Energy security, uncertainty, and energy resource use option in Ethiopia: A sector modelling approach

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- Methodology
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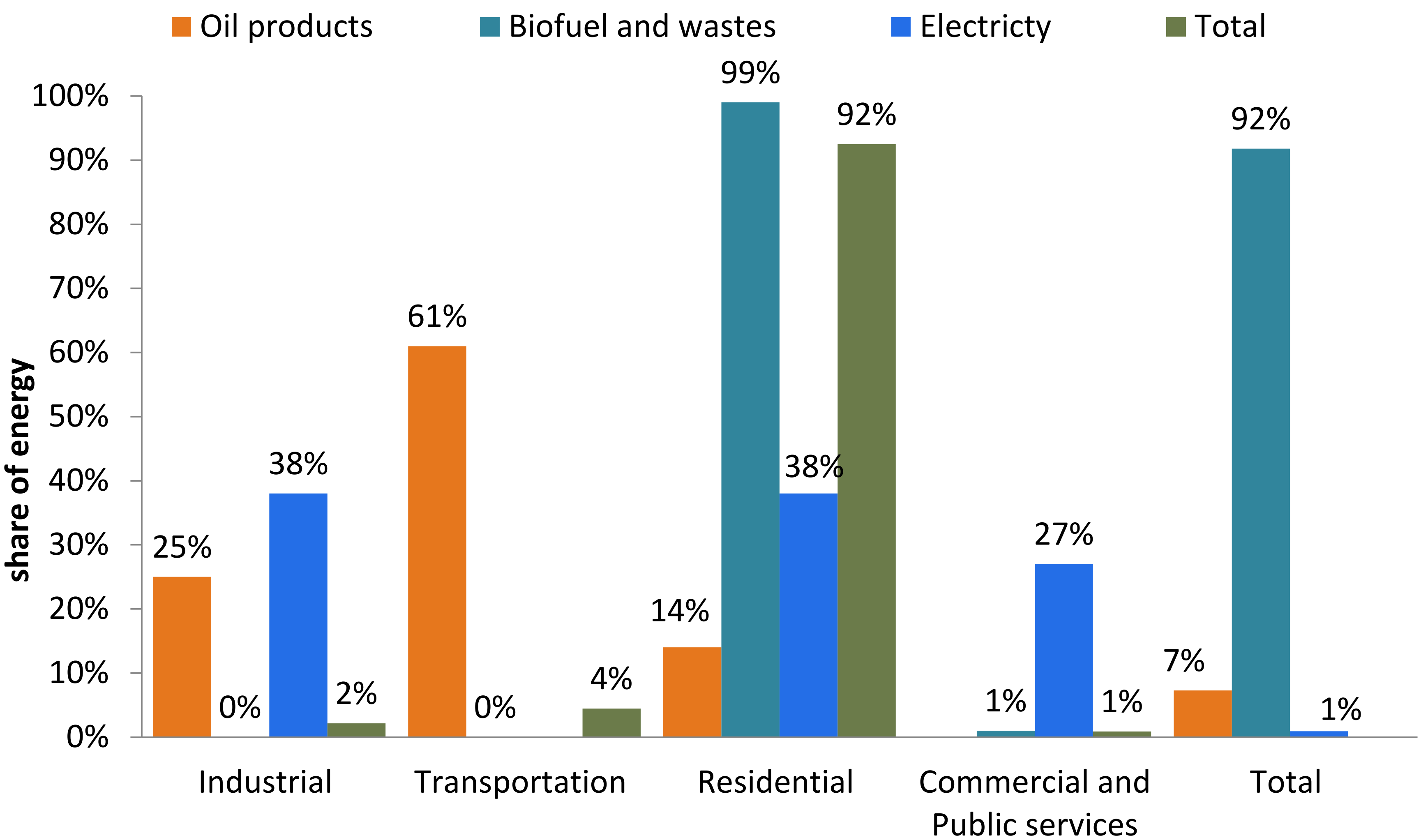
Introduction

Ethiopia's renewable energy resource potential (MoWE, 2013; GMI; 2011)

Energy source	Unit	Potential reserve	Exploited	
			Amount	%
Hydroelectric	GW	45	2.1	5%
Solar	kWh/m²/day	4–6		----
Wind	GW	13.50	0.2	<3%
Geothermal	GW	5–7	0.007	<1%
Woody biomass	t (millions)	1,120	560	50%
Agricultural waste	t (millions)	15–20	≈6	30%
Municipal solid waste	t (millions)	2.8–8.8	50 MW	---

- Potential to become a regional power hub

Ethiopia's percentage distribution of energy consumption by end-user, 2009 (IEA, 2009)



Introduction

- Over 90% of population rely on traditional biomass energy for domestic purposes
- Homogenous electricity mix, reliance on hydroelectricity (90%)
- Steadily increasing electricity demand
- Economic growth outpacing the development of the energy sector
- vulnerability of energy sector to various uncertainties (drought and oil price shocks)

- Energy development considered as core part of the Climate Resilient Growth Economy (CRGE)
- Long term power export plan

- But high capital cost of alternative energy technologies

- Energy sector model of optimal energy resource use, and technological alternatives can help to evaluate future energy security

Objective

Objectives

1. To investigate least-cost energy source diversification option for Ethiopia
2. To estimate the impact on energy mix and cost of energy production of various uncertainties and understand implication for future energy security

Methodology

Energy sector model: Linear programing model using General Algebraic Modelling Systems (GAMS)

$$min\, C = \sum_{t=1}^{T} [(1+\rho)^{-t} (c_t^o + c_t^k + c_t^a)]$$

Where C = the total discounted minimized cost, ρ = discount rate,

$c_t^k = \sum_{i=1}^{n} \sum_{j=1}^{J} \sum_{t=1}^{T} k_{ijt} \,.\, Q_{ijt}$ = total capital cost ,

$c_t^o = \sum_{i=1}^{n} \sum_{j=1}^{J} \sum_{t=1}^{T} o_{ijt} \,.\, P_{ijt} \,.\, \emptyset_{\boldsymbol{d}}$, = total operating and management (O&M) costs ,

$c_t^a = \sum_{m=1}^{9} r_{bmt} \,.\, Q_{bmt} + \sum_{m=1}^{9} r_{smt} \,.\, Q_{smt}$ = land rental cost

T = set of years from 2010 to 2110

t = time in years ($t = 1,2,3, \ldots t$)

i = energy sources ($i = 1, 2, \ldots, 6,$), hydropower, fossil thermal, geothermal, wind, solar, and biomass

j = plant type ($j = 1, 2, 3, \ldots$ J)

m = region (m = 1, 2, 3,…9)

$\emptyset_{\boldsymbol{d}}$ = duration of each electricity demand block in hours per year

d = blocks of electricity demand (peak, and off-peak)

k_{ijt} = capital cost per MW, and o_{ijt} = O&M cost per MWh/year,

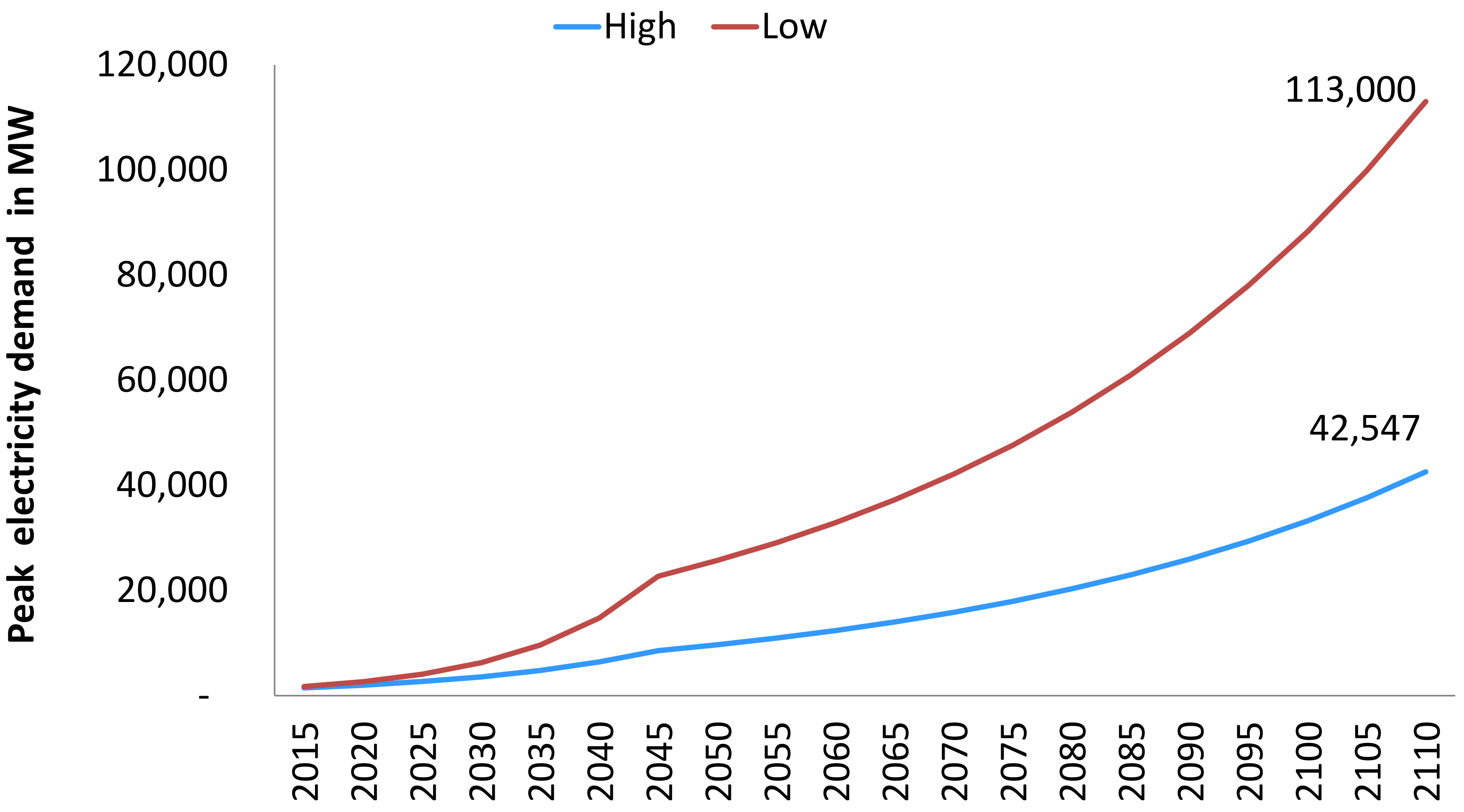
r_{bmt} = the land costs per MW, and r_{smt} = the land costs per tonne

Q_{ijt} and P_{ijt} energy output and installed capacity respectively

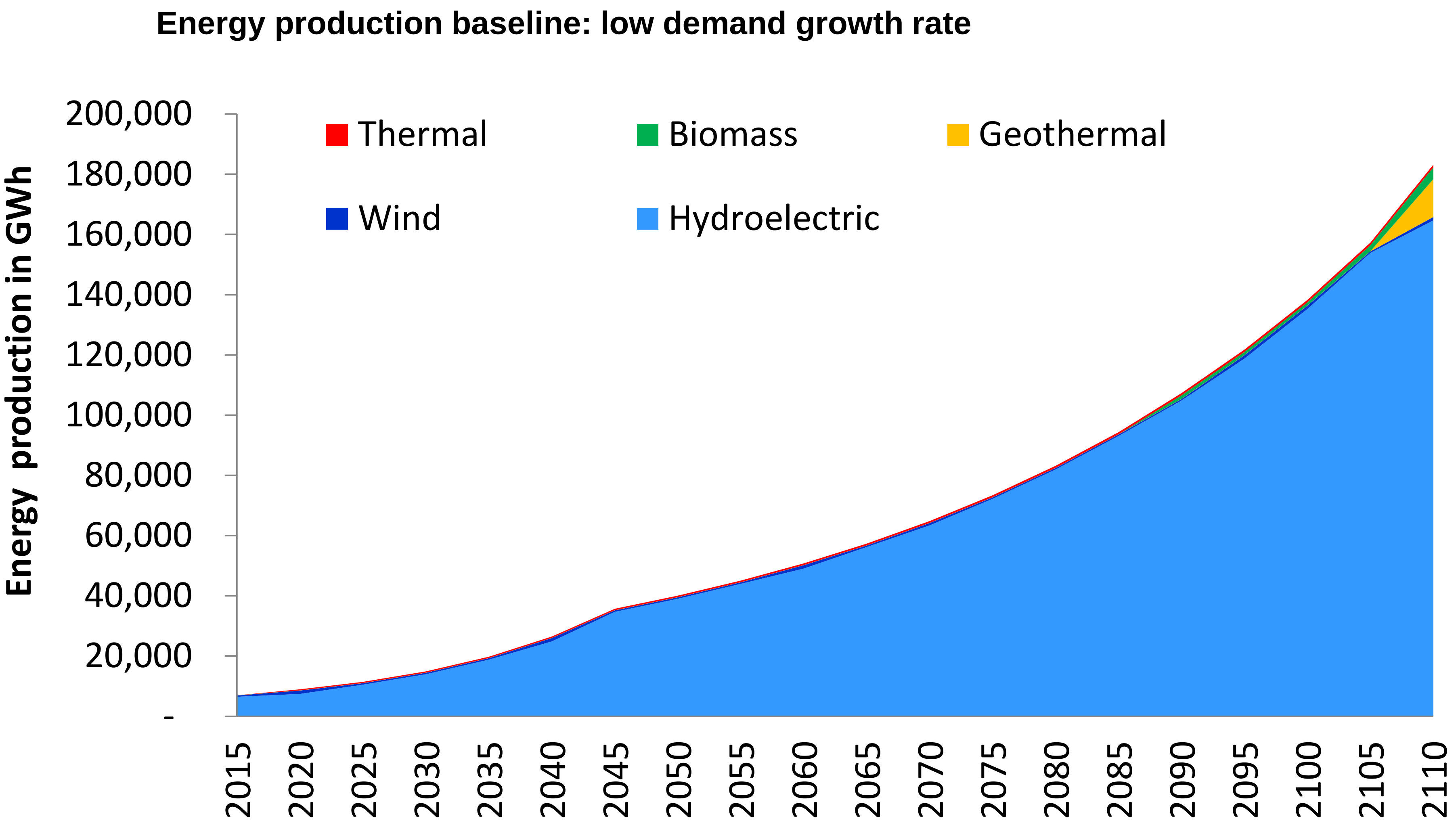
Q_{smt} and Q_{bmt} solid and electrical biomass capacities respectively

Result

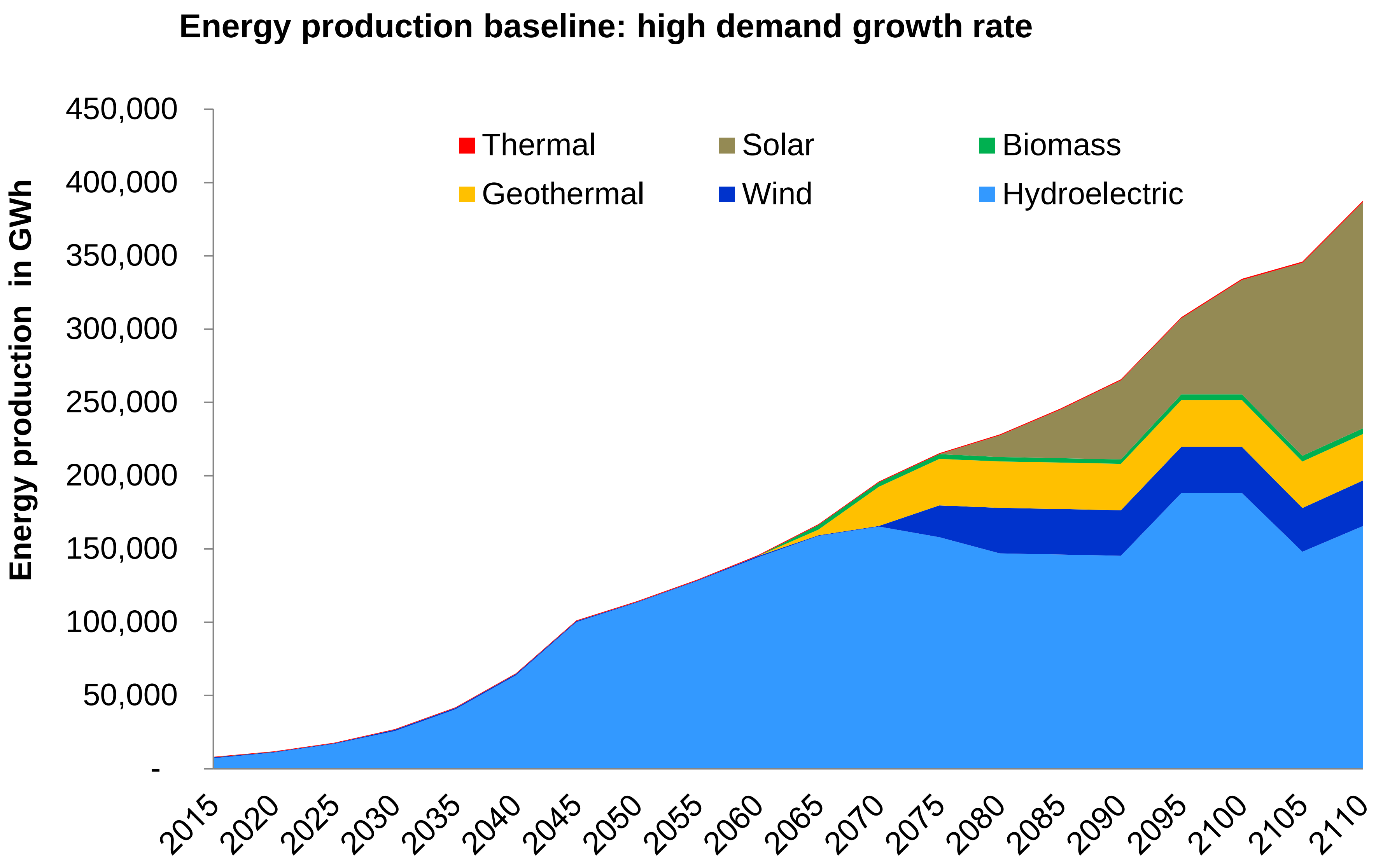
Annual electricity demand projection: high growth rate of 9% and low growth rate of 6% (2010-2045); and 2.5% 2045-2110



Result


Energy production baseline: low demand growth rate
Energy production in GWh
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
-
Thermal
Biomass
Geothermal
Wind
Hydroelectric
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
2105
2110

Result


Energy production baseline: high demand growth rate
Energy production in GWh
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
-
Thermal
Solar
Biomass
Geothermal
Wind
Hydroelectric
2015
2020
2025
2030
2035
2040
2045
2050
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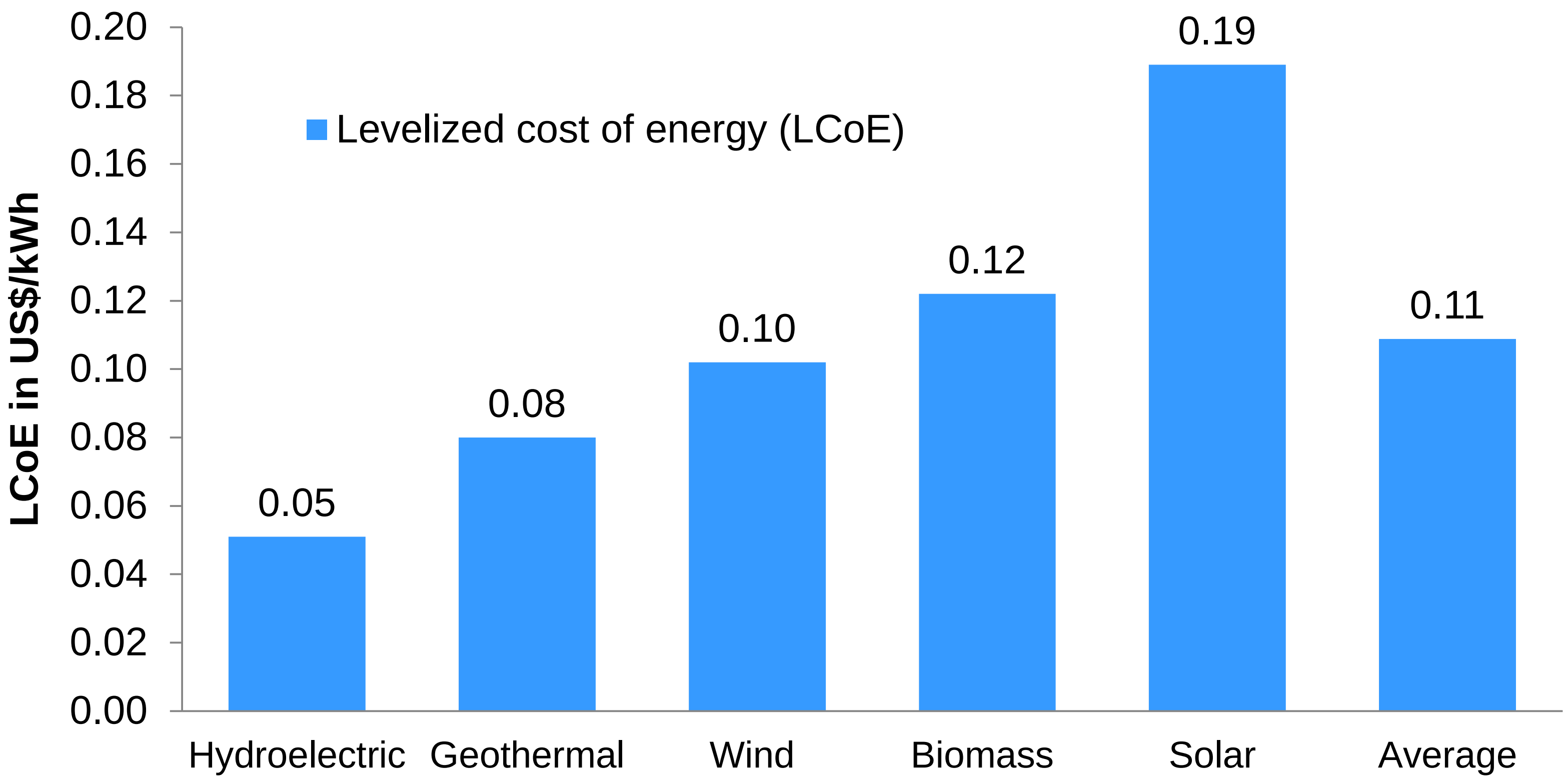
2080
2085
2090
2095
2100
2105
2110

Result

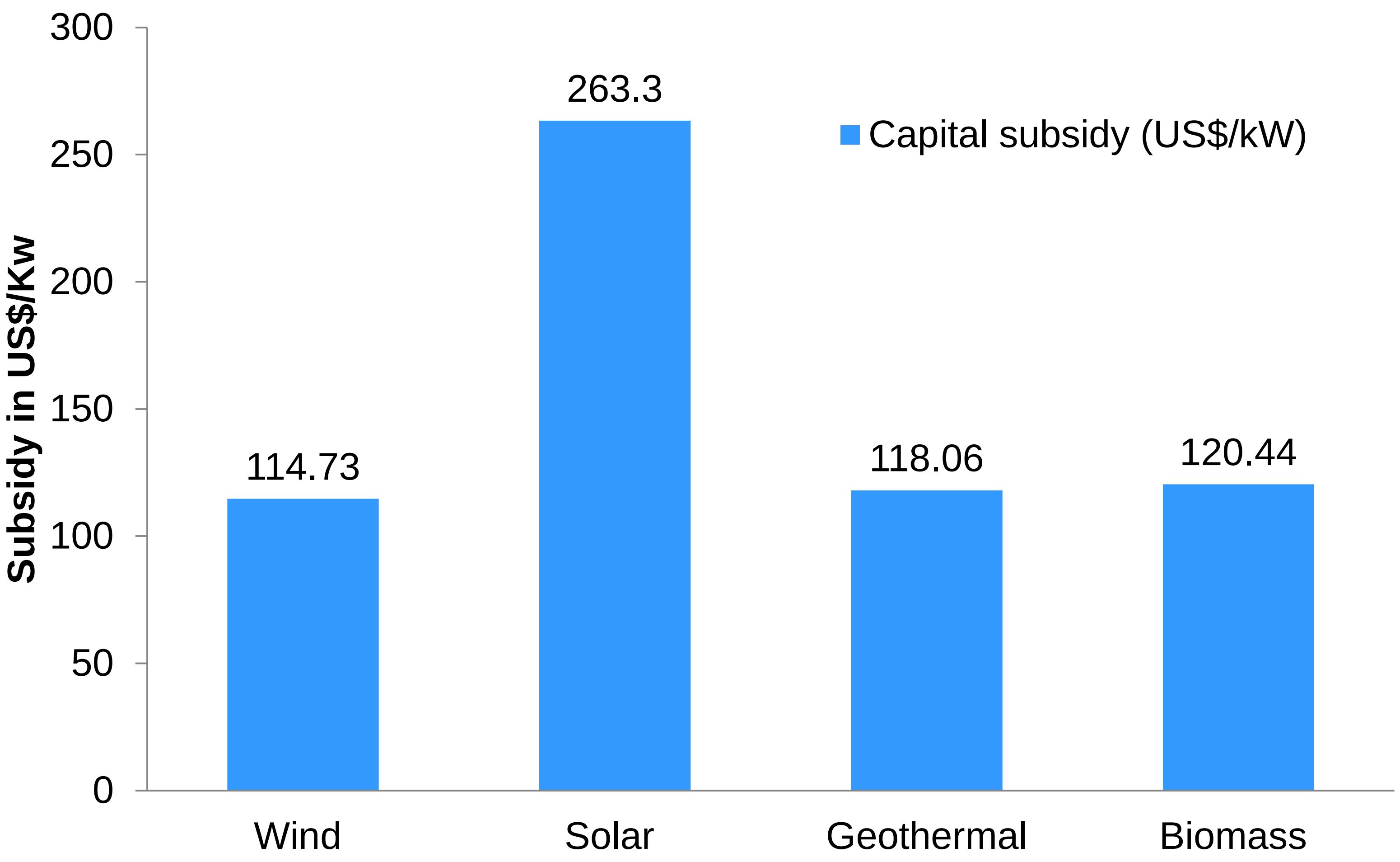
Cost competitiveness of renewable energy sources



- Levelized cost of energy (LCoE) lowest for hydroelectric power and highest for solar

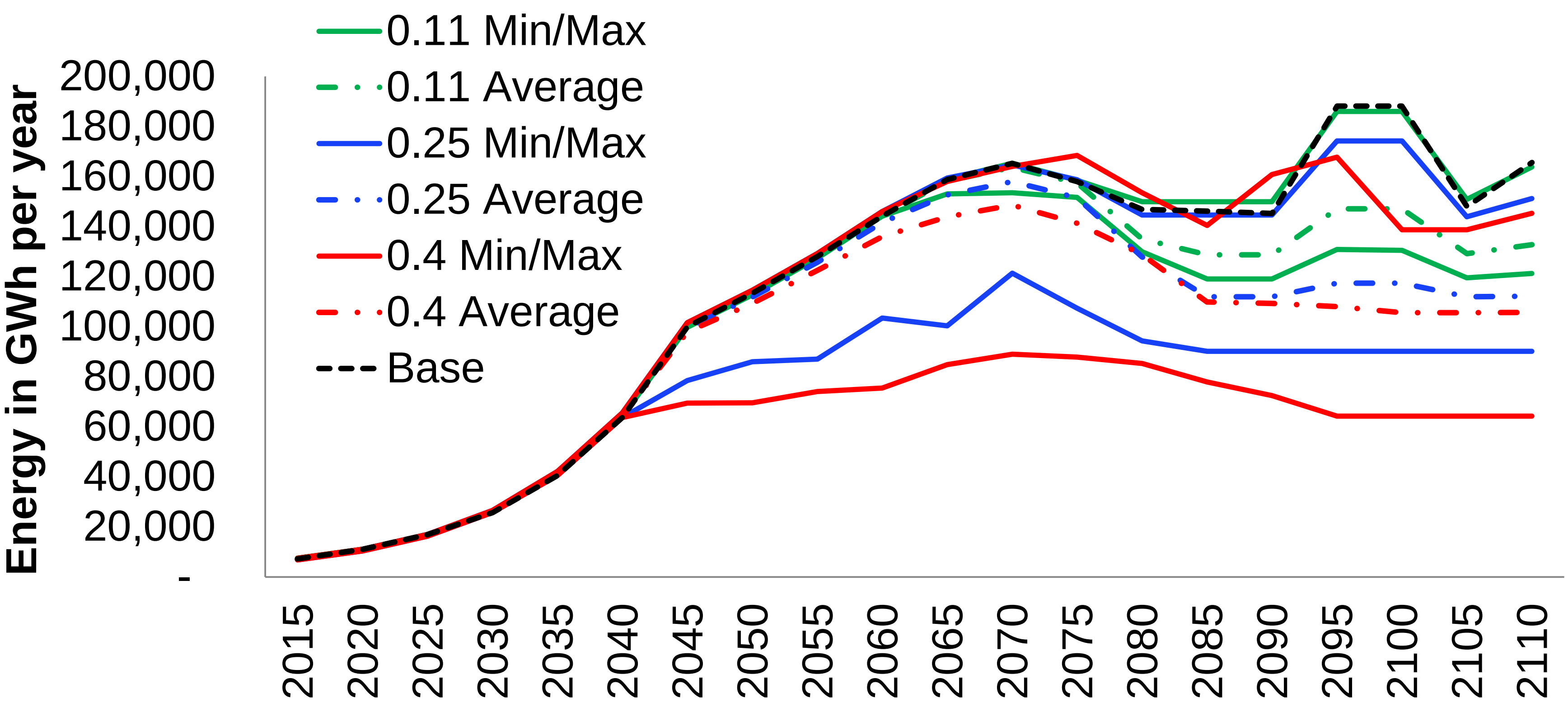
Result

Capital subsidy required to make alternative sources competitive with hydroelectric power



Result

Climate change scenarios, Hydroelectric power production (high demand growth rate)



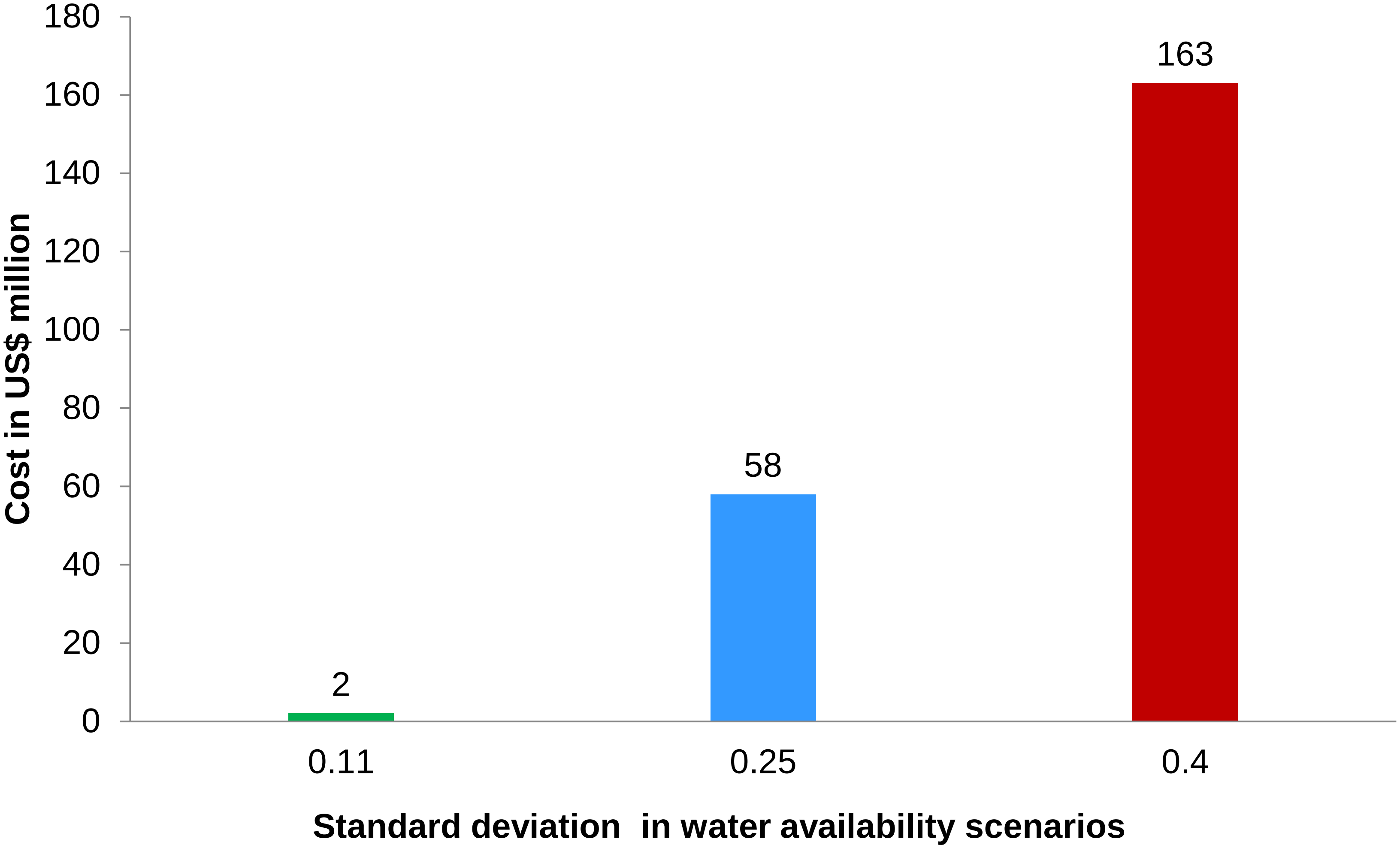
→ may led to reduction in hydroelectric energy production in the long run (but depends on electricity demand growth, and severity of drought)

→ Ethiopia needs to diversify to alternative expensive source

⇒ cost of energy production increases

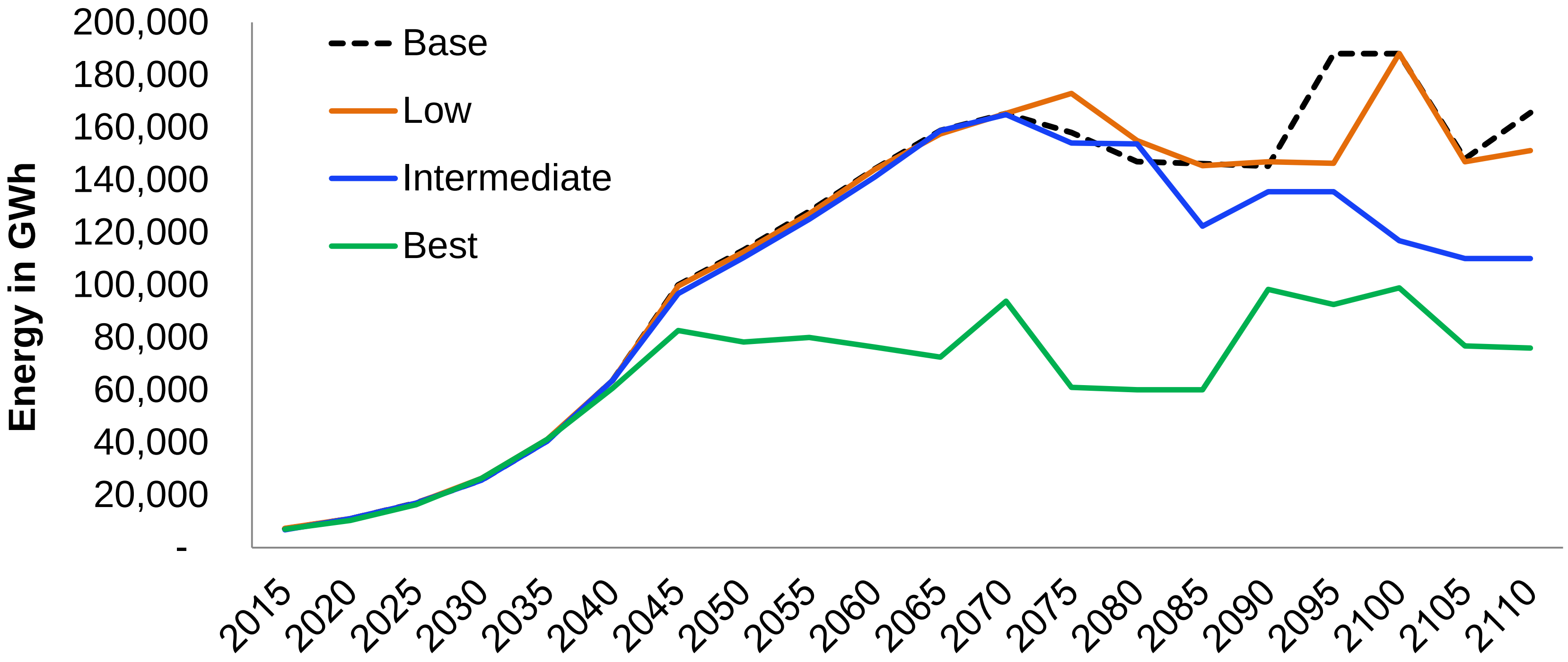
Result

Climate change scenarios, cost of energy production (high electricity demand growth rate)



Result

Effect of technological and efficiency innovation growth scenario, Hydroelectric power (high demand growth rate)

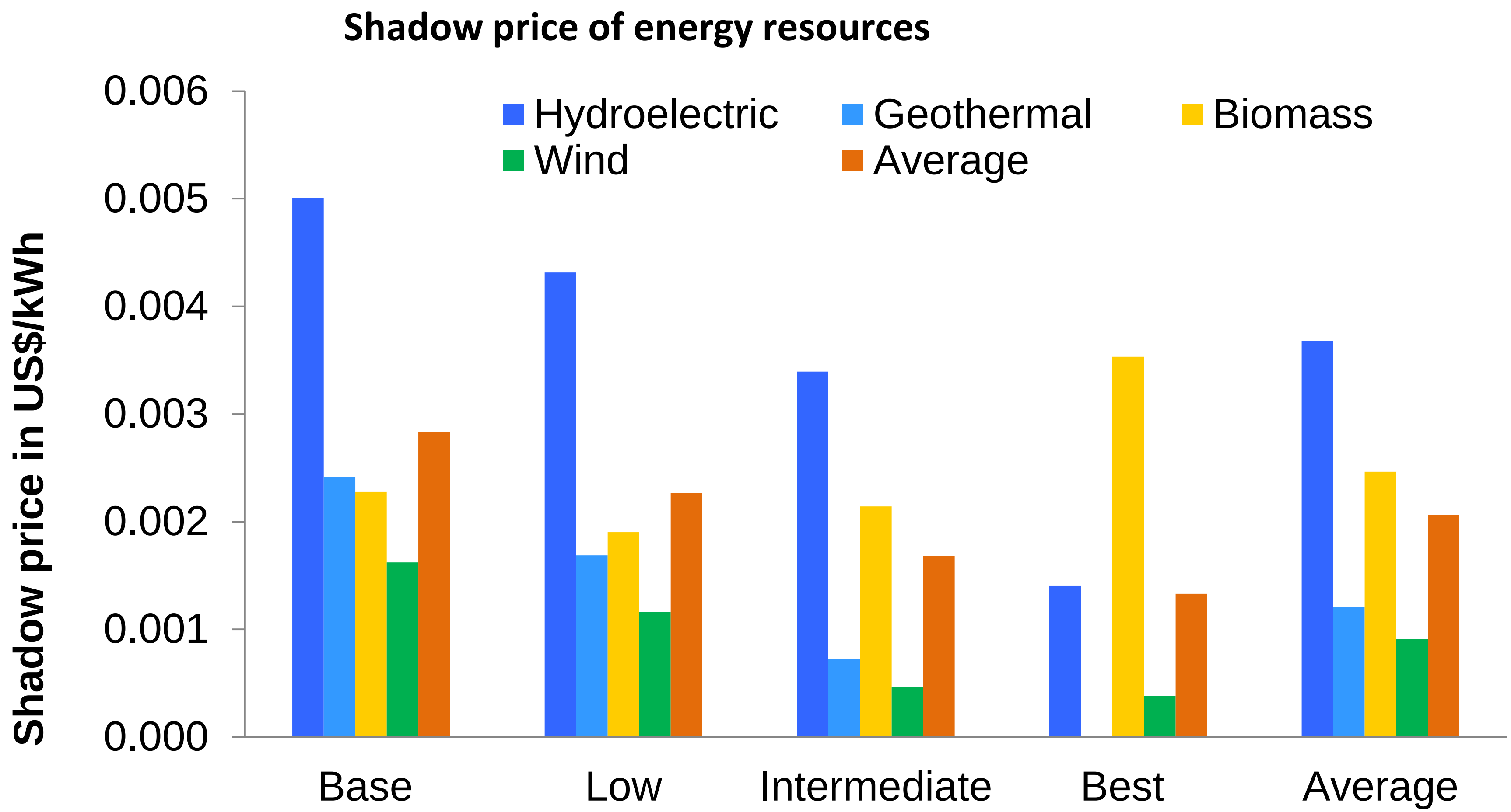


→reduction in cost of solar, wind and biomass

→ substitution for hydroelectric power

→ enhance energy security

Result

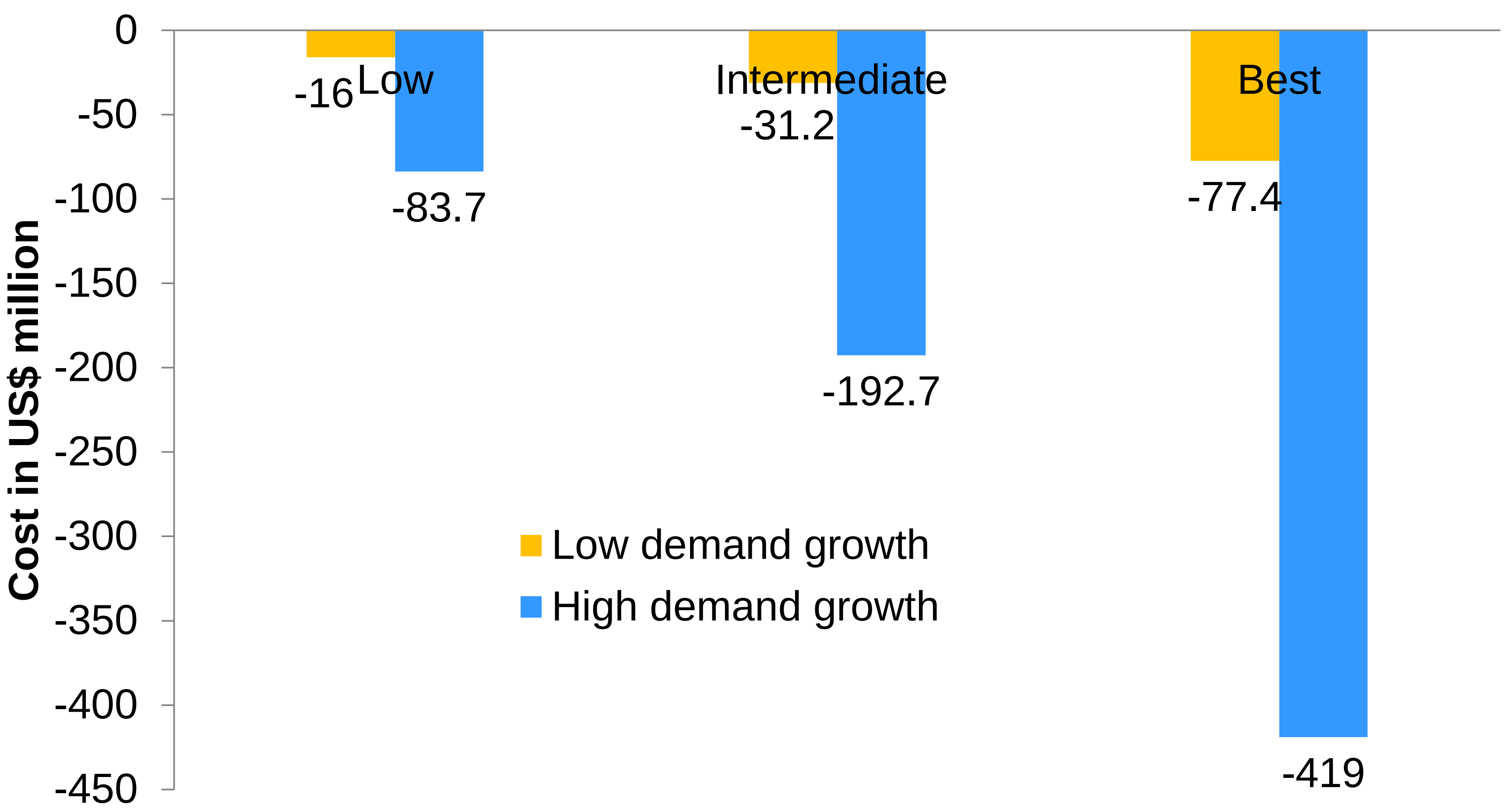


→reduction in shadow price (scarcity) of energy resources

→ technological and efficiency innovations can be an engine of growth

Result

Decrease in cost of energy production for different technological and efficiency innovation growth



Conclusion

- Reliance on hydroelectric power may increase the risk of vulnerability to climate change uncertainty in the long run

→the country needs to diversify to expensive resources

→ this increases cost of energy production

- Technological and efficiency innovations are key for reducing the risks posed on hydroelectric reservoir due to climate change uncertainty

→decrease in cost of energy production

→substitution for drought vulnerable hydroelectric power

→decrease in shadow price of energy resources

⇒ enhances energy security and creates economic growth opportunity

Recommendation

- Closing technical, financial, and efficiency gaps that exist in the country’s energy sector
- Strategies for promoting technological and efficiency innovation

→ promoting R&D

→ local technological capability building

→ human skill development (learning and adaptability)

→ Innovative clean energy financing approaches (capital subsidies)

- Integrating afforestation and reforestation initiatives with watershed management

→reduce reservoir siltation risks and enhance hydroelectric power generation

Acknowledgements

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Thank you!