Supporting Hydro Generation with PV in Costa Rica

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Benefits of higher PV shares in a primarily hydro-based system

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7th Solar Integration Workshop

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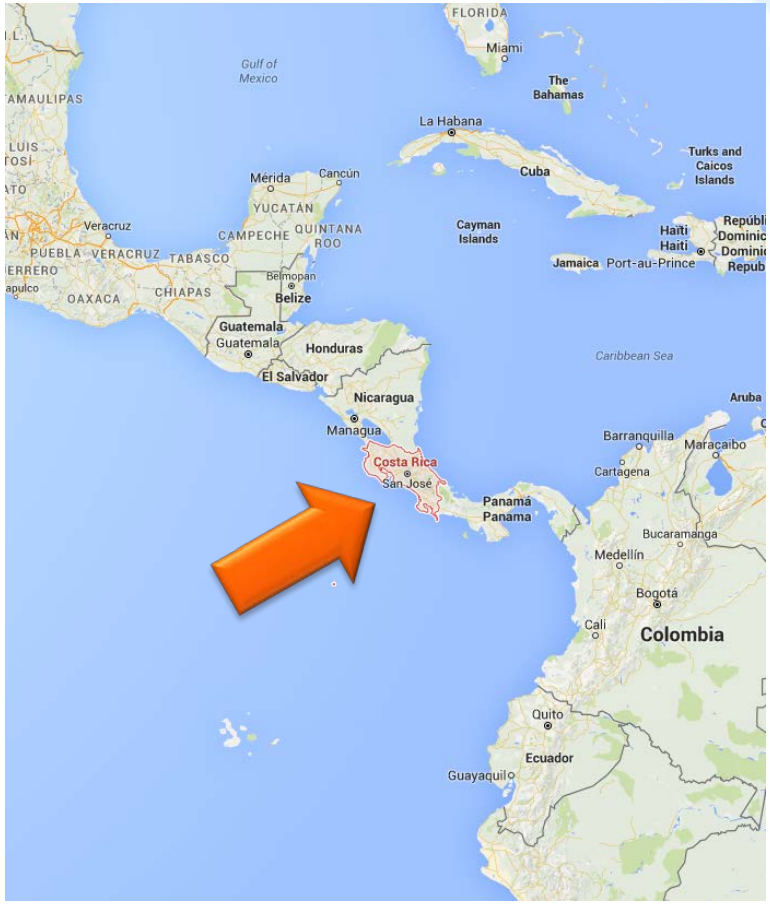
BACKGROUND: COSTA RICA

- Central American country
- 51,100 sqkm
- 4.3 mio citizens
- One of the wealthiest Latin American countries
- Disbanded its army in 1948
- World leader in ecotourism
- Ca. 90 % renewable electricity generation
- Mainly hydro generation, but excellent wind, solar and geothermal potential



BACKGROUND: PROJECT

Project consortium

Clients

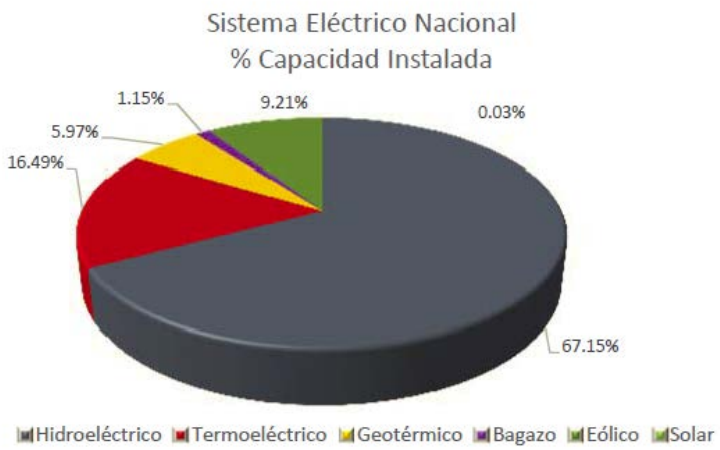
Study on Large Scale Integration of Variable Renewable Energy in Costa Rica

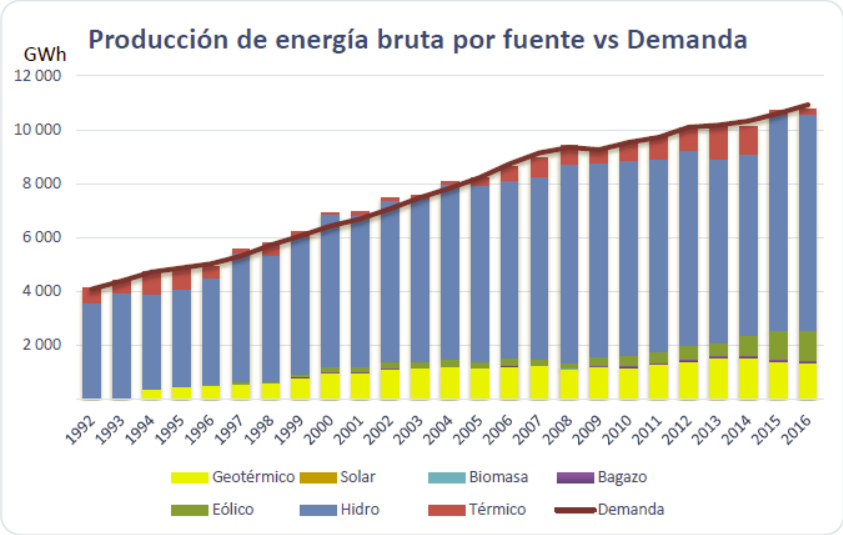
- Financed by the Inter-American Development Bank
- Commissioned by the IDB, Costa Rican utility ICE and the Costa Rican Ministry of Energy and Mines, MINAE to a project consortium of Energynautics, DIgSILENT, MCG and freelance consultants
- First results in December 2015, final report in September 2016

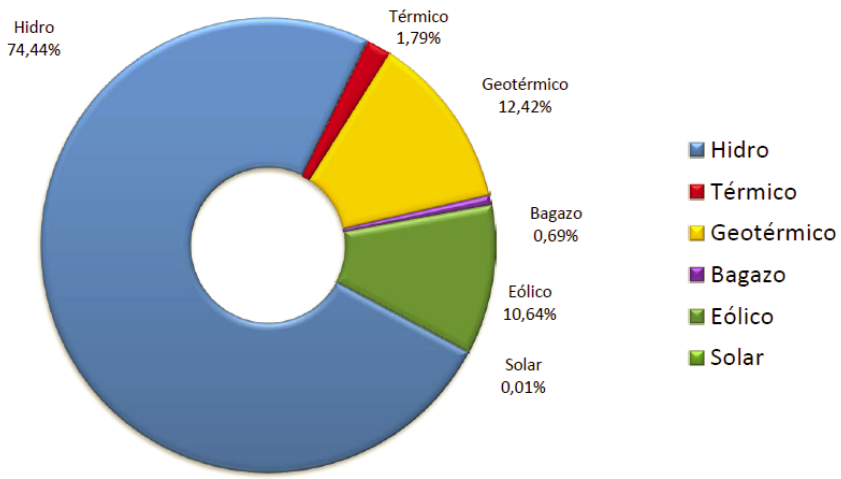
POWER SYSTEM FACTS

- Peak load of ca. 1600 MW
- Installed capacity of ca. 3300 MW
- 99.2 % grid access
- Demand 11 TWH p.a.
- 138 kV and 230 kV transmission system, 60 Hz
- Vertically integrated
- Connected to the Central American Grid (230 kV SIEPAC interconnector)
- Low exchanges with neighboring countries

POWER GENERATION



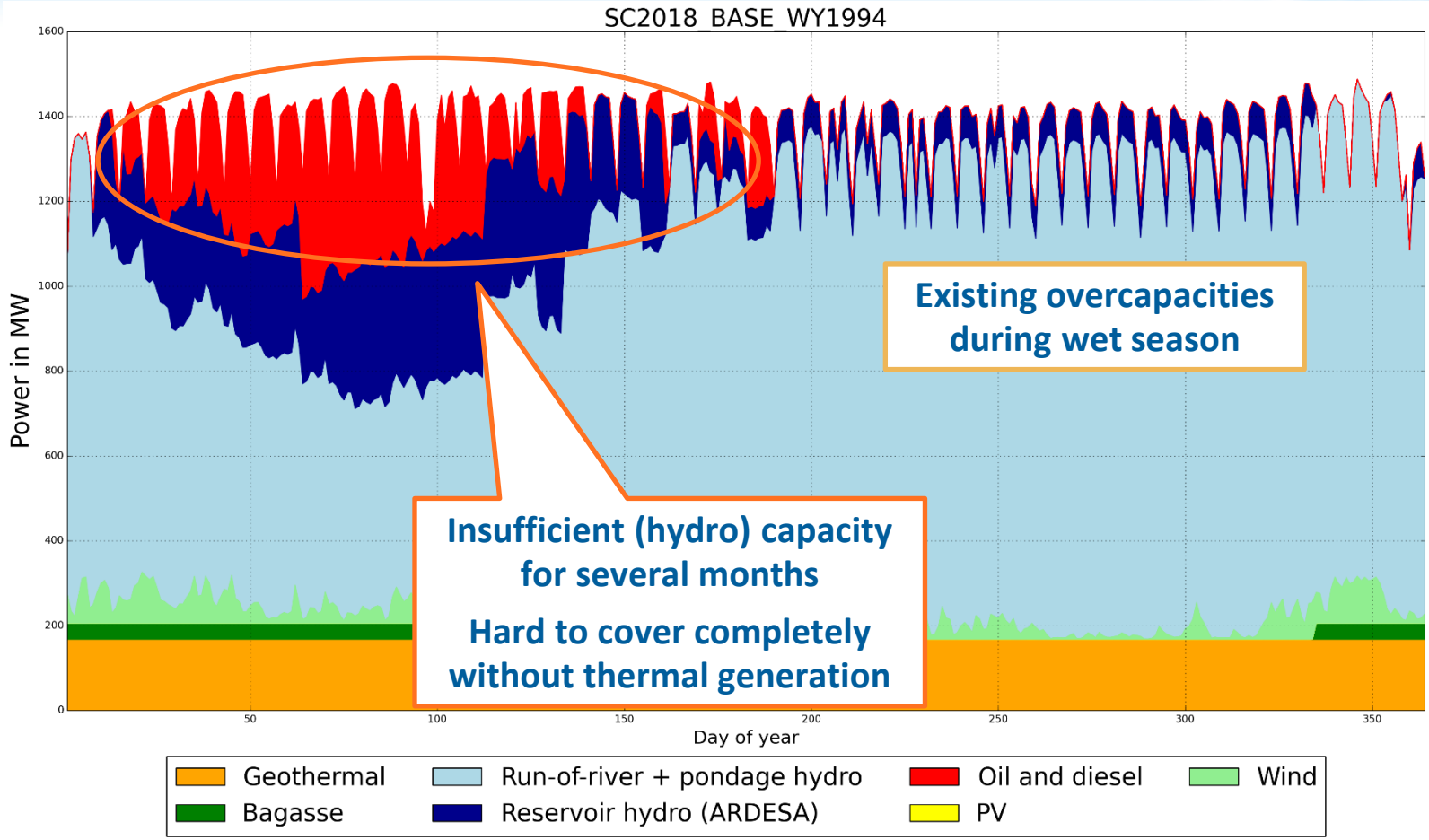




Balance eléctrico por fuente 2016 - Acumulado a Diciembre

Tipo de Fuente	GWh	%	Tipo de fuente	GWh	%
Termoeléctrica	193,03	1,79%	Hidroeléctrica	8 025,95	74,44%
			Geotérmica	1 339,51	12,42%
			Bagazo	74,51	0,69%
			Eólico	1 147,29	10,64%
			Solar	1,41	0,01%
No renovable	193,03	1,79%	Renovable	10 588,67	98,21%
Generación bruta: 10 781.69 GWh - ↑ 0.64%					
Intercambio de energía: 150.38 GWh					
Demanda Nacional: 10 932.08 GWh - ↑ 3.06%					

POWER GENERATION



Goal: Cover demand increase without increase in thermal generation during dry year

STUDY OBJECTIVES

- **Analysis of the Costa Rican power system in 2024**
- **Scenario:** Demand increase between 2018 and 2024 needs to be covered with VRE only
- **Scenario development:** Determine shares of different VRE technologies and their distribution in the grid
- **Technical analysis:** Dispatch optimization, reinforcements, contingency and stability analysis
- **Economic analysis:** Estimated cost of VRE scenario in comparison to a scenario based around conventional generation

TRANSMISSION GRID MODEL

230 kV

138 kV

34.5 kV

AC power flow model with dynamic generator models, developed by ICE in PSS/E, imported into PowerFactory refined by DIgSILENT.

Embedded into Central American model which is maintained by all TSOs.

Derived DC power flow model imported into ENAplan.

MODELLING: GENERATOR DISPATCH

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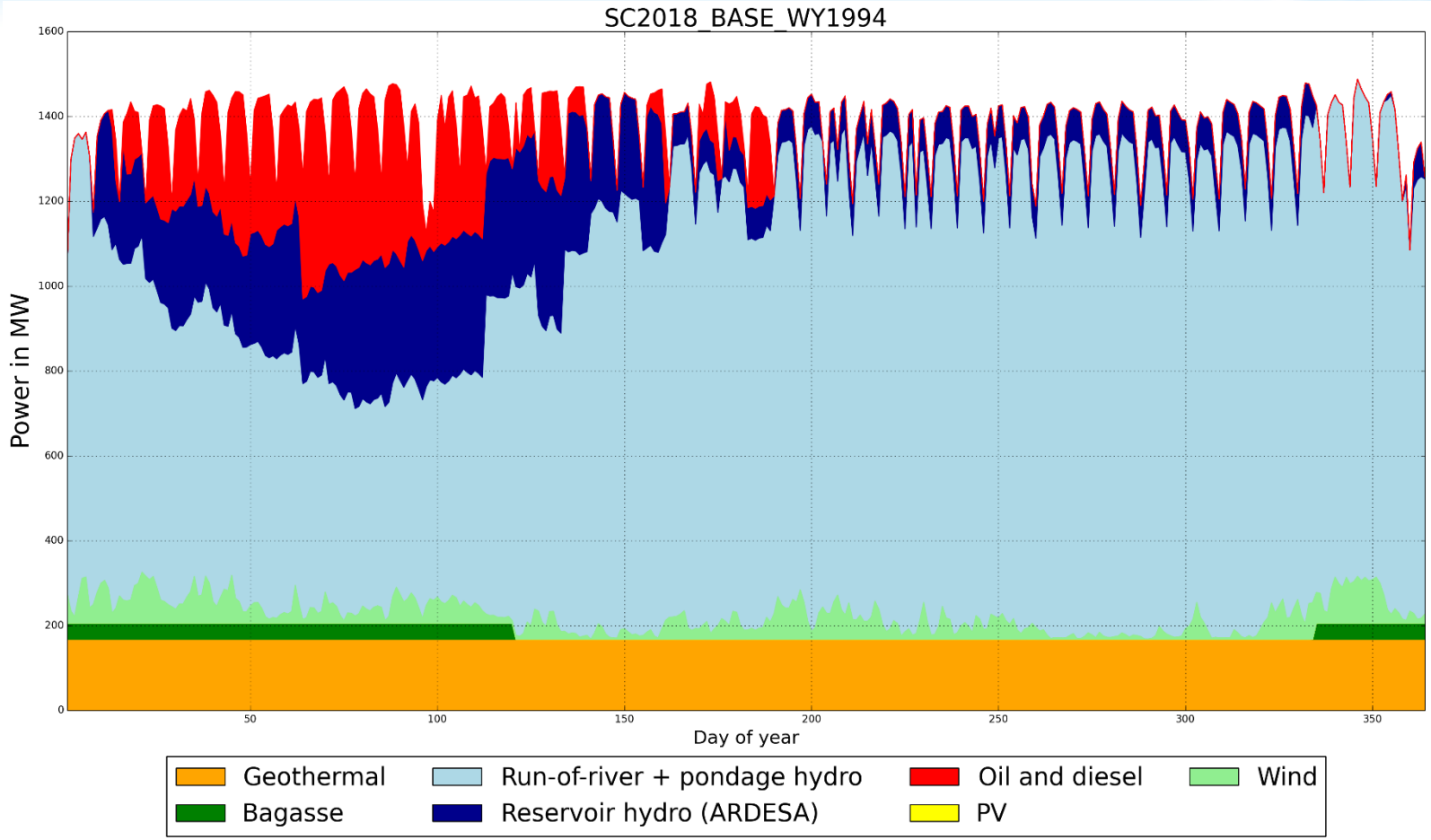
Security Constrained Optimal Power Flow

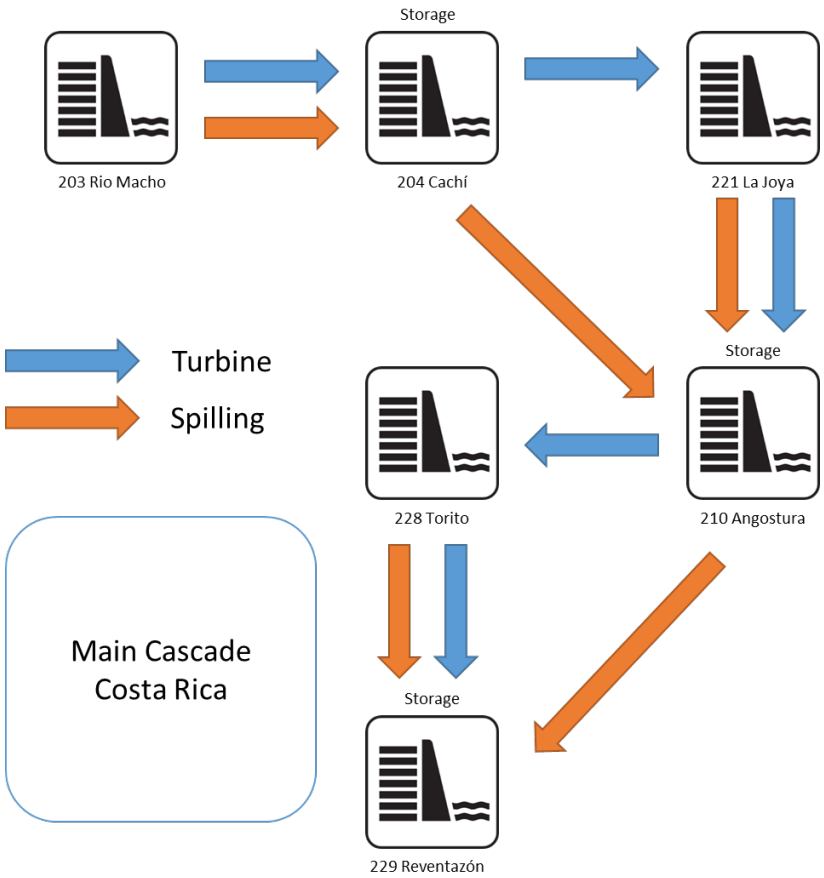
- Advanced linearized (DC) **optimal power flow**
- Generation and demand **are balanced for each time step for every day** – always an entire day at once – **at lowest cost** and under consideration of grid and storage constraints
- Grid constraints are expanded by **(n-1) and selected (n-2) cases as well** as **100 MW North-South transfers**, which set additional limits on lines and thus generation distribution
- VRE are allowed to be curtailed, but the scenario was tuned **so curtailment stays below 3 %** of yearly available energy
- AC contingency constraints (voltage, reactive power) were determined by AC load flows in DIgSILENT PowerFactory

DISPATCH MODEL



-> we had to recreate this (in 15 minute resolution) based on real operational data and work from there

MODELLING: HYDRO STORAGE



- Hydro storage in Costa Rica: Main source of operational flexibility!
- One seasonal storage reservoir (Arenal / ARDESA, 370 MW)
- Multitude of pondage units with mostly small daily reservoirs
- Larger capacities in main cascade (left, 870 MW) and Pirrís (140 MW)
- Ca. 190 GWh of short term (sub-seasonal) storage available, 2.23 GWh of this is daily storage only

➢ Storage capacity is already available, cheap and flexible: “Charge” by natural inflows when VRE feed in, “discharge” when VRE feed-in is low

SOLAR: COSTA RICA VS. GERMANY

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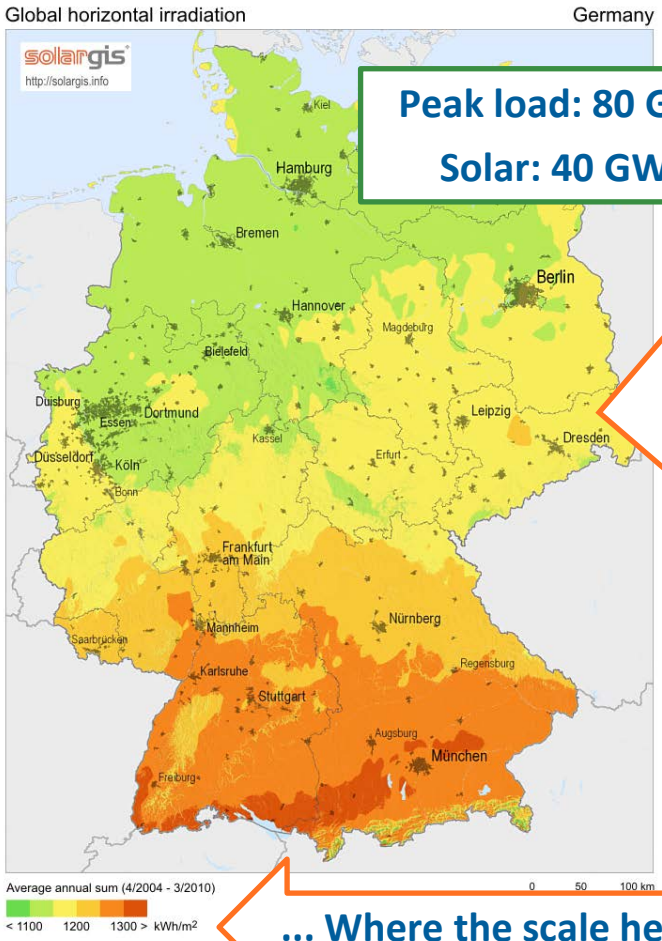
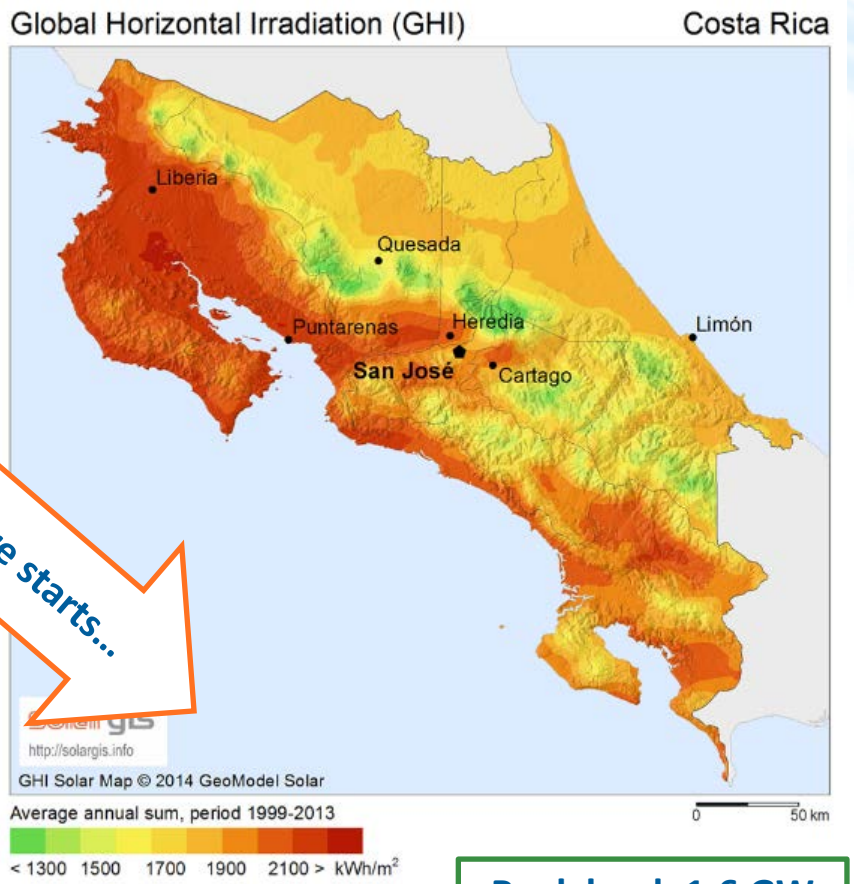


Peak load: 80 GW

Solar: 40 GW

The scale here starts...

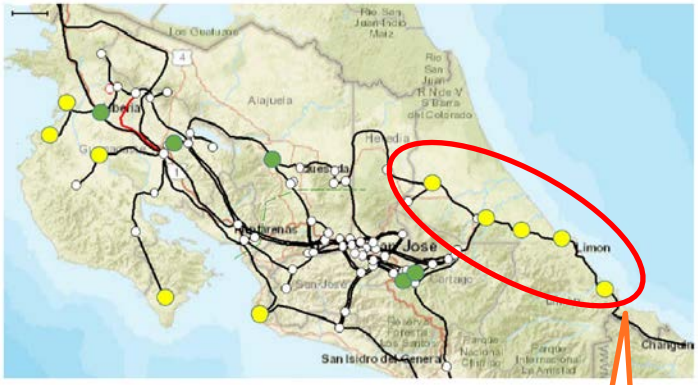
... Where the scale here ends!



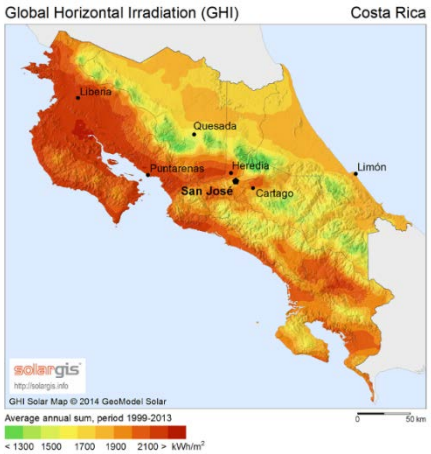
Peak load: 1.6 GW

Solar: 0.001 GW

VRE SCENARIO



VRE distribution: Wind parks are green, centralized PV yellow



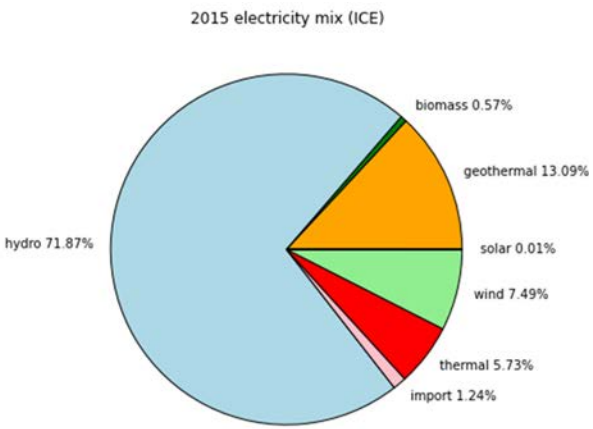
Second rate solar locations

- 5 x 94 MW wind park
- 10 x 39 MW utility scale centralized PV
- 400 MW distributed PV

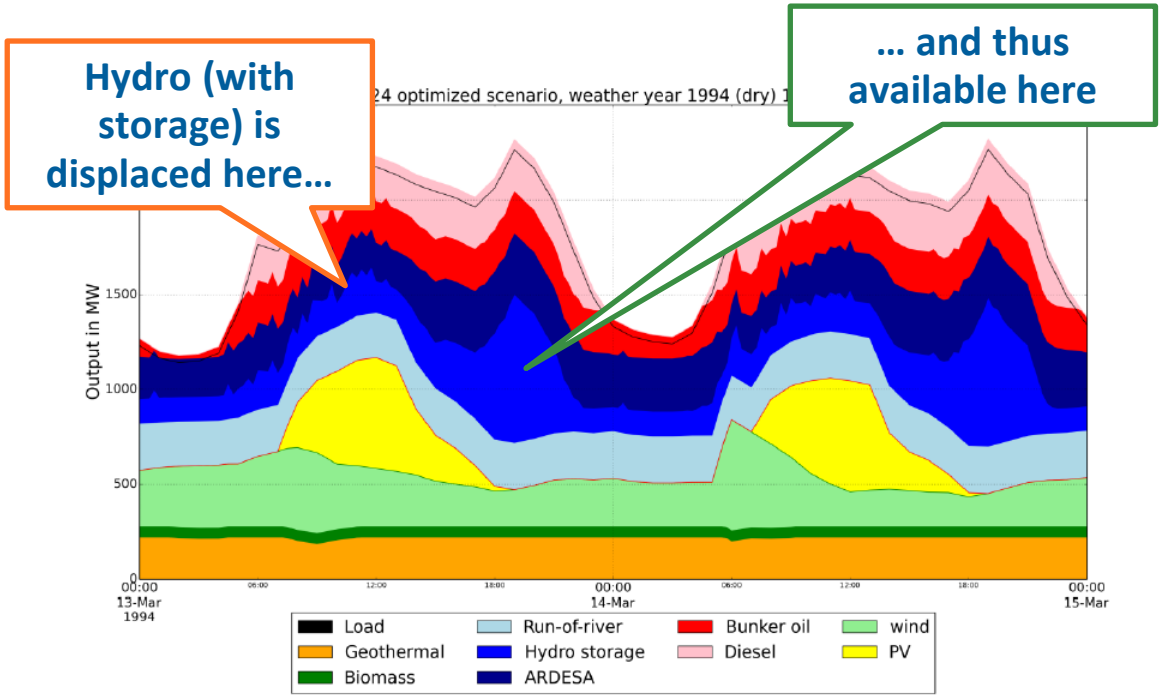
➢ Wind and C-PV distributed according to potential and re-distributed to avoid grid congestion

➢ D-PV distributed according to load

ELECTRICITY MIX

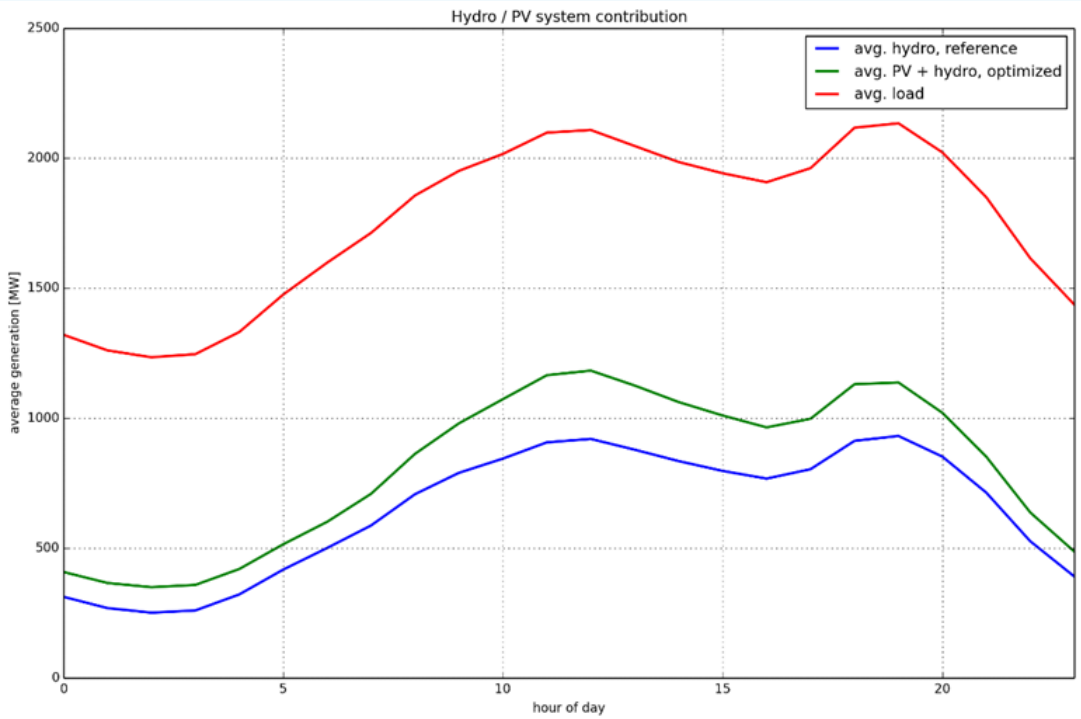


PV-HYDRO SYSTEM



- PV provides more reliable capacity during the dry season, replacing storage hydro in the morning which in turn displaces thermal in the evening
- Hourly PV fluctuation is higher than wind fluctuation, and solar forecasting is less advanced than wind forecasting
- Wind is cheaper, but displaces more hydro and less thermal
- Wind and solar fluctuation mitigate each other instead of adding up

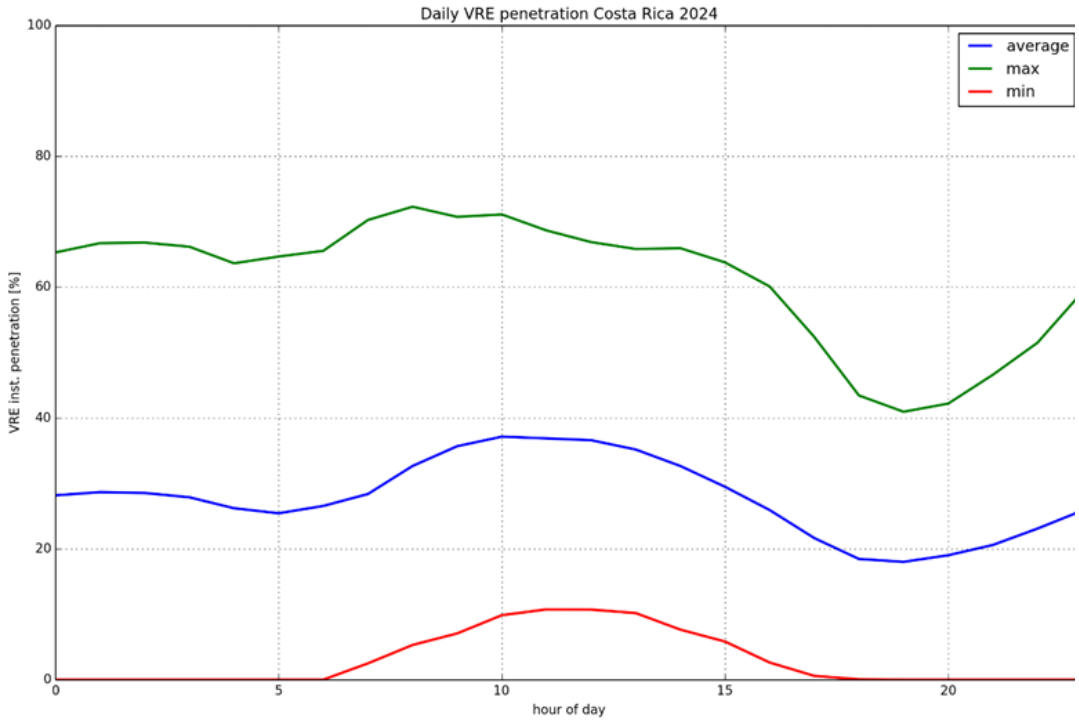
SECURITY OF SUPPLY

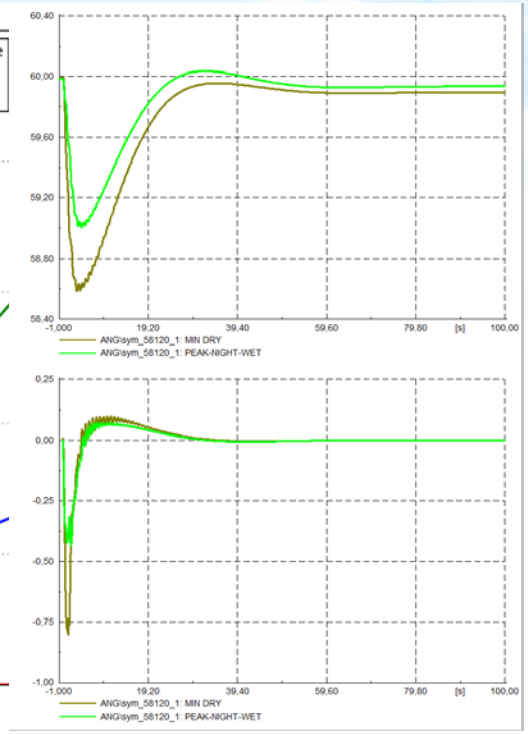


(Hydro in the figure excludes run of river and seasonal storage – daily and weekly storage only)

Available firm hydro capacity is increased by PV – the energy supplied by PV during mid-day is available from saved water later and spread out across the day!

CONTINGENCIES AND STABILITY





- (n-2) security in the Northern Ring area may be an issue
- Hydro close to the load centers also serve as synchronous condensers when not dispatched for active power
- Steady state voltage stability is not a problem at all
- The system is dynamically stable at instananeous non-synch penetration rates > 75 %, even if the Costa Rican system is islanded (which happens).

CONCLUSIONS

- The Costa Rican system with ist high short term hydro storage capacities forms a **formidable PV storage system**, while wind displaces far more hydro long term
- **Displacement of some amount of hydro and geothermal is inevitable** – it can be minimized by the **right share of wind and PV** as well as by exports
- It is still **difficult to get rid of the last small share of thermal generation** with wind and solar only
- **Very high shares of VRE**, covering 27 % of demand in 2024 and reaching instantaneous penetrations of > 70 % **can be integrated into the system without major technical problems**
- Given excellent resources and a system with a large amount of daily storage, **Costa Rica should consider PV as well as wind**

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THANK YOU FOR YOUR ATTENTION!

MORE ON VRE IN COSTA RICA:
WIND WORKSHOP, FRIDAY 09:00, SESSION 7C!