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Externalities in the bottom-up energy system modeling framework

Analyses with the MARKAL model

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Scope

Definition of externalities

Methodology for internalisation of external costs

Scenario results & sensitivities

Combining externalities with other policies

Insights from modelling experiments

Externalities and energy system

External costs are introduced if

- the emissions from the energy system imply damages to the society
- the resulting costs are not included in the market price of energy

Internalisation of external costs intends to

- compensate for the health and environmental damages
- yield a full-cost pricing of energy services

Beside the air emissions, additional externality burdens are considered:

- solid and liquid wastes, risk of accidents, occupational exposure to hazardous substances, noise, others

Quantification and monetization of damages requires

- site-specific impact assessment of technologies
- comparisons between different energy chains and fuel cycles

External costs in the MARKAL framework

Different methods applicable:

1. Ex-post quantification of damages and valuation of impacts

   - no feedback into the optimisation

2. Externality charged to every unit of output

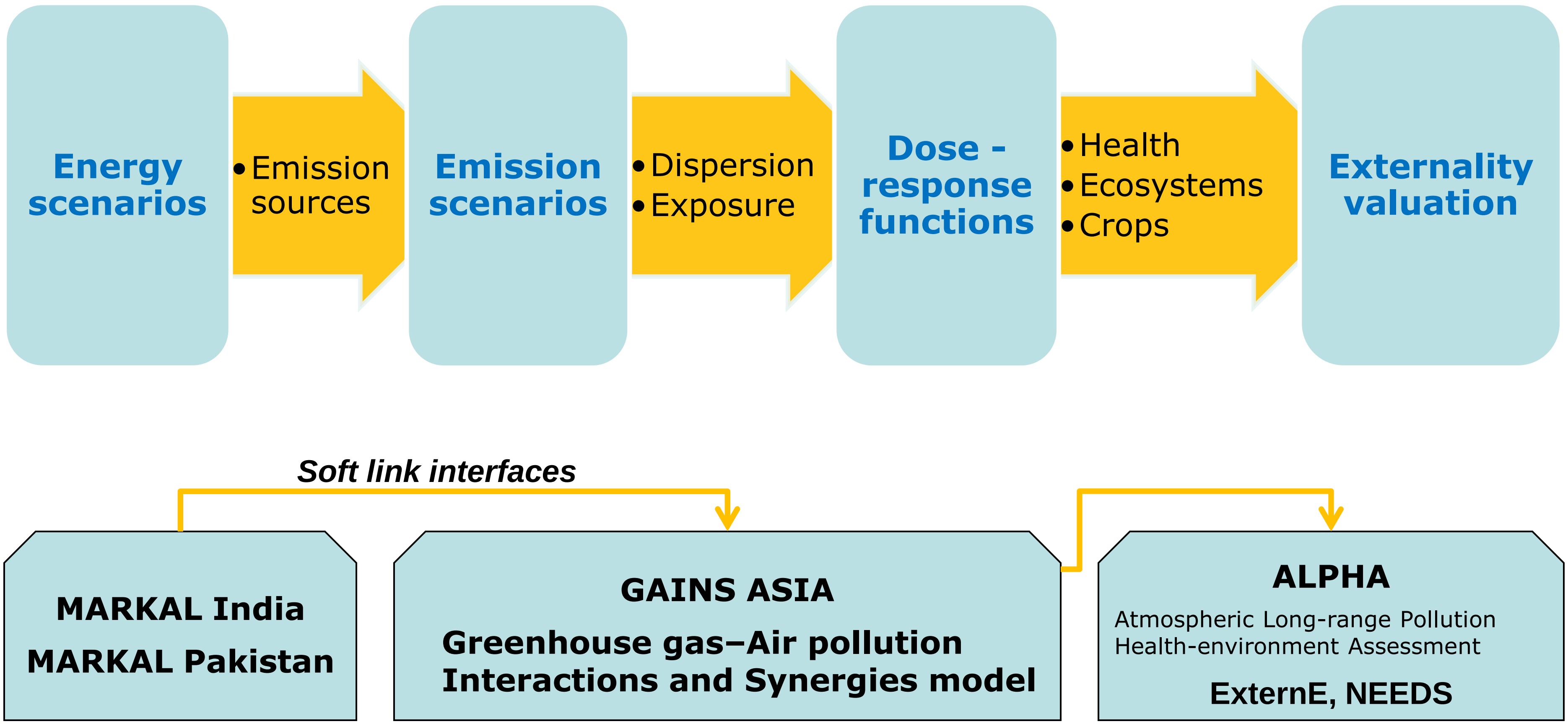
$$Z_{extern} = Z + \sum_t ExtCost_t * ypp * Q_t * (1+d)^{-1}$$

3. Damage function implying a tax on air emissions

$$DAM_{t,r} = \sum_{poll} DV_{t,r,poll} * EM_{t,r,poll}^{\beta}$$

Ex Post Analysis of Externalities using MARKAL

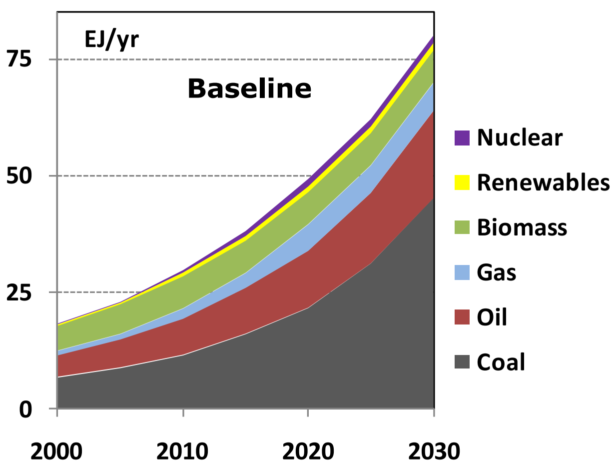
Impact pathway approach

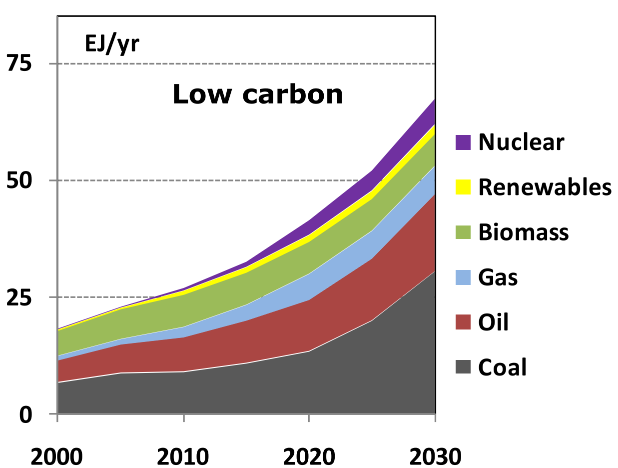


Economic Benefits of Climate Mitigation Policy

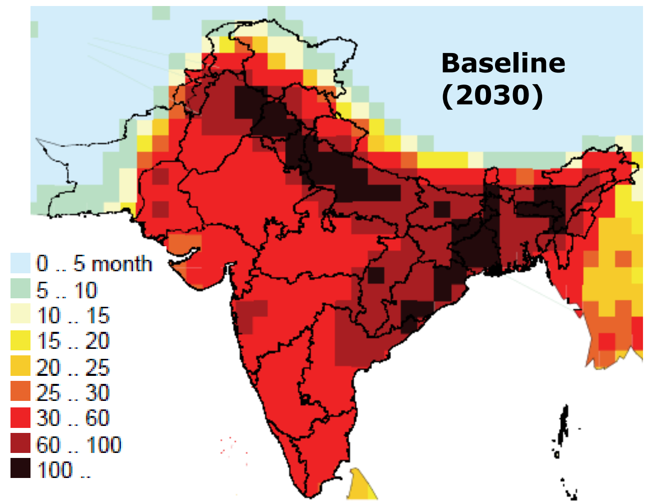
Example India

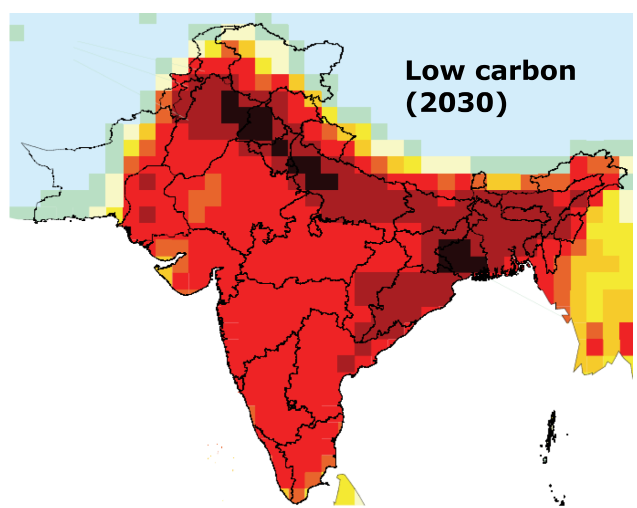
Energy projections: MARKAL





Emissions and health impacts: GAINS





Monetization of damages (€million/year)

Baseline	2030
Ozone mortality	377
Ozone morbidity	572
$PM_{2.5}$ mortality	227,442
$PM_{2.5}$ morbidity	86,655
Total	**315,046**

Low carbon	2030
Ozone mortality	304
Ozone morbidity	461
$PM_{2.5}$ mortality	185,314
$PM_{2.5}$ morbidity	70,605
Total	**256,684**
Co-benefit	**58,362**

Integration in the Global Markal Model (GMM)

Main features

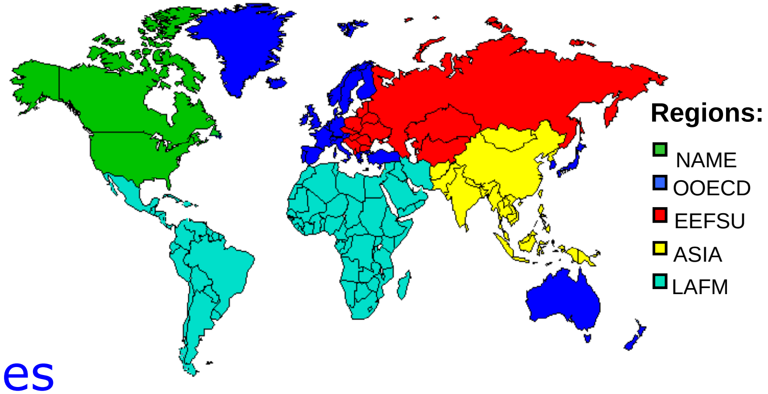
“Bottom-up” techno-economic model → Explicit representation of technologies

Optimisation under perfect foresight assumptions

Time horizon 2000-2050, 10-year steps

Partial equilibrium → Elastic demands

Energy system of five world regions →



Multi-regional trading of selected commodities

Endogenous technological learning

Learning spill-over across regions

Internalisation of externalities in power sector

Basic assumptions

- External costs from local pollution (SO_2, NO_x, PM) and/or CO_2 internalized in the power sector

- External costs for each power plant in ¢/kWh derived from the EU ExternE-Project

- Externalities adjusted for regional differences in population density, fuel quality, power-plant efficiency and application of emission-control systems

Determinant for scaling	Unit	SO_2	NO_x	PM	CO_2
Average damage cost per pollutant	*€$_{1995}$/t*	8000	7000	14000	19
Population density adjustment factor (AF)	*High*	1.5	1.5	1.5	n.a.
	Medium	1	1	1	
	Low	0.75	0.75	0.75	
Reference thermal efficiency	*%*	**coal**	**oil**	**natural gas**	
		41	40	55	

Scaling of external costs

Options considered

1. Population density

- *NAME, EEFSU, LAFM – Medium*
- *ASIA, OOECD - High*

2. Improved conversion efficiency

$$ExtCost_t = ExtCost_{original,t=0} * \frac{\eta_{original,t=0}}{\eta_t}$$

3. Welfare in regions (GDP/cap)

$$ExtCost_{t,r} = ExtCost_{original,t,r} * \frac{GDP^r_{ppp,t}}{GDP^{EU}_{ppp,t=0}}$$

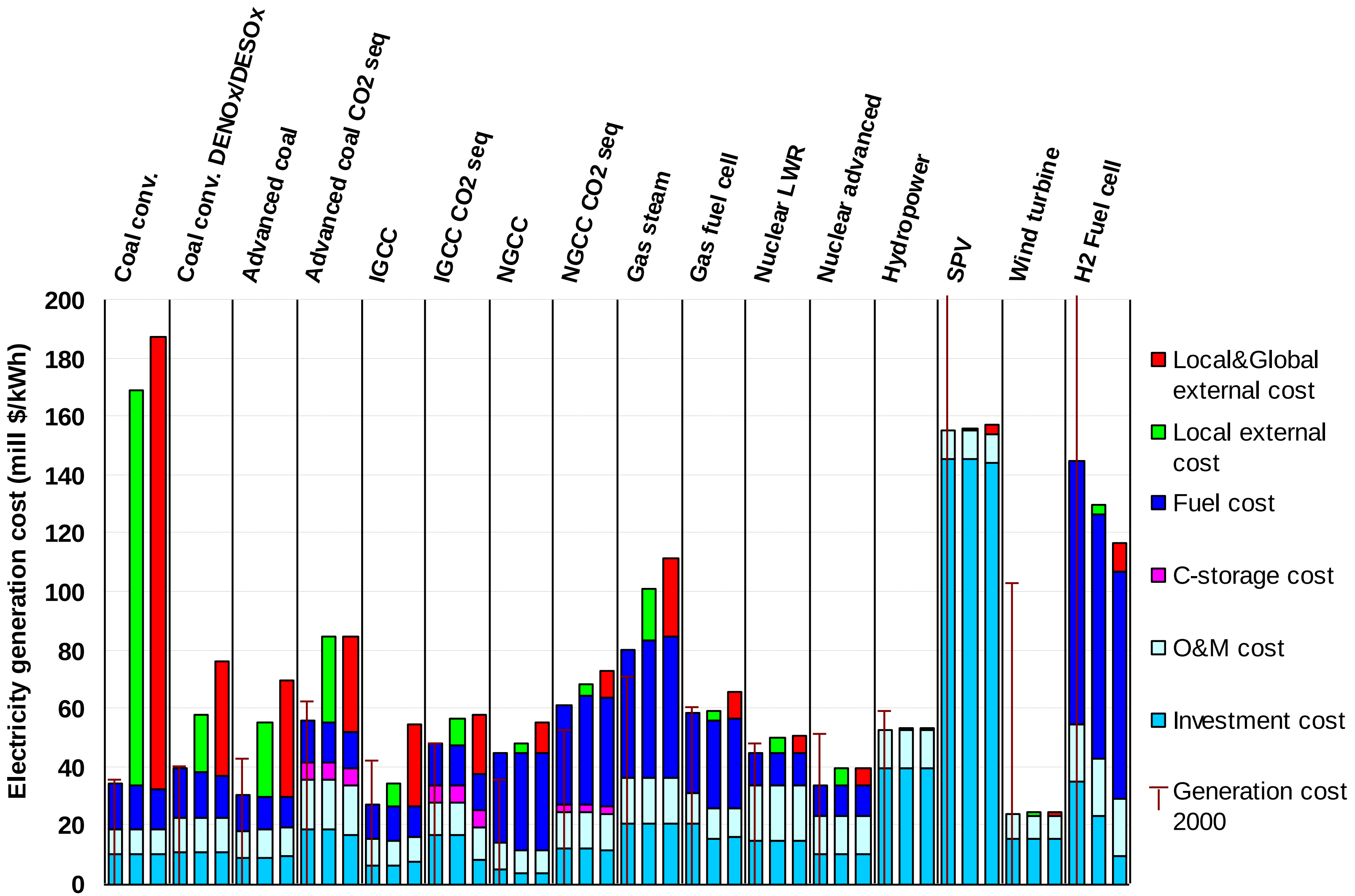
$$ExtCost_{t,r} = ExtCost_{original,t,r} * \frac{GDP^r_{mex,t}}{GDP^{EU}_{mex,t=0}}$$

Technology	External cost (cent/kWh)			
	excl CO_2		*incl CO_2*	
Fossil-fuel based power plants	*min*	*max*	*min*	*max*
Coal conventional	8.1	19.0	9.8	20.8
Coal conventional with $DeSO_x/DeNO_x$	1.2	1.8	2.9	3.6
Coal conv. with $DeSO_x/DeNO_x$ and CO_2 seq	1.5	2.3	1.8	2.9
Coal advanced	1.6	2.4	2.8	3.8
Coal advanced with CO_2 seq	1.8	2.8	1.9	3.0
Coal IGCC	0.5	1.0	2.2	2.9
Coal IGCC with CO_2 seq	0.6	1.2	1.2	1.7
Natural Gas Combined Cycle (NGCC)	0.3	1.1	0.8	1.7
NGCC with CO_2 sequestration	0.3	1.3	0.7	1.5
Gas steam conventional	1.1	3.0	1.9	3.8
Cogenaration gas turbine	1.2	2.3	2.2	3.3
Oil conventional	1.3	5.9	2.5	7.2
Non-fossil power plants				
Nuclear plant - Light Water Reactor (LWR)	0.5		0.5	
Hydro-electric plant (small and large)	0.1		0.1	
Solar photovoltaics (SPV)	0.1		0.3	
Wind turbine	0.1		0.1	
Biomass power plant	0.3		0.4	
Geothermal electric	0.1		0.4	

Total electricity generation cost analysis

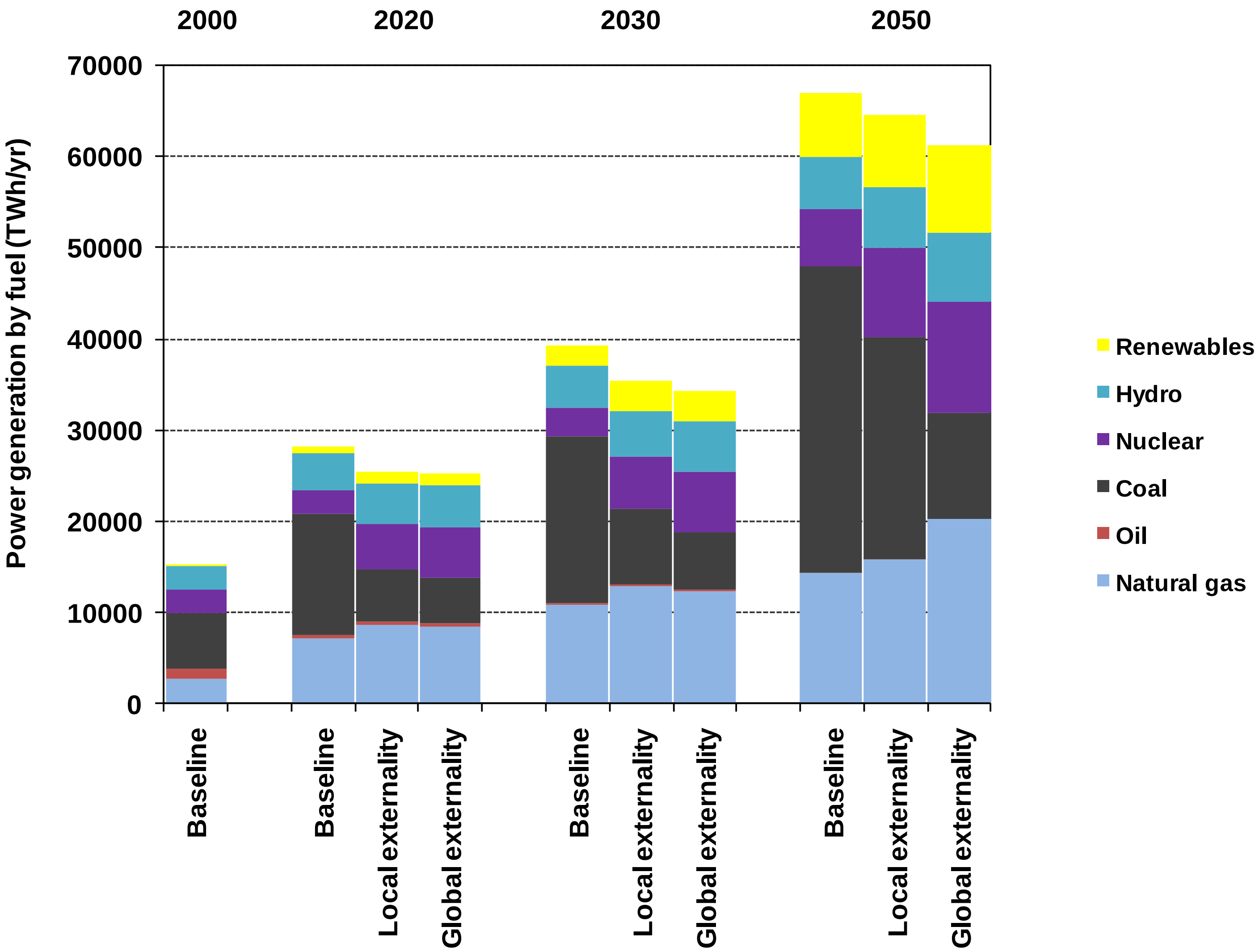
Example Asia, year 2050

$$TGC = \frac{I * CRF}{Q} + \frac{FIXO\&M}{Q} + \frac{VARO\&M}{Q} + \frac{F}{Q} + \frac{E}{Q}$$



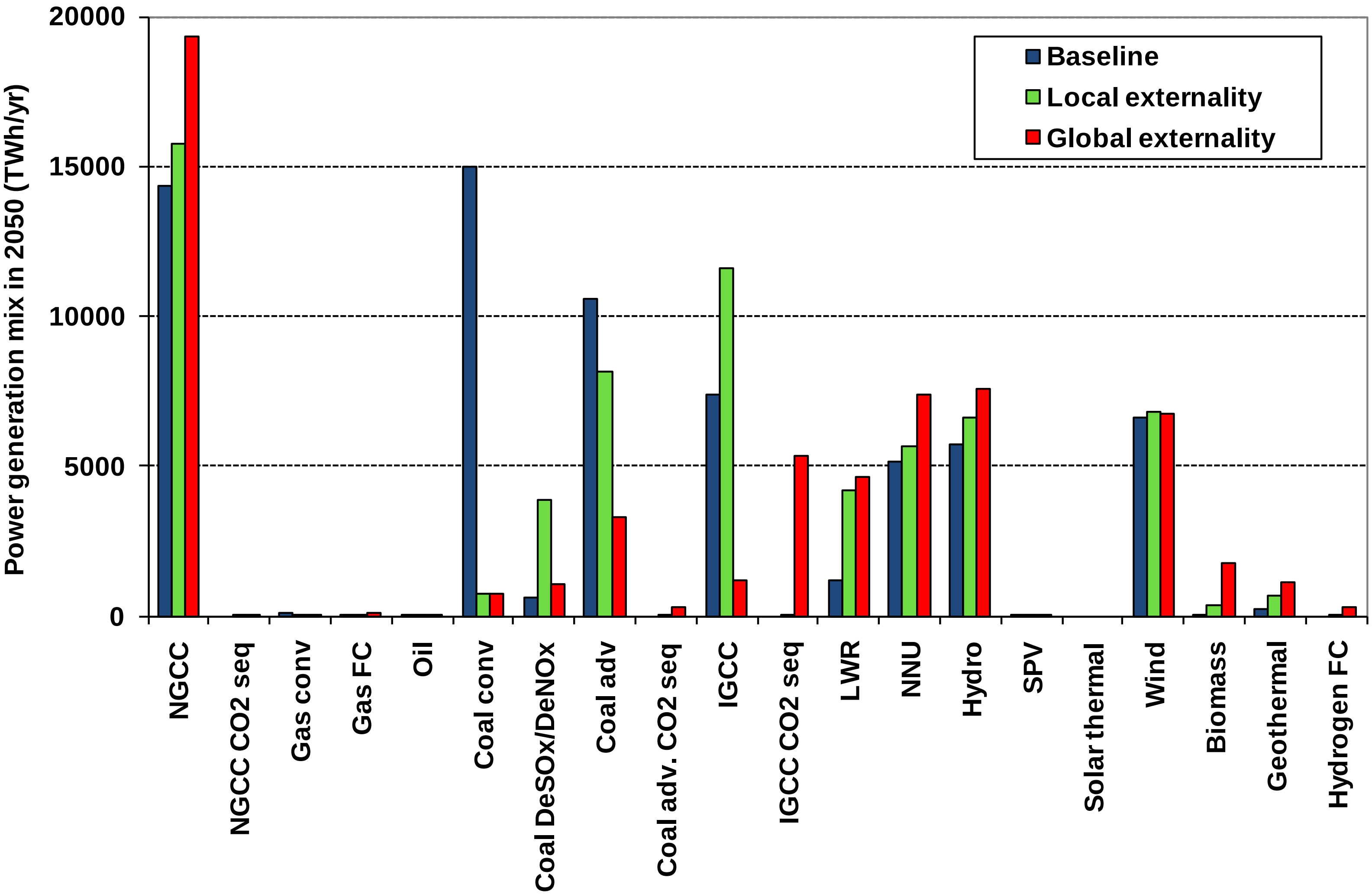
Development in global electricity production

Fuel mix changes due to integration of externalities



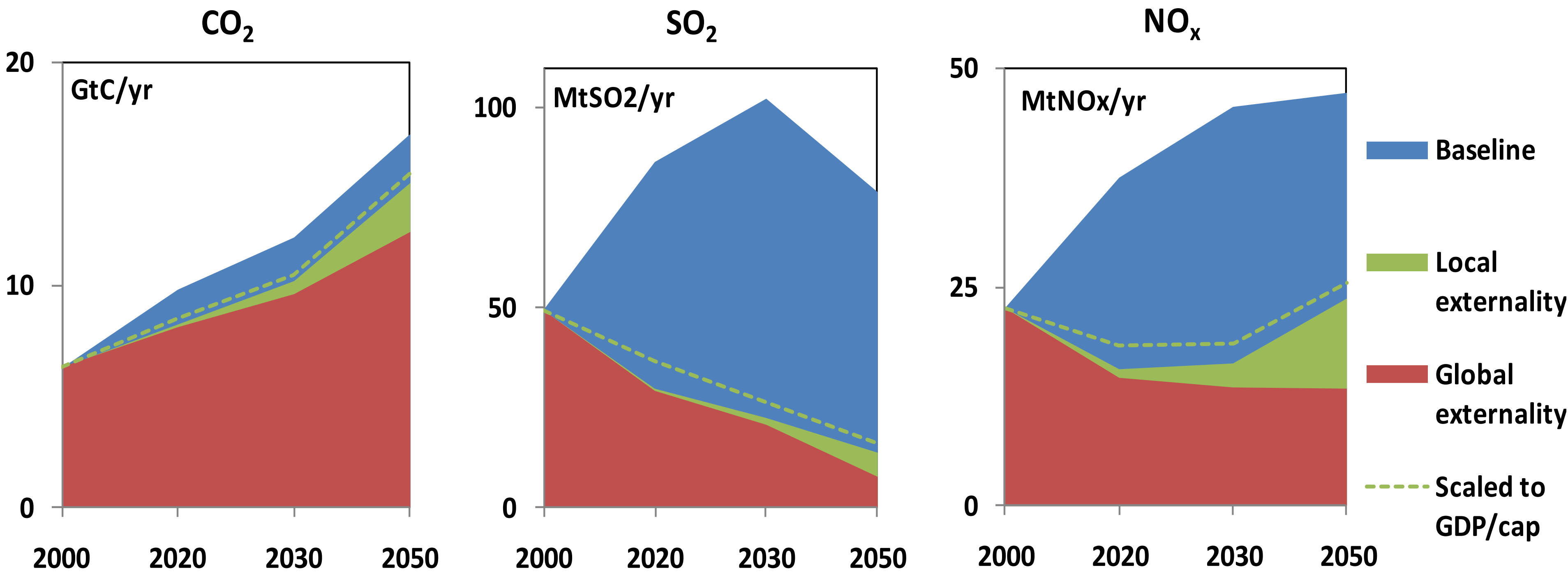
Impact on electricity generation profile

Technology portfolio in 2050



Global air emissions

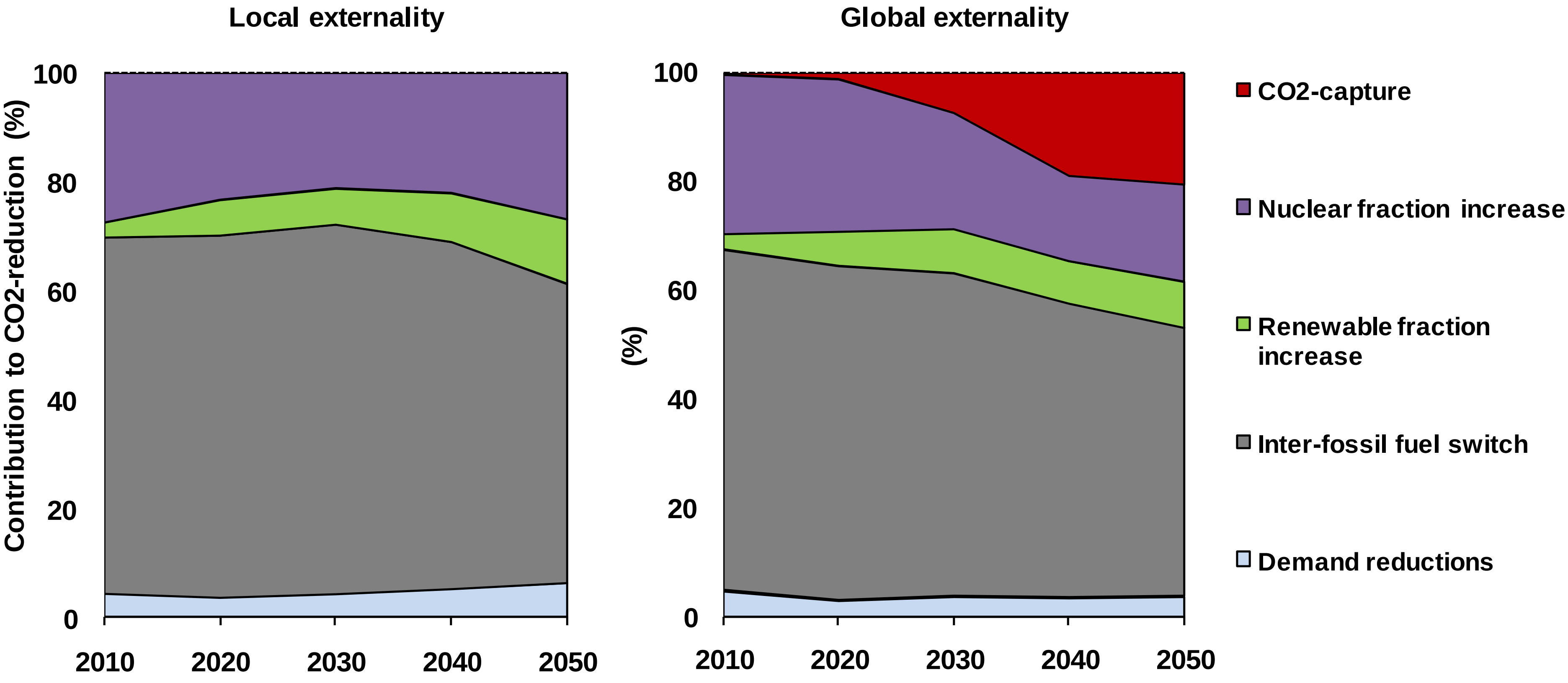
CO_2 from all sources; SO_2/NO_x from power sector



- Alternative scaling of externalities with GDP results in lower cost penalty, still the impact on emissions is significant.

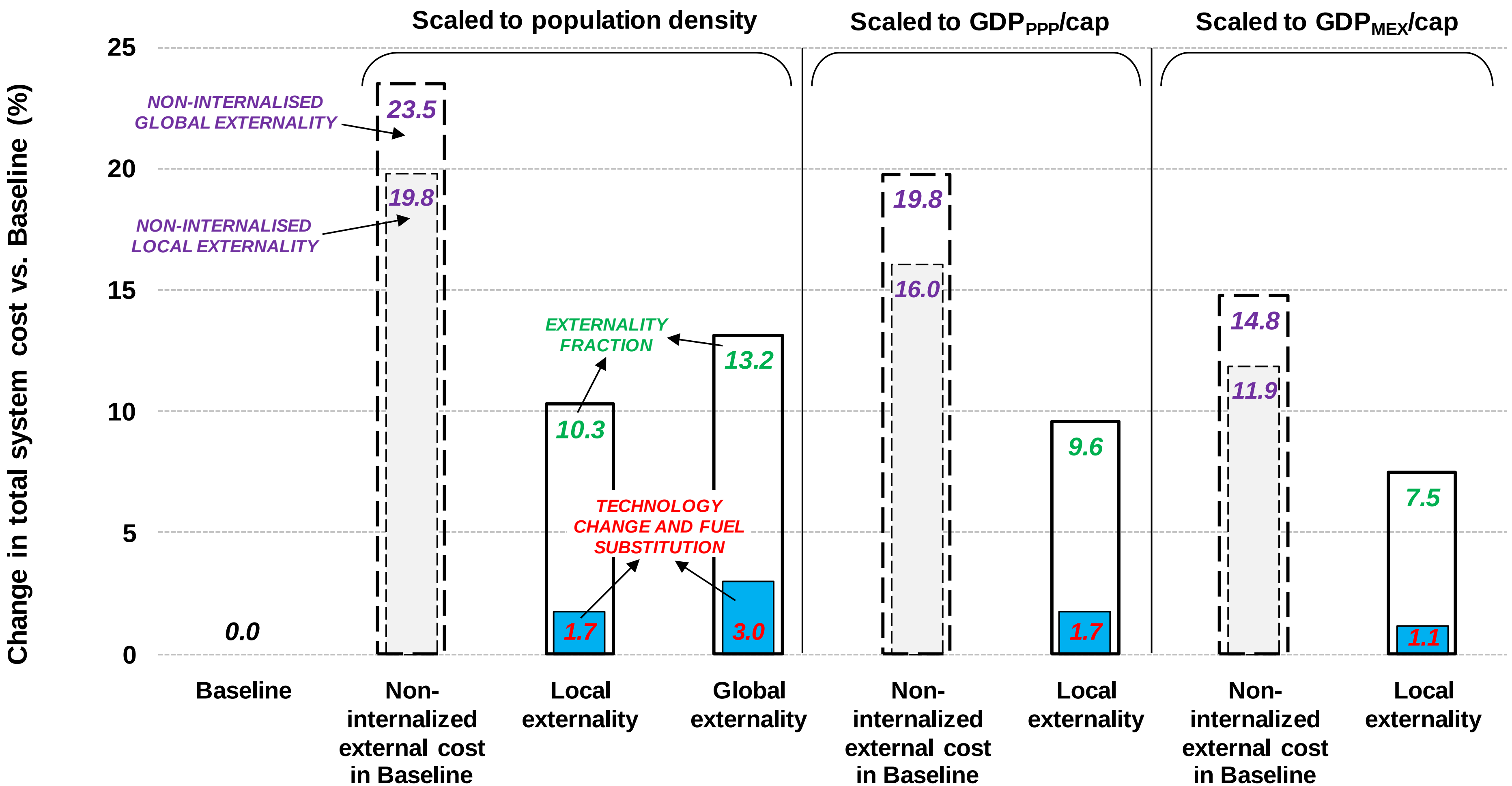
CO_2 emissions reduction components

Relative to the Baseline



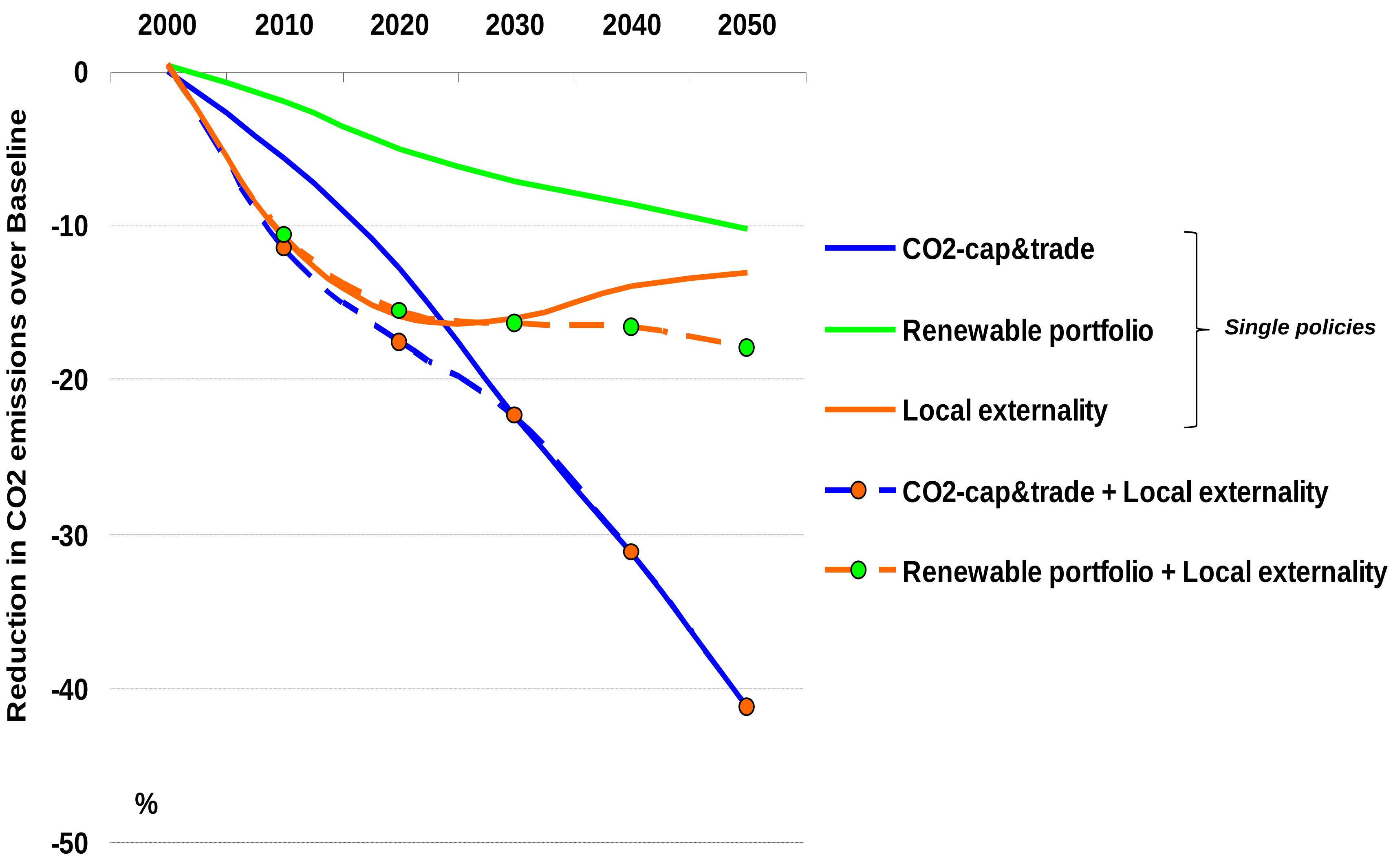
Change in the cumulative energy system cost,

including external cost fraction



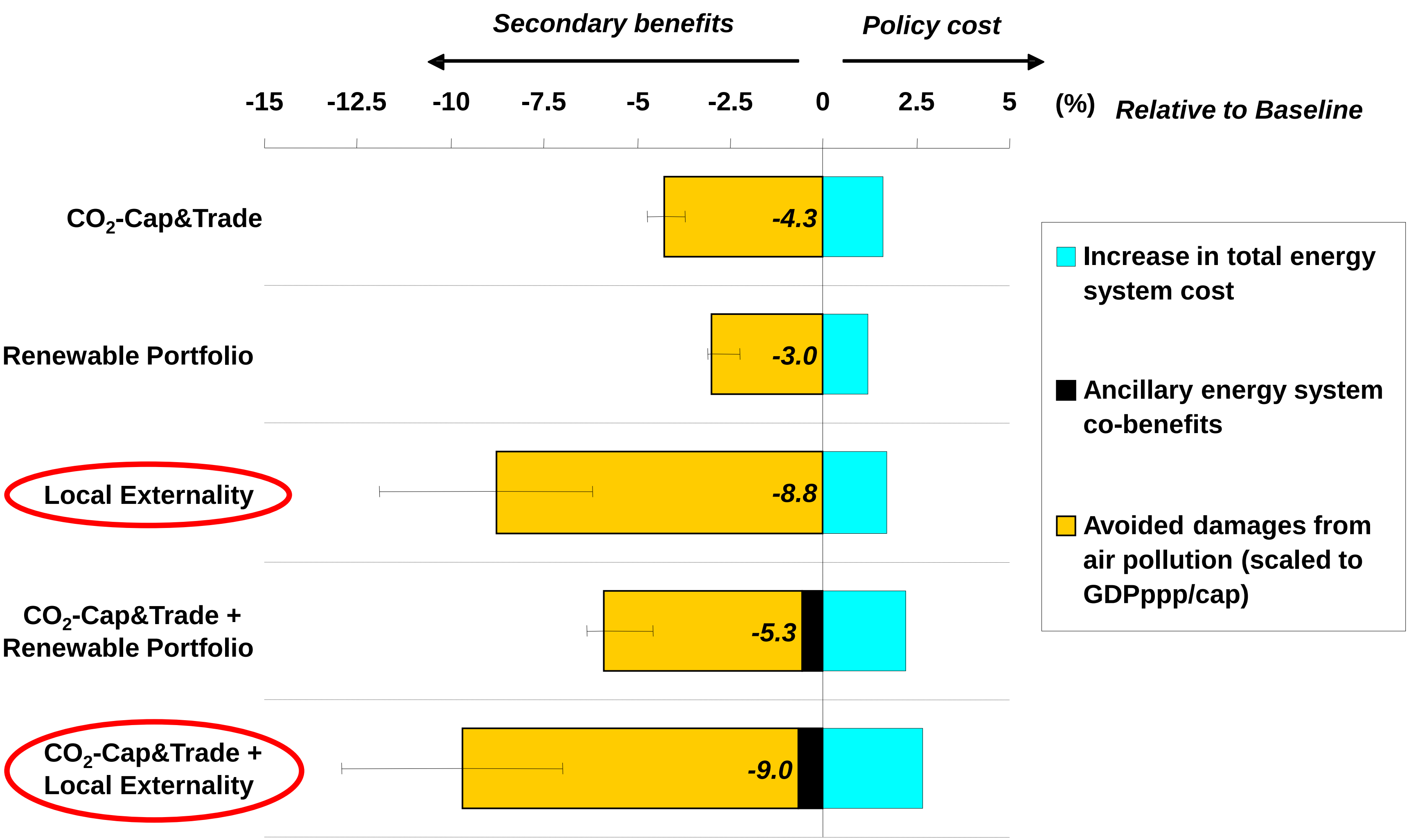
Synergies in combined policy adoption

Global CO_2 emission reductions



Cost and Benefit Assessment

Large uncertainties



Conclusions

- Monetary evaluation of the (co)benefits of emission control strategies provides relevant insights for decision makers
- Quantification of impacts based on MARKAL-inputs, but outside the optimization procedure, brings detailed assessment of a policy, when linked with dedicated air quality models (GAINS)
- Externalities integrated in the MARKAL's cost function allows to balance trade-offs between environmental ambition and the economic implications
- Modeling results indicate a large scope of co-benefits resulting from the parallel application of different policy instruments
- Monetization of health & environmental benefits are associated with a wide range of uncertainties and controversies
- If the externality analyses are used in an international policy context, it is challenging to attribute economic values to non-market goods: human life and ecosystems