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Techno-economic Life-cycle Assessment of Medium and Heavy-duty Fuel Cell Trucks in Japan

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Background Information

- Road transport of Japan contributed 15.9% of the nation's CO_2 emissions in 2022 and 44.3% of CO_2 emissions from the road transport are generated by freight trucks.

- The New Energy and Industrial Technology Development Organization (NEDO) designed a roadmap for the introduction of FCTs into the vehicle fleet.

- Prototype FCTs have been designed and produced by Toyota and Hino Motors.

Issues Focused on the Study

- Cost of FCT deployment and life-cycle GHG emissions of FCTs
- Hydrogen supply cost
- Investment cycles of hydrogen production and distribution equipment
- Fuel cell system
- Benefits of FCTs over conventional diesel trucks (ICETs)

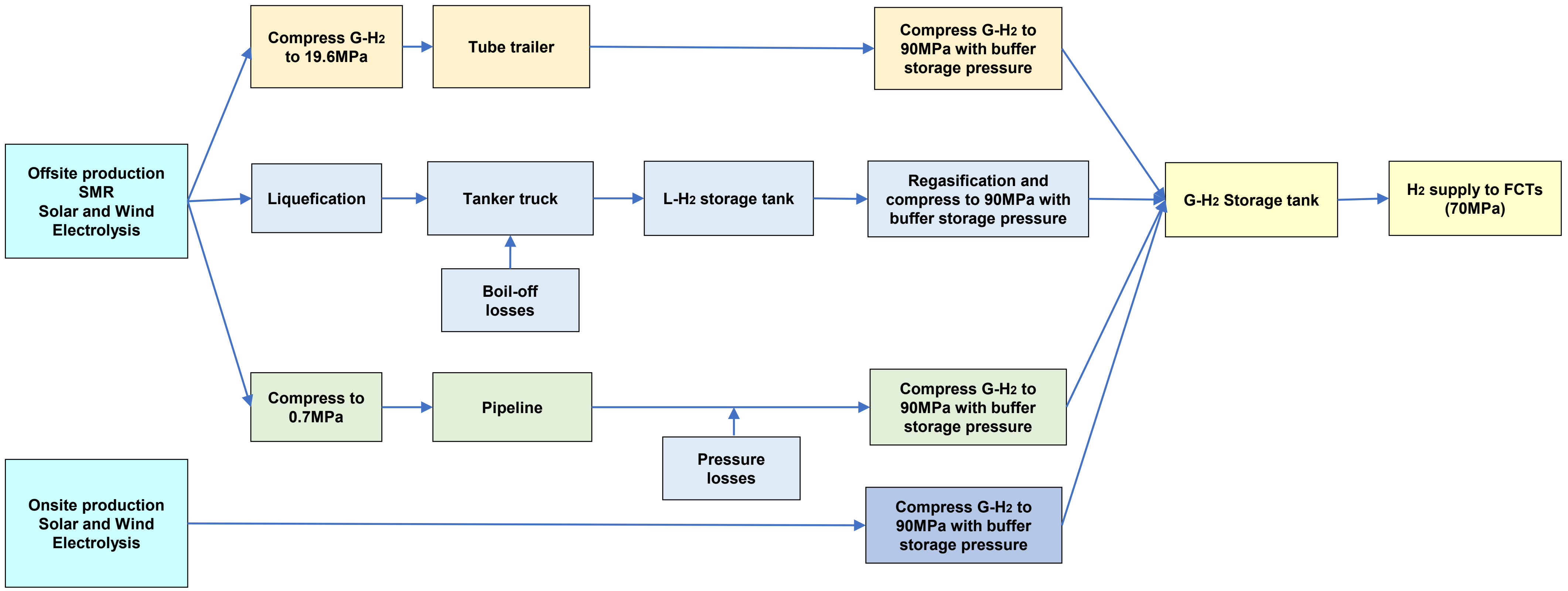
Purpose of the Study

- Examines economic and environmental benefits of a transition to FCTs for 2025-2060.
  - Examines the life-cycle GHG emissions reduction
  - Examines the differential total cost of FCTs compared with ICETs
  - Examines the marginal cost of the life-cycle GHG emissions reduction

Model Description

- System dynamics simulation model.
- FCT types: Medium and Heavy-duty trucks
- FCTs growth: A stock turnover model with survival rates
- Hydrogen supply pathways
  - Production methods: SMR with CCS, solar and wind electrolysis
  - Production locations: Offsite, Onsite
  - Hydrogen transport modes: Road transport with Gaseous H2 or Liquefied H2, and Pipeline

Hydrogen Supply Pathway



Methodology

Projection of LC GHG emissions

- LC GHG emissions from FCTs and ICETs
  - GHG emissions from well-to-tank, tank-to-wheel, truck production, FC stack and onboard storage tank production
  - GHG emissions from H2 production and distribution equipment are excluded.

- Calculation of LC GHG emissions
  - Based on energy consumption of sources and the emission factors.
  - Based on the projected FCTs growth.

Methodology

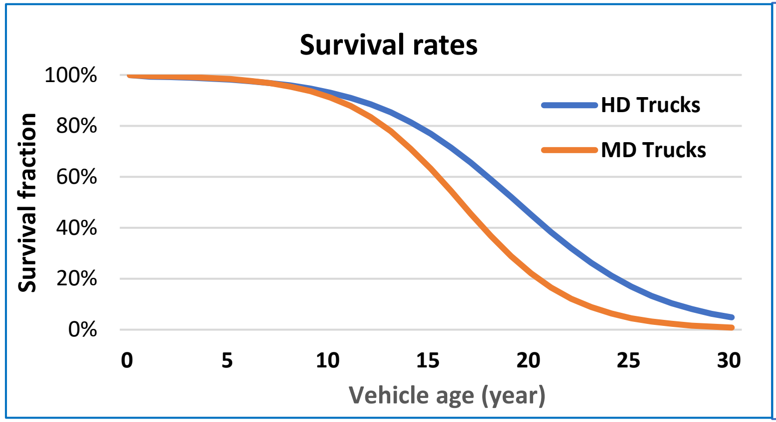
Projection of total costs

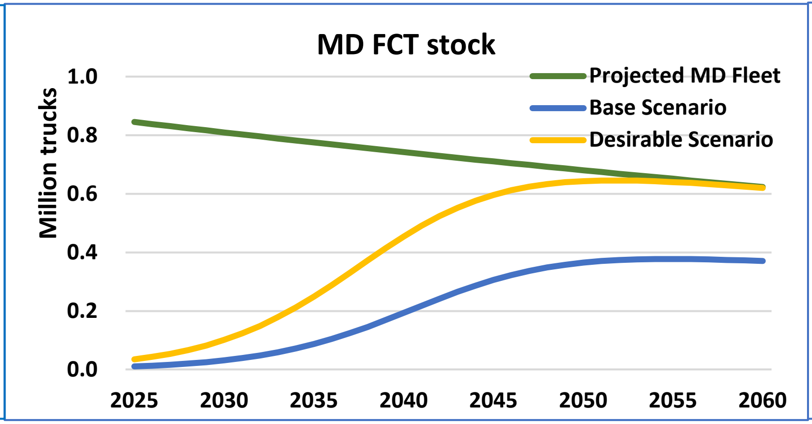
- Costs of FCTs and ICETs
  - Capital cost, fuel cost, maintenance cost, FC system cost, Storage tank

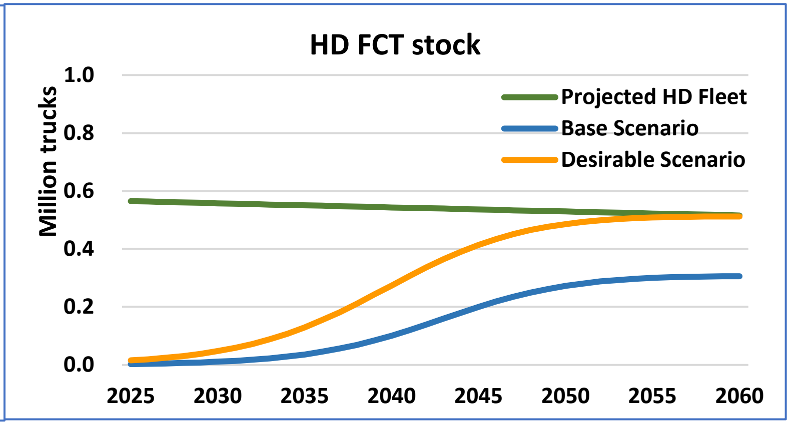
- Replacement costs
  - Electrolyzer device, compressors, liquefiers, H2 transport trucks, refueling stations, FC system, H2 storage tank

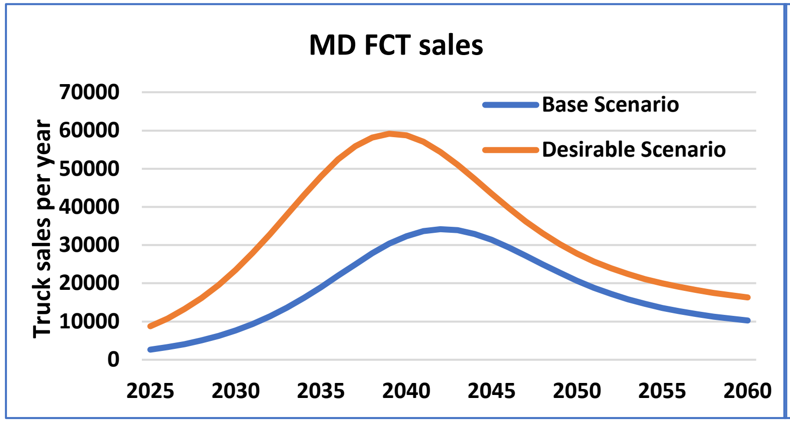
Methodology

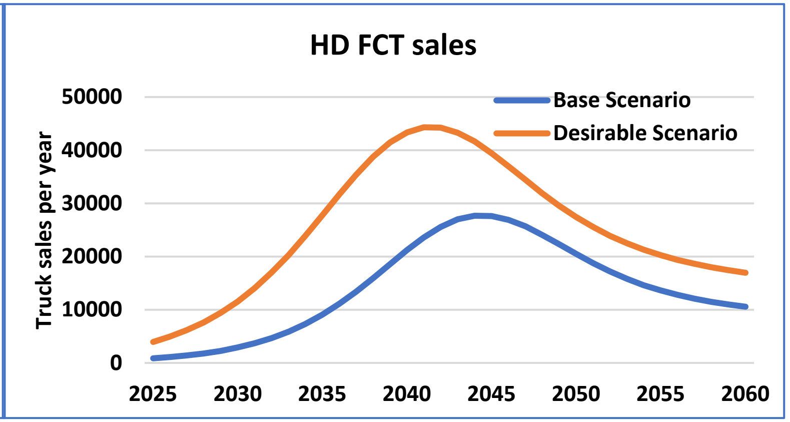
- **Stock turnover model**
  - A survival rate of MD and HD trucks: Based on the historical data.
  - Growth scenarios: Basic and desirable scenarios











Fuel Cell Trucks Specification

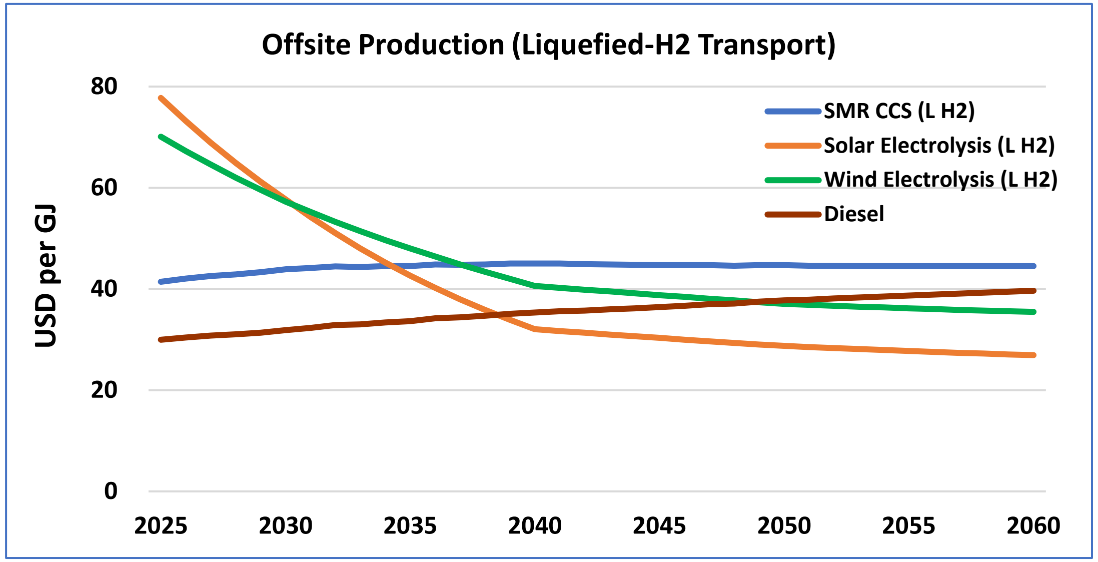
	Medium duty FCT	Heavy-duty FCT
Fuel Cell Stack	150 kW	300 kW
Onboard H2 Storage Tank	50 kg	70 kg
Weight	11 tons	25 tons

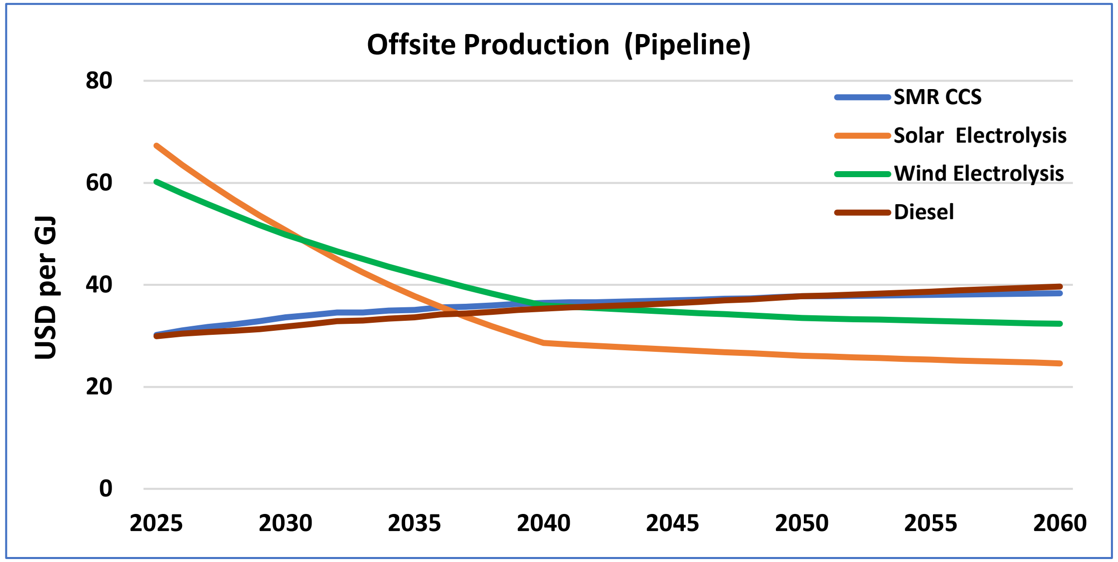
Data on SMR and Electrolysis

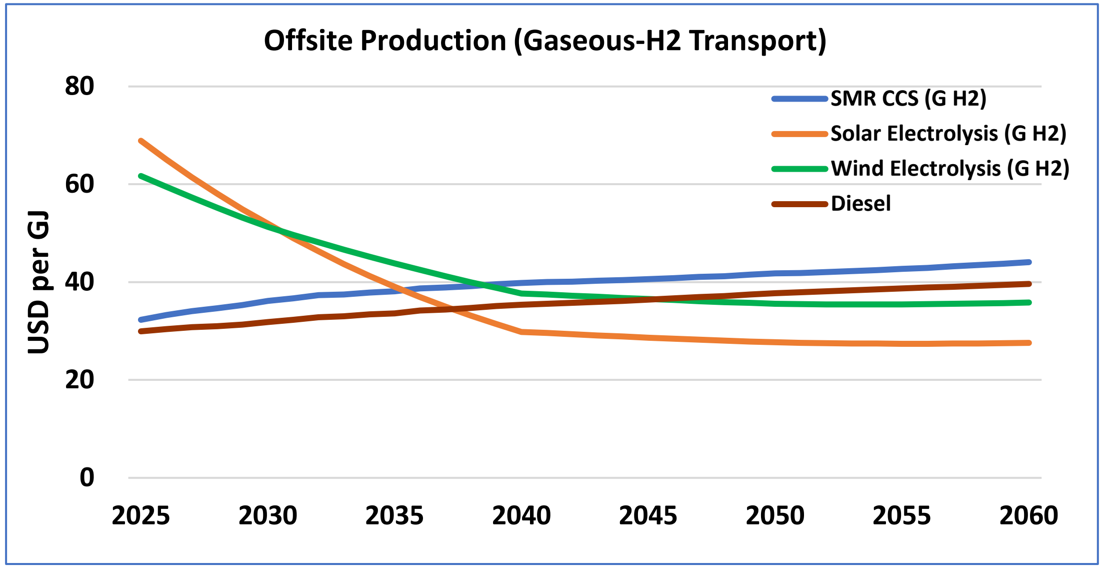
	Parameter	Value	Unit	Reference
SMR	Electricity consumption	0.567	kWh/kg-H_2	Sun et al. (2019)
	Natural gas requirement	0.165	GJ/kg-H_2	Sun et al. (2019)
	Production capacity	110,000	Nm^3/hour	Sun et al. (2019)
	CAPEX	0.08	\$/kg-H_2	Khan et al. (2021)
Alkaline Electrolysis	System cost	687.26 (2020) 229.00 (2040)	\$/kW	NEDO (2023)
	OPEX	14.1 (2020) 9.22 (2030)	\$/kW	NEDO (2023)
	Electricity consumption	55.68 (2020) 49.34 (2050)	kWh/kg-H_2	IEA (2019) METI (2020)
	Lifetime	10	Year	NEDO (2023)
	Discount rate	6	%	Assumption
	Production capacity	1200 (Off-site) 200 (On-site)	Nm^3/hour	NEDO (2020, 2023)

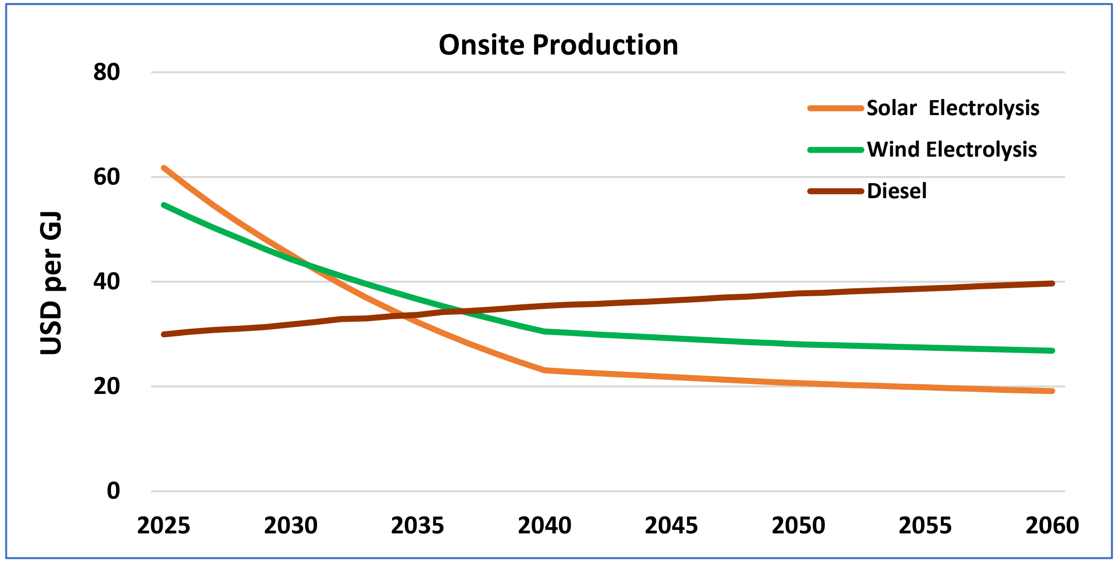
Result of the Analysis

Hydrogen Supply Costs

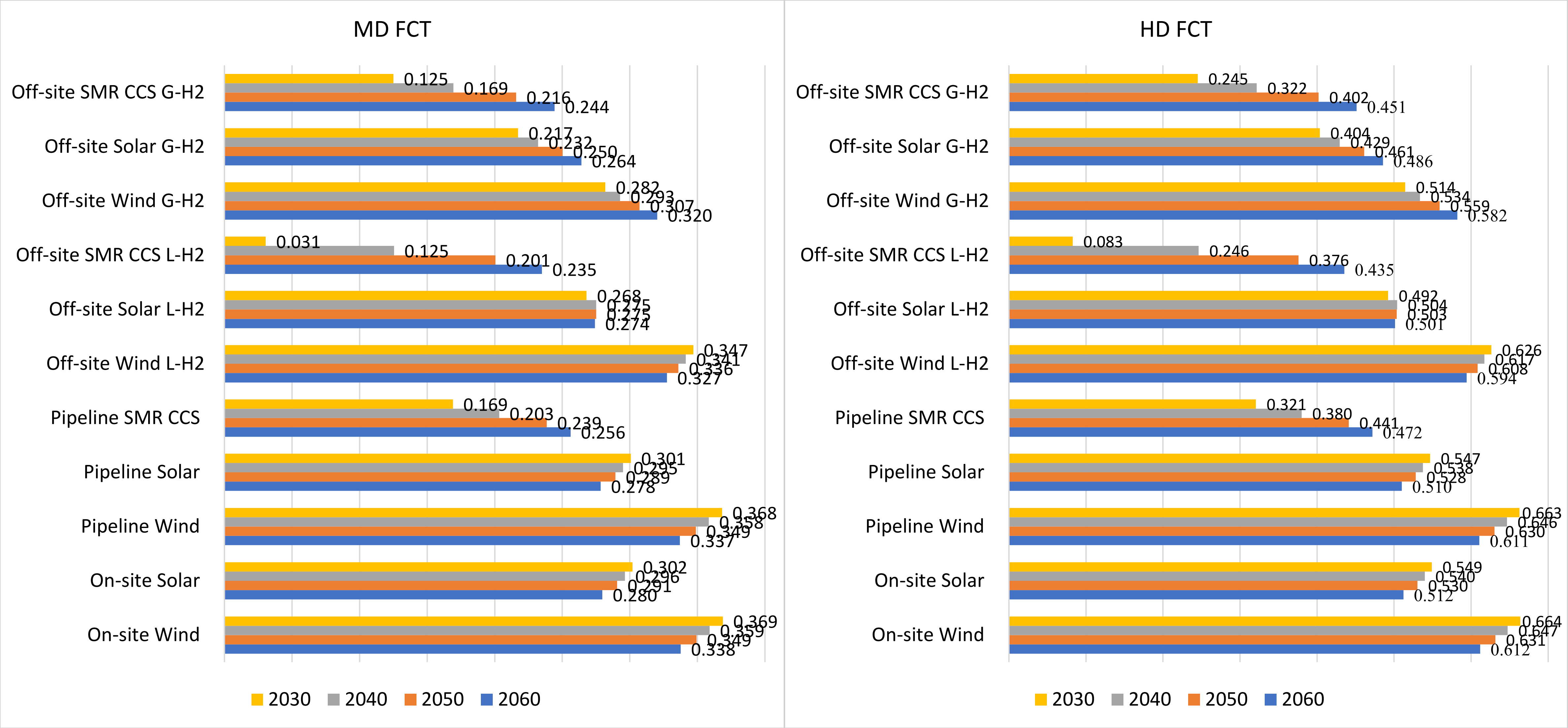




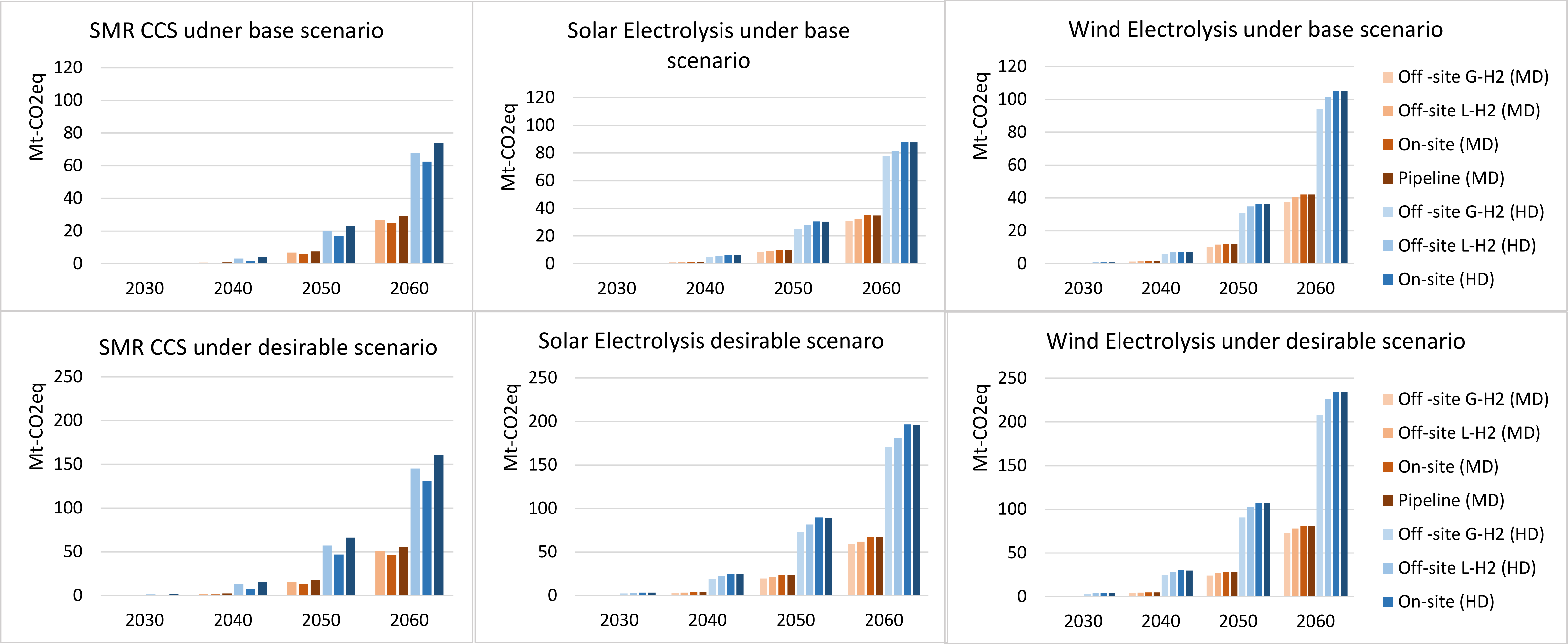




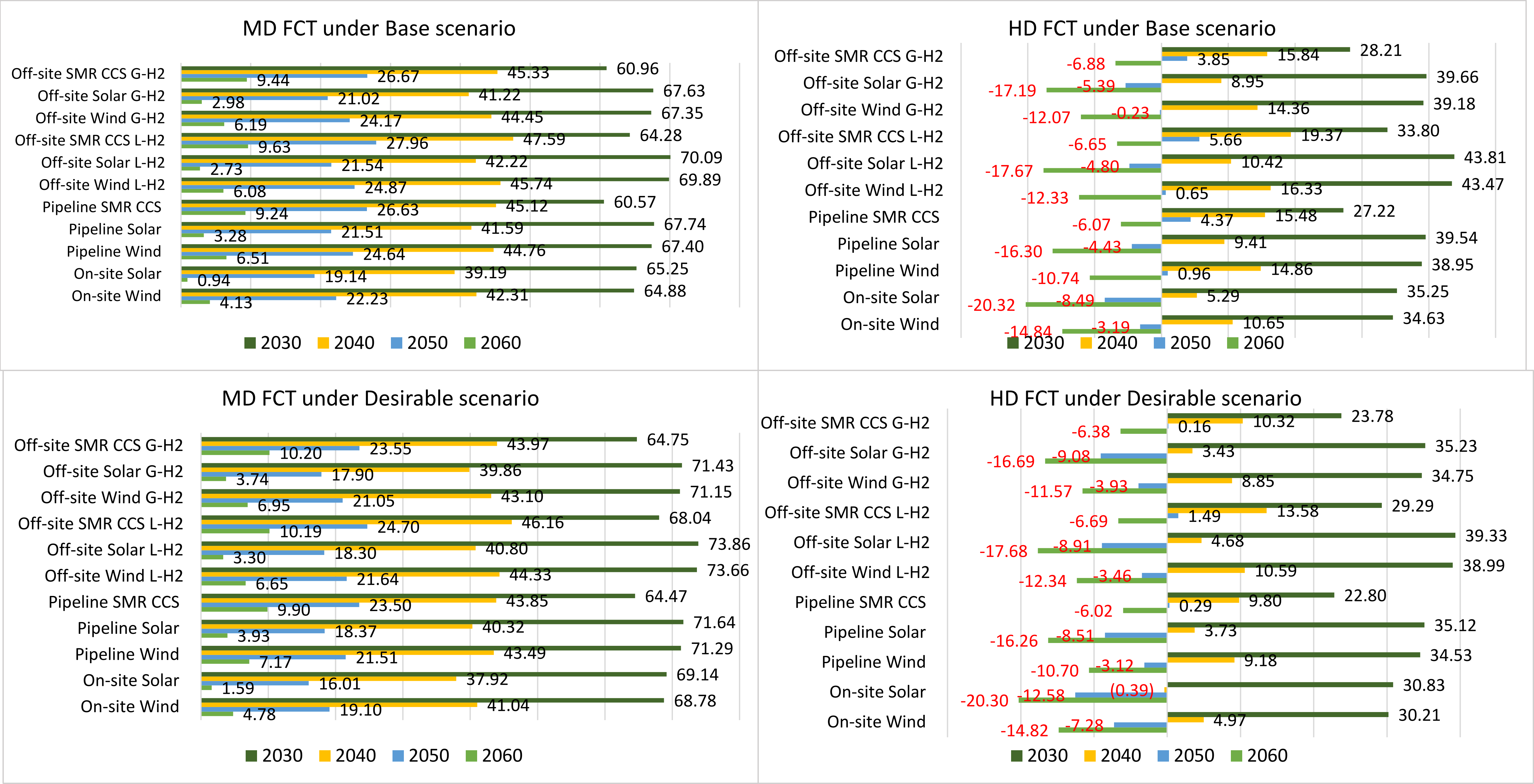
LC GHG Emissions Reduction per km



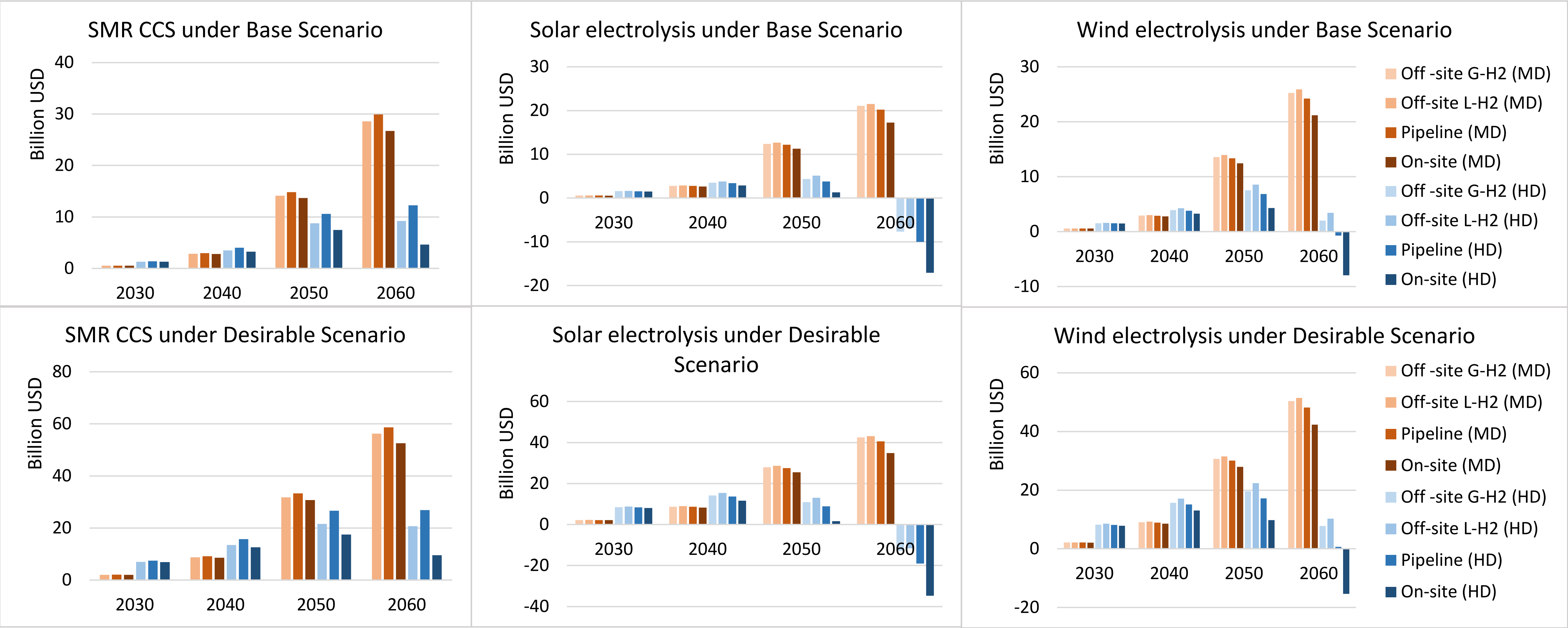
Cumulative LC GHG Emissions Reduction



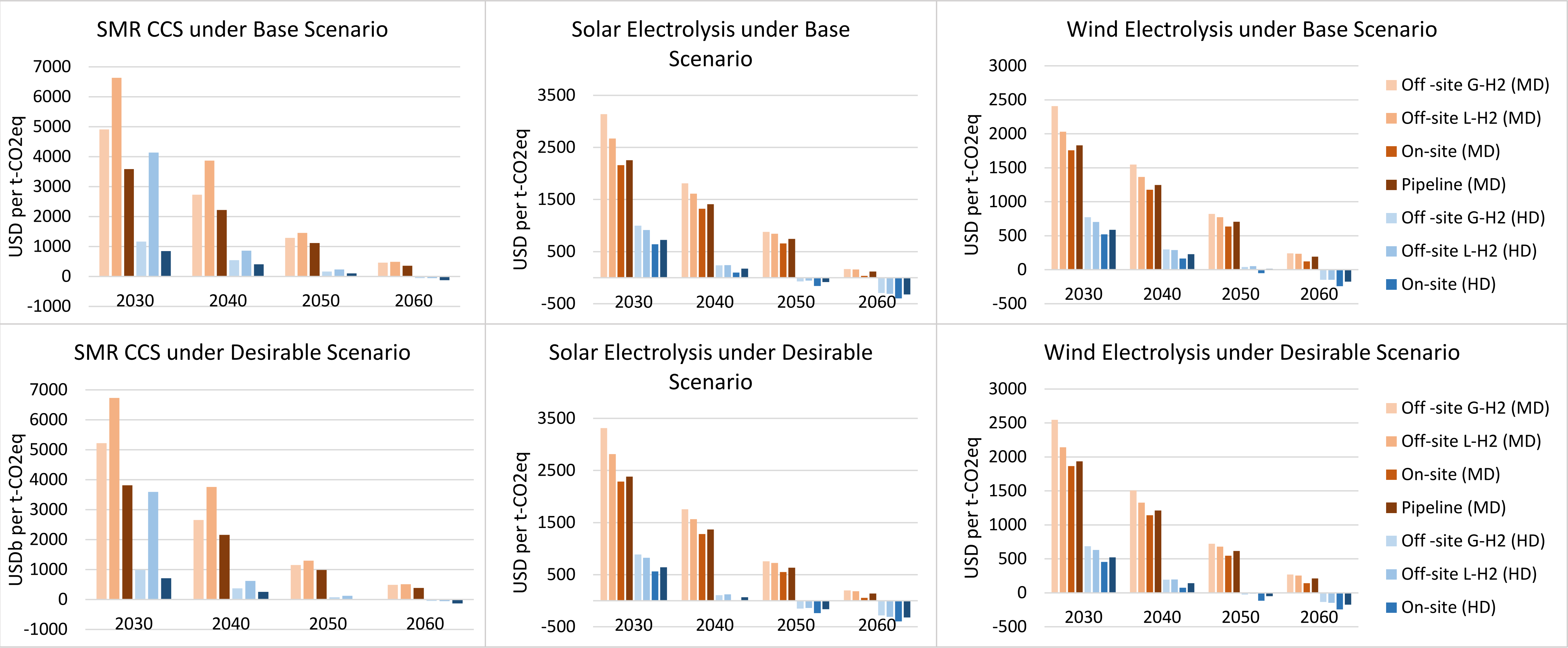
DTCOs between FCTs and ICETs



Cumulative DTCOs



Marginal Costs of LC GHG Emissions Reduction



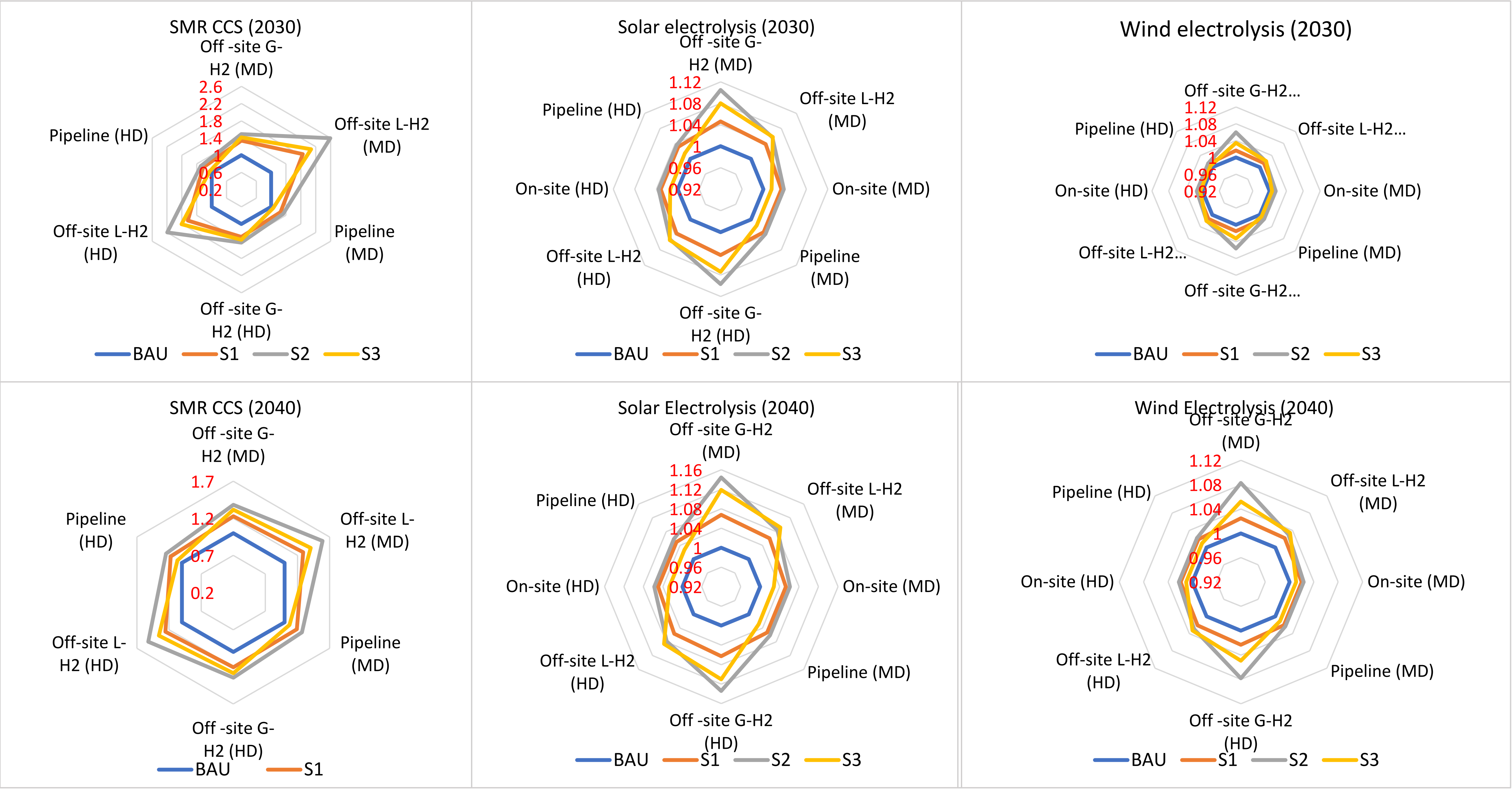
Sensitivity Analysis

Scenarios

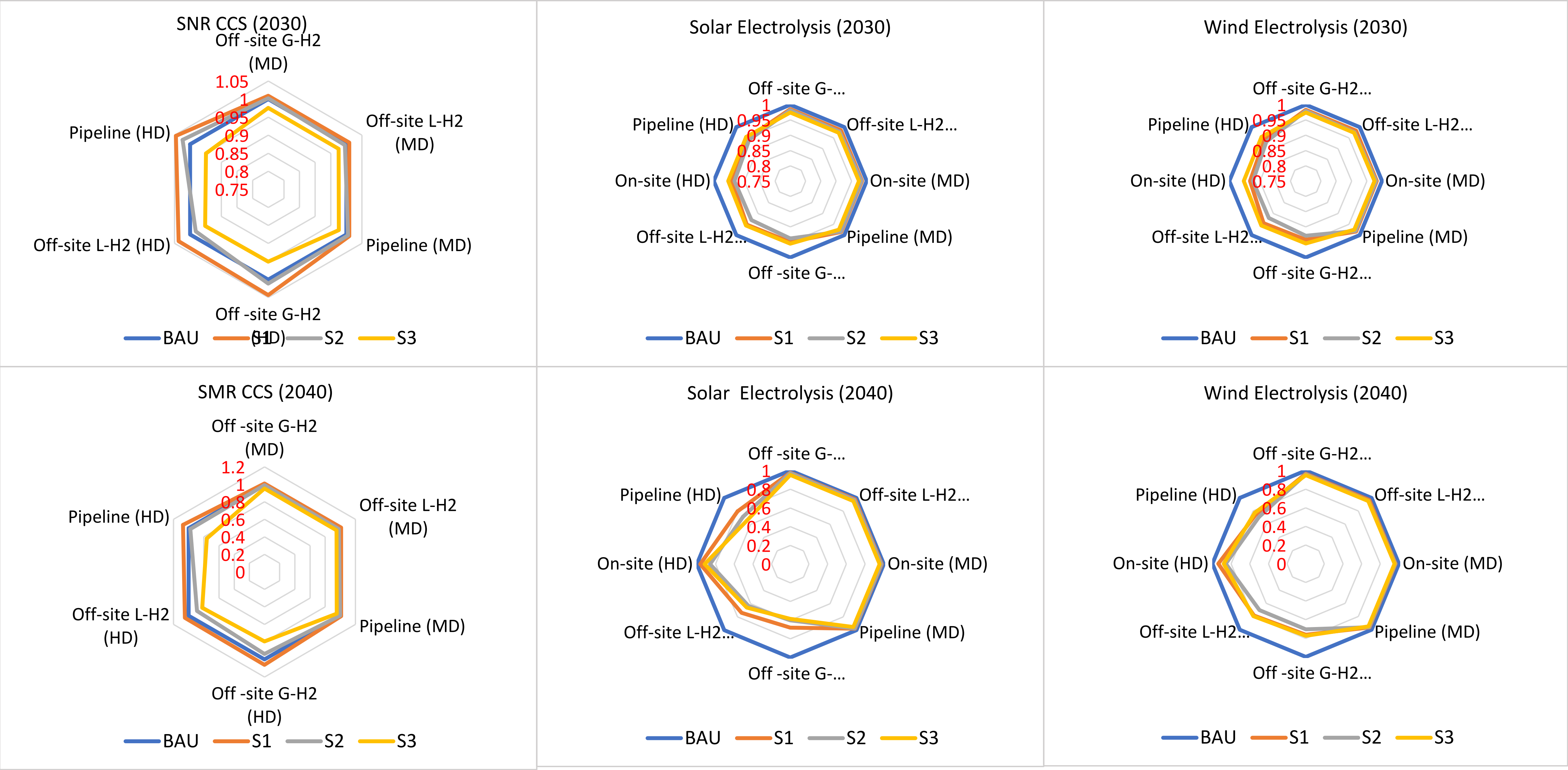
	SMR and electrolysis	Hydrogen compression and liquefaction	Fuel economy of FCTs
Scenario 1	✓		
Scenario 2	✓	✓	
Scenario 3			✓

	BAU	Improved Technology	Unit	Reference
SMR with CCS	12.44 (2020) 4.6 (2050)	12.44 (2020) 3.4 (2050)	kg-CO2eq/kg-H_2	Japan Hydrogen Association (2022), Timmerberg et al. (2020)
Electrolysis	55.68 (2020) 49.34 (2050)	55.68 (2020) 39.24 (2050)	kWh/kg-H_2	IEA (2019), METI (2023), NREL (2014)
Hydrogen compression	3 (tube trailer, pipeline) 2.7 (storage tank) 2.43 (refueling station)	20% improvement by 2050	kWh/kg-H_2	Assumption
Hydrogen liquefaction	13.83 (2020) 6 (2050)	13.83 (2020) 3 (2050)	kWh/kgH_2	Bauer et al. (2019), METI (2023)
Fuel economy of FCTs	Increase by 0.12% annually	Increase by 0.5% annually	kg-H_2/km	H2Accelerate (2022), Assumption

Impact of Technology Development on LC GHG Emissions Reduction



Impact of Technology Development on Differential Total Cost



Impact of Technology Development on Marginal Cost

Conclusions

Conclusions

- **HD FCTs vs MD FCTs**
  - **HD FCTs outperform MD FCTs for both the life-cycle GHG emissions reduction and economic benefits.**
  - **Solar and wind electrolysis with pipeline transmission under transitioning MD FCTs will result in additional cumulative costs by 2060 of between $20 billion and $48 billion with a cumulative GHG reduction of 35 to 81 Mt-CO2eq**
  - **The transition of HD FCTs will result in economic impact ranging from savings of $19 billion to costs of $20 billion and a cumulative GHG reduction of 88 to 235 Mt-CO2eq.**
  - **MC of emissions reduction for HD FCTs with solar and wind electrolysis will be less than the estimated marginal cost of GHG emissions reduction in 2030 for the INDC of Japan (MOFA, 2021) of $452 per t-$CO_2$eq before 2040. HD FTCs with SMR with CCS fail to achieve this estimate until 2050. MD FCTs will not achieve this by 2050.**

Conclusions

- **Policy Perspectives**
  - **Produce hydrogen onsite using solar or wind electrolysis or offsite with pipeline transmission and use SMR with CCS only for early stage of the fuel cell truck deployment.**
  - **The selection of road transport modes such as G-H_2 and L-H_2 needs to be determined based on production methods.**
  - **Improving fuel economy can be more effective in reducing life-cycle GHG emissions than improving hydrogen production efficiency.**

Thank you

Questions and Comments please?