Understanding the role of transportation in meeting California's greenhouse gas emissions reduction target: a focus on technology forcing policies, interactions with the electric sector and mitigation costs

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The CA-TIMES Model

- TIMES (The Integrated MARKAL-EFOM1 System) model is an Energy–Economy–Engineering–Environment (4E) model.
- 4E models are widely used for transition scenarios for multidisciplinary subjects.
- Identifies most cost-effective pattern of resource use and technology deployment over time under various technological, behavioral, resource, and policy constraints.

Motivation

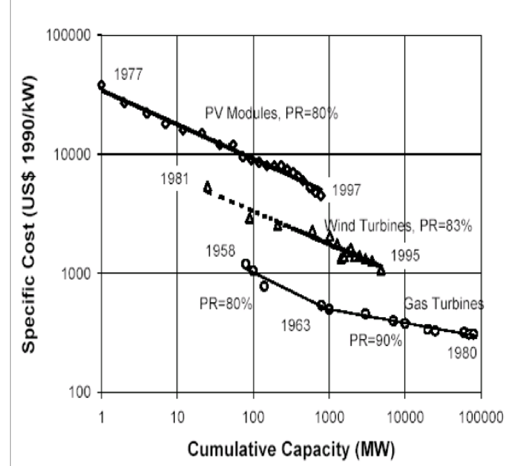
- The underlying assumption of a technology-forcing policy, where a regulator specifies a standard that cannot be met with the existing technology without switching to more expensive options, is that technology costs will eventually come down with more investments in R&D and/or deployment of technologies due to so-called "endogenous technological learning"
- Many of the climate policies adopted in California are considered technology-forcing policies. Examples such as the Zero Emission Vehicle (ZEV) program, the Low Carbon Fuel Standard (LCFS), and the energy storage were intended to elicit advancements in technology and/or technology costs reductions by forcing firms to commit resources to R&D or technology deployment
- In the electricity grid with a high penetration of renewable energy, demand management could also maximize the capacity factor of the electricity network and save a lot of investments in infrastructure
- Marginal abatement cost (MAC) curves have become a very popular tool in the policy world to answer this question, since they can represent the complex issue of cost-effective emissions reduction in a simple manner

Research Questions

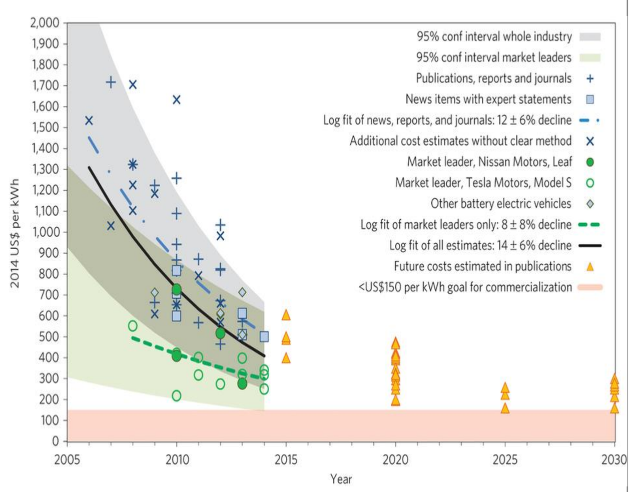
- What is the role of technology forcing policies of California in promoting uptake and cost reduction of alternative fuel vehicles?
- What is the impact of technology-forcing policies in the transportation sector on the entire economy and other sectors?
- What are the possible global implications of different countries' attempts to promote uptake of alternative fuel vehicles?
- What are the implications of various global learning and deployment scenarios for California?
- What is the role of electricity and hydrogen in scenarios in which the benefit for learning are share between different cars?
- How can we account for the seasonal and daily variability of supply and demand in order to develop expansion plans of the electricity system with a high penetration of renewables and taking into account the existence of energy storage systems and Evs?
- How can the shift to electric vehicles help reduce GHG emissions and what is the impact of EVs on the electricity system?
- What is the impact of flexible charging on the transportation sector and on the adoption of EVs (given the learning effect)?
- What is the contribution of different measures (sectors, end-uses, technologies) in reducing GHG emissions up to 2050?
- What influences abatement cost curves and to what extent? (e.g. technology availability, cost assumptions)

Learning

Historical experience has shown that the improvement of a technology is related to the knowledge accumulated through the construction or use of this technology, and can be described with so-called learning or experience curves.



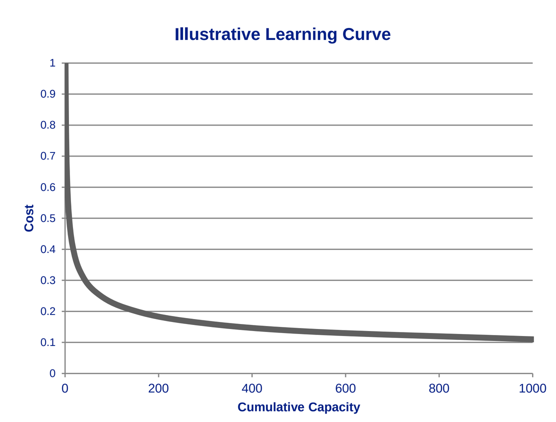
Source: Messner, S., Endogenized Technological Learning in an Energy Systems Model, Journal of Evolutionary Economics, Vol. 7, issue 3, pages 291-313, 1997.



Nykvist, Björn, and Måns Nilsson. "Rapidly falling costs of battery packs for electric vehicles." *Nature Climate Change* (2015).

$$C_t = C_0 \cdot \left(\frac{Q_t}{Q_0}\right)^{-b}$$

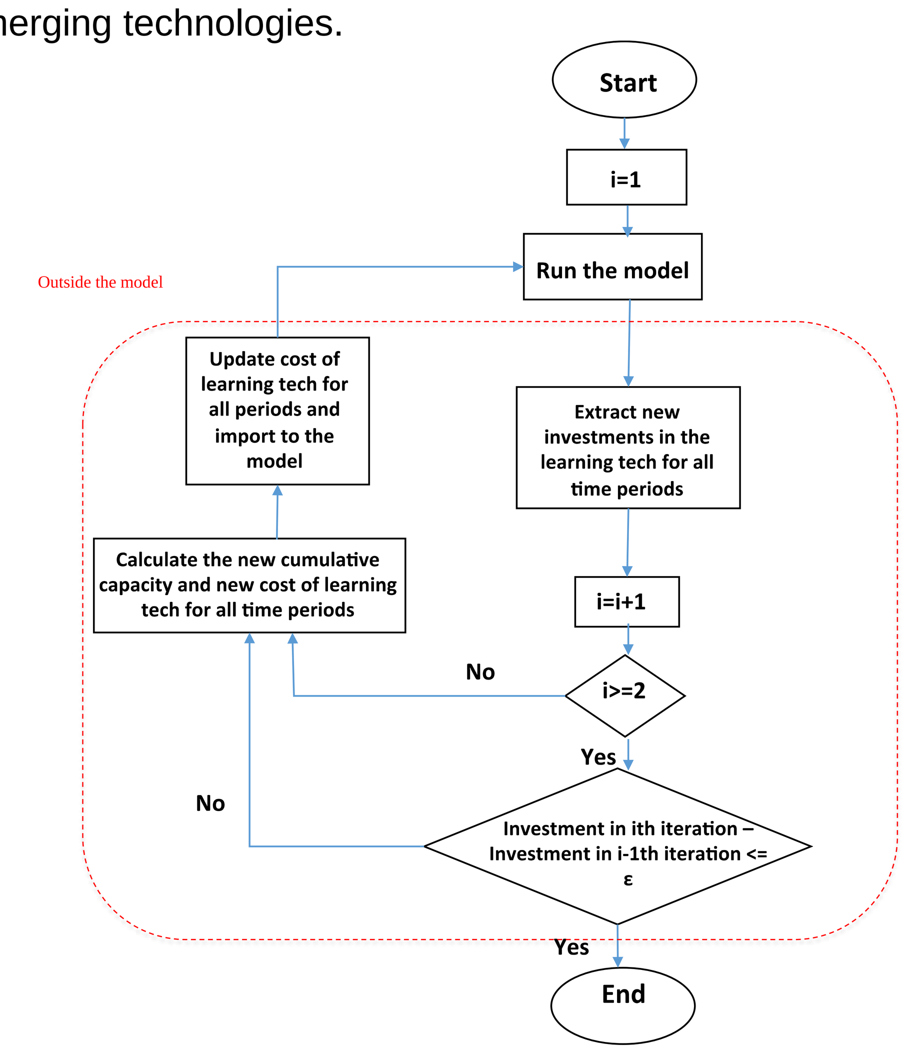
$$PR = 1 - LR = 2^{-b}$$



- C_t: Capital cost at cumulative installed capacity Q_t at time *t*
- C_0, Q_0: Initial costs C_0 at initial capacity of C_0
- **b**: Learning index
- **PR**: Progress ratio
- **LR**: Learning rate

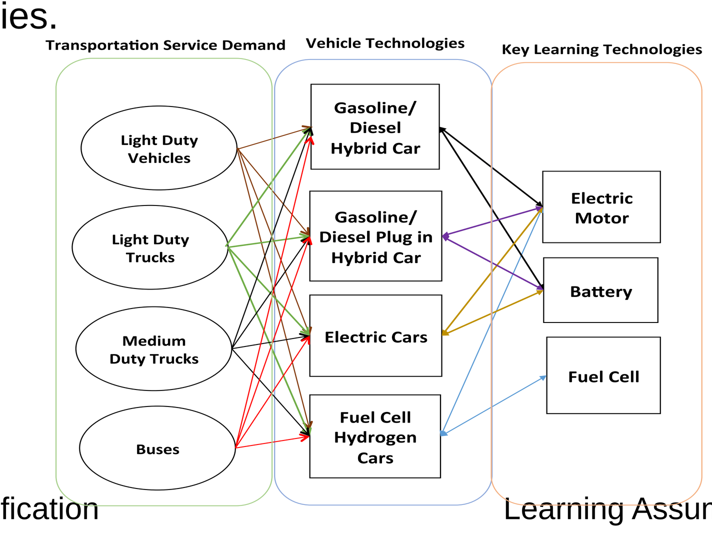
Learning Implementation

- In linear optimization models, the cost reduction of technology based on experience requires the use of technology as a trigger that contradicts with the original paradigm of TIMES (selecting least-cost technology)
- Methods have been developed to implement endogenous learning in linear models using MLIP, which is computationally burdensome
- In the proposed methodology –the same as in the real world– technology-forcing policies play a very crucial role in imposing the learning process and consequently cost reduction of emerging technologies.



Cluster Learning

- In the cluster approach, a group of technologies share a common component –"key technology"– which is subject to learning.
- Only the investment costs undergo the learning process. Therefore, we only attribute capital cost to key component technologies.



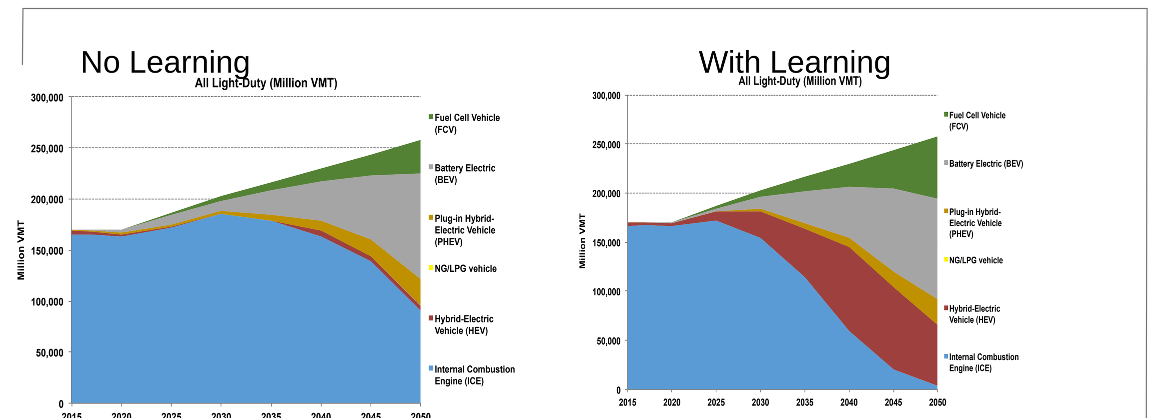
Vehicle Specification

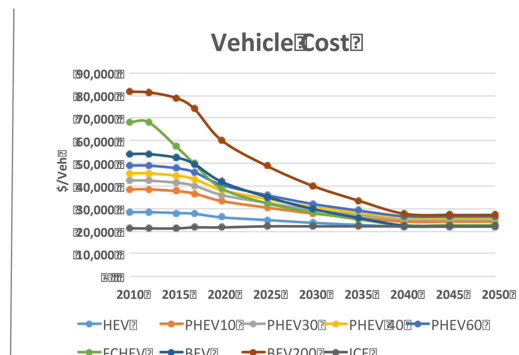
	Battery	Electric Drive	Fuel Cell System
Initial Cost	$600/kWh	$25/kW	$216/kW
Learning Rate	7%	10%	4%
Exogenous Cost Reduction	0.7%/yr	1.2%/yr	2.5%/yr
Initial Cumulative Capacity	6.04 GWh	250 GW	0.88 GW

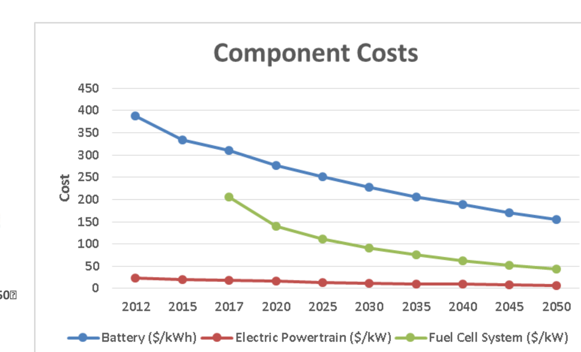
Learning Assumptions

	Electric Powertrain (kW)	Battery Size (kWh)	Internal Combustion Engine Size (kW)	Fuel Cell System (kW)
Hybrid Car (HEV)	26	1	73	
Plug-in Hybrid 10 (PHEV10)	60	3	70	
Plug-in Hybrid 30 (PHEV30)	62	7.2	75	
Plug-in Hybrid 40 (PHEV40)	63	11.1	77	
Plug-in Hybrid 60 (PHEV60)	65	15	77	
Fuel Cell Hydrogen Car (FCEV)	103	0.93		83
Battery Electric Car 100 (BEV100)	80	24		
Battery Electric Car 200 (BEV200)	100	54		

Learning Results

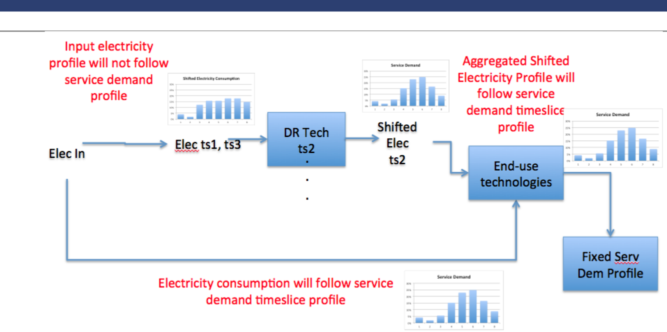






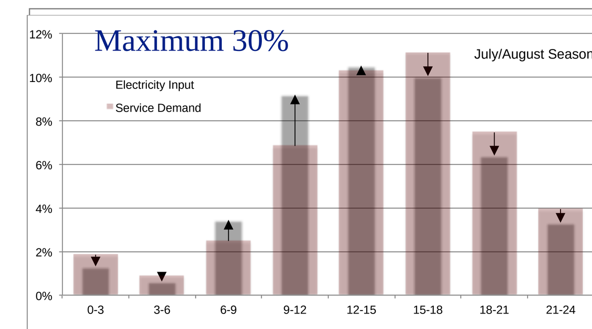
- With learning adoption of hybrid vehicles as well as fuel cell vehicles increase significantly.
- In 2050 alternative fuel vehicles become competitive with the conventional vehicles

Demand Response Implementation

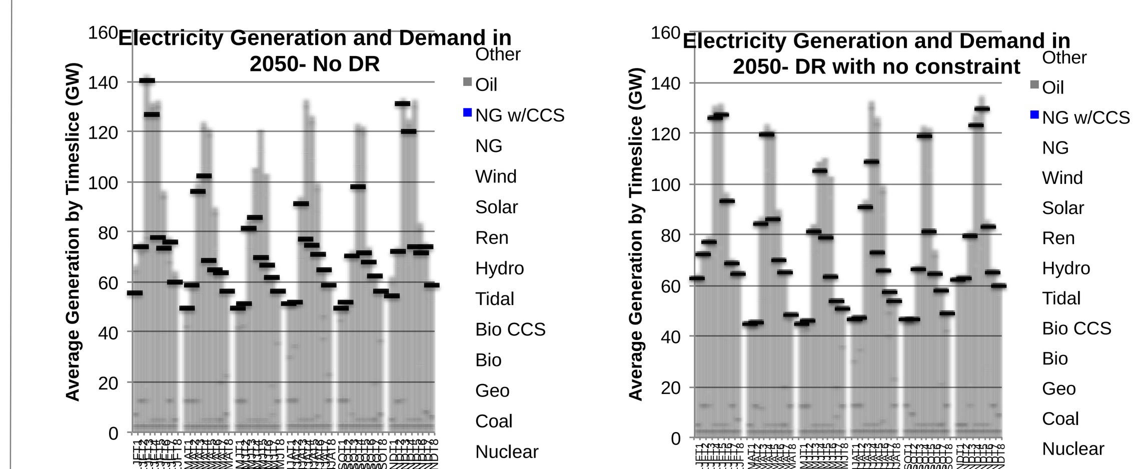


- Electricity sector in CA-TIMES has 48 timeslices (6 representative months and 8 representative hours in each day)
- Load profile of commercial and residential service demands are defined
- We can implement *Load shifting* and *Peak shaving* in CA-TIMES.

Demand Response Results



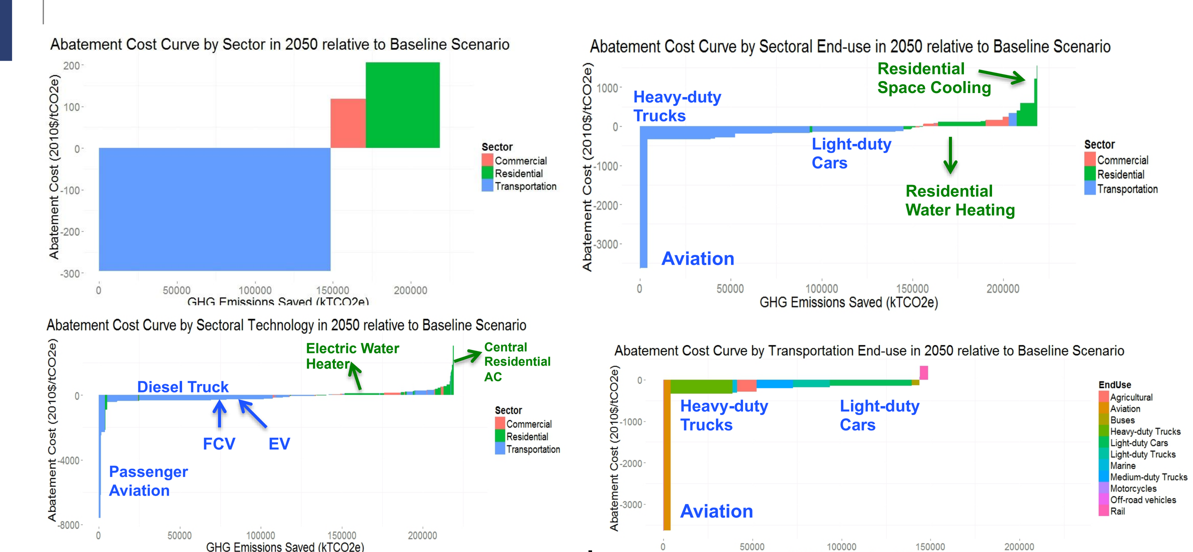
- Sample results for residential space cooling:
  - 3 hour load shifts
  - Maximum constraint: 30% of service demand can be shifted to adjacent timeslice



- Excess generation decreases significantly in each timeslice with DR.
- Electricity generation peak decreases in each timeslice with DR.
- There is less need to have dispatchable generation with DR.

Mitigation Cost Curves

- Mitigation abatement cost (MAC) curves have become a very popular tool in the policy world : they can represent the complex issue of cost-effective emissions reduction in a simple manner.
- MAC curve is a graph that shows the cost associated with the emission abatement against the baseline for varying amounts of emission reduction



- MAC curves can give valuable insights to policy makers for the introduction of a CO2 tax (price- based) and the introduction of a carbon cap system (quantity- based)
- Transportation sector is the most cost-effective sector for emissions reduction.
- Many of transport end-uses rely (in part) on the same fuels to decarbonize (i.e. biofuels).

Future Work

- In the future work, we increase the spatial and temporal resolution of the CA-TIMES model electricity sector in order to include a representation of the Western US electricity grid into the long-term energy system model of California
- The spatial modeling addition (inclusion of the entire WECC) will enable the CA-TIMES model to accurately represent electricity imports/exports, reduction in the variability of renewable energy due to geographic aggregation, and track spatial locations of power plants and related emissions
- we can model benefits of the electric grid with high penetration of renewables to optimally charge electric vehicles. On the top of these transportation sector related results, we also study how the implementation of smart grid and flexible demand in the building sector can benefit the grid and utility companies.
- we investigate how cost reduction in fuel production (hydrogen and electricity) and storage technologies can facilitate the adoption of alternative fuel vehicles and pave the road for low-carbon energy future

UCDAVIS SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

An Institute of Transportation Studies Program

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