OSeMOSYS

Integrated Systems Analysis of Energy

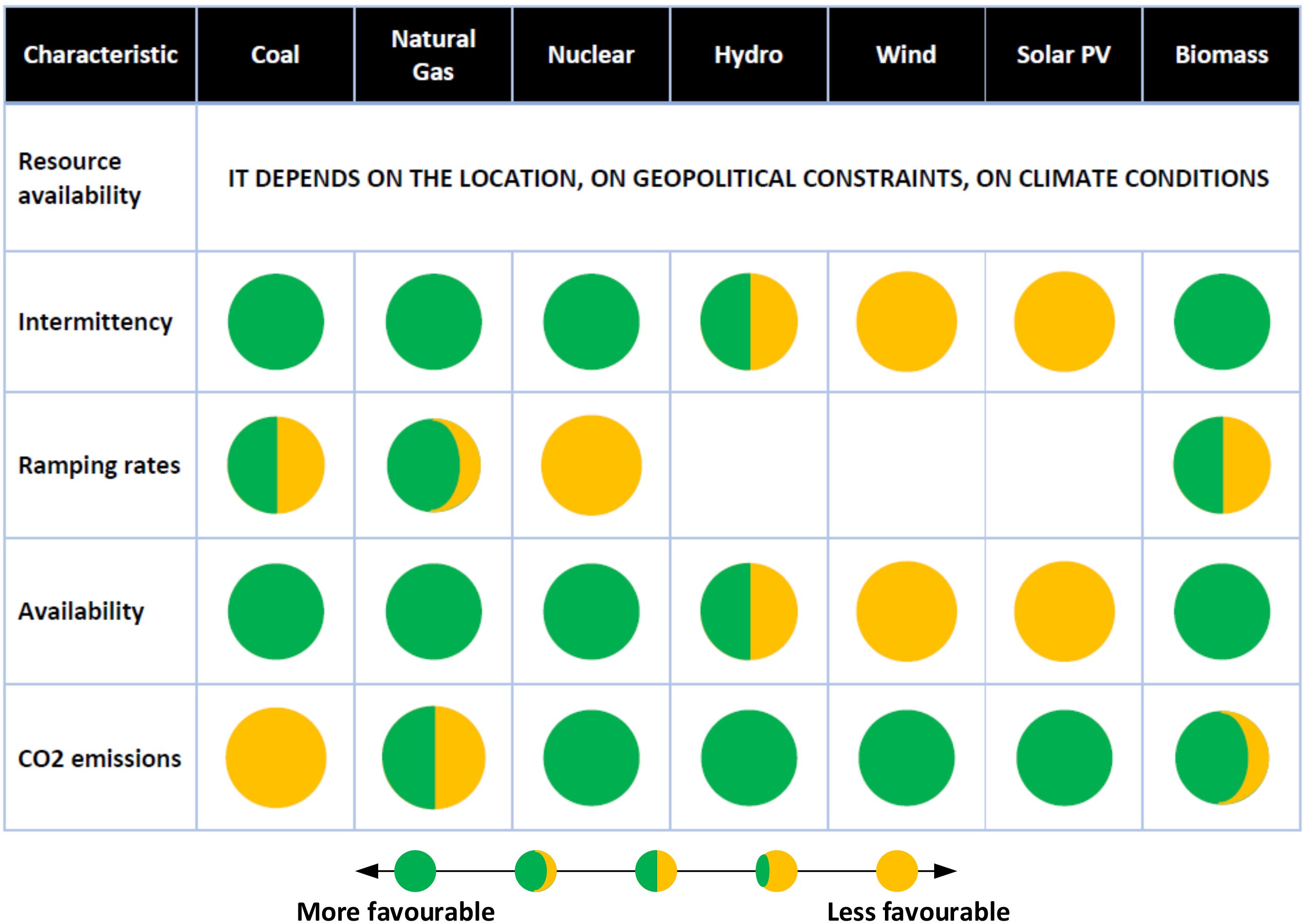
Outline

1. Introduction to OSeMOSYS and MoManI
2. Main application - The Cyprus model

1. Introduction to OSeMOSYS and MoManI

Is LCoE the only decision criterion?

Technologies compete to gain a share in the energy supply, based on their techno-economic characteristics (e.g. **Levelized Cost of Electricity)**, but also on a number of other constraints – **e.g. resource availability, intermittency of production, ramping rates**, etc.



Open **S**ource **e**nergy **MO**delling **SYS**tem (OSeMOSYS)

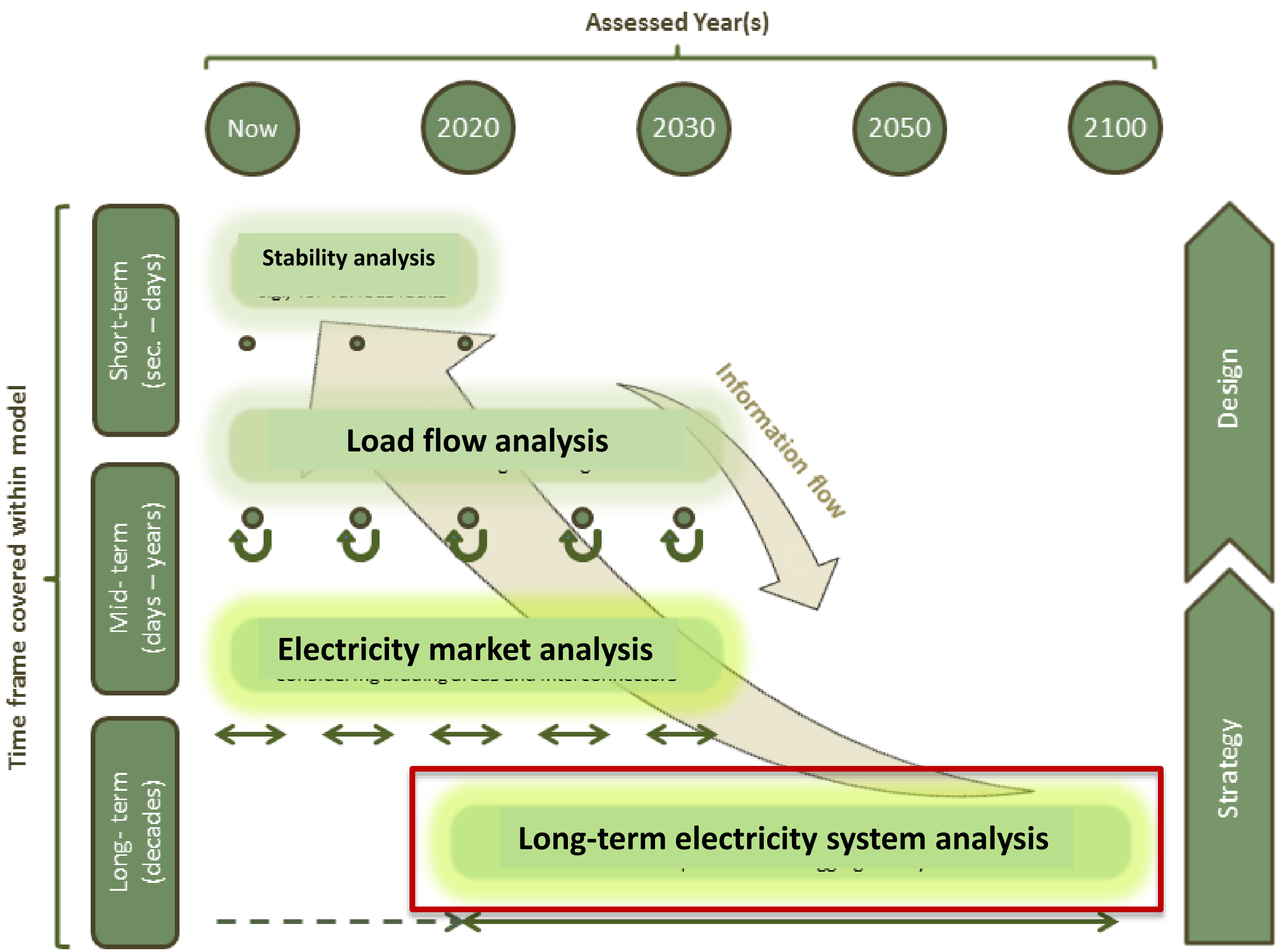
www.osemosys.org

2011, Howells et al., *OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development*, Energy Policy

Model generator converting the energy system structure represented by equations into a matrix to be solved by specific solvers

- Open source
- Deterministic
- Dynamic
- Perfect foresight
- Demand driven
- Paradigm comparable to MESSAGE or TIMES
- ***Linear optimisation***

Models in electricity systems planning and analysis



What is Linear Programming ?

- A special case of Mathematical programming which can be represented by linear relationships.
- Devoped by Leonid Kantorovich in 1939 for use during World War II to plan expenditures and returns – minimize costs to the army and maximize losses to the enemy.
- Kept secret till 1947
  - Now used in energy system planning, banking, education, forestry, petroleum, and logistics.
  - Survey of Fortune 500 firms: 85% said they had used linear programming.[2]

- Linear Programing model consists of:
  A linear objective function subject to linear equalities and/or linear inequalities.

[2] From Operations Research: Applications and Algorithms, 4th Edition, by Wayne L. Winston (Thomson, 2004)

Linear Programming – A simple example

Optimal allocation of oil and gas for electricity generation

Let's assume the electricity demand in our country can be met only by oil-fired and gas-fired generation. We have a demand of 7 electricity units. The sum of the oil-fired and the gas-fired generation must meet at least this demand. Whatever is produced in excess can be exported.

To produce 1 unit of electricity we need 3 units of oil or 2 units of gas.

We import both oil and gas and we have an upper limit of 15 units on the import of oil and a lower limit of 5 for use in the transportation sector.

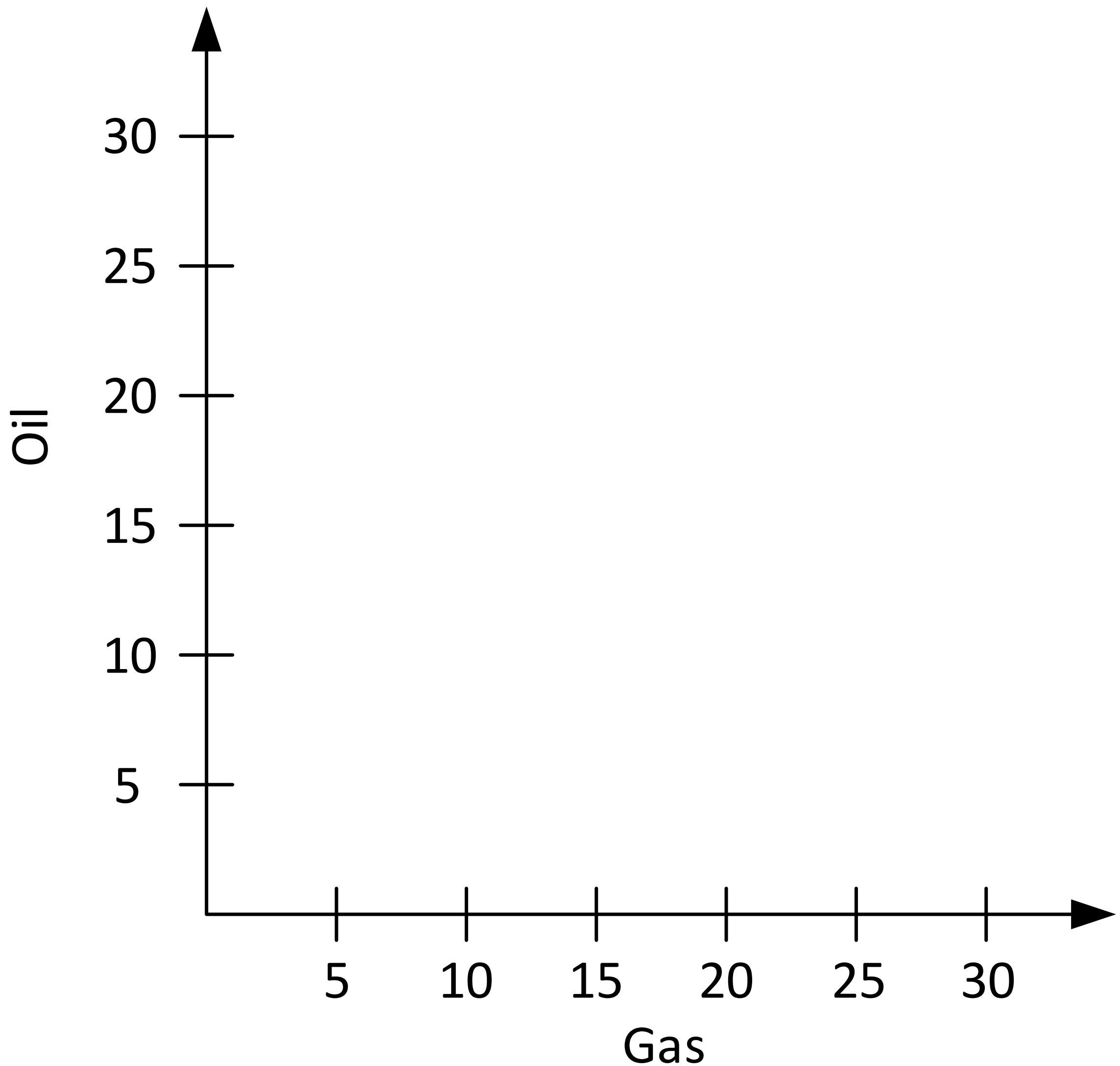
In addition, we have a limit of 10 units of CO_2 emissions and we know that 1 unit of CO_2 is produced by 2 units of oil or 3 units of gas.

Finally, we know that we minimize our generation costs if we export as much as possible and gas has the highest possible share.

We want to find the cost-optimal, feasible mix between oil-fired and gas-fired generation which allows us to meet the electricity demand.

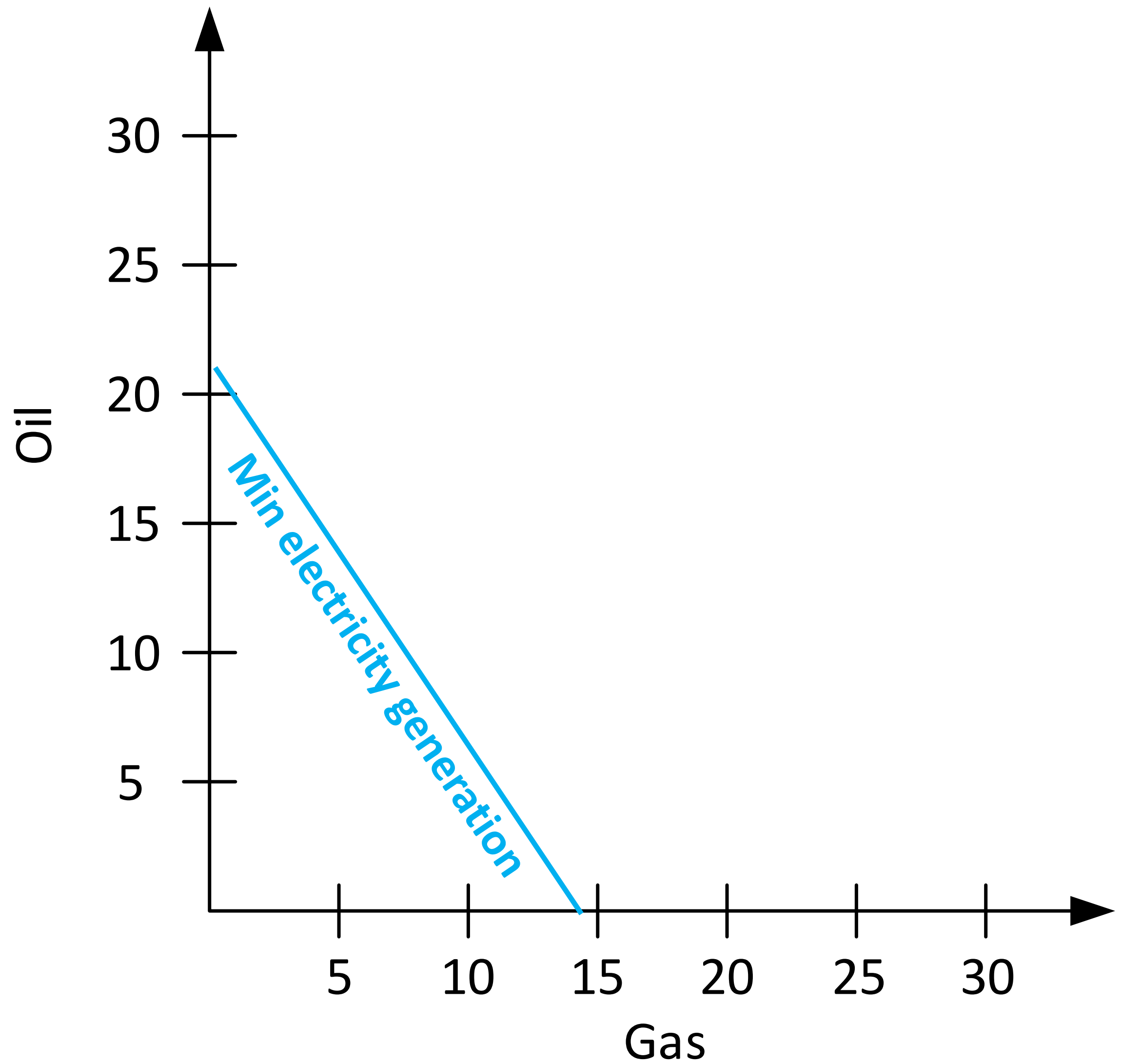
Linear Programming – A simple example

Optimal allocation of oil and gas for electricity generation



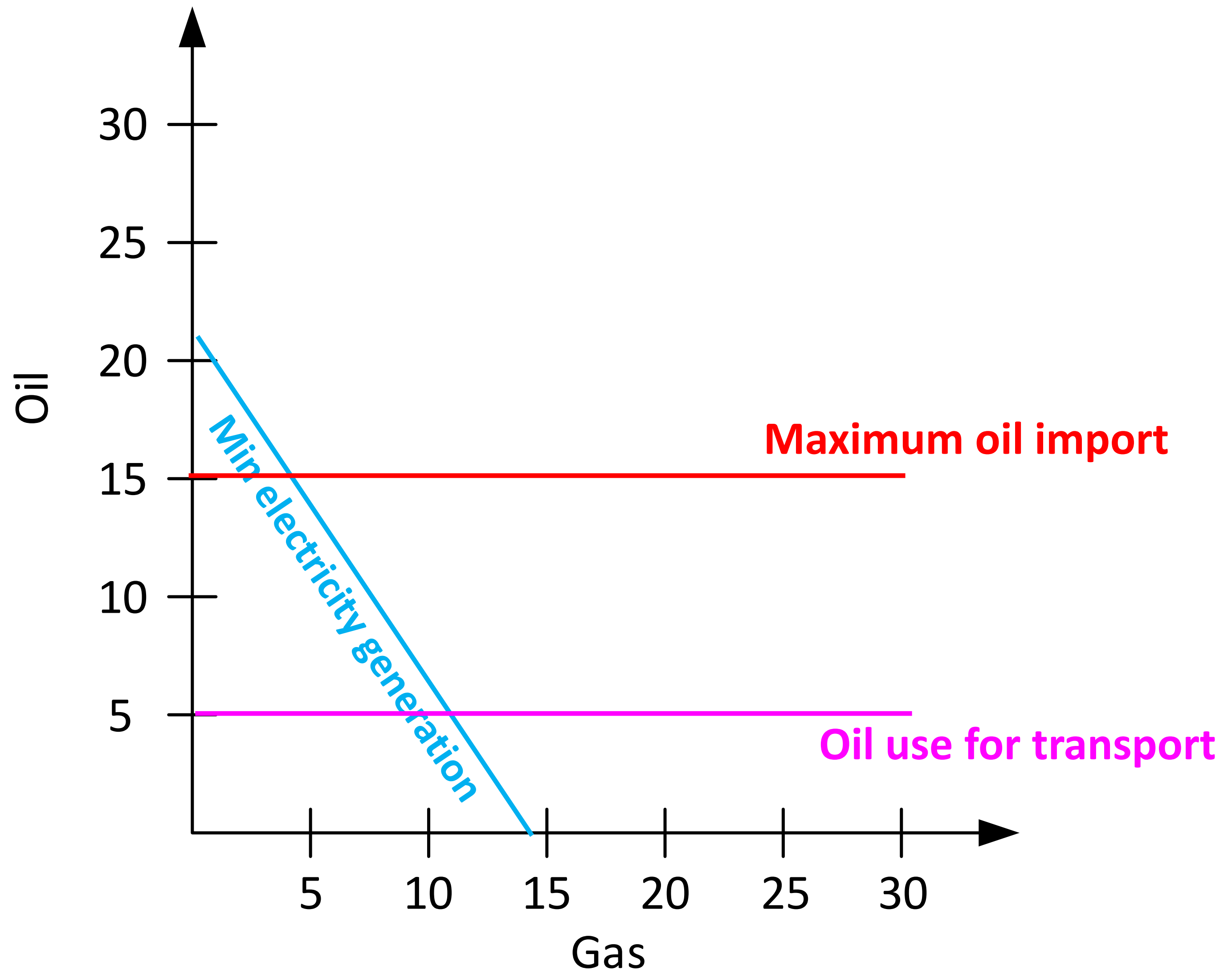
Linear Programming – A simple example

Optimal allocation of oil and gas for electricity generation



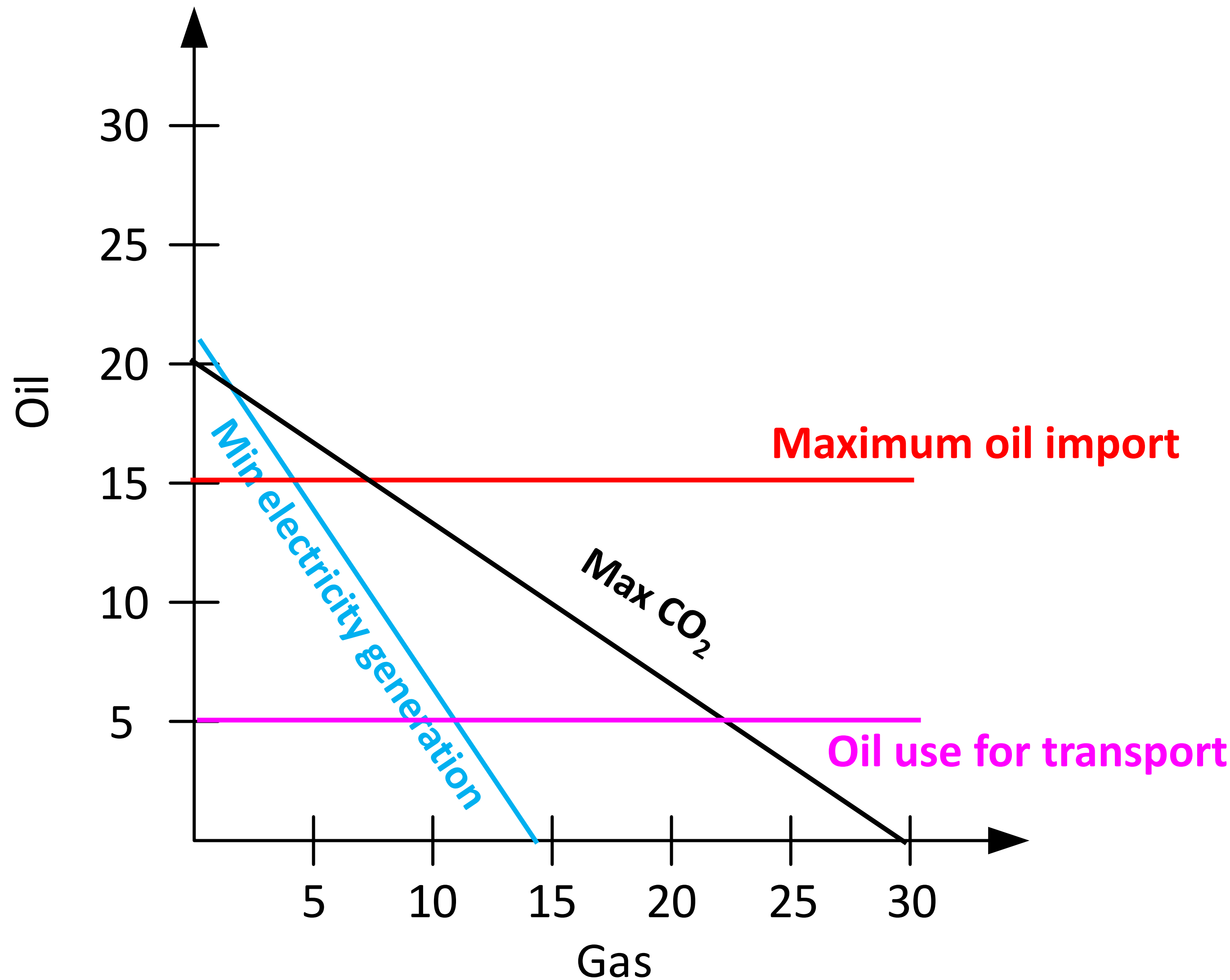
Linear Programming – A simple example

Optimal allocation of oil and gas for electricity generation



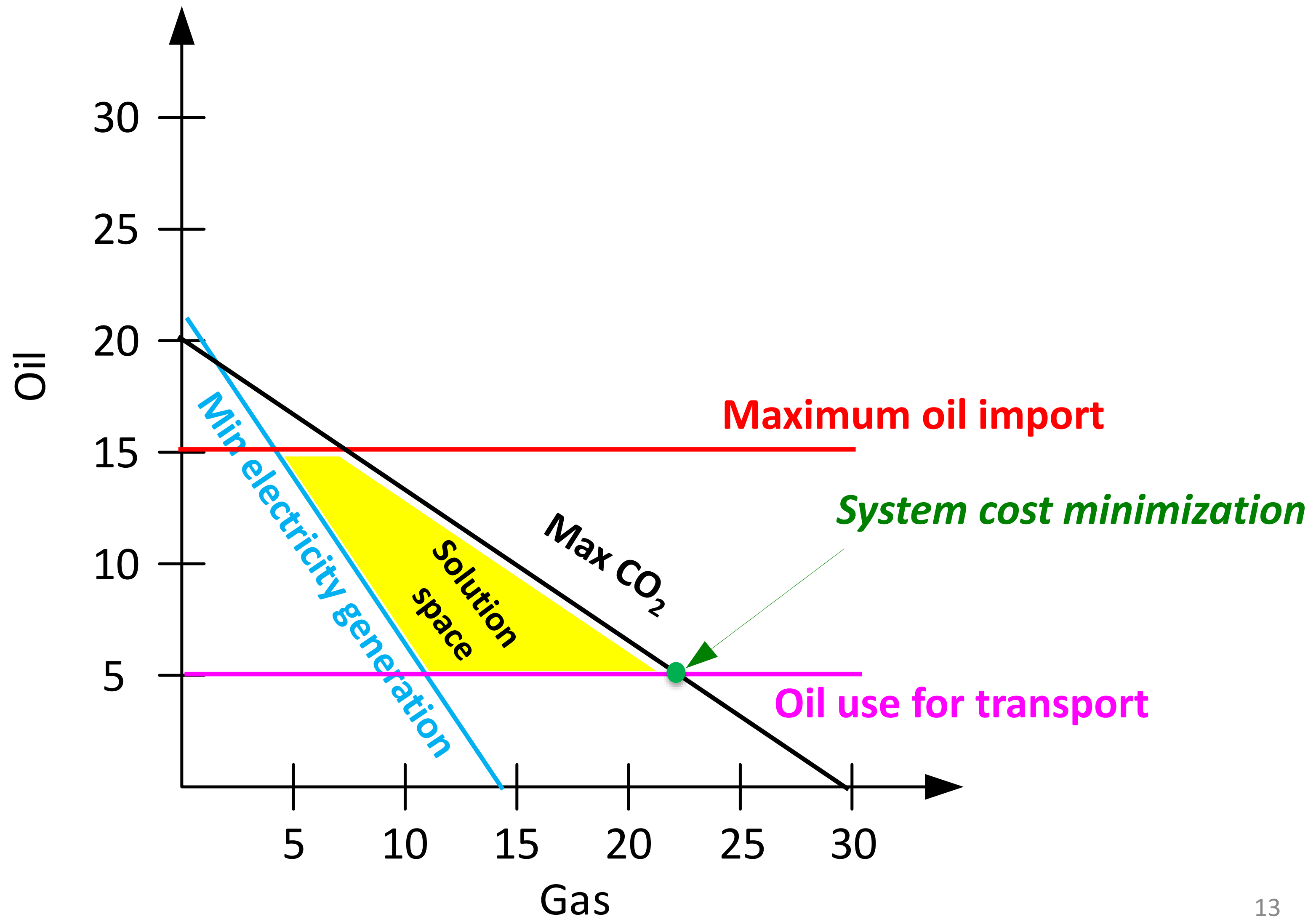
Linear Programming – A simple example

Optimal allocation of oil and gas for electricity generation



Linear Programming – A simple example

Optimal allocation of oil and gas for electricity generation



What does OSeMOSYS do?

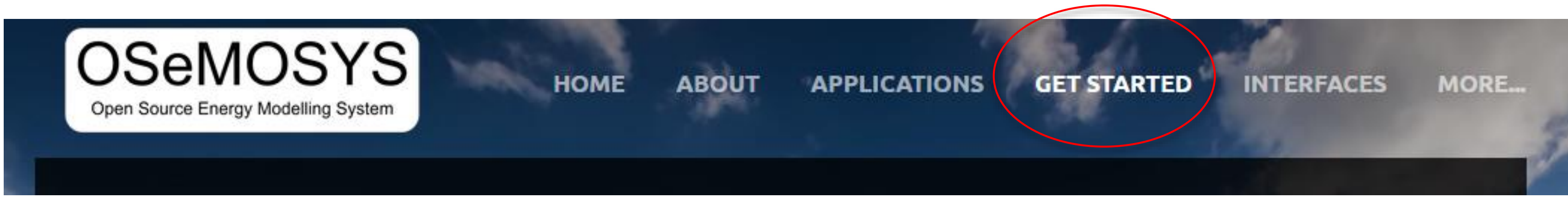
It determines the energy system configuration with the **minimum total discounted cost** for a time domain of decades, constrained by:

- Demand for energy (e.g. electricity, heating, cooling, km-passengers, etc.) that needs to be met
- Available technologies and their techno-economic characteristics (**Levelised Cost of Electricity**, efficiency, lifetime, etc.)
- Emission taxations, generation targets (e.g. renewables)
- Other constraints (e.g. ramping capability, availability of resources, investment decisions, etc.)

Getting started with OSeMOSYS

- Visit: http://www.osemosys.org/

- Go to Get Started:



- For questions: https://www.reddit.com/r/optimuscommunity/comments/5qb0hm/osemosys_qa/

OSeMOSYS capabilities

- Consideration of various types of costs
- Constraints on various parameters
- Modelling of energy system (broad perspective):
  - Heating, cooling, electricity, transportation, user-defined demands;
  - Storage;
  - Add-ins for short-term operational constraints (minimum load, ramping rates and costs, load shedding and shifting);
  - Links to behavioral models;
  - Links to Monte-Carlo analysis and scripts for batch runs
- Integrated systems analysis (targeted applications):
  - Energy-water resources assessment (e.g. Sava and Drina transboundary river basins);

Sample input parameters of OSeMOSYS

Accounted for in LCoE:

- Existing historical capacity
- Efficiency
- Load factor
- Life time
- Fuel costs
- Capital costs
- O&M costs
- …

Other constraints:

- Ramping characteristics
- Emission factors
- Production targets
- Investment constraints
- Taxations on emissions
- Availability of resources
- …

param CapitalCost default 0 :=

	2014	2015	2016	2017	2018	2019
CCGT	950	950	950	950	950	950
GT	500	500	500	500	500	500
COAL PP	2200	2200	2200	2200	2200	2200
DIESEL	450	450	450	450	450	450
HYDRO	2000	2000	2000	2000	2000	2000
NUCLEAR	5000	5000	5000	5000	5000	5000
CSP	6000	6000	6000	6000	6000	6000
PV	2500	2500	2500	2500	2500	2500
WIND	1600	1600	1600	1600	1600	1600

;

param FixedCost default 0 :=

	2014	2015	2016	2017	2018	2019
CCGT	15.4	15.4	15.4	15.4	15.4	15.4
GT	7	7	7	7	7	7
COAL PP	28.1	28.1	28.1	28.1	28.1	28.1
DIESEL	7	7	7	7	7	7
HYDRO	12	12	12	12	12	12
NUCLEAR	63	63	63	63	63	63
CSP	40	40	40	40	40	40
PV	20	20	20	20	20	20
WIND	25	25	25	25	25	25

;

Input parameters

Data collection

- Electricity demand projections
- Primary resources potentials
- Existing capacity
- Technology costs and characteristics
- Country/region specific constraints
- Fuel prices

Data pre-processing

- Discretization of demand curves
- Assume data if not available
- Etc…

Model calibration

I.e. set the starting year of the model as a historical year for which actual data are predominantly available. Tweak inputs for that year, for the outputs to resemble what actually happened.

Interpreting modelling results

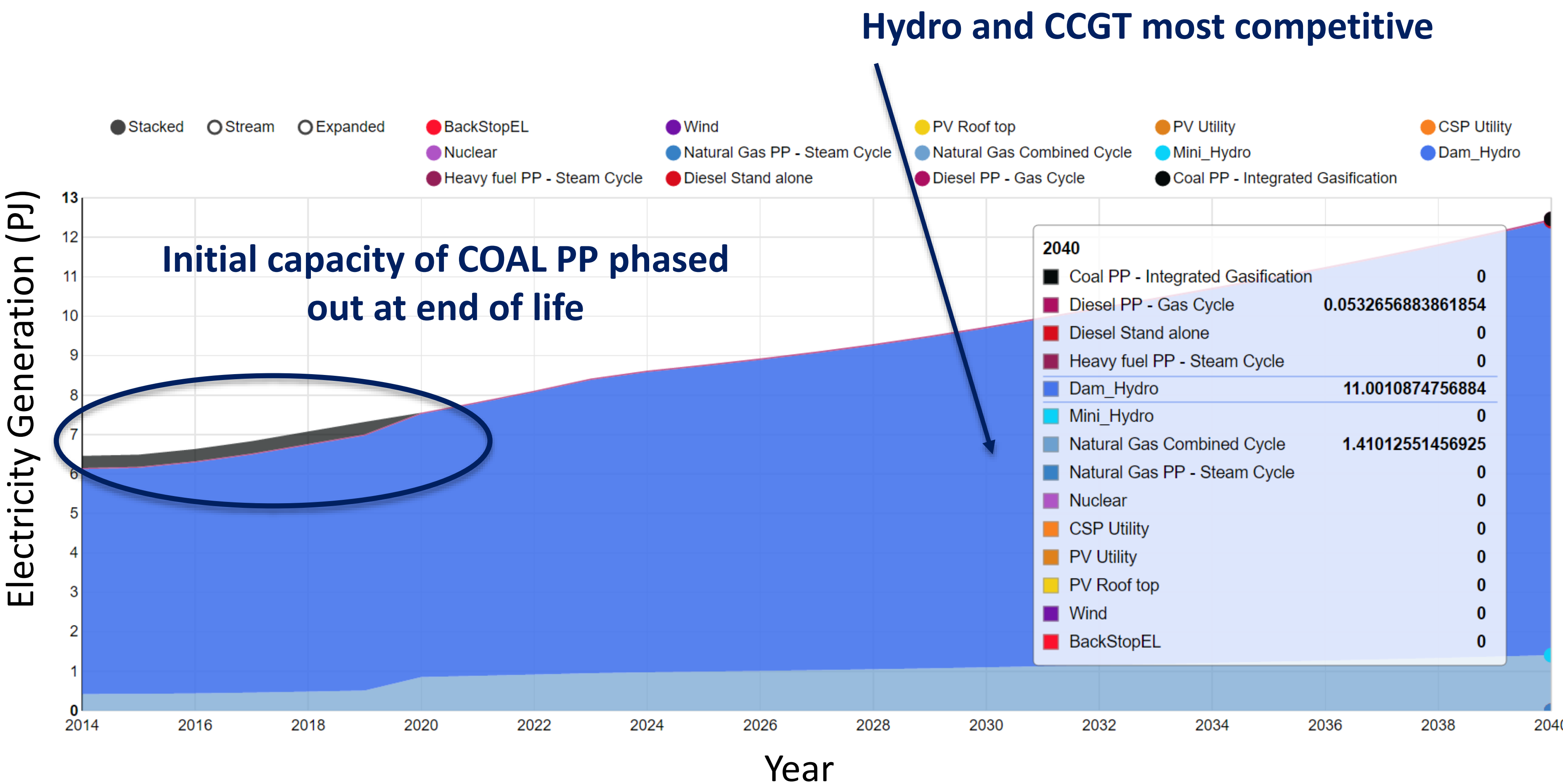
The results answer questions such as:

- Which technologies are phasing out? By when?
- What are the optimal investments in new technologies to meet the demand in the future? When is it best to invest?
- What are the key generation technologies in the total energy mix?
- Which capacities are NOT being utilized? Why?
- What costs will the energy system incur?

Interpreting modelling results

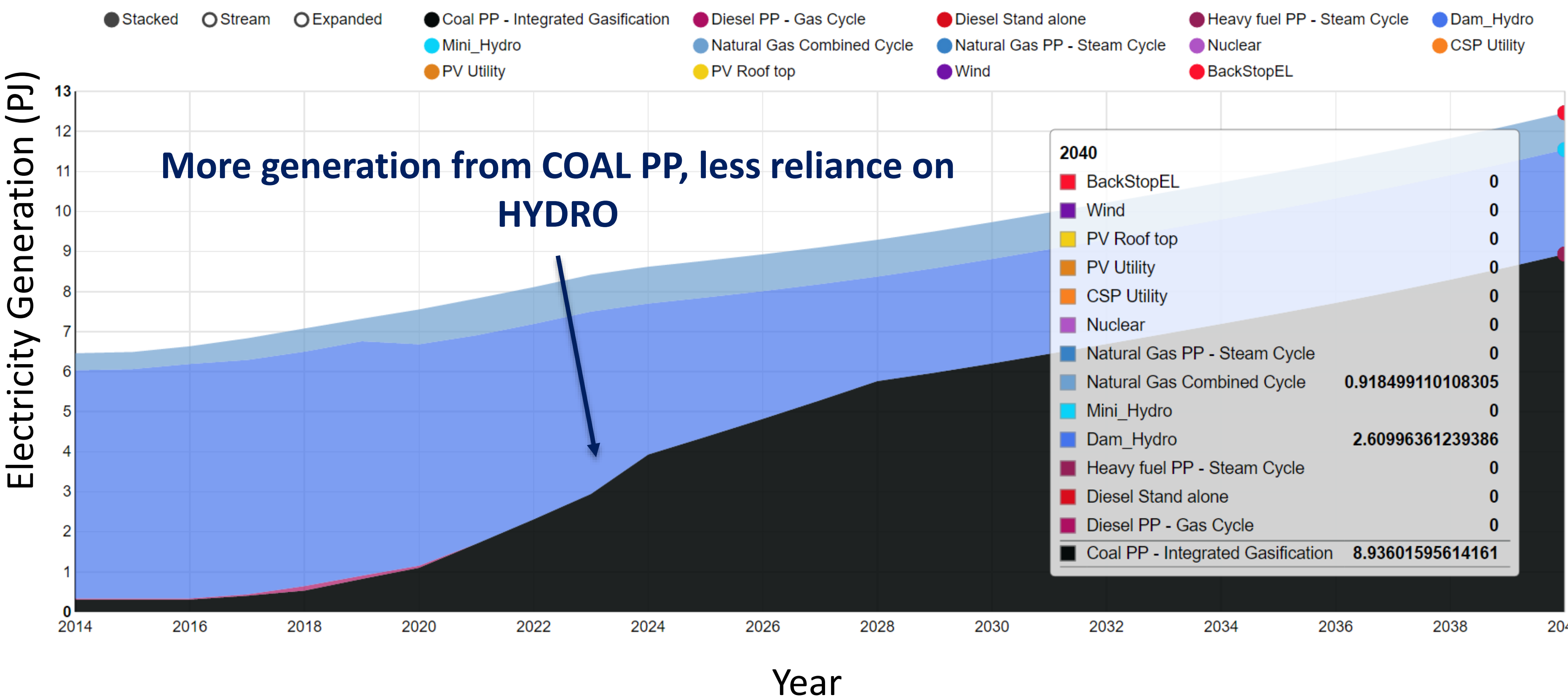
- ✓ What would be the impact of large swings in oil prices?
- ✓ Can we fully rely on renewables?
- ✓ If not, what is the maximum share of renewables that the energy system can accommodate? Is it financeable?
- ✓ Should the tax on transport fuels increase to encourage the use of public transportation?
- ✓ Would switching to "advanced technologies" allow us to continue improving living-standards & simultaneously avoid climate change?
- ✓ Can we really afford heavy up-front investment technologies? E.g (Wind, CSP, PV, Hydro ..etc)
- ✓ What is the impact of energy efficiency measures on the supply mix?

Representative OSeMOSYS results



Representative OSeMOSYS results

What happens in a climate change adaptation scenario?

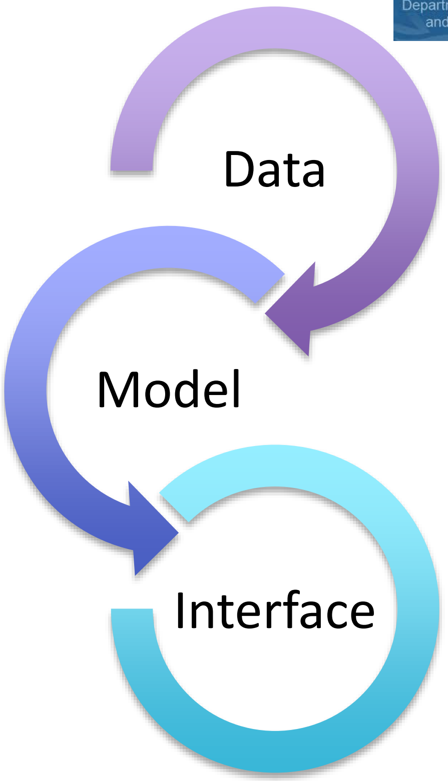


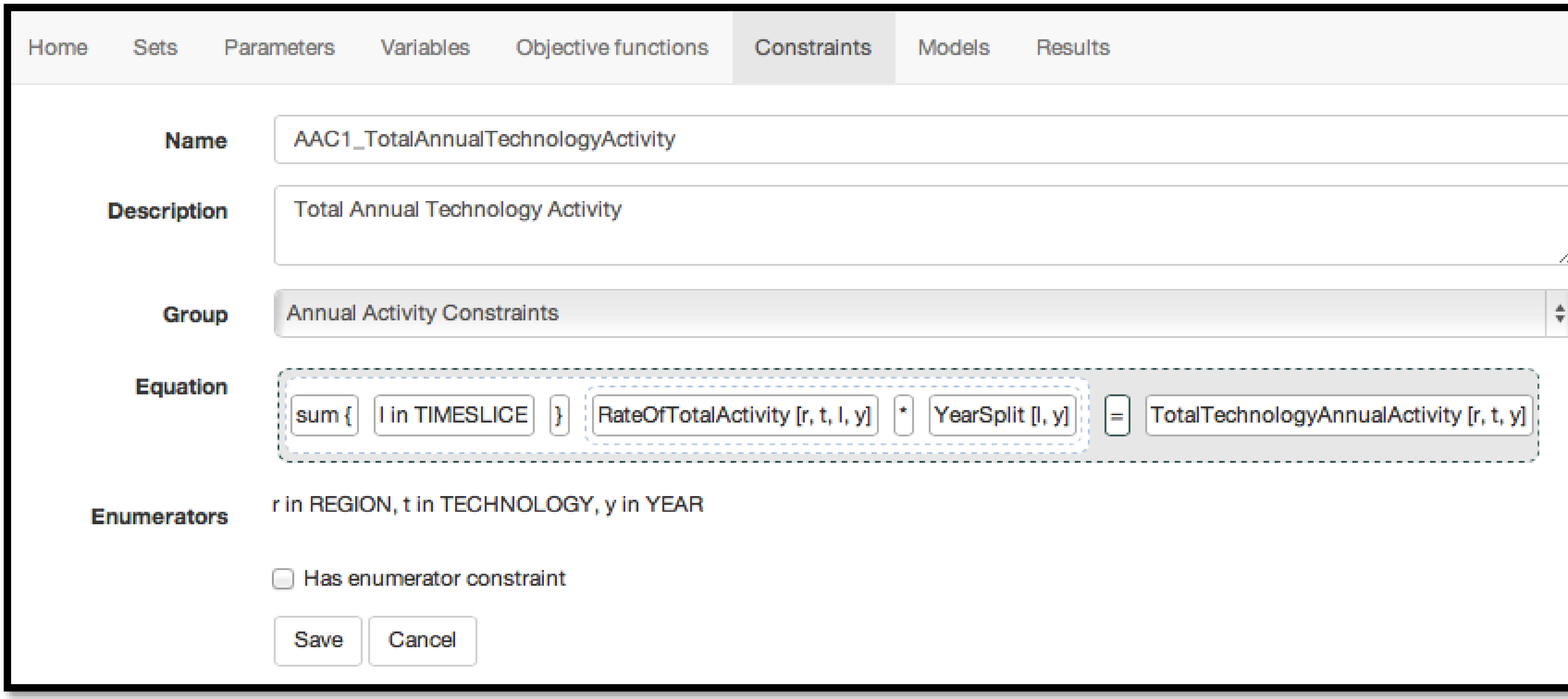
What is MoManI?

- It is an infrastructure for any type of linear programming optimization.

Features:

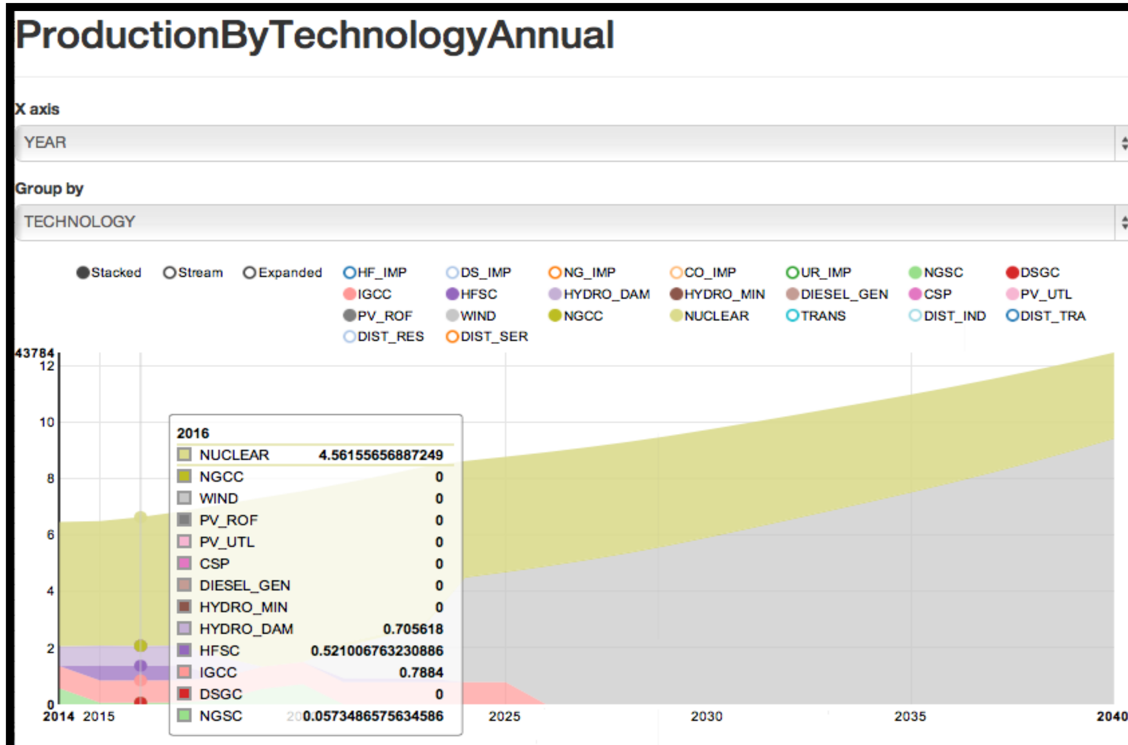
- Browser-based interface and available on standalone version also.
- ‘Building block’ structure to develop new equations.
- Open and accessible at 3 levels:
  - Data.
  - Model equations.
  - Interface source code.




Home
Sets
Parameters
Variables
Objective functions
Constraints
Models
Results
Name
AAC1_TotalAnnualTechnologyActivity
Description
Total Annual Technology Activity
Group
Annual Activity Constraints
Equation
sum {
l in TIMESLICE
}
RateOfTotalActivity [r, t, l, y]
*
YearSplit [l, y]
=
TotalTechnologyAnnualActivity [r, t, y]
Enumerators
r in REGION, t in TECHNOLOGY, y in YEAR
Has enumerator constraint
Save
Cancel

Results Visualization in MoManI:

- Uses D3.js package
- Flexibility of variables and sets to visualize
- Easy comparison between scenarios



United Nations
Department of Economic and Social Affairs

Comparing results for Atlantis00A

Left scenario

BAU (The Baseline scenario - With residual cap / Constraint on fuel import / Constraint on max cap)

Right scenario

100%Electrification (100% Electrification - Tier 5 assumption for house households elec. consumption + Service demand)

Variable

ProductionByTechnologyAnnual

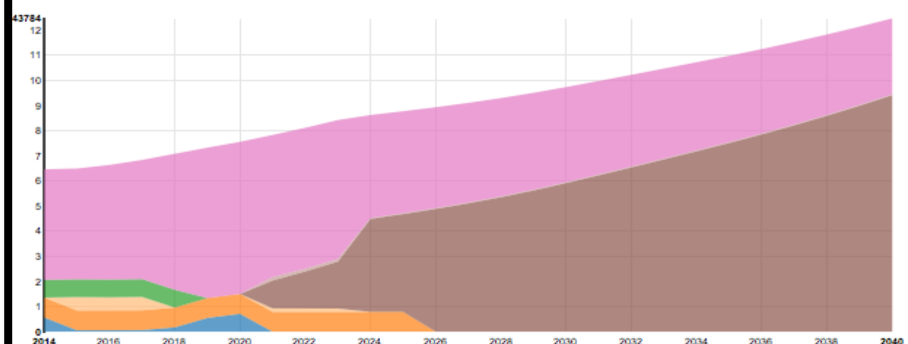
X axis

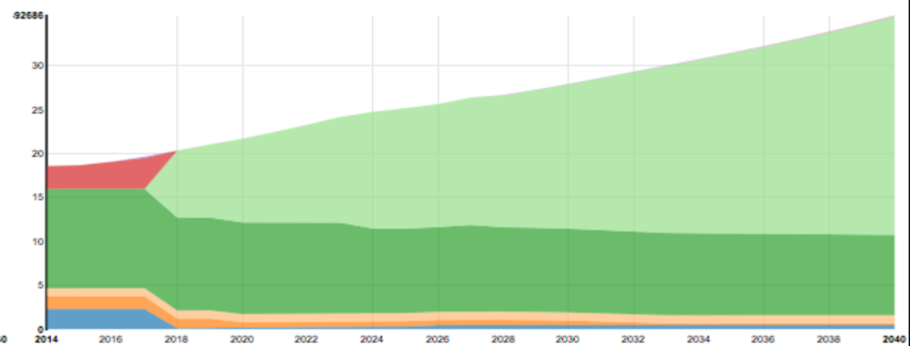
YEAR

Group by

TECHNOLOGY

Show legend





2. Main applications - The Cyprus model

APPLICATIONS

- Cyprus model: A complete, analytical country model including electricity, heating, cooling and transportation
- Continental models: TEMBA (Africa), SAMBA (South America), PAN-EU (ongoing), ASIA (planned)
- CLEWs applications: either entirely in OSeMOSYS (Mauritius) or coupling with WEAP (Nicaragua and Uganda)

The Cyprus model - Scope of study

Modelling the energy system of Cyprus

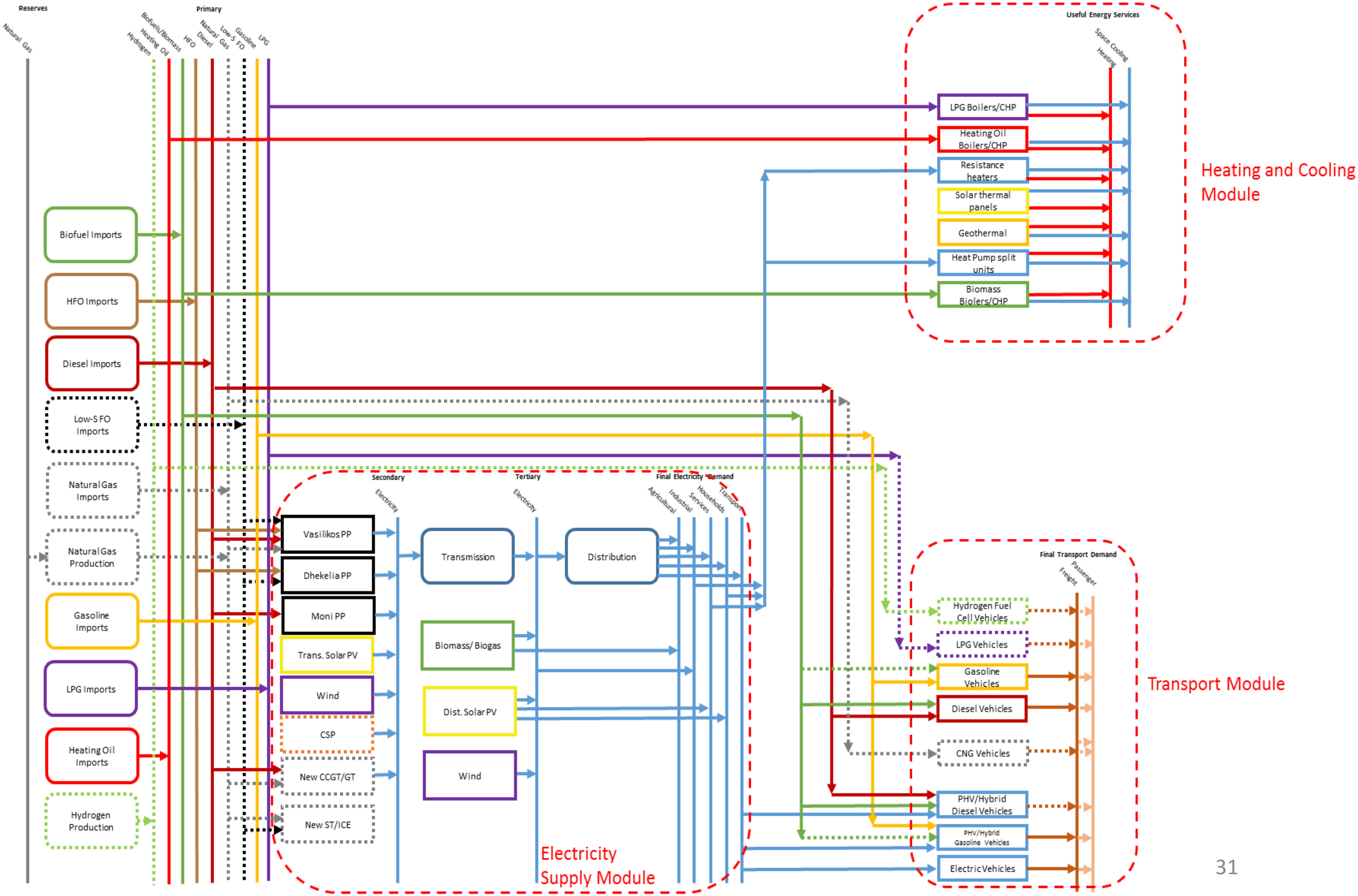
- Achievement of national targets (RE, Transport, emission limits etc.)
- Cost-optimal development pathways
- Scenario analysis

Aim: Facilitate in the formulation of a consolidated energy plan

Model structure

- Developed in OSeMOSYS – cost-optimization.
- Energy system divided into three sectors:
  - Electricity Supply
  - Transport
  - Heating and Cooling
- 2020 RES target of 13% implemented on the system as a whole
- CO_2 (ETS and non-ETS sectors) and SO_x emission limits on the entire system
- Model horizon to 2050

Reference Energy System



Scenarios

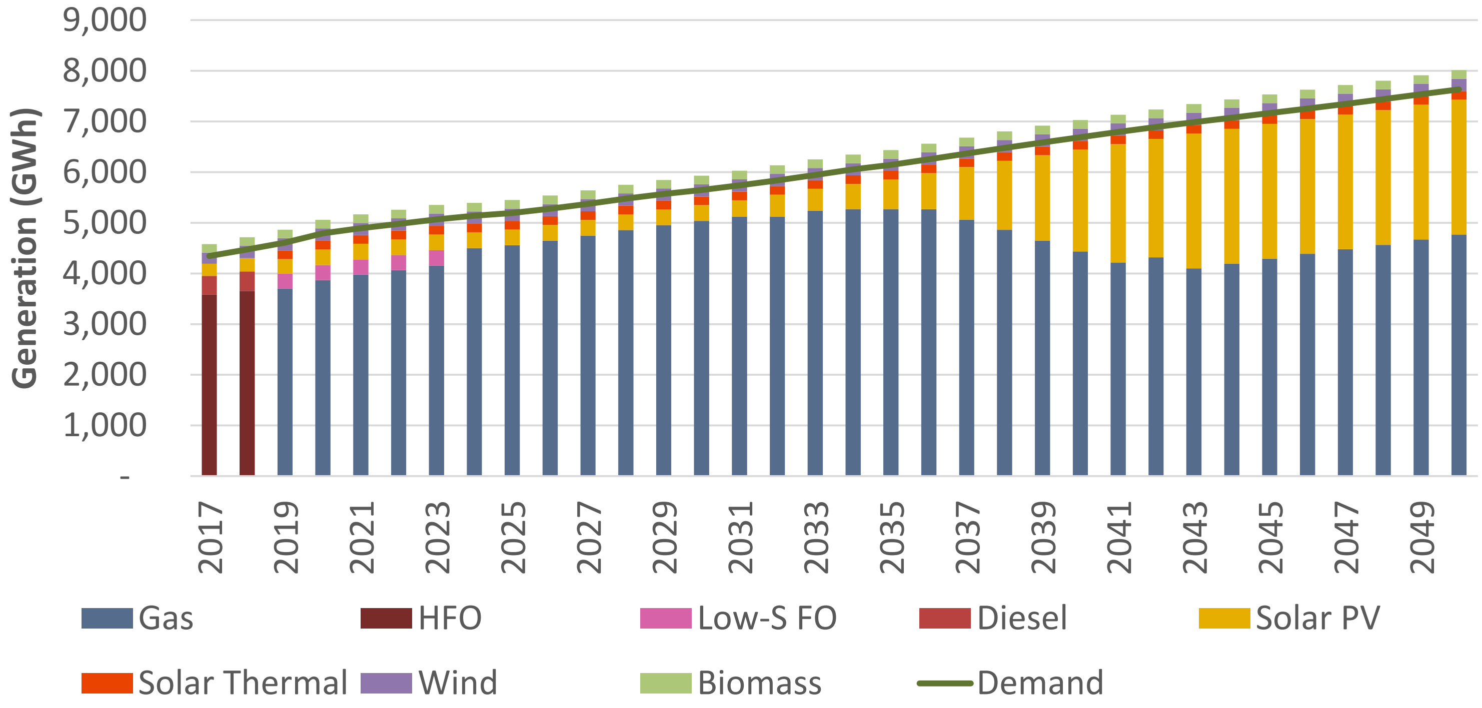
Three main scenarios – varying degree of difficulty in achieving 2020-2030 targets

- Reference Scenario: Natural gas is available via an LNG regasification terminal by 2019. This fuel is made available for generation and transport sectors only.
- Delayed Gas Scenario: Natural gas arrival is delayed to 2024.
- No Gas Scenario: Natural gas is not made available at any point in time – most demanding scenario in terms of emissions reduction.

Fuel prices correspond to IEA Low Oil price scenario (IEA WEO 2015)

Electricity supply results

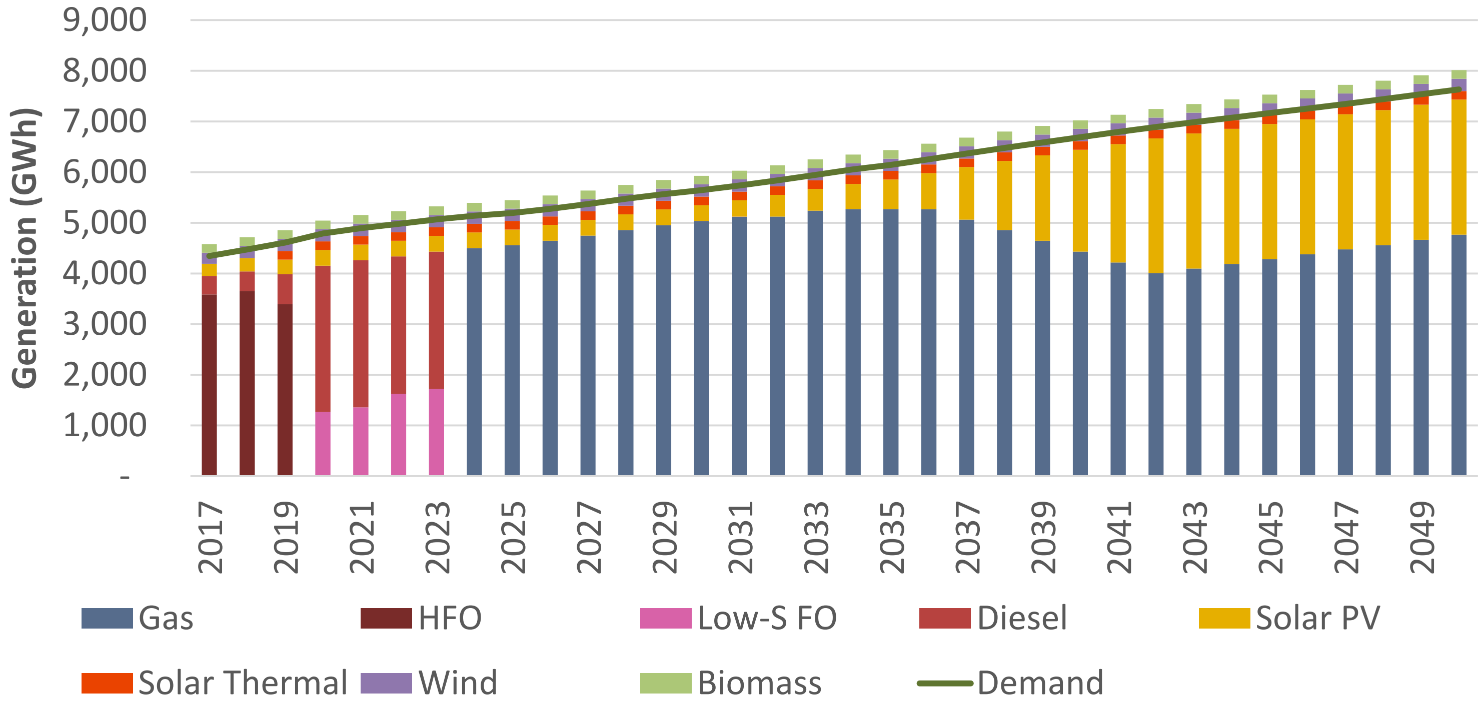
Reference scenario - generation



Reference scenario - capacity

MW	2020	2025	2030	2035	2040	2045	2050
Vasilikos	868	868	868	608	0	0	0
Dhekelia	460	102	102	102	0	0	0
Moni	150	150	150	0	0	0	0
New CCGT	0	216	216	432	864	864	864
New ICE	0	0	0	0	0	0	0
New ST	0	0	0	0	0	0	57
New GT	0	0	0	0	0	62	248
Solar PV	191	191	191	359	1239	1639	1639
Solar Thermal	50	50	50	50	50	50	50
Wind	175	175	175	175	175	175	175
Biogas	40	40	40	40	40	40	40
Pumped Hydro	0	0	0	130	130	130	130
Li-Ion Batteries	0	0	116	260	503	523	479

delayed gas scenario - generation

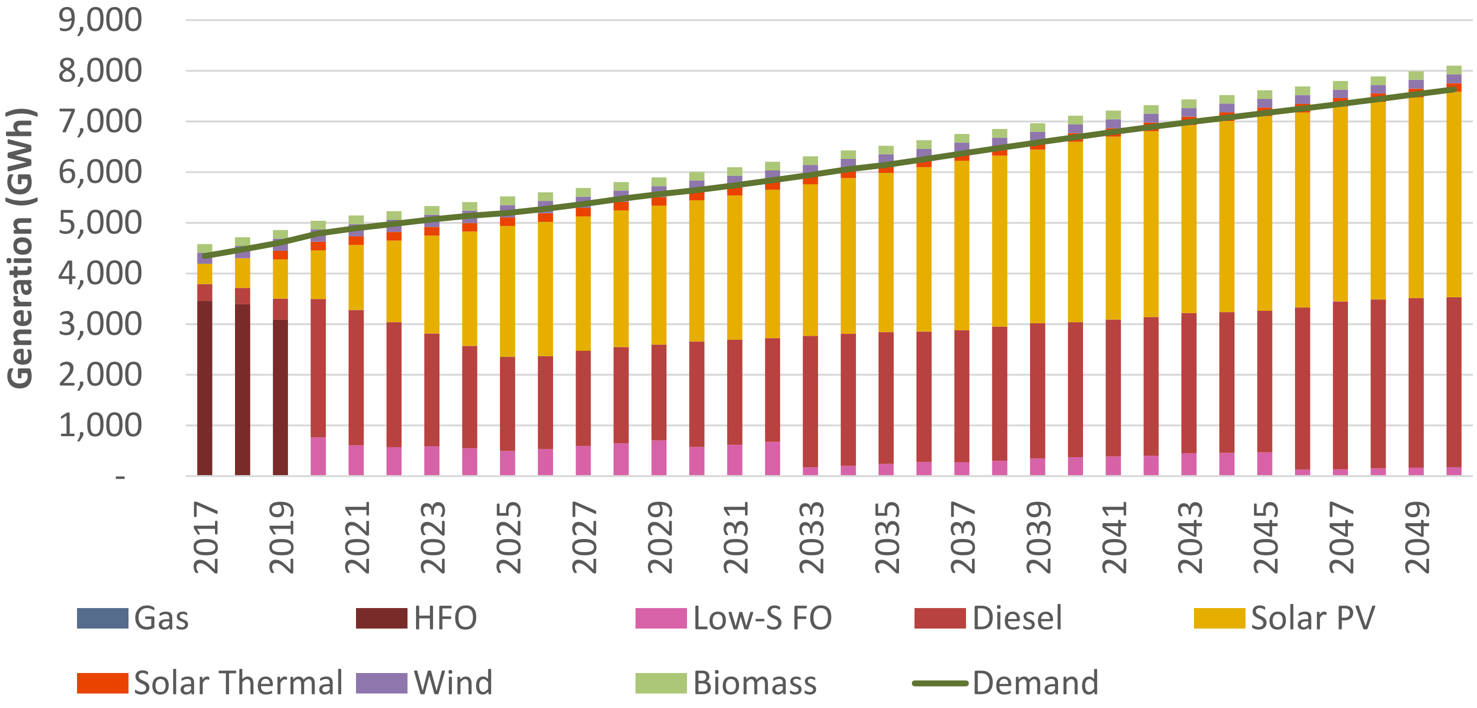


4/22/2017

delayed gas scenario - capacity

MW	2020	2025	2030	2035	2040	2045	2050
Vasilikos	868	868	868	608	0	0	0
Dhekelia	460	102	102	102	0	0	0
Moni	150	150	150	0	0	0	0
New CCGT	0	216	216	432	864	864	864
New ICE	0	0	0	0	0	0	0
New ST	0	0	0	0	57	57	57
New GT	0	0	0	0	0	0	248
Solar PV	191	191	191	359	1239	1239	1642
Solar Thermal	50	50	50	50	50	50	50
Wind	175	175	175	175	175	175	175
Biogas	40	40	40	40	40	40	40
Pumped Hydro	0	0	0	130	130	130	130
Li-Ion Batteries	0	0	116	260	446	446	478

no gas scenario - generation



4/22/2017

no gas scenario - capacity

MW	2020	2025	2030	2035	2040	2045	2050
Vasilikos	868	868	868	608	0	0	0
Dhekelia	462	102	102	102	0	0	0
Moni	150	150	150	0	0	0	0
New CCGT	0	0	0	216	648	648	864
New ICE	0	0	0	0	0	0	0
New ST	0	0	0	0	171	171	171
New GT	0	0	0	0	0	0	0
Solar PV	591	1591	1721	2003	2355	2547	2694
Solar Thermal	50	50	50	50	50	50	50
Wind	175	175	175	175	175	175	175
Biogas	40	40	40	40	40	40	40
Pumped Hydro	0	130	130	130	130	130	130
Li-Ion Batteries	0	110	110	147	325	448	402

Heating and cooling results

Table 15 – Useful heating demand (PJ) provided by each technology in the three scenarios.

			2013	2020			2030			2040		
	Resource	**Technology**	**Estimated by JRC**	**Reference**	**Delayed Gas**	**No Gas**	**Reference**	**Delayed Gas**	**No Gas**	**Reference**	**Delayed Gas**	**No Gas**
Services, industry and agricultural sector	Electricity	Heat pumps/split units	1.543	1.70	1.56	1.56	4.97	4.97	4.80	6.84	6.73	7.30
	Electricity	Resistance heaters	0.309	0.19	0.19	0.19	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Boilers	3.734	2.31	2.38	2.31	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	CHP	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Efficient Boilers	-	2.21	2.28	2.35	2.43	2.43	2.60	1.26	1.36	0.78
	LPG	Boilers	0.247	0.15	0.15	0.15	-	-	-	-	-	-
	Biomass/waste	CHP	-	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
	LPG	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	Boilers	0.780	0.48	0.48	0.48	-	-	-	-	-	-
	Biomass	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Solar	Solar panels	0.296	0.36	0.36	0.36	0.54	0.54	0.54	0.71	0.71	0.73
Residential sector	Electricity	Heat pumps/split units	0.846	4.85	4.85	4.85	6.17	6.17	6.17	6.34	6.34	6.34
	Electricity	Resistance heaters	1.080	0.67	0.67	0.67	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Boilers	0.518	0.32	0.32	0.32	-	-	-	-	-	-
	Gas oil, light fuel oil, LPG	CHP	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	LPG	Boilers	0.004	0.003	0.00	0.003	-	-	-	-	-	-
	LPG	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	Boilers	0.011	0.01	0.01	0.01	-	-	-	-	-	-
	Biomass	CHP	-	-	-	-	-	-	-	-	-	-
	Biomass	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Solar	Solar panels	1.804	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78

Table 16 – Useful cooling demand (PJ) provided by each technology in the three scenarios.

			2013	2020			2030			2040		
	Resource	**Technology**	**Estimated by JRC**	**Reference**	**Delayed Gas**	**No Gas**	**Reference**	**Delayed Gas**	**No Gas**	**Reference**	**Delayed Gas**	**No Gas**
Services, industry and agricultural sector	Electricity	Heat pumps/split units	5.86	6.099	6.099	6.099	6.746	6.746	6.746	7.389	7.389	7.389
	Electricity	Resistance heaters	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Boilers	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	CHP	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	LPG	Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass/waste	CHP	-	-	-	-	-	-	-	-	-	-
	LPG	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Solar	Solar panels	-	-	-	-	-	-	-	-	-	-
Residential sector	Electricity	Heat pumps/split units	6.05	7.459	7.582	7.582	9.282	9.284	9.369	10.994	11.048	10.422
	Electricity	Resistance heaters	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Boilers	-	-	-	-	-	-	-	-	-	-
	Gas oil, light fuel oil, LPG	CHP	-	-	-	-	-	-	-	-	-	-
	Gas oil, kerosene, light fuel oil	Efficient Boilers	-	0.123	-	-	0.087	0.085	-	0.149	0.094	0.720
	LPG	Boilers	-	-	-	-	-	-	-	-	-	-
	LPG	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	Boilers	-	-	-	-	-	-	-	-	-	-
	Biomass	CHP	-	-	-	-	-	-	-	-	-	-
	Biomass	Efficient Boilers	-	-	-	-	-	-	-	-	-	-
	Solar	Solar panels	-	-	-	-	-	-	-	-	-	-

Transport results

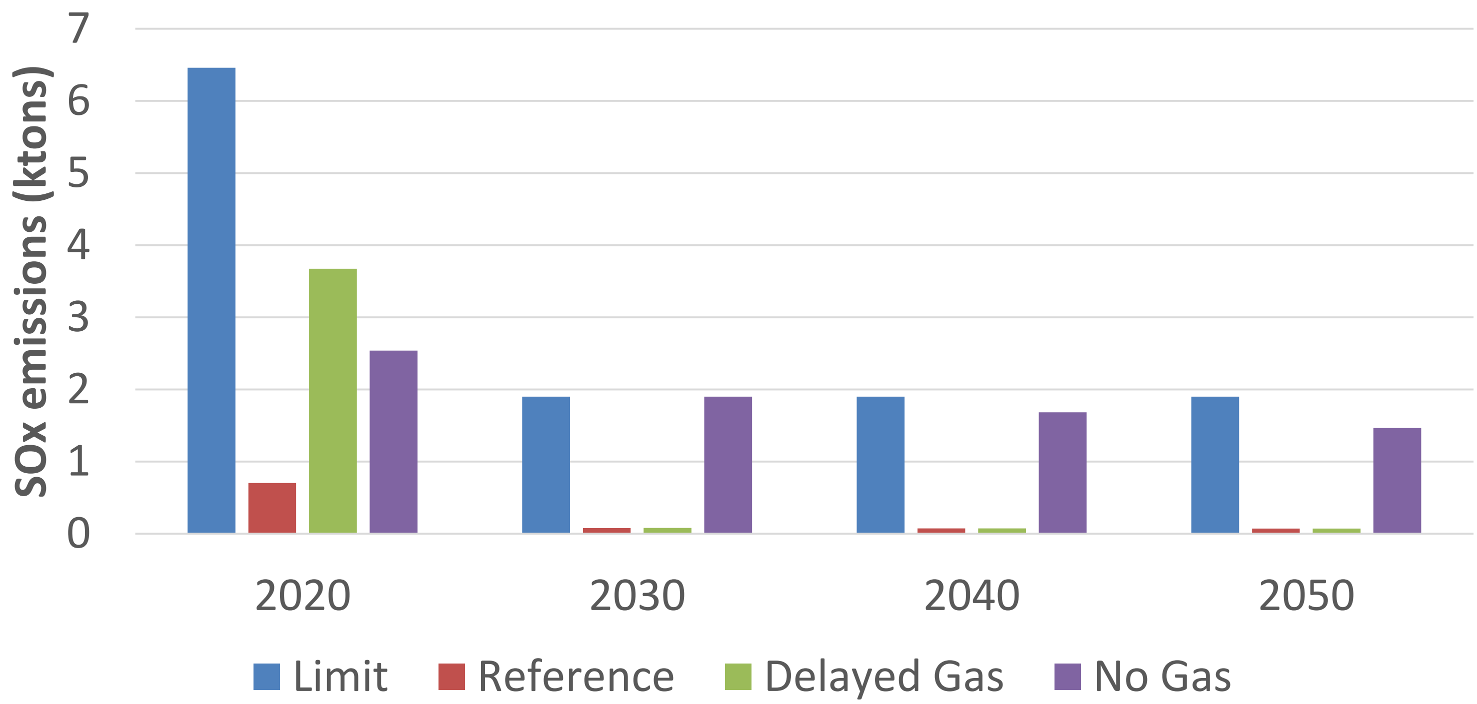
		Biodiesel 1st gen	Biodiesel 2nd gen	Diesel	Gasoline	LPG	Electricity
		Litres	Litres	Litres	Litres	Litres	MWh
2020	Reference	-	21,702,417	283,947,677	221,685,198	21,206,381	67,091
	Delayed Gas	-	21,770,639	284,840,282	220,112,208	21,206,381	65,984
	No Gas	-	21,770,639	284,840,282	220,112,208	21,206,381	65,984
2030	Reference	-	21,948,677	296,350,320	10,719,289	-	59,816
	Delayed Gas	-	21,995,998	296,779,601	10,346,067	-	58,829
	No Gas	-	21,995,735	296,779,842	10,346,067	-	58,835
2040	Reference	-	24,870,491	325,779,557	5,115,319	-	31,075
	Delayed Gas	-	24,870,491	325,779,557	5,115,319	-	31,075
	No Gas	-	24,860,010	325,679,756	5,115,319	-	31,136
2050	Reference	-	27,390,355	358,366,896	5,582,372	-	27,686
	Delayed Gas	-	27,359,114	357,958,151	5,956,297	-	28,152
	No Gas	-	27,283,758	356,972,209	6,807,768	-	29,209

RES share in Final energy demand – Reference scenario

	2017	2018	2019	2020	2021	2025	2030	2040	2050
All sectors	11.4%	12.0%	13.8%	14.6%	14.3%	15.1%	16.4%	30.0%	32.6%
Electricity	14.4%	15.1%	18.8%	18.6%	18.2%	17.2%	15.8%	38.8%	42.5%
Heating and cooling	22.1%	22.8%	24.9%	25.3%	25.6%	26.6%	26.9%	45.2%	45.9%
Transport (ILUC Directive)	2.5%	2.8%	3.1%	10.0%	6.4%	9.1%	15.8%	14.8%	14.7%
Transport (Directive under discussion)	2.4%	2.6%	2.8%	4.4%	3.4%	4.3%	6.8%	6.8%	6.8%

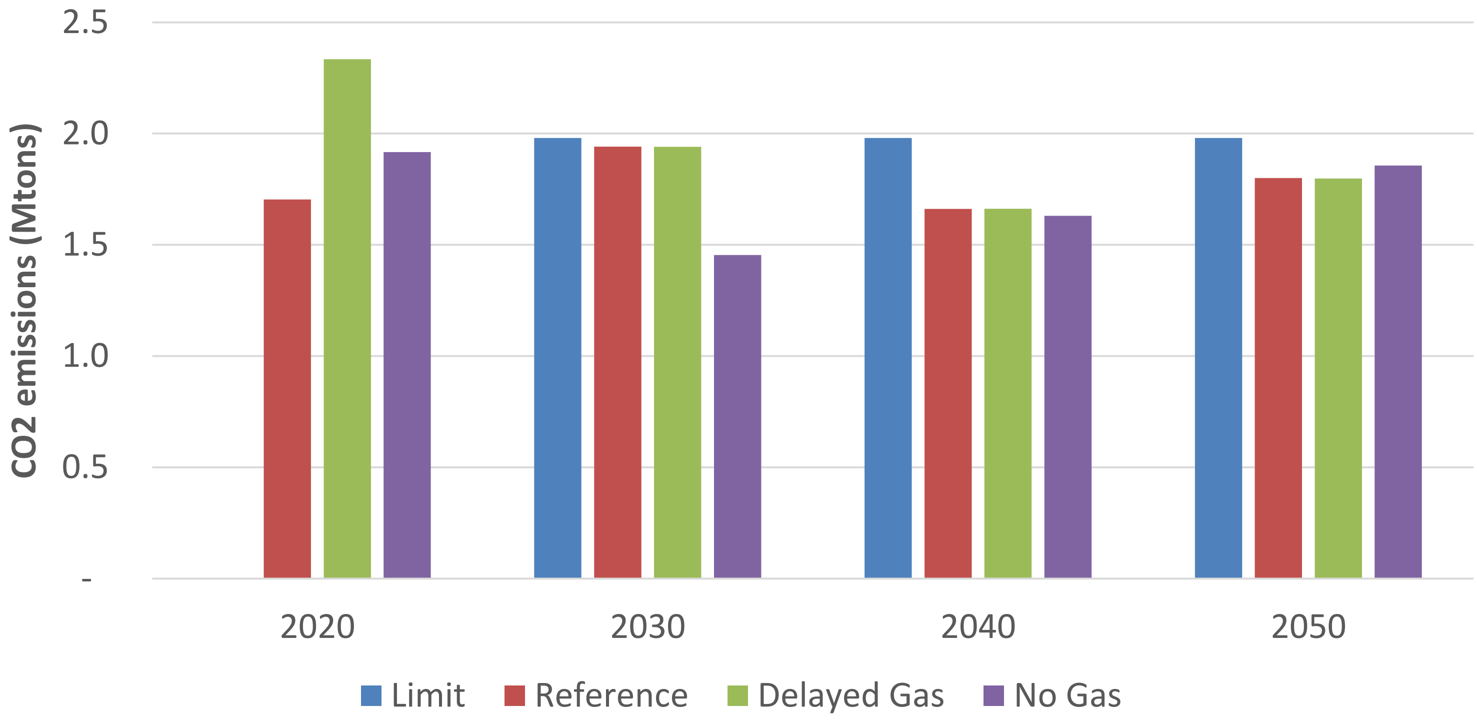
emissions

SO_x emissions across the system



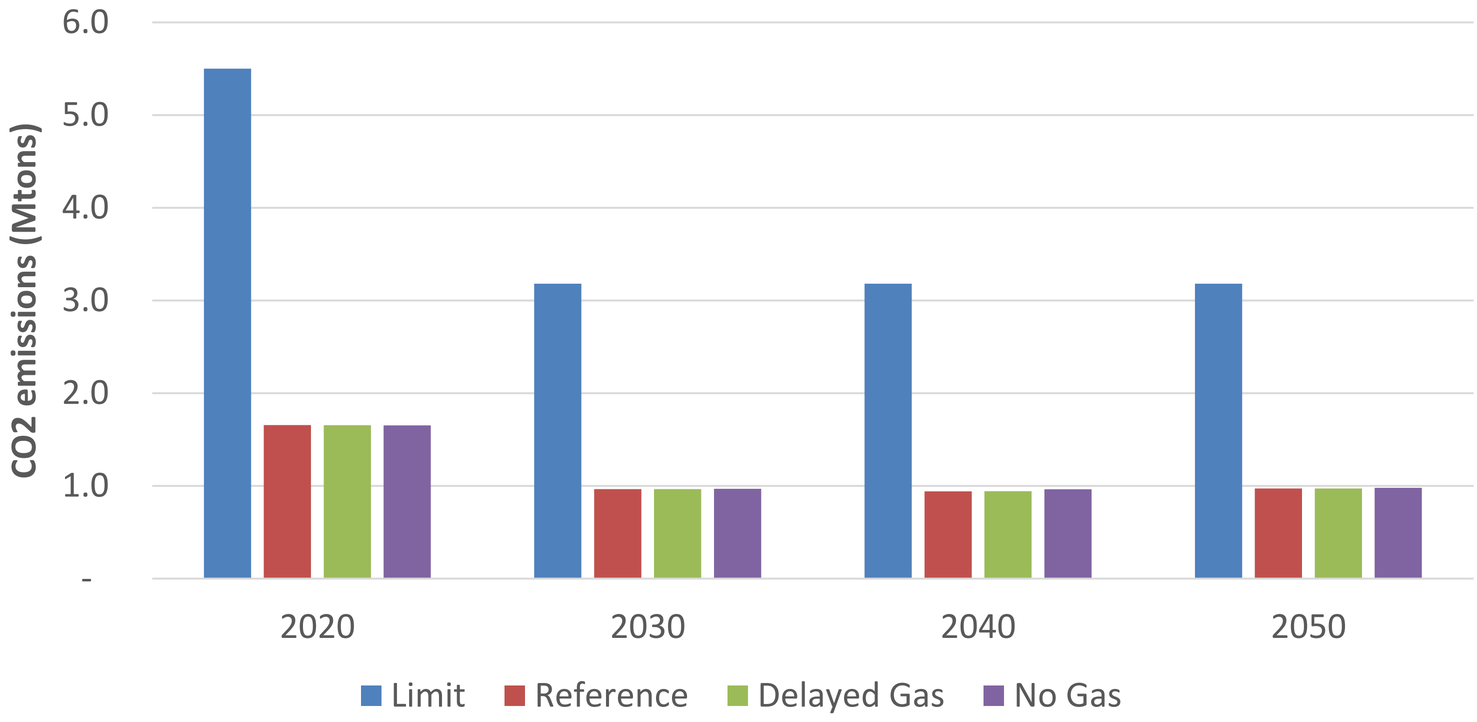
4/22/2017

CO_2 emissions - Generation



4/22/2017

CO_2 emissions – non-ets Sector



4/22/2017

Financial considerations

Electricity cost

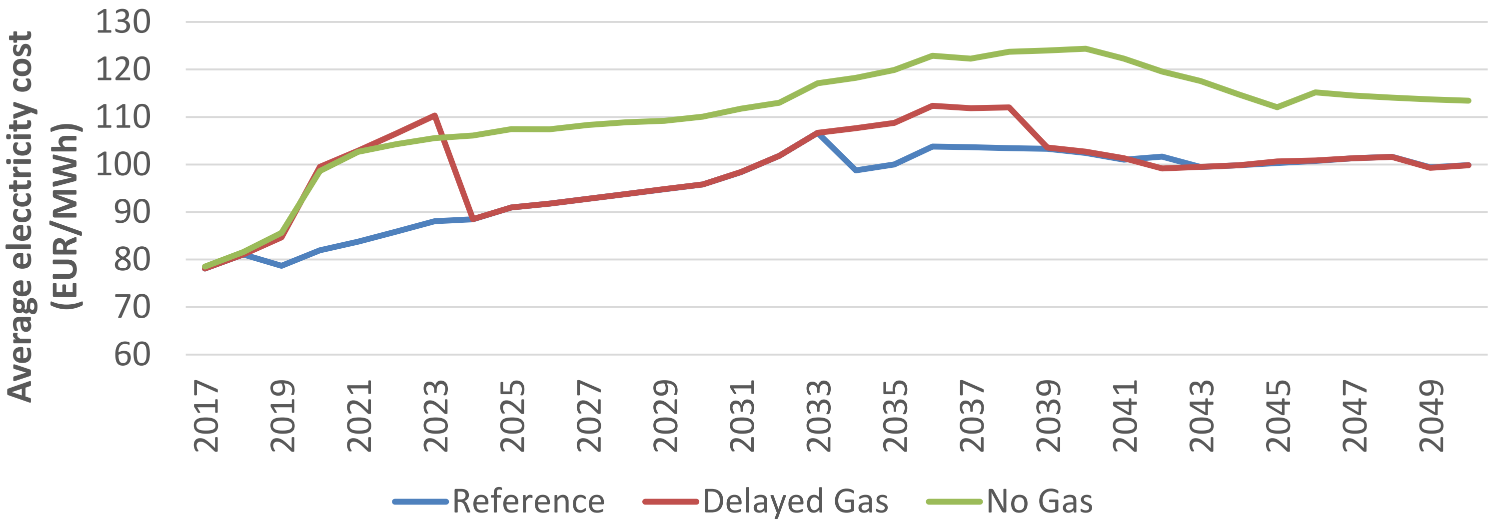


Table 18 – Cumulative annualized investments in the electricity supply sector for each scenario (Million EUR).

	2020	2030	2040	2050
Reference	309	1,528	3,140	5,496
Delayed Gas	202	1,259	3,143	5,515
No Gas	311	2,204	4,775	6,980

Long-term system costs

Cumulative annualized investment cost (Million EUR)

	2020	2030	2040	2050
Reference	2,112	14,532	30,214	48,040
Delayed Gas	2,013	14,258	30,214	48,058
No Gas	2,122	15,204	31,852	49,546

Total System cost (Million EUR)

	2020	2030	2040	2050
Reference	2,000	2,630	3,126	3,461
Delayed Gas	2,136	2,659	3,131	3,474
No Gas	2,134	2,754	3,293	3,594

Conclusions

Based on the data and assumptions of these scenarios

- Availability of natural gas affects electricity cost and emissions (CO_2, SO_x) substantially
- Share of RES-generation increases considerably in all scenarios post-2030
- Futher use of electricity in Heating and Cooling.
- Achievement of RES target in transport requires heavy investments in new vehicles – not cost-effective

Future work

The study highlights the importance of examining a variety of options in all sectors

- Sensitivity analysis and development of an array of scenarios
- Socioeconomic impact of scenarios
- Definition of demands into useful energy services – potential for assessing Energy Efficiency measures

THANK YOU

OSeMOSYS

Integrated Systems Analysis of Energy

[UNDESA – Modelling Tools for Sustainable Development]

[www.osemosys.org]