Supplementary File

Costs of meeting international climate targets without nuclear power

VICKI DUSCHA^{1*}, KATJA SCHUMACHER², JOACHIM SCHLEICH^{1,3,4}, PIERRE BUISSON⁵

¹ Fraunhofer Institute for Systems and Innovation Research, Breslauer Strasse 48, 76139 Karlsruhe, Germany

² Berlin Office, Öko Institut, 5-7 Schicklerstrasse, 10179 Berlin, Germany

³ Grenoble Ecole de Management, 12 rue Pierre Sémard, BP 127, 38003 Grenoble Cedex 01, France

⁴ Department of Agricultural and Applied Economics, Virginia Polytechnic Institute & State University, 202A Hutcheson Hall, Blacksburg, VA 24061, US

Appendix A Description of the POLES model

POLES is a techno-economic model that endogenously projects energy prices and provides a complete account of demand and supply of energy carriers and associated technologies. The model includes, *inter alia*, 24 competing power generation technologies for 57 different countries/regions, and accounts for CO₂ and other GHG emissions. This high level of regional disaggregation allows, to a large extent, country-specific modelling of technology availability. The model builds on price-driven behavioral equations for final energy demand (by carriers and consumption sectors) and cost-driven behavioral equations for energy supply (by fuels and technologies). Supply and demand are balanced on a yearly basis via recursive simulation.

For the Power Generation sector, POLES forecasts the technology-specific development of capacities based on cost competition accounting for endogenous technological learning (i.e. ‘learning by searching’, ‘learning by doing’) and of power generation based on a must-run and merit-order approach. Techno-economic parameters are taken from the TECHPOL¹ database, including investment costs, operation and management costs, efficiencies and lifetimes. The model then calculates full and marginal costs taking into account learning effects, fuel costs and CO₂ taxation. Table A1 displays investment costs per kW (without technology learning) for competing

¹ TECHPOL is compiled and maintained by EDDEN (Economie du Développement Durable et de l’Energie) at Pierre Mendès-France University (UPMF) based in Grenoble, France.

technologies. Regarding nuclear power, the expected lifetime is 40 years (extensions via refurbishment are not modeled). CCS technologies are assumed not to be available before 2020.

Table A1 Investment costs for major power technologies in the POLES model

Technologies	Costs in 2005 (US\$₂₀₀₅/kW)	Costs in 2020 (US\$₂₀₀₅/kW)
Pressurised Fluidised Coal	1890	1777
Pressurised Fluidised Coal + CCS	3329	2864
Integrated Coal Gaseification (IGCC)	2634	2126
IGCC + CCS	3470	2775
Lignite Conventional Thermal	1966	1909
Coal Conventional Thermal	1739	1682
Oil Conventional Thermal	1270	1214
Gas Conventional Thermal	1190	1134
Gas-fired Gas Turbine	589	545
Oil-fired Gas turbine	589	545
Gas-fired Gas Turbine + CCS	1374	1225
Gas-fired Gas turbine Combined Cycle	745	689
Biomass Gasification	3822	3233
Biomass Gasification + CCS	5009	4187
Biomass Thermal	2939	2428
Nuclear	3015	2672
New Nuclear Design (Gen.IV)	11162	8796
Combined Heat & Power	1010	956
Hydroelectricity	2657	2657
Wind onshore	1791	1491
Wind offshore	3163	2597
Solar Power Plant (CSP power plant)	4280	3348
Small Hydro	3672	3672
Distributed Photovoltaics	8685	4333

Appendix B Derivation of marginal abatement cost curves with POLES

The marginal abatement cost (MAC) curves are constructed by introducing a Carbon Value (CV), which is interpreted as a shadow price of CO₂ emissions (i.e. a per unit tax based on the CO₂ content of fossil fuels). The CV affects the competitiveness of the different fuels in the energy system, both in the final consumption sectors and in the energy supply sector. As a consequence, the system becomes less carbon-intensive as the CV increases: at any given date, the CV corresponds with the marginal cost of an emissions reduction (for each sector and country) compared, for example, to a business-as-usual scenario with a CV of zero. It is then possible to quantify annual mitigation costs for specific countries and sectors measuring the area under the MAC curves. It is important to note that external costs such as climate damages or nuclear waste are not taken into account in the model. To derive the MAC curve used in this article, the CV is increased for each simulated year by steps of \$10/tC from 0 to \$700/tC². Values provided are in constant (2005) US dollars. For the analyses presented in this paper the costs were converted into € of 2005. The targeted CV, i.e. the CV which implements the emission targets, is reached linearly between 2011 and the considered year, i.e. climate policy becomes more and more stringent over time. The MACCs therefore integrate the different levels of flexibility of each country and sector to mitigate their CO₂ emissions such as fuel mix in the baseline, nuclear policy in place, existing potentials for renewable energies.

² \$10/tC corresponds to \$2.73/tCO₂ (i.e. (10 x 12)/44).

Appendix C

Table A2 Targets in 2020 compared to 1990 levels for Annex I countries in the climate policy scenario and in the alternative target scenarios

	Climate Policy	EC 30%	Uniform 40%
Australia	-30%	-24%	-40%
EU 27	-30%	-30%	-40%
Canada	-30%	-23%	-40%
Iceland	-30%	-21%	-40%
Japan	-30%	-24%	-40%
New Zealand	-30%	-15%	-40%
Norway	-30%	-28%	-40%
Russia	-30%	-38%	-40%
Switzerland	-30%	-27%	-40%
Ukraine	-30%	-60%	-40%
USA	-30%	-24%	-40%
Annex I	-30%	-30%	-40%

Table A3 Change in certificate prices due to nuclear phase-out in the climate policy scenario and in the alternative target scenarios

	Climate Policy	EC 30%	Uniform 40%
AAUs	24%	26%	23%
CERs	19%	19%	18%