Sustainable Planning

Decision Making Tools for Energy-Water-Food

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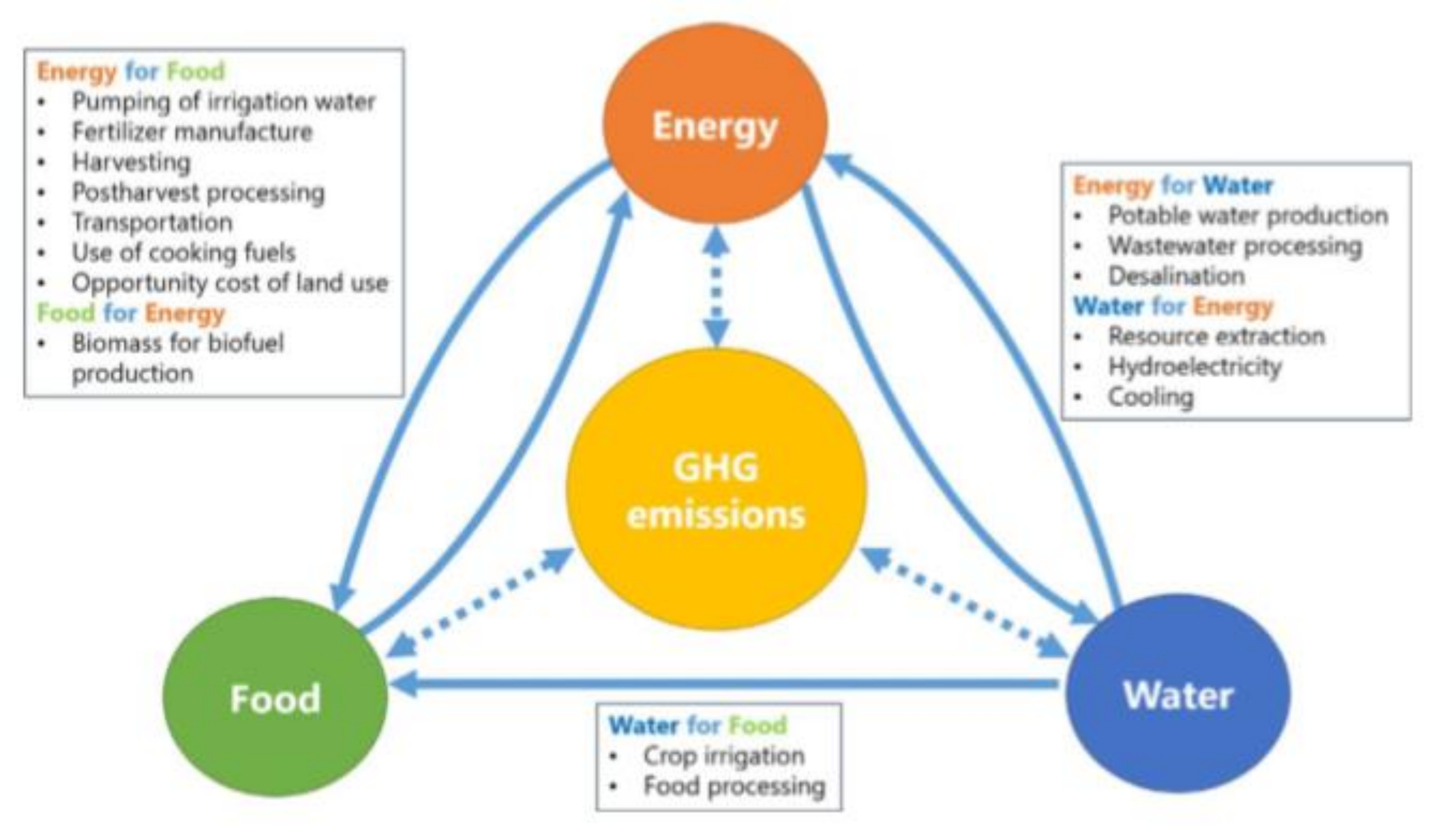
Energy-Water-Food Breakdown



Methodology – Model Structure

Optimization Model Formulation

Methodology – Model Structure

- Weighing:
  - CAPEX
    - Capital Expenditure
  - OPEX
    - Operating Expenditure
  - CO^2 Emissions
    - Future CO^2 Emissions
  - OPF
    - Opportunity Cost of Food Production

$$Z = \sum_{m,tm} OBJWT_{(m,tm)} \cdot VM_{(m,tm)} \quad \textit{Objective function} \tag{1}$$

$$\begin{aligned} VM_{(m,tm)} = & \sum_{i,j} VIJ_{(j,i,tm,m)} \cdot INV_{(j,i,tm)} \\ & + \sum_{i,j,t} VPJ_{(j,i,tm,m)} \cdot P_{(j,i,t,tm)} \\ & + \sum_{i,i',r,t} VQ_{(r,tm,m)} \cdot dist_{(i,i')} \cdot Q_{(r,i,i',t,tm)} \\ & + \sum_{i,i',r} VY_{(r,tm,m)} \cdot dist_{(i,i')} \cdot Y_{(r,i,i',tm)} \\ & + \sum_{i,r,t} VI_{(r,tm,m)} \cdot IM_{(r,i,t,tm)} \\ & + \sum_{j,r} OPFCC_{(j,i,r,tm,m)} \cdot AT_{(j,r,tm)} \quad \textit{Calculation of metrics} \end{aligned} \tag{2}$$

Methodology – Model Structure

- Measuring:
  - Investment Balance
  - Resource Balance
  - Production Constraints

$$N_{(j,i,tm)} = N_{(j,i,tm-1)} + INV_{(j,i,tm)} \quad \textit{Technology balances} \tag{3}$$

$$\begin{aligned} D_{(r,i,t,m)} \;=\; & \sum MU_{(j,r)} \cdot P_{(j,i,t,tm)} \\ & + (1 - lp) \sum Q_{(r,i',i,t,tm)} \\ & - \sum Q_{(r,i,i',t,tm)} \\ & + IM_{(r,i,t,tm)} \quad \forall \; r \quad \textit{Resource balances} \end{aligned} \tag{4}$$

$$P_{(j,i,t,tm)} \geq P_{min\ (j,i,tm)} \cdot N_{(j,i,tm)} \cdot CF_{(j)} \cdot CAP_{(j)} \quad \textit{Minimum production constraints} \tag{5}$$

$$P_{(j,i,t,tm)} \leq N_{(j,i,tm)} \cdot CF_{(j)} \cdot CAP_{(j)} \quad \textit{Maximum production constraints} \tag{6}$$

$$N_{(j,i,tm)} \leq N_{max\ (j,i,tm)} \quad \textit{Maximum technology units constraints} \tag{7}$$

$$Q_{(r,i,i',t,tm)} - \frac{Q_{max}}{(PHI_{(t)}/8700)} \cdot Y_{(r,i,i',tm)} \leq 0 \quad \forall \; r \quad \textit{Flow constraints} \tag{8}$$

Methodology – Model Structure

- Estimating:
  - Ie = Current
  - R = Resistivity p/unit area
  - Dist(I, I') = Distance between nodes

$$P_{Loss} = I_e^2 R \times dist_{(i,i')} \quad (9)$$

Methodology – Optimization Structure

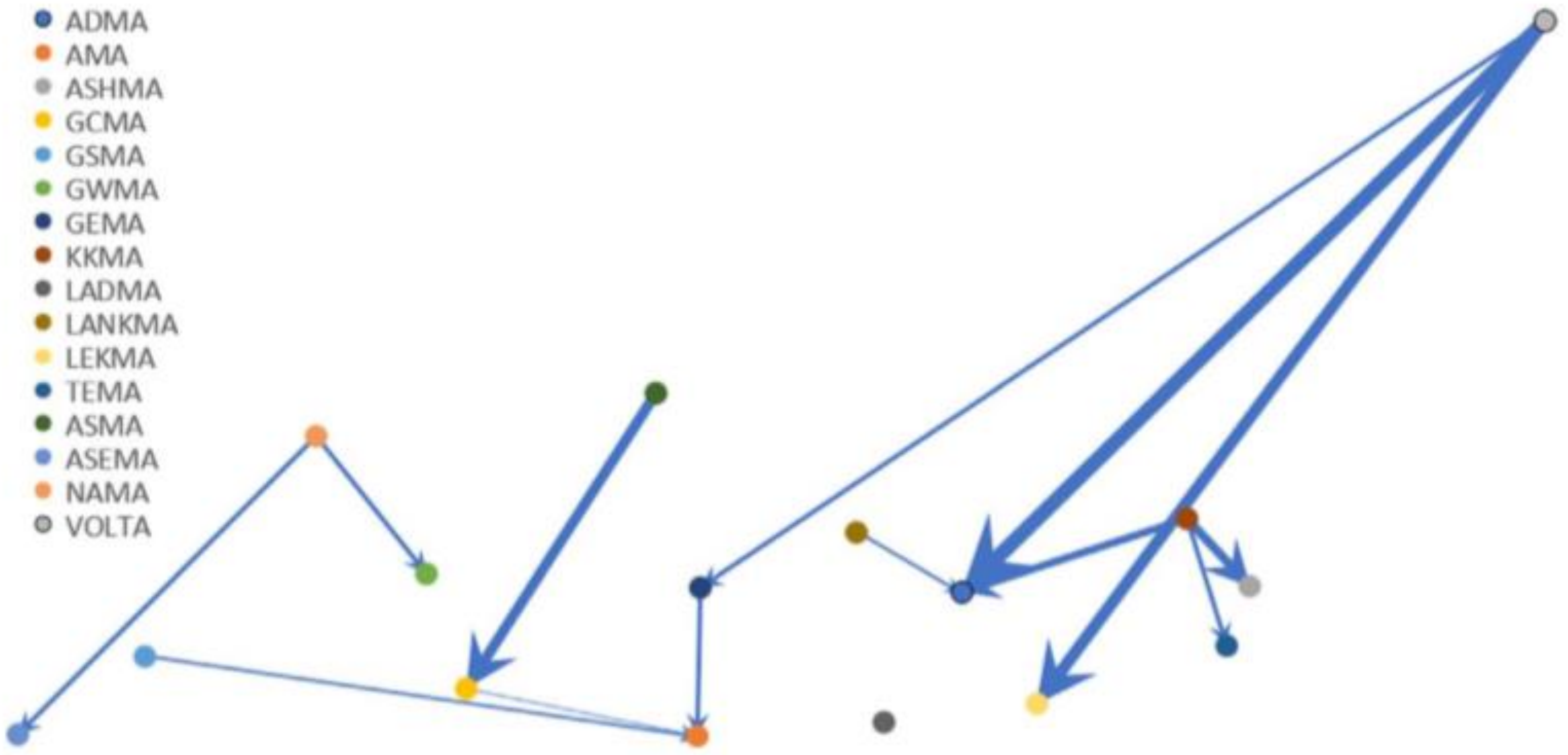


Fig. 3. Energy network structure with distances drawn to scale.

Data Collection

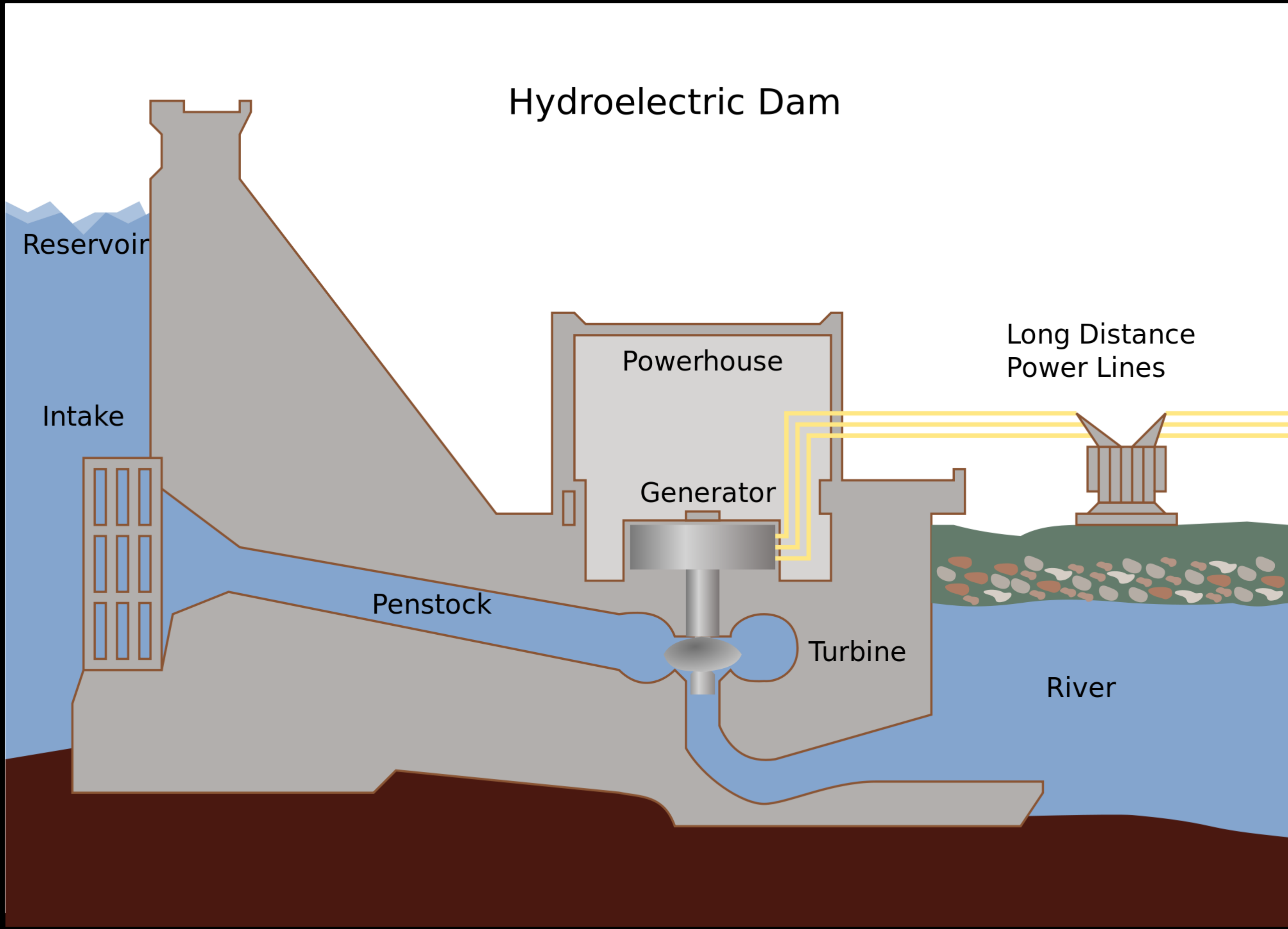
Methodology in Practice

Data Collection - Variables

- Electricity Supply
  - Hydroelectricity
  - Thermal Generation
  - Nuclear Power
  - Solar Power
  - Wind Power
  - Biofuel

Hydroelectricity

- 43.2% of Ghana’s power generation



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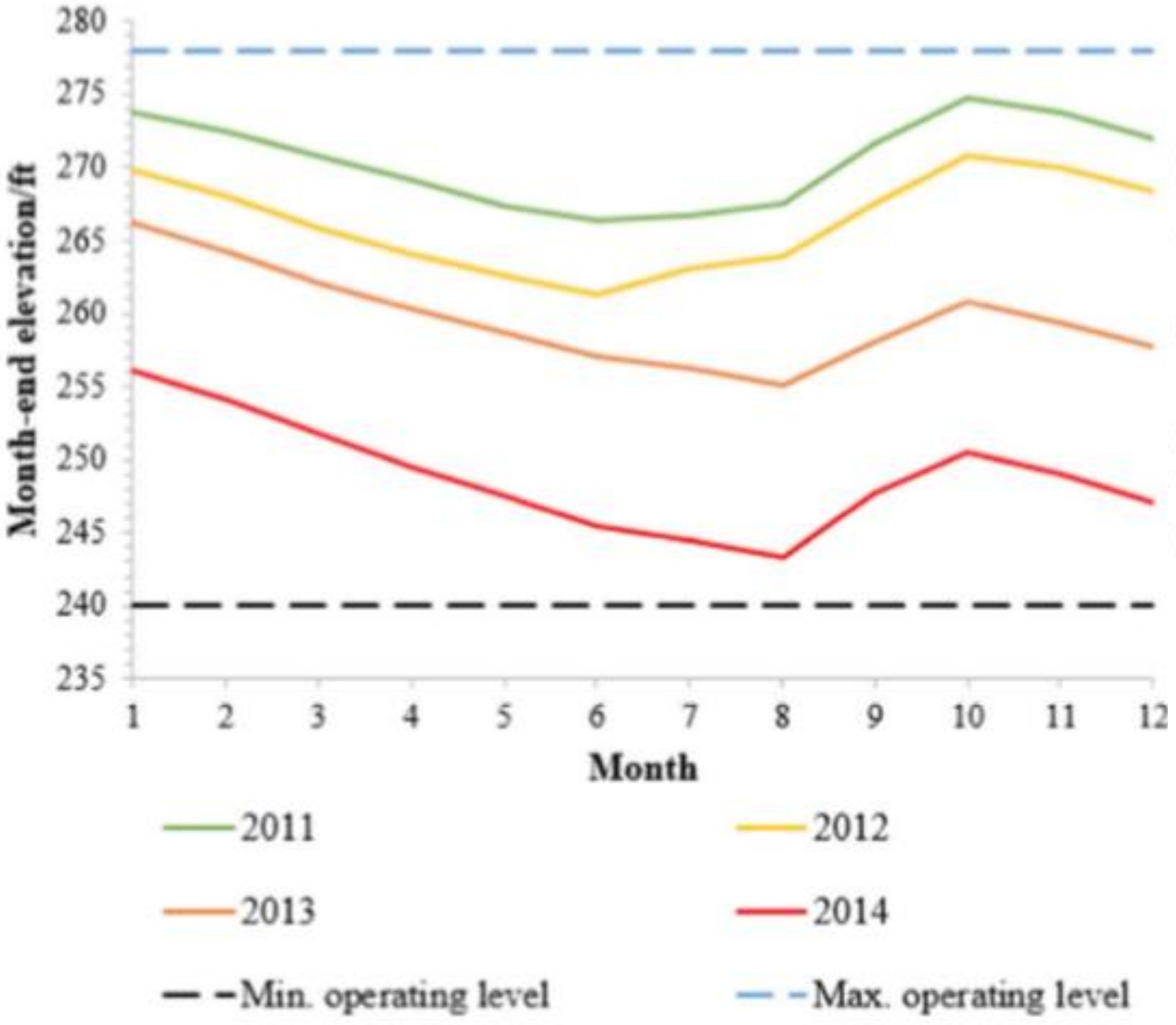
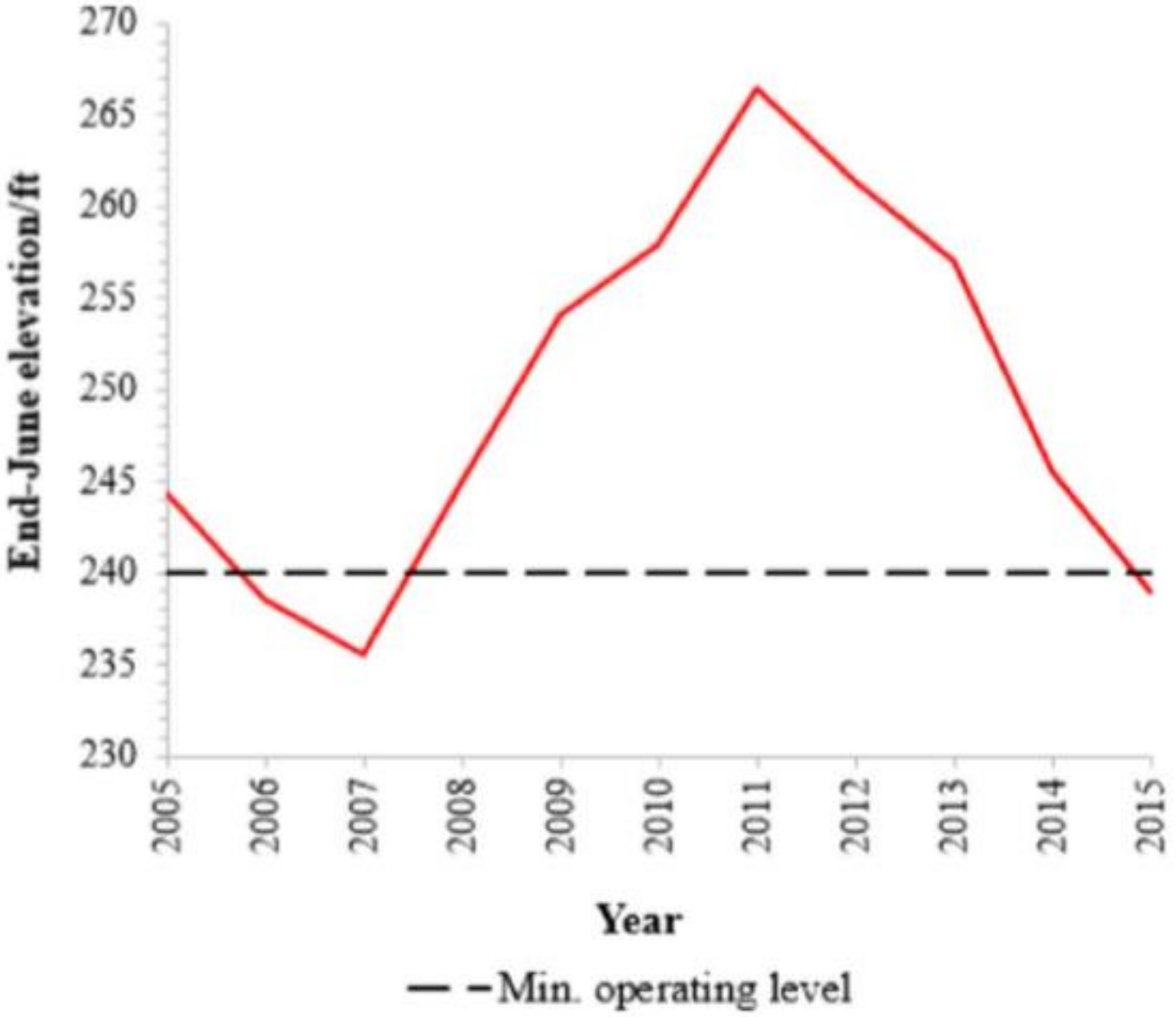
Hydroelectricity & Waterfall



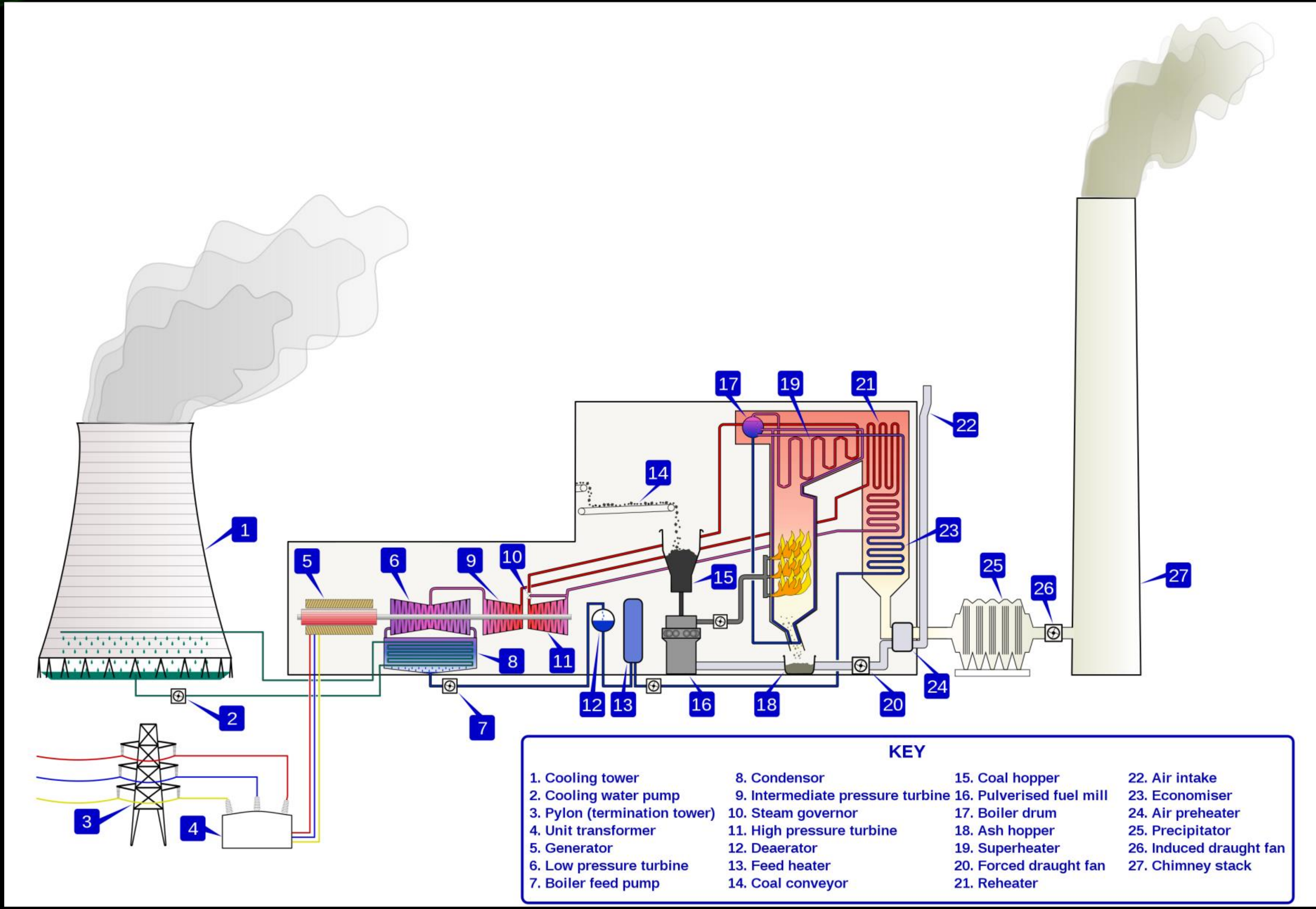
(a) Month-end elevation from 2011 to 2014



(b) End-June elevation from 2005 to 2015

Thermal Generation

- Natural gas cleanliest fossil fuel
  - 56.2% of Ghana's electricity demand
- Different mixes of natural gas
  - Light cycle oil (LCO)
  - Distillate fuel oil (DFO)
  - Heavy fuel oil (HFO)
  - Thermal coal



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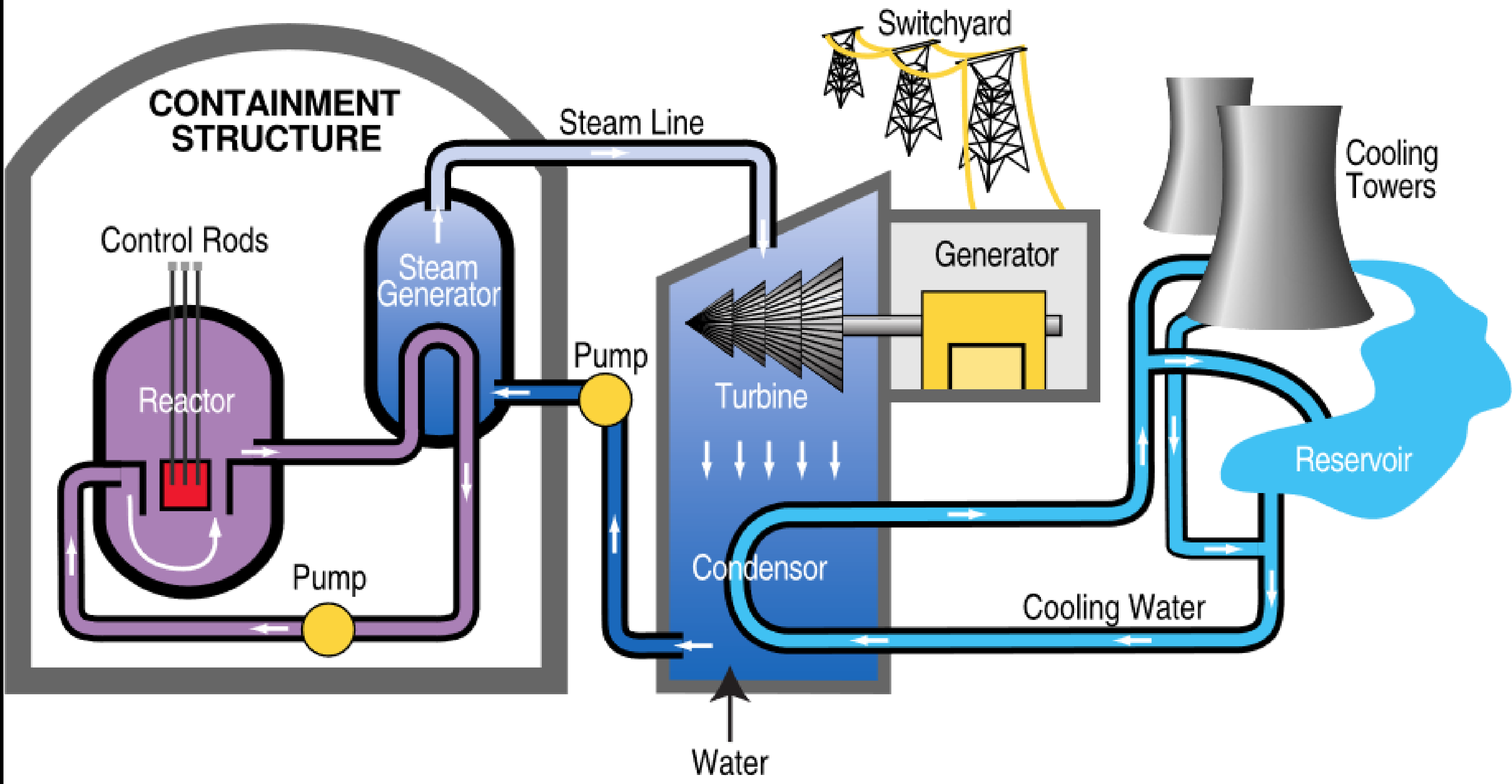
Nuclear Power

- Large supply with high investment cost
- Safety concerns and regulation
  - 10% of total electricity grid capacity



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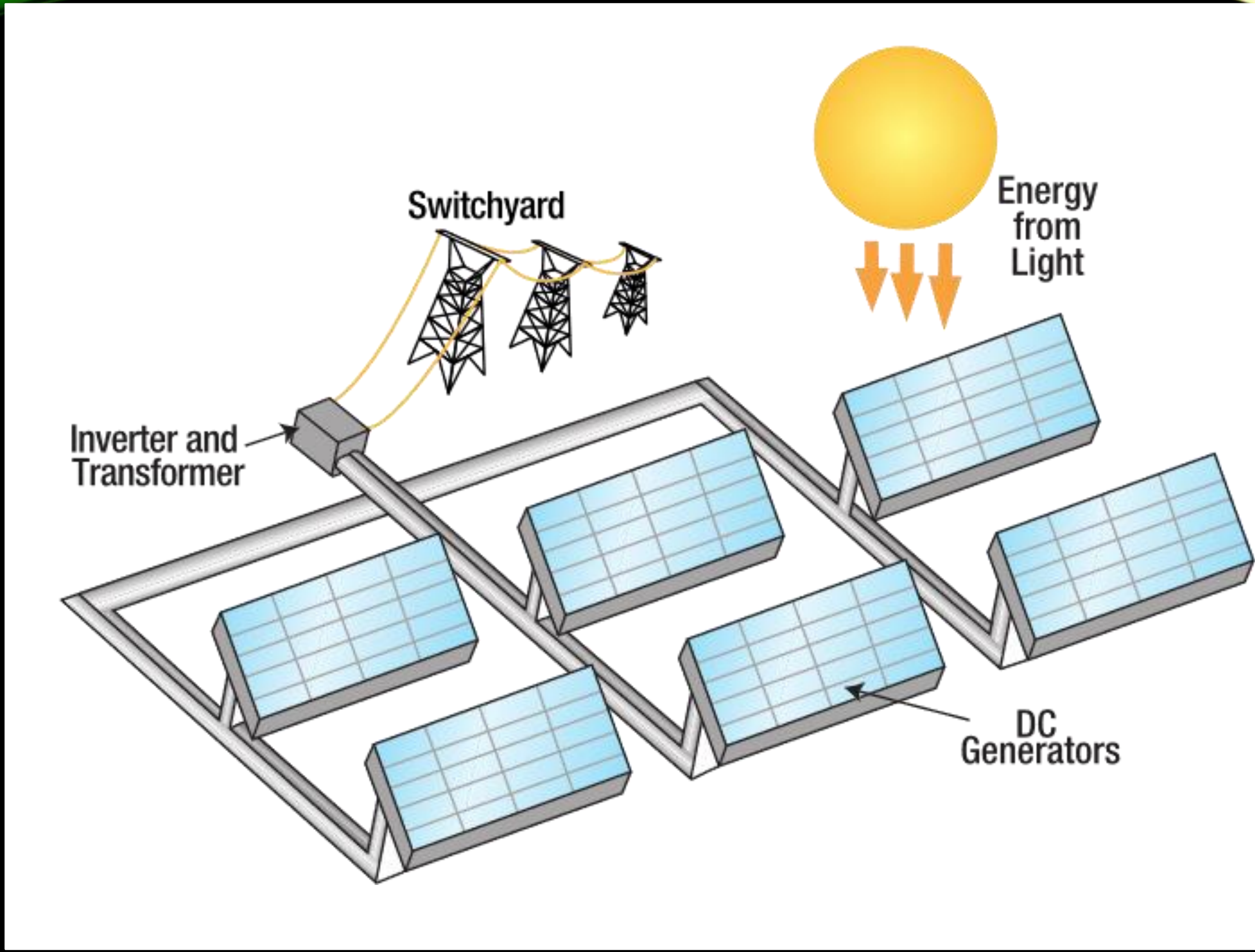
Solar Power

- 0.6% installed capacity
- Direct sunlight
  - Concentrated solar power (CSP)
  - Solar thermal Energy
- Photovoltaic power
  - Indirect sunlight



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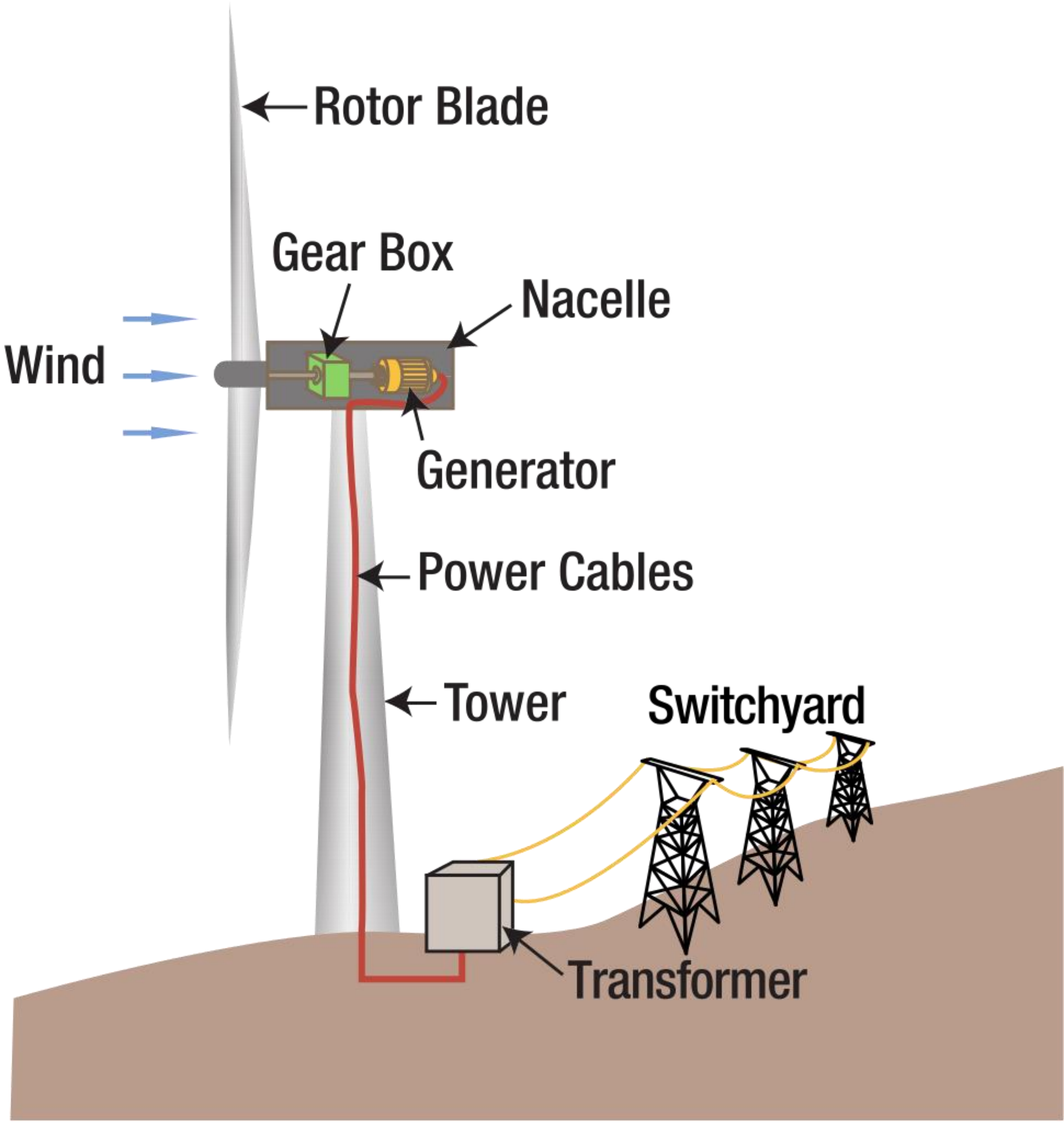
Wind Power

- Onshore wind
  - One of the cheapest renewables
- Offshore
  - One of the expensive renewables



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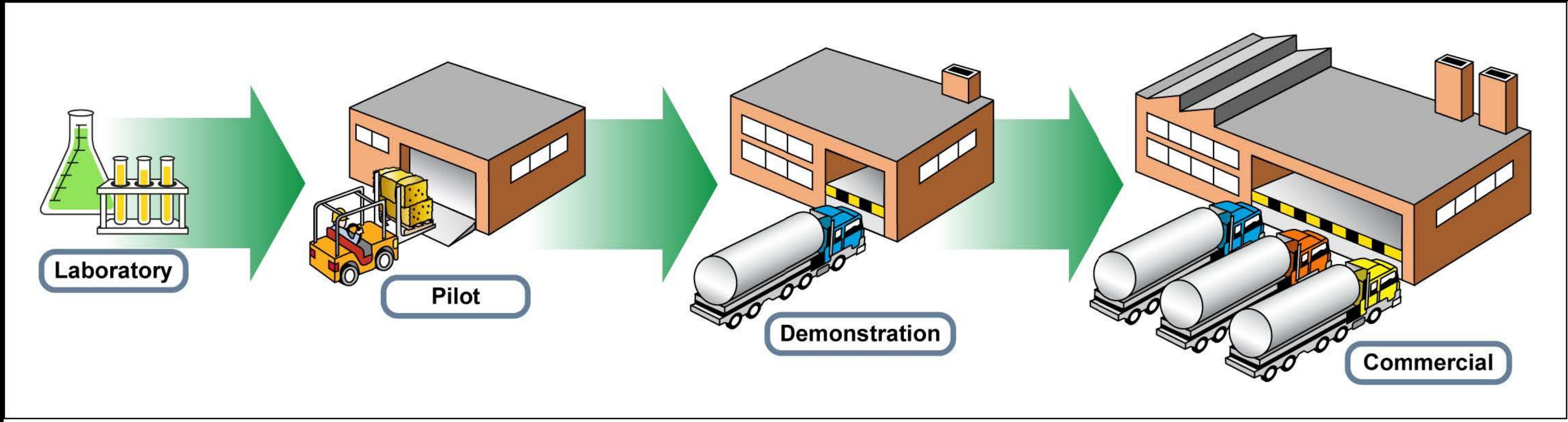
Biofuel

- Biomass-poverty belt
  - Tropical and sub-tropical
  - Extreme poverty
- Advantages
  - Perennial
  - Fast growing
  - Low fertilizer
  - High net energy yield (540%)
  - Marginal land
- Disadvantages
  - Processing
  - Time to reach optimal harvest
  - Requires moist soil



Source: GAO. | GAO-17-108

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Scenario & Policy Evaluation

Methodology & Data in Action

Scenario Outline

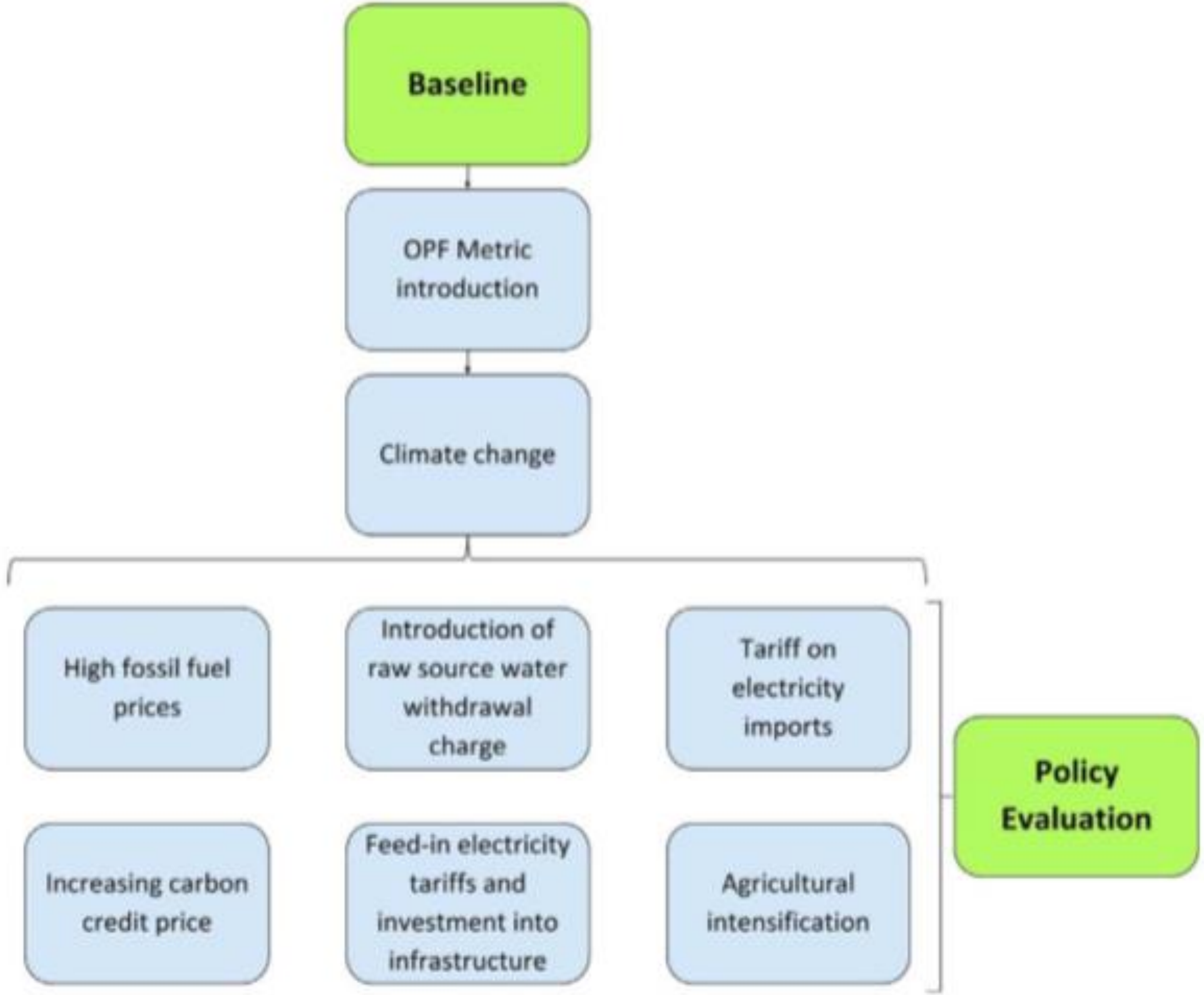
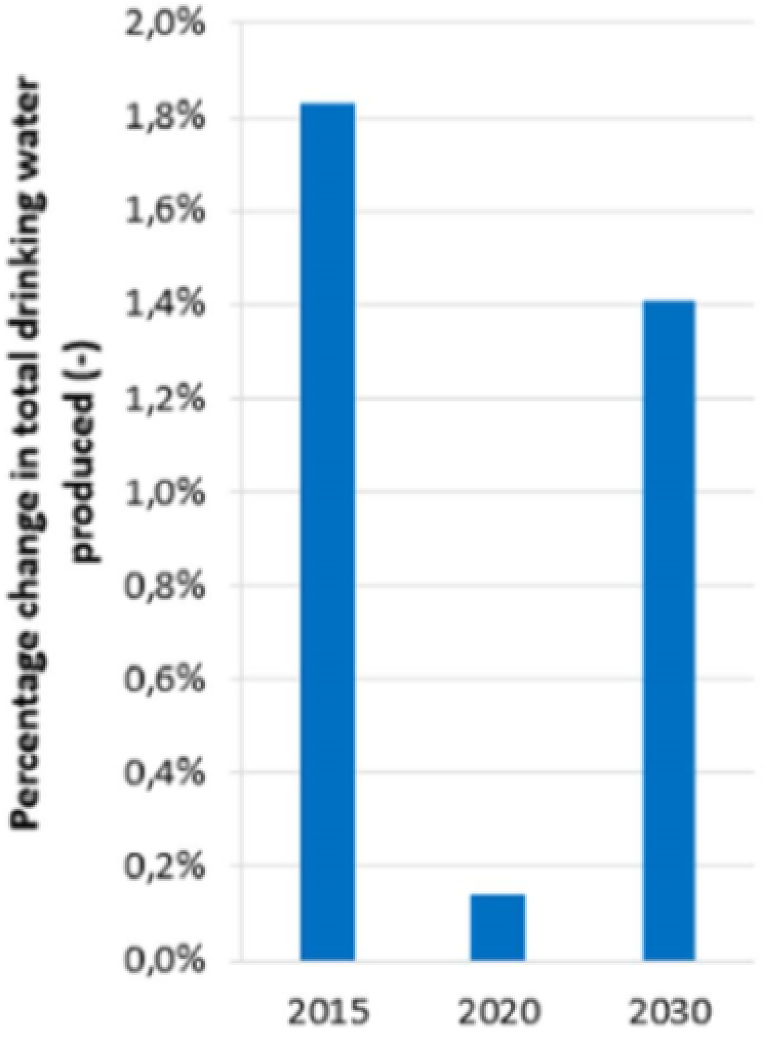
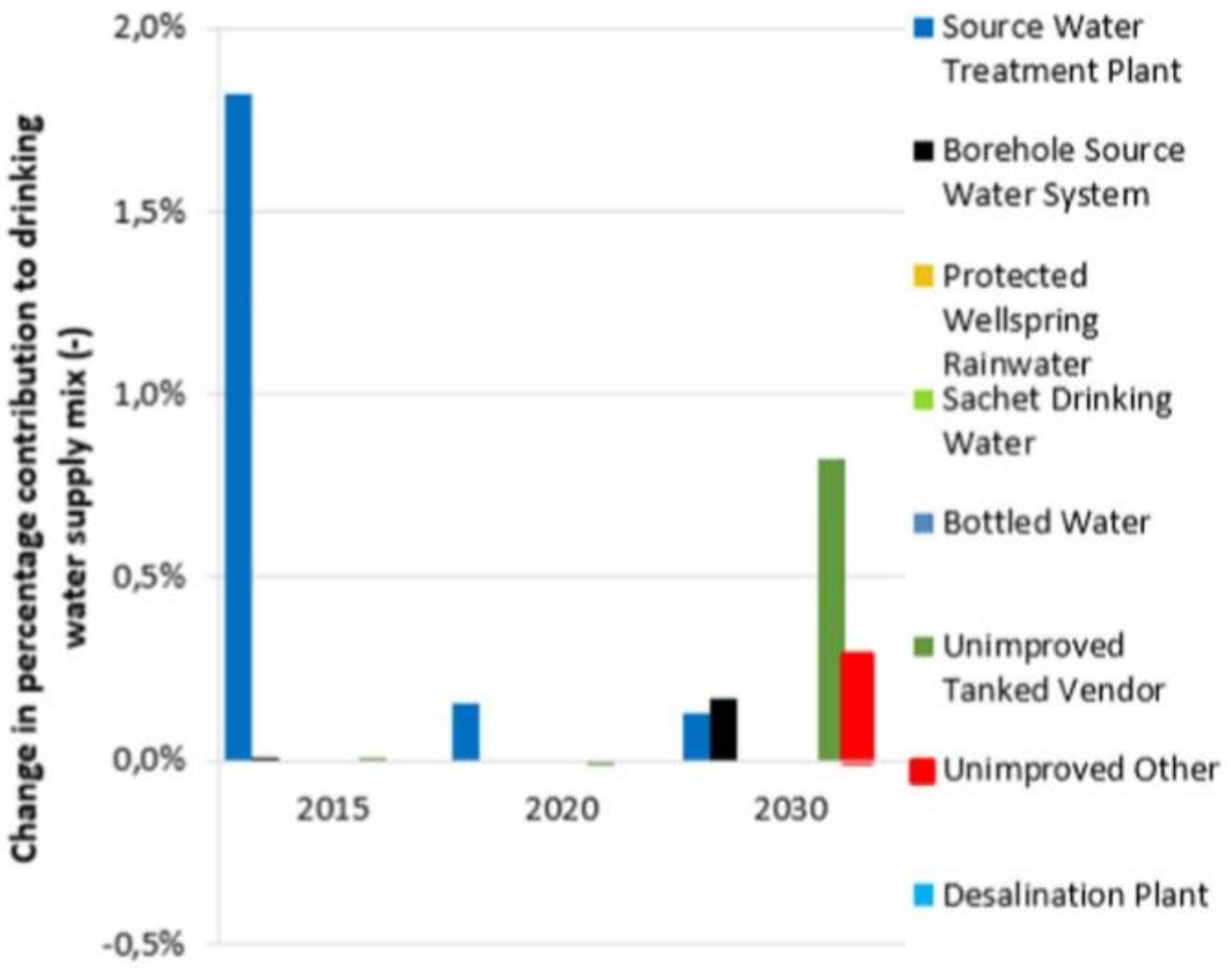


Fig. 5. Schematic of scenarios.

Change in Drinking Water for Energy

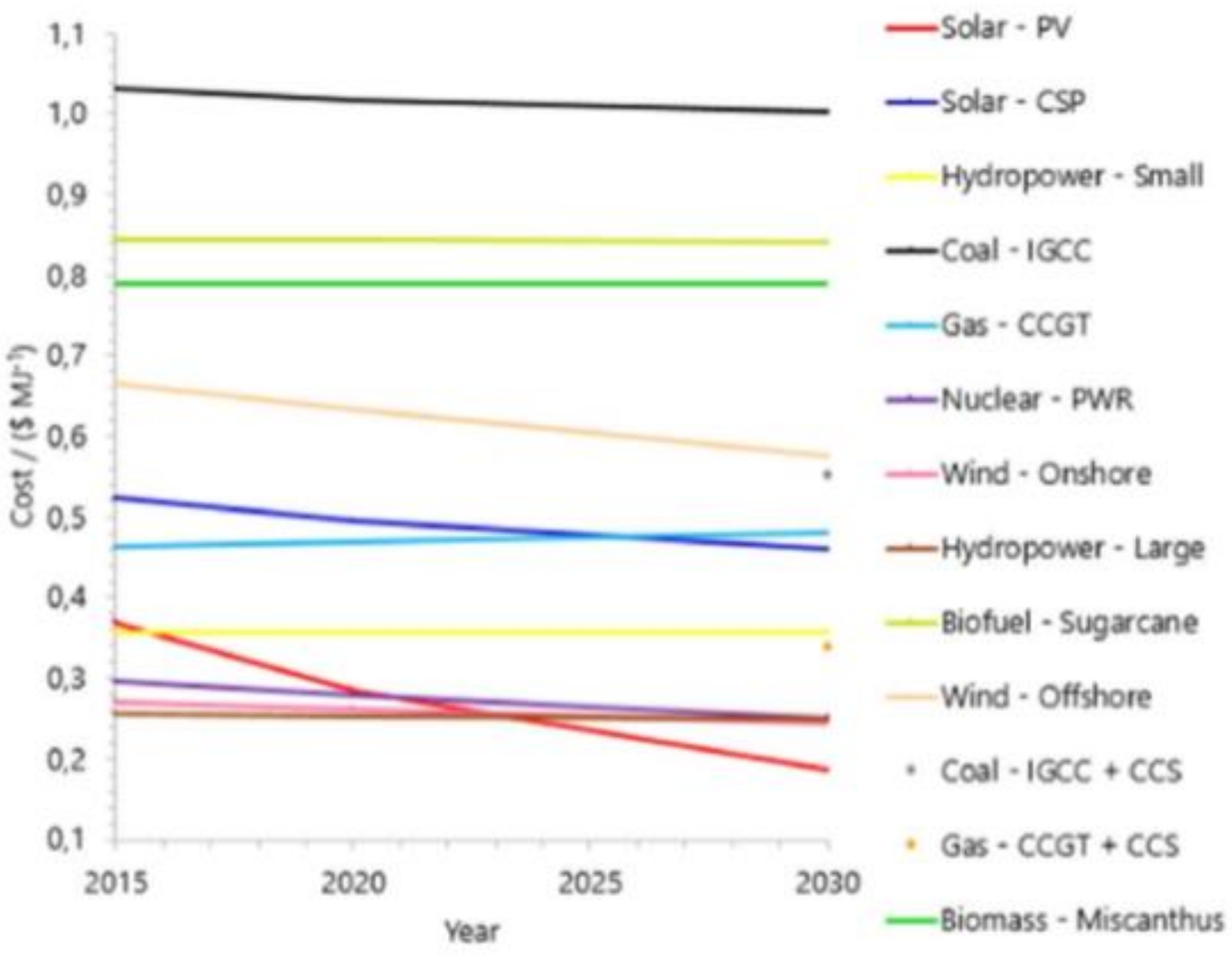


(a) Percentage increase in the production of drinking water

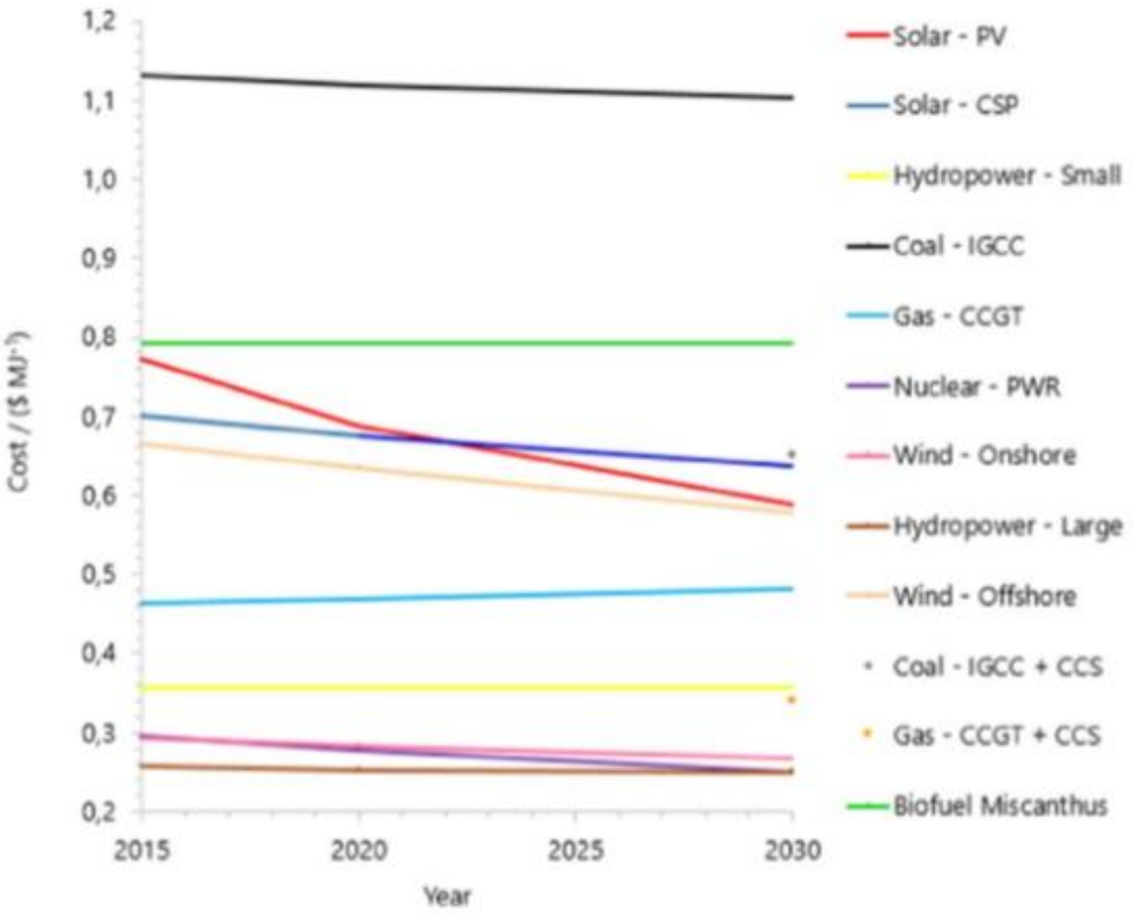


(b) Change in the percentage contribution to the total drinking water production of each technology

Economic Cost - Power Generation

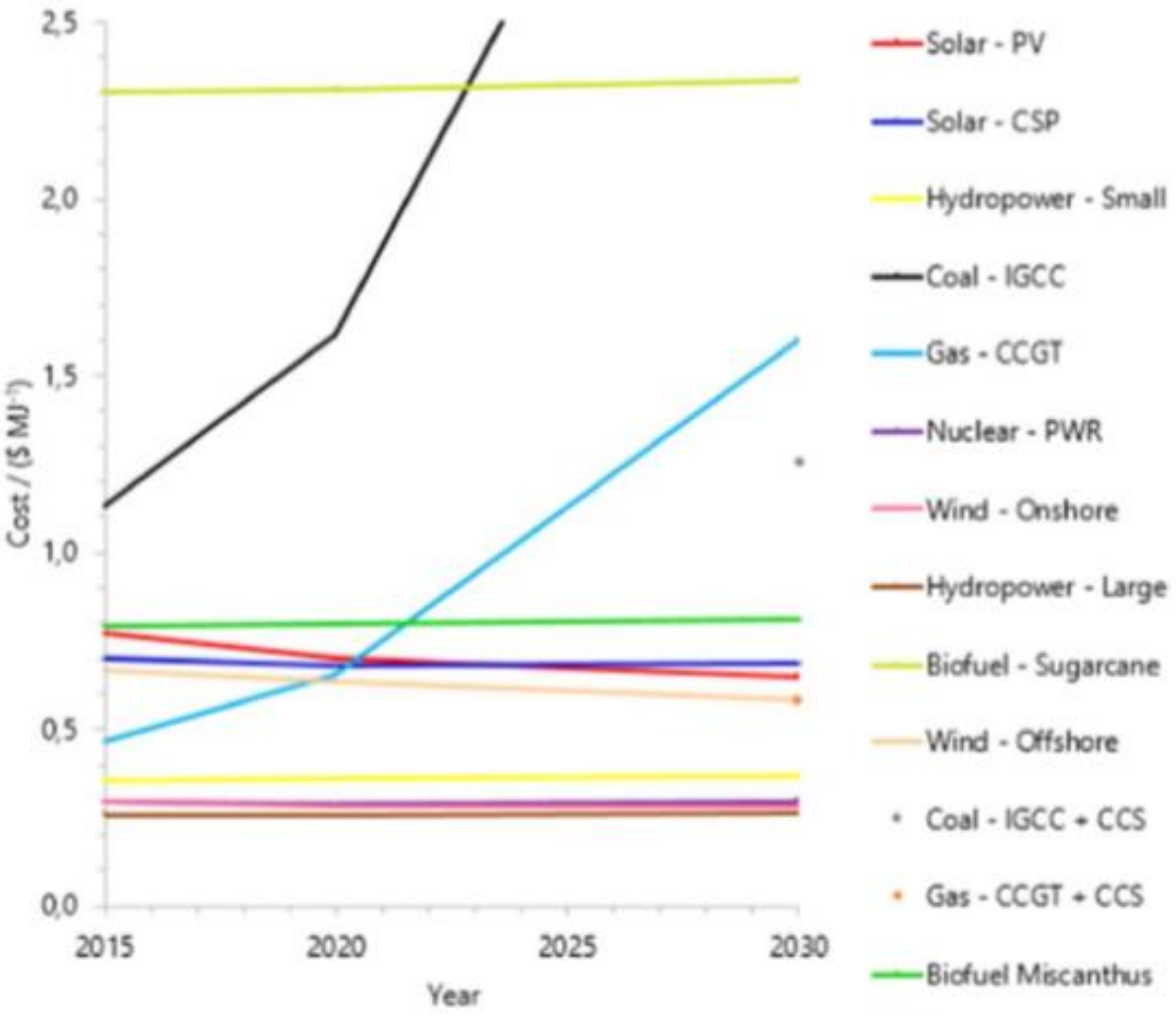


(a) Economic cost and GHG emissions (low fossil fuel prices)

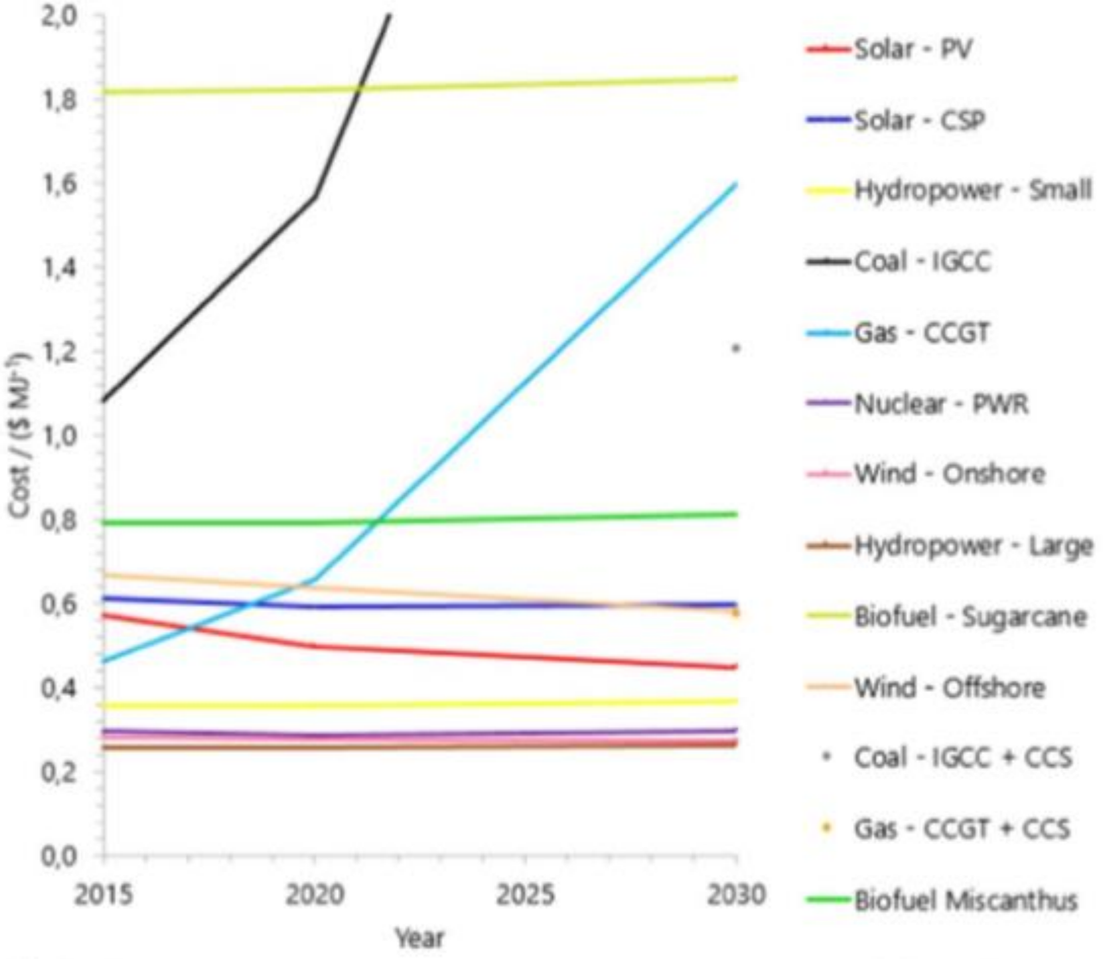


(b) Economic cost, opportunity cost of food production foregone and cost of carbon emissions (low fossil fuel prices)

Economic Cost – Food Production



(a) Economic cost, opportunity cost of food production foregone and cost of carbon emissions, after carbon price increase (high fossil fuel prices)



(b) Economic cost, opportunity cost of food production foregone and cost of carbon emissions, after introduction of increasing carbon prices and the reduction of Ghanas crop yield gap (high fossil fuel prices)

Power Generation Technology Characteristics

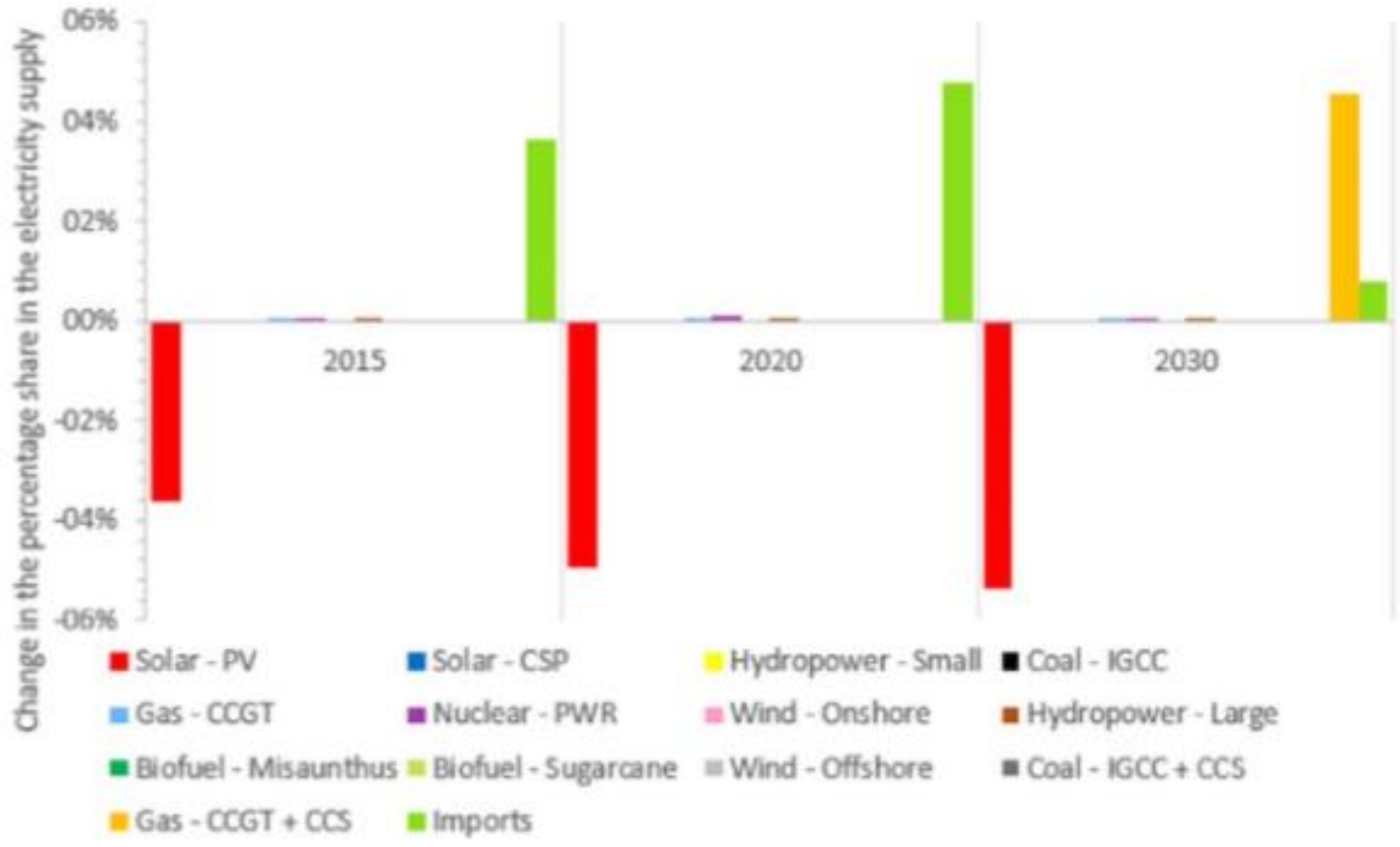
Table 1
Characteristics of power generation technology (cost associated with 2030).

Technology	Subtype	Number of people fed (per plant per year)	Capacity (MW)	CAPEX (USD per MJ)	OPEX (USD per MJ)	GHG (kg CO_2 eq per MJ)
Photovoltaic	P-Si, ground	4334	20	0.169	0.0000844	0.0337
CSP	Trough	9865	50	0.266	0.0121	0.0273
Hydropower	Small	1	2	0.299	0.00359	0.00657
Hydropower	Large	1561	1180	0.216	0.00199	0.00676
Coal	IGCC	101,104	500	0.164	0.00647	1.65
Gas	CCGT	4	250	0.0768	0.00854	0.612
Coal	IGCC + CCS	101,104	500	0.279	0.00828	0.330
Gas	CCGT + CCS	4	250	0.119	0.0110	0.122
Nuclear	PWR	62	300	0.153	0.00570	0.0256
Wind	Onshore	63	3	0.167	0.00494	0.00970
Wind	Offshore	3	3.6	0.366	0.0140	0.00297
Biomass	Miscanthus	4747	500	0.324	0.0307	0.0105
Biofuel	Sugarcane	191,434	87	0.121	0.0473	0.0213

Change Effect

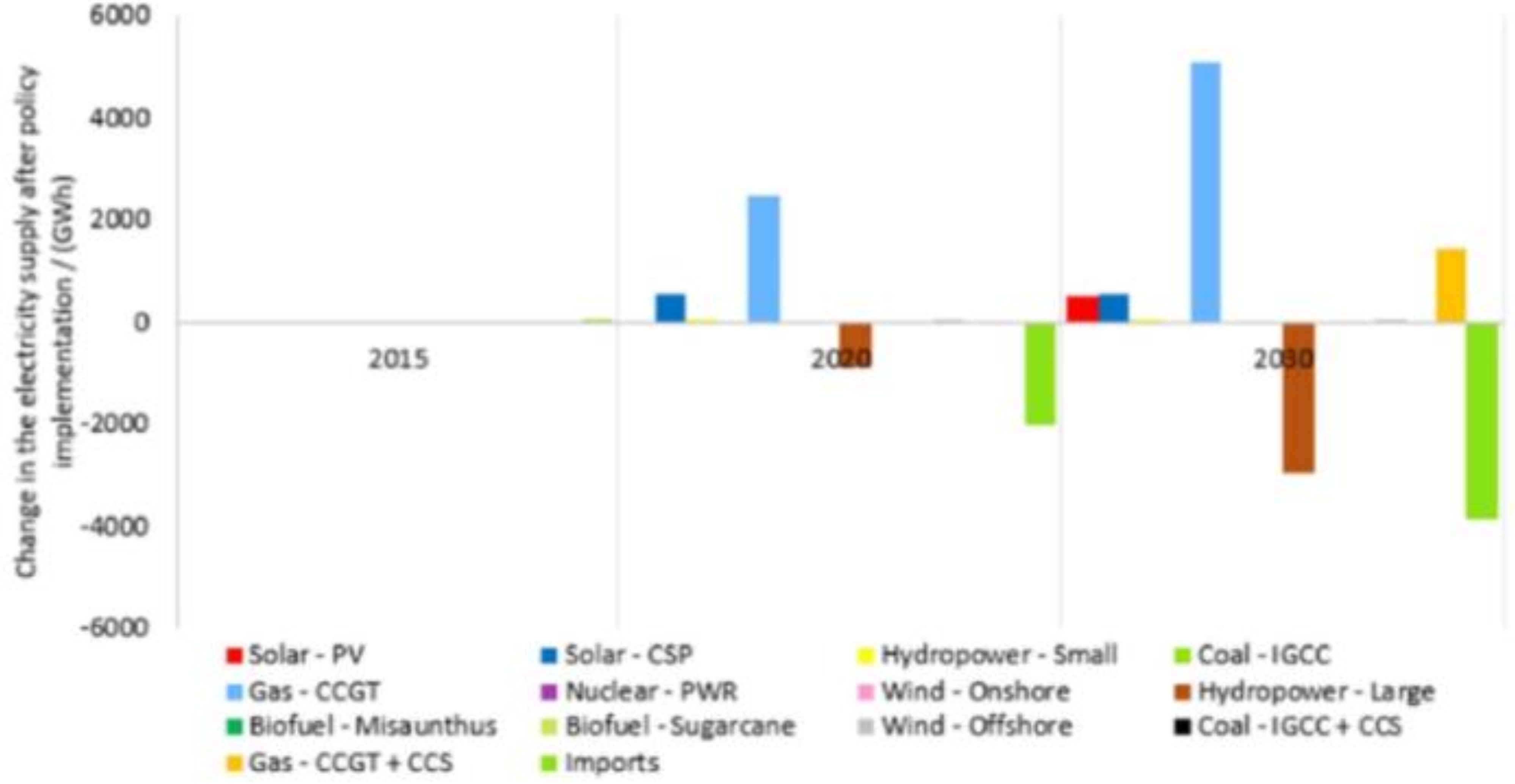
Implementation &
Adaptation Effect

Change Effect - Operating Food Production



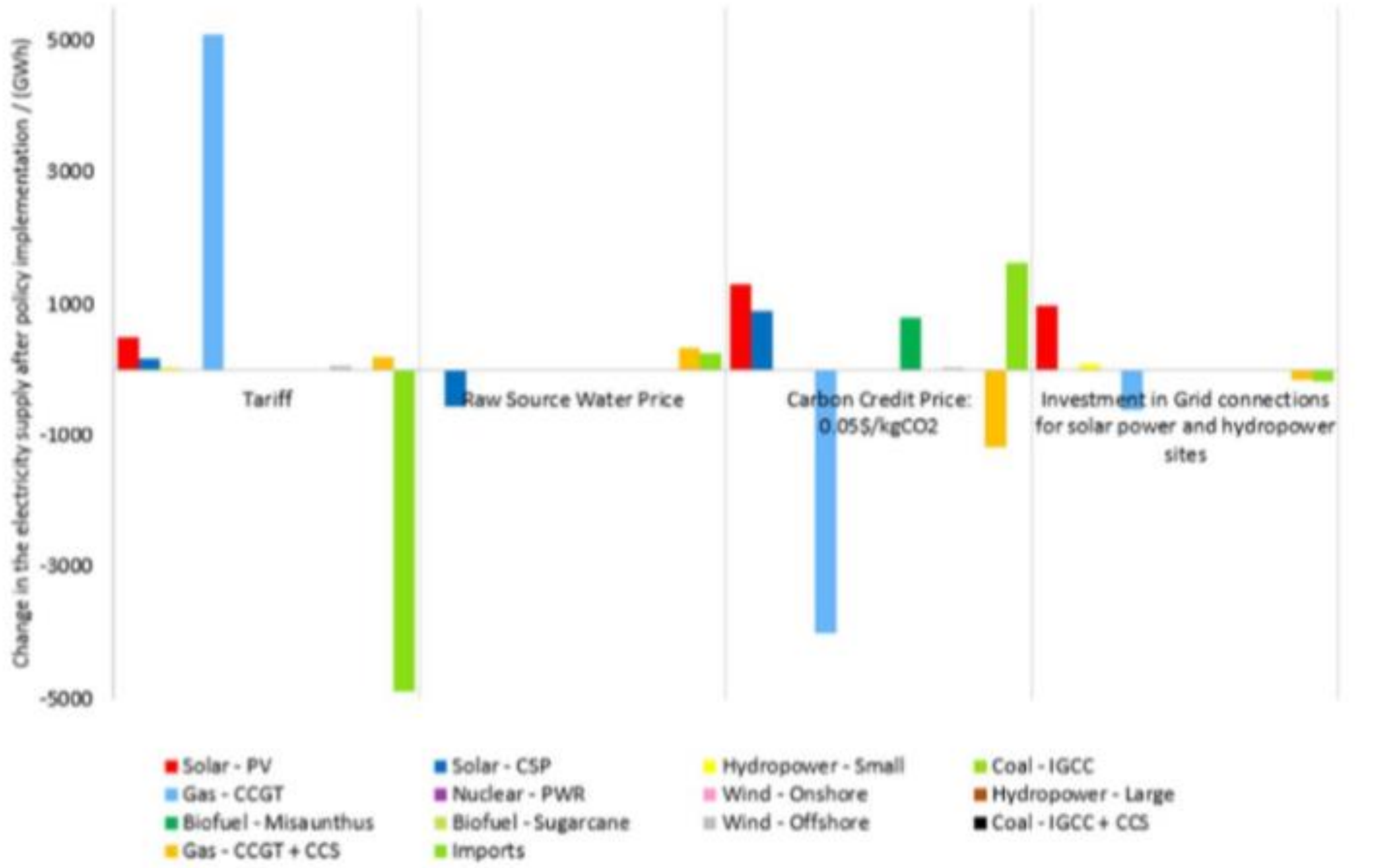
(c) Change in the optimal power technology mix

Change Effect – Due to Climate Change



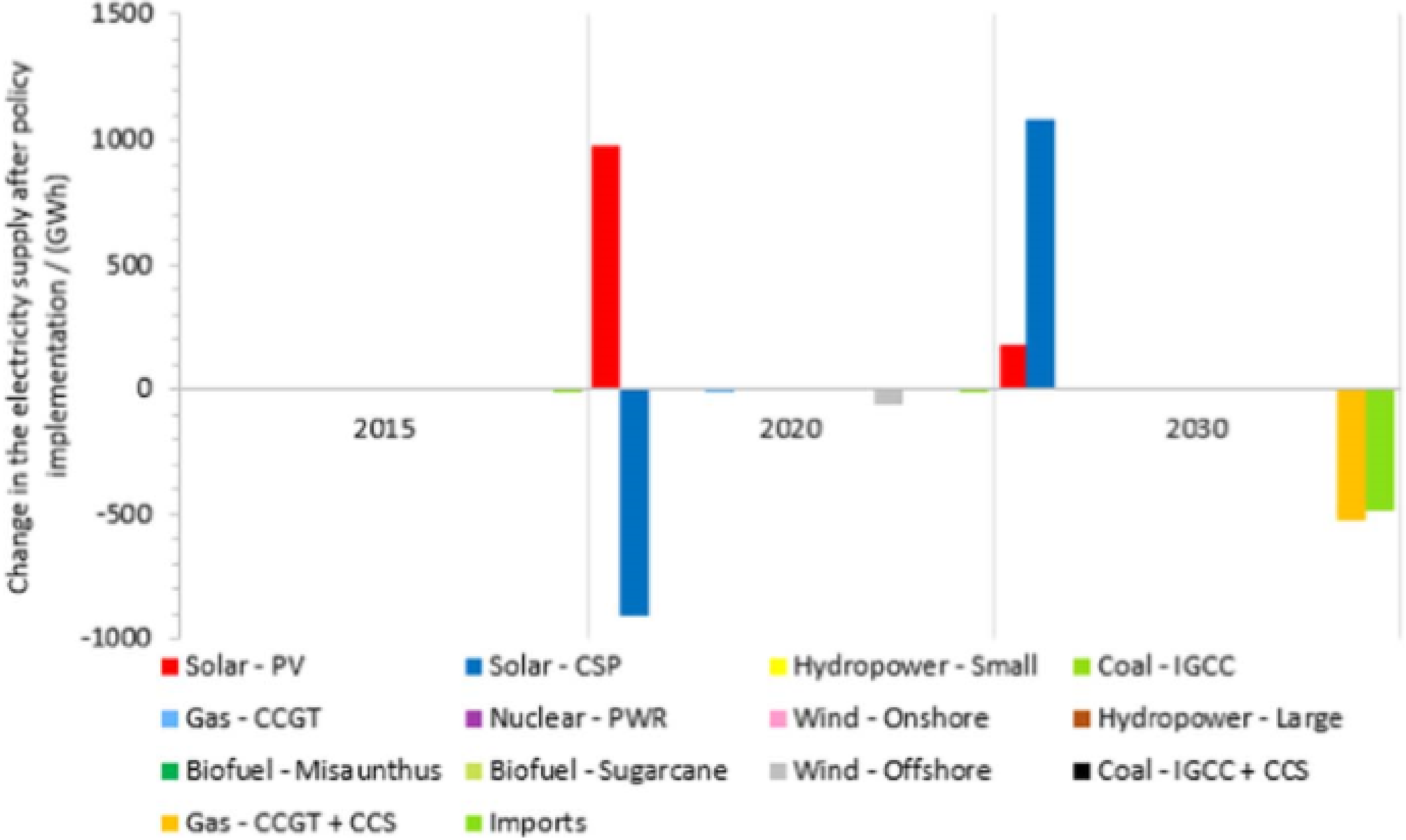
(c) Change in capacity of each power generating technology

Change Effect – Aggregate Effects to Policy



(c) Change in capacity of each power generating technology

Change Effect – Change of Costs, Emissions, & Power Technologies

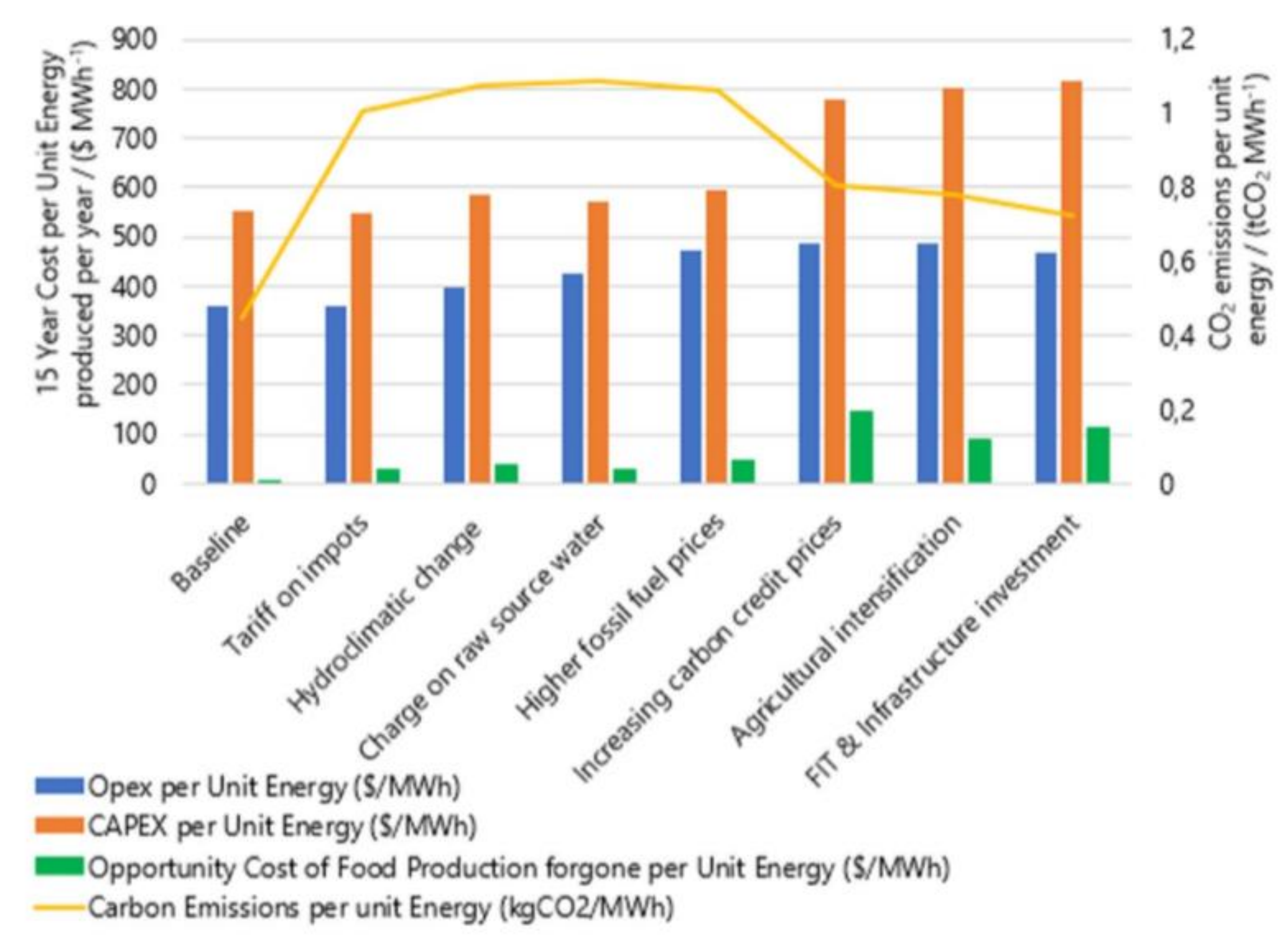


(c) Change in capacity of each power generating technology

Conclusion

Deciding Factors for Ghana

Economic & Opportunity Cost Food Production



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