Breaking down non-cost barriers to technology adoption is critical for the transport-energy transformation

International BE4 Workshop
London, UK
April 20-21, 2015

David McCollum, Keywan Riahi, Volker Krey (IIASA)
Charlie Wilson, Hazel Pettifor (UEA)
Kalai Ramea (UC-Davis)
Oreane Edelenbosch (PBL)
Zhenhong Lin (ORNL)
ADVANCE project

- EU-FP7 project funded for four years (01/2013 – 12/2016) with 5.7 Mio €
  - ADVANCE: “Advanced Model Development and Validation for Improved Analysis of Costs and Impacts of Mitigation Policies”

- Integrated assessment and energy-economy modeling teams:
  - PIK (DE; REMIND, MAgPIE), IIASA (AT; MESSAGE),
  - PBL (NL; IMAGE/TIMER), FEEM (IT; WITCH),
  - IPTS (EU; GEM-E3, POLES), UCL (UK; TIAM-UCL),
  - UPMF, Enerdata (FR; POLES), ICCS/NTUA (GR; PRIMES, GEM-E3)
  - CIRED (FR; IMACLIM)

- Topical research teams:
  - DLR (DE; RE integration & resources),
  - UEA (UK; consumer choice) & Utrecht University (NL; energy demand),
  - NTNU (NO; Material flows & LCA)

- International collaborators:
  - Non-EU modeling teams: JGCRI (GCAM), NCAR (iPETS), NIES (AIM), RITE (DNE21+)
  - Further international expertise: NREL (renewable energy sources), PIAMDDI & EMF (Model diagnostics & comparison), Simon Fraser Univ. (energy demand)
The context of ADVANCE: Exploring transformations

- Whole-systems models - Integrated Assessment Models (IAMs) and E4 models - are central tools for the analysis of climate change mitigation and sustainable development pathways, both globally and nationally.

- A large number of IAM scenarios have been generated over the past few years, and form an important basis for international assessments like the IPCC AR5, UNEP Gap Report, Global Energy Assessment etc. (~1200 scenarios in AR5 DB)
Modelers continue to hone their "map-making" ability

ADVANCE aims to develop a new generation of energy-economy and integrated assessment modeling tools.

The goal is to improve the mapping tools in key areas:

- with strategic importance for the assessment of mitigation pathways
- where substantial improvements are needed
Key areas for model improvement...

- **End-use technologies** providing energy services, drivers of energy demand, and potentials for energy efficiency improvements (WP2)

- **Heterogeneity** of consumer preferences, and how behavioral changes affect energy demand (WP3)

- **Innovation**, technological change and uncertainty (WP4)

- **Supply-side bottlenecks**: system integration of variable renewable electricity (VRE), material and energy requirements, infrastructure lock-ins, land-water-energy-nexus (WP5)
Objectives of ADVANCE WP3

(Task 3.1: Improving the representation of demand-side heterogeneity in IA and E4 models)

- Increase the heterogeneity of consumer groups in IAM transport sectors
- Better reflect (non-cost) barriers to advanced vehicle adoption in models
- Draw upon empirical evidence and detailed behavioral studies to inform the modelling
- Quantify the climate policy cost implications of capturing these barriers
- Understand which policy levers can reduce the barriers over time, by how much, and for whom

New methodologies

New answers to novel questions
Participants in ADVANCE WP3, Task 3.1

• Review of empirical micro-studies led by **UEA**, supported by IIASA.

• Pioneering models for first implementation of behavioral aspects done by **IIASA (MESSAGE)** and **PBL (IMAGE)**.

• Further implementation/model development will be conducted by **UCL (TIAM)**, **FEEM (WITCH)**, **PIK (REMINDE)**, **ICCS (GEM-E3)**, and **DNE-21+ (RITE)**.
Research Questions

• Which consumer/driver attributes can be incorporated into IAMs in order to improve transport sector heterogeneity and better reflect barriers to technology adoption?

• How are IAM transport scenarios impacted by these improved representations of behavior and heterogeneity? (w.r.t. technology choice, climate policy costs, etc.)

• What incentives (policy and financial) might help to nudge consumer/driver behavior in a desired direction?
Modeling Approach

1. Disaggregate IAM transport modules so that LDV demands reflect a heterogeneous set of consumers

2. Monetize non-cost vehicle purchase considerations (barriers to technology adoption) by bringing “disutility costs” from a vehicle choice model into IAMs
Disaggregation of LDV Mode/Demands

Light-Duty Vehicle Consumers/Drivers

- Early Adopter
  - Urban
  - Suburban
  - Rural
  - %

- Early Majority
  - Urban
  - Suburban
  - Rural
  - %

- Late Majority
  - Urban
  - Suburban
  - Rural
  - %

<= structure repeated =>

27 consumer groups in total
(= 3 x 3 x 3)
Implement disutility costs from NMNL Model into IAMs

MA$^3$T (Market Allocation of Advanced Automotive Technologies)
a scenario analysis tool for estimating market shares, social benefits and costs during LDV powertrain transitions, as resulting from technology, infrastructure, behavior, and policies

1458 consumer groups

Nationwide Model
(9 regions in the US)

Source: ORNL & K. Ramea (UC-Davis)
## Example Disutility Cost Data

**Units: 1000$/vehicle**  
**Year: 2020**

| MA3T_ID | MA3T_tech_name       | RUEAA | RUEAM | RUEAF | RUERA | RUERM | RUEMF | RULMA | RULMM | RULMF | SUEAA | SUEAM |
|---------|----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1       | Gasoline ICE Conv    | 0.45  | 0.00  | 1.20  | 0.45  | 0.00  | 1.20  | 0.45  | 0.00  | 1.20  | 0.50  | 0.03  |
| 2       | Diesel ICE Conv      | 5.89  | 5.17  | 7.09  | 6.52  | 5.79  | 7.72  | 7.13  | 6.41  | 8.33  | 5.98  | 5.21  |
| 4       | Gasoline ICE HEV     | 1.88  | 1.44  | 2.61  | 1.92  | 1.48  | 2.65  | 1.96  | 1.52  | 2.69  | 1.82  | 1.41  |
| 5       | Diesel ICE HEV       | 3.54  | 2.80  | 4.76  | 5.76  | 5.02  | 6.98  | 7.94  | 7.20  | 9.15  | 3.45  | 2.75  |
| 7       | Gasoline PHEV10      | 2.68  | 2.31  | 3.34  | 3.70  | 3.33  | 4.36  | 4.69  | 4.33  | 5.36  | 2.62  | 2.28  |
| 8       | Gasoline PHEV20      | 3.00  | 2.67  | 3.61  | 5.00  | 4.67  | 5.62  | 6.97  | 6.64  | 7.59  | 2.95  | 2.64  |
| 9       | Gasoline PHEV40      | 1.37  | 1.14  | 1.91  | 1.46  | 1.23  | 2.00  | 1.55  | 1.31  | 2.08  | 1.34  | 1.13  |
| 10      | Hydrogen ICE         | 87.43 | 49.48 | 149.98| 90.46 | 52.51 | 153.01| 93.44 | 55.49 | 155.99| 91.72 | 51.79 |
| 11      | Hydrogen FC          | 79.56 | 45.24 | 136.13| 82.59 | 48.28 | 139.16| 85.57 | 51.25 | 142.13| 77.87 | 44.34 |
| 12      | Hydrogen FC PHEV10   | 53.21 | 27.51 | 103.30| 56.21 | 30.51 | 106.31| 59.16 | 33.46 | 109.26| 52.94 | 27.68 |
| 13      | Hydrogen FC PHEV20   | 50.77 | 26.16 | 97.13 | 53.73 | 29.13 | 100.10| 56.65 | 32.04 | 103.01| 49.48 | 25.57 |
| 14      | Hydrogen FC PHEV40   | 36.72 | 18.89 | 77.32 | 39.70 | 21.87 | 80.30 | 42.63 | 24.80 | 83.23 | 36.26 | 18.81 |
| 15      | EV 100 mile          | 12.86 | 10.77 | 22.15 | 22.30 | 18.11 | 40.88 | 45.34 | 34.87 | 91.79 | 12.68 | 10.77 |
| 16      | EV 150 mile          | 17.08 | 11.07 | 26.46 | 30.49 | 18.47 | 49.25 | 65.34 | 35.28 | 112.25| 16.90 | 11.07 |
| 17      | EV 250 mile          | 20.29 | 10.91 | 30.40 | 37.28 | 18.52 | 57.50 | 82.45 | 35.55 | 133.00| 20.11 | 10.91 |

**Key:**  
RU (Rural) / SU (Suburban) / UR (Urban)  
EA (Early Adopter) / EM (Early Majority) / LM (Late Majority)  
M (Modest Driver) / A (Average Driver) / F (Frequent Driver)  
Example: RUEAA = Rural + Early Adopter + Average Driver

These disutility costs would be added to the standard capital costs of vehicles in models (in $/vehicle).
Breakdown of Disutility Cost Sub-components

**EV100**

1. EV charger installation
2. Model availability
3. Range anxiety
4. Risk premium

**H2FCV**

5. Refueling station availability

---

Region: NORTH_AM; Year: 2030; Group: UREMA
Sensitivity Analyses to Estimate Disutility Cost Sub-components

Not every existing fueling station in an urban area would need \( H_2 \) in order to provide convenience. Average driving time from home to an \( H_2 \) station goes down fast as \( H_2 \) becomes available at a relatively small fraction of existing stations. Source: M. Nicholas, S. Handy, and D. Sperling, “Using Geographic Information Systems to Evaluate Siting and Networks of Hydrogen Stations,” Transportation Research Record 1880 (2004): 126–34.
Breakdown of Disutility Cost Sub-components

**EV100**

Region: NORTH_AM; Year: 2030; Group: UREMA
Adding disutility costs leads to slower uptake of AFVs

Baseline

500 ppm CO₂eq

without disutility costs

with disutility costs

addition of disutility costs

Electric ↓ Fossil Syn. ICE ↑

Biofuel ICE ↑

Nat. Gas ICE ↓

Fossil ICE ↑

without disutility costs

with disutility costs

addition of disutility costs
Certain consumer groups adopt AFVs much faster with disutility costs.
Regional Differences in Disutility Costs

H2FCV

Cost reduction here is due entirely to lower km/vehicle/yr

But...how should perceptions of low tech. diffusion and limited infra. vary across regions?

Utilize empirical insights from social influences literature

* H2 refueling infrastructure coverage and H2FCV diffusion are at 0%.
Comparison of regional results in a 500 ppm CO$_2$eq scenario

NORTH_AM

- **Modest Driver** (13,930 km/veh/yr)
- **Average Driver** (25,860 km/veh/yr)
- **Frequent Driver** (45,550 km/veh/yr)

INDIA+

- **Modest Driver** (5,602 km/veh/yr)
- **Average Driver** (10,400 km/veh/yr)
- **Frequent Driver** (18,319 km/veh/yr)
Research Questions

• How are IAM and E4 transport scenarios impacted by improved representations of consumer heterogeneity/behavior and better reflections of barriers to technology adoption? (w.r.t. technology choice, climate policy costs, etc.)

• What incentives (policy and financial) might help to nudge consumer/driver behavior in a desired direction?

• How much can be achieved by changing behavior and preferences?
Expected Findings and Policy Insights

• The inclusion of non-cost barriers to technology adoption in the decision-making algorithms of models leads to a considerably slower uptake of advance vehicles than under normal model assumptions.
  – e.g., in climate policy scenarios, a shift from electricity/hydrogen to biofuels
• If these barriers are not removed, climate policy costs may be considerably higher.
• Policies supporting early-stage infrastructure can bring down these barriers, while vehicle purchase subsidies can help compensate for them in the early market phase.
Marginal abatement cost (MAC) curves will likely shift once models better reflect heterogeneity and non-cost barriers to technology adoption.

The impact of vehicle subsidies can be analyzed; these will be affected by heterogeneity and non-cost barriers to technology adoption.

Policies supporting the development of early-stage recharging/refueling infrastructure can aid the diffusion of new technologies.
Questions?
Comments?
Extra slides
References and Documentation

- Kalai Ramea’s (UC-Davis) IEW-2013, IAMC-2013, and BE4-2015 presentations

So far, 5 published and 5 working papers result from the MA³T project.

**Published peer-review articles**

**Working papers**
- Dong, J., Liu, C., Lin, Z., Charging Infrastructure Planning for Promoting Battery Electric Vehicle Market: An Activity-Based Assessment Using Multiday Travel Data. Working paper

Source: Zhenhong Lin (ORNL)
Components of Disutility Cost (illustrative, 2020)

Source: Kalai Ramea (UC-Davis)
Which dimensions are uncertain, and which are the most important?

<table>
<thead>
<tr>
<th>Data availability, quality, uncertainty?</th>
<th>Driver Type (km/veh/yr) (Modest / Average / Frequent)</th>
<th>Attitude to New Technology (Early Adopt. / Early Maj. / Late Maj.)</th>
<th>Settlement Type (Urban / Suburban / Rural)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequate</td>
<td>Adequate</td>
<td>Lacking</td>
<td>Adequate</td>
</tr>
<tr>
<td>Very Strong</td>
<td>Very Strong</td>
<td>Very Strong</td>
<td>Weak</td>
</tr>
<tr>
<td>9 (= 3 x 3)</td>
<td>9 (= 3 x 3)</td>
<td>9 (= 3 x 3)</td>
<td>9 (= 3 x 3)</td>
</tr>
</tbody>
</table>

consumer groups are enough
Key determinants of disutility costs

- Urban / Suburban / Rural splits
- Early Adopter / Early Majority / Late Majority splits
- Modest Driver / Average Driver / Frequent Driver splits
- EV charger cost
- NG and H2 station and EV-charger availability
- km/vehicle/yr for M/A/F Drivers

All of these things could/should vary by region and over time. Also by scenario.
## Workplan Proposal for Task 3.1

<table>
<thead>
<tr>
<th>Project Month</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>May</td>
<td>Jun</td>
</tr>
<tr>
<td>Review of microstudies &amp; Report on microstudies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pioneering implementation in MESSAGE, IMAGE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution of disutility cost data to other teams</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation in TIAM-UCL, WITCH, ReMIND, GEM-E3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run scenarios based on updated model implementations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-model transport paper</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Deadline for deliverable**
- **Work by IIASA**
- **Work by other teams**
- **Report/paper writing**
Improving the behavioural realism of integrated assessment models of global climate change mitigation: a research agenda
(C. Wilson, H. Pettifor, D. McCollum)

• Submitted in Month 19 (July 2014), instead of originally planned delivery date of Month 30 (~June 2015)
• Now online at: www.fp7-advance.eu
• Derivative papers in preparation; insights currently feeding into modeling
Deliverable 3.2

- Specific focus on factors influencing alternative fuel vehicle purchase decisions
- Identifies importance and challenges for introducing behavioural features into IAMs.
  - typology of behavioural features
  - synthesis of current modelling approaches
  - empirical basis for behavioural features (focusing on AFVs)
    - discrete choice experiments (n=16)
    - social influence studies (n=72)
Motivation & Background

How important and/or useful for IAMs are different behavioural features in discrete choice models of vehicle adoption?

<table>
<thead>
<tr>
<th>Behavioural Feature</th>
<th>Effect size / influence on choice</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heterogeneous decision makers</strong></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>high</td>
</tr>
<tr>
<td>Value orientation</td>
<td>medium – low</td>
</tr>
<tr>
<td>Gender</td>
<td>medium</td>
</tr>
<tr>
<td>Environmental Awareness</td>
<td>high - medium</td>
</tr>
<tr>
<td>Education</td>
<td>medium-low</td>
</tr>
<tr>
<td><strong>Non-optimising heuristics</strong></td>
<td></td>
</tr>
<tr>
<td>Driving practices</td>
<td>low</td>
</tr>
<tr>
<td><strong>Non-monetary benefits</strong></td>
<td></td>
</tr>
<tr>
<td>Refuelling network</td>
<td>high</td>
</tr>
<tr>
<td>CO2 emissions</td>
<td>high - medium</td>
</tr>
<tr>
<td>Range, battery time, warranties</td>
<td>high</td>
</tr>
<tr>
<td><strong>Risk preferences (discount rates)</strong></td>
<td></td>
</tr>
<tr>
<td>Refuelling location</td>
<td>high - medium</td>
</tr>
<tr>
<td>Vehicle range</td>
<td>high - medium</td>
</tr>
<tr>
<td>Fuel savings</td>
<td>medium</td>
</tr>
<tr>
<td>Social influences</td>
<td>high - medium</td>
</tr>
<tr>
<td><strong>Social influences</strong></td>
<td></td>
</tr>
<tr>
<td>Neighbourhood effects</td>
<td>high - medium</td>
</tr>
<tr>
<td><strong>Contextual constraints</strong></td>
<td></td>
</tr>
<tr>
<td>Refuelling density</td>
<td>high</td>
</tr>
<tr>
<td>Refuelling location</td>
<td>high</td>
</tr>
<tr>
<td>Incentives</td>
<td>high</td>
</tr>
</tbody>
</table>

Source: Pettifor and Wilson (UEA)