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Exploring decarbonization strategies for Italy through machine learning and socio-economic analysis

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UNIVERSITÀ DEGLI STUDI DI PADOVA
DIPARTIMENTO DI INGEGNERIA INDUSTRIALE
Levi Cases
Centro interdipartimentale di ricerca "CENTRO STUDI DI ECONOMIA E TECNICA DELL'ENERGIA GIORGIO LEVI CASES"

Research Objectives

GOAL: identify **key** (policy) **strategies for the decarbonization** of the Italian energy system by 2050

NEEDS & CHALLENGES:

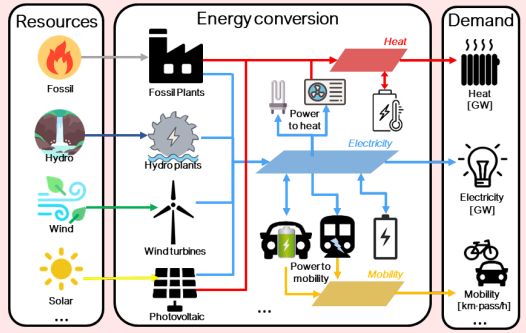
- Representation of the **entire energy system** (electricity, heat, and transport sectors) with sufficient **detail** (+ low computational effort)
- **Uncertainty of** model **variables** → large number of possible scenario, but…what are the **key steps??**
- **Socio-economic assessment** of the scenarios

HOW? → Combining different model structures and methodologies

Methodology

1. TECHNO-ECONOMIC MODEL

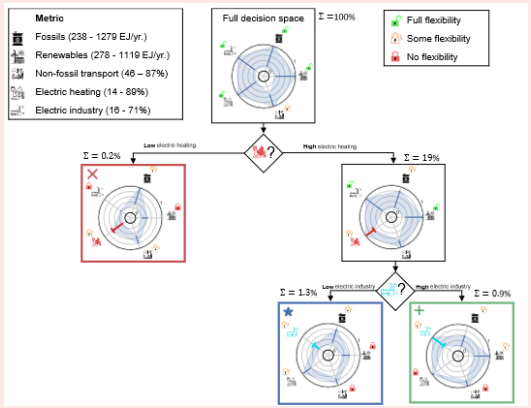
Italy 2019 vs 2050



OUTPUT:

- Technology **capacities** to be deployed
- Changes in **resource** consumption

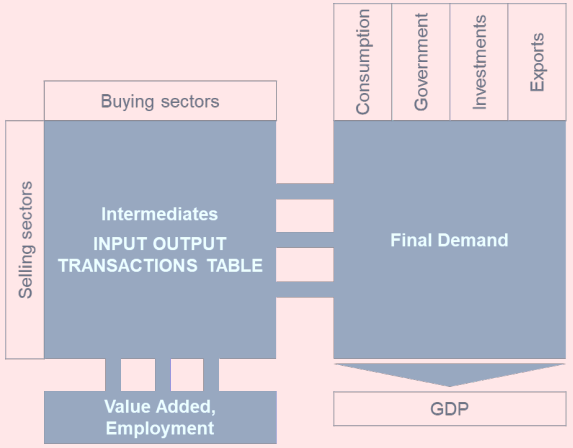
2. UNCERTAINTY ANALYSIS & DECISION TREES



OUTPUT:

- limited number of **key storylines** based on **important decisions**

3. Input-Output MACRO-ECONOMIC MODEL



OUTPUT:

- Changes in sectoral **value added & employment**

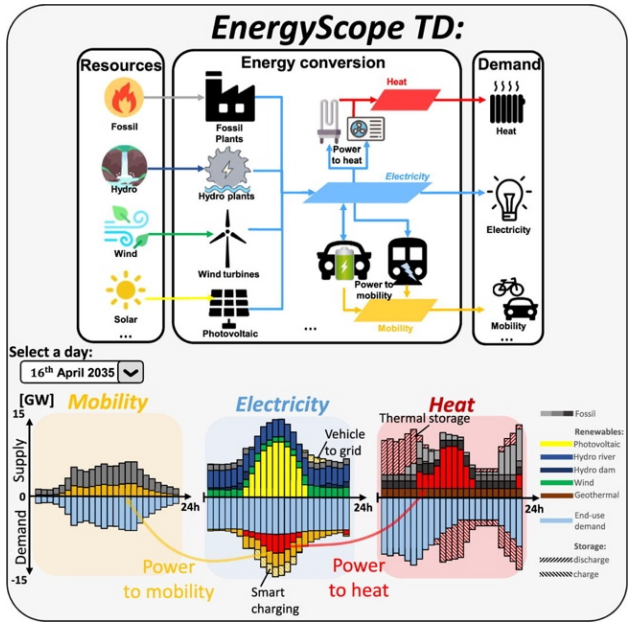
Sources: Limpens et al. (2023); Borasio and Moret (2022); Baader et al. (2023)

The techno-economic model

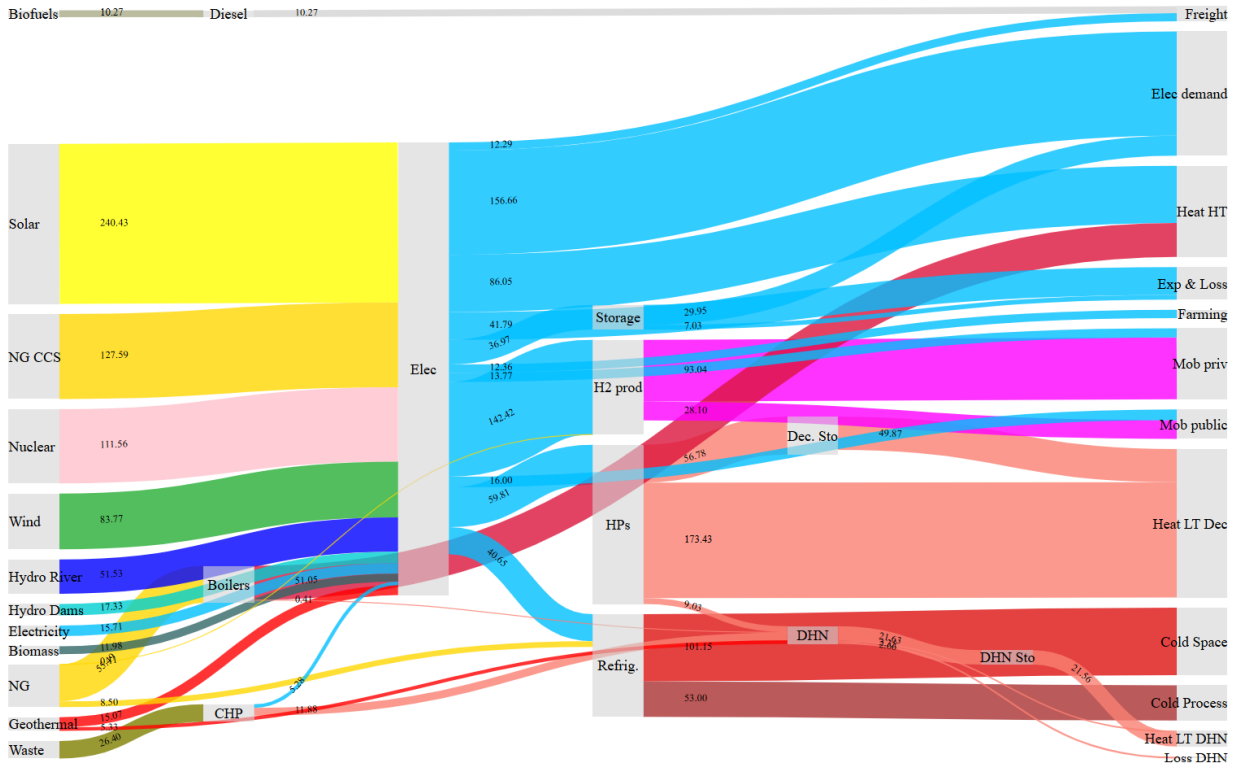
EnergyScope ITALY - 6 zones:

- **For a target (future) year (2050): Optimisation of the design and operation of a national energy system** (min. total system cost)
- Hourly resolution, typical days → suitable for uncertainty analyses

Technology capacities



Energy resources & energy flows

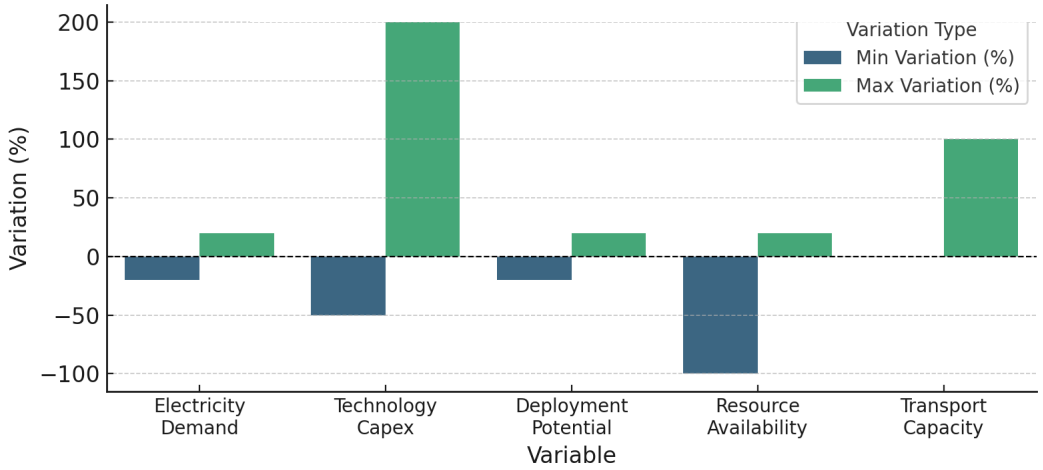


Sources: Limpens et al. (2023); Borasio and Moret (2022)

Monte Carlo uncertainty analysis

Monte Carlo analysis is used to generate a wide range of **possible energy scenarios for 2050 by varying key parameters** such as energy demand, technology costs, installation potentials, and resource availability.

Monte Carlo parameter variations

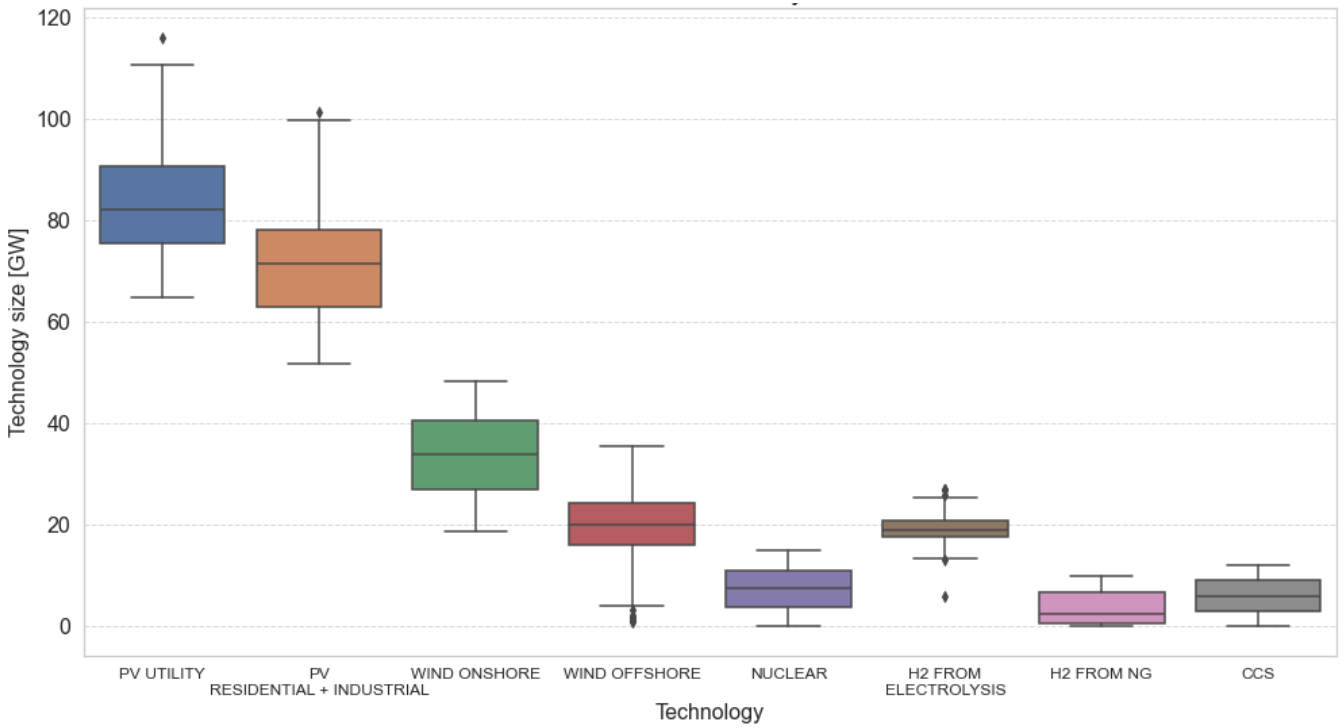


- PV
- Wind
- Nuclear
- Electrolyzers

- PV
- Wind
- Nuclear
- CCS

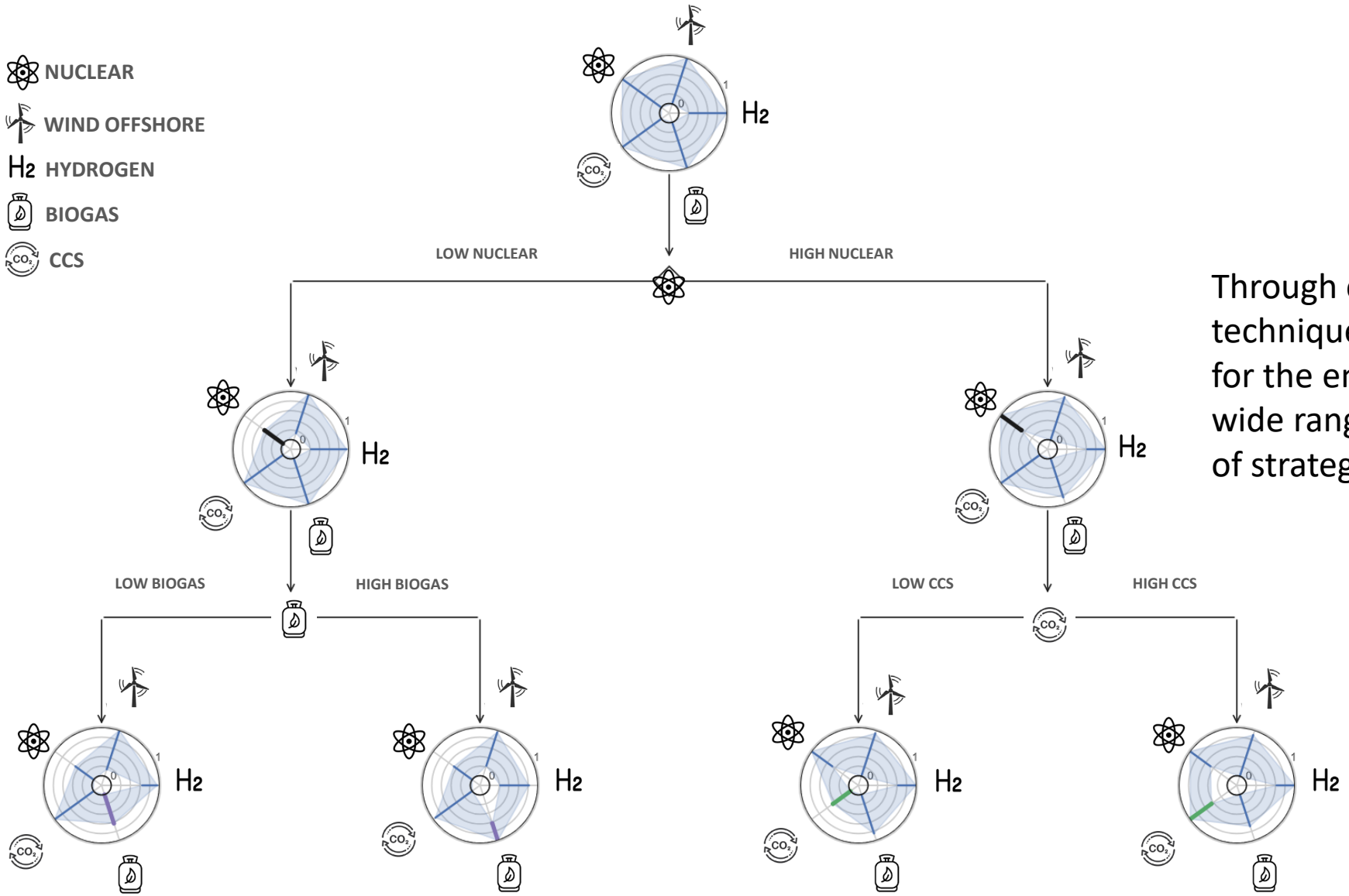
- Electricity import

Monte Carlo analysis results



➔ a **vast number of future configurations is possible**, depending on the values of input parameters

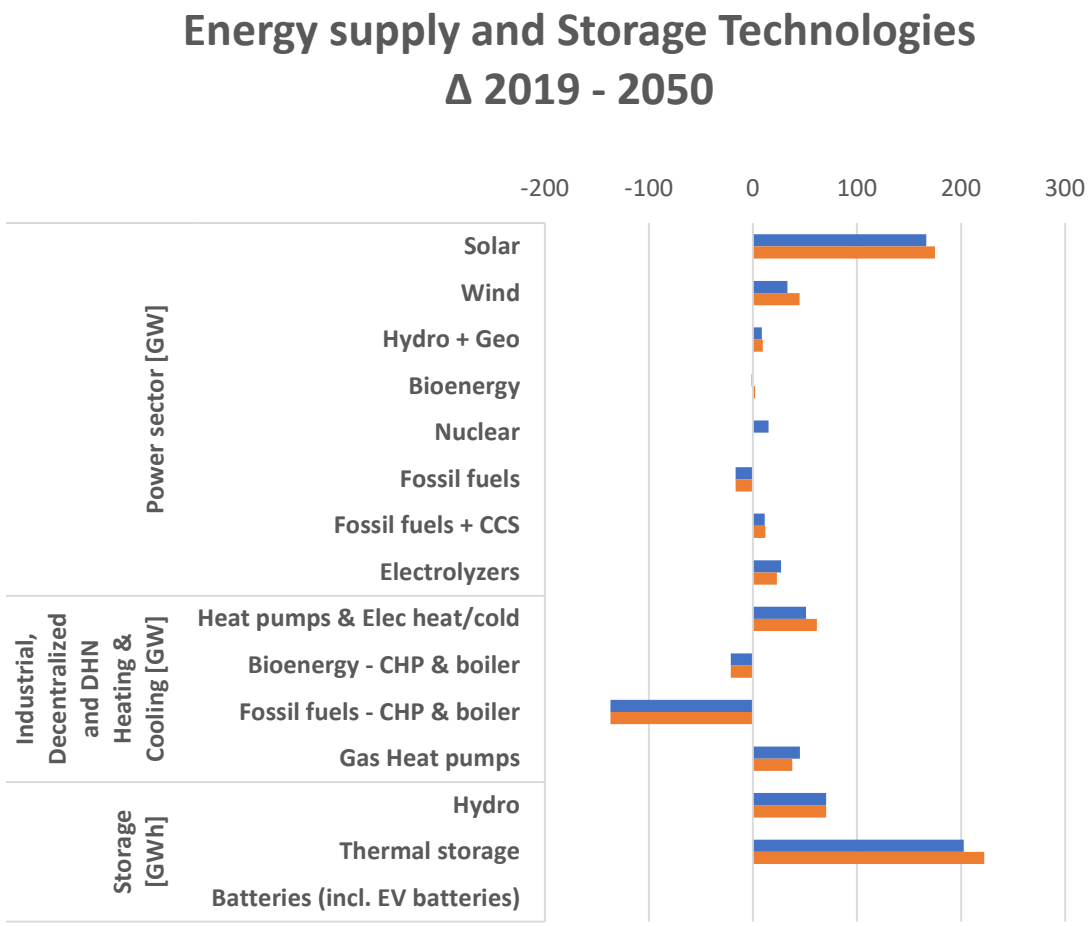
Decision Trees: key strategies for the decarbonization

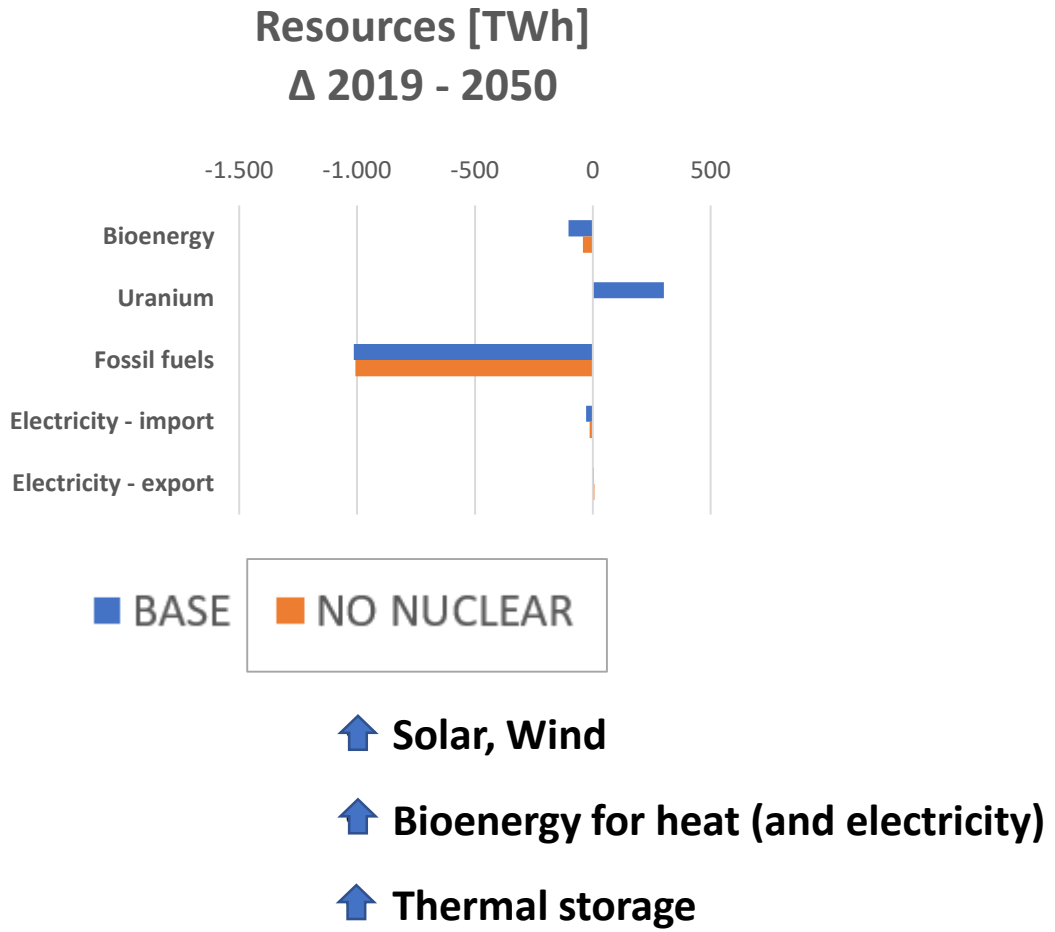


Through **clustering and decision tree** techniques, we identify critical pathways for the energy transition, condensing a wide range of scenarios into a focused set of strategic decisions and their outcomes.

Comparing socio-economic impact of energy scenarios

BASE vs NO NUCLEAR scenarios





- Solar, Wind
- Bioenergy for heat (and electricity)
- Thermal storage

"Vectors of demand"

Elaboration of a database to convert the **investment, operating and resource costs** into goods and services to be delivered by **industries** → inputted as **changes in final demands in the Input-Output model** (based on ISTAT SUTs tables, 2019).

Example: assumptions on the distribution of **investments** for the DEVELOPMENT of **energy supply and storage technologies**

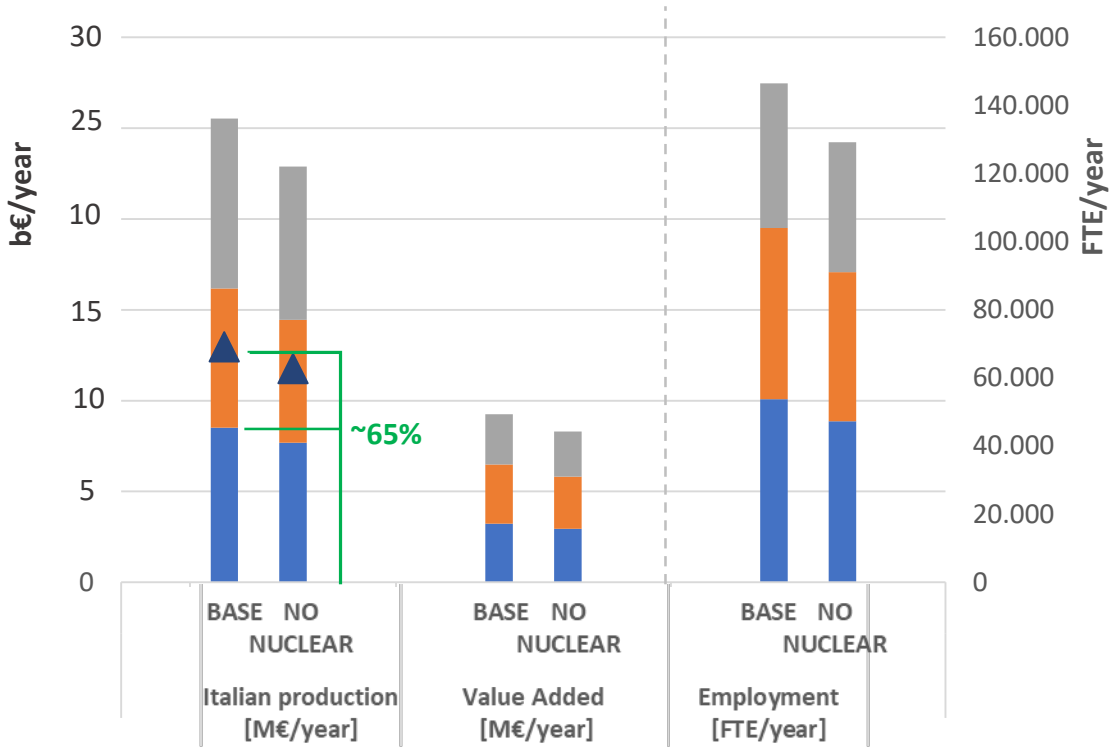
	Technology (example for each category)	Manufacturing products & services							Constructions	Transporta-tion	Financial and insurance services	Legal, accounting, management services	Architecture, engineering, technical services	Other	TOTAL (row sum)
		Metals	Metal products	Electronic components	Electrical equipment	Mechanical equipment	Installation and maintenance	Other							
Power sector	Solar PV (utility)	0%	11%	53%	8%	1%	5%	7%	0%	2%	4%	8%	2%	0%	100%
	Wind (offshore fixed)	0%	6%	0%	12%	13%	14%	6%	34%	0%	8%	4%	3%	0%	100%
	Hydro (river)	10%	0%	1%	19%	22%	3%	0%	26%	3%	8%	2%	8%	0%	100%
	Geothermal	1%	3%	1%	15%	36%	2%	0%	18%	1%	9%	2%	10%	5%	100%
	Bioenergy (ICE bioliquid)	2%	20%	3%	12%	39%	2%	1%	5%	1%	9%	2%	6%	0%	100%
	Nuclear	0%	0%	6%	18%	40%	0%	0%	22%	2%	0%	0%	12%	0%	100%
	Fossil fuels (ICE NG)	2%	13%	4%	16%	27%	5%	1%	0%	3%	17%	4%	9%	0%	100%
	Fossil fuels + CCS (CCGT)	0%	0%	2%	6%	67%	1%	0%	3%	0%	2%	14%	5%	1%	100%
	Electrolyzers	0%	9%	15%	30%	28%	16%	2%	0%	0%	0%	0%	0%	0%	100%
Ind. - Dec. - DHN Heating & Cool.	Heat pumps (decentralized)	0%	5%	4%	3%	35%	18%	6%	19%	2%	0%	5%	1%	2%	100%
	Bioenergy (CHP waste)	2%	12%	3%	16%	30%	3%	0%	20%	2%	7%	2%	4%	0%	100%
	Fossil fuels (boiler NG)	12%	4%	4%	0%	28%	7%	0%	44%	2%	0%	0%	0%	0%	100%
	Gas heat pumps (for cold)	0%	6%	5%	3%	44%	13%	8%	13%	2%	0%	3%	1%	2%	100%
Storage	Pumped hydro storage	0%	2%	0%	5%	23%	0%	0%	60%	1%	2%	0%	0%	8%	100%
	Thermal storage	0%	36%	0%	0%	36%	10%	9%	0%	10%	0%	0%	0%	0%	100%
	Batteries	0%	0%	2%	52%	0%	11%	0%	0%	0%	0%	16%	19%	0%	100%
	% of Italian production	**46%**	**89%**	**24%**	**40%**	**52%**	**97%**	-	**100%**	**96%**	**93%**	**96%**	**89%**	-	-

Impacts on Italian Production, Value Added & Employment

DEVELOPMENT PHASE
from today to 2050

Average annual cost to deploy the technologies:

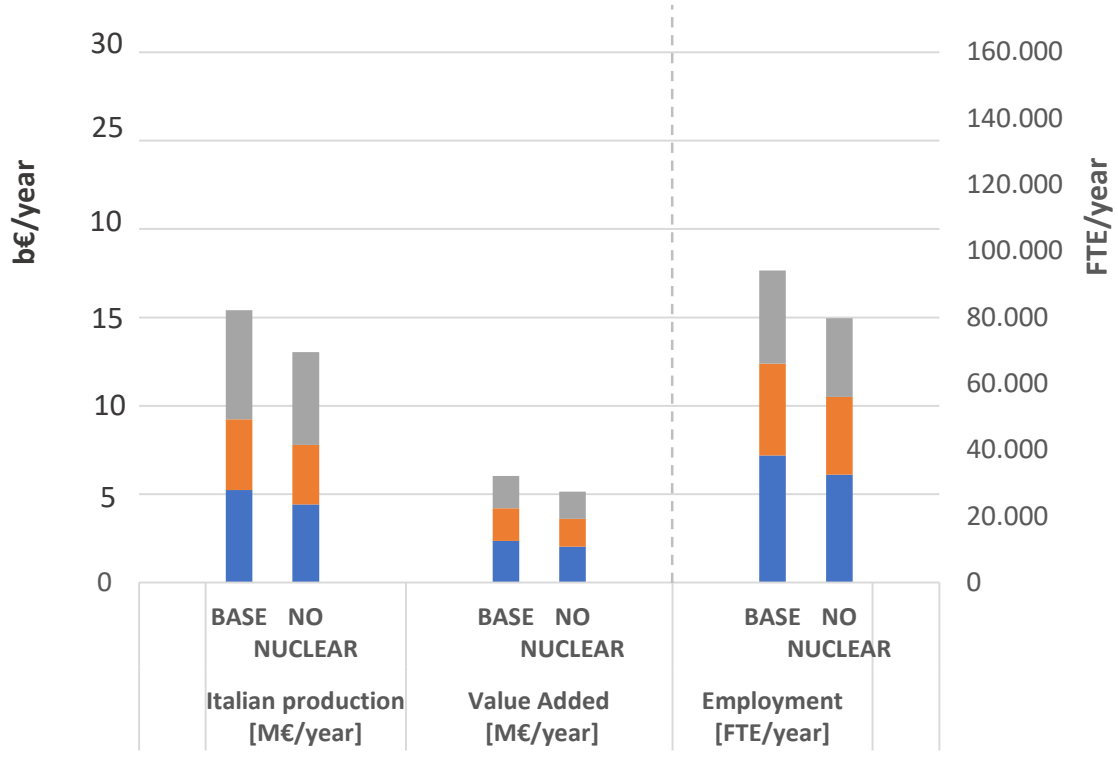
- BASE scenario: ~**11 b€/year**
- NO NUCLEAR scenario: ~**10 b€/year**



OPERATION PHASE (O&M + resources)
after 2050

Average annual operation cost, compared to today's:

	O&M	resources	TOTAL	
• BASE scenario:	6	-75	**-69**	**b€/year**
• NO NUCLEAR scenario:	5	-69	**-64**	**b€/year**

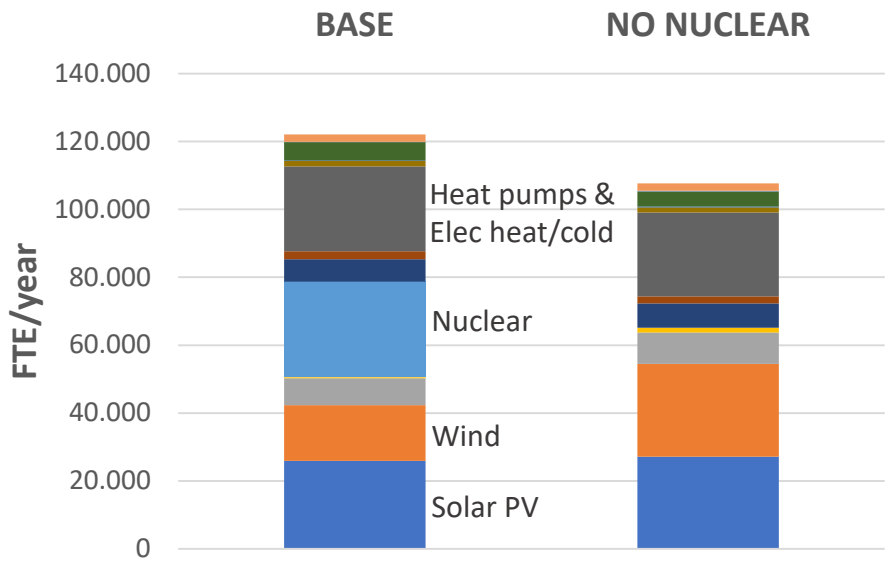


▲ System costs [M€/year] ■ Direct [M€/year] ■ Indirect [M€/year] ■ Induced [M€/year] ■ Direct [FTE/year] ■ Indirect [FTE/year] ■ Induced [FTE/year]

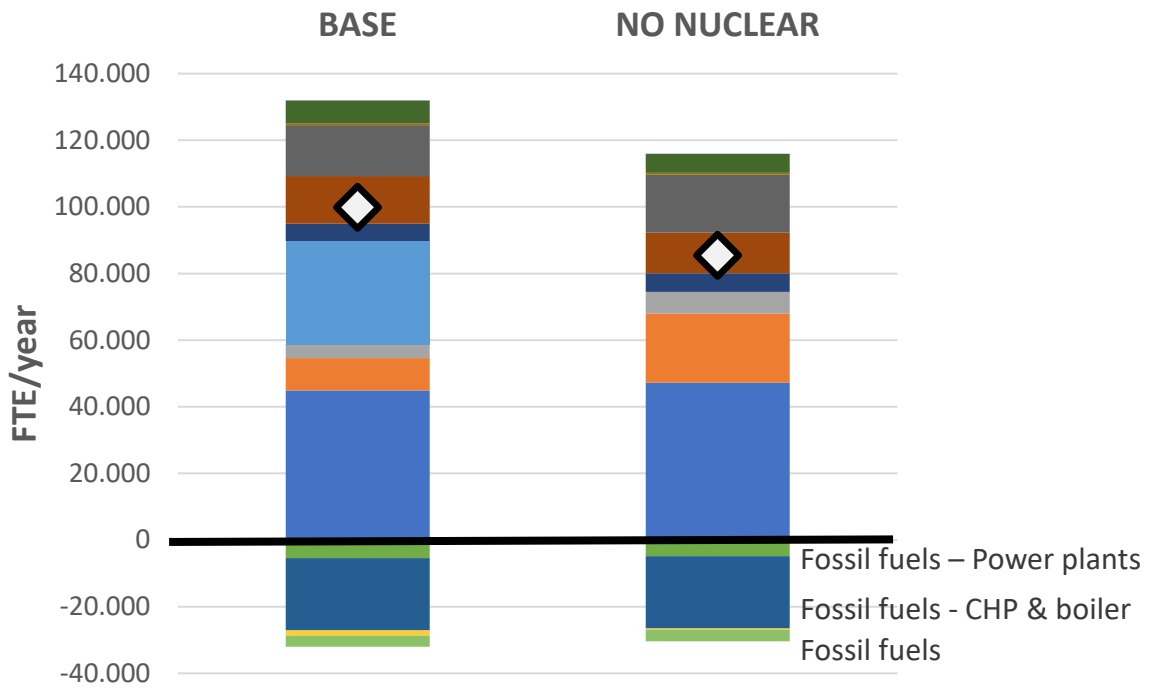
Employment variations by technology & resource

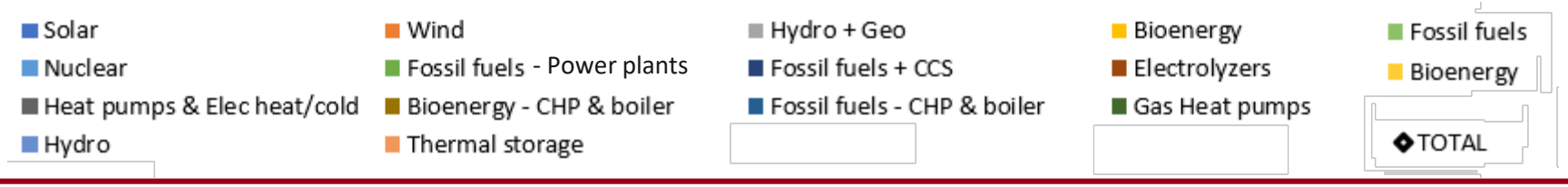
Average annual EMPLOYMENT VARIATIONS compared to today's

DEVELOPMENT PHASE
from today to 2050



OPERATION PHASE (O&M + resources)
after 2050

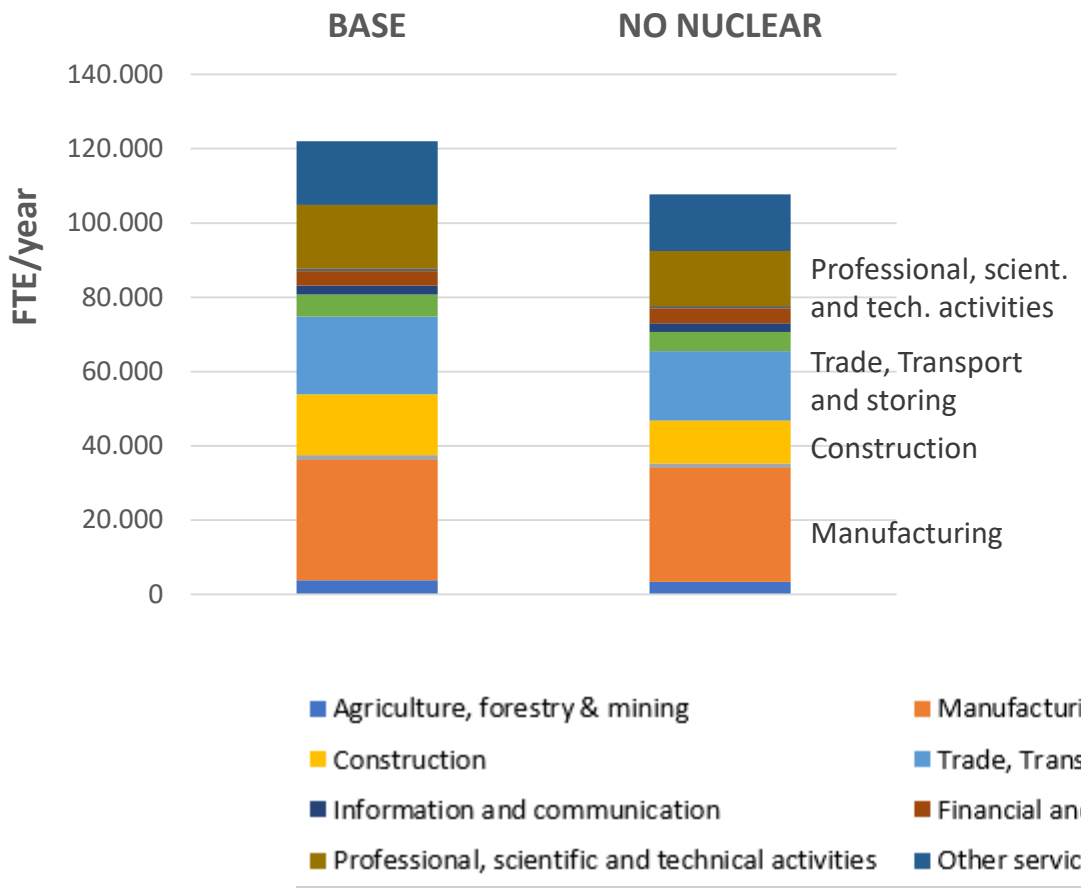




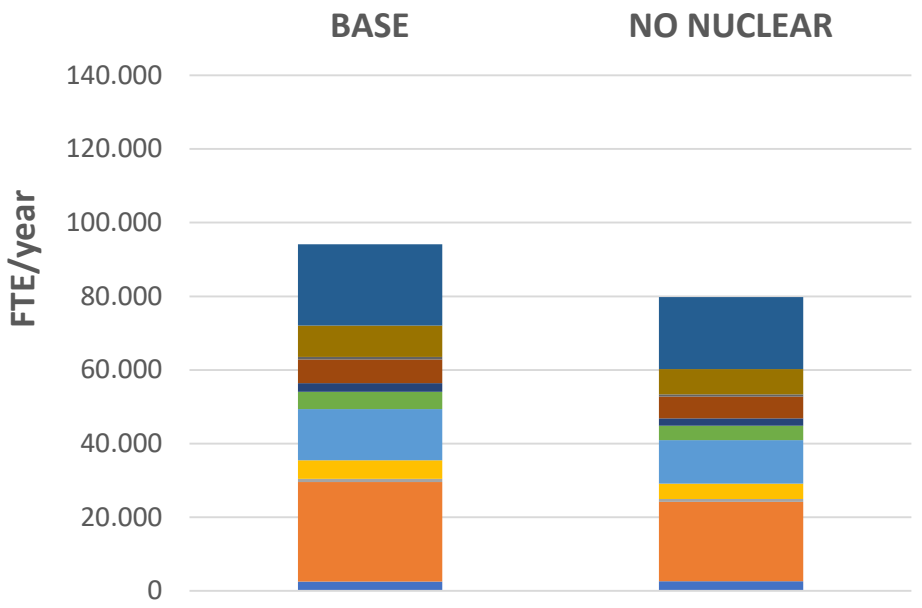
Employment variations by economic sector

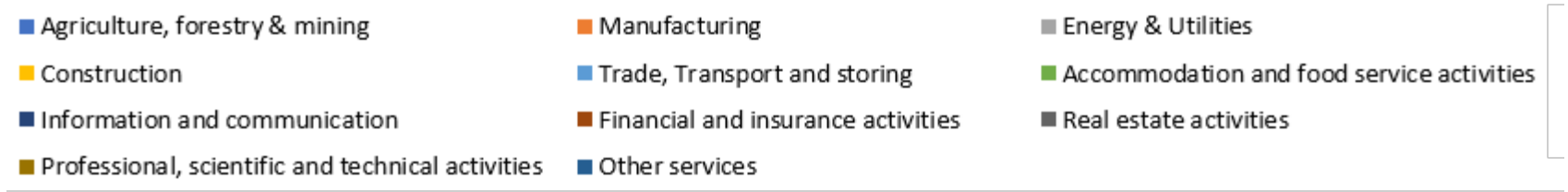
Average annual EMPLOYMENT VARIATIONS compared to today's

DEVELOPMENT PHASE
from today to 2050



OPERATION PHASE (O&M + resources)
after 2050

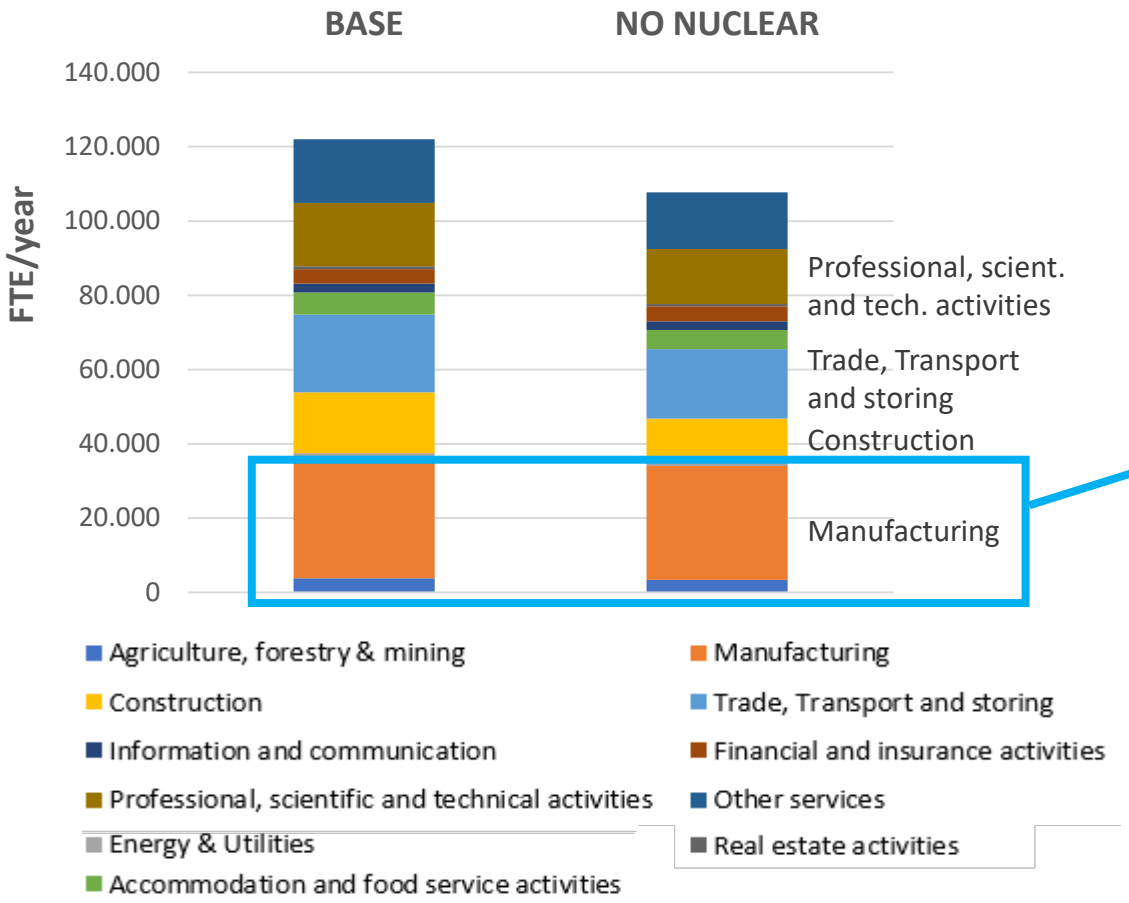


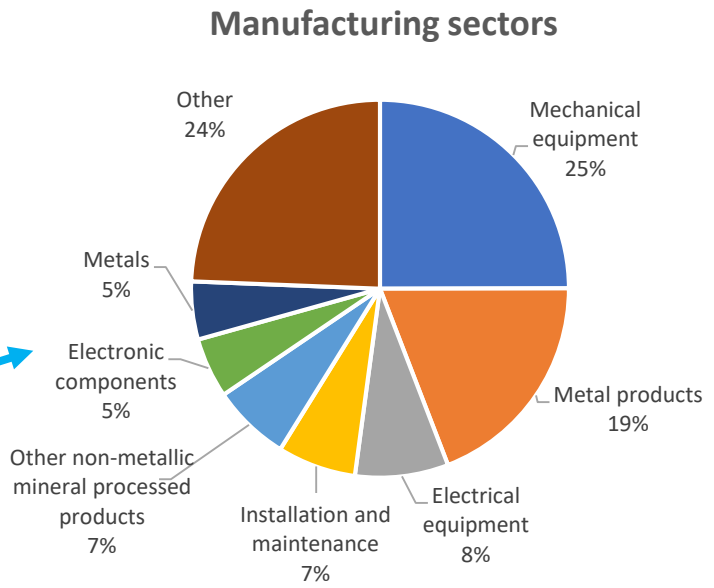


Employment variations by economic sector

Average annual EMPLOYMENT VARIATIONS compared to today's

DEVELOPMENT PHASE
from today to 2050





Final considerations

- **EnergyScope ITALY – 6 zones** as a good tradeoff between comprehensiveness and degree of detail for representing the whole Italian energy system
- **Monte Carlo & Decision Trees** to find clear key strategies for the energy transition
  - To continue exploring strategies: Integration of new uncertainty parameters and involvement of stakeholders in the selection of outputs of interest
- **Input-Output model** to compare energy scenarios (value added and employment variations), highlighting the contributions of different technologies and different sectors and imports
  - Extend the analysis considering other socio-economic parameters
  - Higher integration of the model structures

Thank you for the attention

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