Integrated Resource Planning Training for Decision Makers

Day 1, Session 2 Generation and transmission planning - the heart of an IRP

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Content and objective

- Content:
  - Why is it important to develop an Integrated Resource Plan (IRP)?
  - What information is available in an IRP that can help decision making?
  - Main elements of an IRP
  - What is wrong with Levelised Costs of Energy (LCOE) and why more sophisticated modelling is needed for least-cost planning?

- Objective:
  - The objective of this session is to understand:
    - What is an IRP and its main elements
    - Why an IRP may be a useful tool
    - What information an IRP can provide

Electricity's unique properties as a commodity

- There are high fixed-costs to build the necessary infrastructure to transmit and distribute the electricity to end-users.
  - It requires planning looking at the sector in the long run
  - Asset lives more than 20 years
- It cannot be stored as electricity
  - It must be created to be used immediately and the demands varies over short intervals
  - Fly wheels, batteries, pumped storage all convert electricity into other forms of energy and then convert the energy back to electricity
- There is a cost to storage
  - Once electricity is produced, it is impossible to tell which generator produced which electrons once it is pooled in the network.

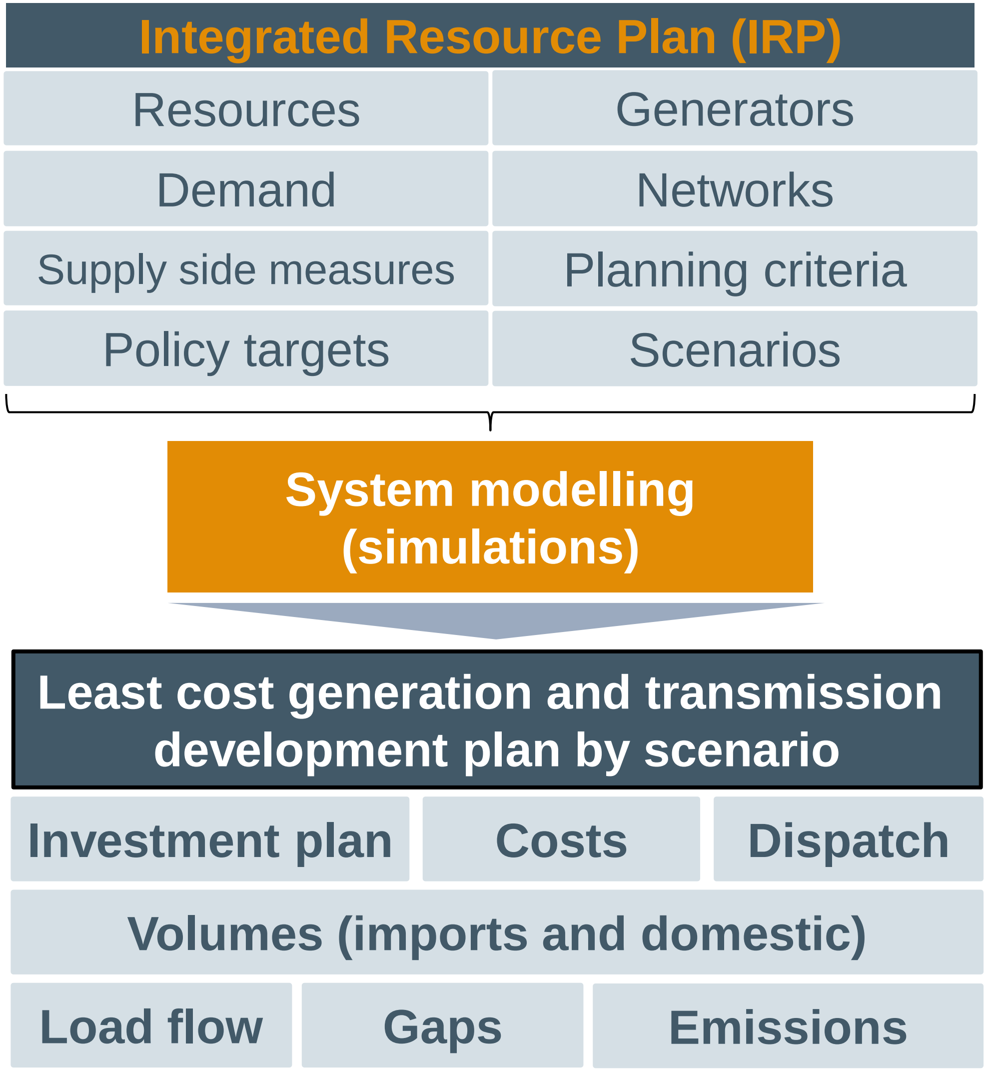
An investment decision taken today will involve high fixed costs and will have an impact in the long run due to long asset lives

Need to assess investment decisions looking the impact in the short, medium and long run

Why is it important to develop an Integrated Resource Plan (IRP)?

Why an IRP is needed:

- Planning by vertically integrated utilities
- Single-buyers deciding what sort of capacity to contract and at what price
- TSOs identifying the best generation locations for network planning
- Interconnection planning with neighbouring countries
- Estimates of supply costs going forward, which informs policymaking and tariff setting
- Assuring International Financing Institutions (IFIs) of the robustness of their investments



An IRP is a very useful tool for planning by utilities

- **An IRP can provide information for the following planning related questions:**
  - **In which technologies should I invest?**
  - **When do I need to invest?**
  - **How much it will cost me?**
  - **What is the impact from retiring power plants?**
  - **How can I ensure security of supply?**
  - **Can I cover my energy and peak demand?**
  - **Can I reduce my operating costs?**
  - **Can I plan under uncertainly?**
  - **Can I achieve my renewable energy targets?**
  - **What should I do if demand rapidly increases?**
  - And many others
  - *Can you think of a decision you had to make recently at your business? Lets see if an IRP could inform you decision.*

- **Example of information given by an IRP regarding the schedule of investments for a system in West Africa**
  - *All types of available options of power plants were assessed to derive a solution that minimises costs and covers peak demand, energy demand and ancillary service requirements.*
  - *When an investment is needed, how much it will cost, which technology I should select and which Solar PV sites should be prioritized.*

Power plant	Status	Unit	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
ICE I Unit 1 - 5	Existing	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ICE II Unit 1	Existing	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ICE III Unit 1 - 4	Existing	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Imports	Existing imports	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ICE IV	Committed	mUS$	0.0	18.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ICE V	Committed	mUS$	0.0	0.0	30.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Imports PPA	Committed	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar PV I	Committed	mUS$	0.0	0.0	19.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Battery I	Committed	mUS$	0.0	0.0	11.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CCGT Imports	Candidate Thermal	mUS$	0.0	0.0	0.0	34.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CCGT Domestic	Candidate Thermal	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ICE (HFO)	Candidate Thermal	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OCGT (LNG)	Candidate Thermal	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar PV - location 1	Candidate Solar PV	mUS$	0.0	0.0	2.0	0.0	0.0	0.9	1.7	0.0	0.0	0.0	0.0
Solar PV - location 2	Candidate Solar PV	mUS$	0.0	0.0	1.1	0.0	0.0	0.0	1.8	0.0	4.6	0.0	0.0
Solar PV - location 3	Candidate Solar PV	mUS$	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar PV - location 4	Candidate Solar PV	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar PV - location 5	Candidate Solar PV	mUS$	0.0	0.0	19.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Generic Wind	Candidate Wind	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1
Generic battery 4h	Candidate battery	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	6.4	26.5
Generic Battery 6h	Candidate battery	mUS$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		mUS$	0	19	91	35	0	1	4	0	7	6	31

- **You could also investigate how much would it cost to the Utility to force the development/retirement off a generation asset in the energy mix.**

An IRP can also be used to inform policy decisions

- Policy makers would want to know the implications of policy decisions
  - An IRP can provide useful insights on the implication of policy decisions
- For example an IRP can provide useful information for setting renewable energy targets:
  - What is the cost of achieving a renewable energy target?
  - Or
  - What is the implication on costs if I set x% as a renewable energy target.
  - Can we achieve the target with the available candidate power plants/resources?

- **Example from an IRP on the impact on costs from different policy targets to inform policy makers:**
  - ***Renewable energy target -*** *how much would it cost me to set a renewable energy target to 30% by 2030?*
  - *Security of supply target - How much would it will cost to set a 50% domestic energy restriction? Can it be achieved?*

Scenario	NPV Capex	NPV Fixed O&M	NPV variable costs	NPV Wheeling	NPV total costs	CO_2 emis-sions	Average costs
	(m$)	(m$)	(m$)	(m$)	(m$)	Mt	($/MWh)
Base case	212	21	585	104	921	10	101
Renewable energy target 30% by 2030	283	38	591	88	1,000	8	108
Domestic energy >=50%	338	46	621	57	1,062	8	117

Overview of an IRP

Integrated Resource Plan (IRP)

Resources	Demand	Generators	Networks
• *Coal, gas* • *Wind, Solar* • *Hydro* • *Geothermal* • *etc.*	• *Peak (MW)* • *Energy (MWh)* • *Demand profile* • *Demand Side Measures (DSM)*	• *Technical, economic and financial characteristics of power plants*	• *Grid stability* • *Extensions* • *Upgrades* • *Interconnections*

Planning criteria

System modelling (Scenarios / simulations)

Dispatch | **Volumes** | **Costs**

Least cost generation, transmission and supply development plan

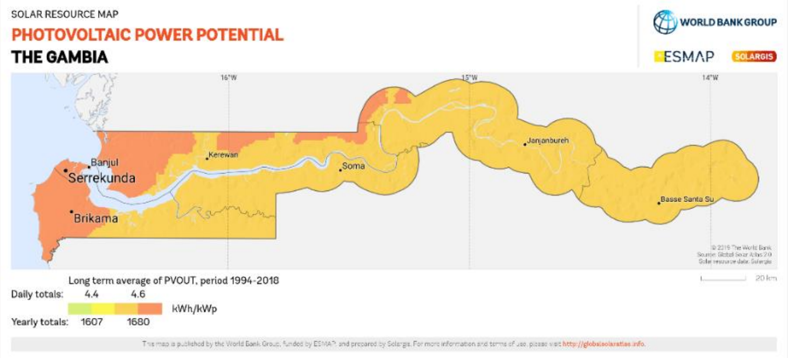
Key insights an IRP can provide:

- Generation and transmission plan under different market conditions including capital, fixed and variable operating costs
- What capacity to contract and at what price for PPAs
- Which are the best generation locations and where should the grid be reinforced
- What could be the supply costs going forward
- What could be the tariff going forward
- Prove that an investment is necessary and legitimate to secure financing

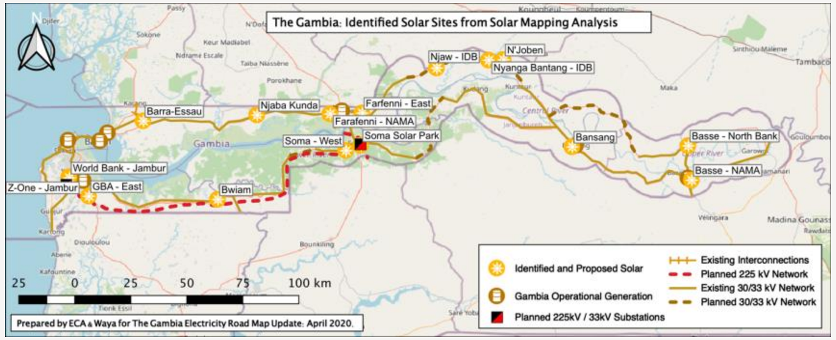
An IRP initially assesses the available resource for power generation

- ***Coal –*** domestic or imported, type (lignite, anthracite, etc), heat value, transportation costs, price, etc.
- ***Natural Gas –*** domestic or imported, gas infrastructure costs (LNG, pipelines, etc), heat value, transportation costs, etc.
- ***Crude Oil distillates (Diesel, HFO, LFO, etc) –*** domestic or imported, heat value, transportation costs, price, etc.
- ***Wind, Solar, Geothermal, Biomass –*** available resources, locations, volumes, associated costs, etc.
- ***Hydro –*** available resources, locations, volumes, associated costs, etc.

- Example for the assessment of Solar PV candidate projects in an IRP
  - Identification of possible Solar PV sites for development



  - Shortlist of potential sites to be developed after the application of exclusion criteria (Characterisation of land, exclusion areas, costs by site, grid availability, etc.)

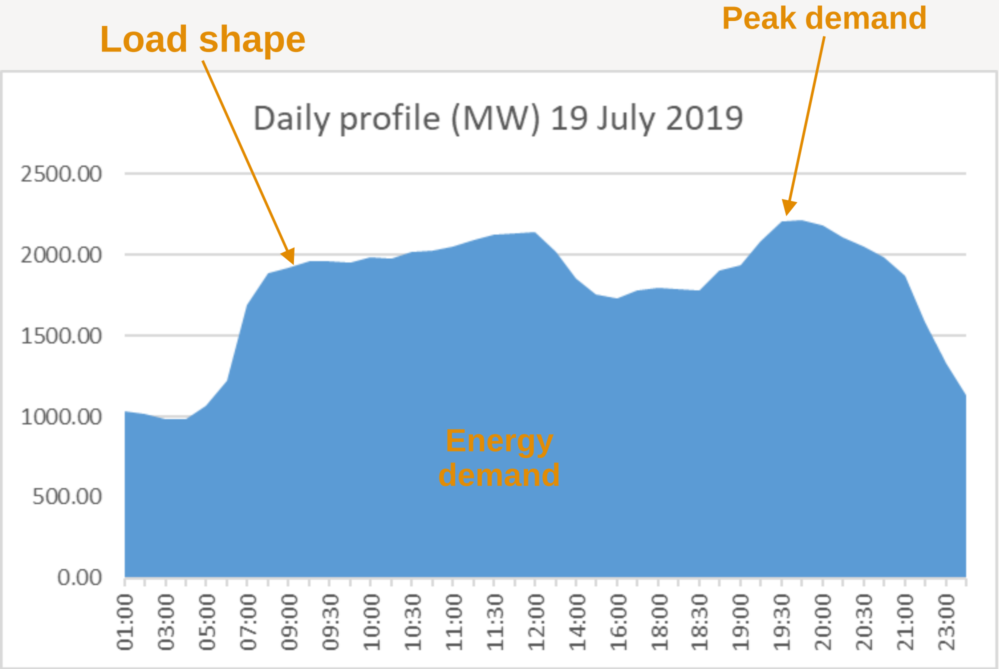


  - The shortlist of candidate Solar PV sites is assessed in the IRP to conclude on the least cost options to be developed.

An IRP includes an assessment of electricity demand

- **The main elements of the electricity demand for power system planning in an IRP cover:**
  - **Energy (GWh)** demand forecast – sets the total amount of energy that needs to be supplied.
  - **Peak (MW)** demand forecast – sets the total amount of capacity that needs to be developed for generation, transmission and distribution.
  - **Load shape** – sets the amount of capacity/energy that has to be satisfied at any given hour. It will determine how much a power plant will operate within a day/year.
  - **Demand side measures –** how the demand may be influenced by demand side measures such as energy efficiency, roof top solar PV, etc.

- **Daily load profile of a system in North Africa.**



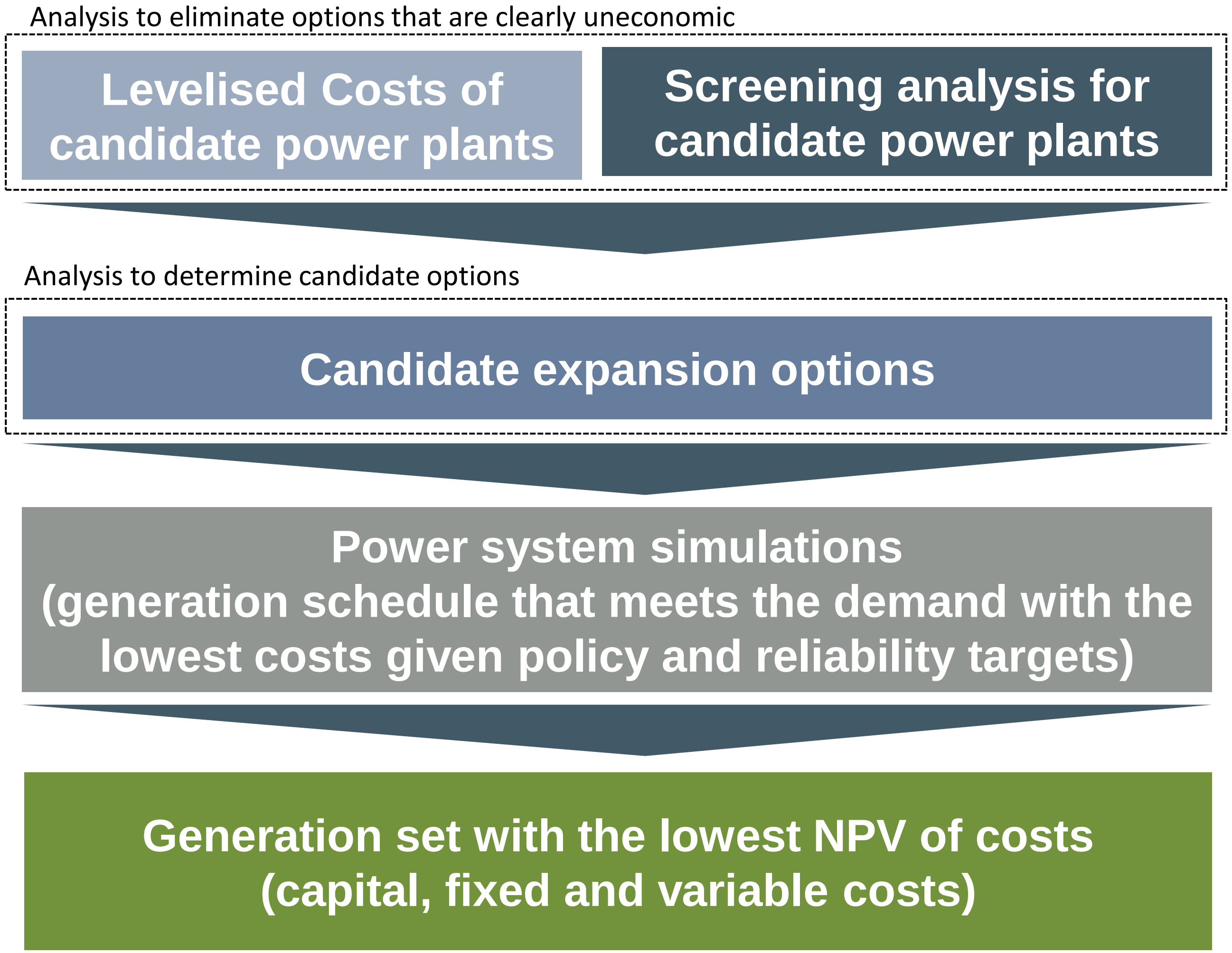
  - *The demand is not the same at all times and requires different amounts of generation in each interval.*
  - *While generators do not constantly operate to full capacity, capacity must be sufficient to meet peak demand.*
  - *The network has to be designed to be able to cover the peak demand*

Typical requirements of electricity demand forecasts

Typical uses of electricity demand forecasts	Typical horizon	Typical spread	Energy demand	Peak demand	Time of Use pattern
Generation planning	Long term (+20 years)	National level	√	√	√
Contracting and purchasing of wholesale/bulk electricity	Long term (+15 years)	Mix	√	√	-
Transmission planning	Medium term (10-20 years)	By location	-	√	-
Distribution planning	Medium term (5-10 years)	By location	-	√	-
Tariff setting	Short to medium term	By tariff category	√	√	√
System operation and scheduling of generation and transmission	Short-term (day ahead)	No	√	√	√

An IRP includes an assessment of the generation least cost plan

- The objective of the generation least cost plan is to establish the
  - long term generation plan
  - that meets the forecast electricity demand
  - at the lowest **economic** cost
  - given policy and reliability targets.
- The plan establishes the mix of
  - import contracts and new generation capacity
  - that results in the lowest cost in present value, real terms.



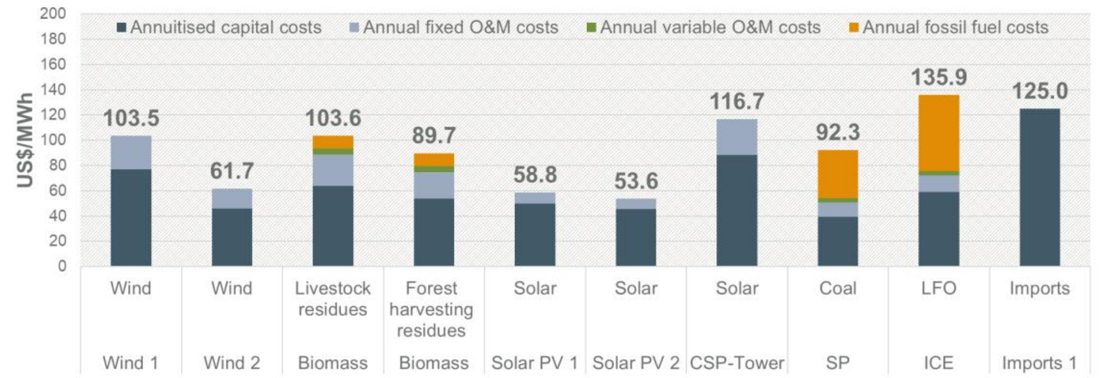
Example of information typically required for existing, committed and candidate power plants for generation planning

Plant Name	Status	Type	Fuel	Installed capacity (MW)	Grid Available Capacity (MW)	Availa-ble gene-ration (GWh)	Capital costs (US$/kW)	Variable O&M (US$/MWh)	Fixed O&M (US$/kW/yr)	Heat rate (GJ/MWh)	Lifetime	FOR (%)	MOR (days)	Year avail. / retired
Hydro 1	Existing	Hydro Dam	Hydro	19.8	19.8	85	-	1.07	10.1	-	50	2%	21	2005
Hydro 2	Existing	Hydro Dam	Hydro	5.6	5.6	28	-	1.07	10.1	-	50	2%	21	1990
Hydro 3	Existing	Hydro Dam	Hydro	20	20	50	-	1.07	10.1	-	50	2%	21	1990
Hydro 4	Existing	Hydro Dam	Hydro	15	15	70	-	1.07	10.1	-	50	2%	21	1990
Bagasse 1	Existing	Subcritical Steam	Bagasse	65.5	0	n/a	-	4.1	80	17.049	25	4%	30	2012
Bagasse 2	Existing	Subcritical Steam	Bagasse	41.5	12	n/a	-	4.1	80	17.049	25	4%	30	2010
Coal 1	Existing	Subcritical Steam	Coal	2.2	0	n/a	-	2.2	48.4	10.970	30	4%	21	2010
Solar 1	Existing	Solar PV	Solar	0.1	0.1	n/a	-	0	10.5	-	25	0%	4	2016
Hydro 5	Committed	Hydro	Hydro	13.6	13.6	71.0	-	1.05	10.0	-	50	2%	21	2021
Hydro 6	Candidate	Hydro	Hydro	120	120	275.6	4,328	0.5	5.8	-	50	2%	21	2026
Coal 2	Candidate	Subcritical Steam	Coal	6 x 50	6 x 42.5	-	2,100	2.2	48.4	10.790	30	4%	21	2025
Bagasse 3	Candidate	Subcritical Steam	Bagasse	50	42.5	-	2,342	2.2	80.2	17.049	30	4%	21	2026
Biomass 1	Candidate	Subcritical Steam	Woodchips	50	42.5	-	2,242	2.2	135.3	14.234	30	4%	21	2027
Solar 2	Candidate	Solar PV	Solar	50	22	-	950	0.3	27.5	-	25	4%	30	2024
OCGT 1	Candidate	OCGT	HFO	30	30	-	848	13.0	21	10.666	25	3%	15	2020
Imports	Candidate	Imports	-	-	50	30	Import price			-	5	-	-	2023

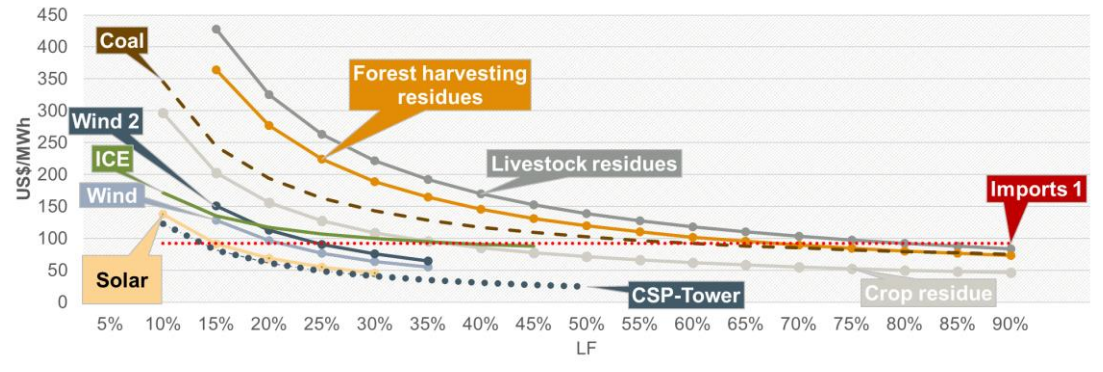
Levelised Costs of Energy (LCOE) compare power plants costs. Why more sophisticated modelling is needed for power planning?

- **LCOE** provide a simple, common basis for comparing generating technologies
  - But technologies are not the same
  - One kWh of electricity is not necessarily as valuable as another:
    - A kWh at peak worth more than at night
    - A dispatchable kWh worth more than non-dispatchable
    - A power plant can also provide other services
  - Does not tell you when to invest
  - Does not capture technical constraints
  - Dynamic dispatch decisions are necessary to assess hydro, pumped storage and batteries
  - Does not capture the intermittent nature of RES and grid constraints

- **LCOE example for a Southern African country (2018)**
  - *It does not tell you when, for how long and if will be dispatch, operational constraints (e.g. minimum stable load or ramping restrictions for thermal plants), if peak can be met, etc.*



Source: Economic Consulting Associates (ECA) analysis, 2018

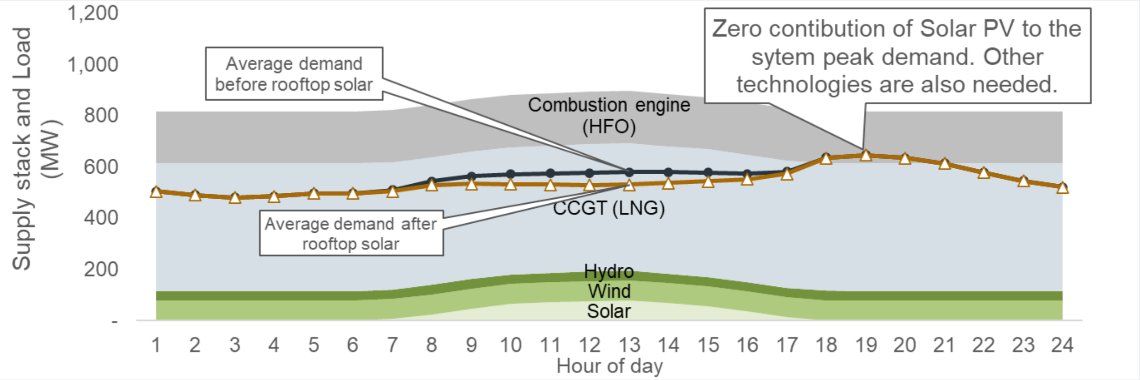


Source: Economic Consulting Associates (ECA) analysis, 2018

Analysing renewable energy (RES) generation in an IRP

- **RES generation is intermittent**
  - Sometimes Solar PV produces electricity and sometime not
  - Hydro generation is constrained by the amount of water that is available
  - Wind generation is generally characterised by volatility
    - For long-term planning, it is uncertain whether it will be windy on a Wednesday evening peak in June for example.
  - Energy is produced when resources are available
- **RES generation has essentially zero variable costs**
  - When energy is available it is dispatched first
- **RES generation may not match the system load profile**
  - Solar PV may not be able to contribute to capacity requirements in systems with an evening peak
- **Fast response reserves may be necessary**
- **Renewable energy has to be assessed in combination with other technologies and at a granularity that can capture its intermittent nature**

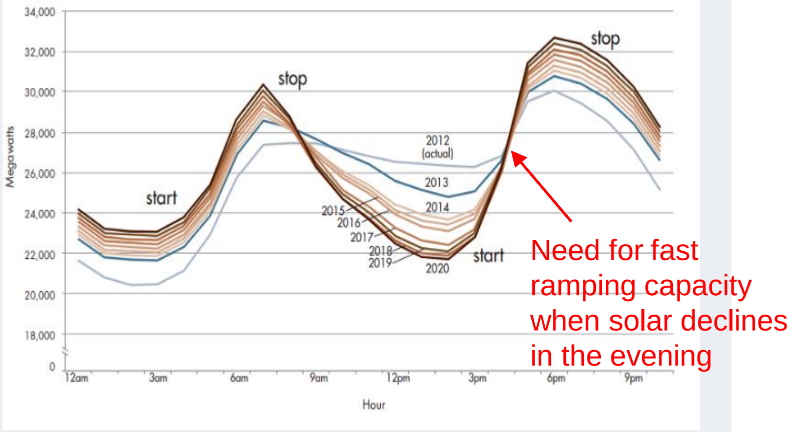
Solar PV in Jamaica does not provide peak capacity



Source: Economic Consulting Associates (ECA) analysis, 2018

California's changing load curve from 2012 to 2020

- Increased solar penetration contributes to 'duck curve' effect on daily load curve
- Need for fast ramp up capacity to meet evening peak as solar declines



Source: California ISO, What the duck curve tells us about managing a green grid, 2013

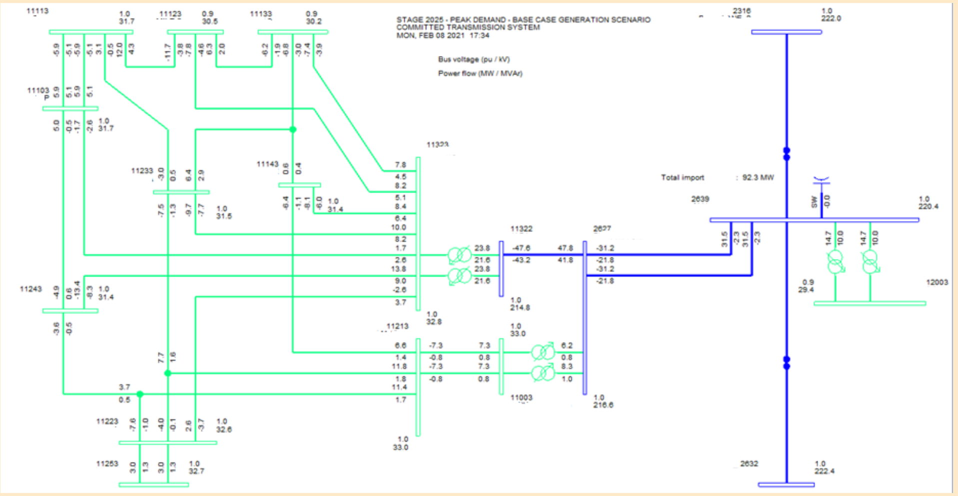
Transmission planning in an IRP

- The objectives of transmission development plans are to:
  - Prepare a least-cost economic transmission development plan
  - Ensure the grid can meet demand
  - Ensure the grid can operate reliably
  - Integrate new power generation facilities
  - Enable power exchange (eg imports or exports)
- The transmission plan builds on the demand forecast and the generation expansion plan

Investment schedule for a system in South Africa from an IRP

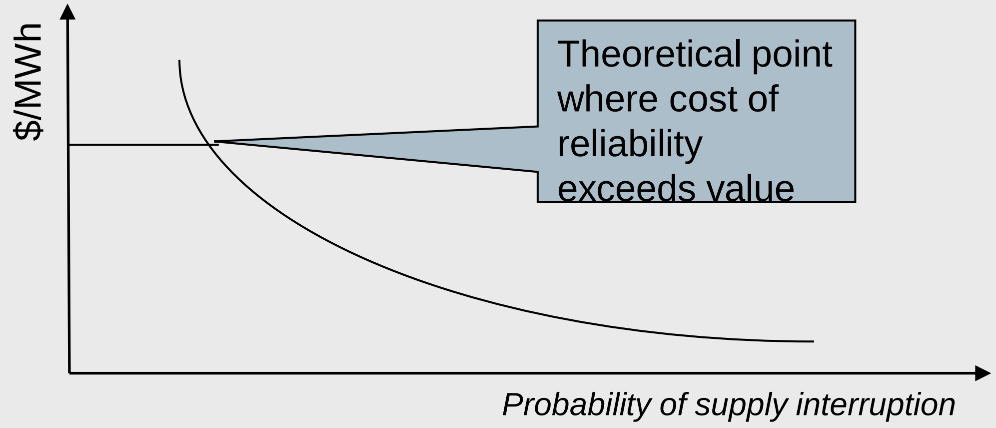
Transmission Network Expansion (US$ million)	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
Ongoing Projects	0.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7
SubstationTransformer Uprating	4.7	1.6	0.7	0.0	0.0	0.0	0.9	0.0	6.1	2.8	0.0	0.0	0.0	16.8
Substation Upgrade Projects	2.5	4.2	6.9	3.3	0.7	1.1	0.0	1.4	2.3	0.0	0.0	0.0	0.0	22.4
Substation Transformer Maintenance	Costs included as part of general Operation and Maintenance costs.													
Network Reinforcement Projects														
HV Network Reinforcement	9.2	13.8	3.2	4.8	0.0	0.0	5.8	8.7	0.0	0.0	0.0	0.0	0.0	45.5
Rural Electrification	6.5	9.8	1.7	2.5	3.2	4.8	0.0	6.3	9.4	0.0	0.0	0.0	0.0	44.2
New Loads (excl. customer contribution)	2.3	3.5	0.0	0.0	1.3	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1
Sub-Total	18.1	27.1	4.9	7.3	4.5	6.7	5.8	15.0	9.4	0.0	0.0	0.0	0.0	98.7
Transmission Reliability Projects	2.0	3.0	1.2	0.9	0.7	1.5	1.7	1.8	0.8	0.0	0.0	0.0	0.0	13.6
SCADA	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Reactive Power Compensation	0.0	0.0	4.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0
Total	28.3	36.9	17.7	11.6	9.8	9.3	8.4	18.2	18.7	2.8	0.0	0.0	0.0	161.7

Example of load flow analysis in an IRP



Reliability criteria in an IRP set system reliability levels that have to be respected by generation and transmission

- **Generation planning criteria**
  - ***Reserves margin –*** how much more capacity is needed to support the reliable operation of the system
  - ***Accepted LOLP/EENS –*** what is the accepted level of the system not being able to meet the demand
- Networks planning criteria
  - ***'N-1' reliability level –*** the system shall be able to meet peak demand even with one transmission line, main power transformer or unit for reactive power compensation out of service.
  - ***Voltage levels –*** Minimum and maximum voltage levels during normal and contingency operation.
  - ***Capacity –*** Maximum thermal loading of equipment.



Indicative planning criteria for SAPP member countries		
Country	**LOLP (days per year)**	**Min Reserve margin (% of available capacity)**
Botswana	-	20%
Eswatini	-	10%
Mauritius	-	10%
Namibia	2 to 5	-
South Africa	-	19%
Tanzania	5	
Zambia	-	50% or 20% (in dry years)
Zimbabwe	-	10.6% for thermal-based power and 7.6% for hydropower
SAPP	-	10.6% for thermal-based power and 7.6% for hydropower

Scenarios and sensitivities in an IRP help to plan under uncertainty

- Scenarios can be used to model uncertainty, policy targets and market conditions in an IRP
  - It can show the least cost plan under different market outcomes
    - Demand, pricing, timing, costs, available options, costs of externalities, etc.
  - It can show the impact from different policy decisions
    - Renewable energy targets, security of supply, national targets
- Sensitivities can be used to identify the robustness of the results
  - Demand forecast, fuel costs, investment costs, national targets, emission costs, discount rates, etc.

Example of scenarios and sensitivities in an IRP

Scenario	NPV Capex	NPV Fixed O&M	NPV variable costs	NPV Wheelin g	NPV total costs	Average costs
	(m$)	(m$)	(m$)	(m$)	(m$)	($/MWh)
Scenarios						
Unrestricted (no policy targets)	212	21	585	104	921	101.5
Base (50% domestic capacity and 30% RES)	283	38	591	88	1,000	108.0
Force regional-scale solar PV	310	45	579	83	1,016	110.1
Imports availability is delayed	286	37	573	126	1,022	110.2
Force CCGT (LNG) in the mix	321	44	608	71	1,045	115.0
Domestic energy >=50%	338	46	621	57	1,062	117.2
High import costs	331	55	739	19	1,144	124.4
Full independence	390	60	713	11	1,175	127.5
Sensitivities on the base case						
WACC 8%	353	52	645	106	1,155	106.3
WACC 12%	230	29	531	78	869	109.6
Low demand	193	26	461	60	741	109.0
High demand	341	44	682	116	1,184	109.3
High fuel prices	293	40	777	102	1,212	130.9
Battery costs rapidly decrease	273	39	590	88	990	107.1

The results of an IRP are highly sensitive to input data

- **The results of an IRP are highly sensitive to input data**
  - Thus there is a need consensus on key assumptions; and
  - The relevant agencies (key stakeholders) need to work together in deriving criteria and assumptions
  - You need to establish databases to effectively and efficiently develop IRPs

- **Key inputs of an IRP:**
  - The forecast electricity demand (MW and GWh)
    - The forecast load shape (i.e. the MW demand in each hour of the year)
  - The available power and energy of hydro electric plants
  - The security standards
    - Reserves margin or accepted LOLP/EENS
  - The costs of existing, committed and candidate generating plants
  - Cost of imports
  - The projections of fuel prices
  - Scenarios
  - The discount rate

Main outputs of an IRP

- The Net Present Value of costs associated with each scenario
  - A measure to compare costs among scenarios, different market conditions and policy decisions
- A forecast of the operating costs of the business
- An approximate operating schedule of power plants and associated costs
- Investment schedule and investment requirements
- Planning under uncertainty
  - Which options would be selected in all market scenarios?
  - What is the least cost way forward under different market conditions?
- The reliability of the system
  - Including under different RES penetration scenarios
- The optimization of imports/exports from/to neighboring countries to inform PPA contracts
- Total quantities of fossil fuels used

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