

Case studies with a multi-fuel market equilibrium model

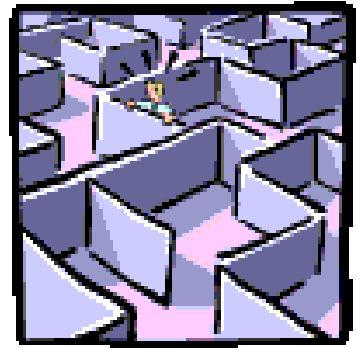
Transatlantic Infraday, 11 Nov 2011

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Outline



- Introduction
- Modeling approach
- Results of case studies
- Conclusions

RESEARCH OBJECTIVES

Research questions

Outline

- Introduction
- Modeling approach
- Contributions
- Case studies
- Results
- Conclusions

Effect of

- GHG emission ceiling/tax
- Renewables
- Carbon Capture and Storage
- Demand side management

On

- Fuel mix in power generation?
- Energy Trade?
- Network expansions?

Relevant aspects

Outline

- Introduction
- Modeling approach
- Contributions
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- Conclusions

- fuel substitution
- market power
- climate aspects
- perception of nuclear

A multi-fuel market equilibrium model

Outline

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- Sector models can't capture fuel-substitution
- Energy system models can't capture market power a la Cournot

MODELING APPROACH

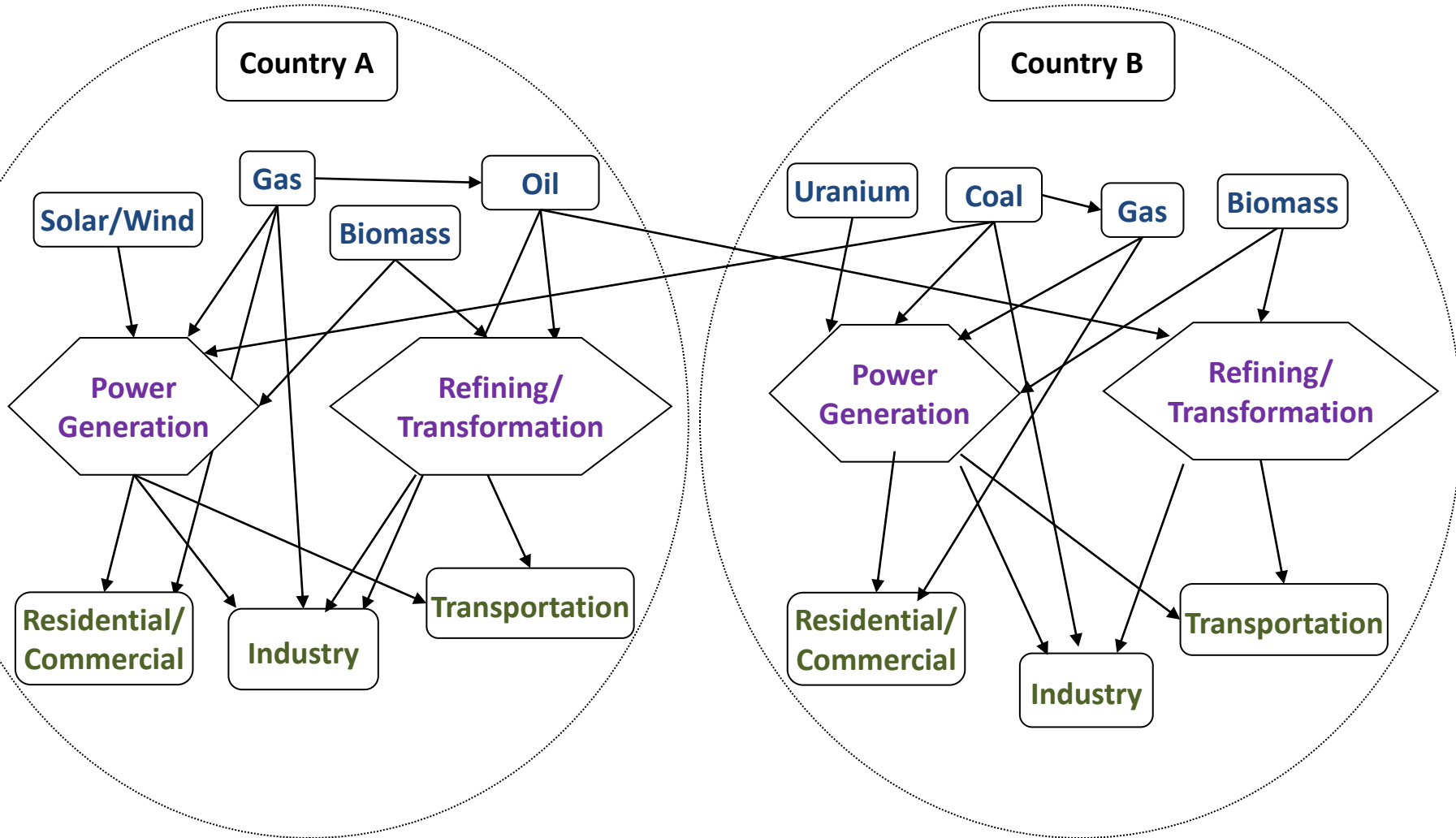
Energy supply chain – agents and characteristics

Outline

- Introduction
- Modeling approach
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- Supply
- Transformation
- Transportation
- Consumption

Trade and supply relations



Model characteristics

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- Single-period
- Mixed complementarity problem
- Transformation and transport are service providing infrastructure operators
- Some suppliers may exert market power vis a vis consumers

SUPPLY and CONSUMPTION	Coal and Peat	Crude Oil	Oil Products	Gas	Nuclear	Hydro	Geothermal, Solar, etc.	Combustible Renewables and Waste	Electricity	Heat	Total*
Production	3415656	4041342	0	2608172	712178	275877	89349	1225490	0	887	12368951
Imports	591765	2332710	995624	782769	0	0	0	8491	52836	4	4764198
Exports	-631034	-2200432	-1074558	-777769	0	0	0	-9320	-52987	-9	-4746108
International Marine Bunkers**	0	0	0	0	0	0	0	0	0	0	0
International Aviation Bunkers**	0	0	0	0	0	0	0	0	0	0	0
Stock Changes	-62205	-28783	-6720	-22101	0	0	0	151	0	0	-119657
TPES	3314182	4144838	-85655	2591071	712178	275877	89349	1224812	-151	883	12267383
Transfers	0	-133750	153948	0	0	0	0	84	0	0	20282
Statistical Differences	-6004	-23209	-13247	-3220	0	0	-321	-25	718	59	-45249
Electricity Plants	-1891000	-24290	-213079	-630358	-705663	-275877	-72862	-50185	1564344	-367	-2299337
CHP Plants	-181069	-11	-21855	-296035	-6515	0	-1057	-28545	171235	145141	-218711
Heat Plants	-96268	-732	-11516	-88826	0	0	-174	-7780	-331	170642	-34986
Gas Works	-12854	0	-3284	9030	0	0	0	-9	0	0	-7118
Oil Refineries	0	-3967041	3929147	-574	0	0	0	0	0	0	-38468
Coal Transformation	-200550	0	-3221	-157	0	0	0	-4	0	0	-203931
Liquefaction Plants	-19925	9014	0	-6731	0	0	0	0	0	0	-17643
Other Transformation	4	30085	-31131	-2052	0	0	0	-54167	0	-334	-57595
Energy Industry Own Use	-81295	-10889	-217658	-232593	0	0	-1	-13704	-147225	-35590	-738955
Losses	-2127	-3914	-394	-26138	0	0	-141	-209	-142456	-21886	-197266
TFC	823094	20101	3482056	1313416	0	0	14792	1070268	1446134	258546	8428407
Industry	645803	5745	326175	460240	0	0	421	190764	602689	113230	2345066
Transport	3450	17	2149823	77410	0	0	0	45450	23122	99	2299371
Other	136417	227	452868	633441	0	0	14371	834055	820323	145217	3036919
Residential	76575	0	222888	418550	0	0	6975	805420	395809	97975	2024193
Commercial and Public Services	23299	0	107323	173785	0	0	1153	16331	338307	32467	692666
Agriculture / Forestry	9574	19	102973	5579	0	0	161	7017	36199	3357	164880
Fishing	13	0	5687	19	0	0	28	1	363	58	6169
Non-Specified	26955	208	13997	35508	0	0	6055	5285	49644	11361	149012
Non-Energy Use	37424	14112	553190	142325	0	0	0	0	0	0	747051
- of which Petrochemical Feedstocks	2431	14028	344555	139385	0	0	0	0	0	0	500398

Energy Balances World, 2008, Mtoe

SUPPLY and CONSUMPTION		Coal and Peat	Crude Oil	Oil Products	Gas	Nuclear	Hydro	Geothermal, Solar, etc.	Combustible Renewables and Waste	Electricity	Heat
		SOL	OIL	FUE/TRP	GAS	NUC	HYD	RES	RES	ELE	N.A.
Production	PROD	3416	4041	0	2608	712	276	89	1225	0	1
Imports	TRADE	592	2333	996	783	0	0	0	8	53	0
Exports	TRADE	-631	-2200	-1075	-778	0	0	0	-9	-53	0
Stock Changes	N.A.	-62	-29	-7	-22	0	0	0	0	0	0
TPES		3314	4145	-86	2591	712	276	89	1225	0	1
Transfers	N.A.	0	-134	154	0	0	0	0	0	0	0
Statistical Differences	N.A.	-6	-23	-13	-3	0	0	0	0	1	0
Electricity Plants	P_XXX	-1891	-24	-213	-630	-706	-276	-73	-50	1564	0
CHP Plants	P_XXX	-181	0	-22	-296	-7	0	-1	-29	171	145
Heat Plants		-96	-1	-12	-89	0	0	0	-8	0	171
Gas Works		-13	0	-3	9	0	0	0	0	0	0
Oil Refineries	REF	0	-3967	3929	-1	0	0	0	0	0	0
Coal Transformation		-201	0	-3	0	0	0	0	0	0	0
Liquefaction Plants	LIQ	-20	9	0	-7	0	0	0	0	0	0
Other Transformation	conv_x	0	30	-31	-2	0	0	0	-54	0	0
Energy Industry Own Use	conv_x	-81	-11	-218	-233	0	0	0	-14	-147	-36
Losses	loss_x	-2	-4	0	-26	0	0	0	0	-142	-22
TFC		823	20	3482	1313	0	0	15	1070	1446	259
Industry		646	6	326	460	0	0	0	191	603	113
Transport	P_TRP	3	0	2150	77	0	0	0	45	23	0
Other	P_GAS	136	0	453	633	0	0	14	834	820	145
Residential	P_OIL	77	0	223	419	0	0	7	805	396	98
Commercial and Public Services	P_ELE	23	0	107	174	0	0	1	16	338	32
Agriculture / Forestry	P_SOL	10	0	103	6	0	0	0	7	36	3
Fishing		0	0	6	0	0	0	0	0	0	0
Non-Specified		27	0	14	36	0	0	6	5	50	11
Non-Energy Use		37	14	553	142	0	0	0	0	0	0

Category coverage

	SOL	OIL	FUE/TRP	GAS	NUC	HYD	RES	ELE
PROD								
TRADE								
TPES								
P_SOL								
P_OIL								
P_etc.								
REF								
LIQ								
conv_c								
loss_c								
TFC								
P_ELE								
P_SOL								
P_GAS								
P_OIL								
P_TRP								

Contributions

Outline

- Introduction
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- Market power
- Fuel substitution
- Climate aspects
- IN SINGLE FRAMEWORK

CASE STUDIES

Data

Outline

- Introduction
- Modeling approach
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- Results
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- Volumes
 - 2010 (BP 2011)
 - 2009 (EuroStat 2011)
 - 2008 (IEA 2010)
- Capacities, costs, losses
 - Various sources
- Prices
 - world averages, adjusted in calibration

Cases Studies

Outline

- Introduction
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- Reference
- CO2 tax in EU-ETS
- CO2 tax global
- Focus Germany

REFERENCE CASE

Energy 2010 (Mtoe, BP 2011)

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WORLD	PROD	CONS
OIL	3914	
FUE		4028
GAS	2881	2858
SOL	3731	3556
BFUE	59	
NUC	626	
HYD	776	
REN	159	
ELE		1834
SUM	12146	

Reference case – global aggregates

Label	ELE	SOL	REN	GAS	LNG	OIL	FUE	BFUE	BTRP	HYD	NUC	TOT
pnet		3633	159	2889		3968		57		756	626	12087
trade	-1	0		25	-46	0	0					
refine						-3863	3631	-57	57			
loss_rfn							-232					-232
power	1822	-826	-60	-374		-37	0			-287	-238	
loss_pow		-1652	-99	-599		-68	0			-468	-388	-3274
D_ELE	1821											1821
D_SOL		1155										1155
D_GAS				1871								1871
D_OIL							1247					1247
D_TRP							2384		57			2441
cons	1821	3633	159	2844		105	3863		57	756	626	

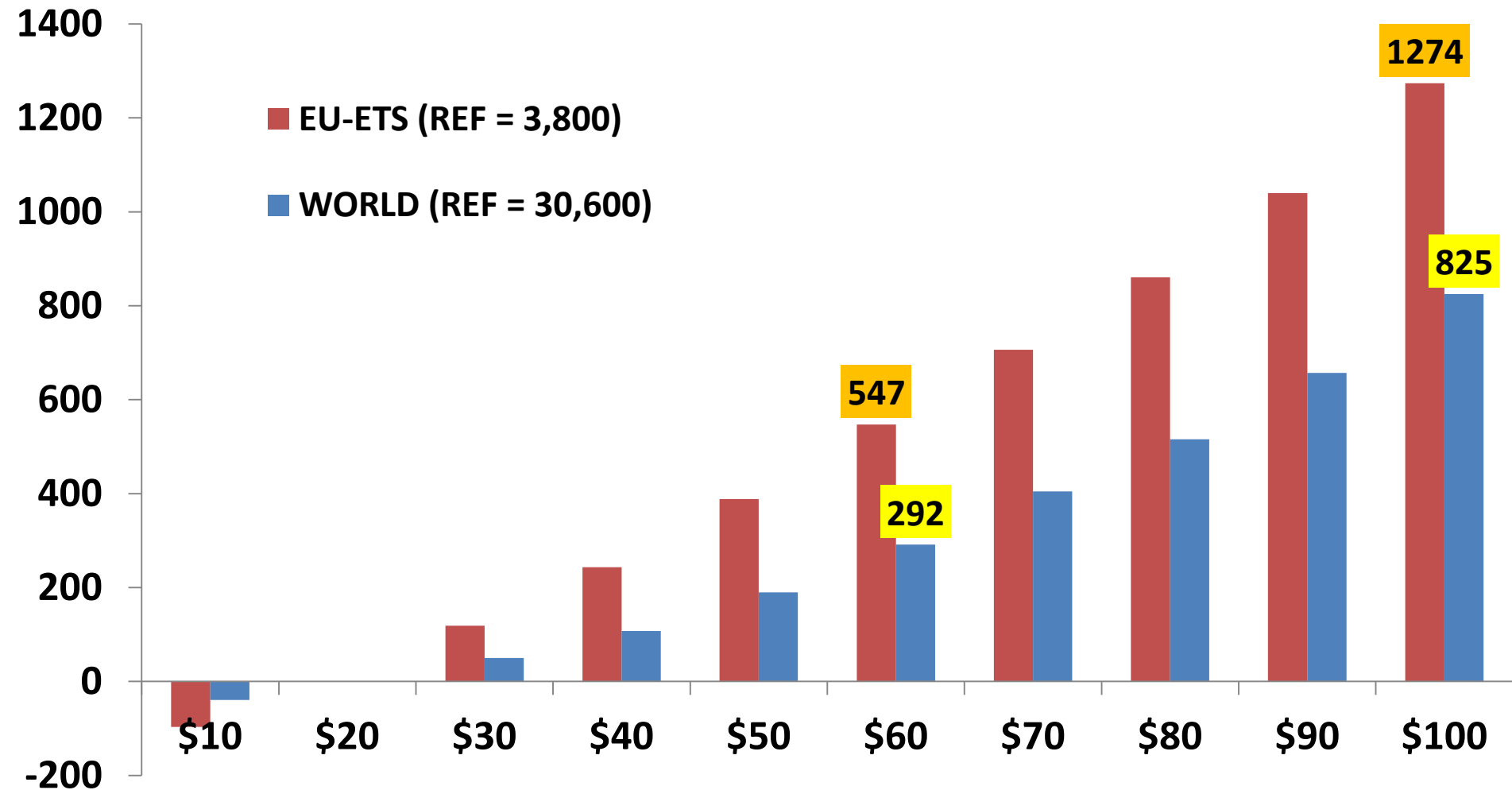
Reference EU-ETS

Label	ELE	SOL	REN	GAS	LNG	OIL	FUE	BFUE	BTRP	HYD	NUC	TOT	tref
pcap		173	68	267		190		9		107	206		
prod		166	68	255		188		9		106	206		
pnet		157	68	246		188		9		106	206	980	987
pref		161	68	248		186		9		109	206	987	
trade	10	123		152	41	478	-15						
refine						-663	623	-9	9				
loss_rfn							-40					-40	
power	292	-87	-26	-60		-1	0			-40	-78		
loss_pow		-150	-42	-74		-2	0			-66	-128	-461	
D_ELE	302											302	296
D_SOL		44										44	44
D_GAS				305								305	307
D_OIL							257					257	259
D_TRP							351		9			360	371
D_TOT	302	44		305			608		9			1267	1277
cons	302	280	68	439		3	648		9	106	206		1674
cref	296	270		441		648						1643	
pow cap	364	96	24	75		60	0			36	73		
ele mix		86	24	59		0	0			35	73	278	297
ref mix		84	24	68		9		3		36	73	297	
pow slk	86	9	0	15		60	0			1	0		

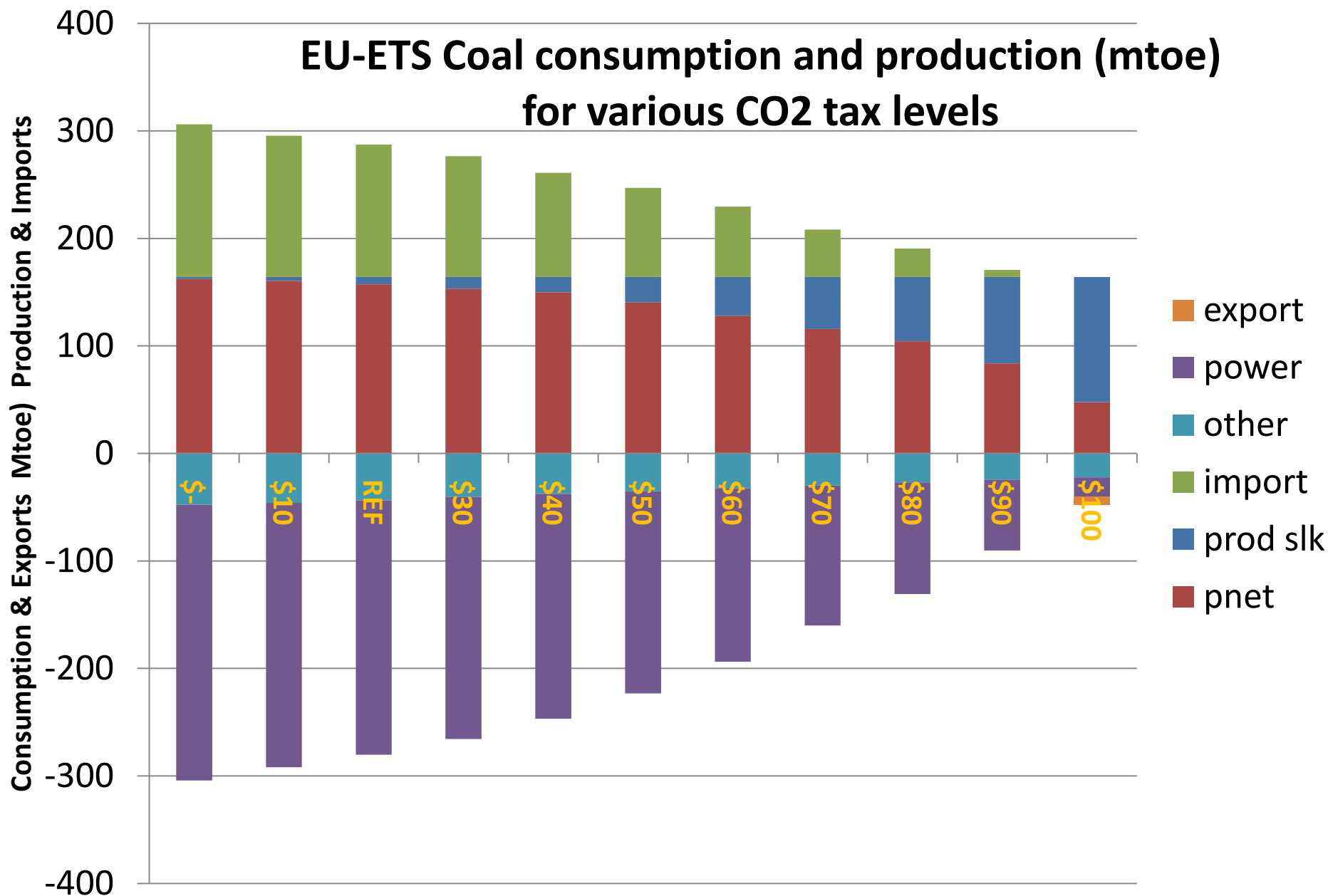
CO2 TAX EU-ETS

Change in CO2-emissions EU-ETS and World for various CO2 tax levels (Mton)

Mton

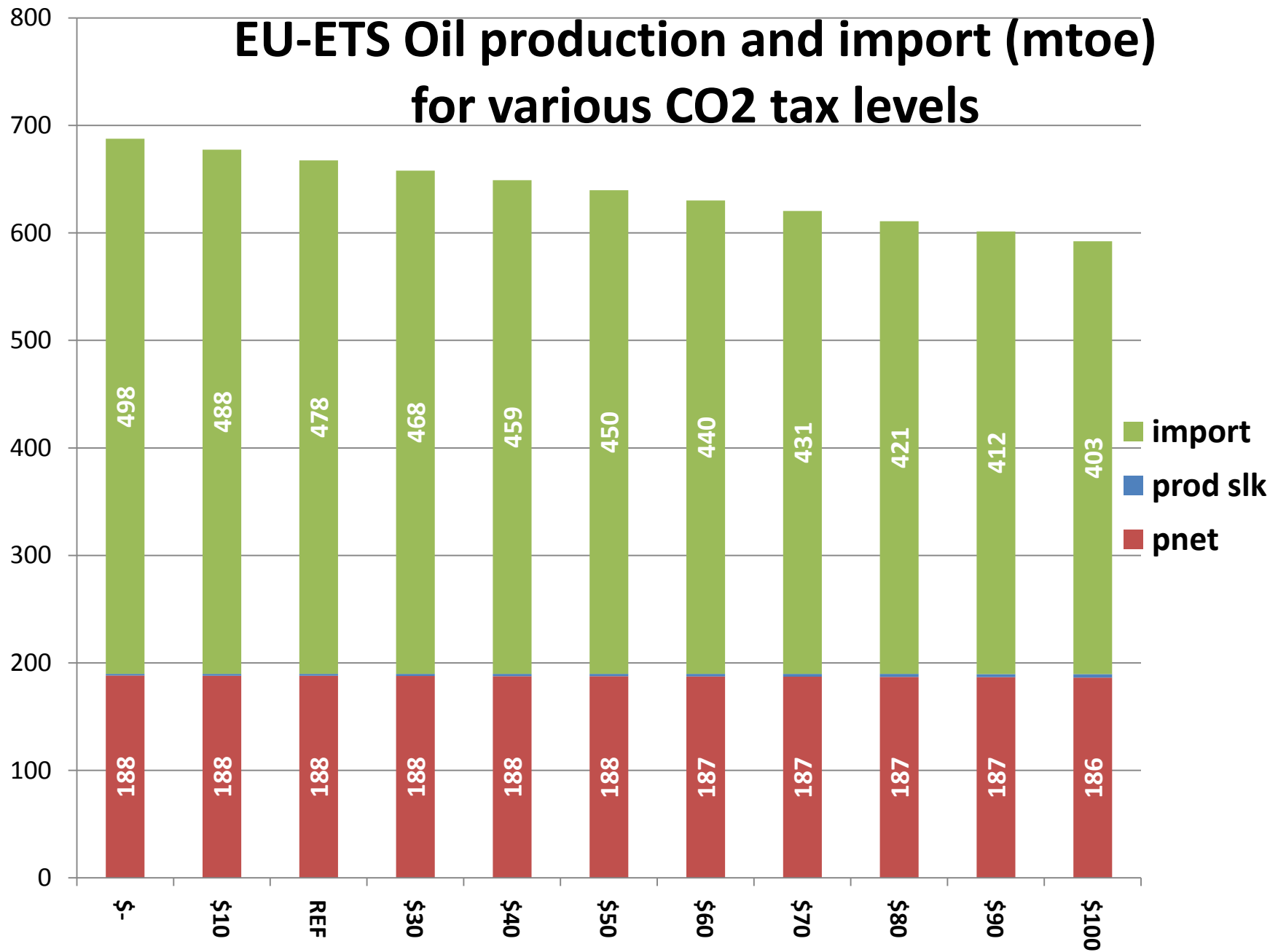


EU-ETS Coal consumption and production (mtoe) for various CO2 tax levels



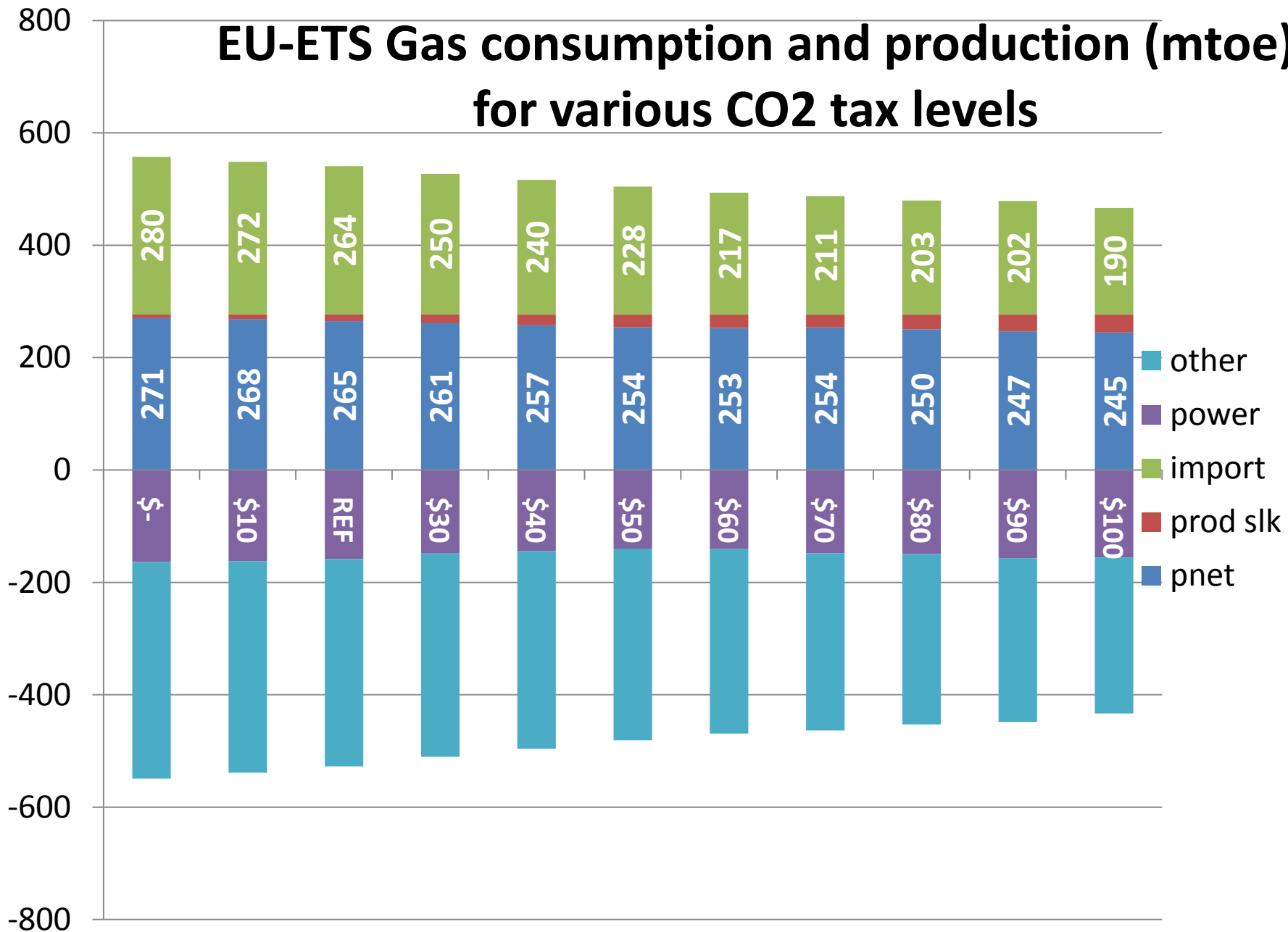
EU-ETS Oil production and import (mtoe) for various CO2 tax levels

Production & Imports

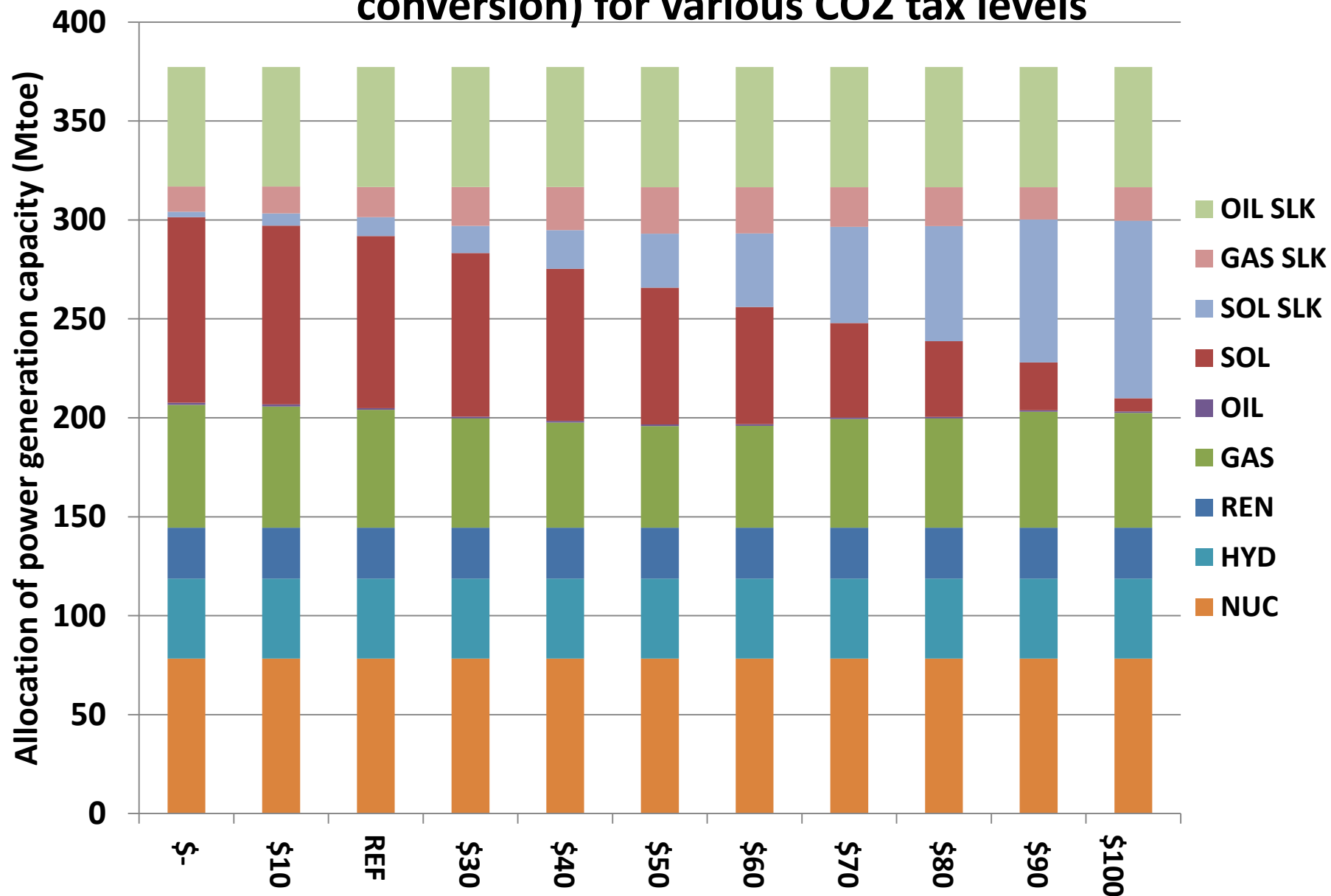


EU-ETS Gas consumption and production (mtoe) for various CO2 tax levels

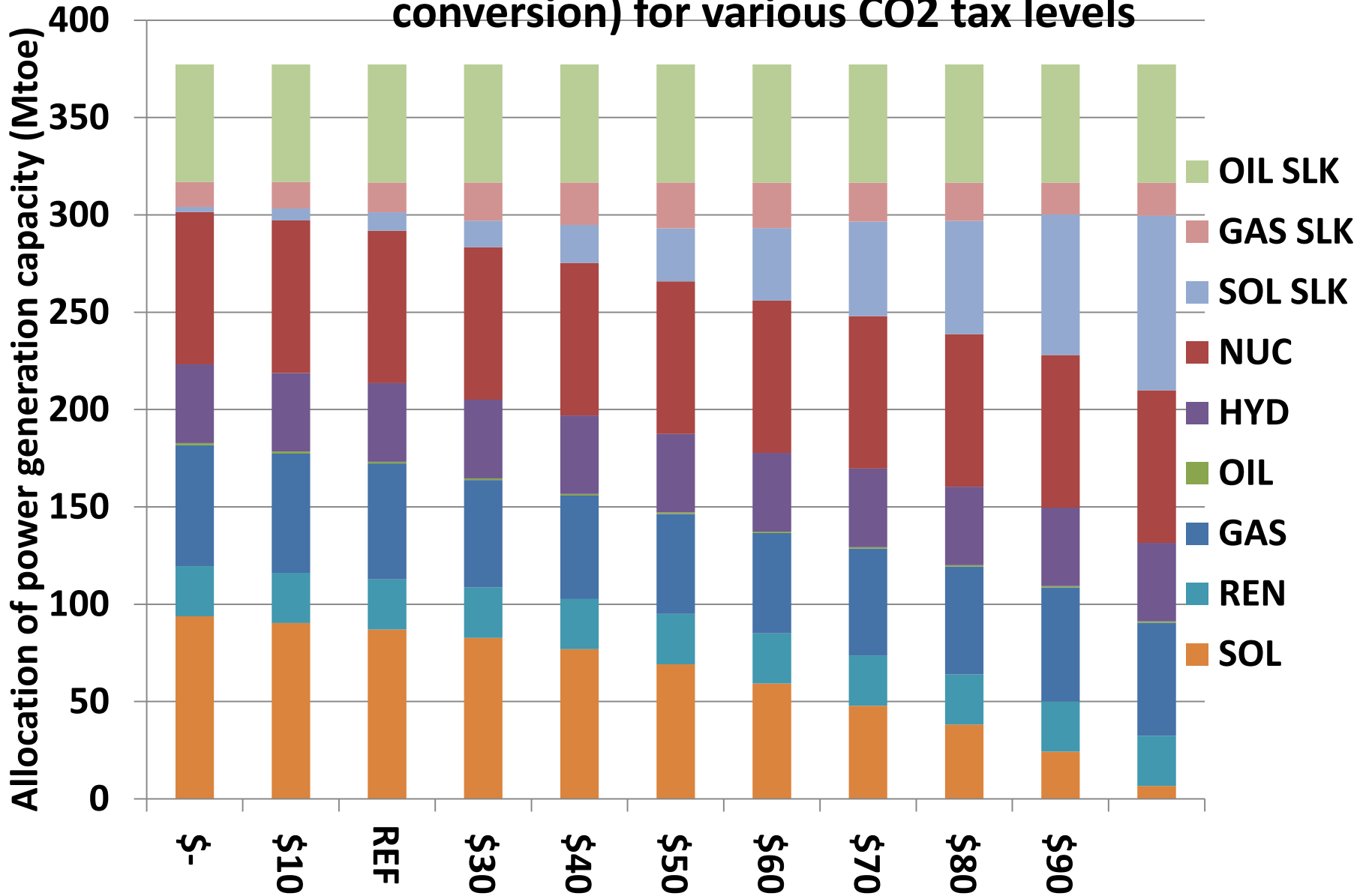
Production & Imports



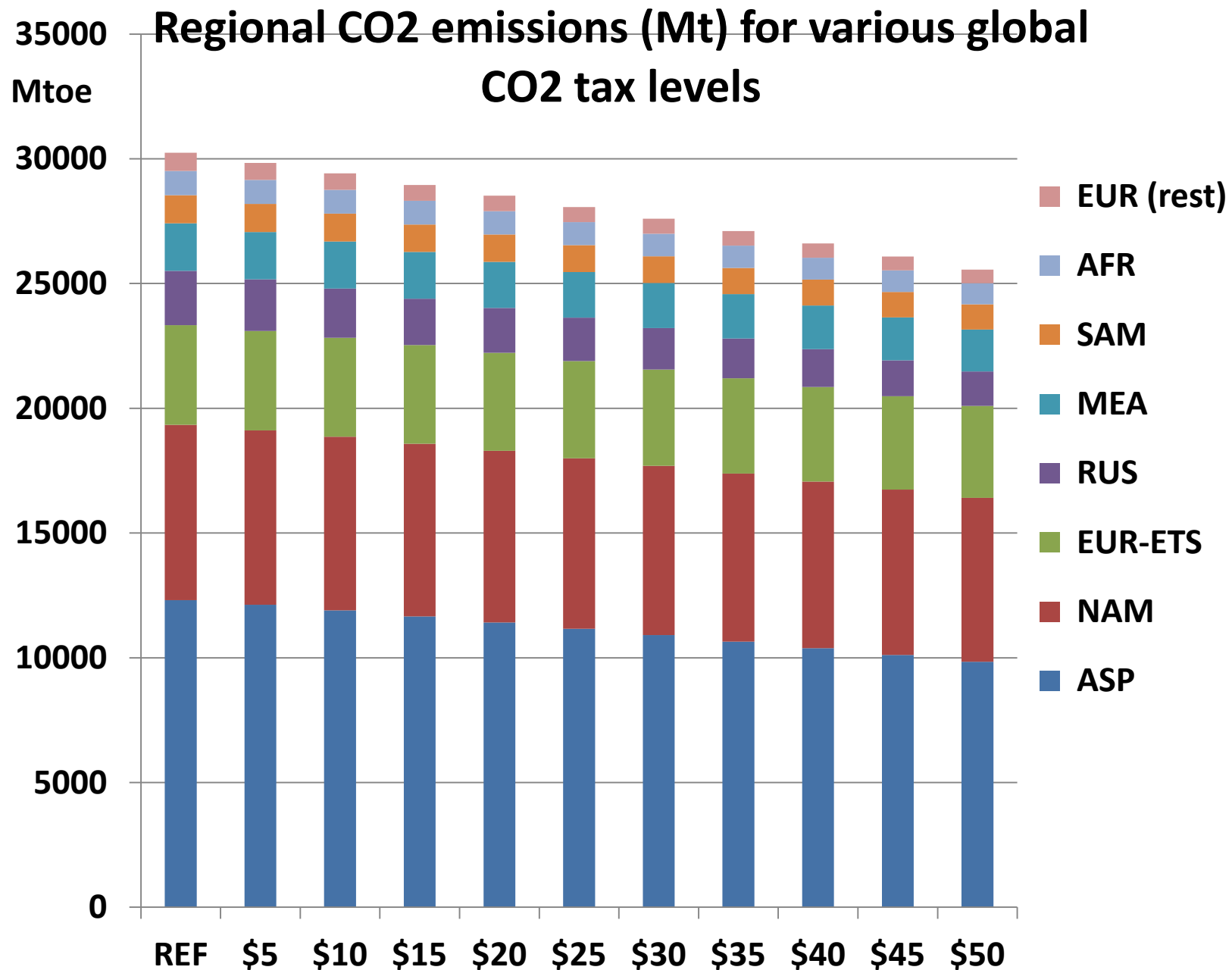
EU-ETS Fuel Mix Power Generation (Mtoe after conversion) for various CO2 tax levels

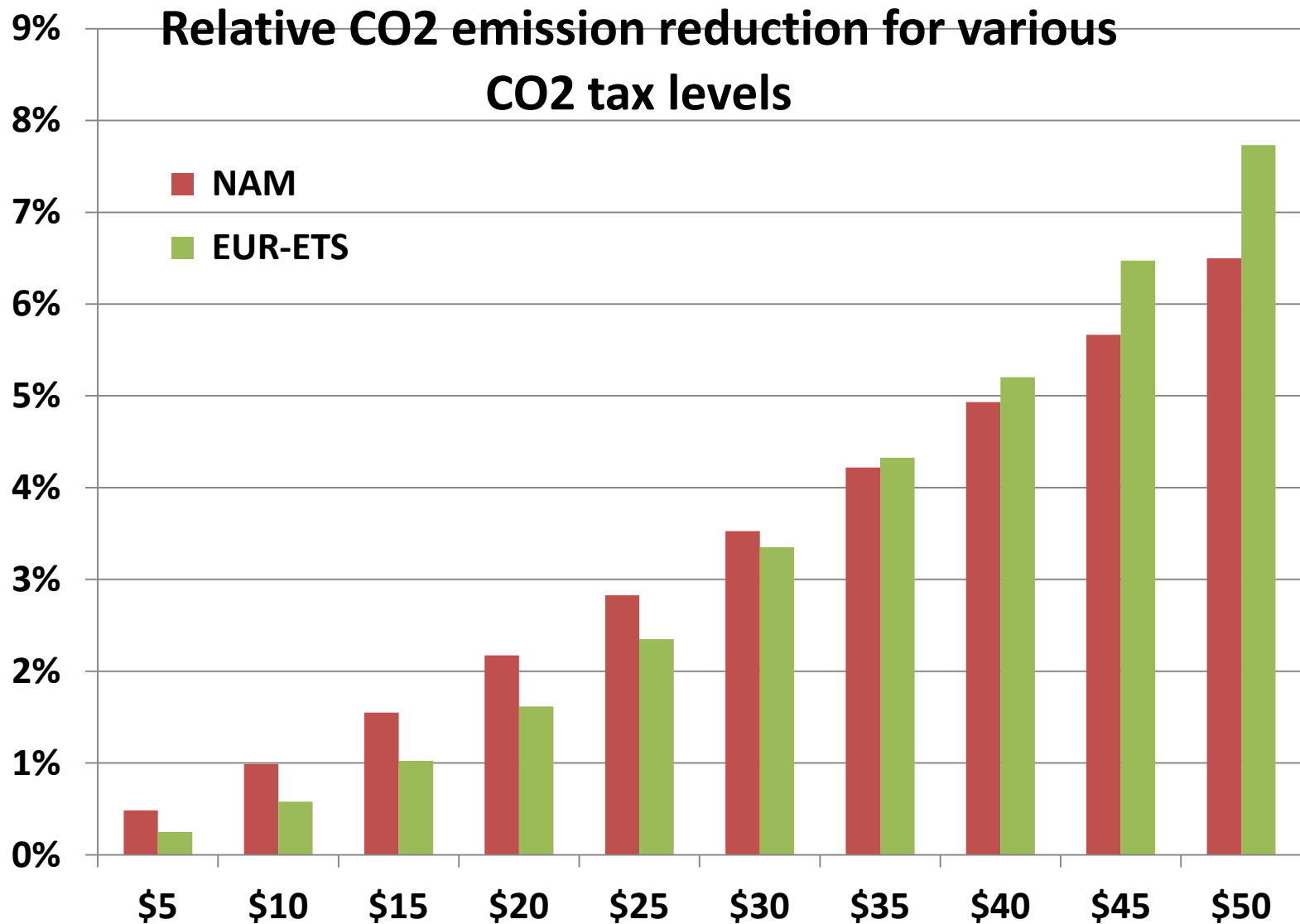


EU-ETS Fuel Mix Power Generation (Mtoe after conversion) for various CO2 tax levels

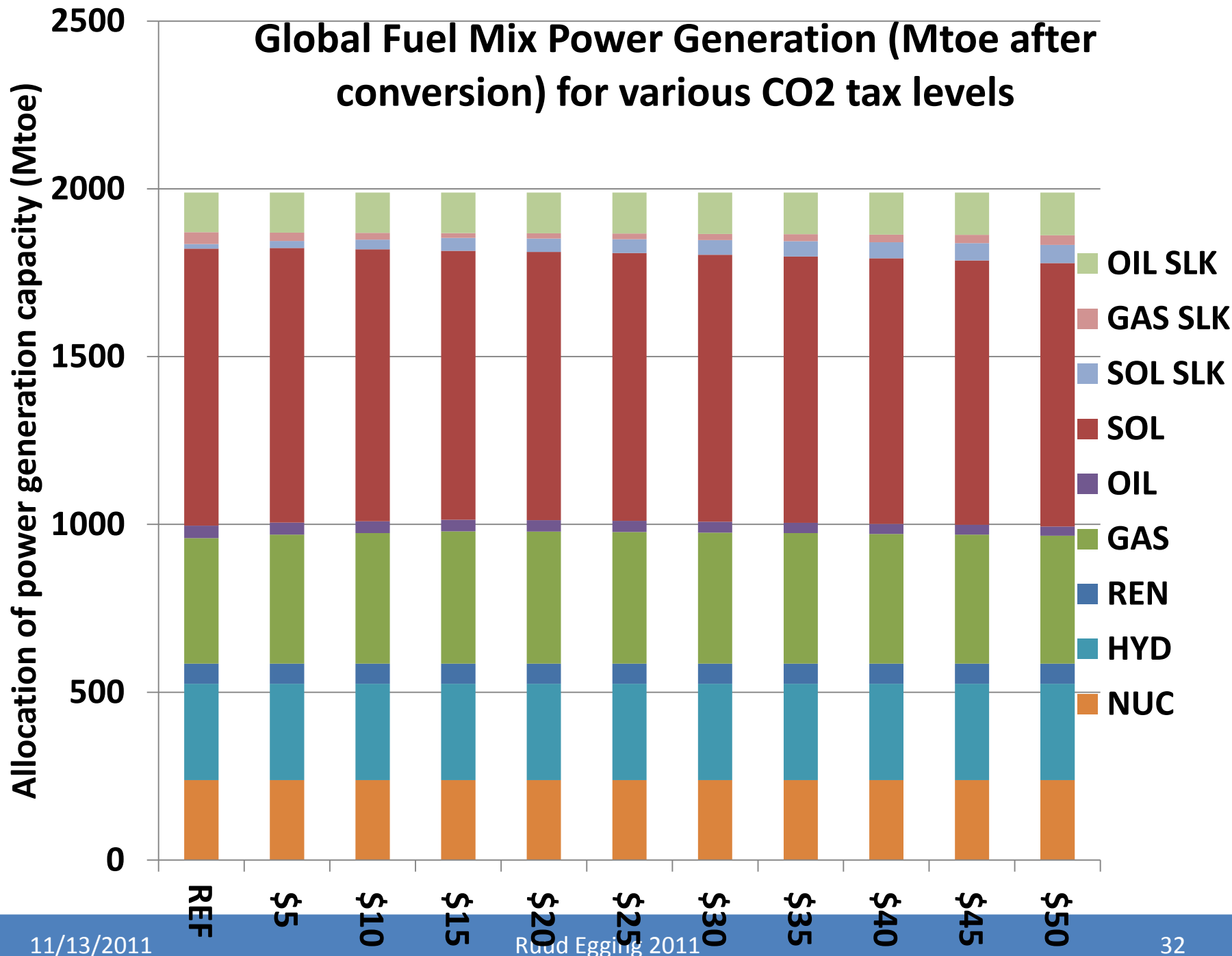


GLOBAL CO2 TAX

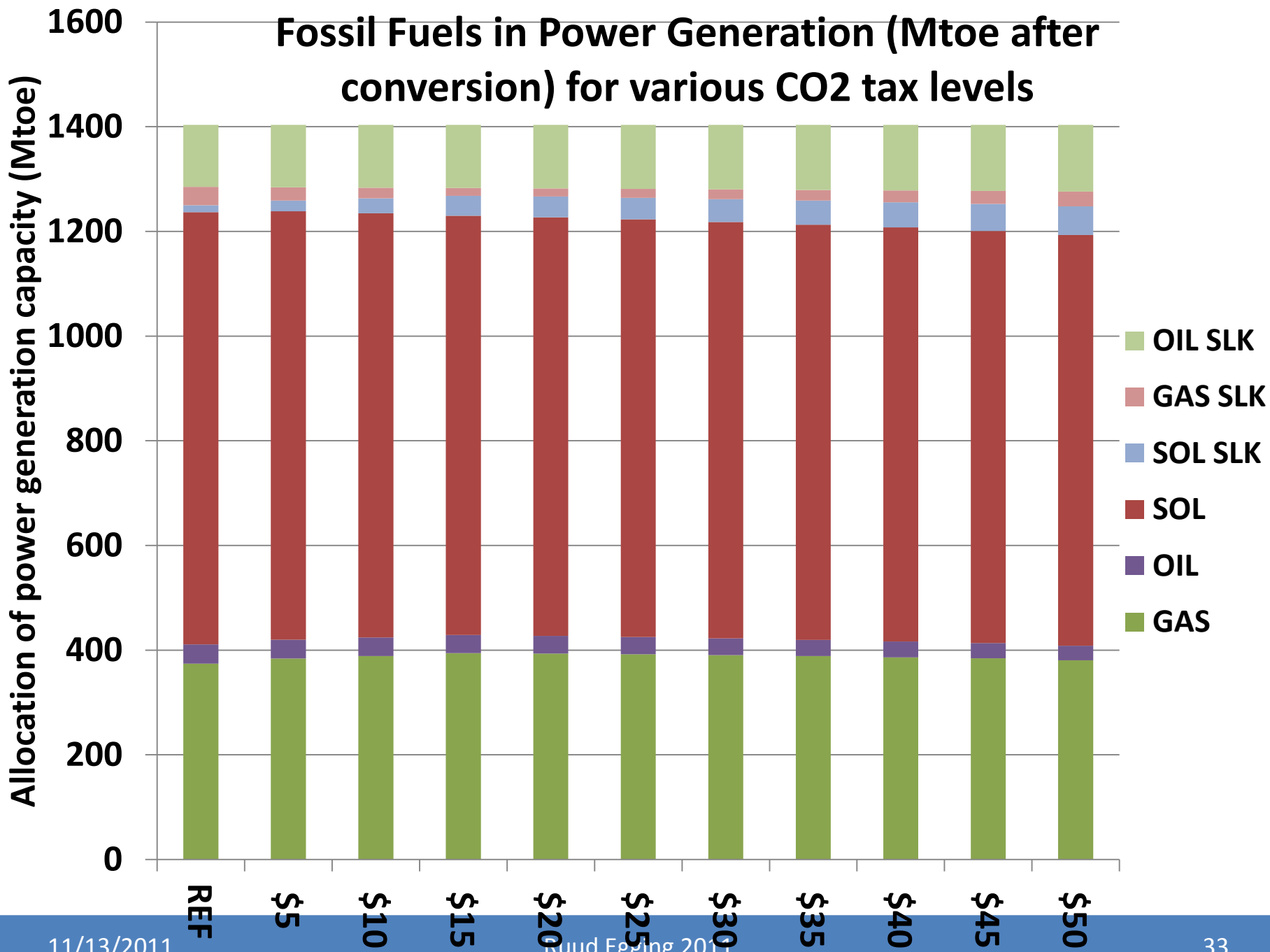




Global Fuel Mix Power Generation (Mtoe after conversion) for various CO2 tax levels



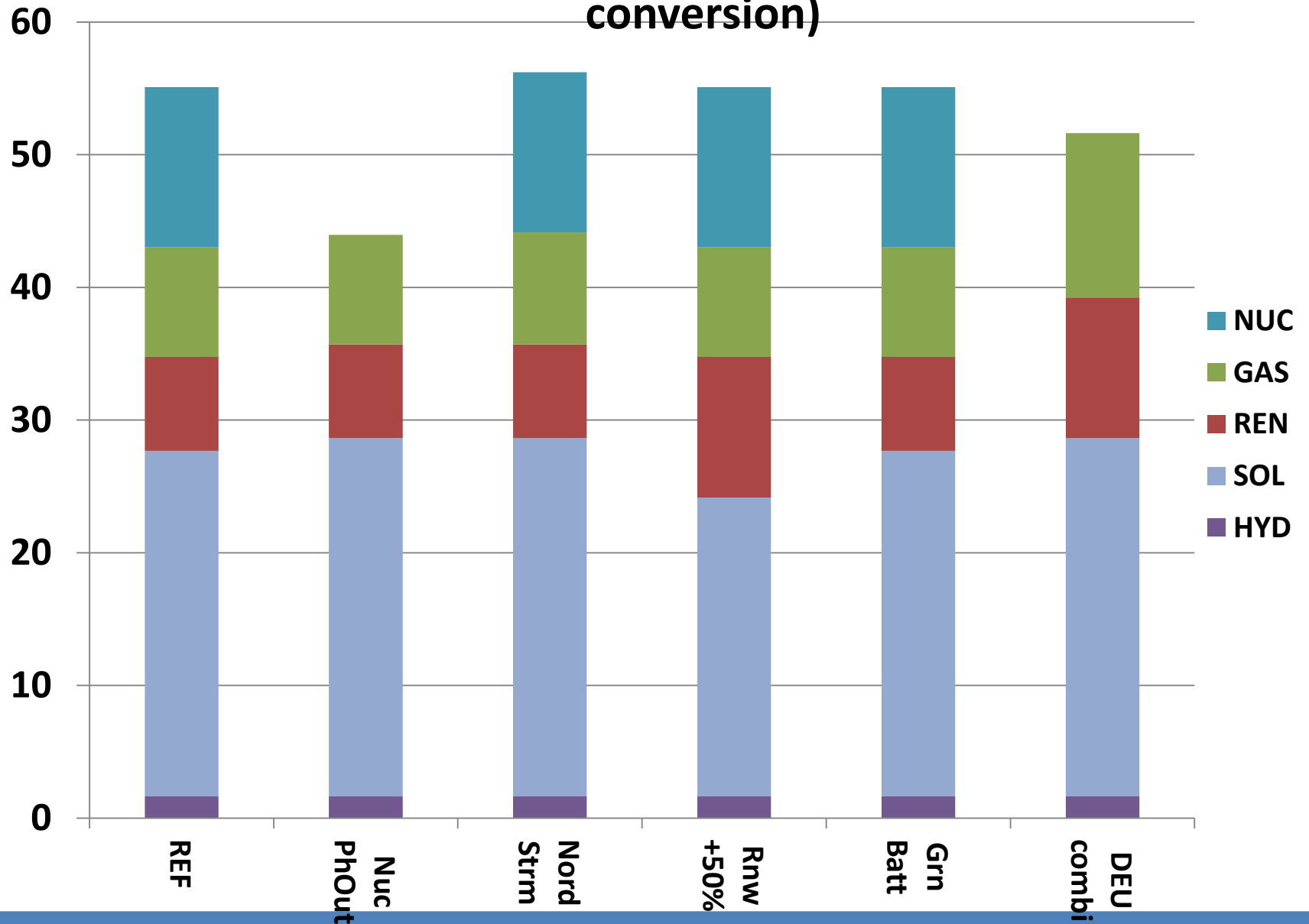
Fossil Fuels in Power Generation (Mtoe after conversion) for various CO2 tax levels

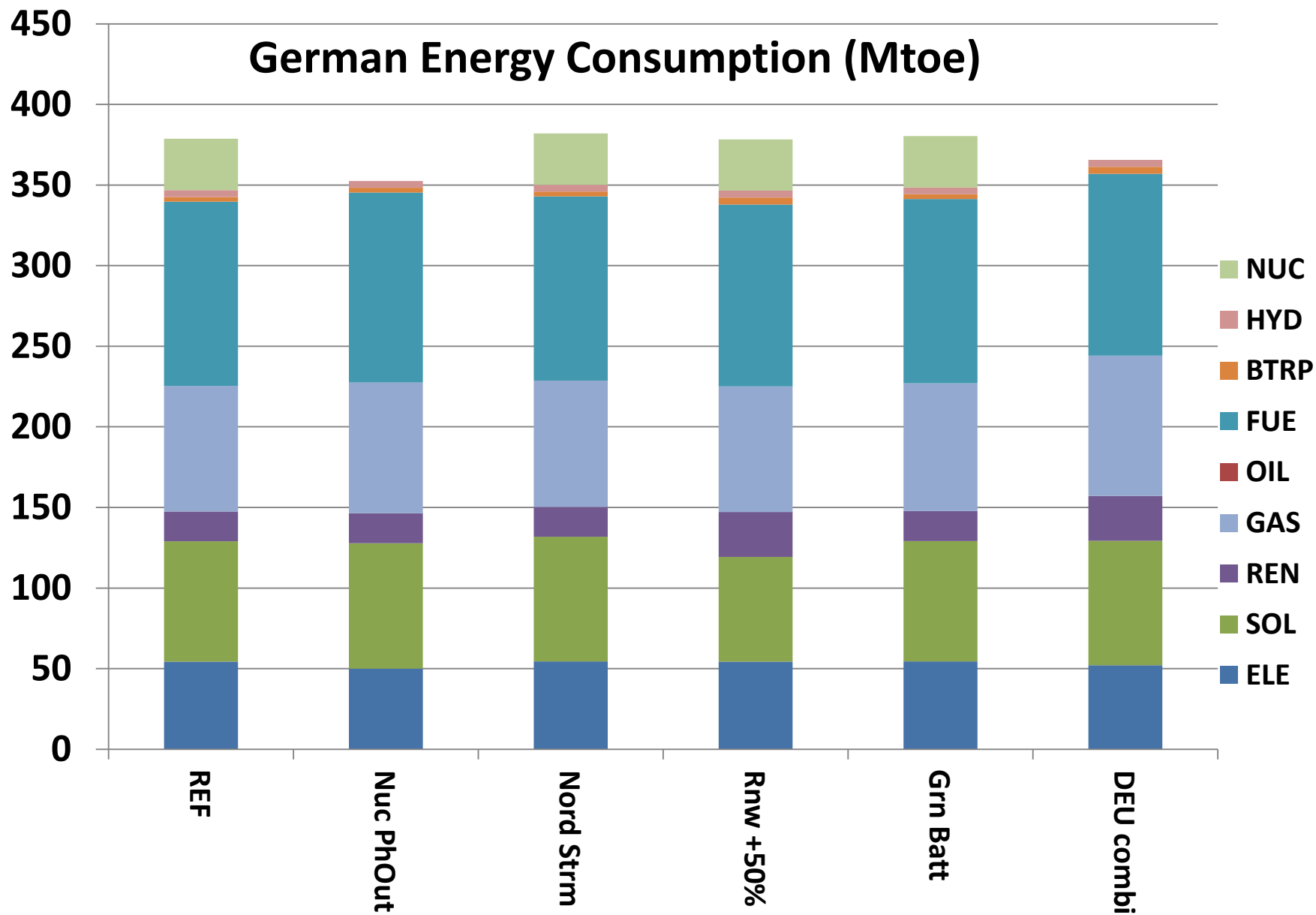


GERMANY

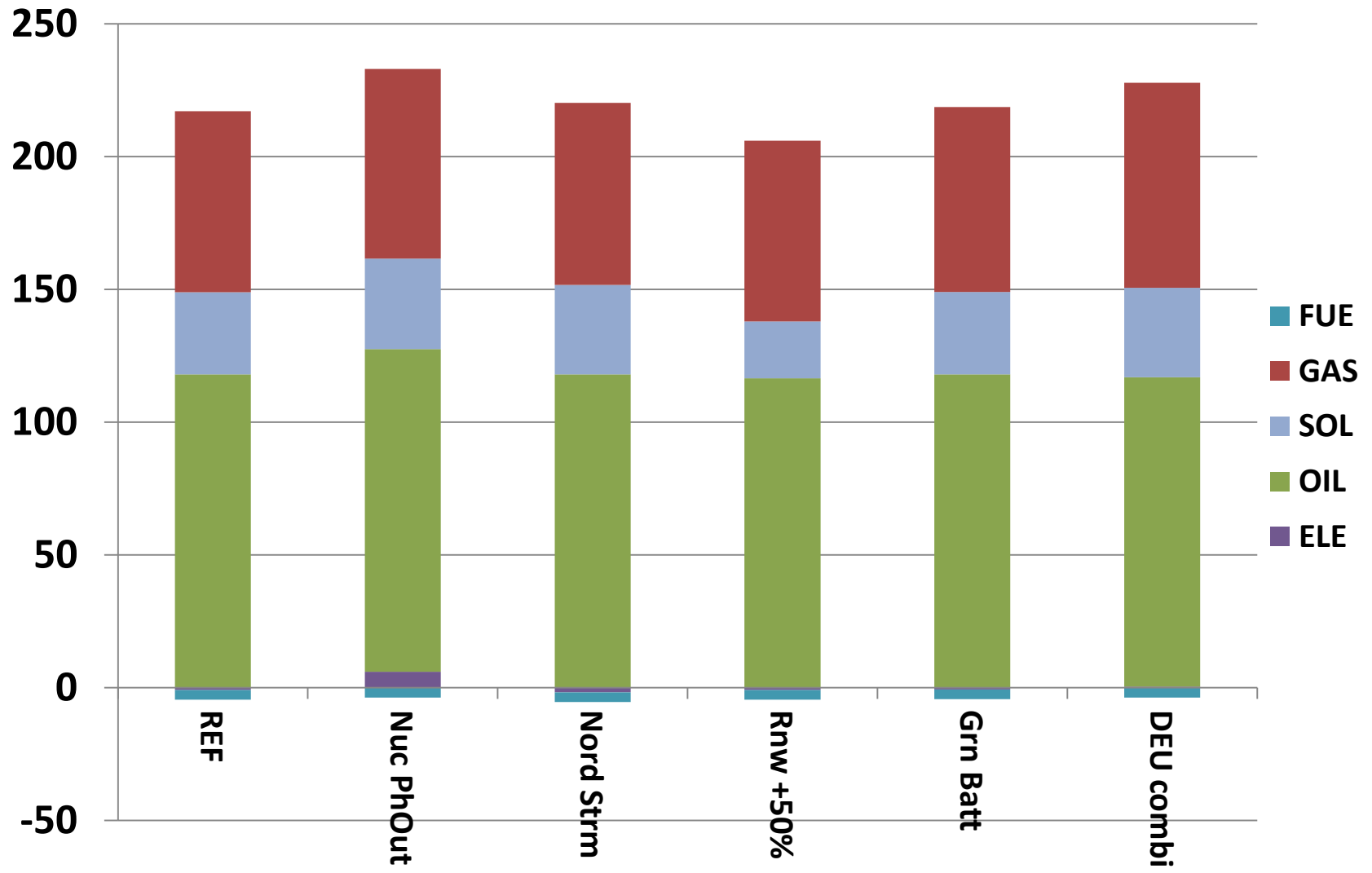
- Nuclear phase out
- Renewables plus 50
- NordStream I
- Green battery Norway
- It all comes together

German Fuel Mix Power Generation (Mtoe after conversion)

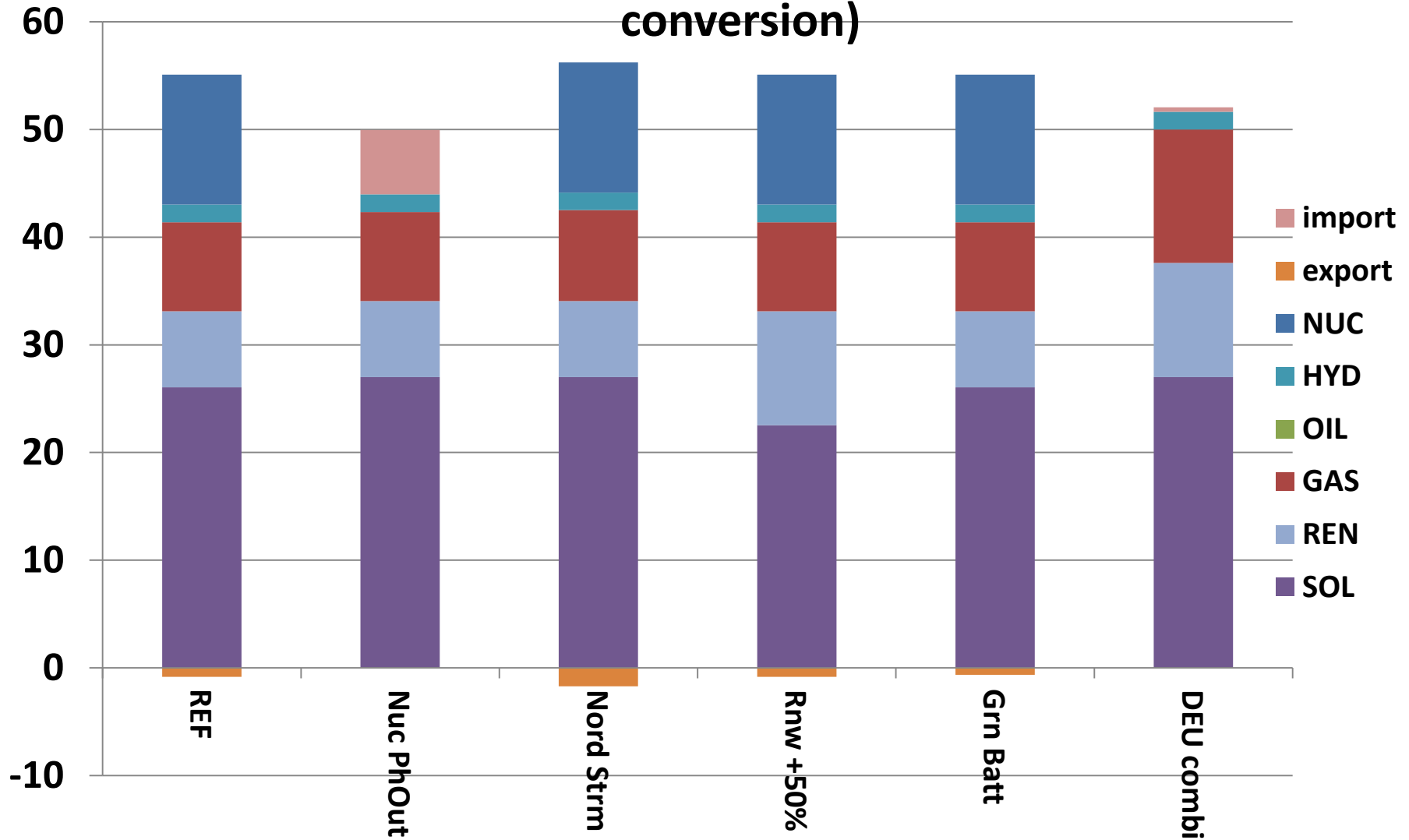




German Energy Trade (Mtoe)



German Supply Mix Power Generation (Mtoe after conversion)



CONCLUSIONS AND FUTURE WORK

Conclusions

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- Effects regional CO2 taxes largely undone elsewhere
- CO2 tax levels affect countries differently (willingness to pay, fuel mix)
- Global tax levels affect regional fuel mixes less

Future work

Outline

- Introduction
- Modeling approach
- Contributions
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- Sectoral consumption
- More detail non-European regions
- Seasonality and load curves
- More detail electricity generation
- network expansions (multi-period)
- Stochasticity

Thank you for your attention

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