Combining the top-down and bottom-up approaches: the MERGE-ETL model

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Presentation's outline

① **MERGE-ETL**
(overall features, database, ETL equations)

② **Solving techniques**

③ **Case studies**

④ **Conclusion**

1.1.a MERGE-ETL features

- 9 regions **ETA-MACRO** model from **MERGE 3** (Manne & Richels, 1997)
- Trade of: oil, gas, synthetic fuels, CO_2 permits, numéraire
- **MERGE:** optimisation equilibrium model combining ‘bottom-up’ & ‘top-down’ approaches
- **MERGE** has been modified to introduce **ETL** (**learning-by-doing** & **by-searching**) for selected electric & non-electric energy technologies

1.1.b ETA-MACRO formulation

$$
\begin{cases}
\max U = \sum_{t=1}^{T} udf_t \log C_t \\
\text{s.t.} \\
Y_t = \left(aK_t^{\rho\alpha} L_t^{\rho(1-\alpha)} + bE_t^{\rho\beta} N_t^{\rho(1-\beta)}\right)^{1/\rho} \\
K_t = I_t + (1-\delta)K_{t-1} \\
Y_t = C_t + I_t + EC_t + NTX_{num,t} + RD_t \\
\text{Other E-M equations}
\end{cases}
$$

- *U* utility
- *C* consumption
- *Y* production
- *K* capital
- *L* labour
- *E* elec. energy
- *N* n-el. energy
- *I* investments
- *EC* energy cost
- *NTX* net export
- *RD* R&D exp.

1.2.a ETL-technologies

MERGE	MERGE-ETL	Identification in MERGE-ETL
ADV-HC	SPV	Solar photovoltaic
ADV-LC	WND	Wind turbine
ADV-LC	NNU	New nuclear designs
COAL-A	IGCC	Integrated coal gasification with CC
GAS-A	GFC	Gas fuel cell
GAS-N	GCC	Gas turbine CC (combined cycle)
NE-BAK	NE-BAK	H_2 from solar photovoltaic
RNEW	RNEW	H_2 from biomass

1.2.b CO_2 capture & disposal

Two new power plants:

- **COAL-D** = **IGCC** with capture *&* disposal
- **GAS-D** = **GCC** with capture *&* disposal

Maximum storage capacity in **depleted oil and gas reservoirs**

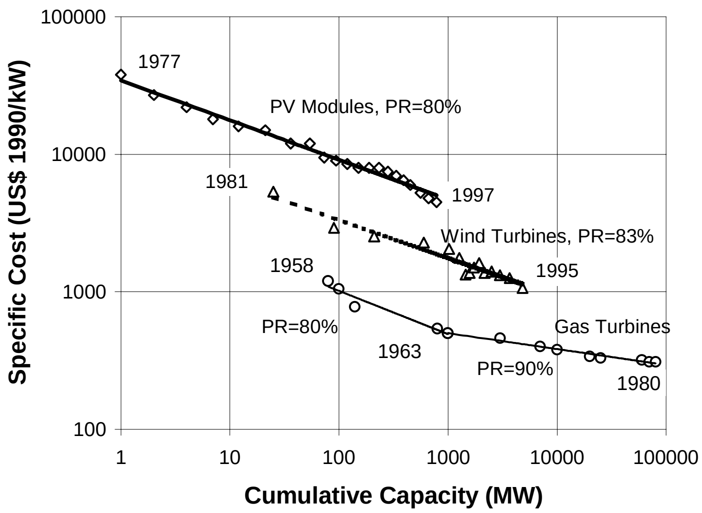
These technologies are **not learning** (yet), *although* they should!

1.3.a One Factor Learning Curve

- **Specific cost** as function of **cumulative capacity**:

$$SC_{te,t}(CC) = a * CC_{te,t}^{-b}$$

- Parameter a is defined by a starting point: SC_0, CC_0
- Learning index b: key parameter defining effectiveness of learning



Data Sources: PV modules and wind turbines: Criqui (2000). Gas turbines: MacGregor et al. (1991) and IIASA-WEC (1995).

Learning curves for different energy technologies (Barreto, 2001)

1.3.b Two-Factor Learning Curve

- Specific cost as a function of
  - **cumulative capacity** and
  - **cumulative R&D expenditures**:

$$SC_{te,t}(CC,CRD) = a * CC_{te,t}{}^{-b} * CRD_{te,t}{}^{-c}$$

b: Learning-by-doing elasticity

c: Learning-by-searching elasticity

1.3.c Cumulative cost

- The new cumulative cost will be given as:

$$TC_{te,t} = \int_0^{CC} SC(CC,CRD) * dCC = \frac{a}{1-b} CC_{te,t}{}^{1-b_{te}} * CRD_{te,t}{}^{-c_{te}}$$

- The corresponding investment costs per technology and period are:

$$ICOST_{te,t} = TC_{te,t} - TC_{te,t-1}$$

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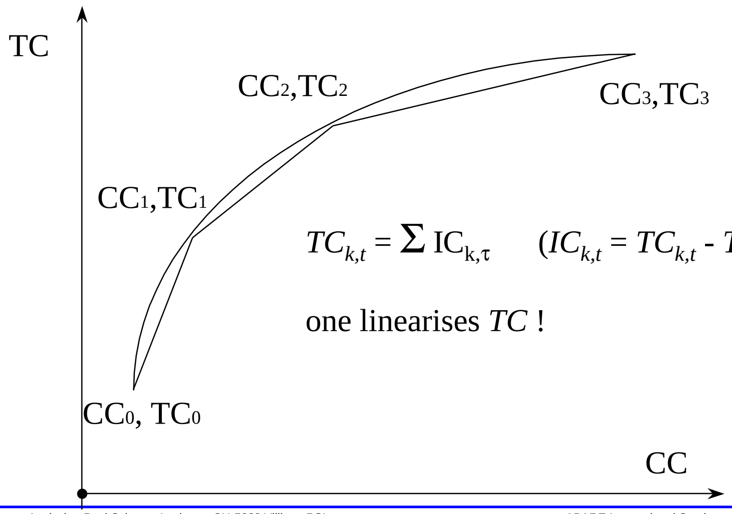
2. Solving MERGE-ETL

- **MERGE-ETL** is an optimisation equilibrium model, cast as a **non-linear**, **non-convex** problem
- It is solved by **heuristic**, iterative **approach**:
  - ***Pre-solving***: **MERGE** solved to define equil. demands for electric & non-electric energy
    Then, **ETA-MIP** optimises regional energy sectors, and defines in particular cumulative installations & cost dynamics of ETL technologies

2.1 Piece-wise linear approximation of cumulative cost



$TC_{k,t} = \Sigma\, IC_{k,\tau}$ $\quad (IC_{k,t} = TC_{k,t} - TC_{k,t-1})$

one linearises *TC* !

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2.2 Piece-wise linear cumulative cost

- Combination of linear segments:

$$TC_{k,t} = \sum_{i=1}^{N} \alpha_{i,k} * \delta_{k,i,t} + \beta_{i,k} * \lambda_{k,i,t}$$

- Intercept: $\alpha_{i,k} = TC_{i-1,k} - \beta_{i,k} CC_{i-1,k}$
- Binary Variables: $\delta_{k,i,t} \in \{0,1\}$
- Slope of linear segment:

$$\beta_{i,k} = \frac{TC_{i,k} - TC_{i-1,k}}{CC_{i,k} - CC_{i-1,k}}$$

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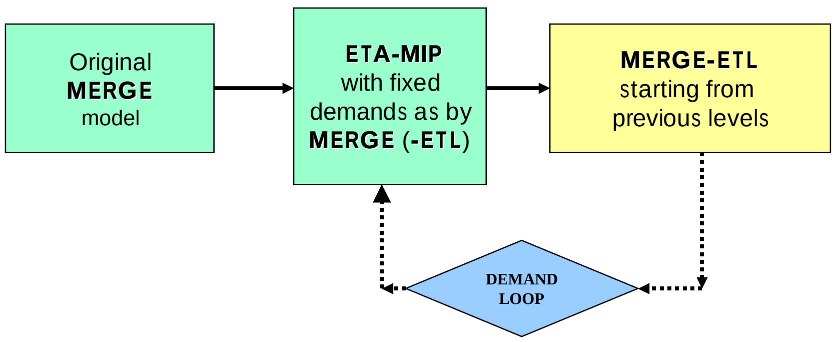
2.3 Solving MERGE-ETL (II)

- *Solved as by **heuristic**, iterative **approach***:
  - ***Solving***: using as a starting point values previously found, **MERGE-ETL** is solved
  - ***Post-solving***: using equil. demands for electric & non-electric energy found before, **ETA-MIP** solved to check whether similar solutions found for cumulative installations of ETL technologies
  - (***If not***: go back to solving)

2.4 Solving MERGE-ETL (III)



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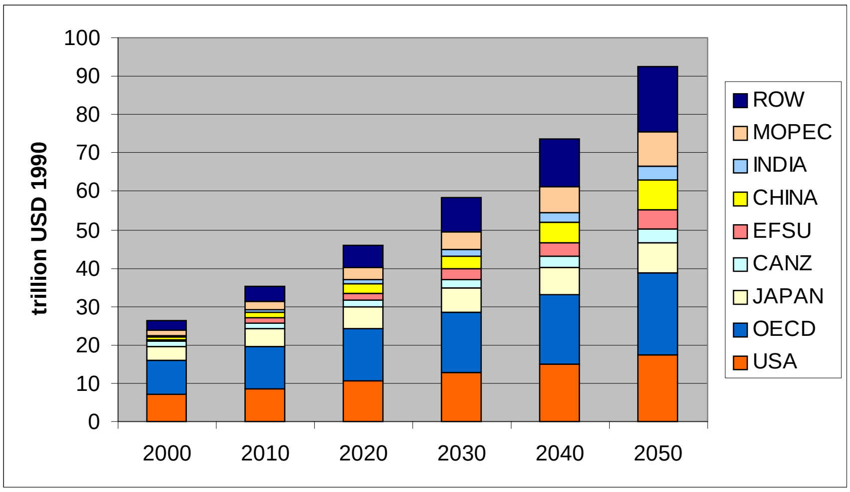
3. CO_2 case studies

9 Regions: CANZ, EEFSU, JAPAN, OECDE, *USA* (Annex I)
CHINA, INDIA, MOPEC, ROW (Non-Annex I)

6 scenarios:

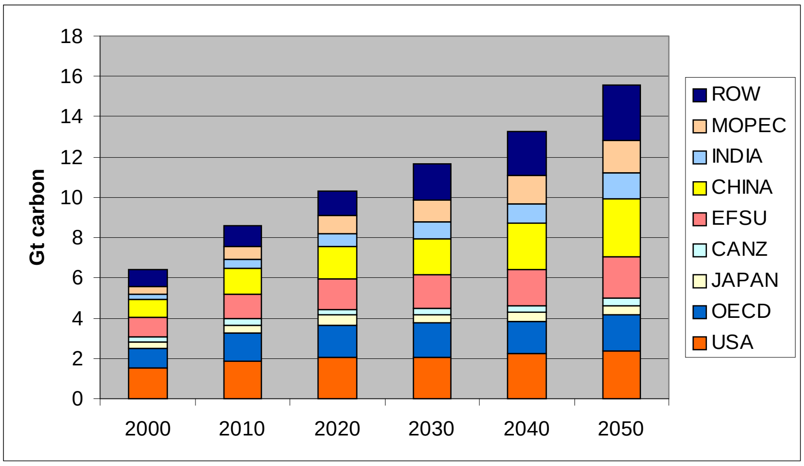
- **3 Baselines: no** CO_2 limits
  BAU (no learning)
  B1F (1FLC) **B2F** (2FLC)
- **3 Soft landings:** to **10Gt C** by 2050
  2010 Limits for CANZ, EEFSU, Japan & OECDE = **Kyoto**
  for other regions (including USA) = BAU levels
  SFL (no learning)
  S1F (1FLC) **S2F** (2FLC)

GDP per region (BAU, by 2050)



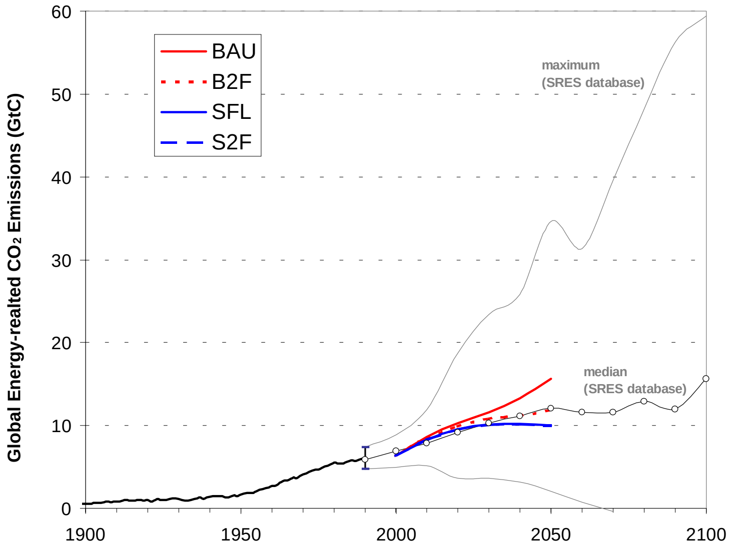
2000-2050: GDP grows 3.5 times; primary energy 2.4; carbon emissions 2.4

Carbon emissions per region (BAU)



Emissions increase by factor 2.4 between 2000-2050
Non-Annex I countries contribute more than 50% of emissions after 2040

Carbon emission trajectories



by 2050:

BAU
(15.6 Gt C)
B1F
(12.6 Gt C)
B2F
(11.9 Gt C)

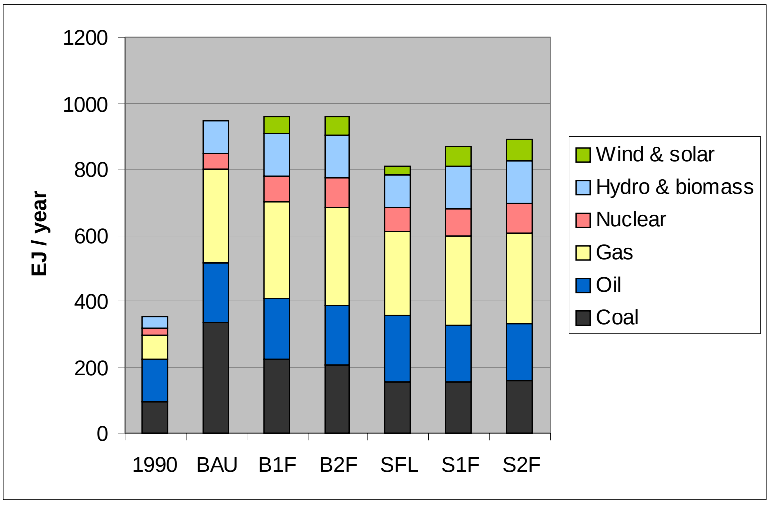
Others
(10.0 Gt C)

3.1 ETL impacts on energy systems

	2000	B1F	B2F	S1F	S2F
IGCC	2020	1355	1254	1349	1252
GCC	713	513	503	514	505
GFC	5096	884	826	856	819
NNU	3999	2454	2366	2460	2371
WND	887	564	525	562	520
SPV	6075	6075	5022	1775	5022

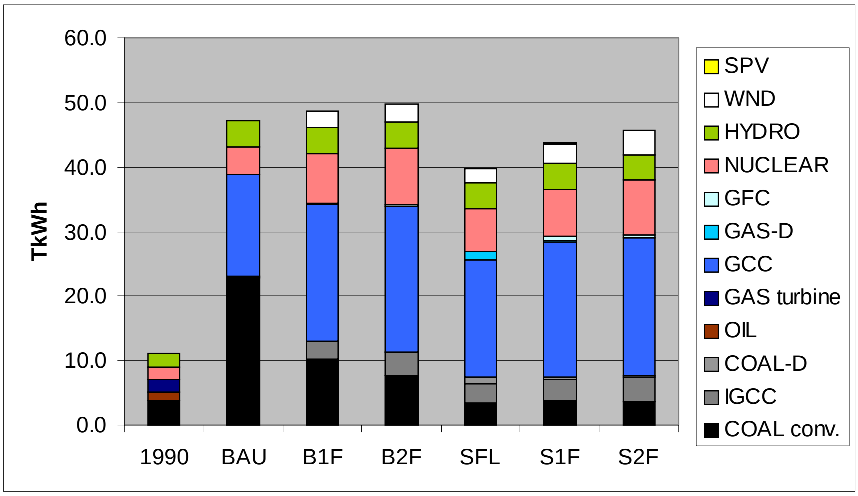
Specific costs (USD/kW) in 2000 and 2050 by cases

World primary energy use (by 2050)



ETL increases primary energy and the use of cleaner sources

World electricity generation (by 2050)



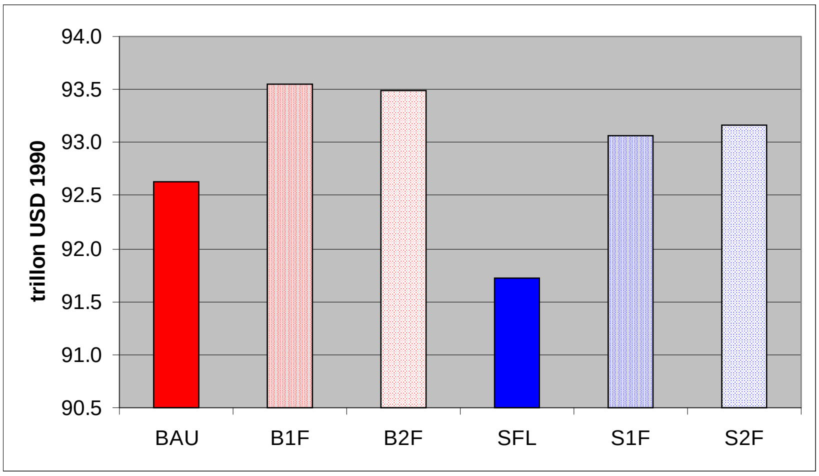
ETL increases electricity generation and the use of cleaner technologies

3.2 Economic impacts of ETL

	2010	2020	2030	2040	2050
SFL	16	26	44	74	122
S1F	13	21	36	59	99
S2F	11	19	31	52	87

Marginal abatement costs (USD/tC)

World GDP per case (by 2050)



ETL induces GDP growth and reduces burdens in constrained cases

4. Conclusions

- **MERGE-ETL**: tool to assess different formulations of ETL (**learning-by-doing** *&* **learning-by-searching**) *&* study implications of CO_2 control policies
- **ETL** shows **early investments** in cleaner & more efficient energy technologies pay off: brings low-cost reduction options and hence reduces abatement costs & GDP losses (CO_2 constrained cases)