The Role of Biomass & Carbon Capture and Storage In Robust Energy Portfolios

Jana Szolgayová, Sabine Fuss, Nikolay Khabarov, Michael Obersteiner

Forestry Program
International Institute for Applied Systems Analysis
Laxenburg, Austria

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Motivation

- Assessing the importance of (B)CCS for robust long-term climate risk mitigation
- Renewables vs. BCCS $\Rightarrow$ economic implications of negative emissions
- Uncertainty & risks: scientific, market, policy, technological, macro-economic $\Rightarrow$ build stylized model factoring in uncertainties

Research Questions

- Optimal operations/investments (e.g. retrofitting or refurbishments) at the plant level?
- Energy mix composition from the top-down view? $\Rightarrow$ Adopting types of capacity, which e.g. respond differently to fuel price volatility, can provide substantial diversification benefits.
- Do changes in profit distributions over time offer an additional source of diversification benefits?
- What is the role of BCCS in the wider energy mix?

Methodology

- New framework of analysis integrating different methodologies: investment & operational decisions at plant level (real options model) $\Rightarrow$ cost distributions informing large investor (e.g. large energy company or a region) of diversification potential (portfolio approach using the Conditional Value-at-Risk (CVaR) as a risk-measure)
- Robustness: if the investor has no knowledge as to which scenario (CO_2 price/socio-economic) will materialize, what is the portfolio that would perform best, even if the worst case came true?
- Time structure: taking into account the changes in distributions over time, we capture characteristics of the profits' time strcuture.

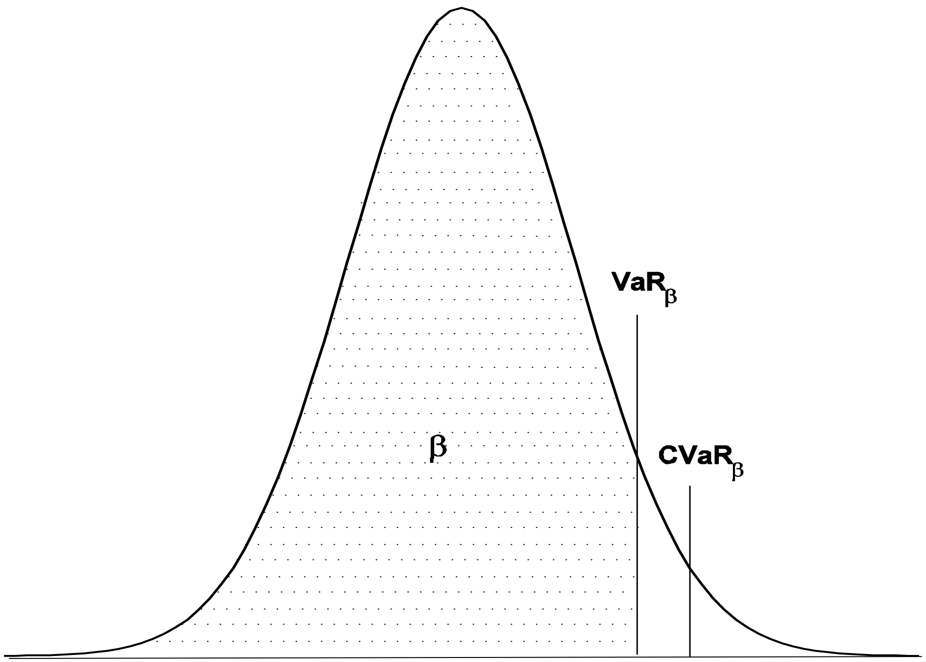
Portfolio Theory

- Trade-off between risk and return: efficient frontier (Markowitz, 1954)
- Two disadvantages when applied to (real) investments in the energy sector:

(1) return/cost distributions often non-normal, thus mean-variance inadequate (Fortin et al, JEM 2008 $\Rightarrow$ use of Conditional Value-at-Risk)

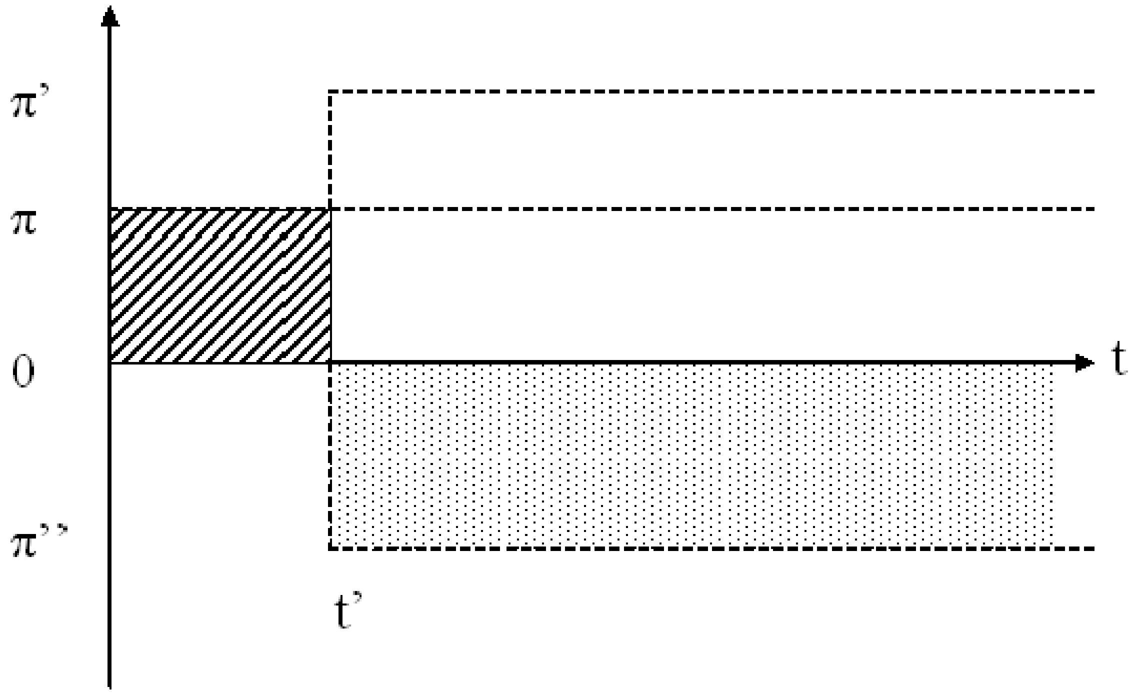
(2) current applications mostly static, i.e. myopic (Szolgayová et al, ETEP 2010 introduce dynamics)

Risk Measure



The β-VaR corresponds to the β-percentile of the distribution, whereas the β-CVaR is the mean of the random values exceeding VaR. ⇒ Capture tail information ignored by mean-variance approach.

Real Options Modeling



Cost of waiting — π Immediate profits

Avoided Losses — π' π'' Potential future profits

New Dimensions of this Model

- Two sources of uncertainty, forecasting and assignment of probabilities to scenarios difficult:

(1) Ignorance about the stabilization target, which will be adopted ⇒ uncertainty about the carbon price

(2) Lack of knowledge about the future development of socio-economic factors, technological change, etc.

- **⇒ the technology mix should be of a composition, which performs best, even if the worst case materializes**
- **Allow for diversification benefits due to different time structure of technologies.**

Robust Portfolio Problem

$$CVaR_{\beta}(x^*) = \min_{x} \max_{s,t} CVaR_{\beta}^{s}(x)$$

y = cost distributions of different technologies, u = auxiliary variables, e = vector of ones, x = technology portfolio shares, q = sample size, m = cost expectations, s = scenario, t = sub-period

Reduce to LP problem:

$$\min_{x,\alpha,u} v$$

$$v \geq \alpha_{s,t} + \frac{\sum_{k=1}^{q} u_{k,s,t}}{q(1-\beta)}$$

$$e^T x = 1,\ m_{s,t}^T x \leq \Pi_{s,t},\ x \geq 0,\ u_{k,s,t} \geq 0$$

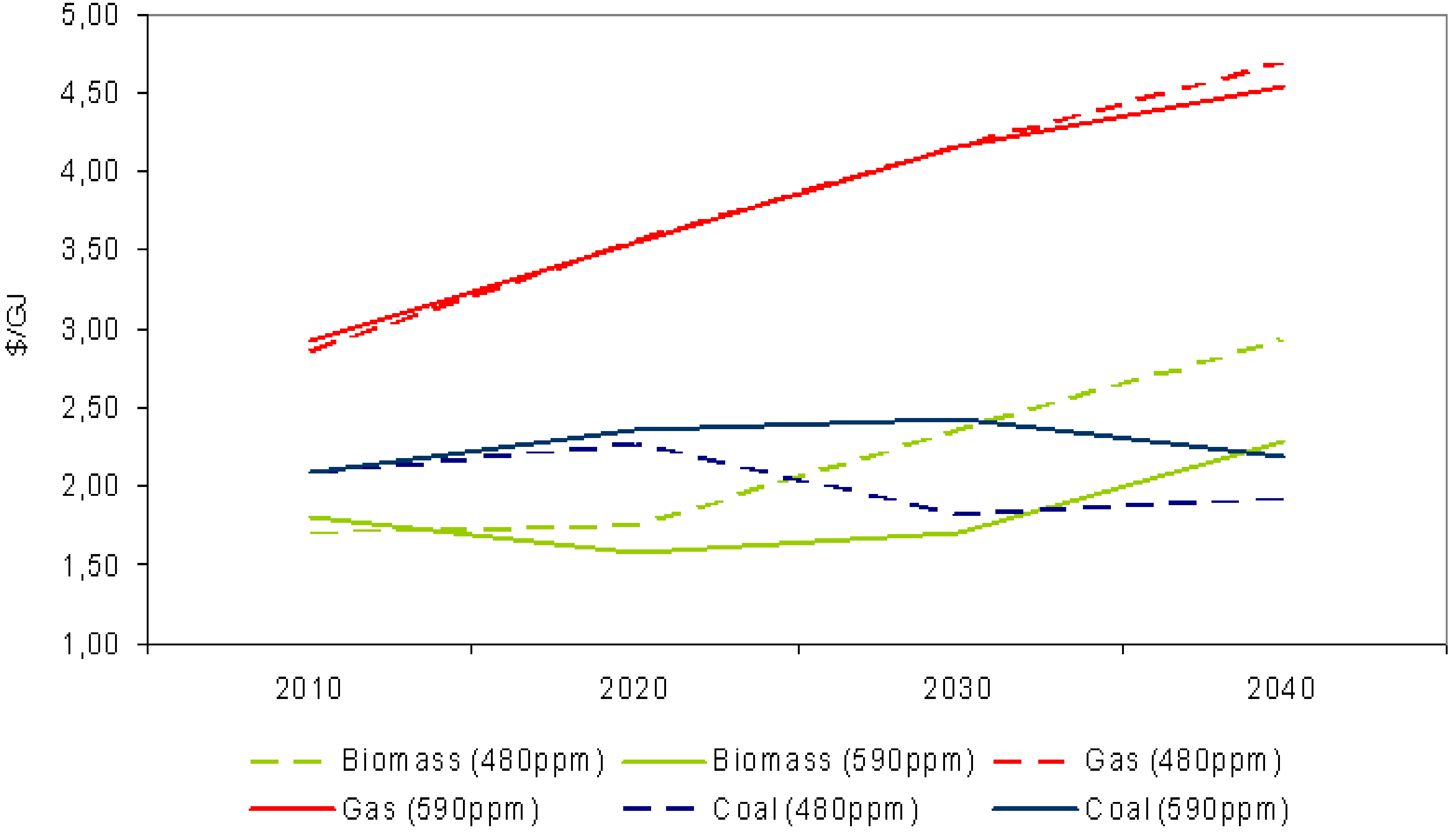
$$y_{k,s,t}^T x + \alpha_s + u_{k,s,t} \geq 0,\ k = 1,\ldots,q,\ s = 1,\ldots,S,\ t = 1,\ldots,6.$$

Technologies

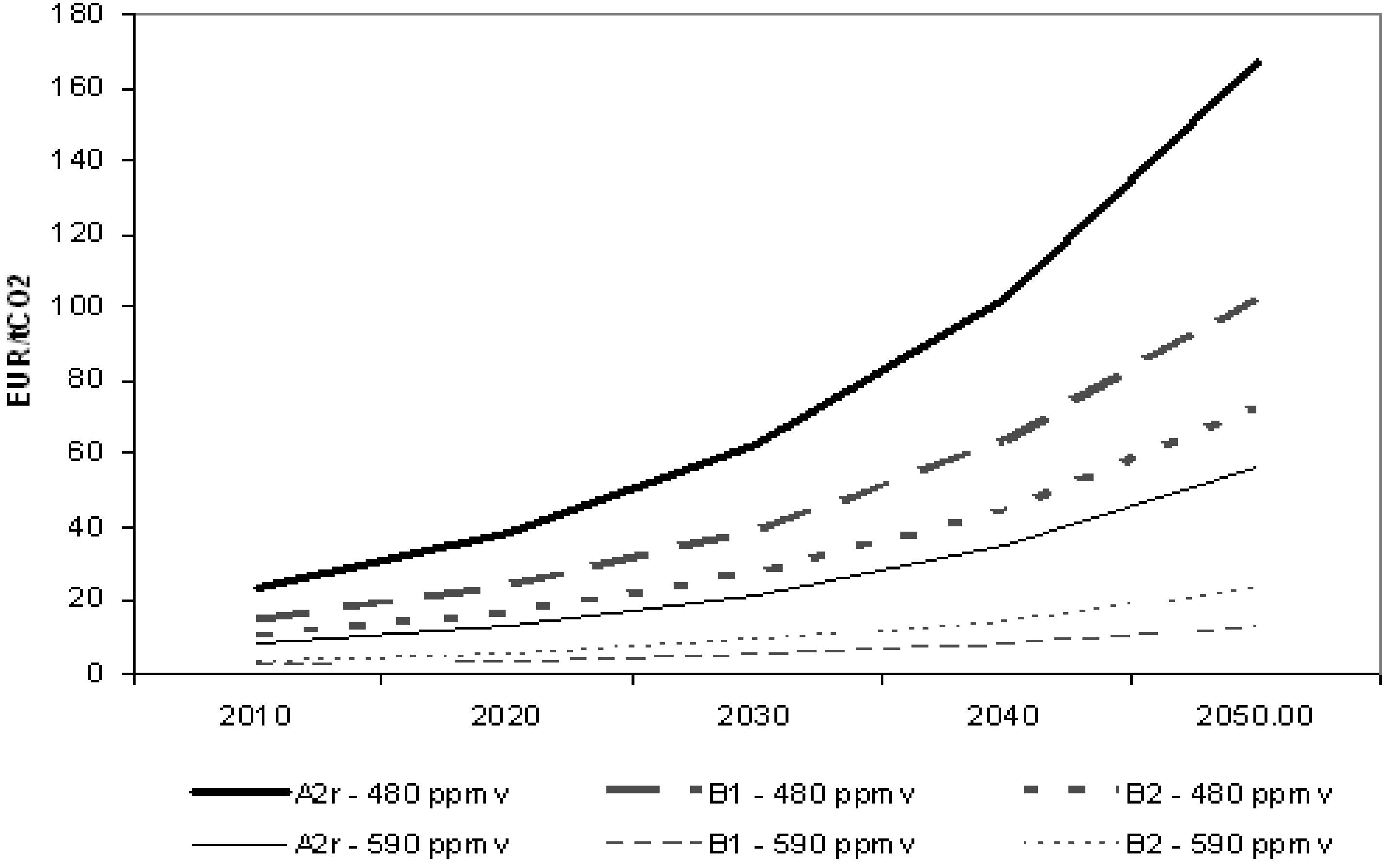
Parameters		*PC*	*PC-CRRF*	*NGCC*	*NGCC-CRRF*
Efficiency	[%]	46	36	58	49
Capacity factor	[%]	89	85	89	85
Capital Cost	[€ /kW]	1,182	1,882	500	848
O&M Cost	[€ /yr/kW]	68.297	101.465	15.281	34.042
CO_2 Emissions	[kg /kWh]	0.74	0.111	0.348	0.052
Technical lifetime	[yrs]	30	30	30	30
		Bio	*Bio-CRRF*	*Wind*	
Efficiency	[%]	35	27	na	
Capacity factor	[%]	89	85	40	
Capital Cost	[€ /kW]	1,537.19	1,880.19	1,800	
O&M Cost	[€ /yr/kW]	43.269	64.282	76	
CO_2 Emissions	[kg /kWh]	0	-0.141	0	
Technical lifetime	[yrs]	30	30	25	

Source: IEA/OECD (2005/2010), Broek et al (2008)
CRRF = capture-ready retrofit

Socio-economic Scenarios: Fuel Prices

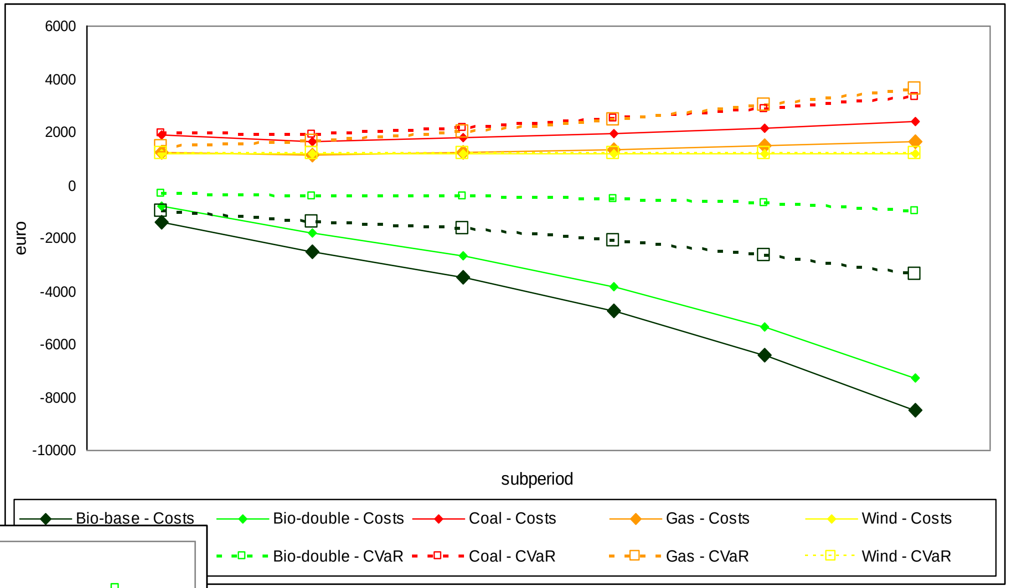


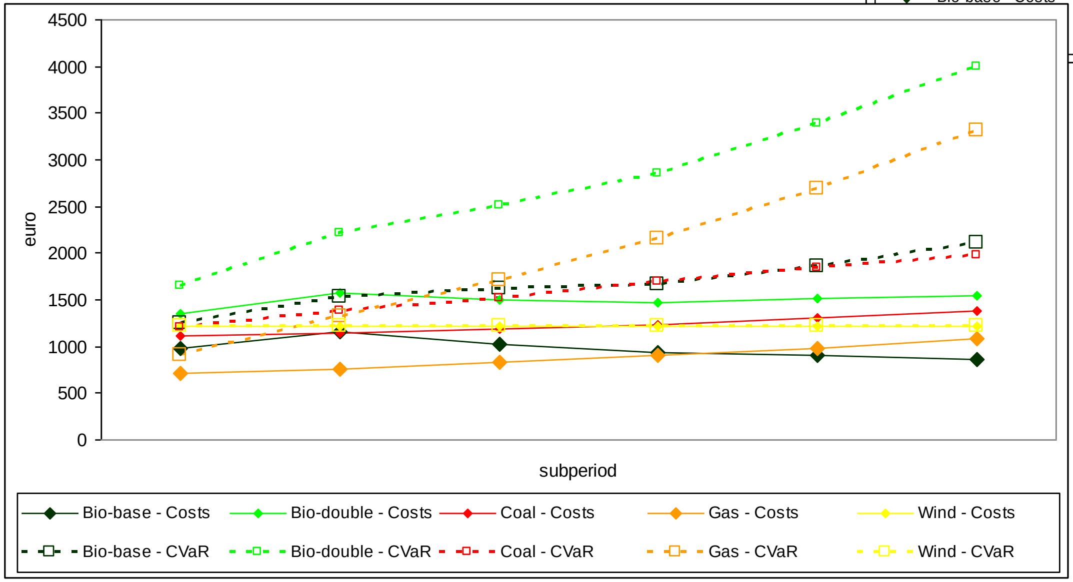
Socio-economic Scenarios: CO_2 Prices



Real Options Results Example

A2r –
450ppm



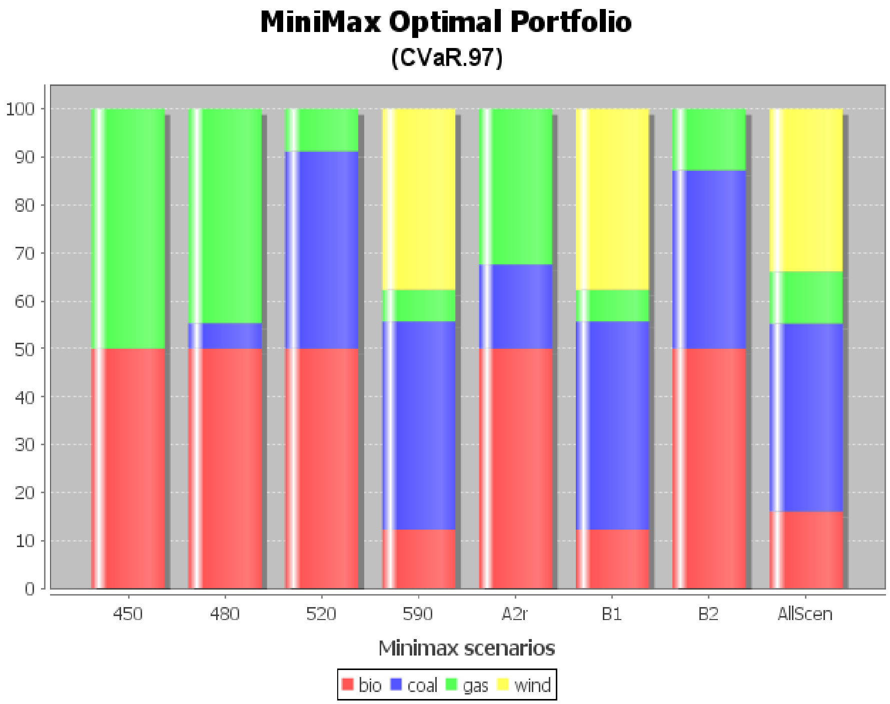


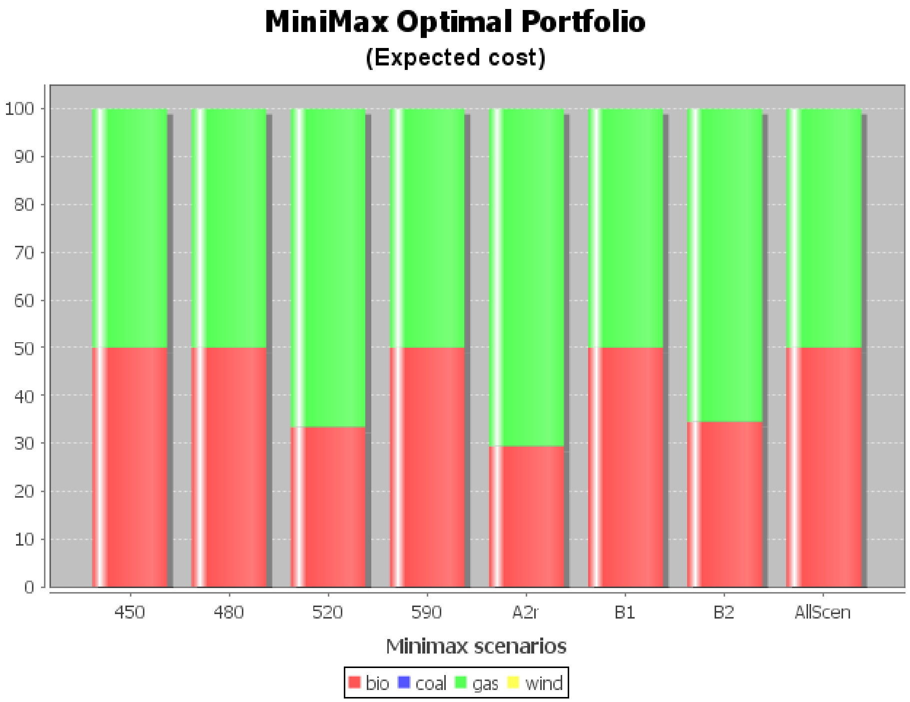
B1 –
590ppm

Portfolio Runs

- 50% constraint on renewables portfolio share
- 2 scenarios for testing energy mix sensitivity to assumptions about biomass data: baseline (shadow prices/GGI Scenario Database for each socio-economic scenario and for each target) vs higher biomass prices (2x baseline, see e.g. V/d Broek et al, 2008).
- Portfolios maximizing profits vs portfolios minimizing risk in terms of CVaR.
- Portfolios are robust across socio-economic scenarios/sub-periods for a specific target, across targets for a specific socio-economic scenario and across all scenarios and targets.

Portfolio Results: Baseline

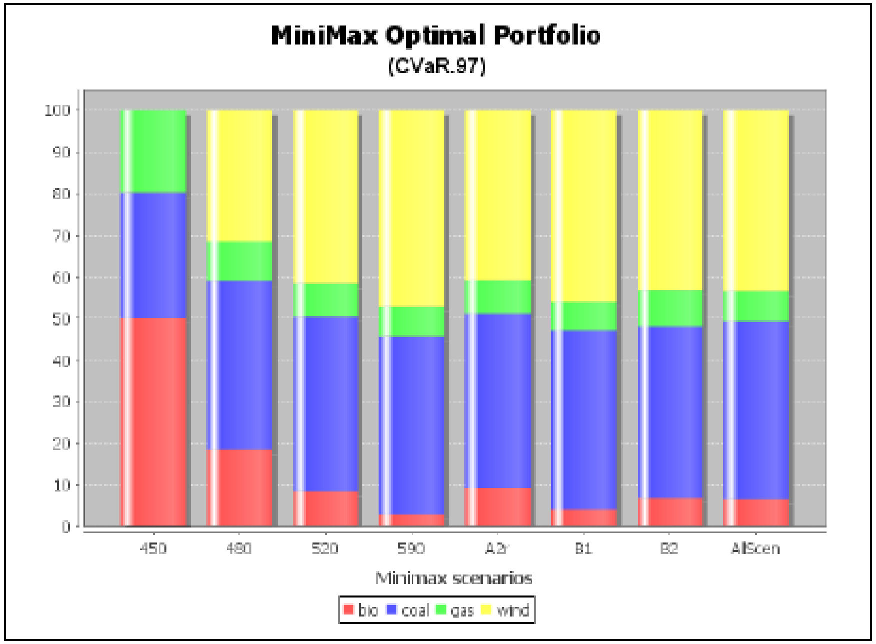


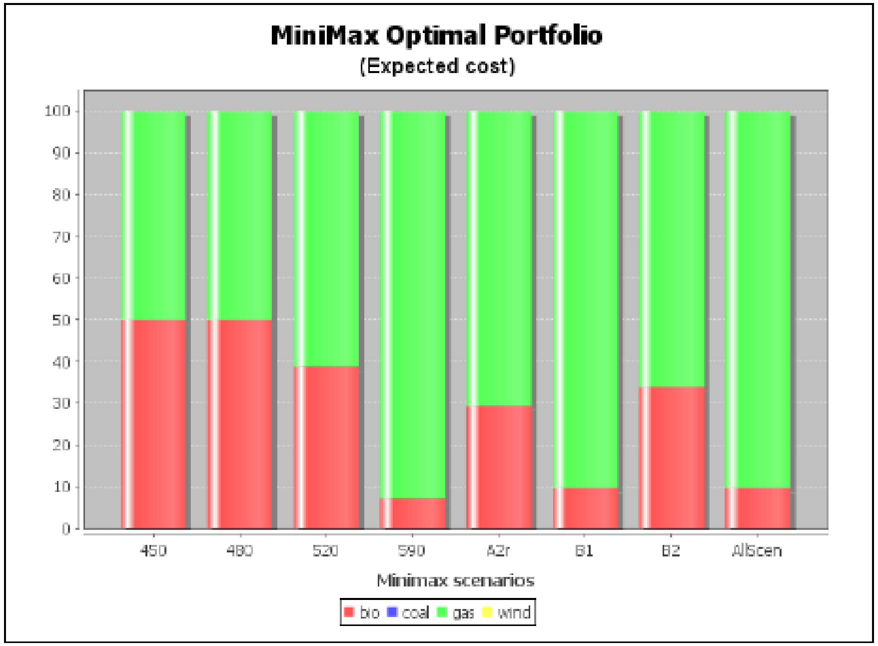


Min Risk

Max Profits

Portfolio Results: Costly B(CCS)

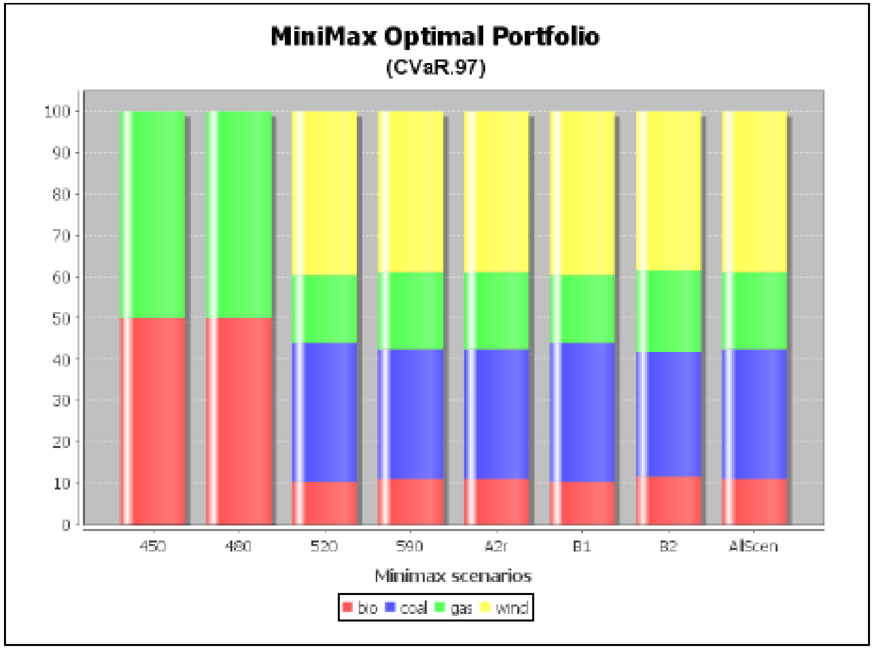


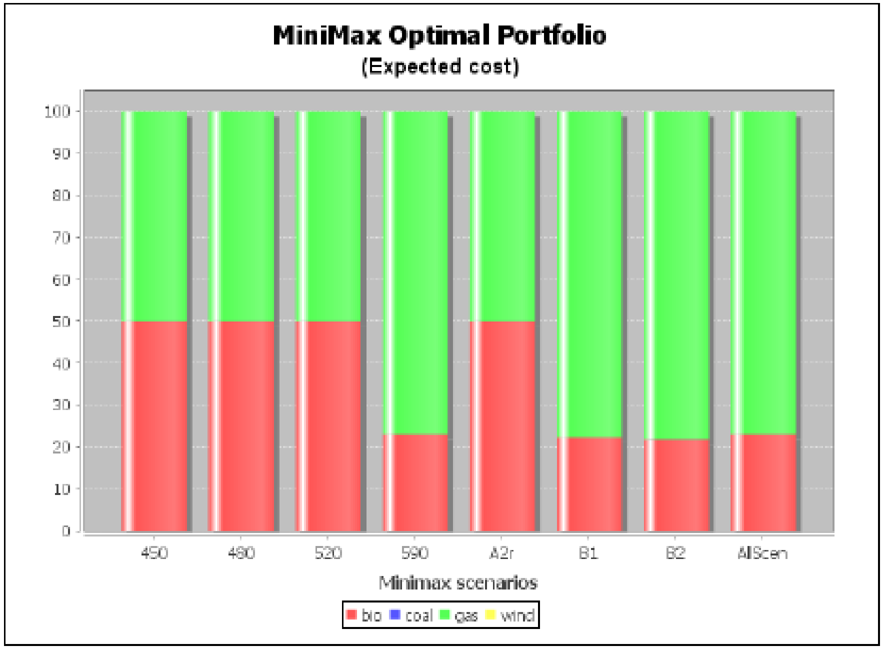


Min Risk

Max Profits

Portfolio Results: Costly B(CCS)/Single Period





Min Risk

Max Profits

Conclusions

- Stylized model for decision-making under uncertainty when probabilities cannot be assigned ⇒ Multi-period version explains why power plant owners hold on to/invest in new coal-fired capacity, although they know they will be facing CO2 policy: coal will eventually be less risky than gas (⇨ fuel price volatility).
- Under complete ignorance of target height, risk-averse investors consider portfolios robust across all of the possibilities. ⇒ up to 50% higher overall costs ⇒ importance of credible policy commitments
- Risk-neutral investor: bio portfolio share lower in multi-period setting.
- More costly bio ⇒ bio almost excluded from mini-max/multi-period portfolios (unless stringent target) ⇒ importance of further exploration of bio+CCS as component of less CO2-intensive energy mix.

Extensions

- Load structure: demand needs to be covered during peaks, so a large amount of renewables would need “backup“ from residual fossil-fuel-based plants.
- Large producers: endogenous prices
- More technologies, transmission investments, storage possibilities, …