UCL Energy Institute

Transport infrastructure and travel demand in energy system models

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ENHANCING THE STATE OF TRANSPORT MODELING IN IAMS
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- Infrastructure as a driver of transport demand

- Energy system modelling
  - TIMES model
  - Long-term socially focussed planning
  - Typical portrayal of transport demand

- Endogenising transport behaviour and infrastructure in ESM
  - Exploratory work and stylised model

Transport infrastructure & mobility

- Volume of mobility: trade-off between
  - Greater access to employment, goods, services, housing
  - Travel time budget and travel money budget

- Determinants of mobility
  - Spatial distribution of housing, employment
  - Availability of transport infrastructure
    - → Location choice, greater mobility need
  - Decrease in real cost of transport
    - → Availability of faster transport, mode shift to car
  - Increase in speed of transport
    - → Greater mobility

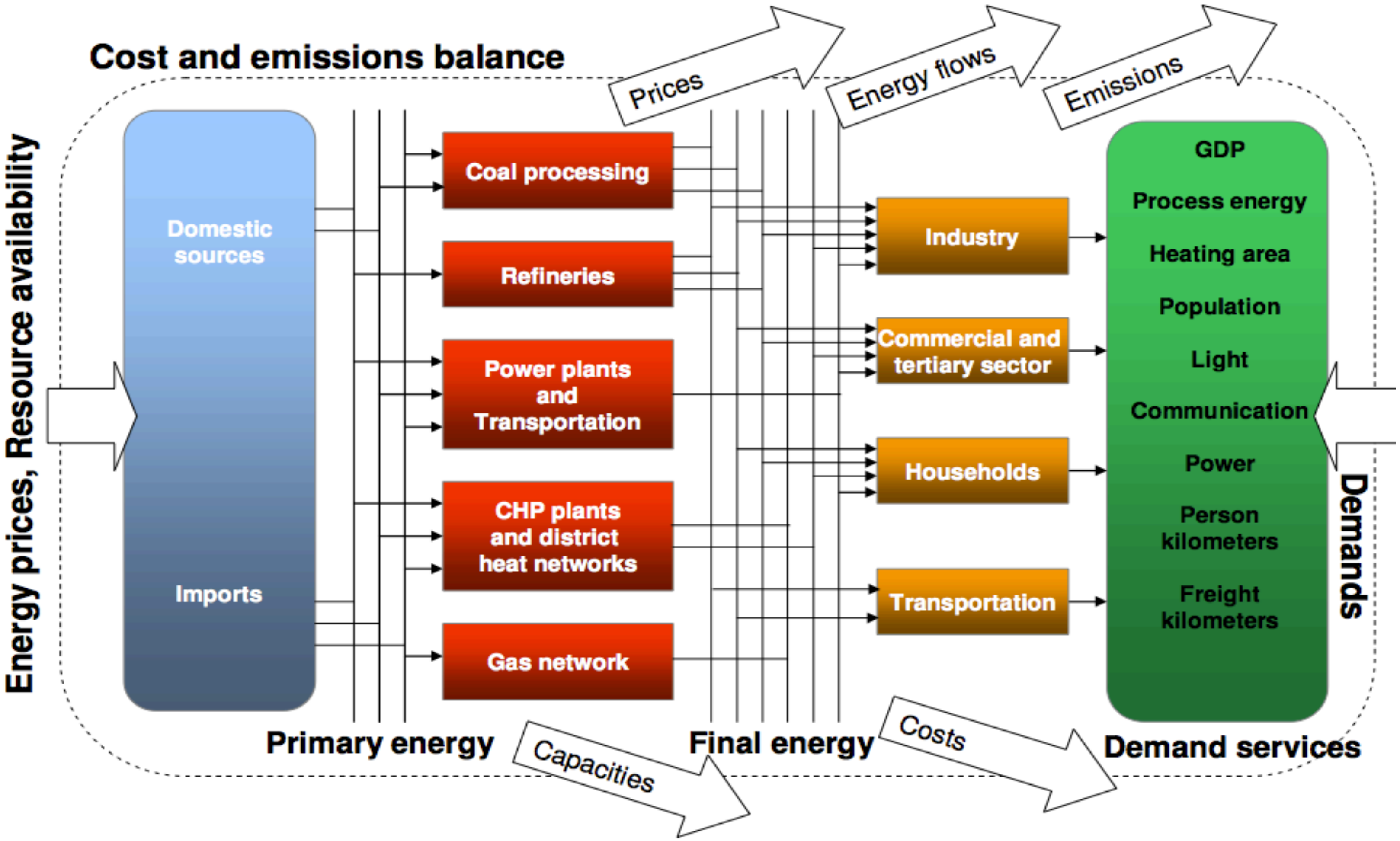
The role of investment and planning in "behaviour"

- Public planning
  - "Predict and provide" planning approach to private car and aviation
  - Land use
- Road pricing, parking charge, taxation system
- Public transport and road infrastructure
  - Generally regulated
  - Infrastructure is a public good with very long lifetime
    - Leading to path dependency and lock-in
    - Public investment needed to break equilibrium towards car use

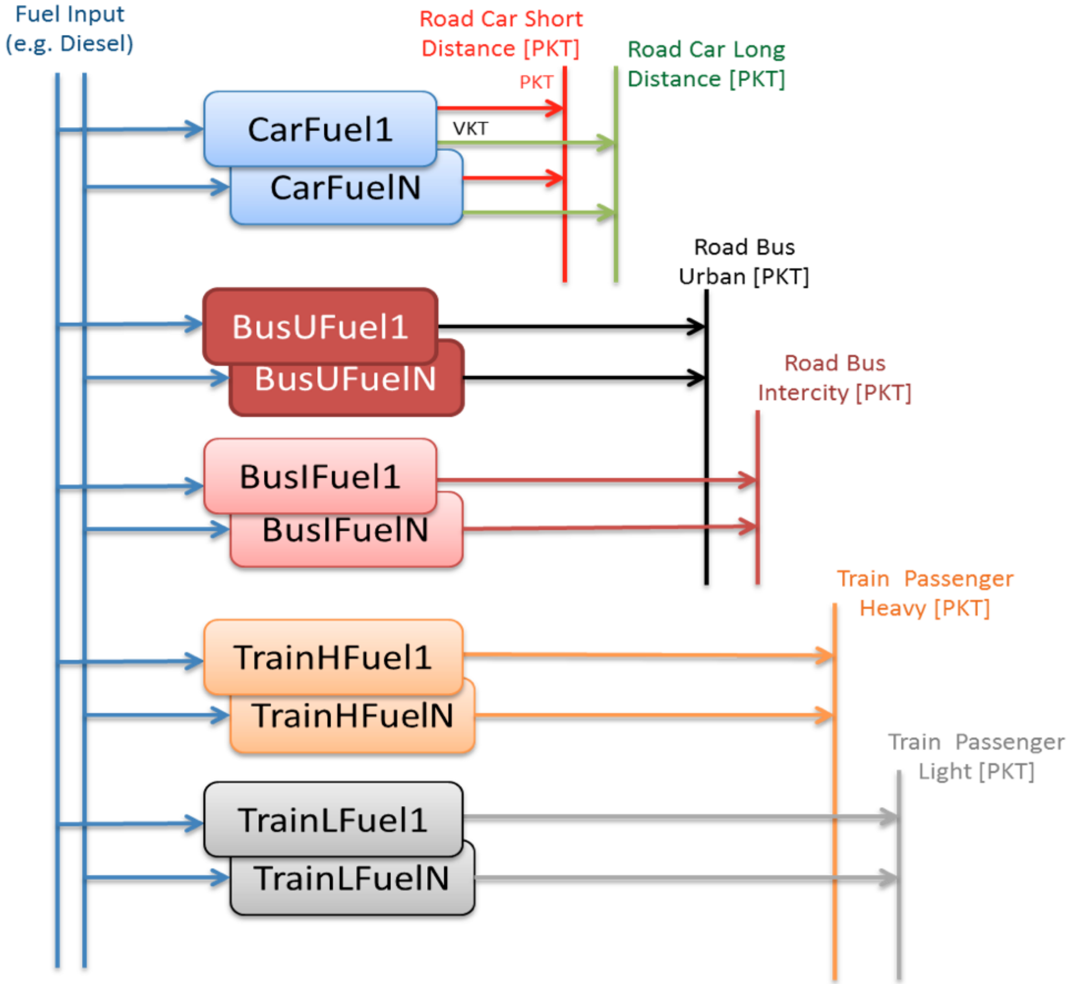
Energy System Modelling

- **"Bottom-up" techno-economic approach**
  - Technology explicit
  - Full energy system coverage
- **TIMES modelling platform:**
  - Widely used tool
  - Partial equilibrium; macro feedbacks possible
  - TIAM: Global coverage, climate module
- Develops long-term **energy supply** & **energy infrastructure pathways** under socially focused planning
  - Price is the main driver of change
  - Poor representation of demand side behaviour (esp. non-price)

Energy System Model: TIMES



Typical transport structure



Inputs:

- service demands
- costs
- technology specification, etc.

Outputs:

- technology mix
- fuel mix
- system cost
- marginal abatement cost

Social planner optimisation in TIMES

- Energy system organised on the basis of least total cost – perspective of *single social planner*
  - More valid in energy supply
    - Competition is on the basis of least technological cost
  - Does not capture human behaviour well
    - Imperfect markets
    - Individuals optimise individual utility – not social welfare
    - Other costs: Time, comfort, prestige, safety…
    - Higher cost of capital
    - Heterogeneity across consumer preference

Passenger transport in TIMES

- Short-term behavioural parameters in TIMES:
  - Own price elasticities
    - Captures response of demand to price increase
    - Transport is quite price inelastic
  - Hurdle rates
    - Higher discount rate/cost of capital
    - Used to capture typical barriers to energy efficiency take-up
    - → Energy efficiency measures are not taken up strongly with carbon price only
- Mode choice is exogenous – not responsive to price
- → Transport often does not strongly decarbonise even in ambitious scenarios

Other approaches to modelling behaviour & demand in ESMs

- Scenario, "what if", off-model analyses
- Logit approach – iteration of a non-linear model with ESM
- Adding non-technology/fuel costs

"Ideal" model of transport in an energy system framework

- Need to break out *system* optimisation from *individual utility* optimisation
  - System/society mitigation options
    - Infrastructure – subsidies – taxes – road pricing – social discount rate
  - Human or firm behaviour;
    - Invest in energy end-use technologies subject to system constraints and incentives
    - "Selfish" – heterogeneous – high cost of capital – non-price motivations
    - Equity considerations of high carbon price

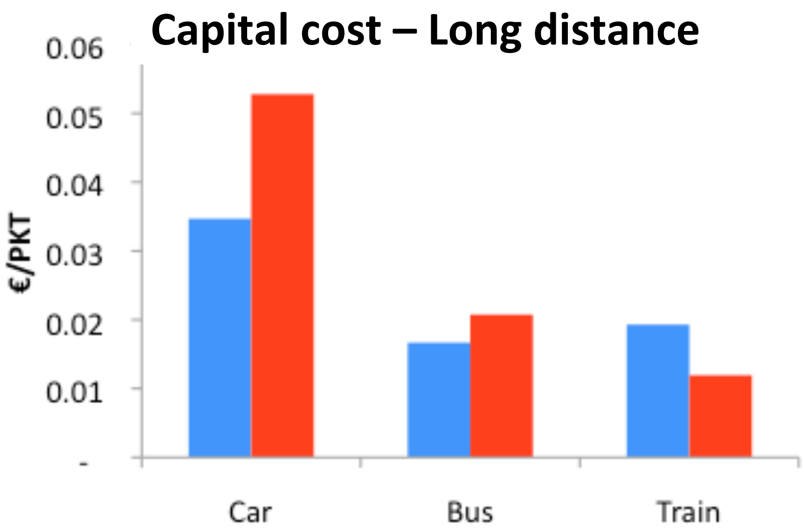
- Use of ESM to choose the best level of public transport, road, land-use infrastructure for societal goals
  - Rethinking "behaviour" as shaped by government investment and planning

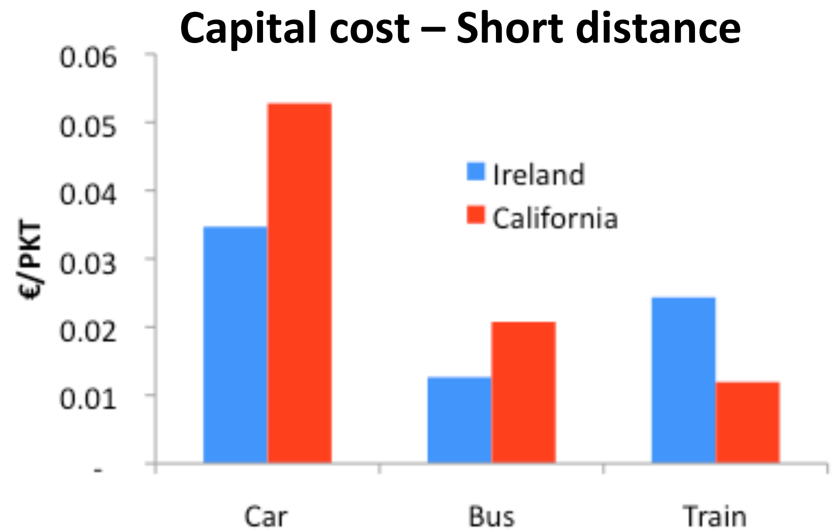
Exploratory work: Stylised model of mode shift in energy system model

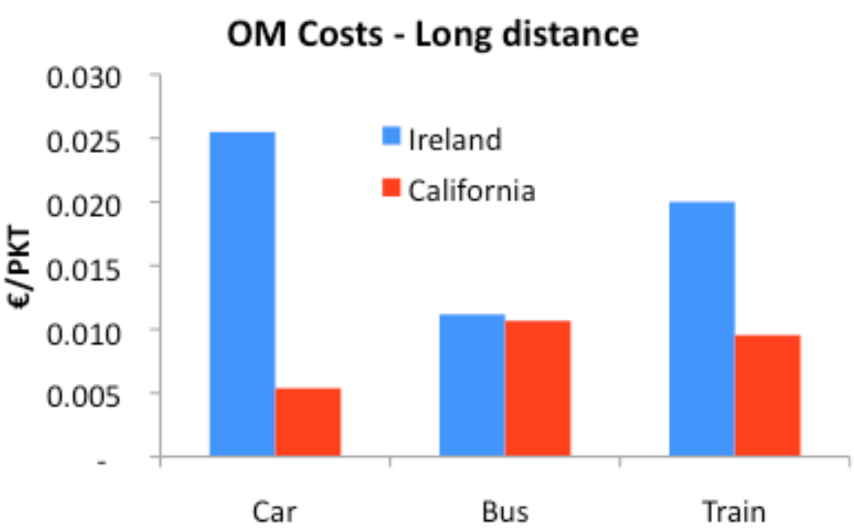
- Case study: California & Irish TIMES energy system models
  - UC Davis & University College Cork collaboration

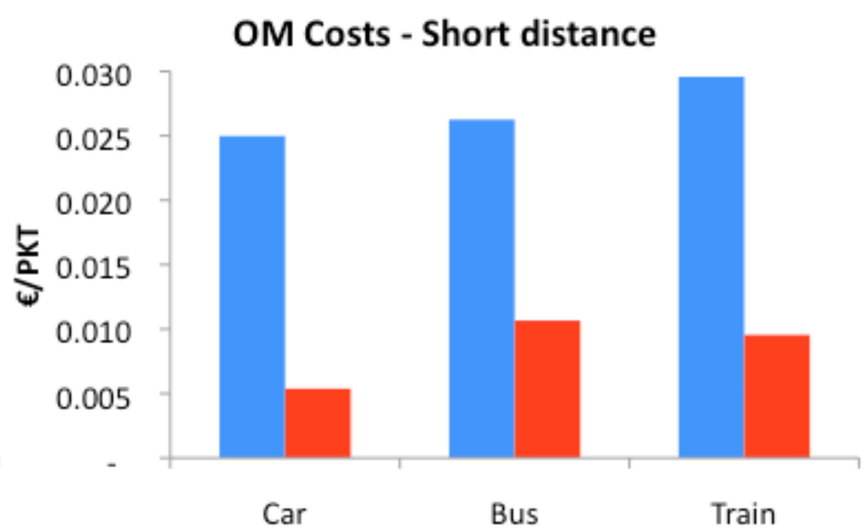
- Add ***TIME* variable** as a resource
  - Time consumed related to speed of mode
  - Constrain total system time:
    - **Travel Time Budget (TTB)**
    - *Annual TTB ≤ population * daily travel budget * 365*
    - Baseline: Rising travel demand met by faster modes

- Allow system to invest in *infrastructure (TTI)* to enable mode shift to bus/train


Capital cost – Long distance
0.06
0.05
0.04
0.03
0.02
0.01
-
€/PKT
Car
Bus
Train


Capital cost – Short distance
0.06
0.05
0.04
0.03
0.02
0.01
-
€/PKT
Ireland
California
Car
Bus
Train


OM Costs - Long distance
0.030
0.025
0.020
0.015
0.010
0.005
-
€/PKT
Ireland
California
Car
Bus
Train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0.020
0.015
0.010
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-
€/PKT
Car
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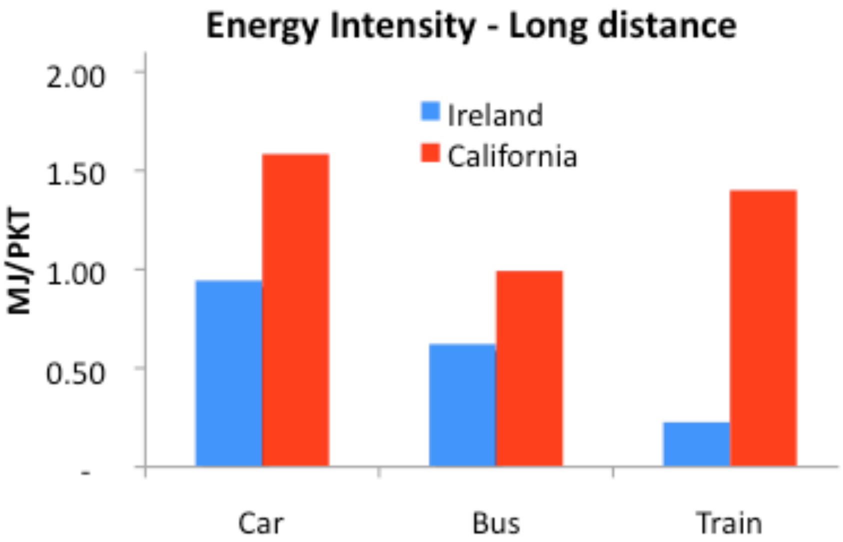
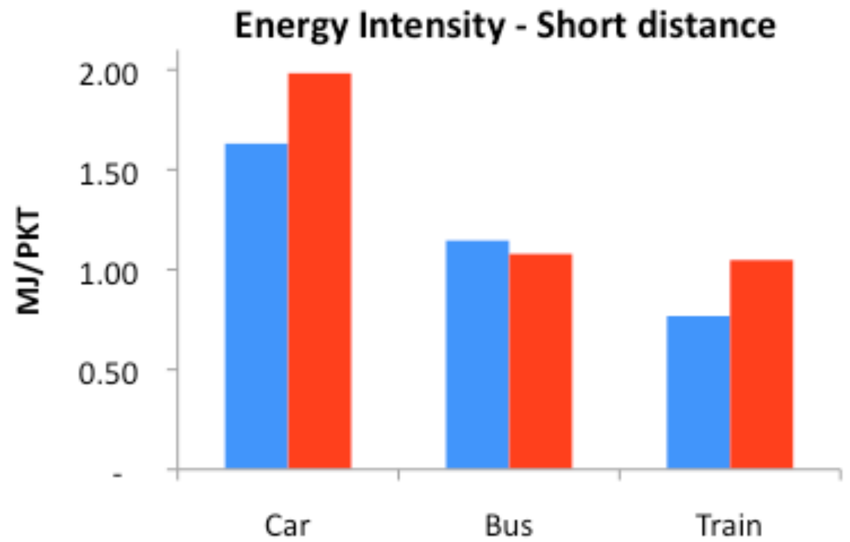
Train


Energy Intensity - Long distance
MJ/PKT
2.00
1.50
1.00
0.50
-
Ireland
California
Car
Bus
Train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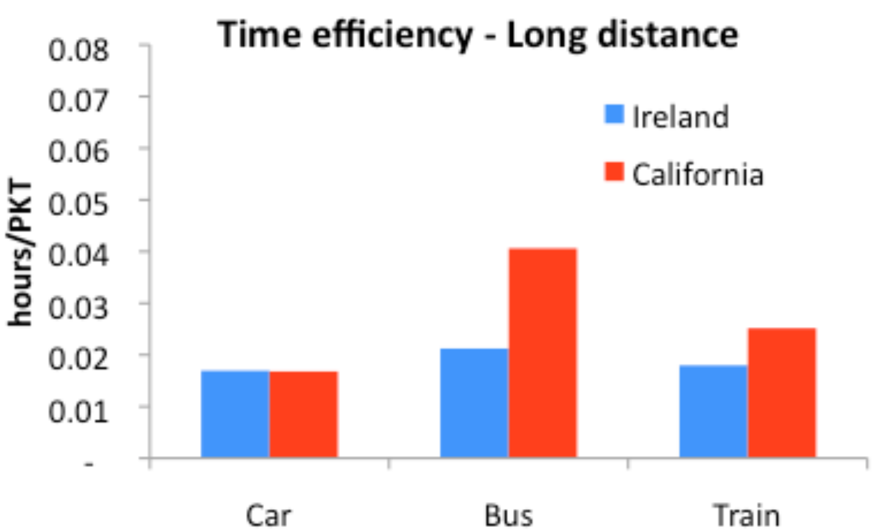
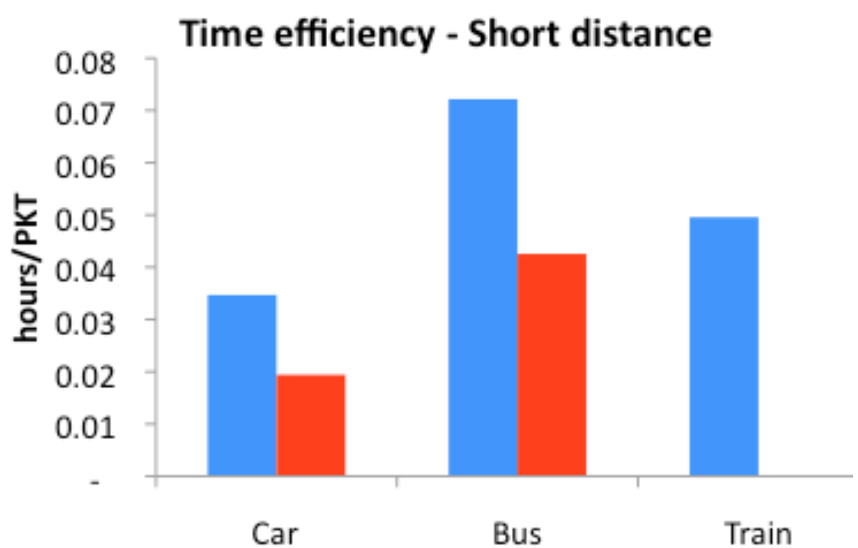
2.00
1.50
1.00
0.50
-
Car
Bus
Train


Time efficiency - Long distance
hours/PKT
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
-
Ireland
California
Car
Bus
Train


Time efficiency - Short distance
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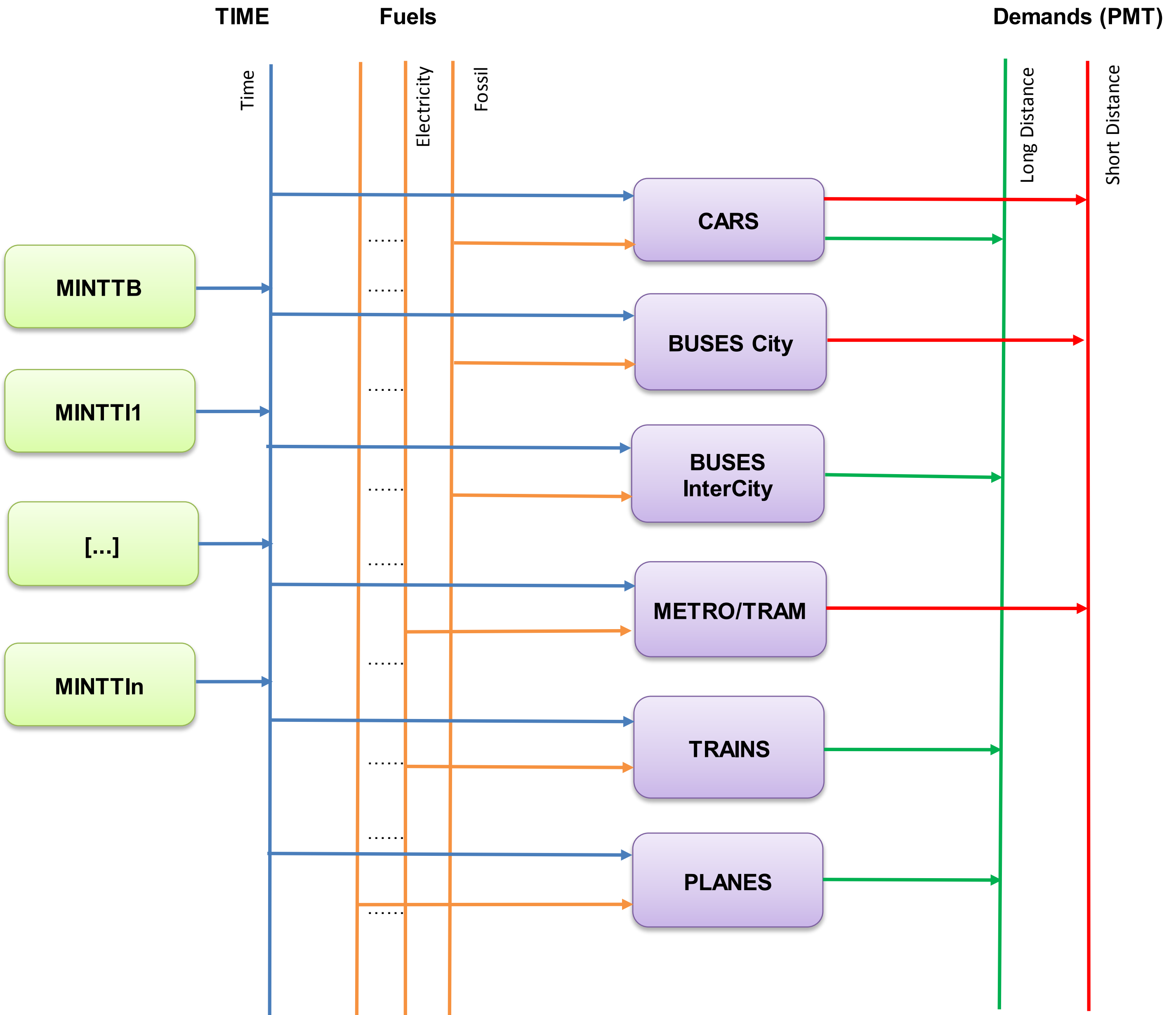
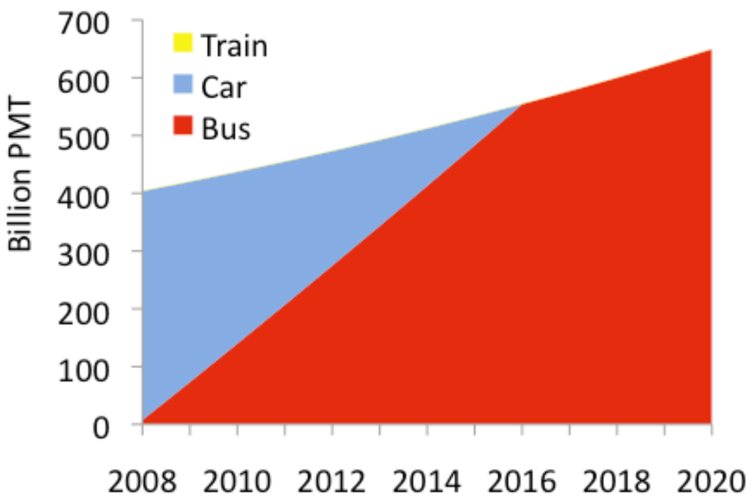
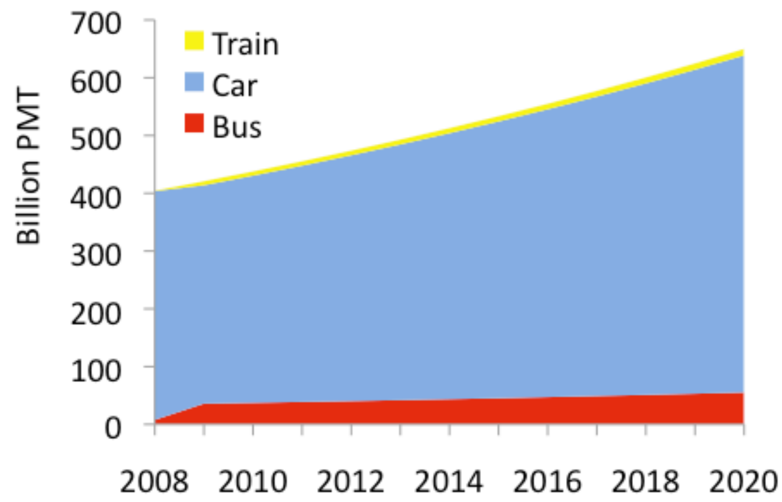
-
Car
Bus
Train


TIME
Fuels
Demands (PMT)
Time
Electricity
Fossil
Long Distance
Short Distance
MINTTB
MINTTI1
[...]
MINTTIn
CARS
BUSES City
BUSES InterCity
METRO/TRAM
TRAINS
PLANES

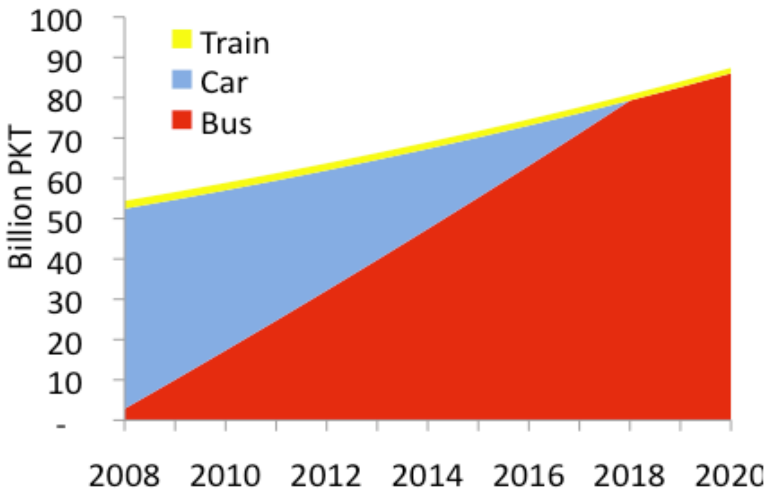
No TTB limit - CA



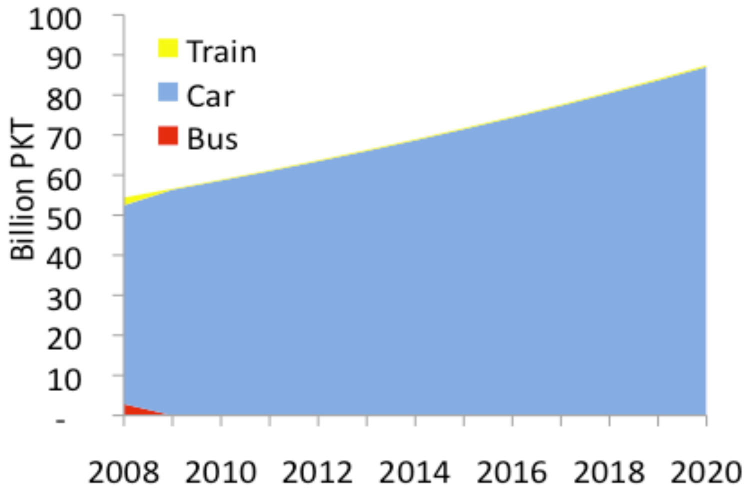
Reference scenario - CA

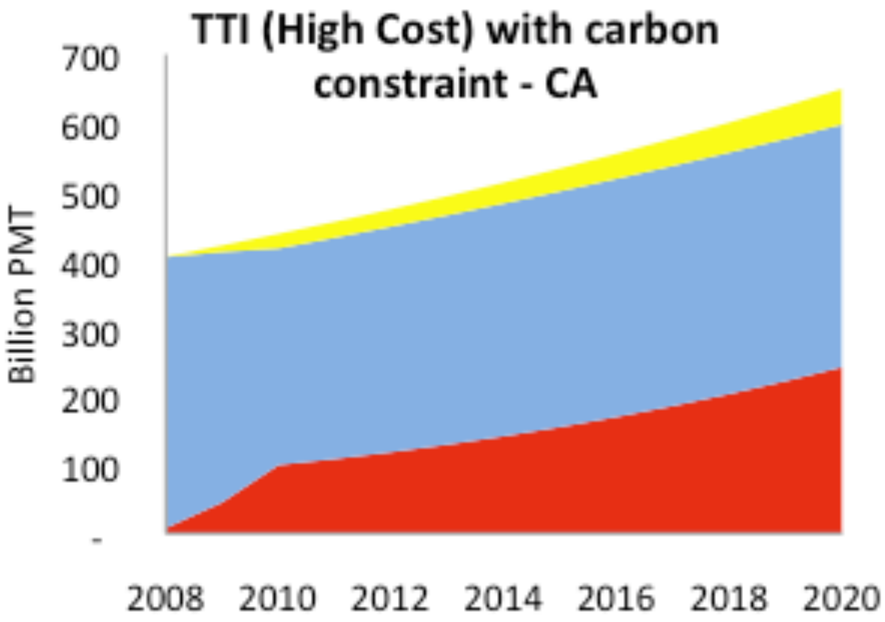


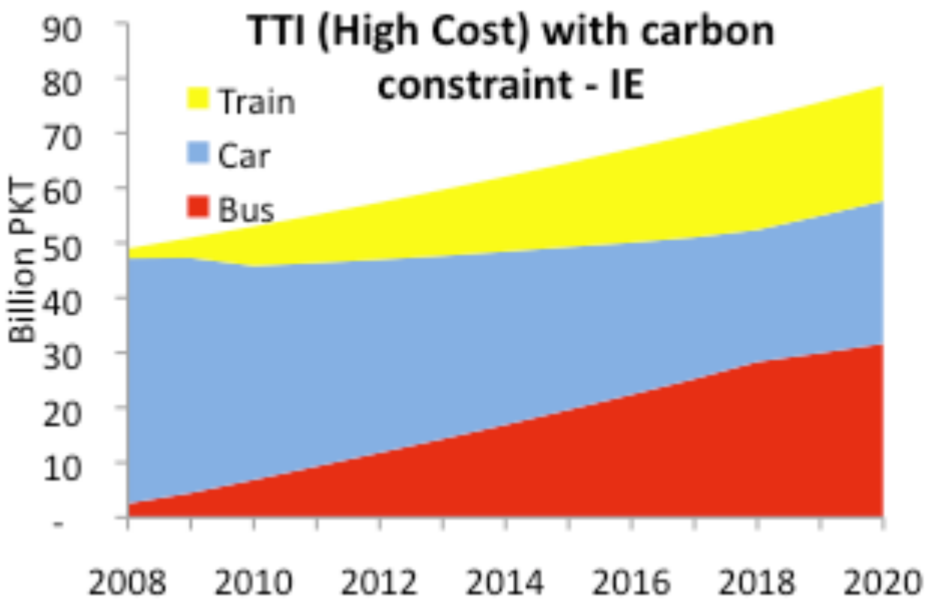
No limit on TTB - IE



Reference scenario - IE




TTI (High Cost) with carbon constraint - CA
Billion PMT
700
600
500
400
300
200
100
-
2008
2010
2012
2014
2016
2018
2020


TTI (High Cost) with carbon constraint - IE
Train
Car
Bus
Billion PKT
90
80
70
60
50
40
30
20
10
-
2008
2010
2012
2014
2016
2018
2020

Future direction

- Expanding boundaries of study
  - Combined modes
  - Non-motorised travel modes & alternatives to mobility
  - Saturation of infrastructure
- Costing transport "infrastructure" in detail (*TTI*)
  - Supply curve representing bus lanes, rail road, airport
  - Other behaviour options – land use, consumer preferences
  - The importance of spatial detail? How scalable is data?
- Scenario exploration and full energy system interactions

Concluding thoughts

- **Widely used bottom-up energy system framework**
  - Lacking behavioural realism
  - Lacking transport infrastrucutre & opportunities for demand management
  - → Model design does not allow mitigation through behaviour

- **An exploratory approach**
  - Ranks transport infrastructure investments with other carbon mitigation measures
  - Captures demand response to price & infrastructure
  - TIMES approach suits long-term investment decisions by governments/social planner
  - Infrastructure investment could feed into detailed transport studies

Methodology: Equations

Determine mode split ($PMT_{t,d}$) and travel time investment ($tti_{t,d}$):

- Minimise total system cost:

$$C = \sum_{t,d} PMT_{t,d} \cdot c_{t,d}$$

- Where:

$$c_{t,d} = f_{t,d} + i_{t,d} + om_{t,d} + tc_{t,d}$$

$$tc_{t,d} = (tti_{t,d} \div s_{t,d}) \cdot i$$

- Subject to constraints:

$$\sum_{t} PMT_{t,d} = PMT_{d}$$

$$\sum_{t,d} \left(\frac{PMT_{t,d}}{s_{t,d}} \cdot tti_{t,d} \right) \leq TTB$$

Travel time budget

$$\sum_{t,d} PMT_{t,d} \cdot e_{t,d} \leq X$$

Carbon constraint

t: Technology/mode; d:Long/short distance demand;