Fondazione Eni Enrico Mattei

Trading woody biomass and "negative" emissions under climate mitigation scenarios

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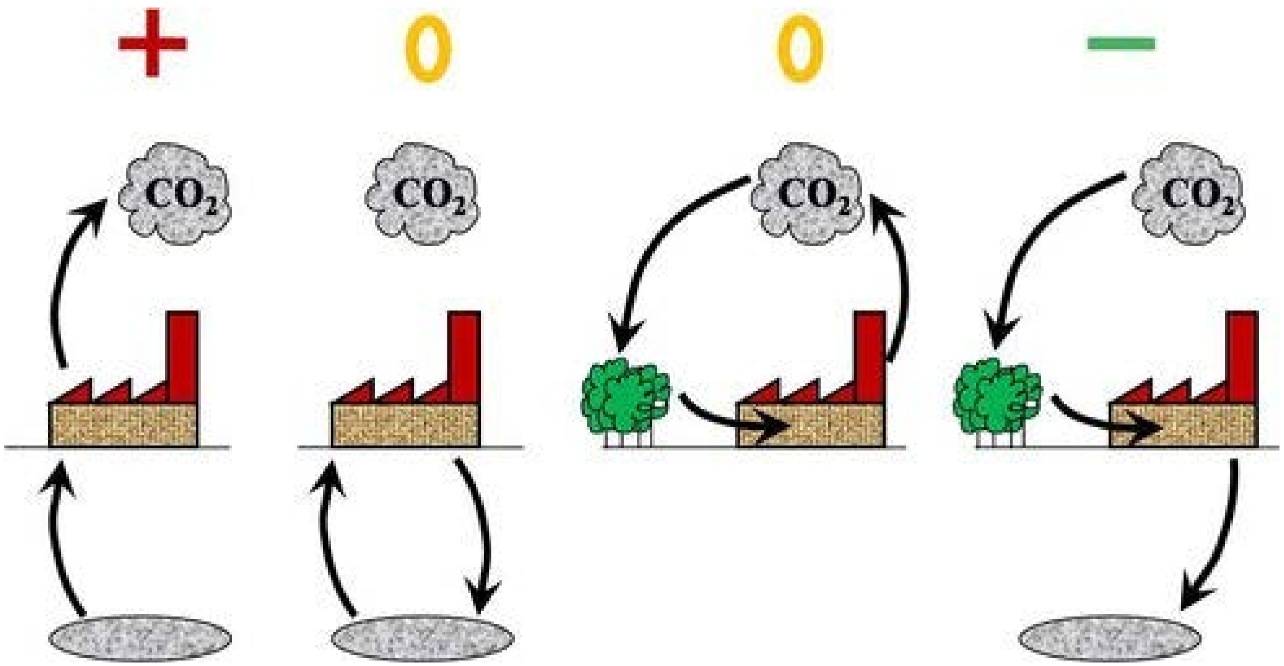
Introduction

- Increasing interest in low stabilization targets (2°C COP15, 3W/m^2 RCP, IPCC)
- Carbon dioxide removal (CDR) technologies (Air capture, Biomass + CCS ecc.)
- BECCS is very helpful to low radiative forcing scenario (Clarke et al., 2009; Edenhofer et al., 2009, 2010; Rose et al., 2012; van Vuuren et al., 2010, 2011)
  - provides energy and removes emissions at the same time
  - increases policy flexibility



Source: Biorecro

Motivation

- Biomass is unevenly distributed
  - Biomass demand from regions with constrained supply, high production costs and high carbon intensity
  - Biomass supply from regions with high potential and low production costs
    - Latin America and Sub-Saharan Africa have the largest potential (Berndes et al., 2003; Rokityanskiy et al. 2007; Smeets et al. 2007; Heinimö et al., 2009; Chum et al., 2011)

- Big incentive to trade

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WITCH Model

- It has Ramsey-Kass-Coopmans optimal growth framework
- Non-cooperative solution: open-loop Nash game between 13 social planners:
  - 13 world regions interact on the environment (GHG emissions), fossil fuels, energy R&D, and learning-by-doing in renewables.
  - Each region's social planner maximizes the present value of discounted log-utility of per capita consumption.
- Dynamic model: investment decisions are taken with perfect foresight.
- Mitigation options: power sector, land use, non-CO_2 gases
- Endogenous technical change in energy technologies (Learning-by-doing, Learning-by-researching)

Bosetti et al. (2006), Bosetti, Massetti and Tavoni (2007), witchmodel.org

Uncertainties

I. Biomass production potential

II. CCS availability and storage capacity

III. Policy stringency

Biomass potential

- The supply curves from the GLOBIOM model of IIASA (Havlík et al., 2011) for each region
  - second generation woody biomass coming from conventional plantations and short rotation forests
  - m^3 of biomass contains 7.5GJ of energy
  - kwh of biomass contains 320 gr of CO_2; kwh of electricity from BECCS contains 910 gr of CO_2
- Maximum biomass potential for each region which guarantees biomass carbon neutrality
- It is not a soft link: we are not able to capture feedbacks of energy and forestland sectors

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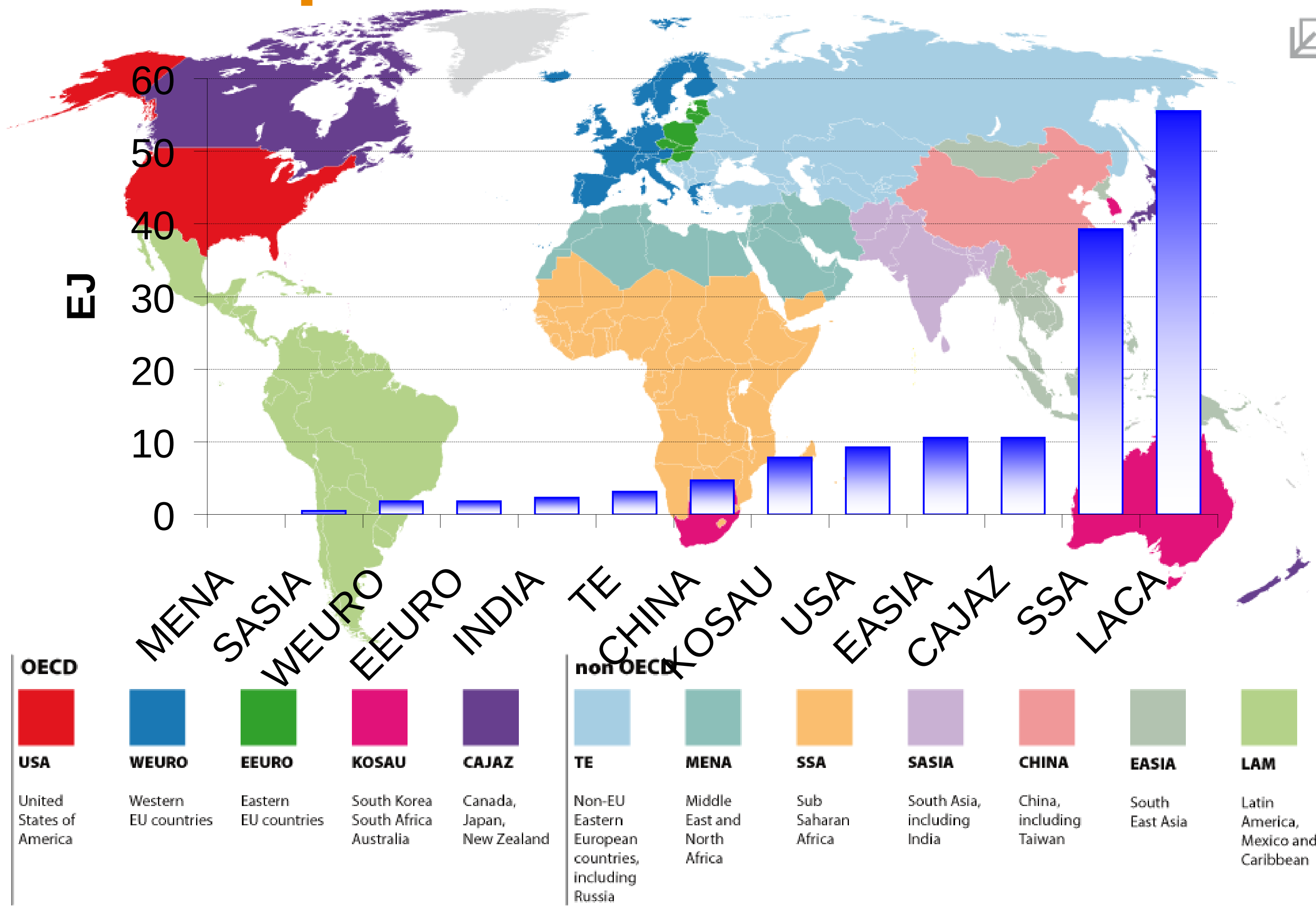
Biomass potential 2050



- Global potential: 148 EJ/yr

Carbon Capture and Storage

- Capture rate = 90%
- Cost of storing CO_2 underground is region-specific
  - it varies according to the estimated size of storage site
  - it increases exponentially as cumulative storage increases
    - MC of storing at 2GtC is equal to 14usd/tC for LACA and INDIA; 24 usd/tC for the USA, WEURO, SSA and CHINA; 47 usd/tC for TE and MENA.

Stringency of the policy

- Three carbon taxes which try to capture possible outcomes of future climate policy:
  - Global tax on all GHGs emissions
  - Start in 2015
  - Tax revenues are recycled lump-sum domestically
- Full immediate co-operation among all countries

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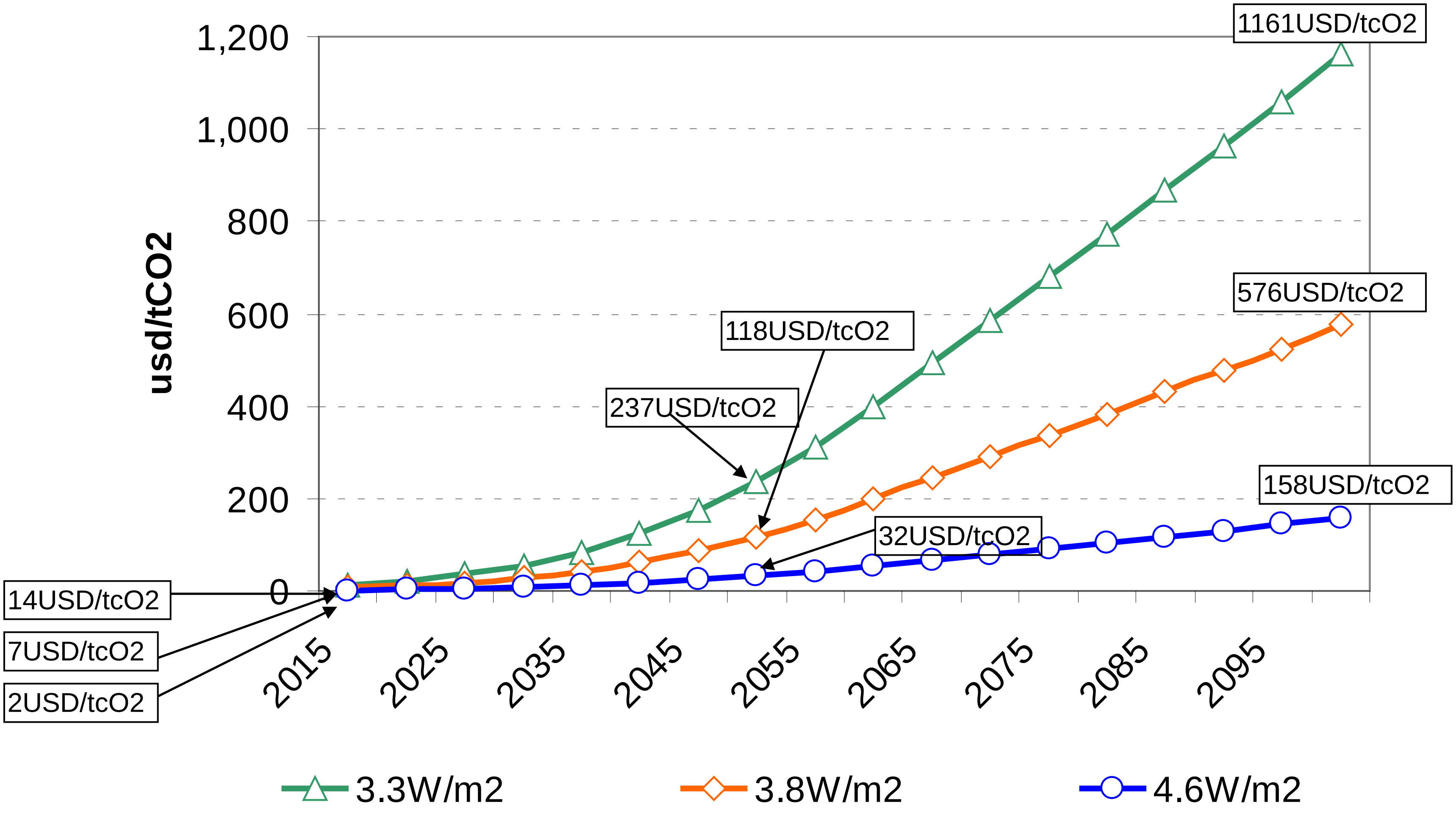
Carbon taxes



Carbon tax and negative emissions

- Optimality conditions require that the carbon tax reflects the discounted MC of increasing the stock of GHGs concentrations in the atmosphere

- "Negative" emissions reduce the stock of GHGs

- The carbon tax penalises emissions and rewards the absorption of emissions with a subsidy

Biomass supply

Biomass producers max π :

$$\underset{qwbio}{Max}\ p_{wbio} \cdot q_{wbio} - C(q_{wbio}) \qquad (1)$$

Subject to $qwbio_{n,t} \leq \overline{qwbio}_{n,t}$

$$p_{wbio} \geq \frac{\partial C(q^*_{wbio})}{\partial q^*_{wbio}} \qquad (2)$$

$$q^*_{wbio} = D_{wbio} + X_{wbio} \qquad (3)$$

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Biomass demand

$$Dwbio_{n,t} = WBIOigcc_{n,t} + WBIOpc_{n,t}$$

Firms that generate electricity with IGCC max π :

$$\underset{elbeccs}{Max}\ p_{elwbio} \cdot el_{BECCS} - C(el_{BECCS}) + tax \cdot \alpha \cdot el_{BECCS} \qquad \text{sub to} \qquad (1)$$

$$el_{BECCS}(n,t) = \min\{\beta F(n,t); \cdot\alpha\, CCS_{wbio}(n,t); \gamma\, K_{wbio}(n,t); \varsigma(n)\, O\,\&\,M_{wbio}(n,t)\} \qquad (2)$$

$$F(n,t) = \min\{(1-\eta(t))COAL(n,t); \eta(t)\, WBIOigcc(n,t)\} \qquad (3)$$

$$p_{elwbio} + tax \cdot \alpha = \frac{\partial C(el^{*}_{wbio})}{\partial el^{*}_{wbio}} \qquad (4)$$

$$WBIOigcc^{*} = el^{*}_{BECCS} \frac{1}{(\beta\eta(t))} \qquad (5)$$

Demand and supply

Equilibrium in the domestic market

$$Dwbio_{n,t} = WBIOigcc_{n,t} + WBIOpc_{n,t}$$

$$Dwbio_{n,t} = qwbio_{n,t} + Mwbio_{n,t}$$

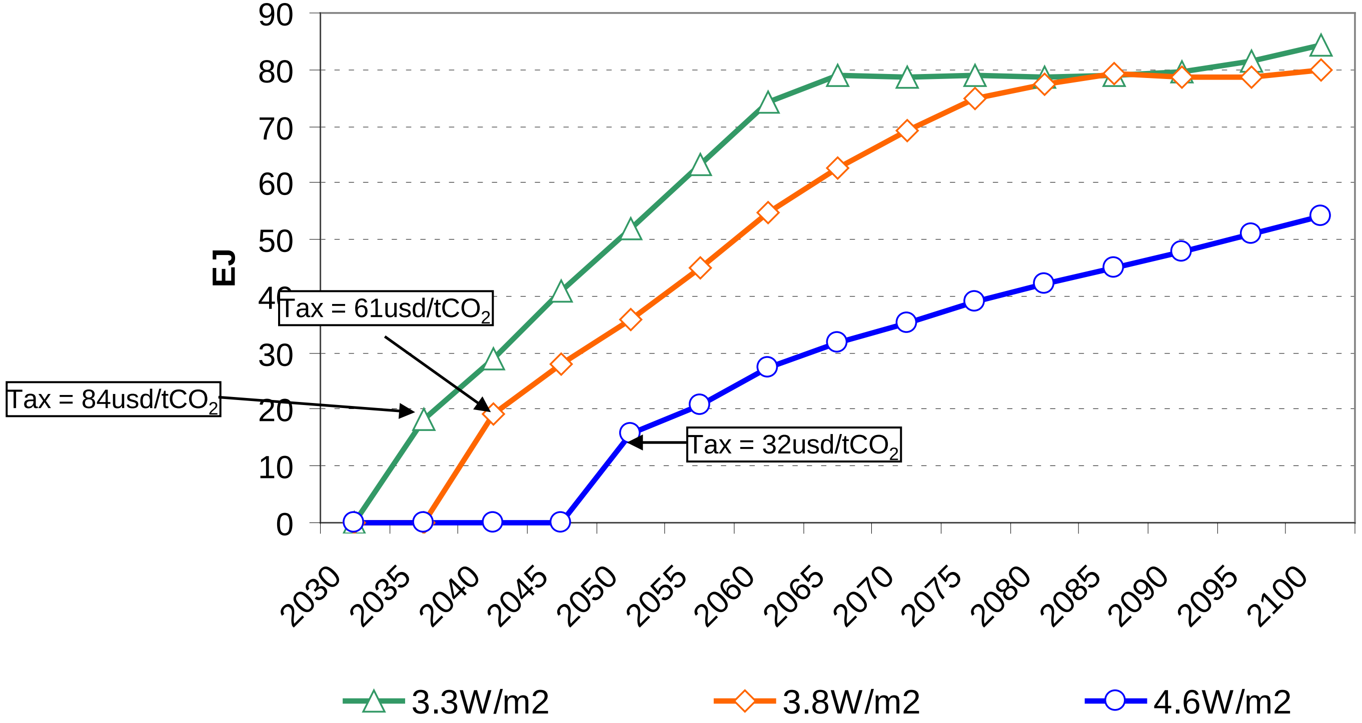
Equilibrium in the international market

$$\sum_n Mwbio_n = 0 \;\; \forall t$$

We iteratively search for the price that guarantees equilibrium in the international market: $pwbio_t$

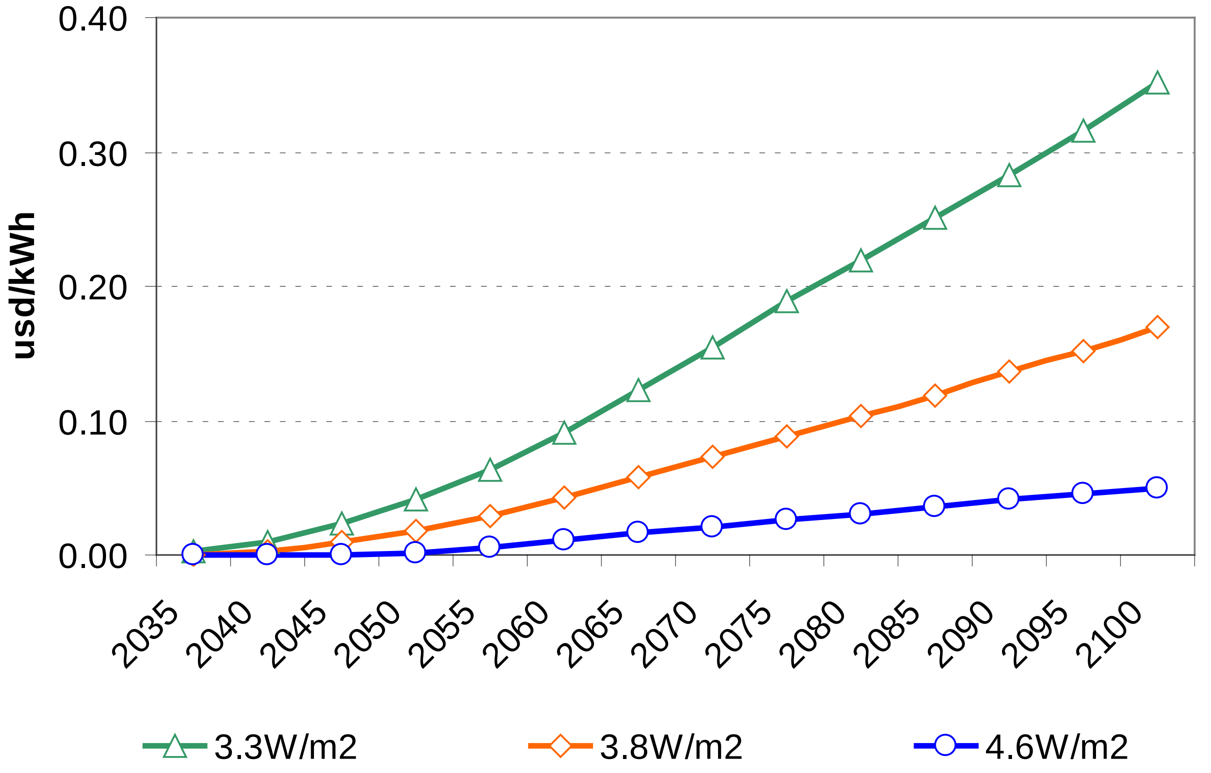
Results

Biomass international mkt - volume



- Market starts between 2035 and 2050
- Market volume 2100: 54-84 EJ/yr
  - more than 50% of the biomass consumed globally
  - more than 4% of TPES is traded in the biomass market in 2040 and 11% in 2100

Biomass international price



In the highest CT scenario, the price is equal to:

- 0.04 usd/kwh (0.11 usd/kwh electricity) in 2050
- 0.35 usd/kwh (1 usd/kwh electricty) in 2100

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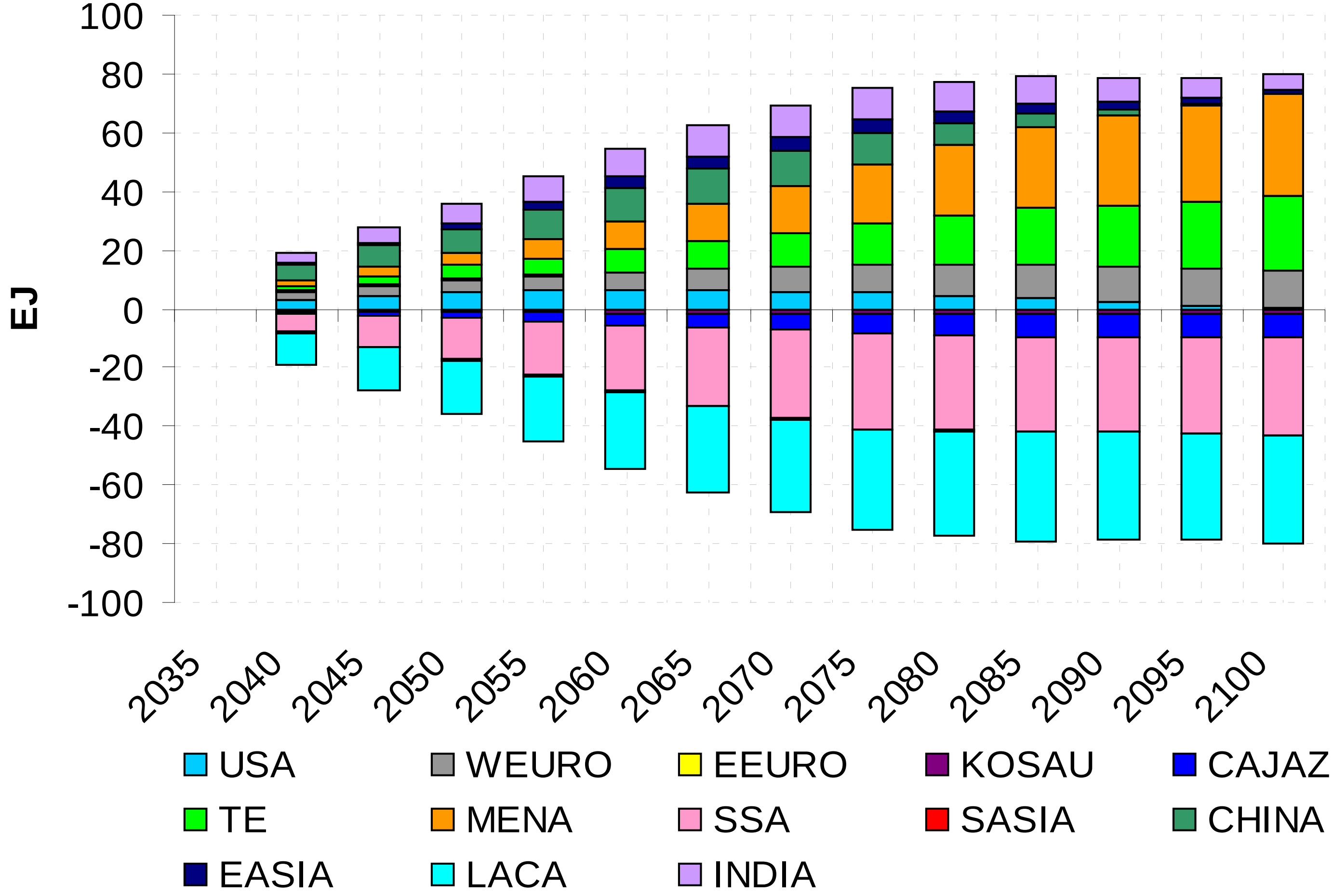
International market - 3.8W/m2



- LACA +SSA: 90% export
- MENA+TE+ WEURO: 30-90% import

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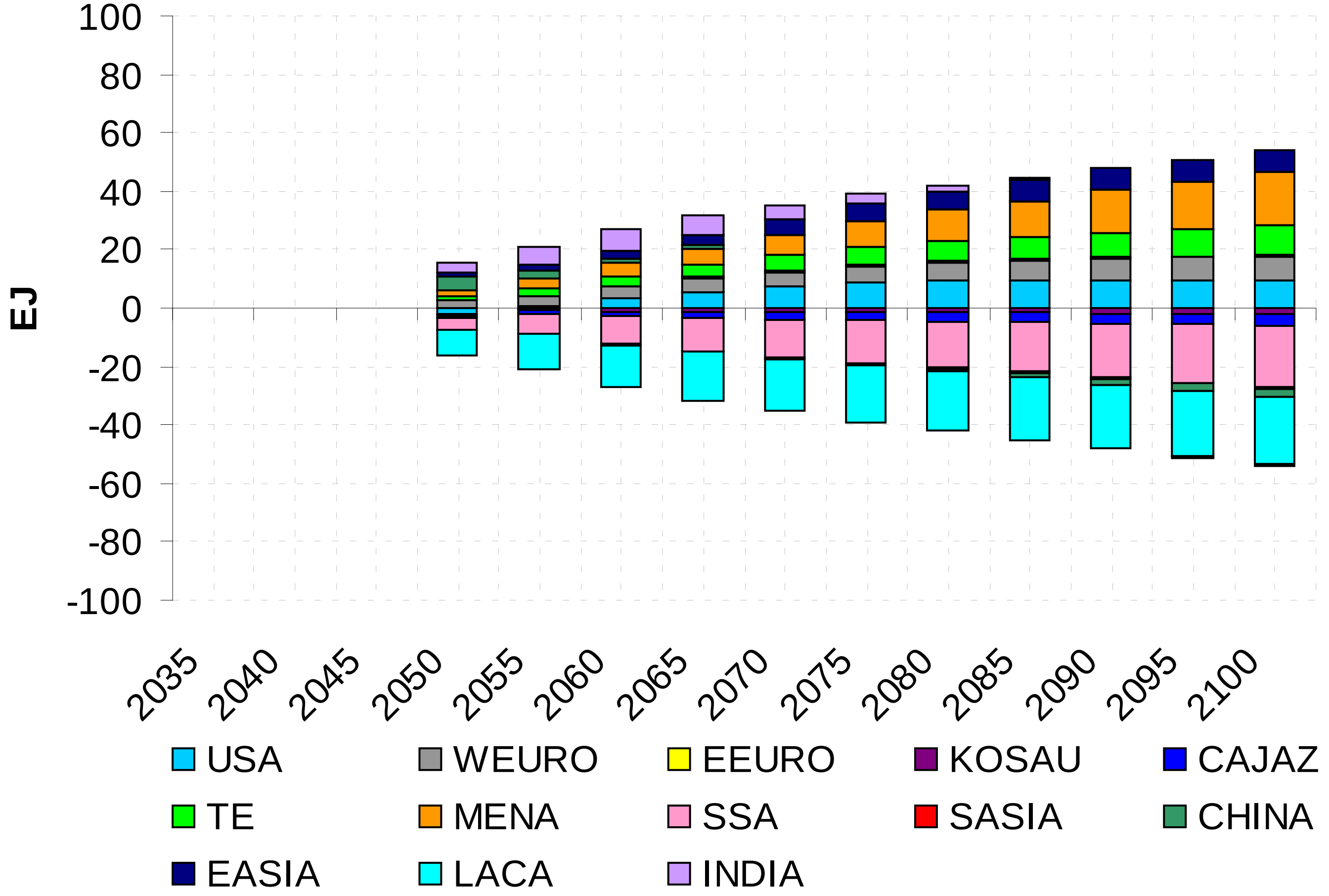
International market – 4.6 W/m2



- LACA +SSA: 80-90% export
- MENA+TE +WEURO: 40-70% import

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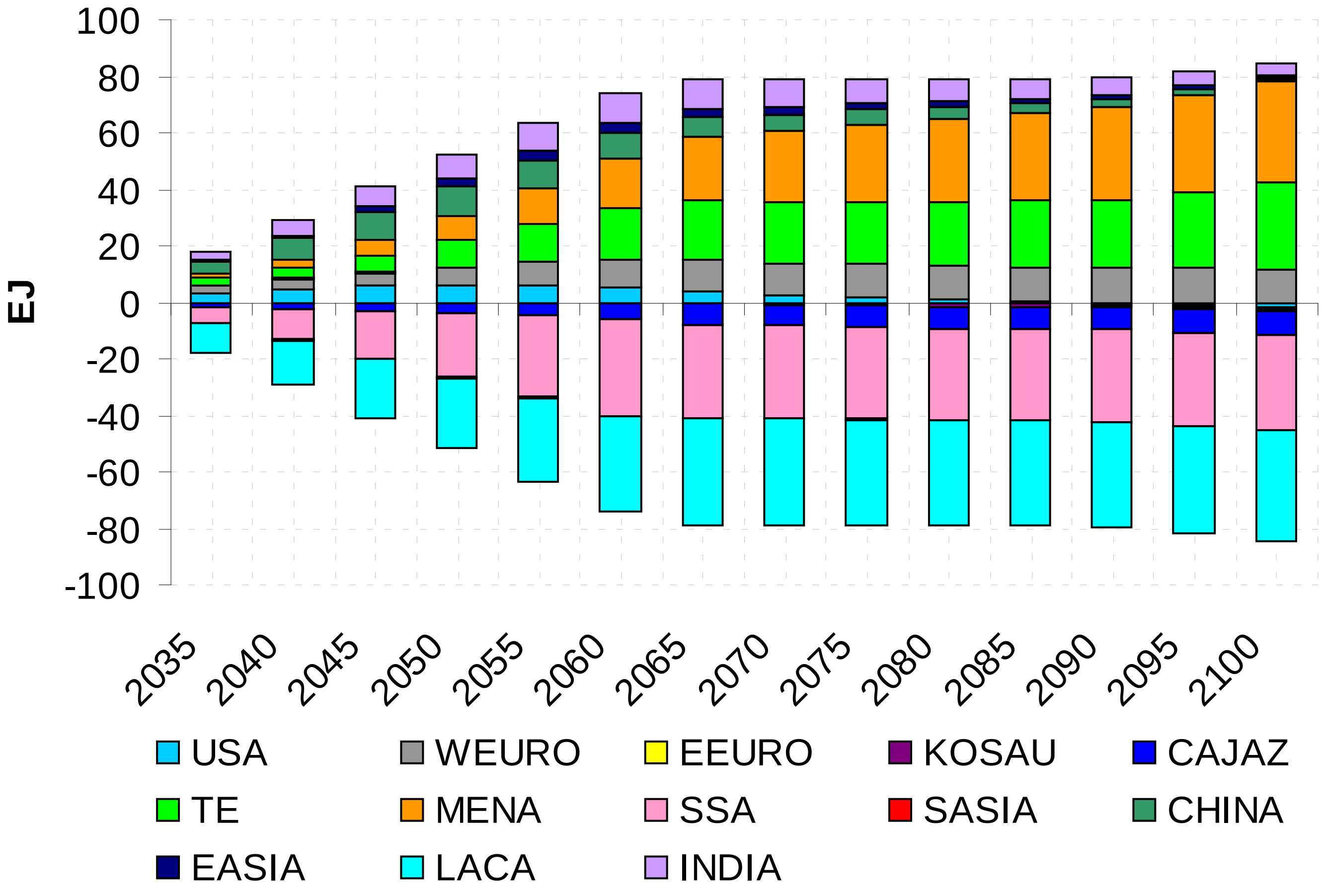
International market – 3.3 W/m2



- LACA +SSA: 90% export
- MENA+TE +WEURO: 40-90% import

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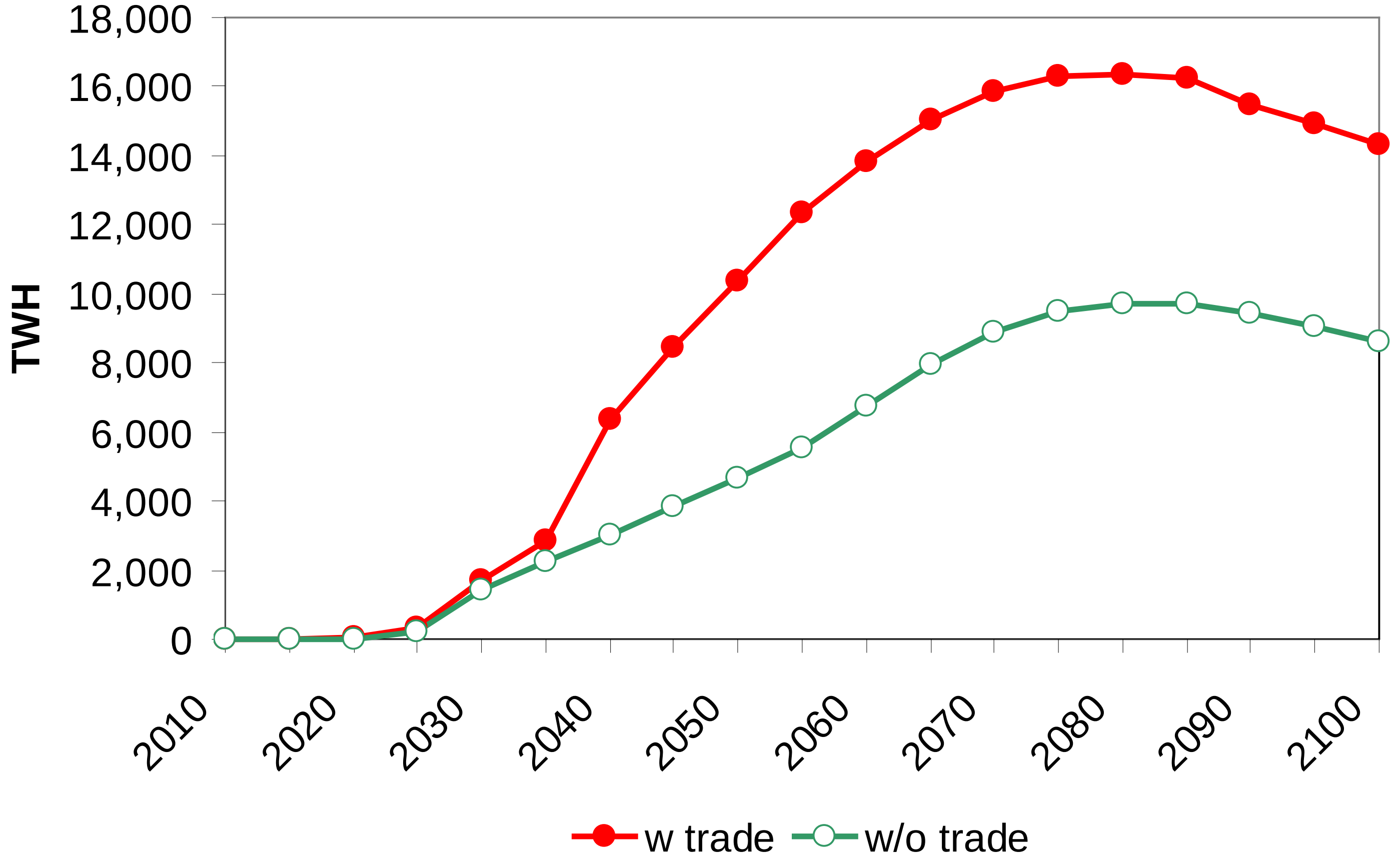
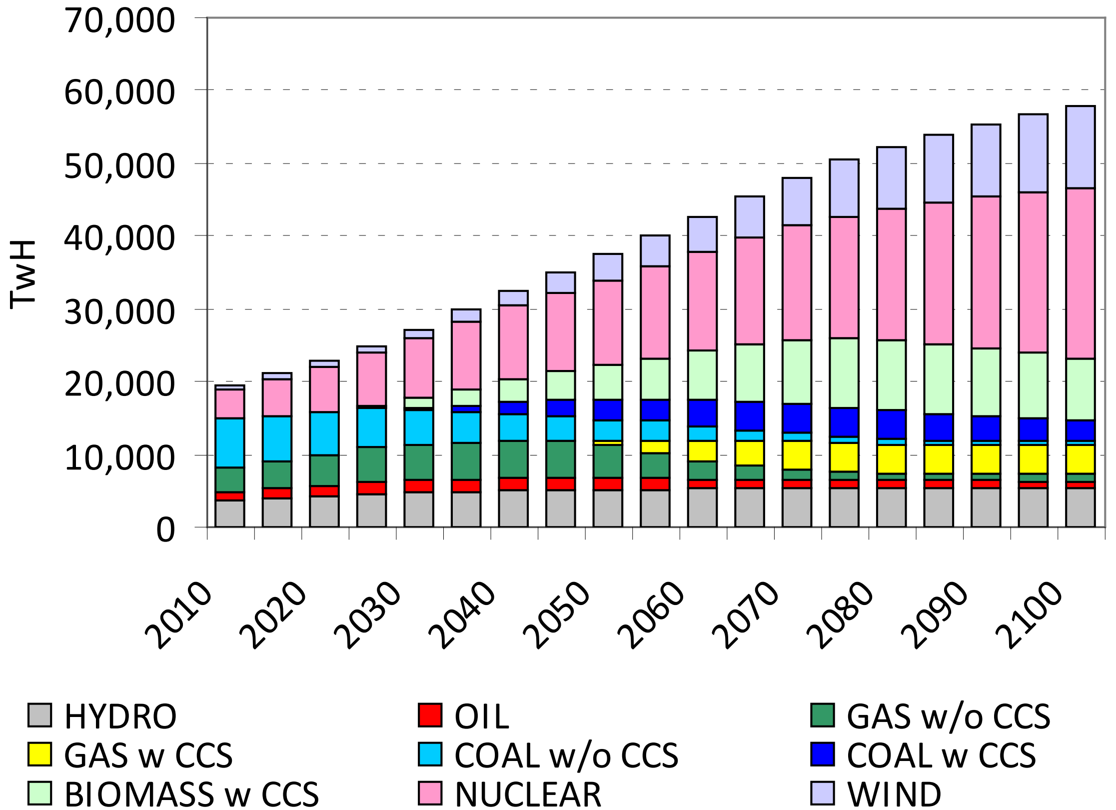
Power sector

Electricity from BECCS – 3.8 W/m2



- 2040: electricity from BECCS w/o trade 3,036 TWh (9% total electricity) w trade 6,355 TWh (19% total electricity)
- 2100: electricity from BECCS w/o trade 8,612 TWh (15% total electricity) w trade 14,315 TWh (24% total electricity)

Electricity mix w/o bio trade



- Share BECCS: 12% (2050), 15% (2100)
- Share coal w CCS: 7% (2050), 5% (2100)
- Share nuclear: 32% (2050), 41% (2100)

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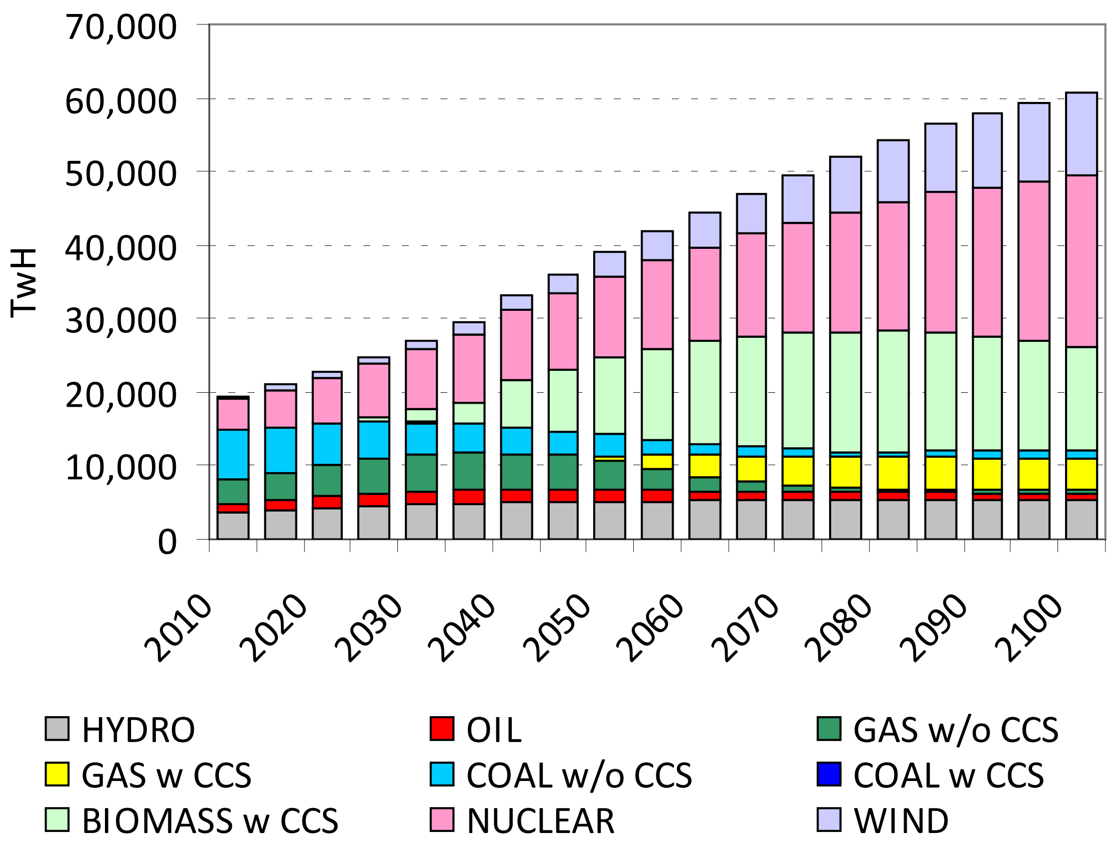
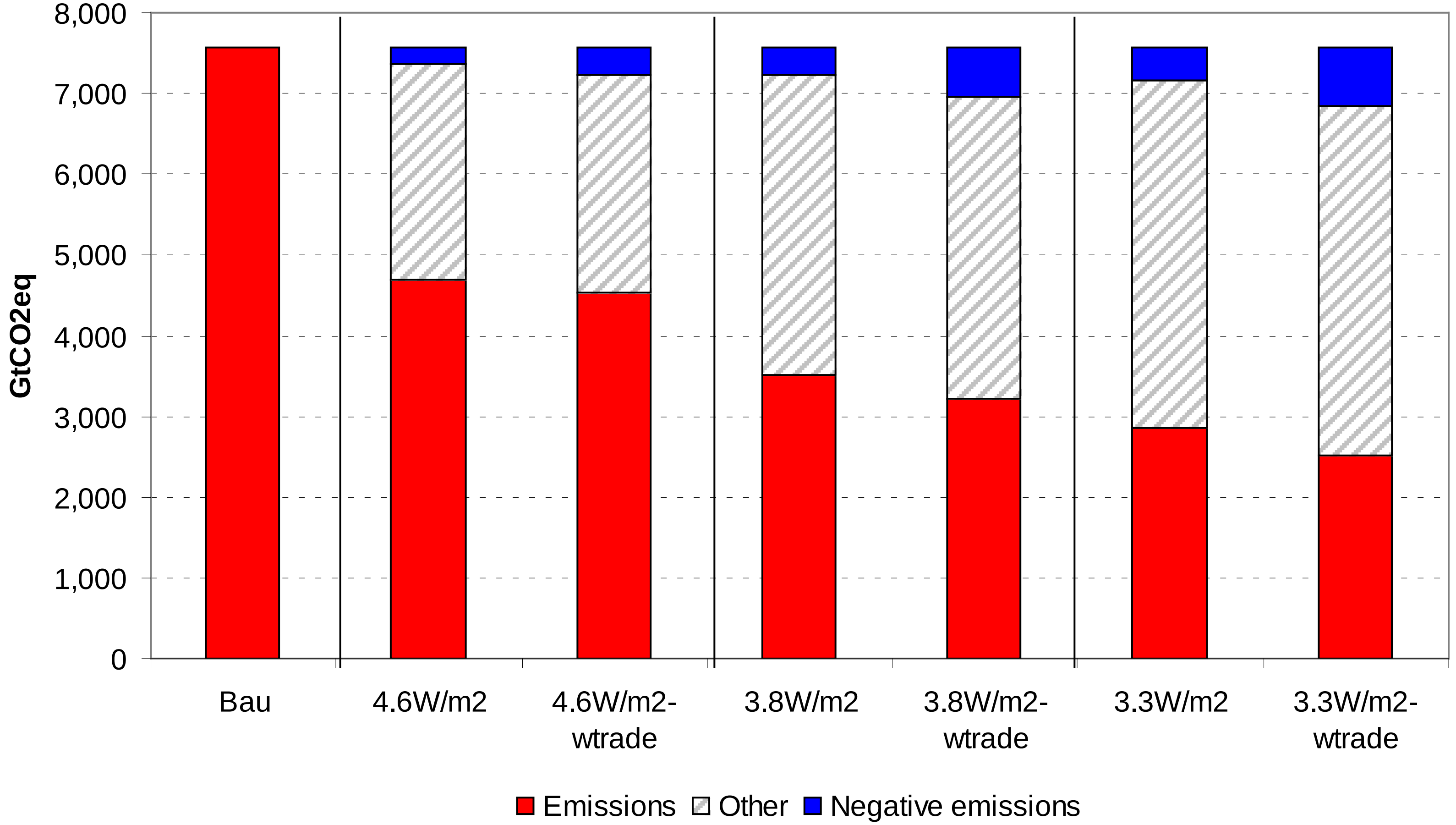
Electricity mix w bio trade



- Share BECCS: 27% (2050), 24% (2100)
- Share coal w CCS: 0.08% (2050)
- Share nuclear: 28% (2050), 38% (2100)
  - - 11% in 2050 and -29% (TE) and -20% (WEURO) in 2100.
  - + 9% in 2050 and +10% in 2100 KOSAU.

Optimal abatement

Cumulative abatement for 2010-2100



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Optimal abatement level

- Additional cumulative abatement 2010-2100 :
  - 150 $GtCO_2$ in 4.6 W/m^2
  - 300 $GtCO_2$ in 3.8 W/m^2
  - 340 $GtCO_2$ in 3.3 W/m^2
- Increase in emissions absorbed with biomass and CCS in 2100:
  - + 54% in 4.6 W/m^2
  - + 66% in 3.8 W/m^2
  - + 59% in 3.3 W/m^2
- Rediction in radiative forcing by 2100:
  - From 4.6 W/m^2 to 4.5 W/m^2 (-13 ppm)
  - From 3.8 W/m^2 to 3.5 W/m^2 (-25 ppm)
  - From 3.3 W/m^2 to 3.0 W/m^2 (-28 ppm)

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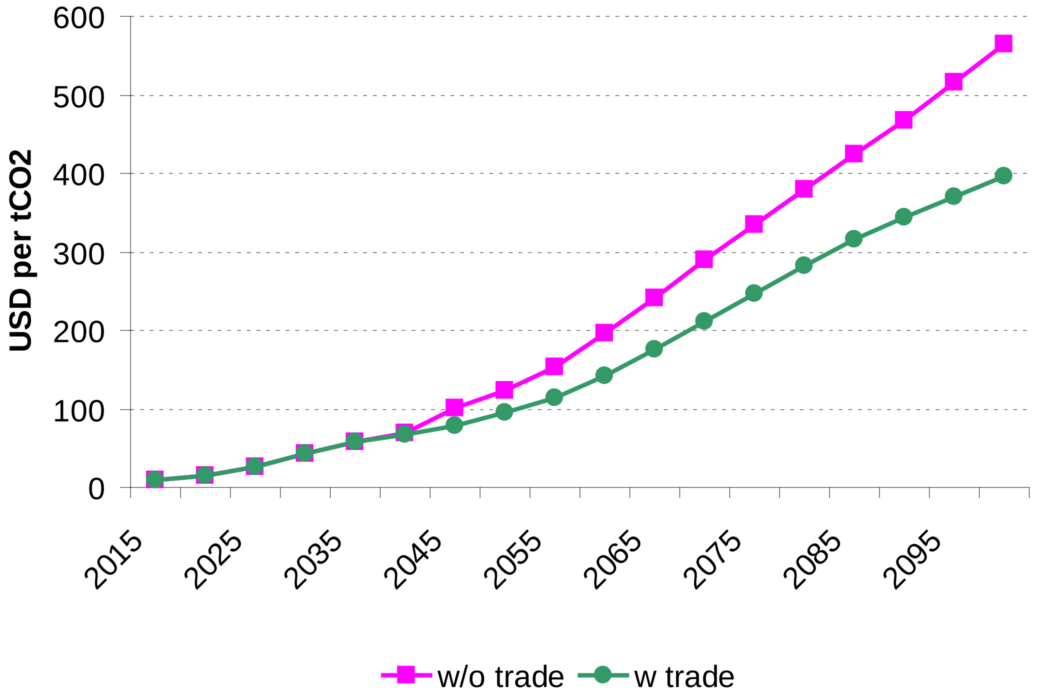
Trade of carbon permits and trade of biomass

Assumptions

- Stabilization scenario 3.8 W/m^2
- Cap-and-trade starts in 2015
- Allocations of carbon permits: emissions per capita
  - emissions permits are distributed in proportion to population
- BECCS provides: electricity and emissions permits

Biomass trade and carbon market: carbon price



- In 2040 the carbon price is reduced by 4%.
- In 2100 the reductions is much greater: a ton of CO_2 will cost 565 USD/tCO_2 when biomass is not traded while it will cost 397 USD/tCO_2

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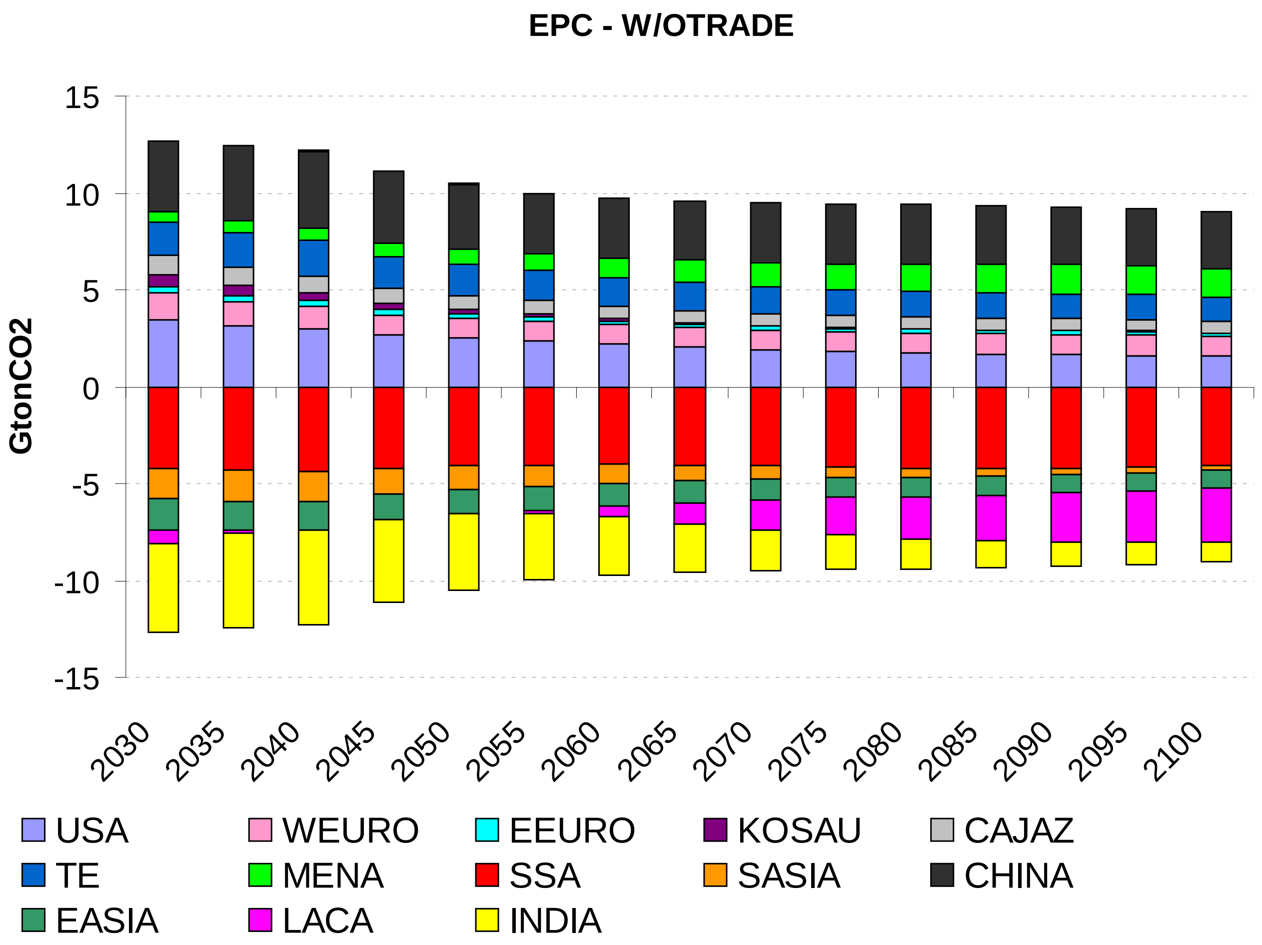
Carbon market: w/o bio trade



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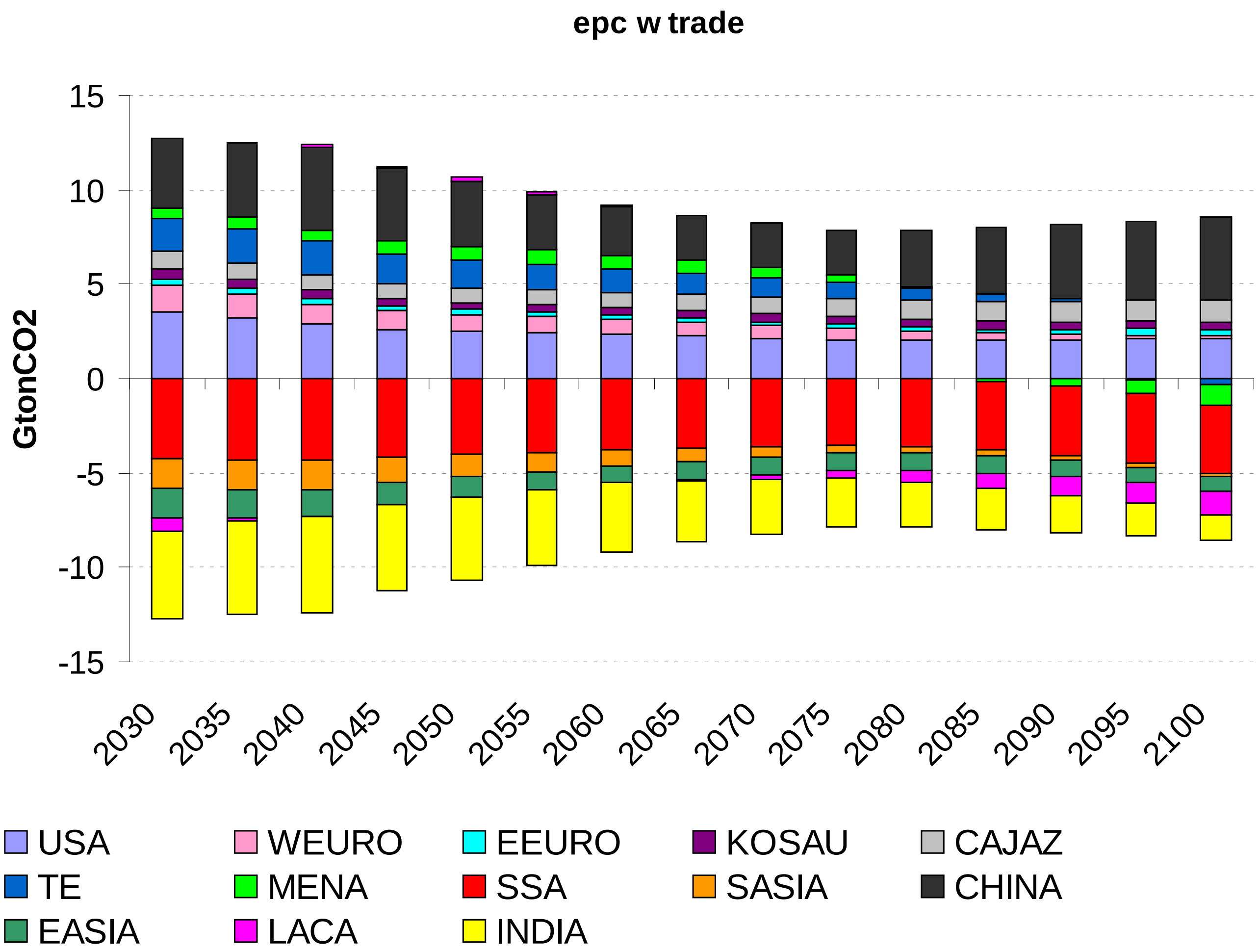
Carbon market: w bio trade



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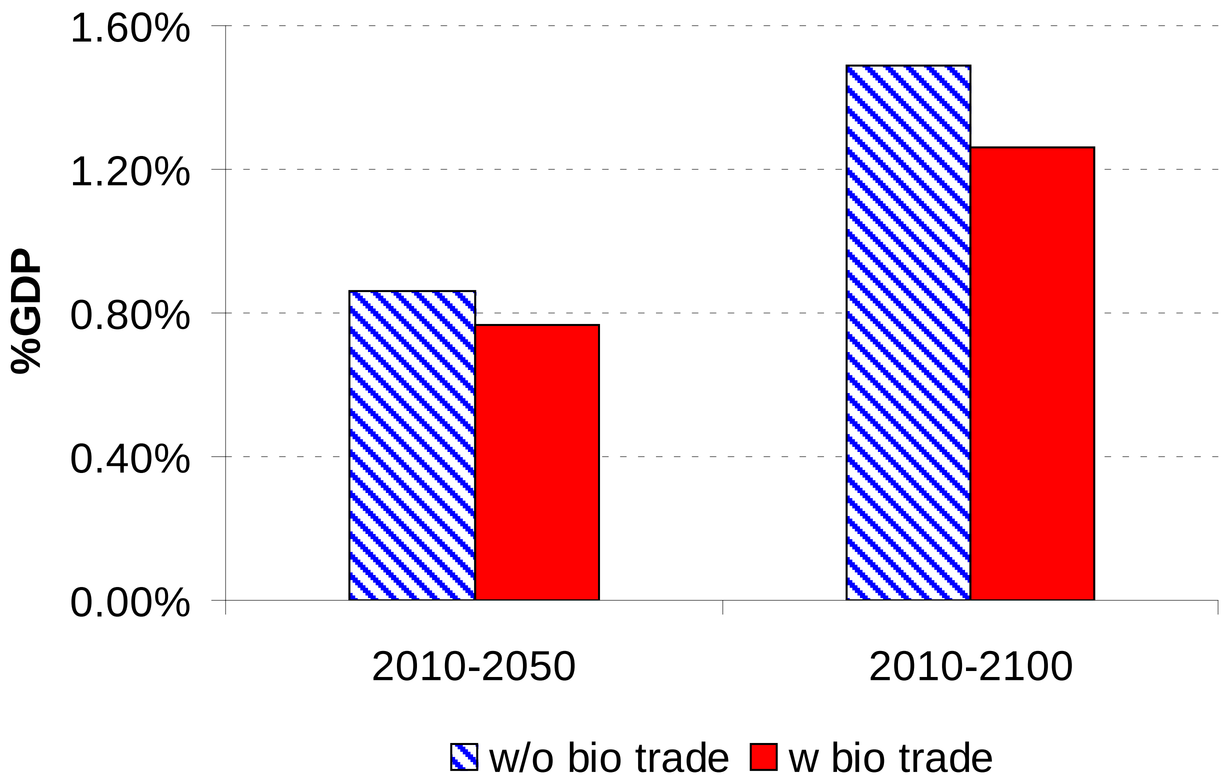
Policy cost – stabilization target 3.8W/m²



- Stabilization cost -11% (2010-2050) and -15% (2010-2100) with biomass trade
- Discount rate 5%

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Conclusions

- Big incentive in trading biomass
  - 50% of biomass consumed is from the international market
- Trade increases total abatement (CT) and reduces policy cost (C&T)
- Shift from trading intangible (carbon credits) to trading tangible (biomass)

But, is it feasible?

- High cost of biomass
- Energy security vs. economic efficiency trade off
  - WEURO: 25% of total electricity is from biomass, 87% is imported
  - Constraining trade will cost US$ 4 billion per year for 2010-2050 and US$ 6.2 billion per year for 2010-2100

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Limits

- Land competition with timber production
- BECCS competition with other forestland based mitigation strategies (e.g. carbon sequestration)

→ Soft link with the forest model GTM (Sohngen and Sedjo 2000; Sohngen and Mendelsohn 2003; Daigenault et al. 2012)

- Climate change impacts on future forestland use (e.g. fires) and implications on biomass supply

- Does not include shale gas which might reduce the demand of BECCS

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