A pathway design framework for sectoral deep decarbonization: the case of passenger transportation

Julien Lefèvre, Yann Briand, Steve Pye, Jordi Tovilla, Francis Li, Ken Oshiro, Henri Waisman, Jean-Michel Cayla and Runsen Zhang

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Séminaire PSL en Economie de l’Energie
Introduction

- Net-zero CO2 emissions required by mid century to meet the well-below 2C objective of the Paris Agreement (IPCC, 2018)
- Transport sector: around 25% of total energy CO2 emissions - deep decarbonization of this sector critical
- From -50% to -90% emission reductions in 2050 compared to 2010 in existing 1.5C scenarios
- However, current NDCs (including most recent updates) unsufficient to meet the long term goal and with limited pledges for the transport sector
- Recent Net-zero emissions pledges by main emitters (70% global emissions and GDP) but generally not supported by detailed policies and roadmaps often without even a long term strategy (economy-wide and sectoral)
Introduction

- Need for **long term low GHG emission development strategies**:
  - Designed at country level
  - To reconcile medium term action with long term objectives
  - Economy-wide systemic perspective with detailed sectoral transformations

- Passenger transport: **a mix of common options across countries** (rapid diffusion of efficient low carbon vehicles and decarbonised fuels, modal shift towards public and non-motorised transport - cycling and walking, and changes to urban systems design and use to reduce mobility needs) but practical implementation and **detailed sequencing over time still unexplained in policy debates** (Creutzig et al., 2015)

- ’Backcasting’ pathways from a desired future towards present conditions to identify the underlying **drivers and enabling conditions for the transformations** needed, and the required **policy packages** to address inertia, lock-ins and innovation (Waisman et al., 2019)
Introduction

Policy relevant decarbonization pathways for passenger transportation should:

- **Explore a broad range of drivers** including individual behaviours, lifestyles, societal and spatial organisation (social dynamics underlying mobility of passengers), infrastructures and technological change

- **Articulate visions/expectations of multiple stakeholders** (individual consumers, urban planners, car industry, etc.) differing in aim and scope

- **Explicit linkages with non-climate goals** (access to affordable mobility, improvement to quality of life, etc.)

**Objectives of the paper**

1. Develop a design and comparison framework of deep decarbonization pathways for passenger transportation
2. Show illustrative application to four countries (Japan, the UK, Mexico and France) to derive cross-cutting insights
Methodological challenges

- A rich literature on national decarbonization scenarios for the transport sector (Gota et al., 2018) mostly derived from integrated assessment models (IAMs), energy-economy models with transport modules or transport-energy models (Pietzcker et al., 2014; Yeh et al., 2017)

- Provide insights on a range of low carbon futures based on the Avoid-Shift-Improve (ASI) paradigm (Bongardt et al., 2013)

- But narratives and modelling focus on technological transformations and underlying drivers ignoring key drivers related to social practice, spatial organisation, and infrastructure change; emphasis on supply-side technological solutions with limited contribution from reduced mobility demand and modal shift (Edelenbosch et al., 2017)

- A limited number of modelling studies have explored the impact of demand-side drivers on decarbonization (Anable et al., 2012; Brand et al., 2018; Girod et al., 2013a)(AIE, 2021)

- Limitations for direct use of modelling studies in policy/stakeholders debates: 'black box' effect, difficulty to reflect qualitative narratives, lack of flexibility to reflect alternative visions
Methodological challenges

**Combined qualitative-quantitative participatory methods** to address challenges:

- **Narratives**, as coherent stories of the future, allow the creative process of investigating contrasted futures driven by alternative combinations of drivers and policies and identifying causal linkages and interdependencies (Banister and Hickman, 2013; Soria-Lara and Banister, 2018, 2017)

- **Quantification of the narratives**, including the description of the physical, economic and social characteristics of pathways can be based on numerical models (Fortes et al., 2015; Garb et al., 2008; Robertson, 2016) or other quantitative techniques (Varho and Tapio, 2013)

- In practice: participatory construction of narratives, identification of drivers and translation into quantitative parameters to use in models (Venturini et al., 2019)

→ Towards a framework with enhanced features for iterative development and quantitative assessment of scenarios + exploring transportation pathways that explicitly recognise underlying demand-side and technological drivers together, under transitions towards deep decarbonization
A pathway design framework for passenger transport deep decarbonization

BUILDING CONSISTENT PATHWAYS

STORYLINE
DRIVERS OF TRANSFORMATION

1. Demography and economy
2. Human settlement, land development and spatial organisation
3. Sociocultural practices and lifestyles
4. Technological development of vehicles
5. Fuel generation and carbon content
6. Penetration of alternative motorisations
7. Income dedicated to transport, modal distribution and costs
8. Speed, infrastructure and time dedicated to transport

QUANTIFICATION
A MIX OF METHODS AND DATA

INCLUDING TRANSPORT-ENERGY MODELS

DASHBOARD
INDICATORS TO 2050

<table>
<thead>
<tr>
<th>Emissions drivers</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy intensity</td>
<td></td>
<td></td>
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<tr>
<td>CO2 Emissions</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Road oil</td>
<td></td>
<td></td>
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<tr>
<td>Air oil</td>
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<td></td>
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<tr>
<td>Population and mobility</td>
<td></td>
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<td></td>
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<tr>
<td>Metropolitan population</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Constrained km</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Modal shares

Private mobility
Public transport

CHECK
BY STAKEHOLDERS AND EXPERTS

ARE LONG-TERM BENCHMARKS SATISFIED?

YES?
NO?

COMPARISON
PATHWAYS VISUALISATION

DECARBONIZATION PATHWAYS

30% of 2020
50% of 2020
70% of 2020

MX.01
MX.02

JP.01
JP.02

Population
Mobility
Energy intensity
Carbon intensity

Monopolized Mobility

REVISED STORYLINE ASSUMPTIONS
Building qualitative storylines considering the full set of decarbonization drivers

- Based on existing storylines methods adapted to deep decarbonization context
- **Address ASI pillars**: What role for a reduction of mobility demand? Reduction of energy intensity of mobility due to vehicle efficiency, modal shift, higher occupancy rate of vehicles? Decarbonization of fuels?
- **Go deeper in exploring complex underlying drivers across ASI pillars** for a richer discussion of the policy-relevant conditions, option levers, uncertainties and potential transformations over time: For which household situations, in which geographical context, for which trip purpose, for which distances, and at which speed and cost, would people shift from private car to public transport?
- **Connect to non-climate objectives**: mobility access, quality of life, affordability, health, etc.
- **Eight categories of influencing drivers**

→ A detailed and consistent description of the interactions between drivers and their impacts towards deep decarbonization of transport
Deriving full quantified pathways

- No single energy-transport model usually captures all dimensions of the storylines: demographic profile, the geography of urban spaces, urban planning, consumer preferences and their impact on travel demand, etc.

- Using a comprehensive data template with variables across all dimensions informed from various sources: a combination of modelling runs and out-of-the-box assessments and expert-based assumptions.

Examples:
- Travel surveys to project future patterns of mobility demand
- Modal choice model (Pye and Daly, 2015)
- Energy model to explore the transport supply side (vehicle stock, fuel use, etc.)

- Quantitative implications of qualitative drivers sometimes based on proxies
- Full quantitative information collated in the data template designed to be self-consistent (check points for consistency amongst intermediate indicators)
- Flexible approach for transparent sensitivity analysis of main uncertain aspects
Using a standardised quantitative dashboard for iterative backcasting and comparison

**Characteristics**

- **Summary description of quantitative pathways** using policy-relevant indicators
- **Align accounting measures** to get common understanding and comparables results
- **Inform key questions posed by different stakeholders** (beyond ASI decomposition): e.g. about mobility patterns across geographies, evolution of car sales, individual transport budget, etc.

**Objectives**

- **A tool for transparent dialog between stakeholders**: comparing how different policy objectives are met under alternative pathways, framing policy interventions, discussion on the plausibility of transformations
- **The corner stone for an iterative construction of pathways**
- **Summary of pathways in a common language for comparisons, benchmarking and learning accross country** perspectives
Using a standardised quantitative dashboard for iterative backcasting and comparison

<table>
<thead>
<tr>
<th>Passenger Transport Indicators</th>
<th>Units</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aggregated drivers of decarbonization</strong></td>
<td></td>
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</tr>
<tr>
<td>Average individual emissions due to 1km-trip</td>
<td>gCO2 / pkm</td>
<td>105</td>
<td>62</td>
<td>59</td>
<td>39</td>
<td>26</td>
</tr>
<tr>
<td>Average yearly distance travelled per capita</td>
<td>pkm / cap</td>
<td>13,757</td>
<td>13,578</td>
<td>12,879</td>
<td>11,986</td>
<td>11,182</td>
</tr>
<tr>
<td>Average individual energy consumption due to 1km-trip</td>
<td>MJ / pkm</td>
<td>1.4</td>
<td>1.2</td>
<td>0.9</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Average carbon emissions due to 1J of energy consumption</td>
<td>gCO2 / MJ</td>
<td>7.3</td>
<td>7.0</td>
<td>6.2</td>
<td>5.5</td>
<td>4.2</td>
</tr>
<tr>
<td><strong>Energy supply transformations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Oil consumption</td>
<td>EJ</td>
<td>12.2</td>
<td>0.9</td>
<td>0.5</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Electricity consumption</td>
<td>TWh</td>
<td>5.6</td>
<td>5.7</td>
<td>216</td>
<td>323</td>
<td>403</td>
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<tr>
<td>Natural gas consumption</td>
<td>EJ</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Hydrogen consumption</td>
<td>EJ</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Biofuels consumption (biodiesel, bioethanol, biomethane, biokerosene)</td>
<td>EJ</td>
<td>0.03</td>
<td>0.06</td>
<td>0.08</td>
<td>0.08</td>
<td>0.083</td>
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<td><strong>Modal transformations</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>NMT (non motorized)</td>
<td>% of total pkm</td>
<td>2%</td>
<td>4%</td>
<td>7%</td>
<td>9%</td>
<td>11%</td>
</tr>
<tr>
<td>Public mode (bus, rail)</td>
<td>% of total pkm</td>
<td>13%</td>
<td>15%</td>
<td>18%</td>
<td>21%</td>
<td>23%</td>
</tr>
<tr>
<td>Private mode (car, 25W)</td>
<td>% of total pkm</td>
<td>72%</td>
<td>62%</td>
<td>54%</td>
<td>51%</td>
<td>57%</td>
</tr>
<tr>
<td>Air</td>
<td>% of total pkm</td>
<td>12%</td>
<td>12%</td>
<td>11%</td>
<td>10%</td>
<td>9%</td>
</tr>
<tr>
<td><strong>Constrained mobility and spatial organization</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individual daily average distance travelled</td>
<td>km/day / cap</td>
<td>15.8</td>
<td>15.0</td>
<td>14.1</td>
<td>12.7</td>
<td>11.5</td>
</tr>
<tr>
<td>Individual daily average travelling time</td>
<td>min/day / cap</td>
<td>34.6</td>
<td>35.0</td>
<td>36.3</td>
<td>34.0</td>
<td>32.4</td>
</tr>
<tr>
<td>Household revenue share dedicated to mobility</td>
<td>% of household revenues</td>
<td>17%</td>
<td>17%</td>
<td>13%</td>
<td>10%</td>
<td>8%</td>
</tr>
<tr>
<td><strong>Infrastructures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas refuelling stations</td>
<td>1000's of units</td>
<td>0.000</td>
<td>0.025</td>
<td>0.111</td>
<td>0.165</td>
<td>0.210</td>
</tr>
<tr>
<td>Charging stations</td>
<td>1000's of units</td>
<td>1003.8</td>
<td>1501.4</td>
<td>3359.0</td>
<td>5011.7</td>
<td>6286.4</td>
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<tr>
<td>New mobility capacity created</td>
<td>New Gpkm capacity / 10-year period</td>
<td>-529</td>
<td>-1229</td>
<td>-2751</td>
<td>-4271</td>
<td></td>
</tr>
<tr>
<td><strong>Zoom on private car mobility transformations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of vehicles per 1000's inhab.</td>
<td>Nb of veh / 1000's inhab.</td>
<td>510</td>
<td>500</td>
<td>434</td>
<td>373</td>
<td>310</td>
</tr>
<tr>
<td>Low Carbon Car stock (under 41/100 km, eq. 100gCO2/3km)</td>
<td>Mio vehicle</td>
<td>0.0</td>
<td>0.8</td>
<td>5.2</td>
<td>18.4</td>
<td>19.9</td>
</tr>
<tr>
<td>Share of electric vehicles in low carbon vehicle stock</td>
<td>% of electric in low carbon stock</td>
<td>0%</td>
<td>10%</td>
<td>92%</td>
<td>43%</td>
<td>60%</td>
</tr>
<tr>
<td>Household revenue share dedicated to CAR mobility</td>
<td>% of household income</td>
<td>16%</td>
<td>17%</td>
<td>12%</td>
<td>10%</td>
<td>7%</td>
</tr>
<tr>
<td><strong>Zoom on Metropolitan areas transformations</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metropolitan daily average distance travelled</td>
<td>km / day / cap</td>
<td>13.1</td>
<td>12.6</td>
<td>12.1</td>
<td>11.3</td>
<td>10.7</td>
</tr>
<tr>
<td>Metropolitan daily average travelling time</td>
<td>min / day / cap</td>
<td>35.8</td>
<td>36.3</td>
<td>37.1</td>
<td>35.3</td>
<td>34.1</td>
</tr>
<tr>
<td>New urban spaces allocated to public road + parking</td>
<td>km2</td>
<td>0.00</td>
<td>-15.00</td>
<td>-15.00</td>
<td>-15.00</td>
<td>-15.00</td>
</tr>
<tr>
<td>New urban spaces allocated to BRT + NMT</td>
<td>km2</td>
<td>0.00</td>
<td>0.22</td>
<td>0.29</td>
<td>0.27</td>
<td>0.26</td>
</tr>
<tr>
<td><strong>PPMC Indicators</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CO2 emissions of Metropolitan areas</td>
<td>tCO2</td>
<td>19</td>
<td>15</td>
<td>10</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Electricity carbon content</td>
<td>gCO2 / kWh</td>
<td>54.9</td>
<td>40.5</td>
<td>25.0</td>
<td>21.9</td>
<td>21.9</td>
</tr>
<tr>
<td>Private car - wtw emission intensity</td>
<td>gCO2 / km</td>
<td>168</td>
<td>138</td>
<td>96</td>
<td>87</td>
<td>42</td>
</tr>
<tr>
<td>Rail - wtw emission intensity</td>
<td>gCO2 / pkm</td>
<td>12</td>
<td>10</td>
<td>7</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Aviation - wtw emission intensity</td>
<td>gCO2 / pkm</td>
<td>139</td>
<td>136</td>
<td>126</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td>Car mobility demand</td>
<td>Gpkm</td>
<td>417</td>
<td>375</td>
<td>326</td>
<td>295</td>
<td>263</td>
</tr>
<tr>
<td>CO2 price</td>
<td>$ / tCO2</td>
<td>0</td>
<td>30</td>
<td>100</td>
<td>230</td>
<td>360</td>
</tr>
<tr>
<td>Country</td>
<td>Scenario type</td>
<td>Scenario name in country study</td>
<td>Brief description</td>
<td>CO₂ red. in 2050 (rel. 2010)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>---------------</td>
<td>--------------------------------</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>TEC</td>
<td>AdvancedTech (ADV)</td>
<td>Focuses on technical transformations in the transport and energy sector, with restricted consideration of societal demand-side changes</td>
<td>-69%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DEM</td>
<td>Balanced (BAL)</td>
<td>Similar to ADV, but with an emphasis on social changes, such as urban structure, lifestyle and infrastructure</td>
<td>-89%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>TEC</td>
<td>Freedom to Roam (F2R)</td>
<td>Supply side focused rooted in the development of new technologies (notably autonomous vehicles) with patterns of mobility demand similar to those seen today</td>
<td>-65%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DEM</td>
<td>No Place Like Home (NPLH)</td>
<td>Technology development shifts mobility trends towards a sharing services model with greater use of other modes of transport, particularly in metropolitan areas</td>
<td>-63%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>TEC</td>
<td>Technological (TEC)</td>
<td>Focuses on technological options, but not demand reduction measures, as in DEM</td>
<td>-50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DEM</td>
<td>Demand (DEM)</td>
<td>Focuses on demand reduction from changes in urban organisation and accessibility, inequality reduction, and behaviour of commuters on top of technologies</td>
<td>-50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>TEC</td>
<td>Technology-First (TECH-F)</td>
<td>Assumes current mobility trends and favours technological innovations and low carbon technologies over systemic change</td>
<td>-79%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DEM</td>
<td>Mobility-First (MOB-F)</td>
<td>Prioritises social, organisational and technical transformations of the mobility systems while subsequently exploring technological contribution to deep decarbonization</td>
<td>-77%</td>
<td></td>
<td></td>
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</tbody>
</table>
Decarbonization potential and pillars

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% CO₂ emissions variations relative to 2010

-120 -90 -60 -30 0 30 60

0.60 tCO₂/cap in 2050

0.30 0

% CO₂ emissions variations relative to 2010

- Mobility (pkm/cap)
- Population (M inhab.)
- Energy intensity (MJ/pkm)
- CO₂ intensity (gCO₂/MJ)
- Total CO₂ emissions

DEM TEC
Japan

DEM TEC
UK

DEM TEC
Mexico

DEM TEC
France
Mobility demands
Modal shift

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Constrained Non-constrained

- Non-motorized transport (walking, biking...)
- Public transport (bus and rail)
- Air
- Private Mobility (car and 2W)

M = Metropolitan
NM = Non-metropolitan
Technology deployment: LDV fleet structure in TEC scenarios

Japan

UK

Mexico

France

Julien Lefèvre, Yann Briand, Steve Pye, Jordi A pathway design framework for sectoral deep
Final energy consumption (EJ) in TEC scenarios

Japan

UK

Mexico

France
Difference of car sales and stock between TEC and DEM scenarios in the UK
Convenience and costs

Japan

France

TEC

Transport budget share

DEM

Mexico

Indicators for constrained mobility

Transport budget share
A new approach to decarbonization analysis

- Understanding deep decarbonization of the passenger transport sector requires a novel conceptual approach that articulates metrics across diverse dimensions (social, economic, energy, etc.): in particular, by incorporating the factors impacting mobility trends - uncertainties around social practice or opportunities for policy to shape urban design and alternative transport systems - a much richer picture of the challenges and opportunities emerges.

- Cross-cutting insights from the application:
  - Significant potential for reduced mobility demand and modal shift to reduce energy consumption and emissions - typically underexplored.
  - Decarbonization can be consistent with satisfying mobility needs in all countries, while demand-side actions can help alleviate time and monetary burden of constrained mobility.
  - Different strategies see stronger potential in different country contexts, according to policy and development goals, demographic characteristics, spatial organisation, and socio-cultural practices.
Discussion/Conclusions

A framework to structure stakeholders and policy debates

- **Organizing principles** to enable the development of a shared definition of deep decarbonization strategies: to inform national public debates, to support planning and target-setting exercises - such as the NDCs, to be used by cities, corporations or NGOs to design their own scenarios, for international collaboration projects, etc.

- Key benefit of the approach: **transparency** which allows for a wide range of stakeholders to scrutinize assumptions and test alternatives.

- **Challenges for practical co-production of pathways** in actual stakeholder processes.

- **Need for an additional policy layer** in order to connect more explicitly the pathways to the specific policies consistent with meeting the goals.

- Framework that could be adapted to other sectors: e.g. freight transport, industry.
Merci pour votre attention !
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