Modelling the role of transport infrastructure in a low-carbon World

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CIRED

• CIRED founded in Paris in 1973 as an environment and development focused research centre in the aftermath of the Stockholm conference

• 77 staff in 2014
  – 27 Researchers
  – 10 Contractors
  – 40 PhD Students

• Modelling – IMACLIM suite of models
• Hybrid dynamic general equilibrium model
• Recursive iteration of annual static equilibria and dynamic modules for the period 2001–2100 in yearly steps
IMACLIM-R

Static equilibrium with short term constraints

Bottom-up sub models (reduced forms)
Macroeconomic growth engine

Price signals, rate of return
Physical flows

Evolution of the constraints
ADVANCE
FP7 PROJECT

• Advanced Model Development and Validation for Improved Analysis of Costs and Impacts of Mitigation Policies (ADVANCE)
• Deliver a new generation of Integrated Assessment Models (IAMs)
• WP 5: Explore supply-side bottlenecks to the transition to low carbon energy systems are not fully considered.
• Task 5.4: Infrastructure and Network externalities
• Deliverable 5.3 -> http://www.fp7-advance.eu/
Static equilibrium under short-run constraints: consumption choices and modal choices resulting from current utility maximization

Utility (U) maximization from consumption of goods (C) and services (S):

\[
U_k \left( \tilde{C}_k, \tilde{S}_k \right) = \prod_{\text{goods } i} \left( C_{k,i} - b n_{k,i} \right)^{\xi_{k,i}} \prod_{\text{services } j} \left( S_{k,j} - b n_{k,j} \right)^{\xi_{k,j}}
\]

\[
S_{k,mobility} = \left( \frac{p k m_{k,air}}{b_{k,air}} \right)^{\eta_k} + \left( \frac{p k m_{k,public}}{b_{k,public}} \right)^{\eta_k} + \left( \frac{p k m_{k,cars}}{b_{k,cars}} \right)^{\eta_k} + \left( \frac{p k m_{k,nonmotorized}}{b_{k,nonmotorized}} \right)^{\eta_k}
\]

Under constraints of income budget and travel time budget (Zahavi’s law).
Marginal efficiency in transport time

(the time necessary to travel an additional passenger.kilometer with mode $T_j$ in region $k$) – a function of infrastructure capacity.
Assumptions

Evolution of mobility per region (historical data)

Evolution of modal shares per region (historical data)
Captransport to date

Matrix of PKM’s of transport infrastructure for three transport modes (air, public, automobiles) for 12 regions.

\[
\text{Captransport}(:,1) = \text{Captransport}(:,1) \cdot \frac{\text{PKM}\_\text{prev}(:,\text{indice_air})}{\text{PKM}\_\text{prev}\_\text{prev}(:,\text{indice_air})};
\]

\[
\text{Captransport}(:,2) = \text{Captransport}(:,2) \cdot \frac{\text{PKM}\_\text{prev}(:,\text{indice_OT})}{\text{PKM}\_\text{prev}\_\text{prev}(:,\text{indice_OT})};
\]

\[
\text{Captransport}(:,3) = \text{Captransport}(:,3) \cdot \frac{\text{stockautomobile}}{\text{stockautomobile}\_\text{prev}};
\]
Model Development – Task 5.4 ADVANCE

• Step 0: Harmonize baseline population and GDP growth scenarios to SSP2
• Step 1: Add costs of infrastructure deployment
• Step 2: Add more constraints on road deployment
• Step 3: Compare new and old baselines
• Step 4: Run Scenarios
# Infrastructure Costs

<table>
<thead>
<tr>
<th>IMACLIM REGION</th>
<th>Road Construction</th>
<th>Road Upgrade</th>
<th>Road O&amp;M</th>
<th>Parking Construction</th>
<th>Parking Upgrade</th>
<th>Parking O&amp;M</th>
<th>Public Transport Construction</th>
<th>Air Construction</th>
<th>Air O&amp;M</th>
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</thead>
<tbody>
<tr>
<td>USA</td>
<td>1.2</td>
<td>0.2</td>
<td>0.03</td>
<td>300</td>
<td>240</td>
<td>9</td>
<td>0.5</td>
<td>0.05</td>
<td>0.25</td>
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<td>Canada</td>
<td>1.2</td>
<td>0.2</td>
<td>0.03</td>
<td>300</td>
<td>240</td>
<td>9</td>
<td>0.5</td>
<td>0.05</td>
<td>0.25</td>
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<tr>
<td>Europe, Turkey</td>
<td>1.2</td>
<td>0.2</td>
<td>0.03</td>
<td>300</td>
<td>240</td>
<td>9</td>
<td>0.5</td>
<td>0.05</td>
<td>0.25</td>
</tr>
<tr>
<td>JANZ, Korea</td>
<td>1.3</td>
<td>0.25</td>
<td>0.04</td>
<td>250</td>
<td>200</td>
<td>7.5</td>
<td>0.5</td>
<td>0.05</td>
<td>0.25</td>
</tr>
<tr>
<td>CIS</td>
<td>1.2</td>
<td>0.2</td>
<td>0.03</td>
<td>250</td>
<td>200</td>
<td>7.5</td>
<td>0.5</td>
<td>0.05</td>
<td>0.25</td>
</tr>
<tr>
<td>China</td>
<td>1.2</td>
<td>0.2</td>
<td>0.035</td>
<td>150</td>
<td>120</td>
<td>4.5</td>
<td>0.5</td>
<td>0.05</td>
<td>0.25</td>
</tr>
<tr>
<td>India</td>
<td>1</td>
<td>0.15</td>
<td>0.03</td>
<td>150</td>
<td>120</td>
<td>4.5</td>
<td>0.5</td>
<td>0.05</td>
<td>0.25</td>
</tr>
<tr>
<td>Brazil</td>
<td>1.1</td>
<td>0.2</td>
<td>0.035</td>
<td>150</td>
<td>120</td>
<td>4.5</td>
<td>0.5</td>
<td>0.05</td>
<td>0.25</td>
</tr>
<tr>
<td>Middle East</td>
<td>1</td>
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<td>0.03</td>
<td>175</td>
<td>140</td>
<td>3.6</td>
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<td>0.25</td>
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<tr>
<td>Africa</td>
<td>1.2</td>
<td>0.2</td>
<td>0.035</td>
<td>120</td>
<td>95</td>
<td>5.3</td>
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<td>0.05</td>
<td>0.25</td>
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<tr>
<td>Rest of Asia</td>
<td>1.1</td>
<td>0.15</td>
<td>0.033</td>
<td>150</td>
<td>120</td>
<td>4.5</td>
<td>0.5</td>
<td>0.05</td>
<td>0.25</td>
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<tr>
<td>Rest of Latin America</td>
<td>1.1</td>
<td>0.2</td>
<td>0.035</td>
<td>150</td>
<td>120</td>
<td>4.5</td>
<td>0.5</td>
<td>0.05</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**Unit**: M$\text{US}_{2010}$/lane-km, M$\text{US}_{2010}$/lane-km, $\text{US}_{2010}$/m², $\text{US}_{2010}$/m², $\text{US}_{2010}$/pkm, $\text{US}_{2010}$/pkm, $\text{US}_{2010}$/pkm

**Notes**: 1 2 3 4 5 6 7 8 9 10
Transport Infrastructure $/yr Investment

Baseline without costs
Baseline with costs
Constraints on road deployment

1. The construction capacity in the region
2. The density of the existing road network
3. The maximum percentage of GDP that can go to road infrastructure – set at 2%.

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>UR_automobile_ideal</td>
<td>50</td>
<td>% pkm/Captransport</td>
</tr>
<tr>
<td>constr_limit</td>
<td>30 – 355</td>
<td>Lane-km/year in thousands</td>
</tr>
<tr>
<td>density_limit</td>
<td>1-6</td>
<td>Lane-km per km² land</td>
</tr>
<tr>
<td>conv_pkm_lanekm</td>
<td>4-5 X 10⁻⁷</td>
<td>Lane-km/pkm</td>
</tr>
<tr>
<td>Max_Infra_Road_Invest</td>
<td>2</td>
<td>% of GDP</td>
</tr>
<tr>
<td>park_space</td>
<td>2X15 – 3X18</td>
<td>Square Metres where 2x means two parking spaces</td>
</tr>
<tr>
<td>share_rail_OT</td>
<td>5 - 70</td>
<td>%</td>
</tr>
</tbody>
</table>
Captransport deployment

![Graphs showing capacity of automobile, public transport, and air travel infrastructure over time with different constraints.]
Comparison to Measured?

Passenger Kilometres Travelled (7 global regions)

Energy demand of Transport Sector (Global)

Average Investment in new roads 2001 to 2013
Scenarios

• Baseline with costs and constraints
• CO₂ emissions follow a fixed carbon emission trajectory (CO₂ CC)
• CO₂ emissions follow the fixed carbon emission trajectory while infrastructure deployment for roads and air travel constrained to 70% of what it was projected to be in previous scenario (CO₂ CC RI)
Service Demand

PKM all modes

PKM Automobiles

PKM Public Transport

PKM Air

Baseline with costs and constraints
Fixed CO₂ trajectory
Fixed CO₂ trajectory and infrastructure deployment constrained
Key Findings

1. Baseline gets improved when transport infrastructure costs and constraints are added to the model

2. Restricting the deployment of infrastructure a policy measure (e.g. roads and airports) when combined with a set carbon trajectory/budget lowers the cost of mitigation.
Thanks!
Danke!
Merci!
Tack!
Go raibh maith agaibh!