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# NUCLEAR ENERGY ROLE IN LATIN AMERICA AFTER THE NEW POLICIES SCENARIOS

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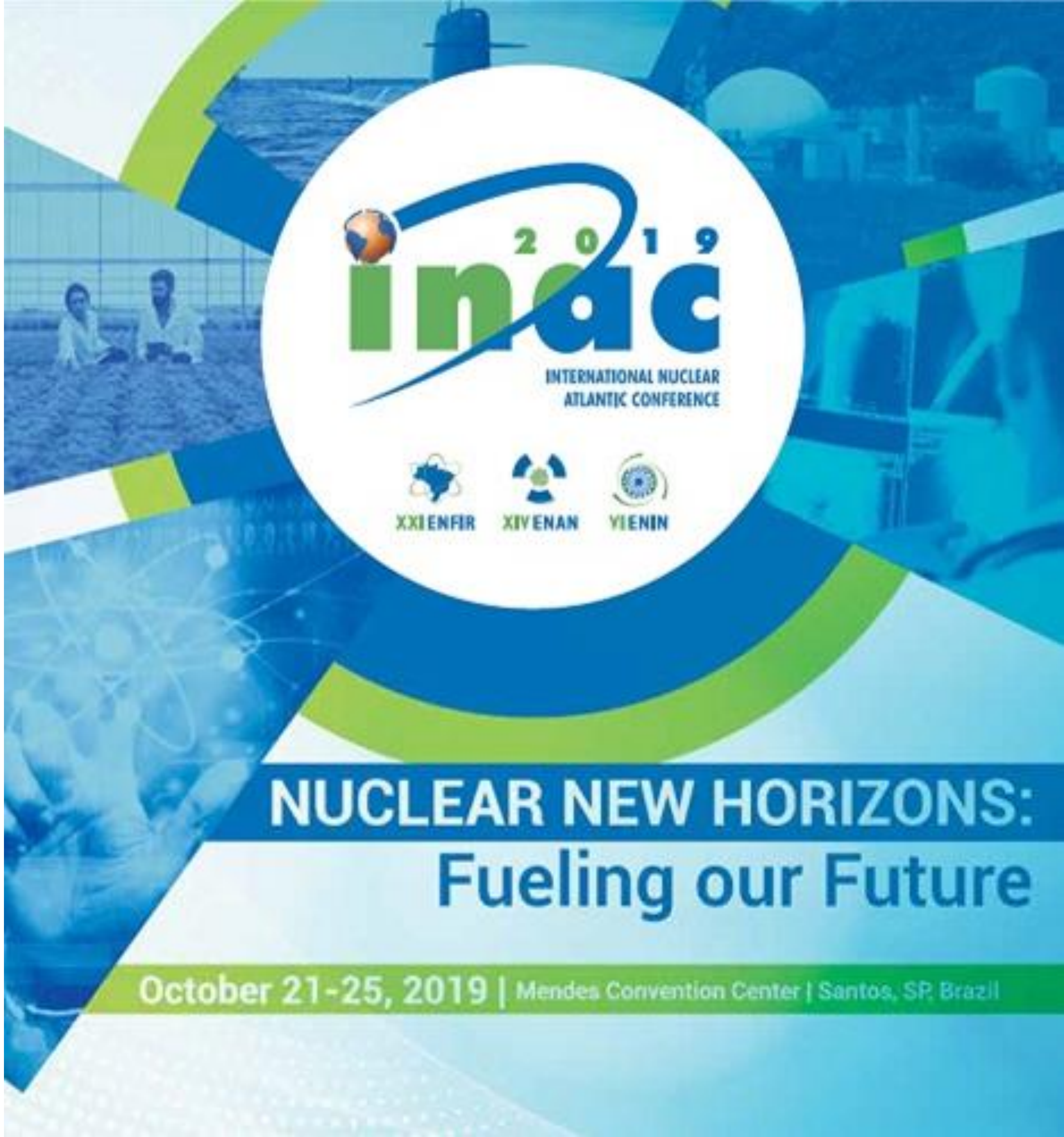


# OUTLINE

- Introduction
- Methodology
- Modelling
- Results
- References

# INTRODUCTION

Electricity production in Latin America:

✓coal,

✓oil and

✓natural gas

→ 42% of genereted energy come from fossil fuels

Fossil fuels → negatively impact the environment (GHG emissions)

Transition to a cleaner electrical matrix → Use of nuclear energy → production of energy without $CO_2$ emission at the point of generation

# INTRODUCTION

- Production of electricity in Latin America by nuclear power plant was accounted 2% of total electricity production (2017).
- Latin America countries with a nuclear program:

- Brazil
  - -Angra 1
  - -Angra 2
  - -Angra 3 (under construction)
- Argentina
  - -Atucha 1
  - -Atucha 2
  - -Embalse
  - -CAREM 25 (prototype)
- Mexico
  - -Laguna Verde 1
  - -Laguna Verde 2

**Goals of this study:**

✓ Analyze which reactors are the most adequate to meet the demand in the Latin American.
✓ Comparison in environmental terms (emission of greenhouse gases) from nuclear technology with other energy resources.
✓ Study the capability of supplying their own demand using domestic resources of uranium.

# METHODOLOGY

- Software used for this study → MESSAGE (The Model for Energy Supply Strategy Alternatives and their General Environmental Impacts) – IAEA (International Atomic Energy Agency) → Chose the most suitable reactors in each case to meet the future demand.
- Time horizon → 2019 to 2050.
- Two scenarios → high demand/low demand according to IAEA projections.
- Uranium resources → evaluated domestic resources for each country and its consume by 2050.
- $CO_2$ avoided by using nuclear resources compared to other fuels.

# MODELLING

- Electricity projection in Latin American and the Caribbean according to IAEA (International Atomic Energy Agency) reports:

| Electricity Production | 2017 | 2030 | | 2040 | | 2050 | |
|---|---|---|---|---|---|---|---|
| | | Low | High | Low | High | Low | High |
| Total (TW.h) | 1559 | 2171 | | 2809 | | 3576 | |
| Nuclear (TW.h) | 31 | 60 | 75 | 54 | 134 | 63 | 162 |
| % of total | 2.0 | 2.8 | 3.5 | 1.9 | 4.8 | 1.8 | 4.5 |

Note: *Open fuel cycle

Source: Adapted from IAEA (2016)

# MODELLING

- Chosen countries in Latin American and Caribean for this study:

- Argentina
- Brazil
- Mexico

| | Electricity Production by Nuclear (MW) | | | | | |
|---|---|---|---|---|---|---|
| | Low scenario | | | High scenario | | |
| | Argentina | Brazil | Mexico | Argentina | Brazil | Mexico |
| **2017** | 653 | 1696 | 1207 | 653 | 1696 | 1207 |
| **2030** | 1266 | 3290 | 2341 | 1579 | 4104 | 2921 |
| **2040** | 1139 | 2961 | 2107 | 2827 | 7345 | 5228 |
| **2050** | 1333 | 3464 | 2465 | 3420 | 8888 | 6326 |

# MODELLING

- The uranium resources were pooled into different grades according to the exploration classification of the uranium resource which are based on four prices categories:
- <USD 40/kgU,
- <USD80/kgU,
- <USD130/kgU and
- <USD 260/kgU

# MODELLING

**Argentina** has three nuclear power plants (NPPs)

- ATUCHA 1 (PHWR) – in operation
- ATUCHA 2 (PHWR) – in operation
- EMBALSE (PHWR) – in operation
- CAREM 25 (PWR) – prototype (start working on 2020).

In Argentina's model was considered six reactors on the total:

- 03 PHWR (Atucha-1, Atucha-2 and Embalse),
- 02 PWR (CAREM-25 and CAREM-120)
- 01 ACR-700, (Advanced CANDU Reactor-700)

ACR -700 is a reactor developed by Atomic Energy of Canada Limited (AECL) with some differences compared to all CANDUs, as the low investment cost, high capacity factor, long lifetime and some changes in the safety components.

# MODELLING

- **Argentina**

| | | Atucha-1 | Atucha-2 | Embalse | CAREM-25 | ACR-700 | CAREM-120 |
|---|---|---|---|---|---|---|---|
| Nuclear capacity | MW | 362 | 745 | 648 | 32 | 703 | 120 |
| Load factor | n.a | 0.75 | 0.88 | 0.85 | 0.8 | 0.95 | 0.90 |
| Thermal efficiency | n.a | 0.31 | 0.34 | 0.31 | 0.32 | 0.35 | 0.32 |
| Discharge burnup | MWd/t HM | 10700 | 10700 | 7200 | 18000 | 21000 | 31500 |
| Residence Time | EFPD | 456 | 456 | 335 | 840 | 456 | 1710 |
| Enrichment of fresh fuel | n.a | 0.00850 | 0.00714 | 0.00714 | 0.03100 | 0.021 | 0.031 |
| Tails assay | n.a. | 0.003 | 0 | 0 | 0.003 | 0.003 | 0.003 |
| Minimum cooling time | year | 5 | 5 | 5 | 5 | 5 | 5 |
| Lifetime | year | 30 | 30 | 30 | 40 | 30 | 40 |
| Investment cost | US$/kW(e) | 1726.86 | 5895.6 | 3909.66 | 7267.5 | 3182.53 | 5814.00 |
| Fixed O&M cost | US$/kW.yr | 87.72 | 87.72 | 87.72 | 51.00 | 128.88 | 51 |
| Variable O&M cost | US$/kW.yr | 1.55 | 1.12 | 1.63 | 10.20 | 0 | 10.20 |
| Conversion | US $/kg HM | 50.898 | 50.898 | 50.898 | 50.90 | 17.5 | 50.90 |
| Enrichment | US $/kg HM | 112.2 | 112.2 | 112.2 | 112.2 | 44 | 112.2 |
| Fuel fabrication cost | US $/kgHM.yr | 663.816 | 525.3 | 220.32 | 1020 | 183.06 | 1020 |
| Cooling storage | US$/kg HM/yr | 5 | 5 | 5 | 5 | 5 | 5 |
| Construction time | year | 6 | 35 | 10 | 5 | 6 | 5 |

# MODELLING

**Brazil** has the following reactors:

- Angra-1 (PWR) – in operation
- Angra-2 (PWR) – in operation
- Angra-3 (PWR) – under construction (start working on 2026)

In Brazil's model was considered five reactors on the total:

- 03 PWR (Angra 1, Angra 2 and Angra 3)
- 01 EPR
- 01 LWR (China)

The EPR is a PWR reactor from generation III+ with a nuclear capacity of 1660 MW and it was developed by Framatome e Électricité de France

# MODELLING

- **Brazil**

| | | Angra 1 | Angra 2 | Angra 3 | EPR | LWR |
|---|---|---|---|---|---|---|
| Nuclear capacity | MW | 626 | 1275 | 1245 | 1660 | 1000 |
| Load factor | n.a | 0.96 | 0.975 | 0.90 | 0.92 | 0.80 |
| Thermal efficiency | n.a | 0.342 | 0.358 | 0.358 | 0.36 | 0.33 |
| Discharge burnup | MWd/t HM | 55000 | 50000 | 50000 | 65000 | 45000 |
| Residence Time | EFPD | 1168 | 1168 | 1168 | 1168 | 1168 |
| Enrichment of fresh fuel | n.a | 0.04 | 0.04 | 0.05 | 0.05 | 0.04 |
| Tails assay | n.a. | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| Minimum cooling time | year | 5 | 5 | 5 | 5 | 5 |
| Lifetime | year | 40 | 40 | 40 | 60 | 40 |
| Investment cost | US$/kW(e) | 2070.15 | 1993.86 | 5423.55 | 2508.00 | 3060.00 |
| Fixed O&M cost | US$/kW.yr | 235.87 | 134.76 | 134.76 | 134.76 | 56.10 |
| Variable O&M cost | US$/kW.yr | 56.16 | 25.73 | 25.73 | 25.73 | 10.20 |
| Conversion | US $/kg HM | 7.05 | 7.05 | 7.05 | 7.05 | 8.16 |
| Enrichment | US $/kg HM | 62.7 | 62.7 | 62.7 | 62.7 | 112.2 |
| Fuel fabrication cost | US $/kg HM.yr | 287.38 | 287.38 | 287.38 | 287.38 | 280.50 |
| Cooling storage | US$/kg HM/yr | 5 | 5 | 5 | 5 | 5 |
| Construction time | year | 10 | 19 | 13 | 8 | 5 |

# MODELLING

**Mexico** has two nuclear power plants (NPPs)

- Laguna Verde 1 (BWR) – in operation
- Laguna Verde 2 (BWR) – in operation

In Mexico's model was considered four reactors on the total:

- 02 BWR (Laguna Verde 1 and Laguna Verde 02)
- 01 EPR
- 01 AP-1000

The AP-1000 reactor designed and sold by Westinghouse, which includes advanced passive safety systems and extensive plant simplifications to enhance the safety, construction, operation, and maintenance of the plant.

# MODELLING

- **Mexico**

| | | Laguna Verde 1 | Laguna Verde 2 | AP-1000 | EPR |
|---|---|---|---|---|---|
| Nuclear capacity | MW | 780 | 780 | 1117 | 1660 |
| Load factor | n.a | 0.982 | 0.987 | 0.93 | 0,92 |
| Thermal efficiency | n.a | 0.34 | 0.34 | 0.33 | 0,36 |
| Discharge burnup | MWd/t HM | 10500 | 10500 | 60000 | 65000 |
| Residence Time | EFPD | 540 | 540 | 540 | 1168 |
| Enrichment of fresh fuel | n.a | 0.037 | 0.037 | 0.036 | 0,05 |
| Tails assay | n.a. | 0.003 | 0.003 | 0.003 | 0,003 |
| Minimum cooling time | year | 5 | 5 | 5 | 5 |
| Lifetime | year | 40 | 40 | 60 | 60 |
| Investment cost | US$/kW(e) | 5948 | 5948 | 3172 | 2508,00 |
| Fixed O&M cost | US$/kW.yr | 110.72 | 110.72 | 53.50 | 134,76 |
| Variable O&M cost | US$/kW.yr | 19.54 | 19.54 | 10.60 | 25,73 |
| Conversion | US $/kg HM | 51.53 | 51.53 | 10.80 | 7,05 |
| Enrichment | US $/kg HM | 612.91 | 612.91 | 108.00 | 62,7 |
| Fuel fabrication cost | US $/kg HM.yr | 325.44 | 325.44 | 324.00 | 287,38 |
| Cooling storage | US$/kg HM/yr | 5 | 5 | 5 | 5 |
| Construction time | year | 13 | 17 | 5 | 8 |

# RESULTS
# Argentina/Brazil/Mexico’s models

# RESULTS

## Argentina

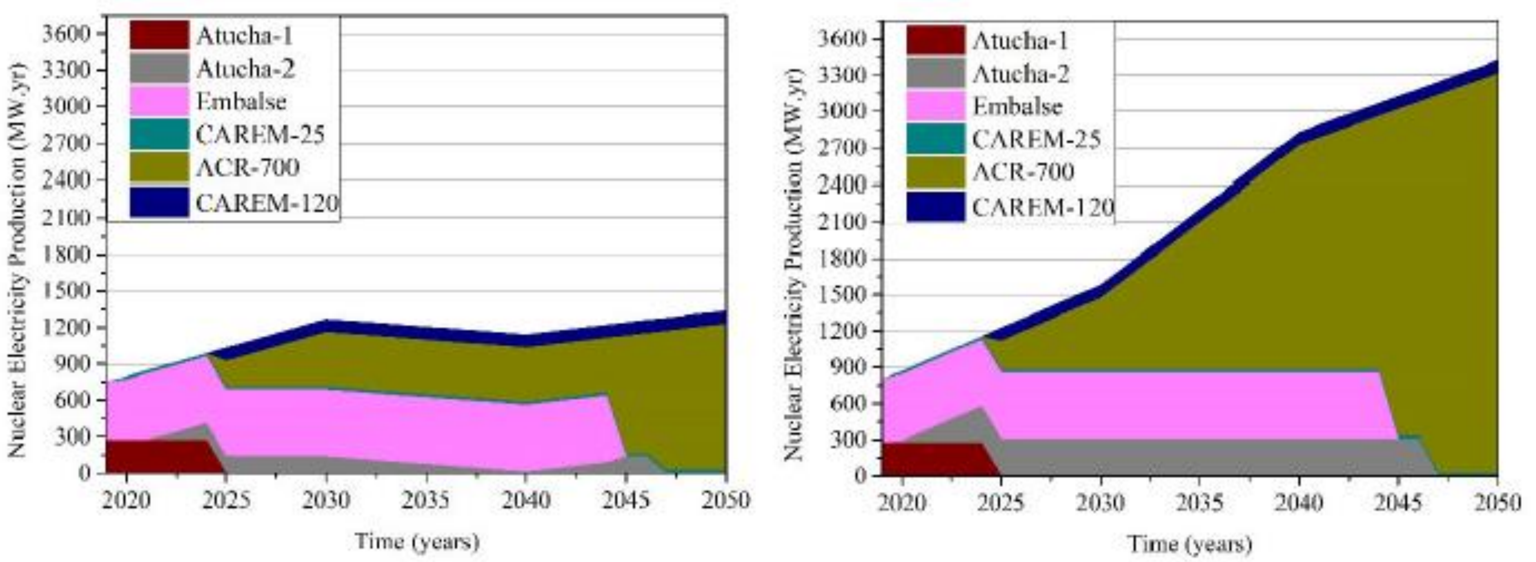



**Figure 1:** Argentina's nuclear electricity production for the low (left) and high (right) scenarios.

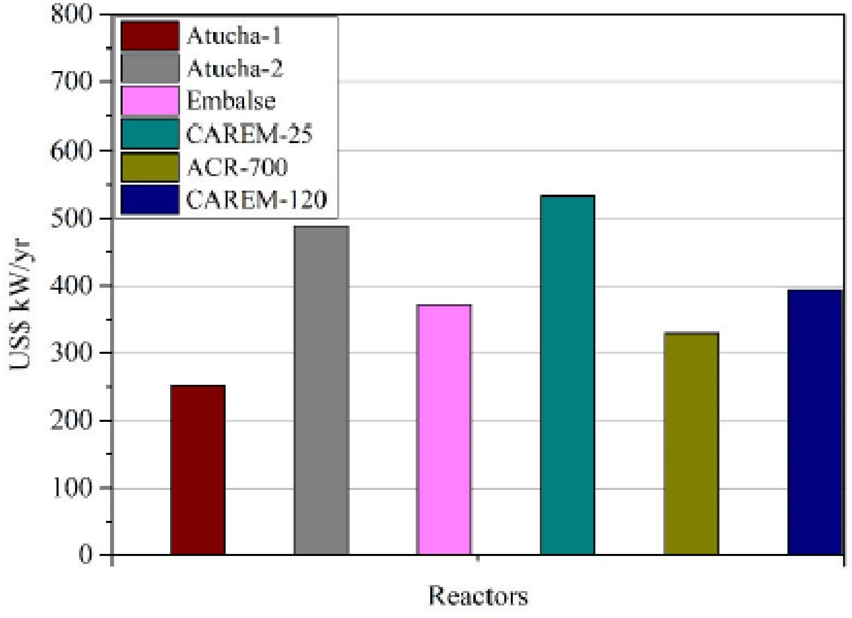



**Figure 2**: LUAC&LUOM from Argentina's reactors

-Atucha 1/Atucha 2/Embalse → operate until the end of their lifetime

-CAREM25/CAREM120 → fixed operating at their maximum power.

-ACR700 → most suitable/ low LUAC&LUOM compared to CAREMs

LUAC – Levelized unit lifecycle amortization cost
LUOM – Levelized unit lifecycle operation and maintenance cost

# RESULTS

## Brazil

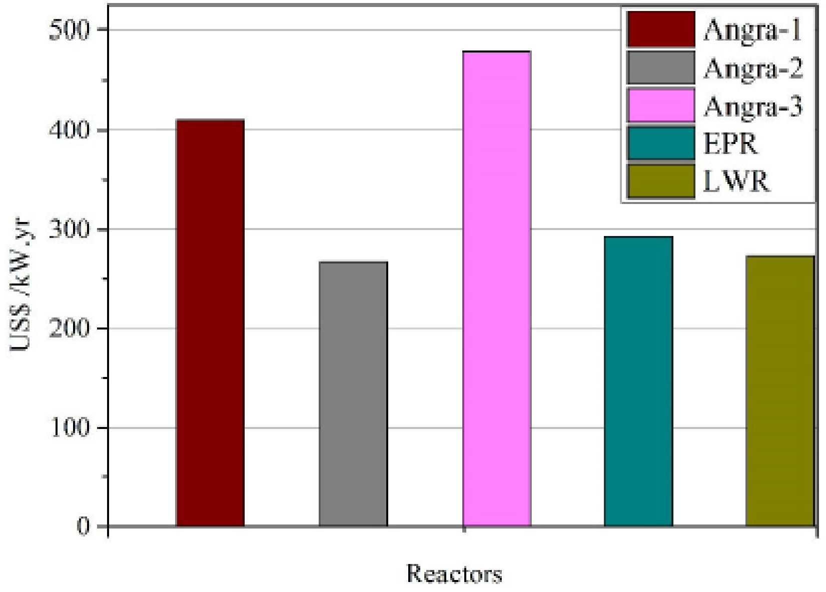



**Figure 4**: LUAC&LUOM from Brazil's reactors

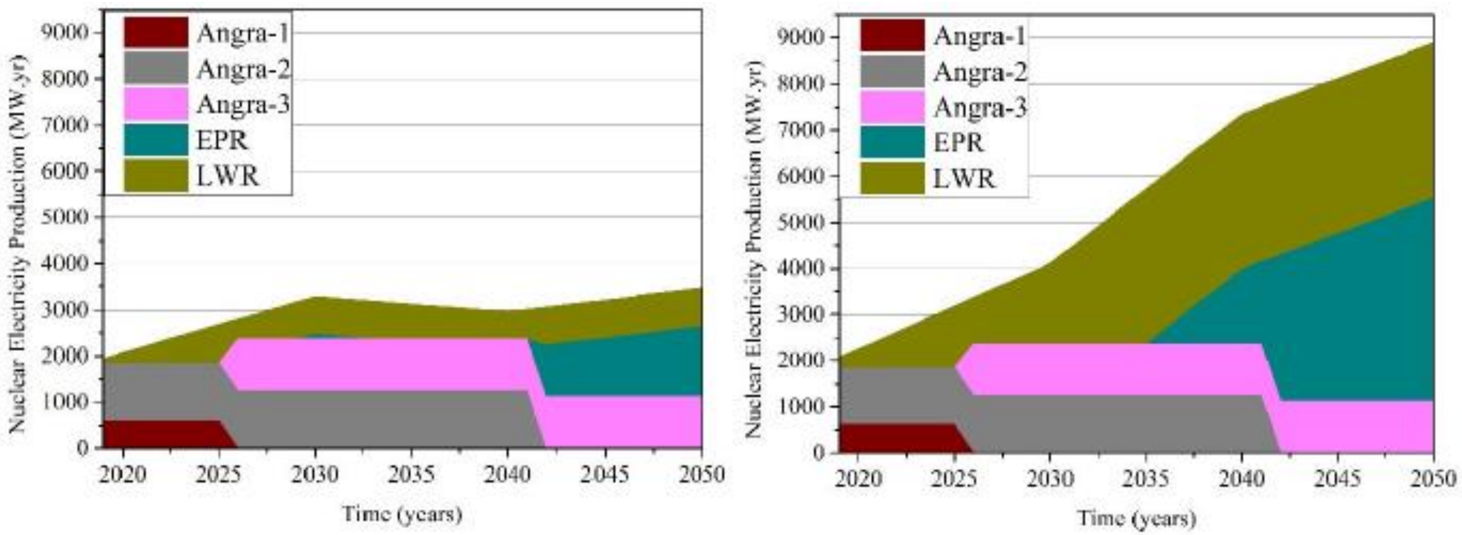



**Figure 3:** Brazil's nuclear electricity production for the low (left) and high (right) scenarios.

-Angra 1 and 2 → operate until 2025 and 2041, respectively.

-Angra 3 → start working on 2026 → fixed maximum output power

-LWR and EPR → most suitable/low LUAC&LUOM compared to Angra 3.

LUAC – Levelized unit lifecycle amortization cost
LUOM – Levelized unit lifecycle operation and maintenance cost

# RESULTS

## Mexico

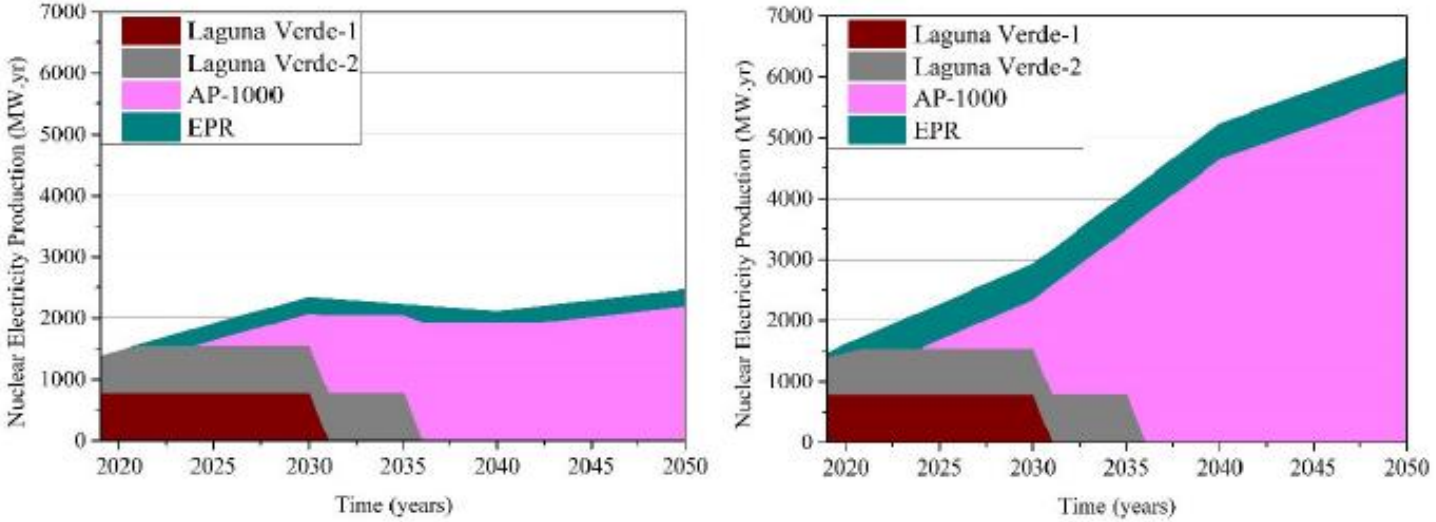



**Figure 5:** Mexicos's nuclear electricity production for the low (left) and high (right) scenarios.

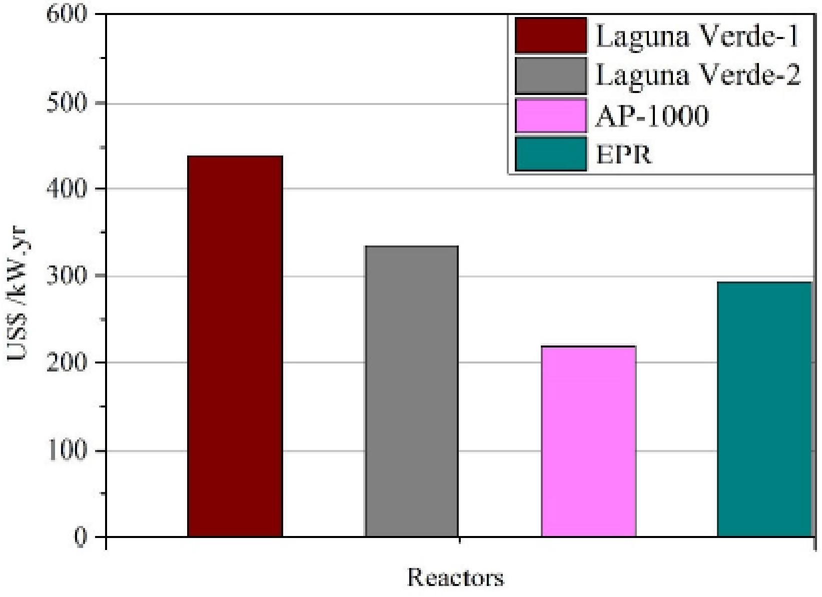



**Figure 6**: LUAC&LUOM from Mexico's reactors

LUAC – Levelized unit lifecycle amortization cost
LUOM – Levelized unit lifecycle operation and maintenance cost

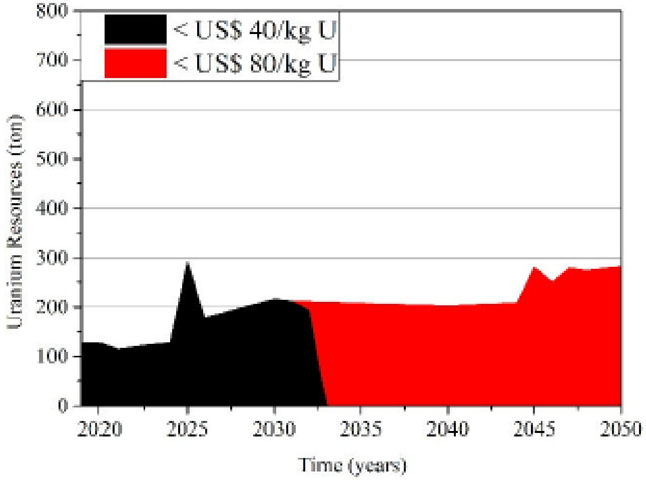
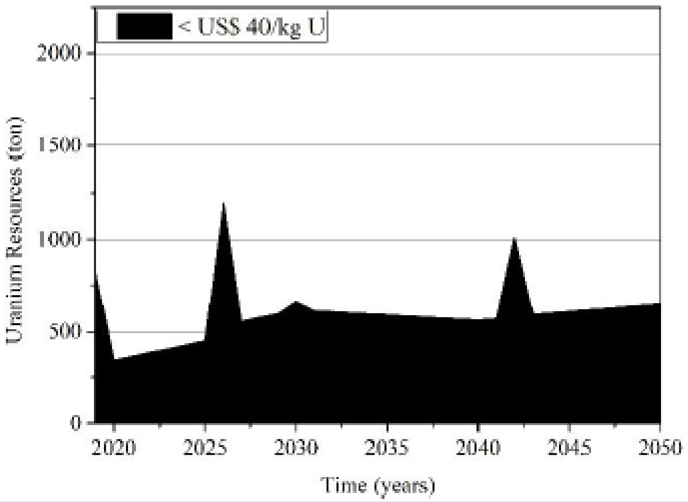
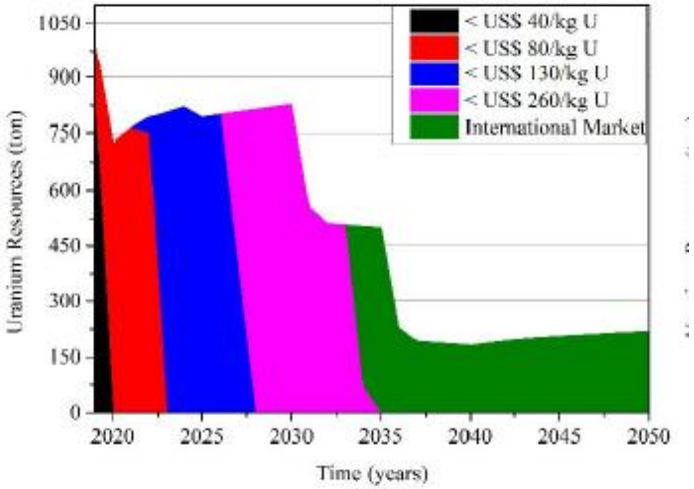
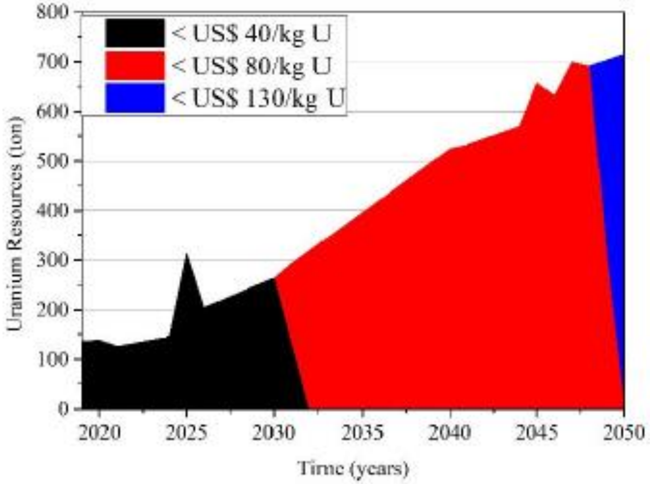
-Laguna Verde 1 and 2 → operate until 2030 and 2035, respectively.

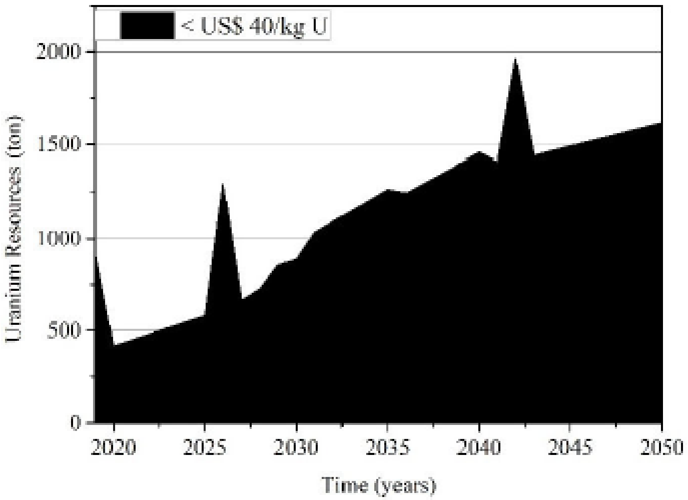
-EPR → fixed maximum output power

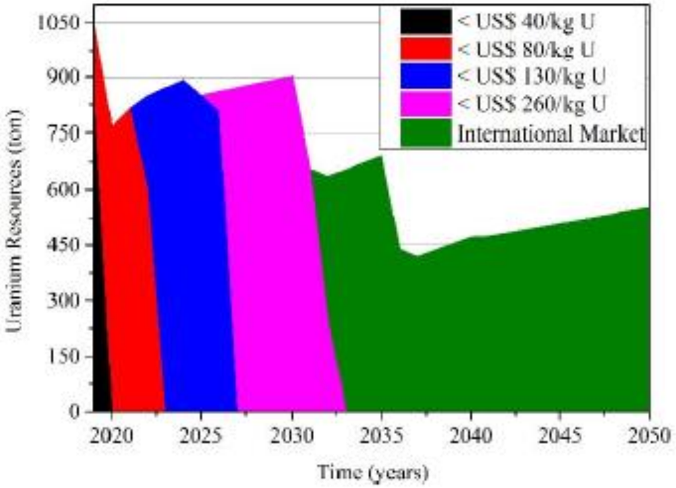
-AP-1000 → most suitable/low LUAC&LUOM compared to others reactors.

# RESULTS

# DOMESTIC RESOURCES OF URANIUM

<table>
<tr><th></th><th>Argentina</th><th>Brazil</th><th>Mexico</th></tr>
<tr><td>Low</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>High</td><td>

Argentina consums resources <US$ 130/kg U</td><td>

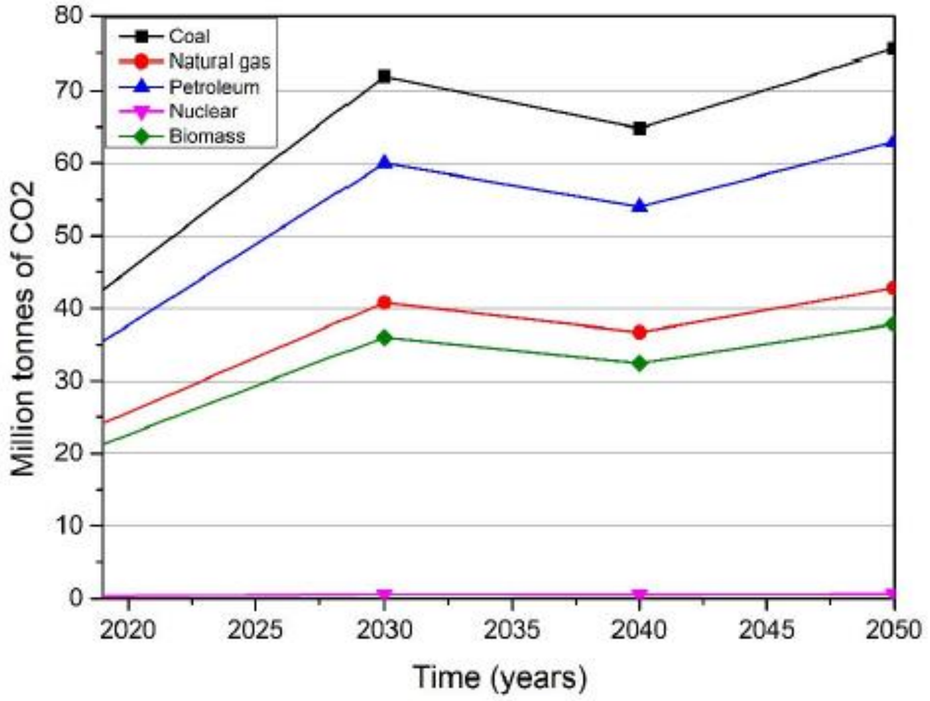
Brazil consums resources <US$ 40/kg U</td><td>

Mexico consums all resources and goes to the intenational market.</td></tr>
</table>

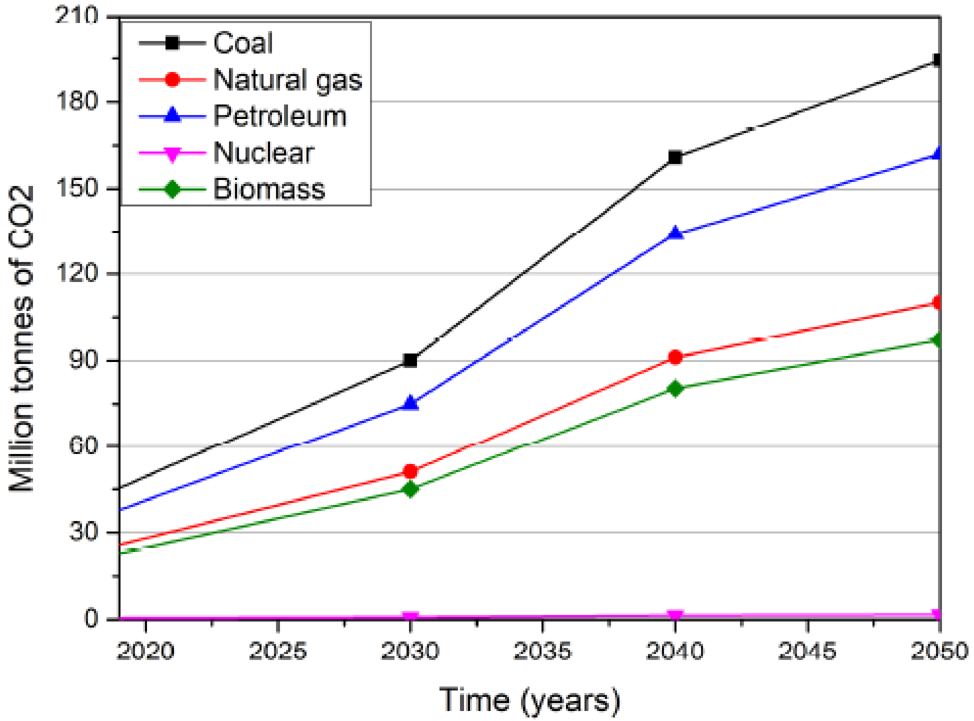
# RESULTS

## CO2 AVOIDED BY NUCLEAR COMPARED TO OTHER FUELS IN LATIN AMERICA

# RESULTS



Coal
Natural gas
Petroleum
Nuclear
Biomass
Million tonnes of CO2
Time (years)
0
10
20
30
40
50
60
70
80
2020
2025
2030
2035
2040
2045
2050

Coal
Natural gas
Petroleum
Nuclear
Biomass
Million tonnes of CO2
Time (years)
0
30
60
90
120
150
180
210
2020
2025
2030
2035
2040
2045
2050

# CONCLUSIONS

- The reactors in operation will shut down in a short period of time.
- News reactors should be introduced in the electrical matrix in order to meet the future demand (high/low scenarios).

## Reactors

- Argentina → CAREM25/CAREM120/**ACR700**
- Brazil → **EPR/LWR(China)**
- Mexico → EPR/**AP1000**

## Domestic Resources

- Argentina/Brazil →can supply their uranium demand by 2050 with their own domestic resources.
- Mexico → will not be able to attend its own demand of uranium and will run to the international resources after 2030.

# CONCLUSIONS

## CO2 Avoided

- The use of nuclear fuel avoids the release of great quantity of $CO_2$ compared to other fuels.

- 2050 → the nuclear power plants will avoid the emission of 74.97 million tonnes of $CO_2$ compared to the coal source and 192.78 million tonnes of $CO_2$ in the low and high case, respectively.

| Emission of CO2 by 2050 (million tonnes) | | | | | |
|---|---|---|---|---|---|
| | **Coal** | **Natural gas** | **Petroleum** | **Biomass** | **Nuclear** |
| **Low demand** | 75,6 | 42,84 | 63 | 37,8 | 0,63 |
| **High demand** | 194,4 | 110,16 | 162 | 97,2 | 1,62 |

- It shows to be a way to reduce emissions instead of using traditional fuels.

# ACKNOWLEDGMENTS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# VEM AÍ:

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# V SENCIR

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**9 a 13 de novembro de 2020**
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