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Modeling high penetration scenarios of clean energy in the electrical grid with SWITCH: A case for México

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MOTIVATION

After undergoing an unprecedented energy reform, **Mexico** is poised to significantly grow its renewable energy share, and evolve **from 80 MW installed solar photovoltaics (PV) capacity in 2015**, to **several GW by next year.**

To plan for a strategic transition, a crucial element is to **determine** where the **generation investments** should be **allocated** to **optimally deploy those assets**.

In this contribution, we use SWITCH, a mixed integer linear program to **model** the **generation, transmission and distribution assets in Mexico** and **optimize the investment in capacity** to **meet policy goals** under different scenarios.

MATERIALS & METHODS

Through SWITCH we optimize the deployment and decommissioning of generation assets by minimizing the net present value of investment and operation costs, as detailed in [1] and shown in Eq. 1:

$$min \sum_{p \in P} d_p \left\{ \sum_{c^f \in C^{fixed}} c_p^f + \sum_{t \in T_p} w_t^{year} \sum_{c^v \in C^{var}} c_t^v \right\} \quad (1)$$

where C^{fixed} and C^{var} correspond to the fixed and variable costs, respectively; t and p variables correspond to timepoints (hours) and periods (years), respectively.

We leverage on the modularity of SWITCH, as seen in Fig. 1, to evaluate the impact of different cost components and operational conditions.

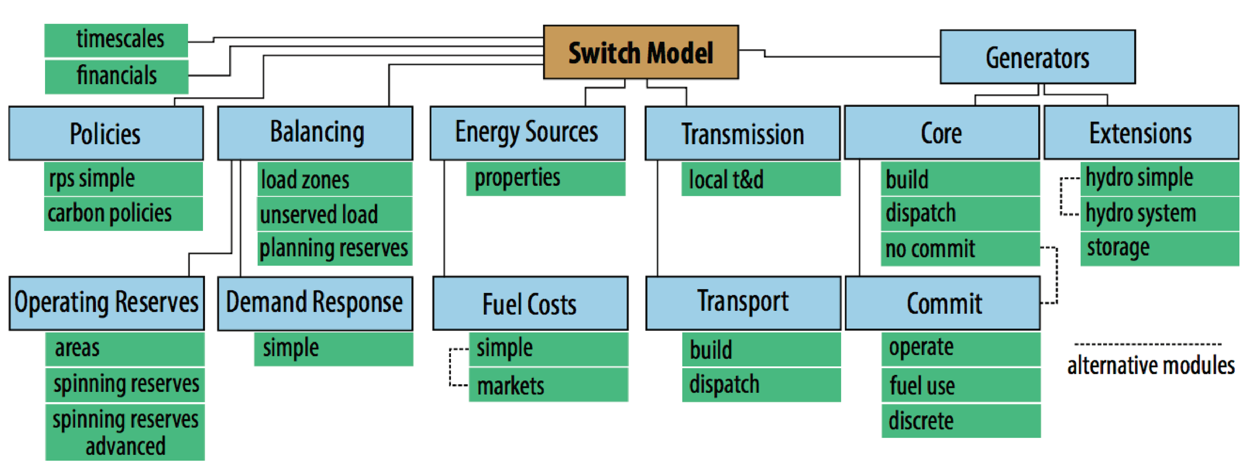

Fig. 1. Module structure of SWITCH where boxes in blue correspond to subpackages and boxes in green to modules.

A. Modeling México's Grid

Load zones (53) are modeled with their respective substations to represent typical renewable source profiles across the country, as seen in Fig. 2.

Fig. 2. Fifty three load zones (color coded) are modeled based on the distribution of substations (white triangles) across Mexico via clustering algorithms.

Five different scenarios (Table 1) represent paths for Mexico's clean energy transition considering (or not): (***a***) the development of big hydroeletric plants, (***b***) consideration of co-generation as a clean technology, (***c***) natural gas price variations, and (***d***) meeting solar PV (DG) expected deployment.

Table 1. Modeled scenarios and their characteristics.

Scenario	Description
1	Hydro >30 MW is possible. Co-gen is clean.
2	Hydro >30 MW not possible. Low natural gas prices.
3	Hydro >30 MW not possible. Average natural gas prices.
4	Hydro >30 MW not possible. Enforcing PV DG forecasts.
5	Hydro >30 MW not possible. Low-cost PV DG forecasts.

RESULTS & DISCUSSIONS

The generation mix in Mexico's electricity sector **can significantly vary** depending on slight **variations in** terms of **resource availability (e.g., water for big hydroelectric plants)** and **price expectations (e.g., natural gas)**.

These variations can **alter the drivers** for the **agressive deployment of solar PV** required for TW global deployment.

Scenario 1: **Hydroelectric plants** are agressively deployed to meet national mandates of **35% clean energy by 2024** and **37% by 2030**. This agressive deployment is favored over other technologies, including solar, wind, and clean co-generation which is considered clean in this scenario.

Scenario 2: With low NG prices, **combined cycle plants** are **heavily deployed**, counter-balancing the hydro deployment which is now constrained. **Wind** is now **deployed at a greater scale**.

Scenario 3: **Co-generation** deployment is **reduced** upon the uptake in NG prices, and **wind** is **aggresively deployed** to compensate.

Scenario 4: Through an enforcement in **PV DG**, that technology now plays a role. **Neither internal combustion, nor bioenergy are deployed. Wind** still continues to **play a dominant role.**

Scenario 5: **PV DG increases** compared to Scenario 4. **Wind** is now **reduced** while both **combined cycle** and **co-generation** technologies **increase**.

The total investment and operational cost of the different scenarios is seen to differ, with the most expensive ones being Scenarios 3 and 4, followed by Scenario 5, 2, and 1. No cost of Carbon is modeled.

Table 2.Total costs for the five different scenarios

Scenario	Total Investment & Operation Costs
1	$327 B USD
2	$359 B USD
3	$387 B USD
4	$387 B USD
5	$386 B USD

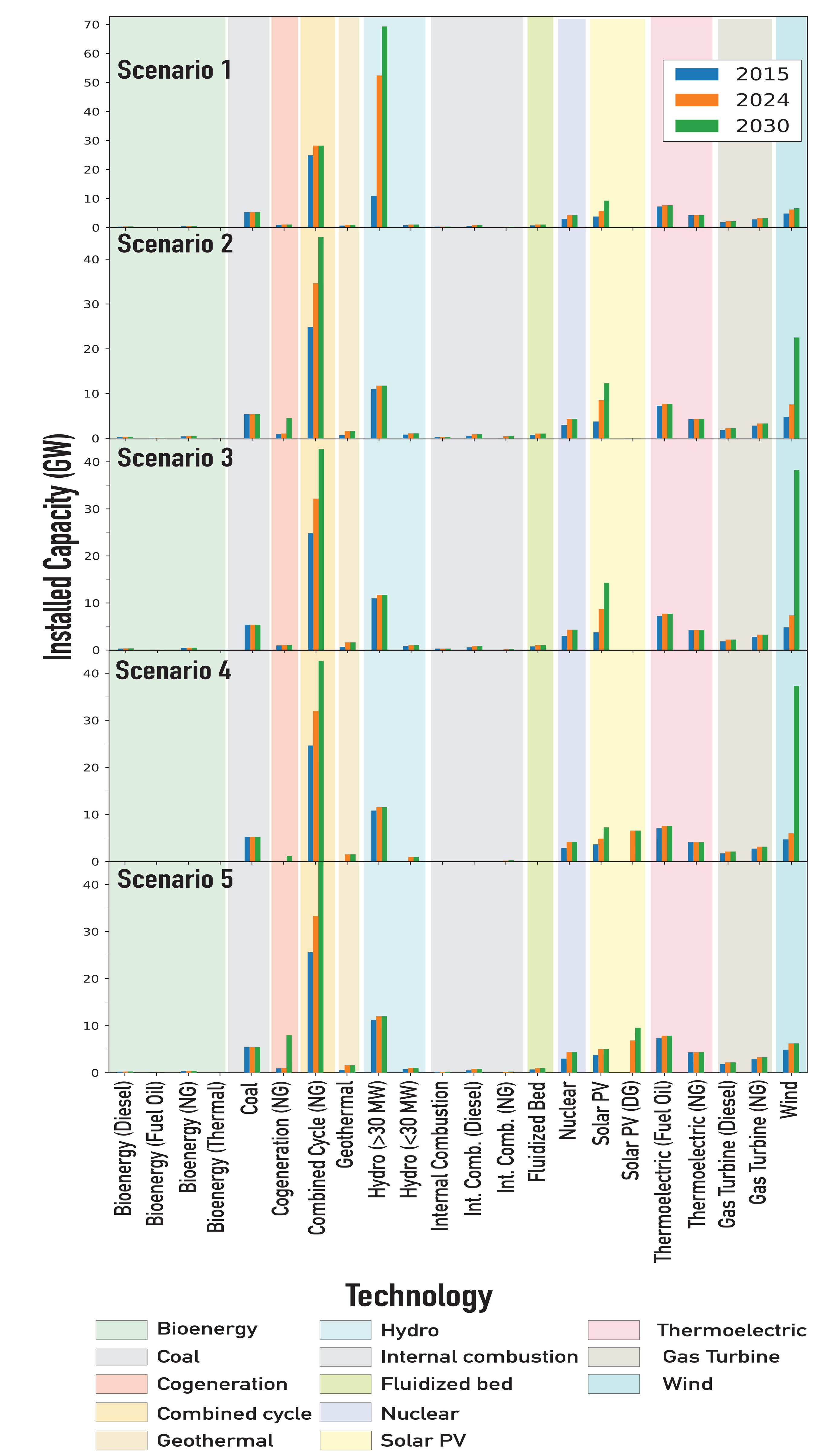

Fig. 3. Technologies deployed and their respective capacity for 5 scenarios comprehending years between 2015 and 2030. Colors refer to technology types.

CONCLUSIONS

- **Solar PV** has the potential to grow, however, continued price reductions are required.
- In an era with **expected droughts** and increased **environmental impacts**, planning with **limited hydro growth** are needed.
- Given **Mexico's reliance on N.G.**, **price variations** can significantly **alter** the **installed capacity** in the near future.
- **Wind energy** constitutes an **important complementary technology** to reach national clean energy targets.
- **Investment costs vary**, but **restrictions on emissions** and a **carbon price** could further help rank feasibility of each scenario.

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