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# Pushing the limits of TIAM – achieving well-below 2 degrees scenarios

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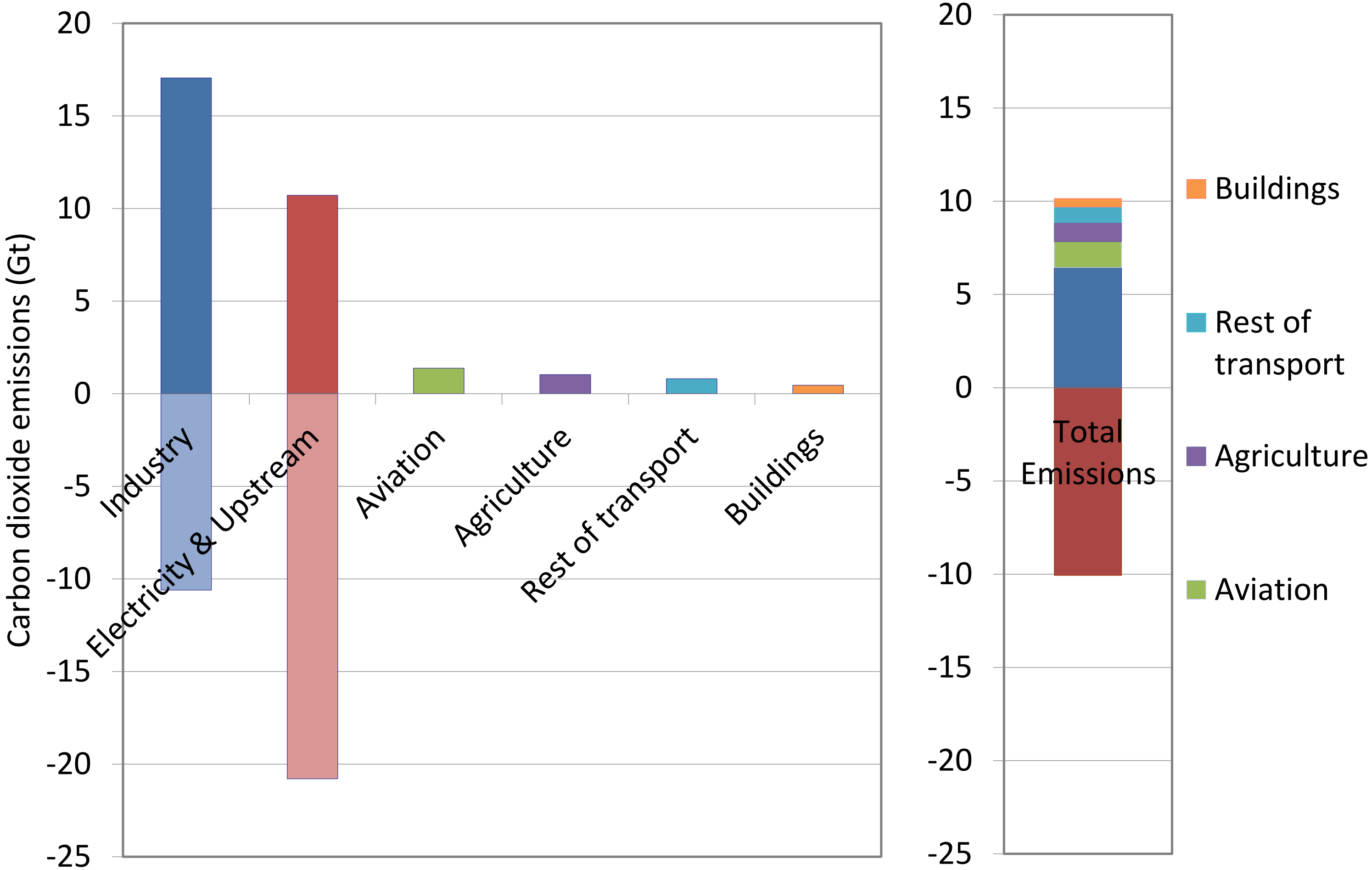
# Project background and aims

- Part of the Climate Works funded project '*Understanding the mitigation implications of a 1.5 degrees C pathway*'
  - What additional effort is required compared to a 2 degrees pathway?
  - What actions do we need to take in the near-term to facilitate this deep decarbonisation in the long-term?
- In order to answer these questions we need to push the model beyond its current capabilities
  - Our current version couldn't go below 1.75 degrees C before it runs out of options (i.e. relies on CO2 backstop technology to solve)
- Looking out to 2100 it is likely that there could be significant technological breakthroughs which would offer new low-carbon alternatives

# Breakdown of global $CO_2$ emissions by sector in 2070 for a scenario having a 50% probability of staying below 2$^{o}$C




*Based on results generated using the TIAM-Grantham energy systems model as part of the AVOID 2 project*

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# What options do we have?

1. Faster deployment of low carbon technologies in the near term
   - More rapid cost reductions
   - Removing growth constraints for key technologies
2. Lower demand representing behavioural changes and improved resource efficiency
3. Advanced (and speculative) technologies for ‘difficult to mitigate’ sectors such as the industrial sector and aviation
4. Non-biomass based (and therefore less constrained) Carbon Dioxide Removal (CDR) technologies

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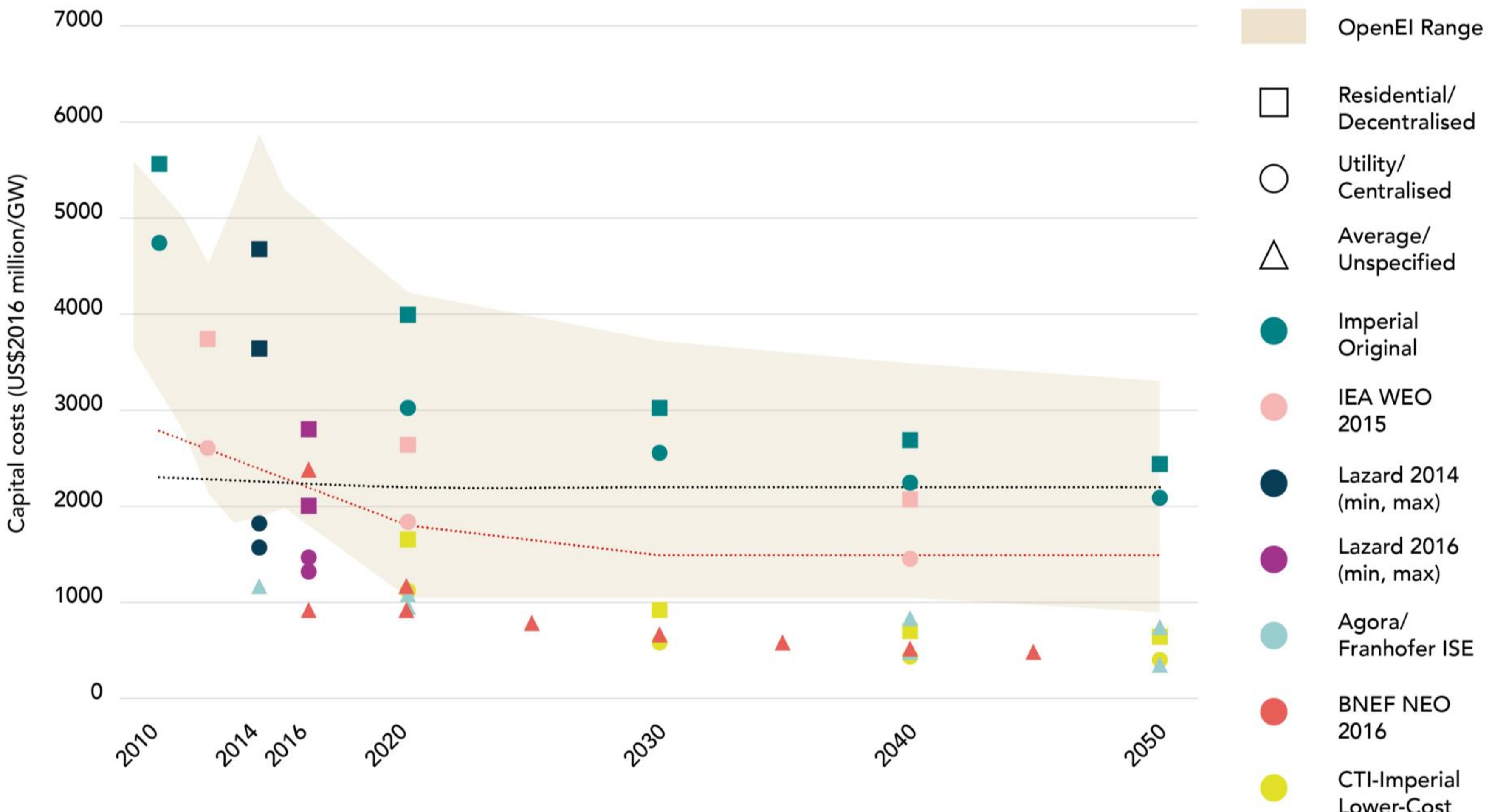
# Lower cost estimates: Solar PV




Source: OpenEI data includes Lazard 2009-13, IPCC 2014, EIA AEO 2012, 2013 & 2015, IIASA 2014, US DOE 2011 & 2012, IEA PV 2010 & 2012, US EPA 2013. Additional sources include Agora/Franhofer ISE 2015, IEA WEO 2015, IEA WEIO 2014, BNEF NEO 2016, Lazard 2014 and CTI-Imperial 2016.

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# Advanced technologies

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# Table of advanced technologies under consideration

| Sector | Technology | Status | Comments |
|---|---|---|---|
| Transport | Road: Electric trucks and electric 2- & 3-wheelers | Completed | Tesla recent announcement of all-electric semi-truck capable of carrying heaviest loads. Model assumption: Cost competitive with ICE vehicles by 2030. |
| | Hydrogen and biofuels in aviation | Completed | Technically feasible. Hydrogen necessary to have a realistic alternative to biofuels in the model. Assumed cost competitive with conventional planes by 2075. |
| | Hyper loop (alternative to rail and domestic aviation) | Completed | Elon Musk believes that this could come out cheaper than High Speed Rail. |
| Industry | Improved representation of industrial CCS (Incorporating changes from ETSAP) | Completed | CCS plays a key role in mitigating emissions from the industrial sector. Many energy intensive processes are running out of options for further energy efficiency improvements. Good representation of these technologies is key to achieving deep decarbonisation in the industrial sector. |
| | Advanced steel processes with CCS such as BF-TGR and Corex process (Incorporating changes from ETSAP) | Completed | |
| | Electrolysis | Not started | Currently only possible technology which could achieve zero-carbon steel without CCS. |
| Power generation | Nuclear fusion (Incorporating changes from ETSAP-TIAM) | Completed | Would need to be cost competitive with conventional nuclear to see uptake. No CO2 benefit over conventional nuclear but other benefits include environmental and resource sustainability. |
| | Wave and tidal (Incorporating changes from ETSAP-TIAM) | Completed | Global resource potential for Tide and Wave power generation is around 800 and 3000 TWh/yr, respectively. |
| Other | Negative emissions technology (e.g. direct air capture) | In progress | Given the challenges, uncertainties and sustainability issues around BECCS there is a need for a non-biomass based negative emissions technology in these models. |

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# Improvements to the aviation sector

**The problem: Current representation of Aviation in TIAM is extremely simplified - Just base year technologies which continue into the future.**

- Crude representation of hydrogen planes but represented as 'additional cost' and if included it just takes over completely
- No biofuel option for aviation.

→ Therefore no actual mitigation options in aviation.

**The solution:**

- Converted demand from PJ to bp-km and forced a retirement date on existing base year planes
- Introduced new-build conventional planes with full CAPEX and O&M costs and allowed an efficiency up to 53% by 2050 (in line with ICCT ambitious scenario) or by 2090 (ICCT conservative scenario)
- Added biofuels as an option for conventional planes in the same manner as for cars (i.e. blended)
- Included hydrogen planes based on conventional engines but not those based on fuel cells. Allowed to start from 2040 (domestic) and 2050 (international)

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# Demand reductions

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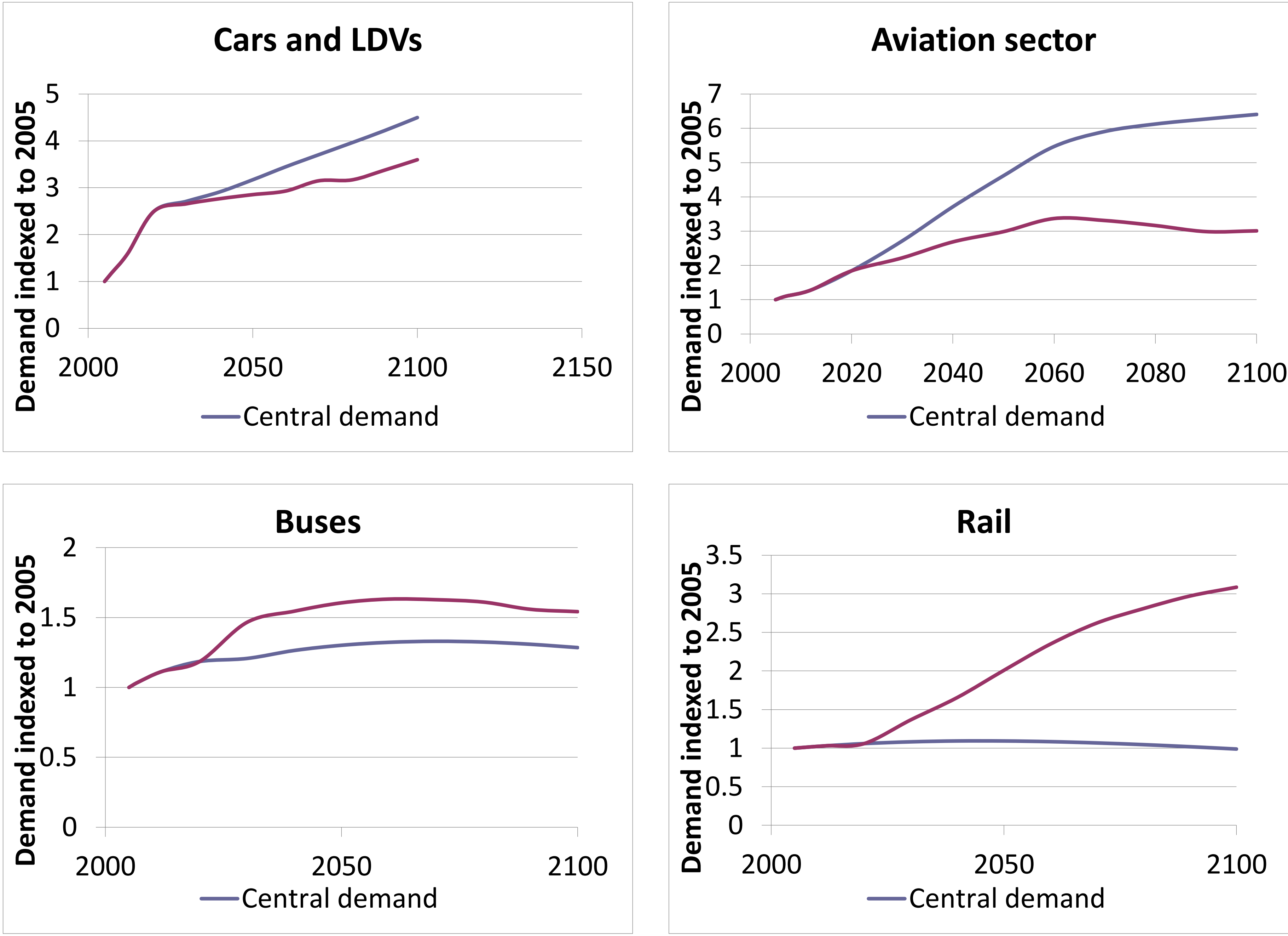
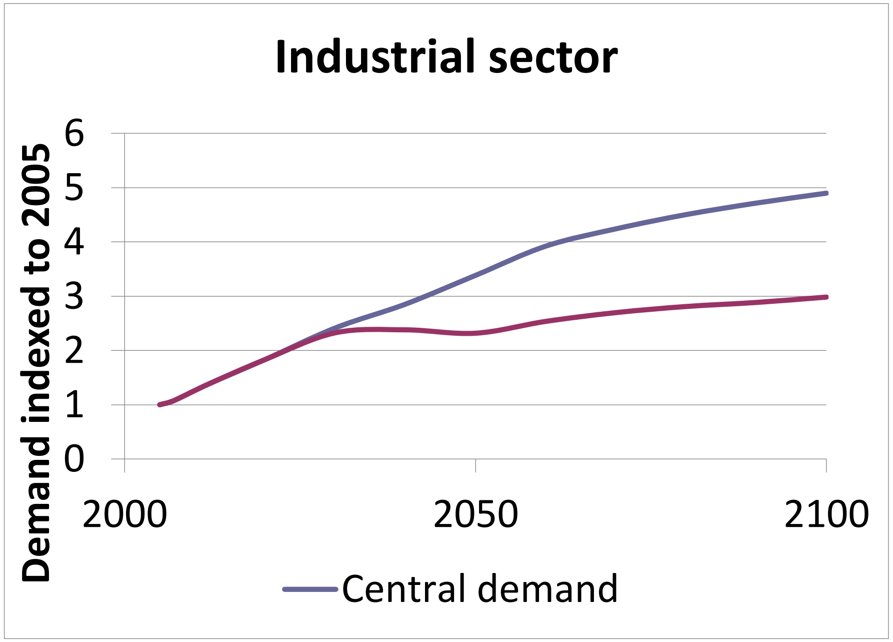
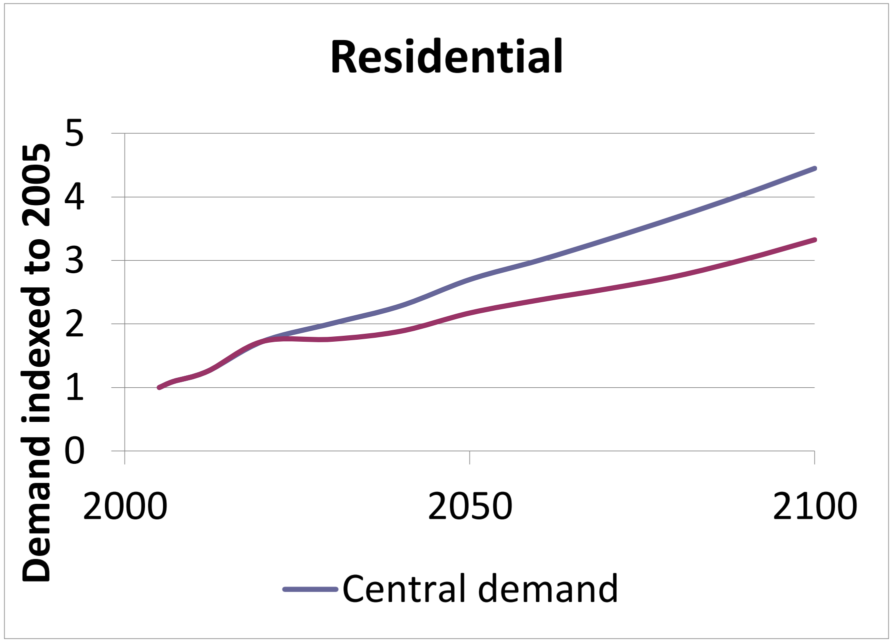

Cars and LDVs
Demand indexed to 2005
5
4
3
2
1
0
2000
2050
2100
2150
Central demand
Aviation sector
Demand indexed to 2005
7
6
5
4
3
2
1
0
2000
2020
2040
2060
2080
2100
Central demand
Buses
Demand indexed to 2005
2
1.5
1
0.5
0
2000
2050
2100
Central demand
Rail
Demand indexed to 2005
3.5
3
2.5
2
1.5
1
0.5
0
2000
2050
2100
Central demand


Industrial sector
Demand indexed to 2005
6
5
4
3
2
1
0
2000
2050
2100
Central demand


Residential
Demand indexed to 2005
5
4
3
2
1
0
2000
2050
2100
Central demand

# Approach

- Testing the minimum cumulative emissions is time consuming → requires iterative runs which incrementally reduce the cumulative budget until the model relies on the CO2 backstop technology to solve
- Approach to test impact of modifications:
  - Applied CO2 price consistent with a 2 degrees scenario
  - Determined the new cumulative emissions under this carbon price following modifications
  - Assumption: with modifications we should have lower CO2 emissions for the same carbon price

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# Results

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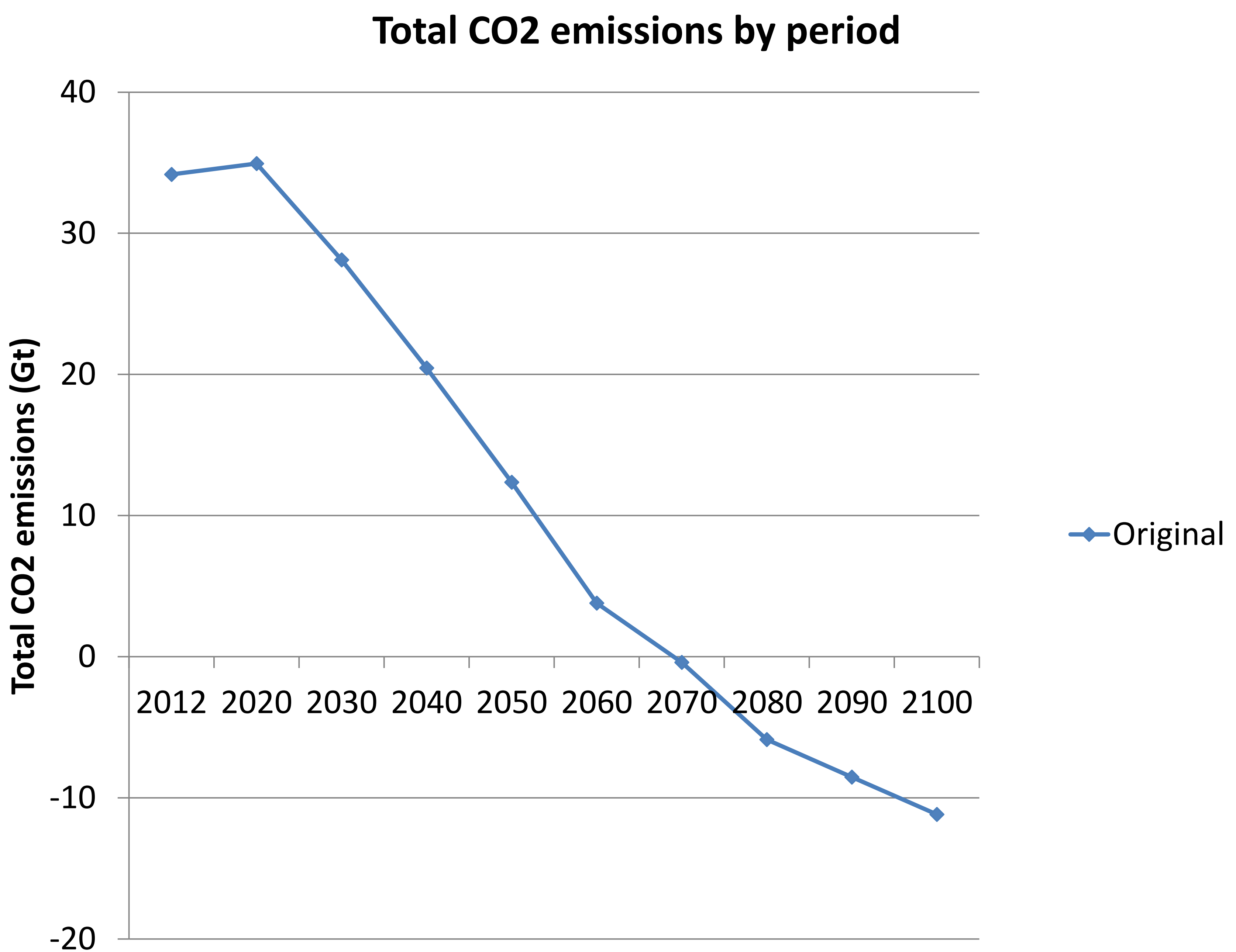
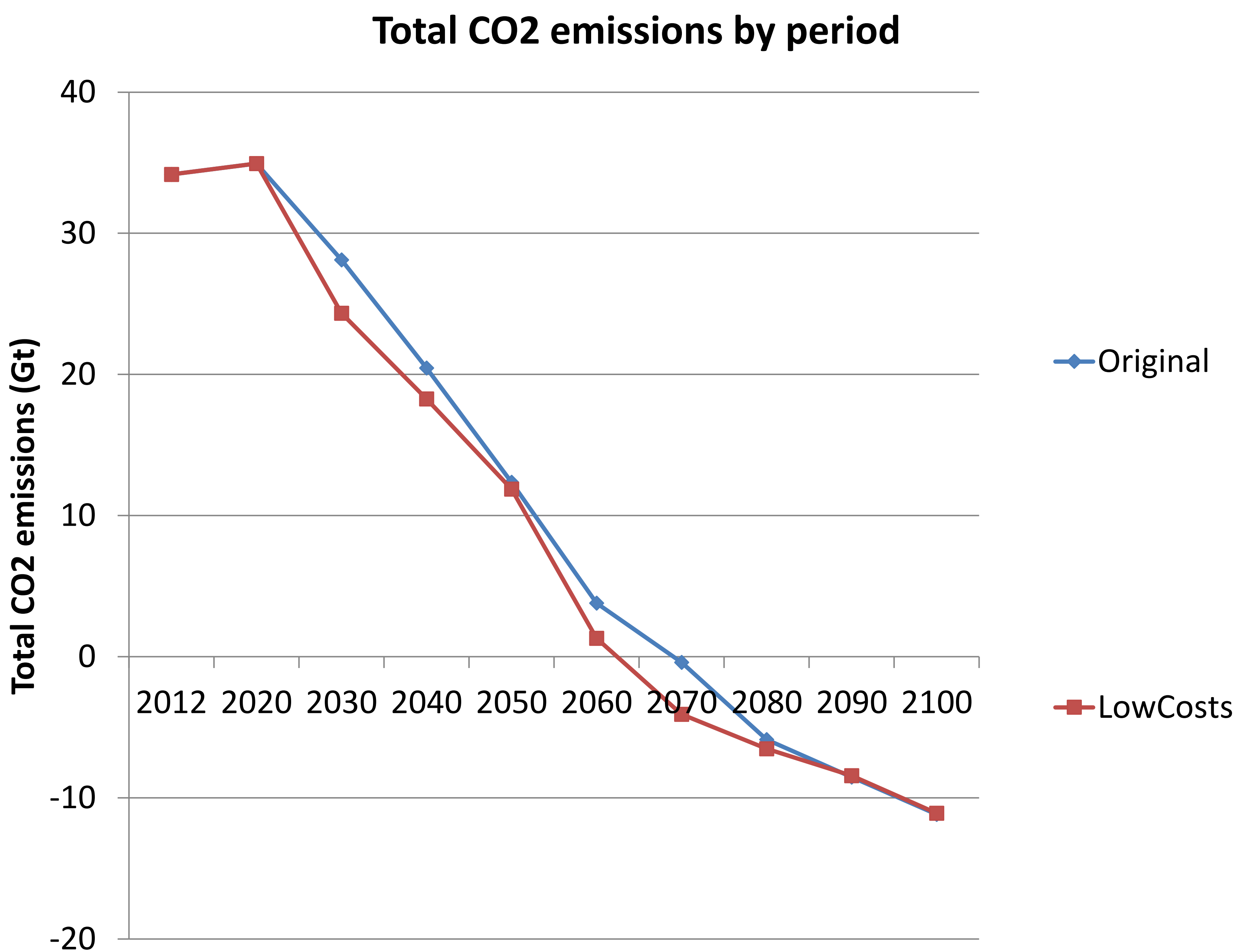
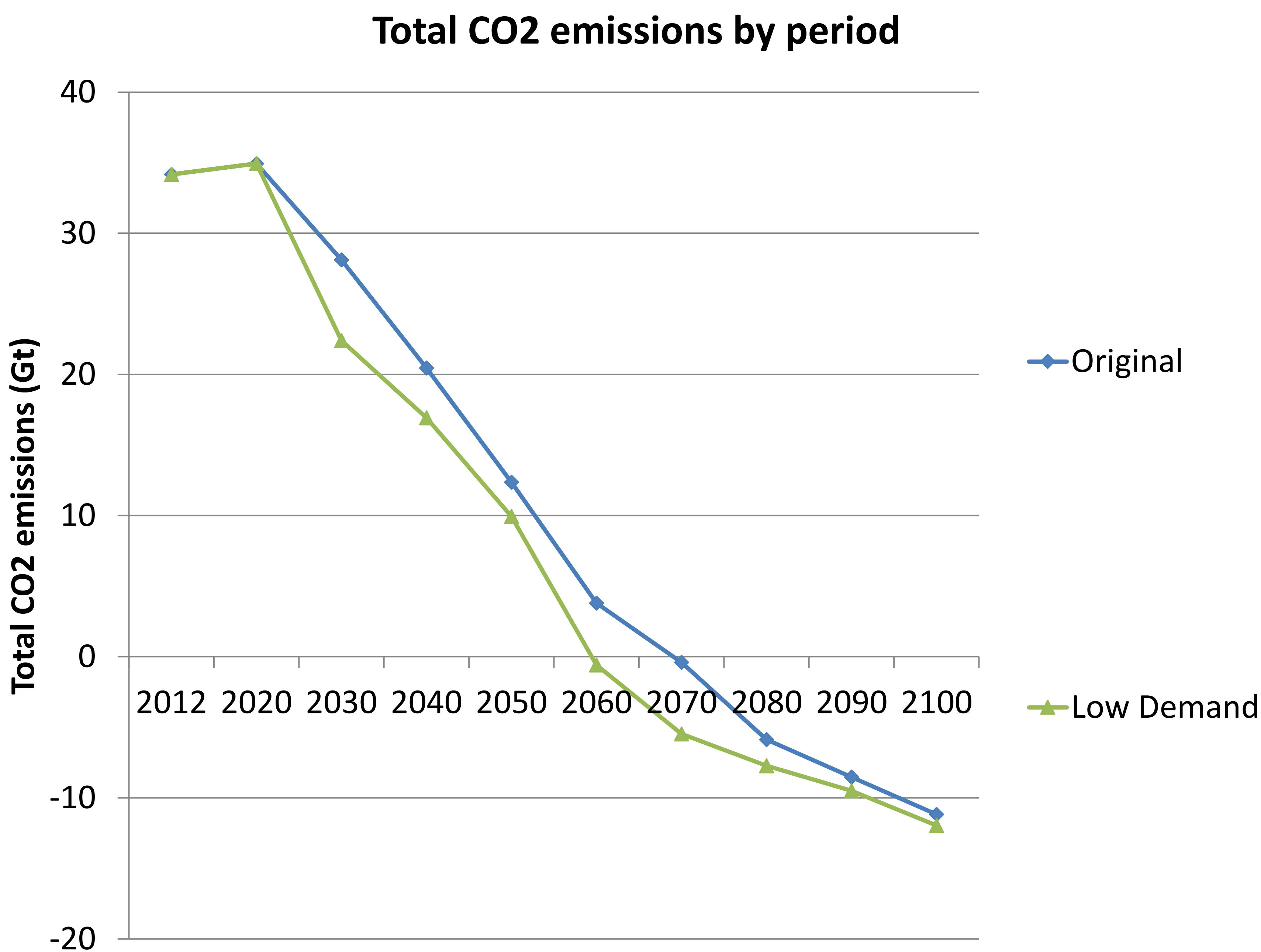
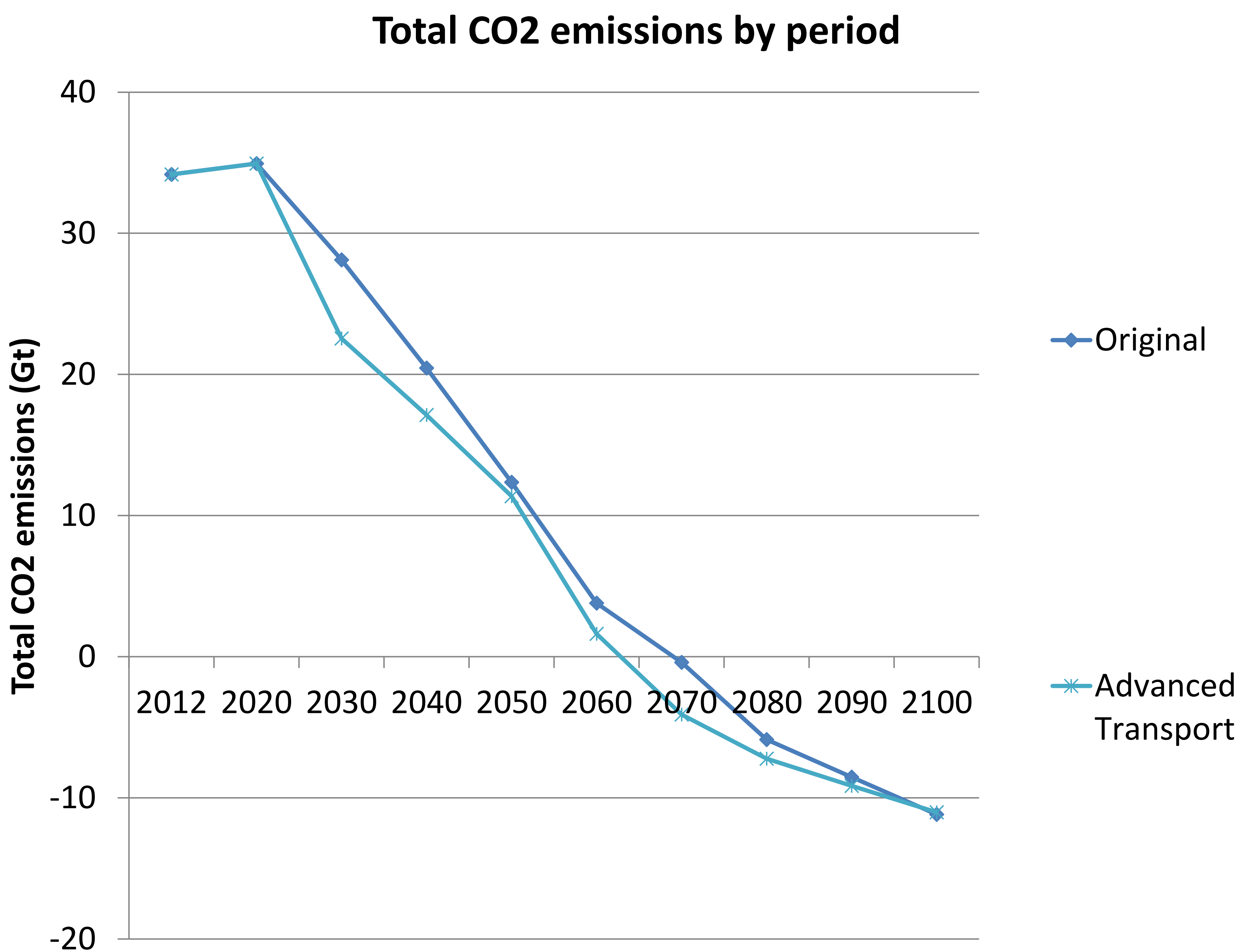


Total CO2 emissions by period
40
30
20
10
0
-10
-20
Total CO2 emissions (Gt)
2012
2020
2030
2040
2050
2060
2070
2080
2090
2100
Original

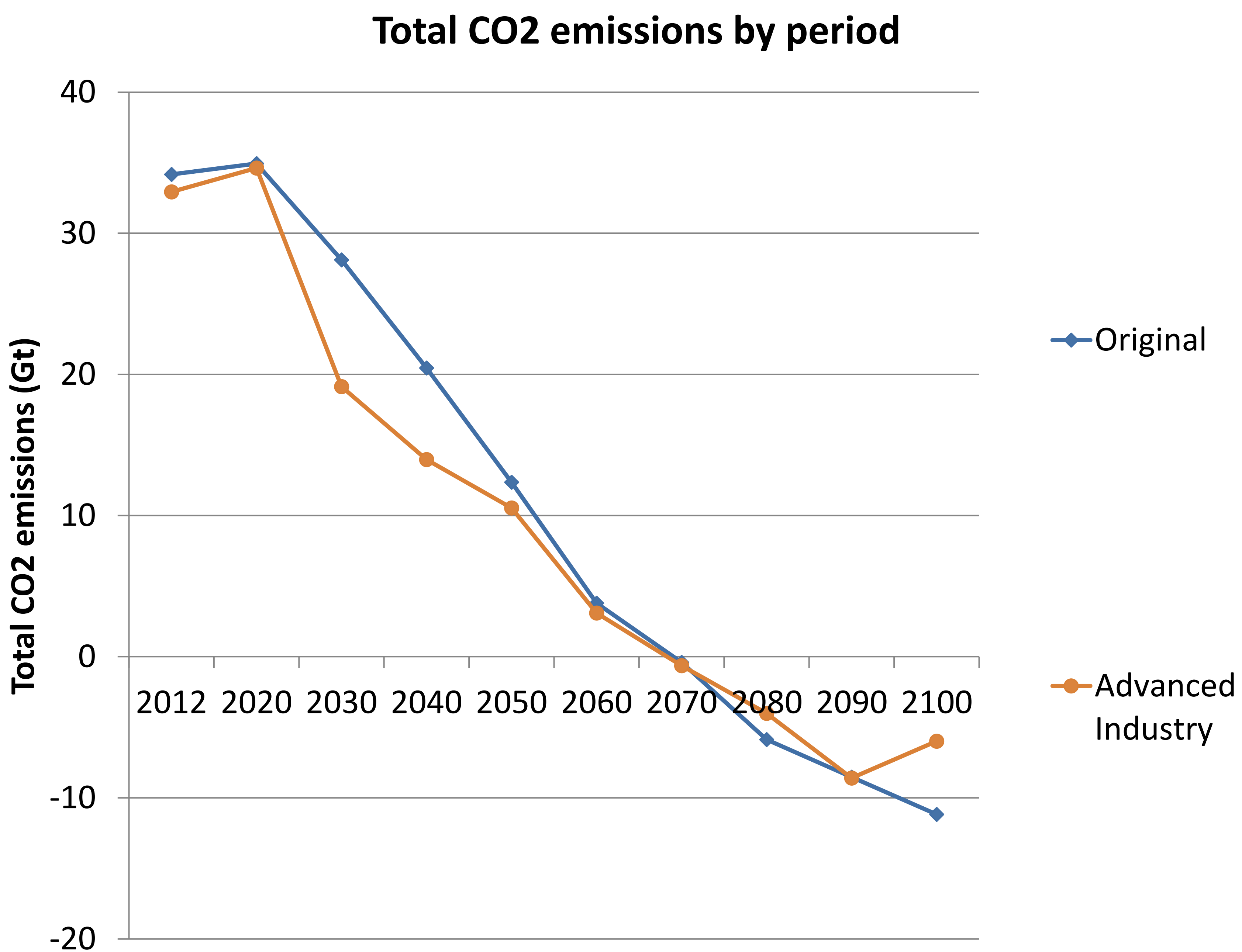

Total CO2 emissions by period
Total CO2 emissions (Gt)
40
30
20
10
0
-10
-20
2012
2020
2030
2040
2050
2060
2070
2080
2090
2100
Original
LowCosts

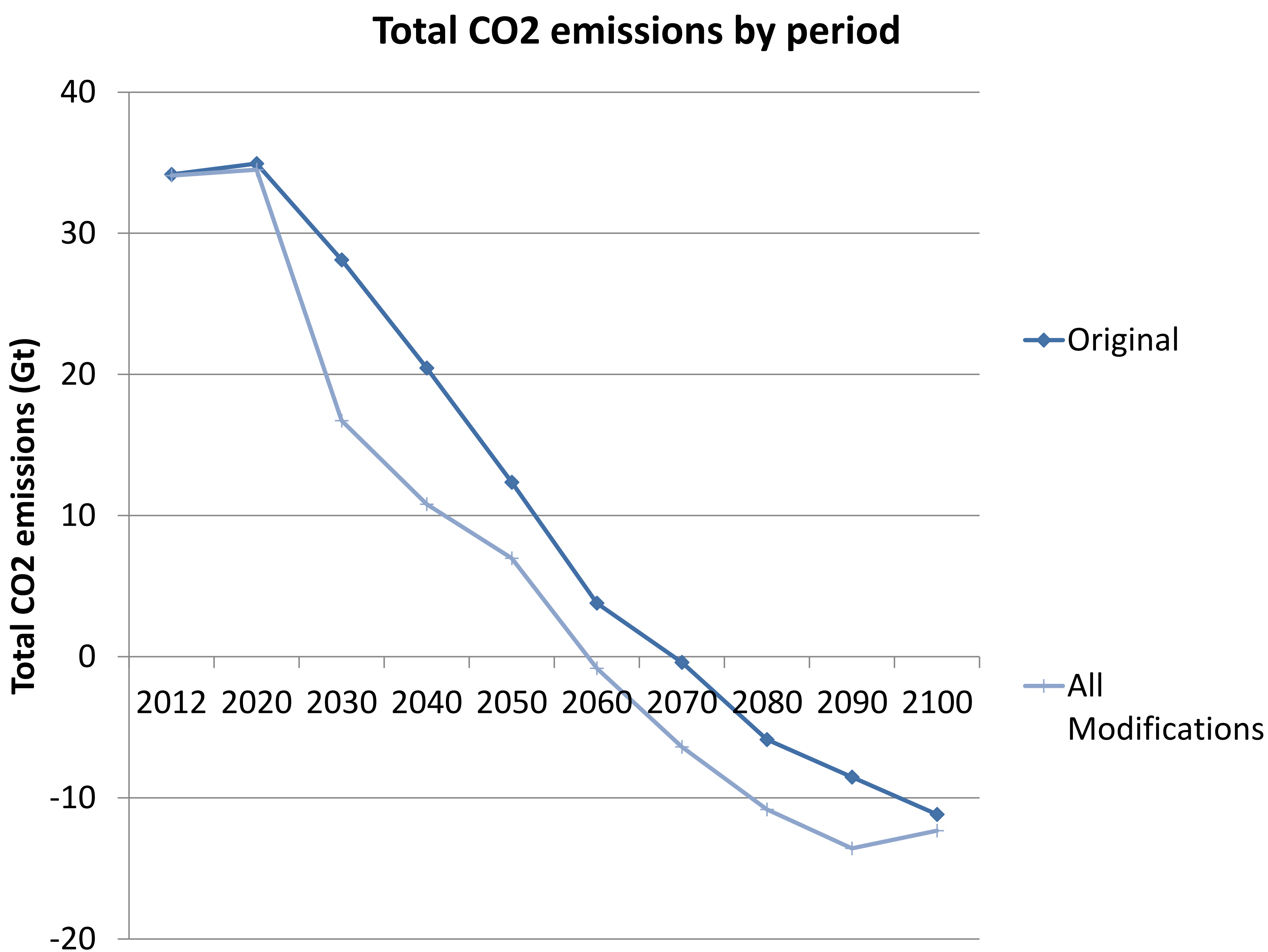


Total CO2 emissions by period
40
30
20
10
0
-10
-20
Total CO2 emissions (Gt)
2012
2020
2030
2040
2050
2060
2070
2080
2090
2100
Original
Low Demand

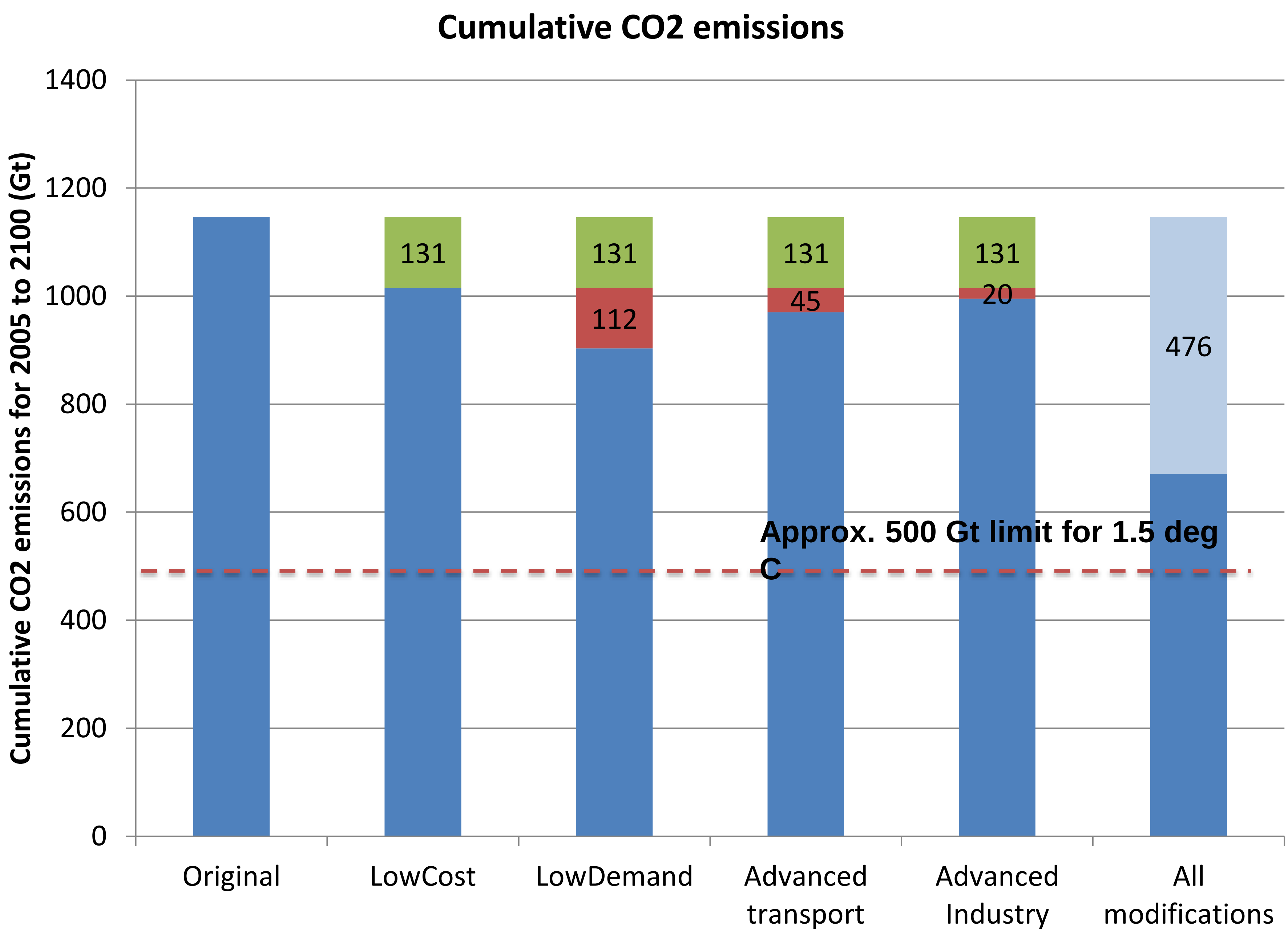


Total CO2 emissions by period
Total CO2 emissions (Gt)
40
30
20
10
0
-10
-20
2012
2020
2030
2040
2050
2060
2070
2080
2090
2100
Original
Advanced Transport


Total CO2 emissions by period
Total CO2 emissions (Gt)
40
30
20
10
0
-10
-20
2012
2020
2030
2040
2050
2060
2070
2080
2090
2100
Original
Advanced Industry



Total CO2 emissions by period
40
30
20
10
0
-10
-20
Total CO2 emissions (Gt)
2012
2020
2030
2040
2050
2060
2070
2080
2090
2100
Original
All Modifications


Cumulative CO2 emissions
Cumulative CO2 emissions for 2005 to 2100 (Gt)
1400
1200
1000
800
600
400
200
0
131
131
112
131
45
131
20
476
Approx. 500 Gt limit for 1.5 deg C
Original
LowCost
LowDemand
Advanced transport
Advanced Industry
All modifications

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# Conclusions

- Improved representation of the transport sectors to capture advanced technologies
- Optimistic scenarios for cost reduction of technologies and demand reduction
- Modifications to the model together can allow the model to achieve deeper decarbonisation
- Additional reduction of up to 476 Gt of CO2 achieved over the century
- Major challenge: Trade off between reaching 1.5 degrees and plausibility

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