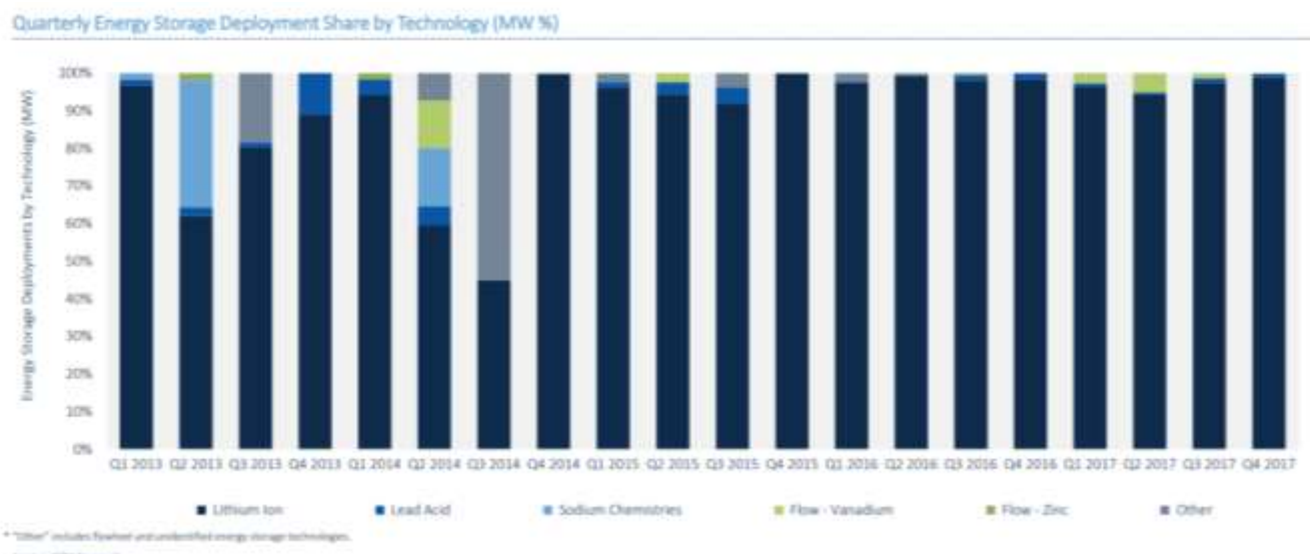
Store in batteries instead of exporting, and use later



Storage – technical aspects governing ROI

- Lead-acid versus Li-ion?





Roadmap

PERSPECTIVES

End-user (rooftop owner)	Distribution utility (e.g. municipality)	System operator (e.g. Eskom)

Return on investment	Safety & quality of supply	System stability

VARIABILITY'S IMPACT ON:

PV and batteries on distribution networks

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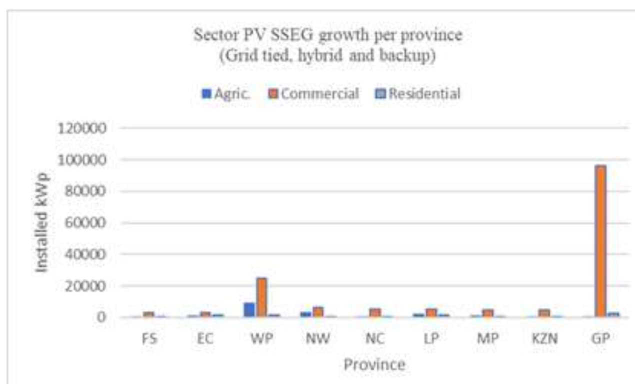
- PV on distribution networks increasing
  - 85% of PV capacity in Germany is produced by installations < 1MW
  - 98% of installed PV (~40GW) connected to LV and MV networks

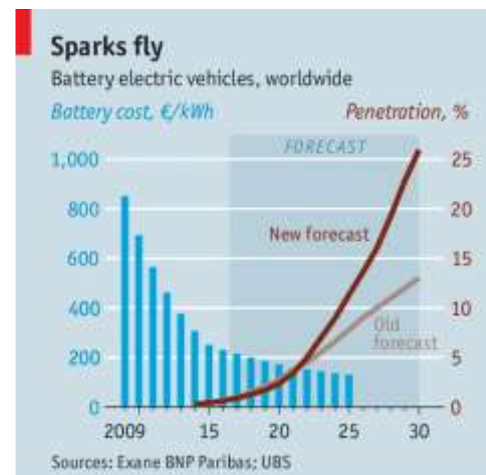
- Batteries and electric vehicles on LV and MV increasing
  - Eskom currently rolling out 360MW / 1440MWh batteries

PQRS Estimated South African SSEG Capacity

Year	Verified Installations (kWp)	Estimated growth per year (kWp)
2010	465	1 107
2011	877	2 090
2012	1 339	3 090
2013	9 561	22 784
2014	11 209	26 713
2015	43 570	103 831
2016	50 355	120 000
2017		136 000
Total		**415 615**

SSEG PV: 415MWp by end 2017

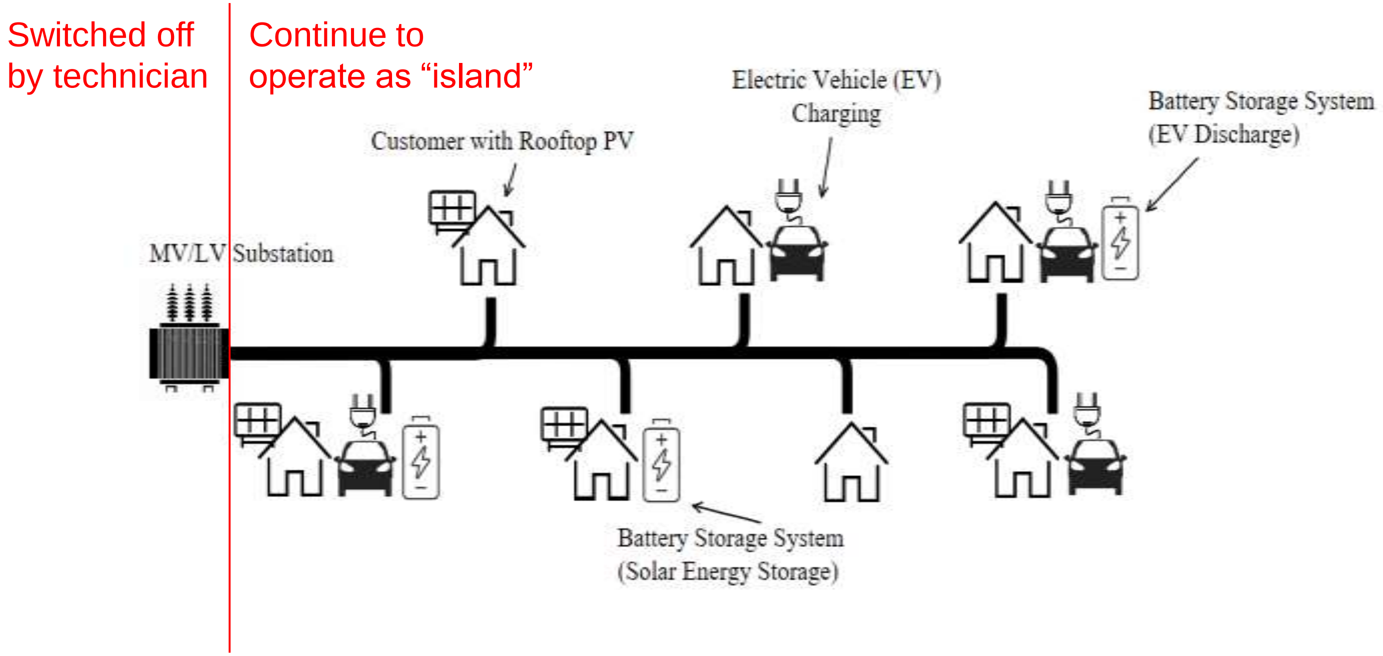




Waswa & Bekker 2018 , IMPACT OF PV SMALL SCALE EMBEDDED GENERATION ON SOUTH AFRICA'S SYSTEM DEMAND PROFILE
I Pérez Arriaga and C. Knittel et al, Utility of the Future. An MIT Energy Initiative response. 2016.
PQRS – Carel Ballack

Safety on the future distribution network

- Distributed generation and storage increases the risk of "islanding": where islands of power remain after technicians have switched off network sections



Safety on the future distribution network

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All installed LV inverters must be certified against this standard

NRS 097-2-1:2017
Edition 2

GRID INTERCONNECTION OF EMBEDDED GENERATION

PART 2: SMALL-SCALE EMBEDDED GENERATION

SECTION 1: UTILITY INTERFACE

This document is not a South African National Standard

4.2.2 Safety disconnect from utility network

4.2.2.1 General

4.2.2.1.1 All SSEG shall comply with the safety requirements in accordance with SANS/IEC 62109-1 and IEC 62109-2.

NOTE In principle, IEC 62109 documents only apply to PV inverters. However, other SSEG shall prove compliance to these safety requirements to the satisfaction of the utility.

4.2.2.1.2 The embedded generator shall automatically and safely disconnect from the grid in the event of an abnormal condition. Abnormal conditions include:

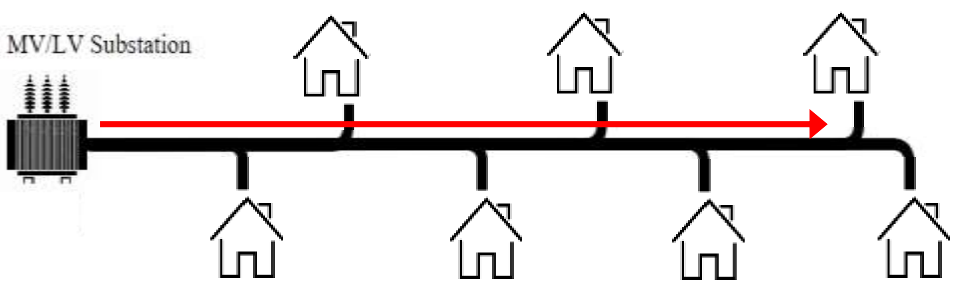
a) network voltage or frequency out-of-bounds conditions,
b) loss-of-grid conditions,
c) d.c. current injection threshold exceeded (per phase),
d) and residual d.c. current (phase and neutral currents summated).

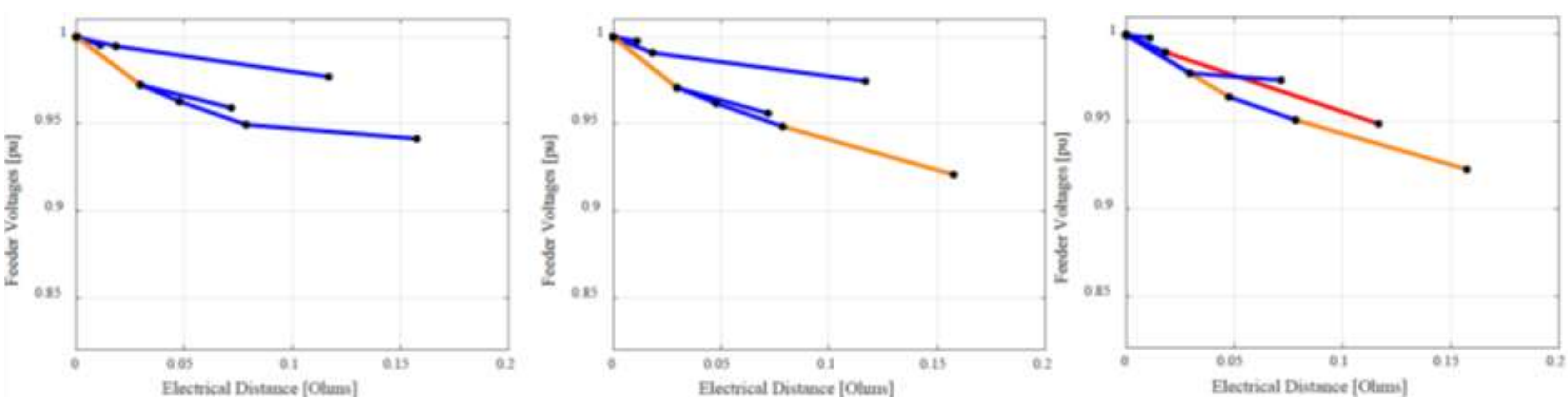
4.2.2.2 Disconnection device (previously disconnection switching unit)

4.2.2.2.1 The embedded generator shall be equipped with a disconnection device, which separates the embedded generator from the grid due to abnormal conditions. The disconnection unit may be integrated into one of the components of the embedded generator (for example the PV utility-

QoS on the future distribution network

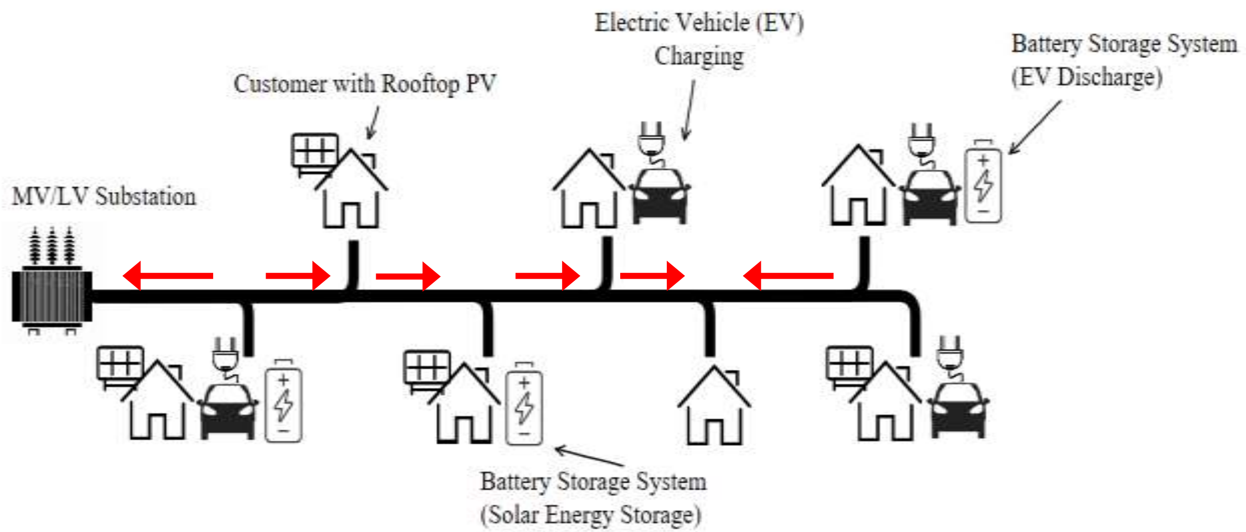
- Traditionally current flowed in one direction: from power stations to loads
  - Networks designed to maintain voltage and currents within specific bounds

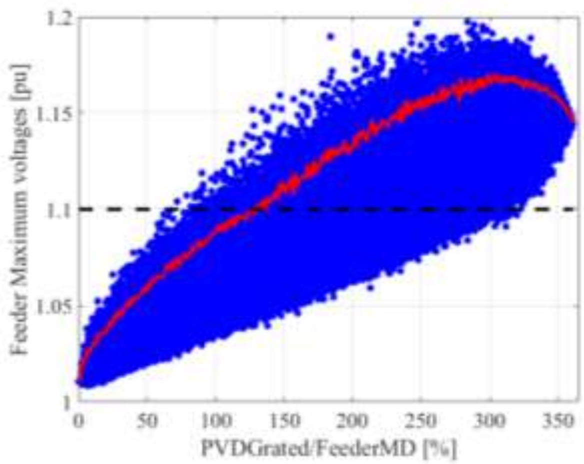


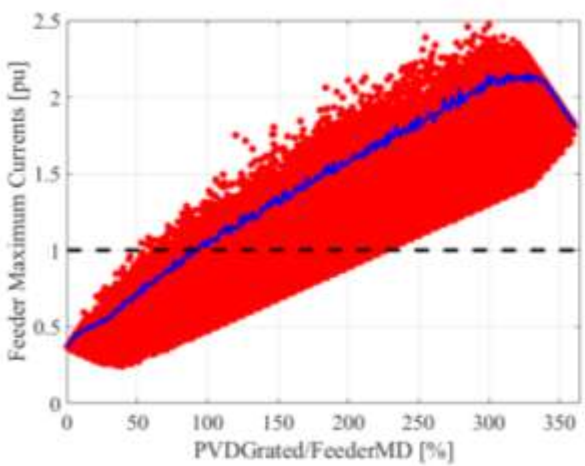


QoS on the future distribution network

- Future flow bi-directional: impacts difficult to model / predict







QoS on the future distribution network

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- Short-term solution: simplified connection criteria limits PV installation size

NRS 097-2-3:2014

Edition 1

GRID INTERCONNECTION OF EMBEDDED GENERATION

Part 2: Small-scale embedded generation

Section 3: Simplified utility connection criteria for low-voltage connected generators

This document does not have the status of a South African National Standard.

All LV PV installations limited to these sizes (unless further study is done by customer)

Table 1 — Maximum individual generation limit in a shared LV (400 V/230 V) feeder

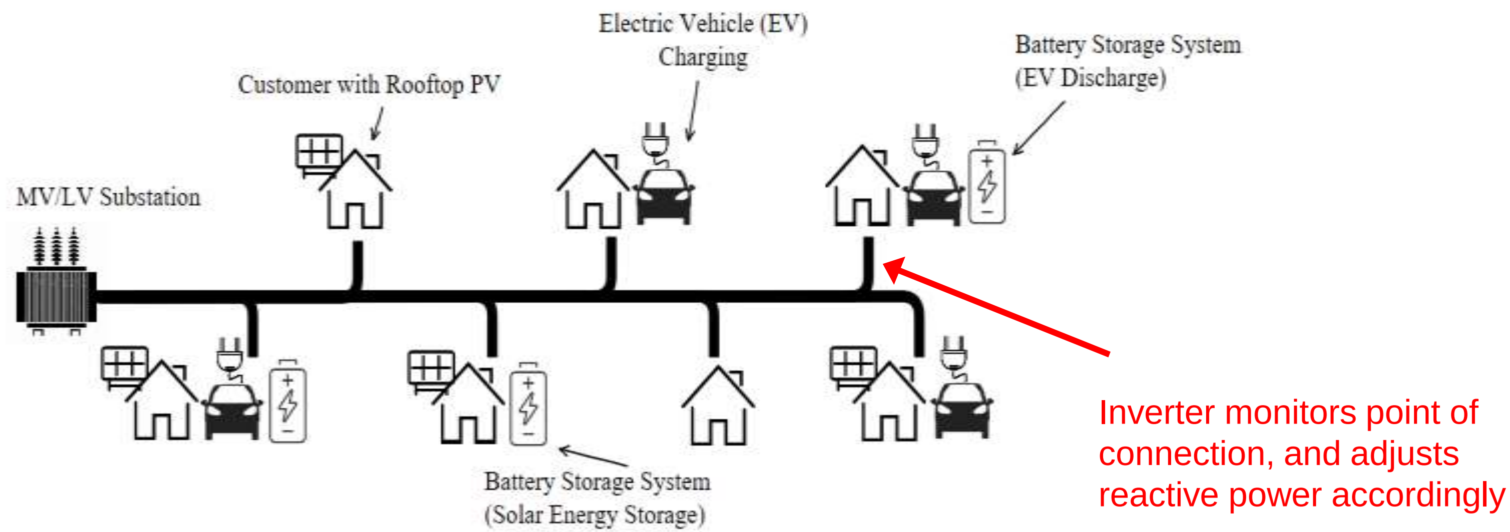
1	2	3	4
Number of phases	Service circuit-breaker size	NMD kVA	Maximum individual generation limit kVA
1	20 A	4,6	1,2
1	60 A	13,8	3,68
1	80 A	18,4	4,6
3	60 A and 80 A	41,4	13,8 (4,6 per phase)

4.2.3 In shared LV feeders, any generator greater than 4,6 kVA should be balanced across phases.

4.2.4 In the case of LV customers with supplies greater than those given in table 1, the maximum individual generation limit in a shared LV feeder is 25 % of the customer's NMD. For example, a LV customer with a 100 kVA NMD supplied through a shared LV feeder could connect up to 100 × 25 % = 25 kVA of generation. Since 25 kVA is greater than the 20 kVA limit for a shared

QoS on the future distribution network

- Long-term solution: intelligent inverters that automatically assist the network to maintain QoS



Roadmap

PERSPECTIVES

End-user (rooftop owner)

Distribution utility
(e.g. municipality)

System operator
(e.g. Eskom)

Return on investment

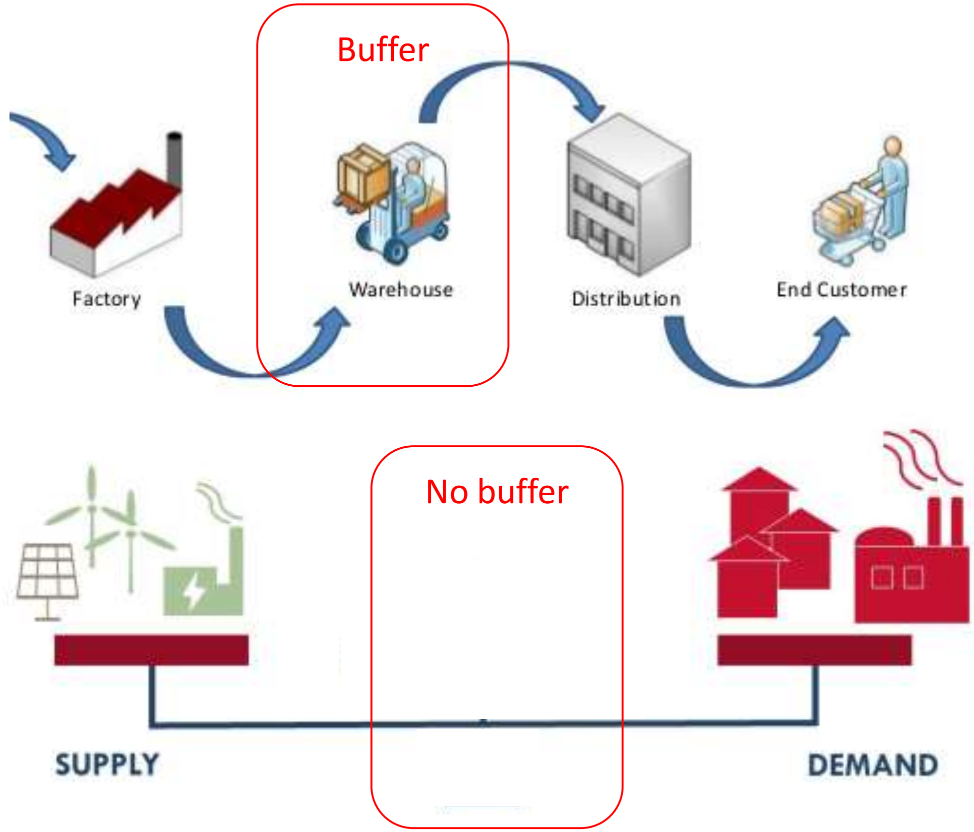
Safety & quality
of supply

System
stability

VARIABILITY’S IMPACT ON:

Ensuring system stability

- In electric power systems a direct interdependency between supply and demand exists: no buffers
  - traditionally little control over demand, so supply must be controlled, or "dispatched"

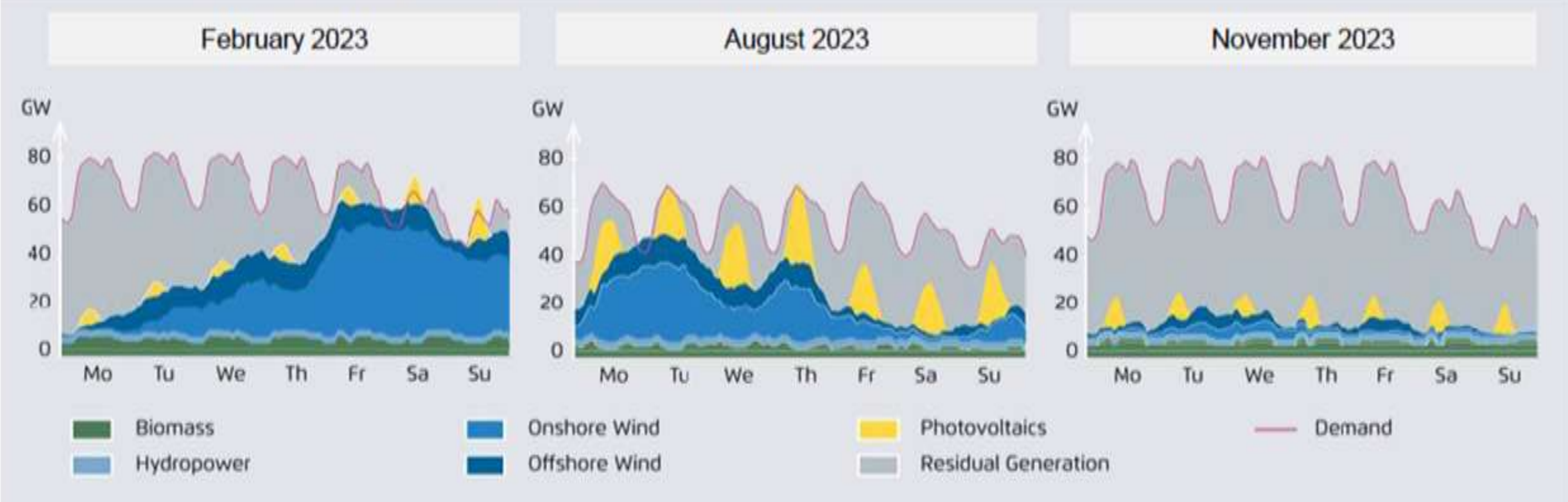


http://energylive.aemo.com.au/Energy-Explained/Managing-frequency-in-the-power-system
Supply chain management presentation, https://www.slideshare.net/hari3hhh/e-scm-45891860

Ensuring system stability

- Optimal dispatch complicated by variable renewable energy (VRE)
  - VRE definition includes both variable (predictable) and intermittent (non-predictable) variations

Electricity generation* and consumption* in three sample weeks, 2023

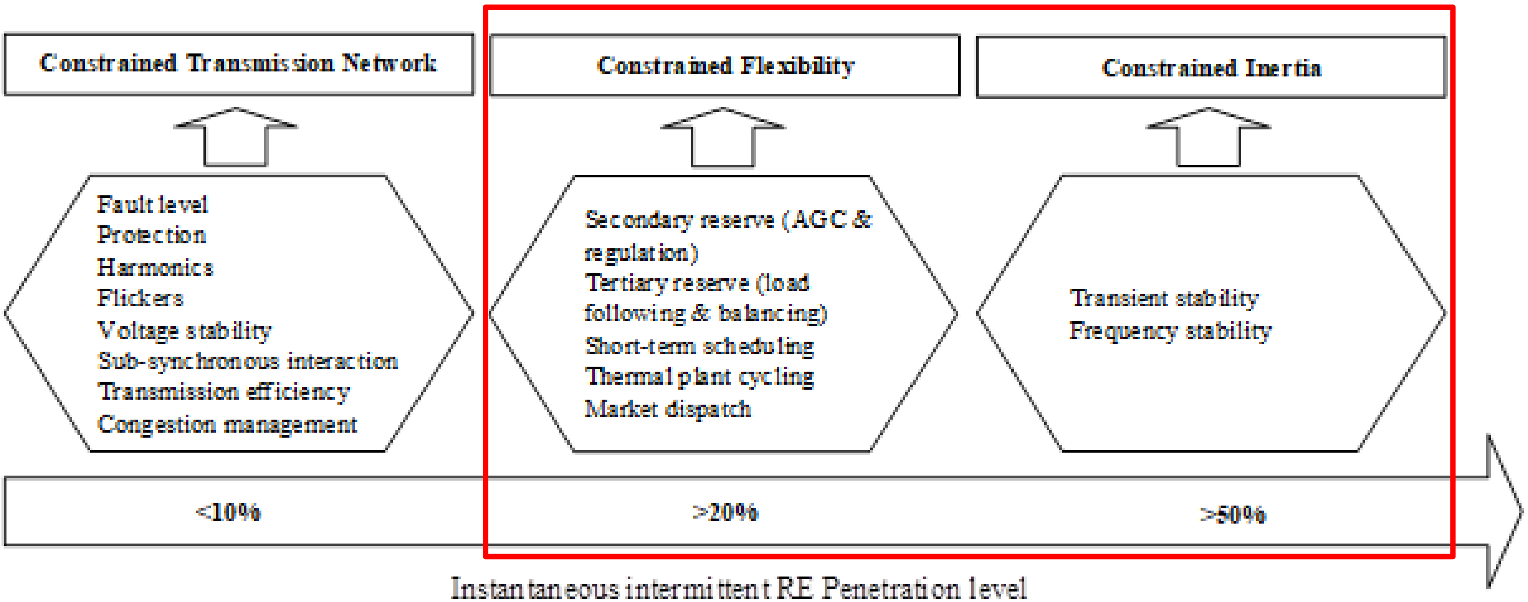


Fraunhofer IWES (2013)

* Modelling based on 2011 weather and load data

Ensuring system stability

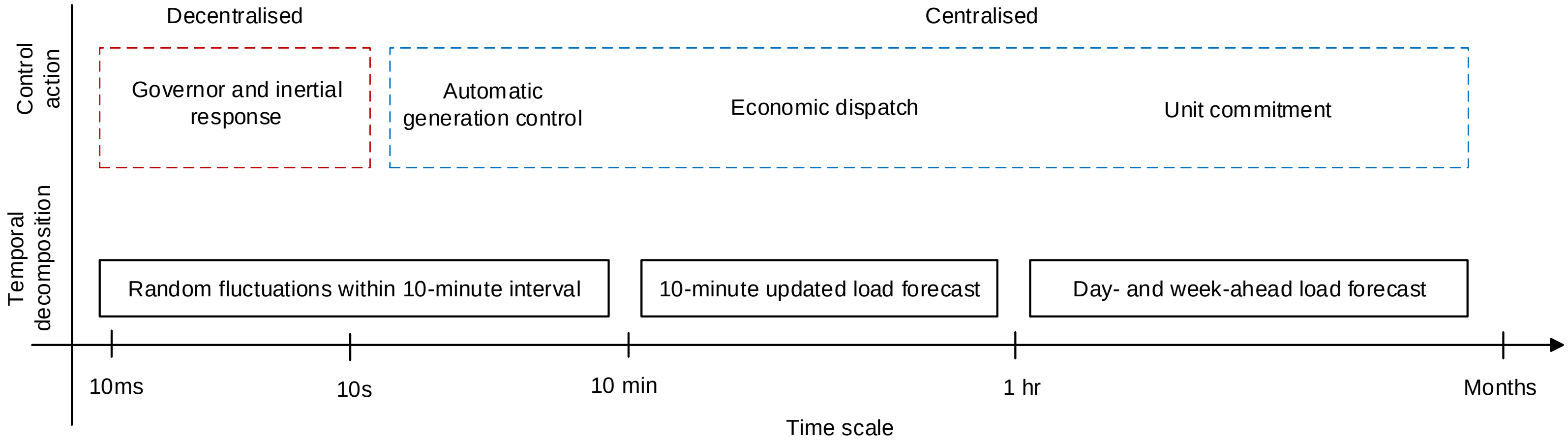
- Only at higher levels of penetration does power system stability become a challenge



Mararakanye & Bekker 2019 - A conceptual framework for assessing the impact of intermittent renewable energy systems on the grid

Ensuring system stability

- As VREs increase, forecasting becomes a critical aspect



Mararakanye & Bekker 2019 – Draft CIGRE colloquium paper

Ensuring system stability

- Grid code and Integrated Resource Plan allocations also become critical

INTEGRATED RESOURCE PLAN 2018

	Coal	Nuclear	Hydro	Storage (Pumped Storage)	PV	Wind	CSP	Gas / Diesel	Other	Embedded Generation
2018	39 126	1 860	2 196	2 912	1 474	1 980	300	3 830	499	Unknown
2019	2 155					244	300			200
2020	1 433				114	300				200
2021	1 433				300	818				200
2022	711				400					200
2023	500									200
2024	500									200
2025					670	200				200
2026					1 000	1 500		2 250		200
2027					1 000	1 600		1 200		200
2028					1 000	1 600		1 800		200
2029					1 000	1 600		2 850		200
2030			2 500		1 000	1 600				200
TOTAL INSTALLED	33 847	1 860	4 696	2 912	7 958	11 442	600	11 930	499	2600
Installed Capacity Mix (%)	44.6	2.5	6.2	3.8	10.5	15.1	0.9	15.7	0.7	

Installed Capacity
Committed / Already Contracted Capacity
New Additional Capacity (IRP Update)
Embedded Generation Capacity (Generation for own use allocation)

Table 7: Proposed Updated Plan for the Period Ending 2030

Ensuring system stability

- Understanding of the aggregation effect of siting of Independent Power Producers

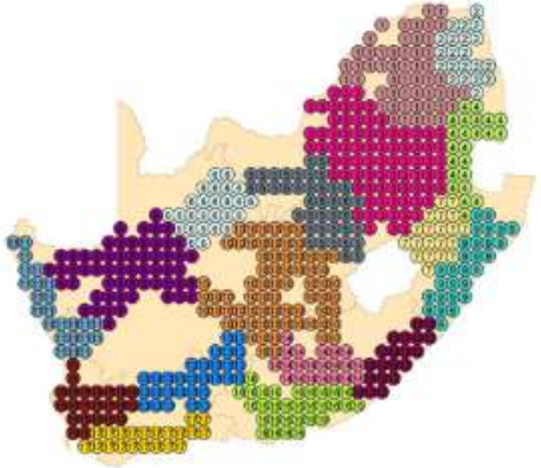
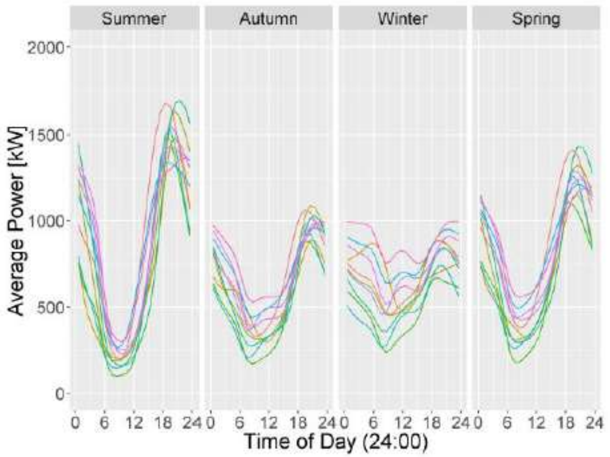


Fig. 9.23 Spatial distribution of solar photovoltaic site clusters obtained using Ward's method for 17 clusters.



Cluster 3: 10 Sites

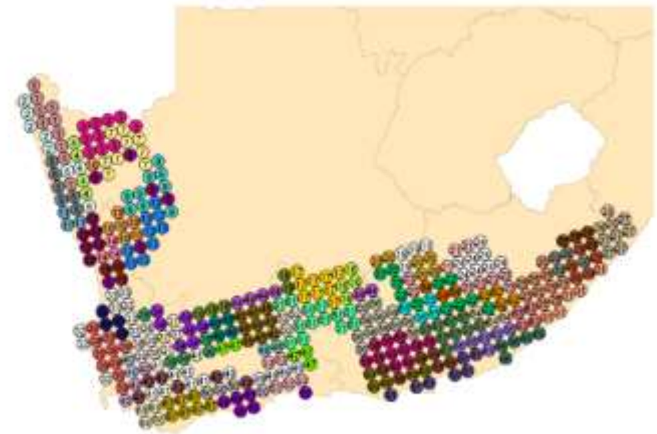
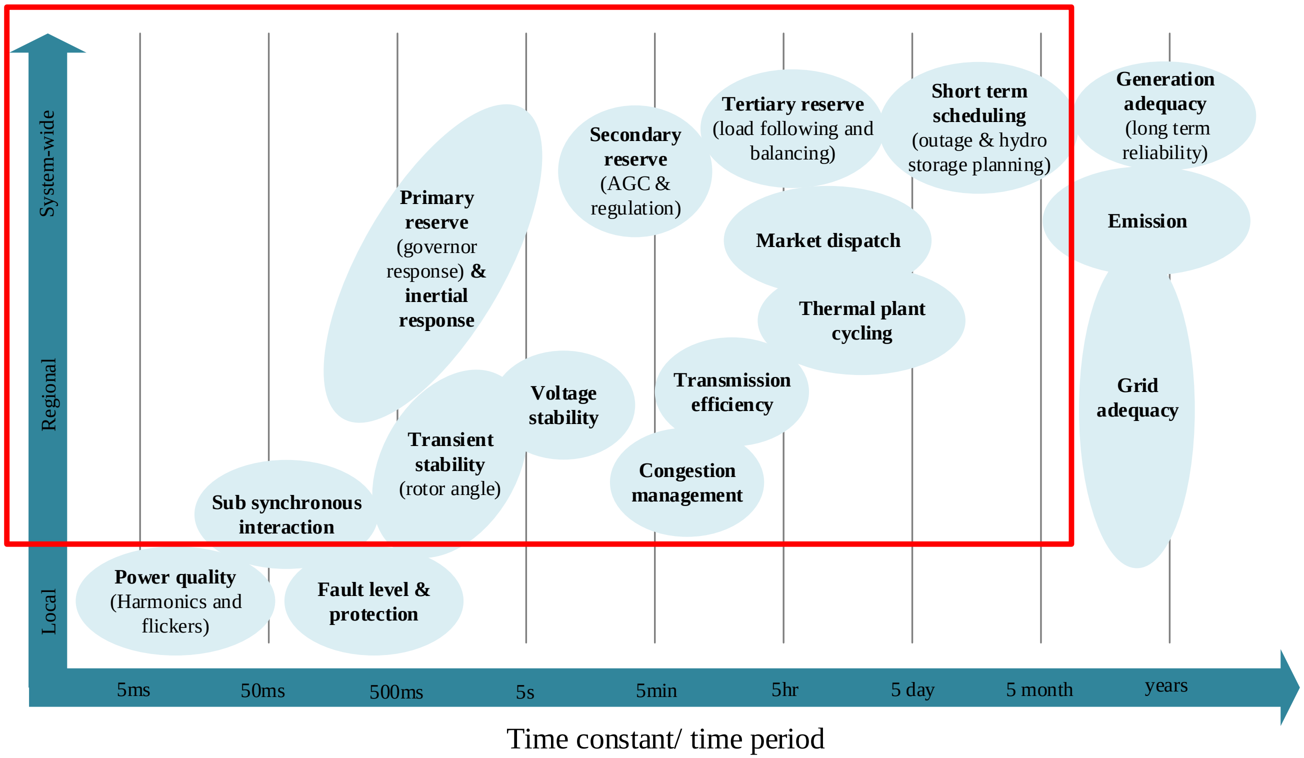


Fig. 9.14 Spatial distribution of wind site clusters obtained using Ward's method for 69 clusters.

Chris Joubert and Prof Johan Vermeulen 2017 - Geographical Location Optimisation of Wind and Solar Photovoltaic Power Capacity in South Africa using Mean-variance Portfolio Theory and Time Series Clustering

Other system operator challenges

- Optimal dispatch not the only challenge…



Mararakanye & Bekker 2019 - A conceptual framework for assessing the impact of intermittent renewable energy systems on the grid

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(e.g. municipality)

System operator
(e.g. Eskom)

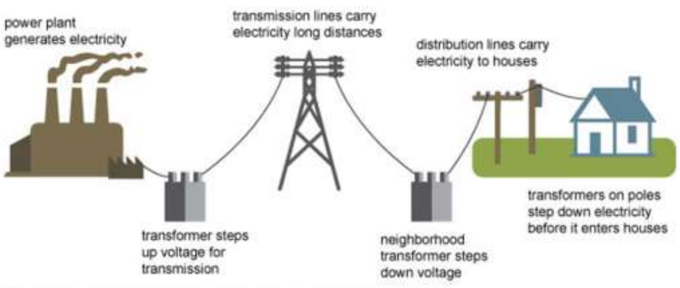
Return on investment

Safety & quality
of supply

System
stability

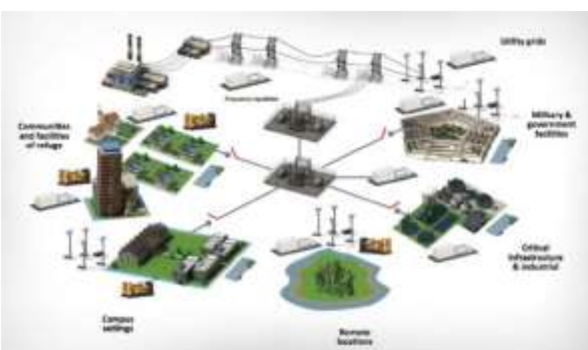
VARIABILITY'S IMPACT ON:

Conclusions



TRADITIONAL POWER SYSTEM

FUTURE POWER SYSTEM



For a successful transition

- Manage variability through:
  - Improved technology & data analytics
  - Updated regulations and standards

- Continuous dialogue between stakeholders are key
  - Academia – Industry collaboration
  - EPPEI specialisation centre in RE
  - Eskom chair in Power System Simulation
  - Scatec Solar chair
  - Muncipality – University forum

Clark W. Gellings, "The Smart Grid: Enabling Energy Efficiency and Demand Response", 2009
Adapted from National Education Development Project (public domain)
http://www.eaton.com/RU/ecm/groups/public/@pub/@ftc/documents/content/pct_1760115.jpg

Questions?

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