POWER SYSTEM MODELLING AND ANALYSIS:
A NEW CAPABILITY DEVELOPED WITH PESS AND NPTDS

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International Atomic Energy Agency

Some questions from yesterday

For the other speakers: In terms of energy matrix for each of the countries, are you working in defining the nuclear portion / renewables in medium / long terms forecasts?
-- Can you elaborate in terms of activities and partnerships in the area of public acceptance?

I would like to know if these IAEA economic tools consider renewable energy presence in the energy matrix

I would like to ask have you ever analyse the influence of renewable energy sources (PV station) to the grid in general and to the safe operation of SMRs, this became more important for the countries with small grid. Thank you.

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Background

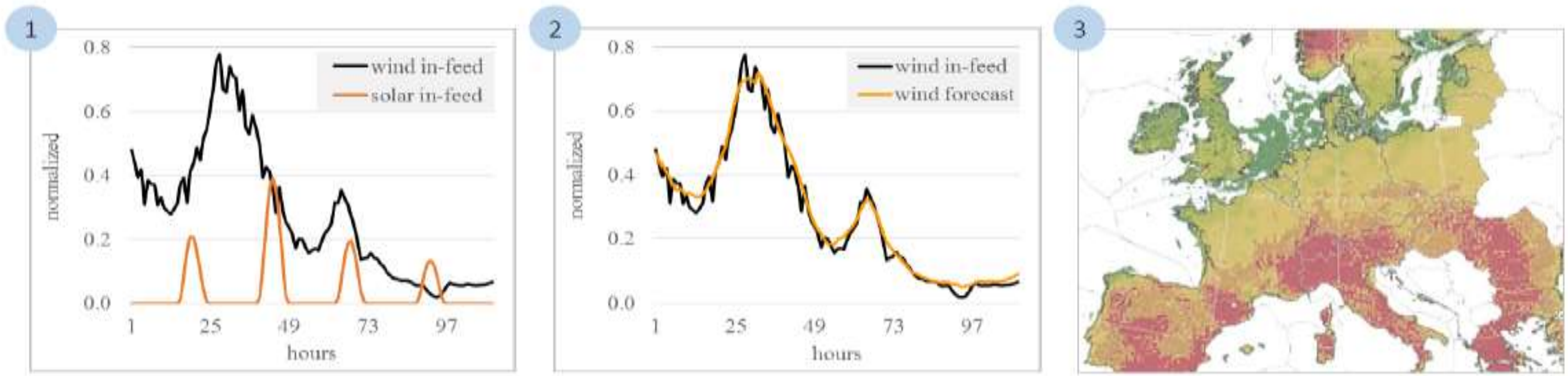
The power sector is undergoing a substantial revolution:

- Commitments by many Member States to limit the CO_2 emissions in a relatively short timeframe.
- Large deployment of Variable Renewables (VRE) driven by policy objectives and subsidies.
- Impressive cost reductions of solar PV and wind technologies, which are already competitive with dispatchable technologies on a pure cost basis in many countries.
- Emergence of new mechanisms/technologies that could disrupt the system:
  - ✓ Storage technology
  - ✓ Demand Side Measures
  - ✓ Smart Grids
- Trends to an electrification of other energy uses (transport, heat, etc.).

➡ **Large impact on the competitiveness of nuclear plants, on the operation and planning of power systems and on the tools used for power system planning and analysis.**

Characteristics of VRE and Three Main System Effects

Challenges of VRE integration



Wind does not always blow | Difficult to predict | Good sites are distant from load centers

Source: L. Hirth

Profile costs | **Balancing costs** | **Transmission and distribution costs**

- System effects are **technology-** and **country**-specific and depend on the **generation share**
- Crucially important is the **time horizon**, when assessing economical cost/benefits and impacts on existing generators from introducing new capacity.
- The costs of grid-level system effects remain difficult to assess and can be **understood and quantified only by comparing two systems**.

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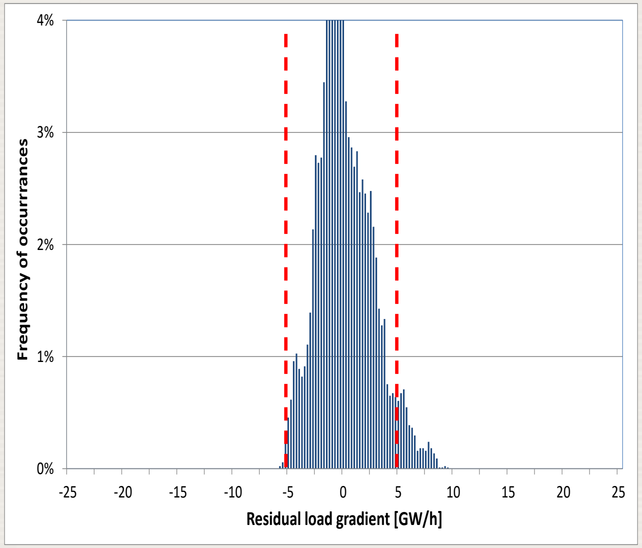
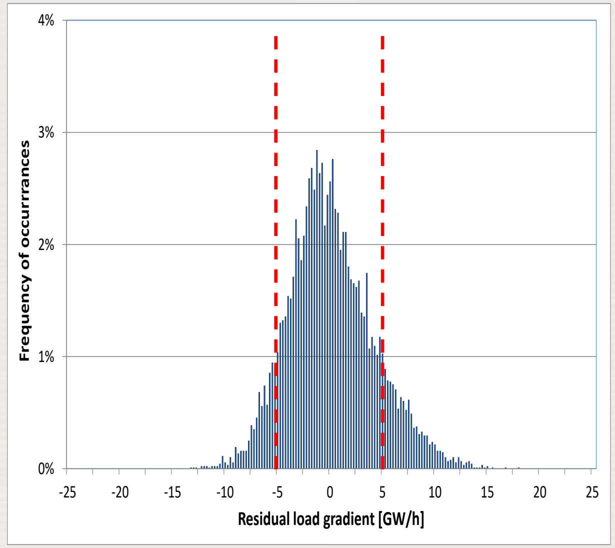
Impact of VRE on the system: Ramping Rates Requirements

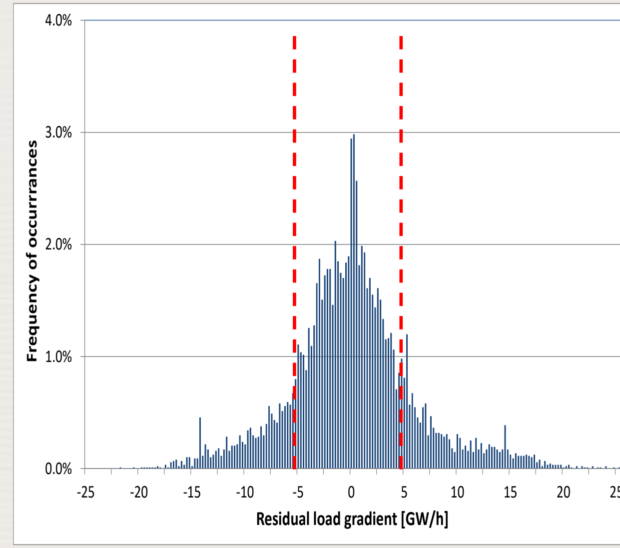
10% VRE Scenario



50% VRE Scenario



75% VRE Scenario



- No significant changes at 10% VRE penetration level and small changes at 30% (not shown)
- **High gradient of change in residual load** (more than ± 20 GW/h, about 25% of max load)
- **Frequency of occurrence of large positive and negative gradients increases**.
- Those changes must be assured by a reduced number of dispatchable generators.
- The unpredictability of those changes adds an additional difficulty to the challenge.

➡ **More and more flexibility is required from all components of electricity system. More advanced modelling tools are needed to deal with the increased complexity of power systems.**

IN SUMMARY

- It is clear that the electricity systems are changing dramatically in many countries;
- The traditional metrics to estimate the economic performance of generating technologies (e.g. levelized cost of electricity of individual technologies) are no longer sufficient;
- New quantitative, integrated computational tools are needed to assess the overall cost of electricity generation with high shares of VREs, as well as the technical requirements of future electricity systems;
- This applies also to the role of nuclear in future energy systems.

In response to these needs, and after an expression of interest by several MS at the 2019 SCM, a new **integrated power system modelling capability** is under development by INPRO together with PESS and NPTDS.

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Description of the new capability

FRAMES (**FRA**mework for **M**odelling **E**lectricity **S**ystems)

- Intended to perform detailed analyses of electricity systems.
- Realistic operational constraints of the thermal units.
- Other important features of future electricity systems (e.g. storage, demand response, provision of reserves and regulation, CO_2 constraints etc.).
- Power transmission between regions.
- Possibility of coupling with the broad energy system (heat, hydrogen, etc.)

- The model calculates the optimal (in economic terms) dispatch of existing generating units (***Unit commitment***) subject to all the relevant constraints.
- It can also determine the best investments in new generating technologies for greenfield or brownfield cases (***Capacity expansion***).

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Objectives of the new capability

For quantitative and defensible analyses:

- On the role that nuclear energy can play in present and future electricity systems;
- On the optimal share of nuclear and renewables for each particular grid, demand profile, VRE potential etc.;
- On the optimal policy mechanisms to achieve climate targets;
- On the optimal grid integration of advanced nuclear technologies, such as SMRs, microreactors, fast reactors etc.;
- On the flexibility requirements for nuclear power plants in future energy systems;
- On non-electric application of nuclear energy (cogeneration, energy storage, multigeneration etc.).

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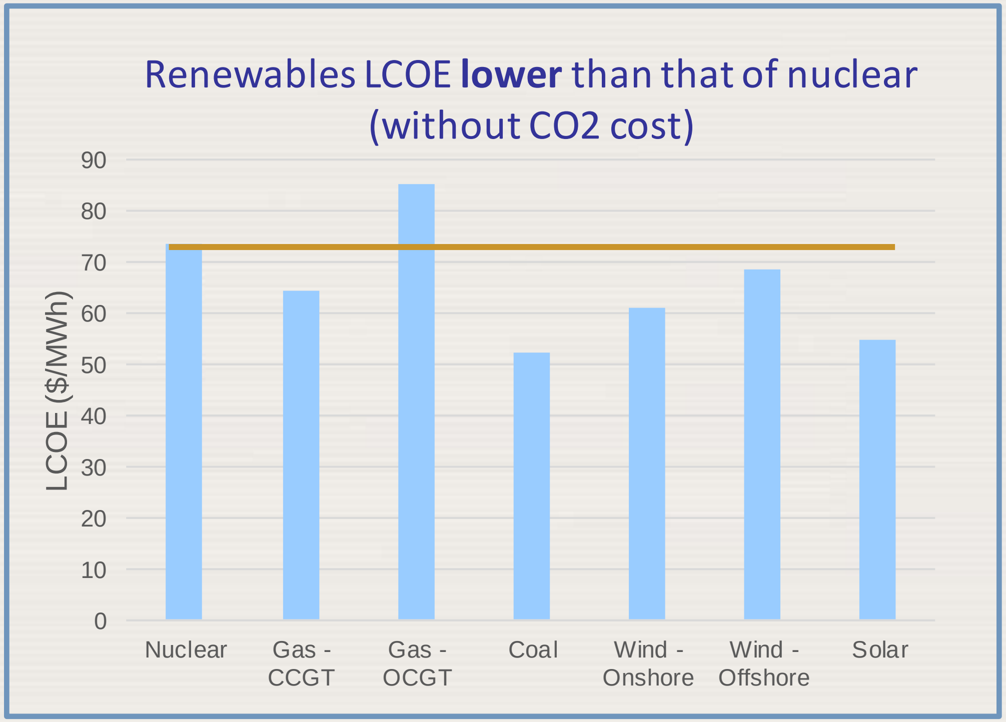
An example application

- We studied the system costs with **different shares of VRE and nuclear** for a system similar to France.
  - A CO_2 emissions objective is fixed at 50 g/kWh and **the same for all scenarios**.
  - **Identical** demand profile and carbon emission targets
- Implemented **realistic** representation of the power system.
  - We represented a large system (continental scale) with abundant hydro resources (reservoir and pumped) and different regimes of VRE generation.
  - Use of actual data from 2015 (demand, VRE load factors, realised production from hydro resources and real water inflows).
  - Same assumptions as the NEA "System cost study" (2019) but with updated **lower** costs for renewables and storage, using **optimistic assumptions** for the cost of VREs and storage for 2050.



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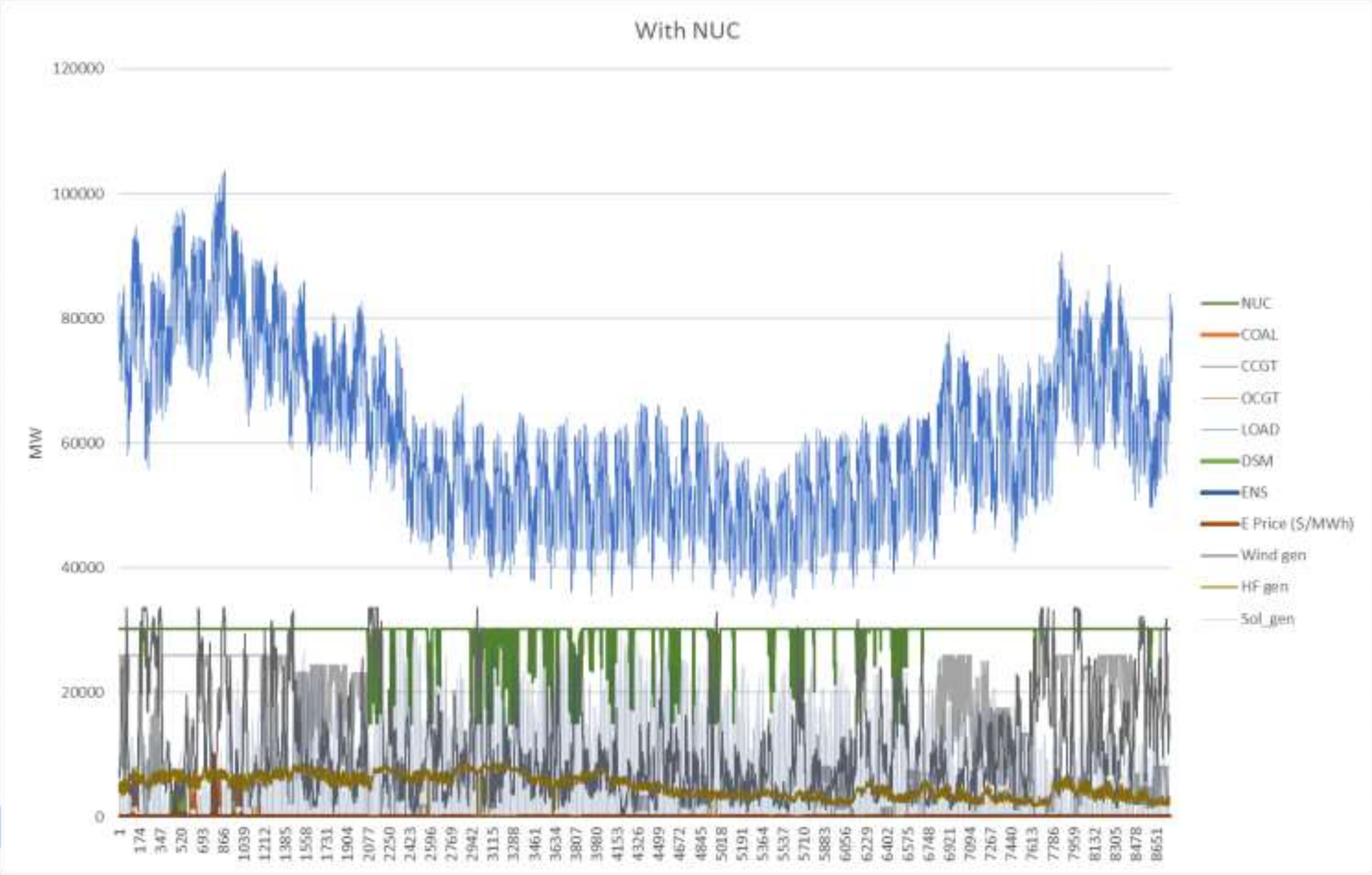
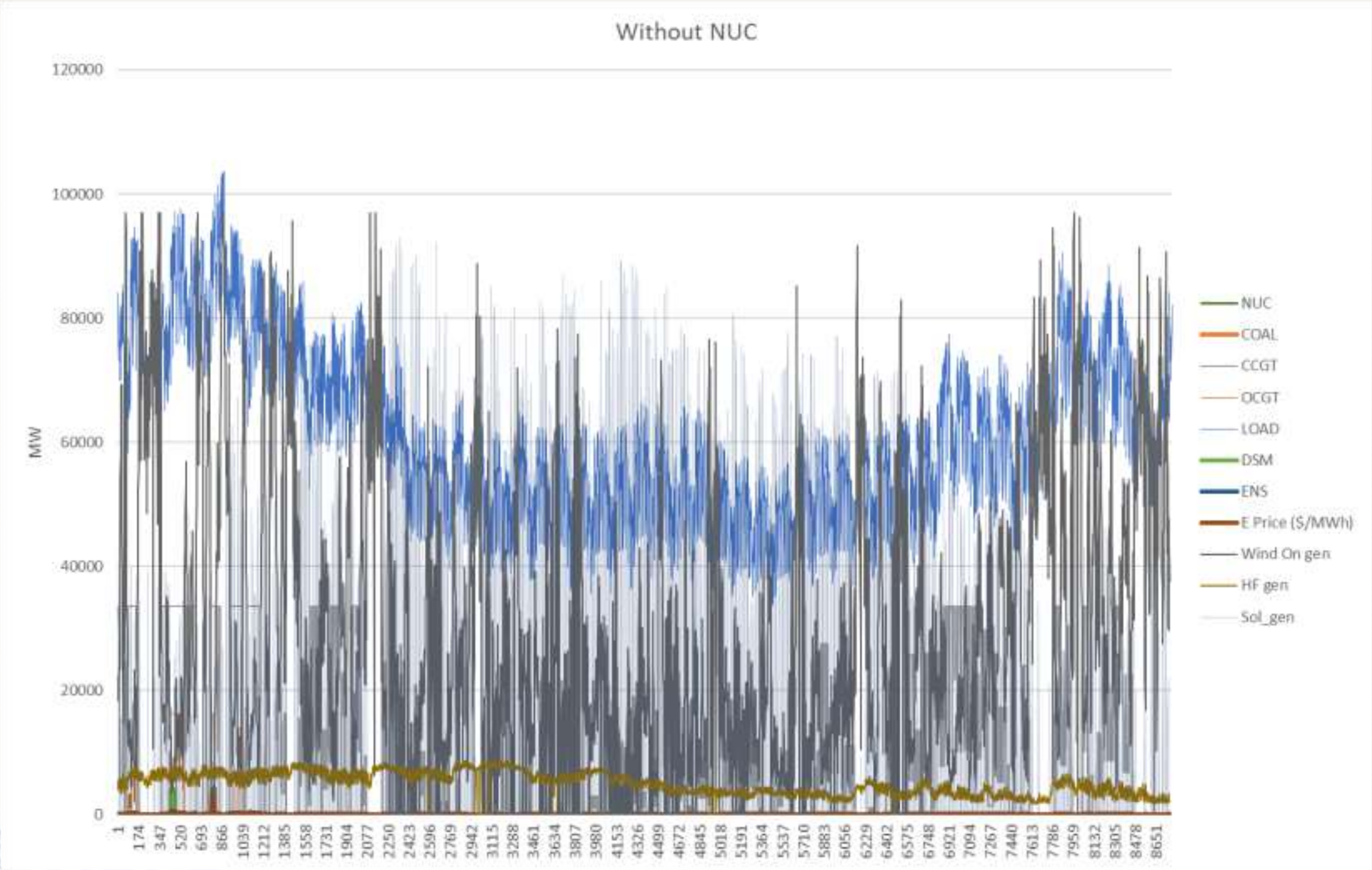
Optimal system with and without nuclear

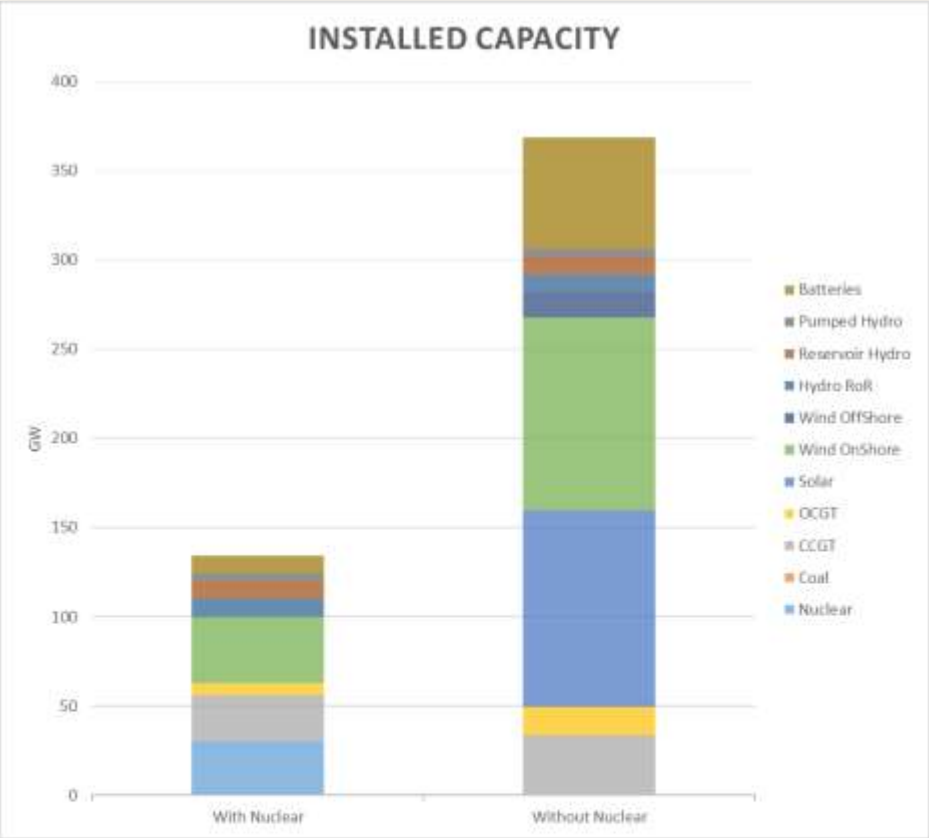
- **Minimum total cost** achieved with a substantial amount of nuclear – Despite the lower LCOE of renewables!

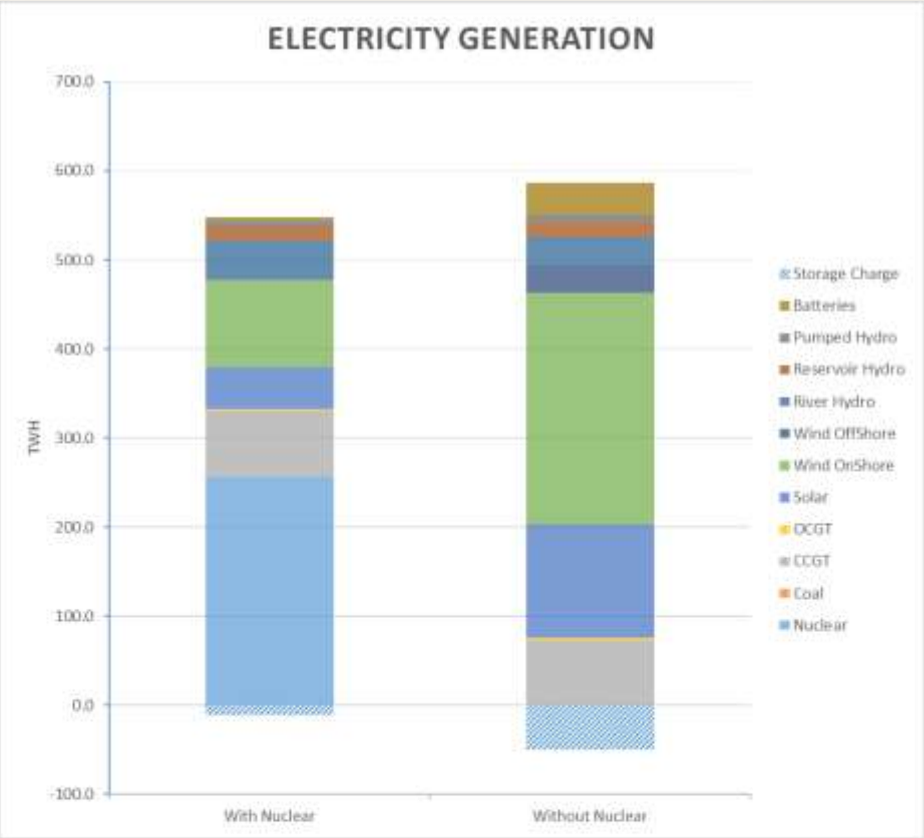


Optimal system with and without nuclear



In summary





Nuclear	48%	0%
VRE	27%	78%
Natural gas	14%	14%
Hydro	11%	8%

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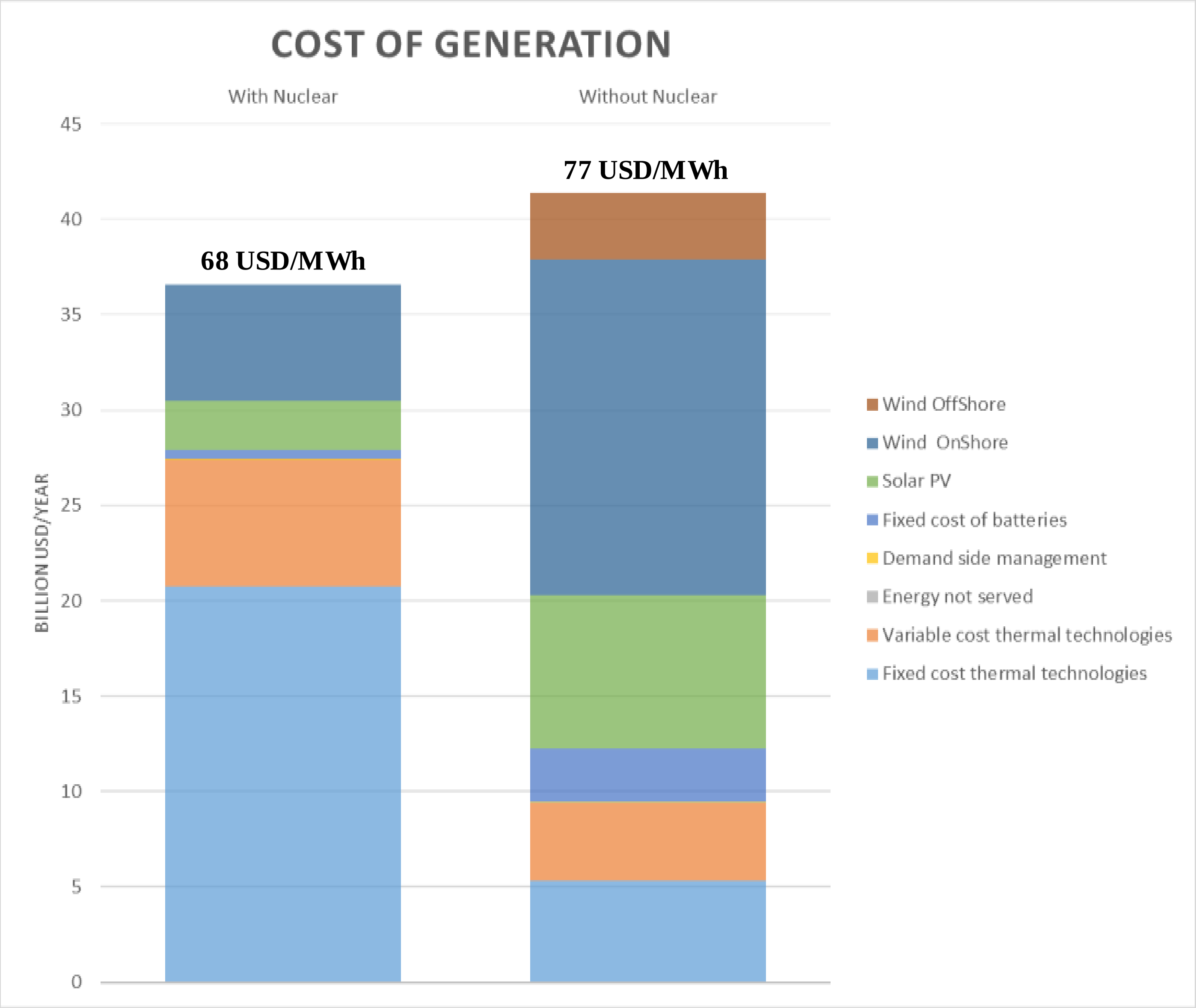
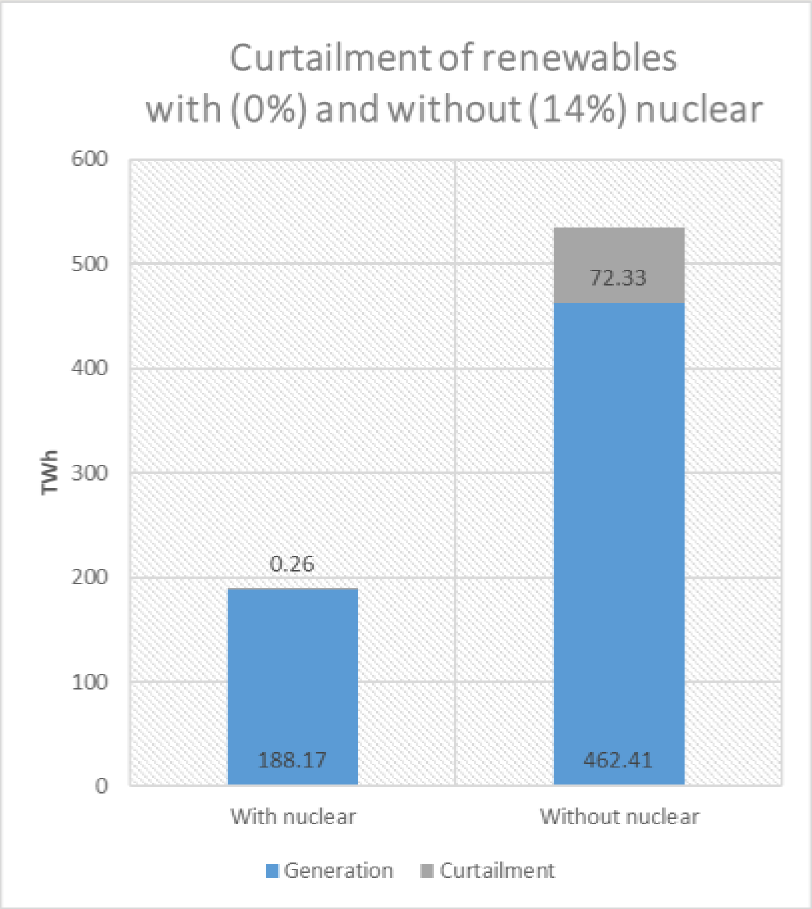
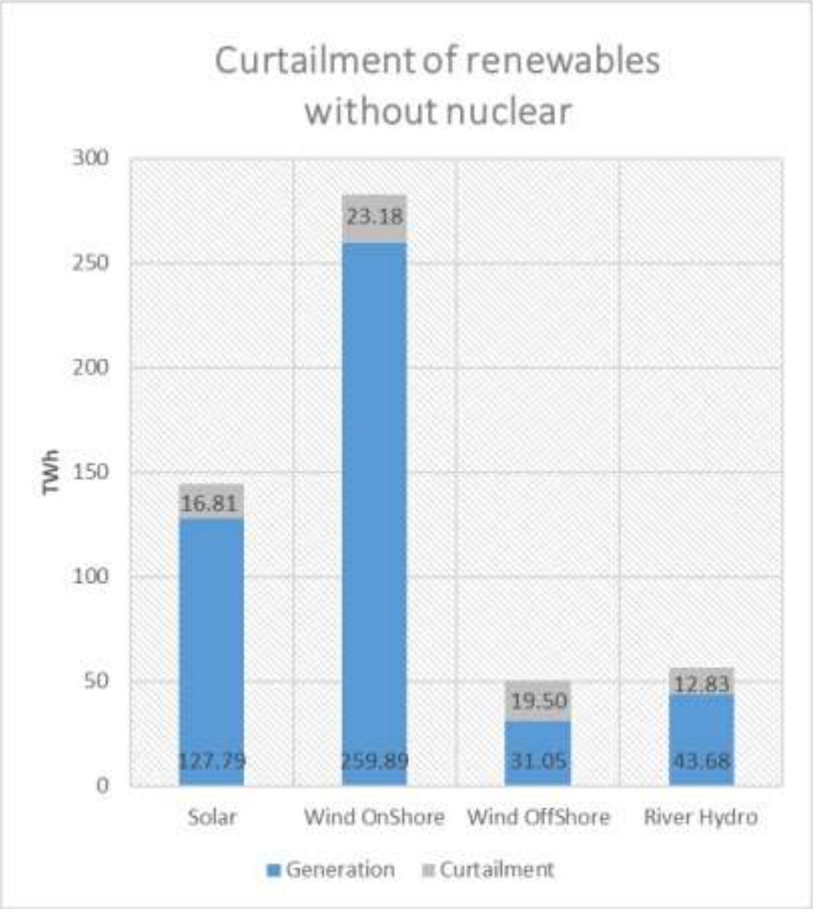
In summary


COST OF GENERATION
With Nuclear
Without Nuclear
68 USD/MWh
77 USD/MWh
BILLION USD/YEAR
45
40
35
30
25
20
15
10
5
0
Wind OffShore
Wind OnShore
Solar PV
Fixed cost of batteries
Demand side management
Energy not served
Variable cost thermal technologies
Fixed cost thermal technologies

Renewable curtailment





Extra slides

Thank you for your attention

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Some questions and answer DF

From Sonia to everyone: 2:34 PM

For the other speakers: In terms of energy matrix for each of the countries, are you working in defining the nuclear portion / renewables in medium / long terms forecasts? -- Can you ellaborate in terms of activities and partnerships in the area of public acceptance?

INPRO is developing a computational model (FRAMES) together with other sections at the IAEA (PESS and NPTDS) that allows a defensible and robust identification of the optimal mix of nuclear and renewables, in the specific situation of each Country or region (e.g. including the actual historical and forecasted load, renewable potential at the hourly resolution etc.).

From Luis MANRIQUEZ to everyone: 2:50 PM

I would like to know if these IAEA economic tools consider renewable energy presence in the energy matrix

IAEA-FRAMES is specifically designed to look at the full complexity of future energy systems, including not only detailed renewable representations, but various types of storage, hydro, demand side management etc. Additionally, we are developing the capability to include non-electric applications of nuclear energy, i.e. thermal hydrogen generation, district heating, desalination and other direct uses of nuclear heat. This should really allow to quantify the value that nuclear can bring to future systems with high renewable penetration and large issues associated with intermittency.

From Artem Petrosyan to everyone: 2:54 PM

I would like to ask have you ever analize the influence of renewable energy sorces (PV station) to the grid in general and to the save operation of SMRs, this is became more important for the countries with small grid. Thank you.

At the IAEA (and in INPRO in particular) we are developing a specific model (FRAMES) to look exactly into this issue, among others. FRAMES has the granularity to include specific features of SMRs (besides their smaller scale), such as faster ramping in some cases, high temperature heat etc. Also, by utilizing a discrete formulation (even though computationally much more difficult to solve), it allows to really see the effect of discrete additions of unit of different sizes to smaller grids (which obviously would highlight the benefit of SMRs for smaller grids). This would not be possible with models that do not allow a discrete formulation, but only allow a continuous formulation.

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