Opportunities for Power-to-Hydrogen in CO_2-reduced Energy Scenarios: the Italian Case

S. Bellocchi, M. Gambini, M. Manno, T. Stilo, M. Vellini
Department of Industrial Engineering
University of Rome Tor Vergata

13th CONFERENCE ON SUSTAINABLE DEVELOPMENT OF ENERGY, WATER AND ENVIRONMENT SYSTEMS

Outline

Italian energy system at 2015

RES and EVs future scenarios

Issues and Challenges for high-RES capacity

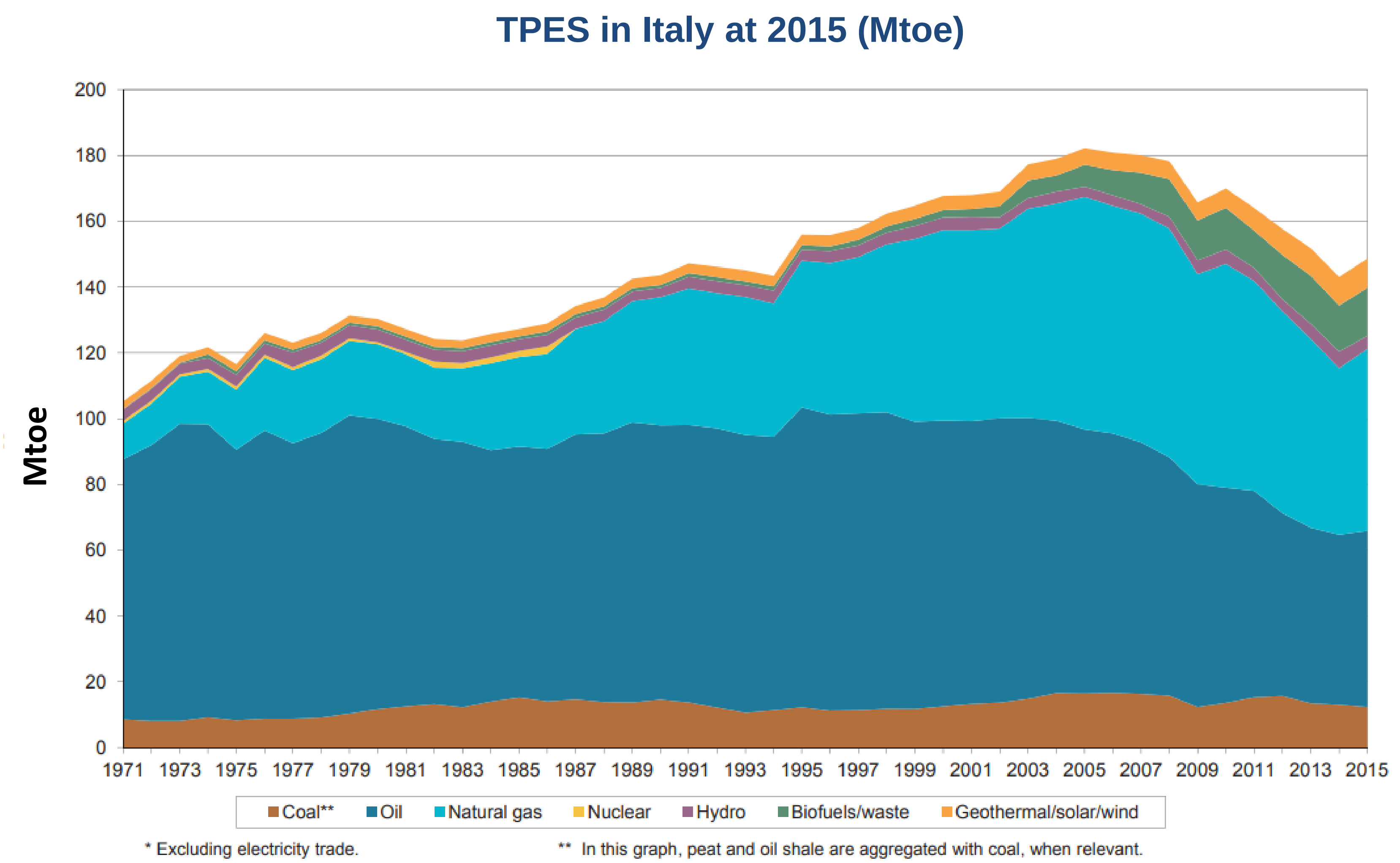
Power-to-Hydrogen as a possible solution

SynGridGas and Electrofuels production

Results and discussion

Conclusions

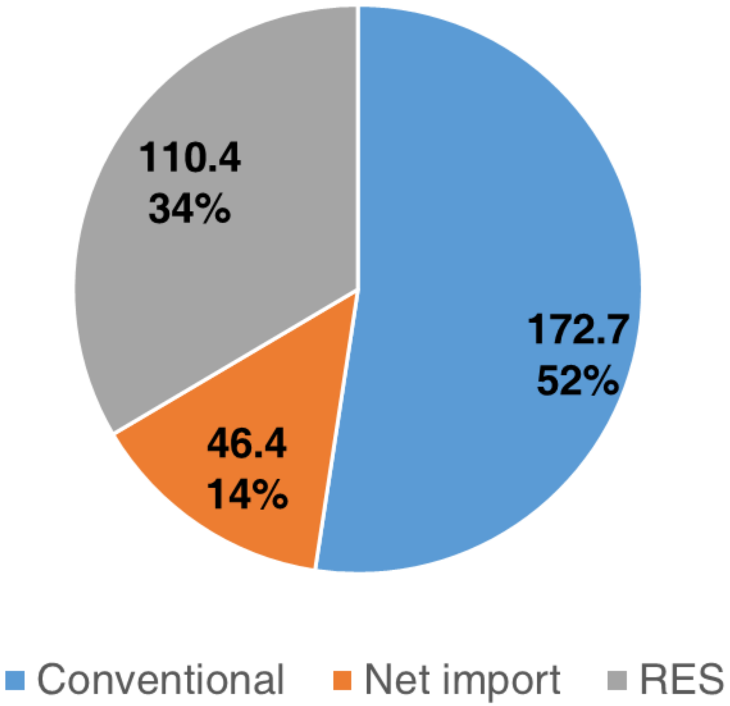
Total Primary Energy Supply (TPES)



Source: IEA, Energy Statistics 2015

Electricity supply by source

Electricity supply by source in Italy at 2015 (TWh)



	TWh	EJ
RES	**110.4**	**0.40**
Hydro	*47.0*	0.17
Geothermal	*6.2*	0.02
Wind	*14.8*	0.05
PV	*22.9*	0.08
Bioenergies	*19.4*	0.07
Conventional	**172.7**	**0.62**
Solid	*43.2*	0.16
Natural gas	*110.7*	0.40
Oil	*5.6*	0.02
Other fuels	*13.0*	0.05
Energy to pump hydro plants	*1.9*	*0.01*
Energy to auxiliary systems	*10.6*	*0.04*
Net production	**270.5**	**0.97**
Import/Export	**46.4**	**0.17**
Electricity demand	**316.9**	**1.14**

Source: Terna, Dati statistici sull’energia termica in Italia

RES integration: assumptions

RES integration options: RES2015, RES2030 and RES2050

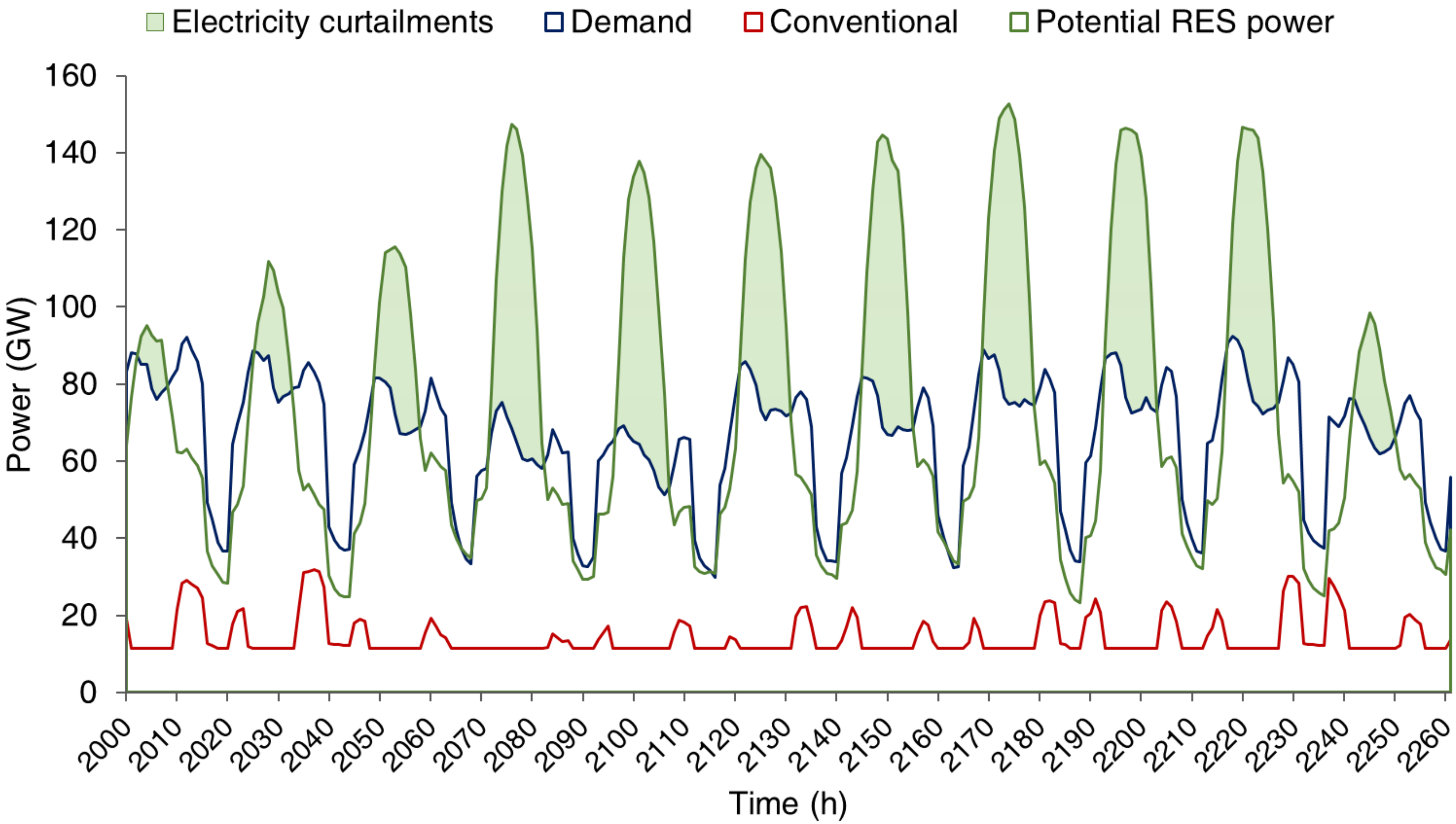
Intermittent RES capacity [GW]			
	RES2015	RES2030*	RES2050*
Onshore wind	6.29	15.80	15.80
Offshore wind	-	1.15	1.15
PV	10.94	32.63	97.89
CSP	-	2.00	6.00

*Derived from 2030 RES energy target as reported in "Strategia Energetica Nazionale 2017" and from current power hourly distribution. For 2050 wind capacity remains unchanged according with "Anev 2017 annual report" and capacity for solar increased until covering potential 93% of electricity generation as targeted by SEN2017.

SEN2017 RES energy target [TWh]		
	RES2030	RES2050
Onshore wind	37	37
Offshore wind	3	3
PV	68	205
CSP	4	11

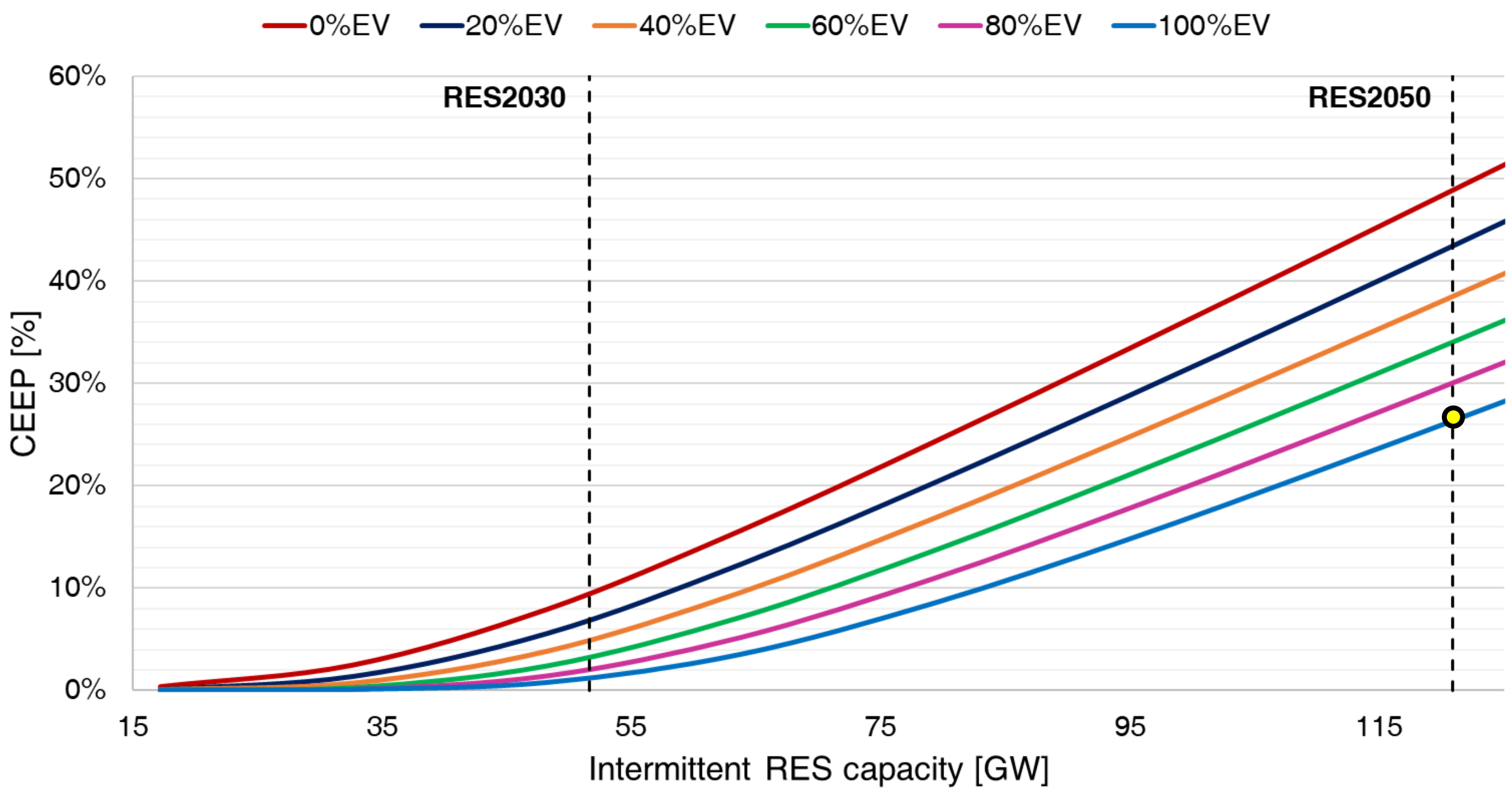
RES integration: …drawbacks…

Mismatch between power generation and demand – RES2050 and 0%EV



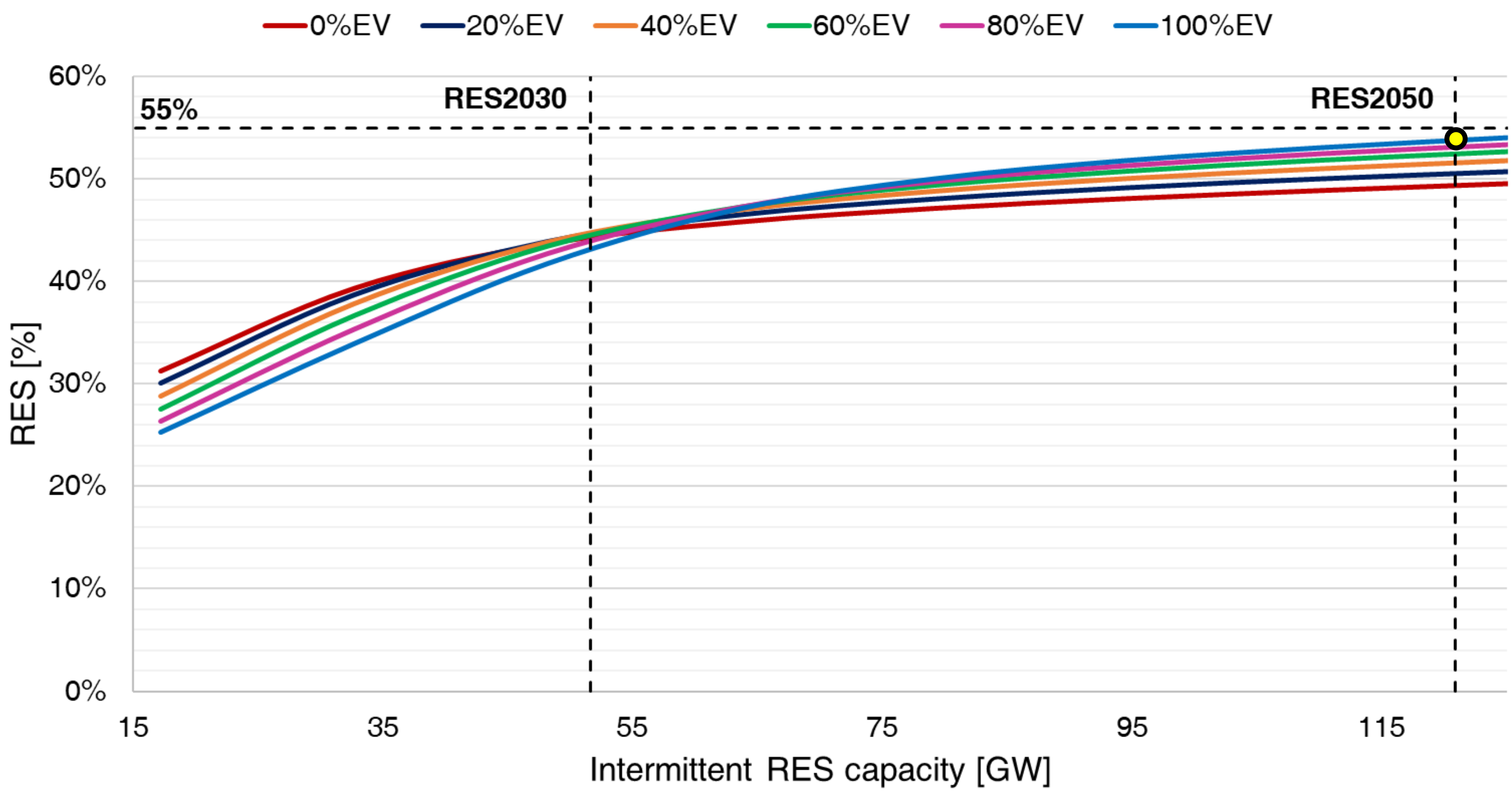
RES integration: …and challenges

Despite a significant reduction, curtailments still occur at 100% EV penetration at high RES capacity



RES integration: …and challenges

Despite a considerable power increase in intermittent RES from 2015 level (from 17 to 121 GW), RES penetration increase only slightly (54% of total production)…



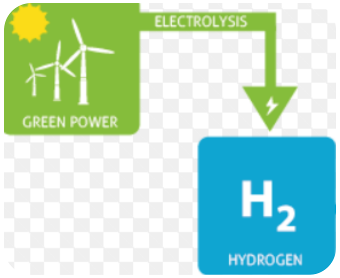
Flexible Smart Energy Systems implementation

Grid extension, flexible demand and electricity storage

High costs, low public acceptance and limited integration capacity (not feasible or sufficient)

Energy system electrification

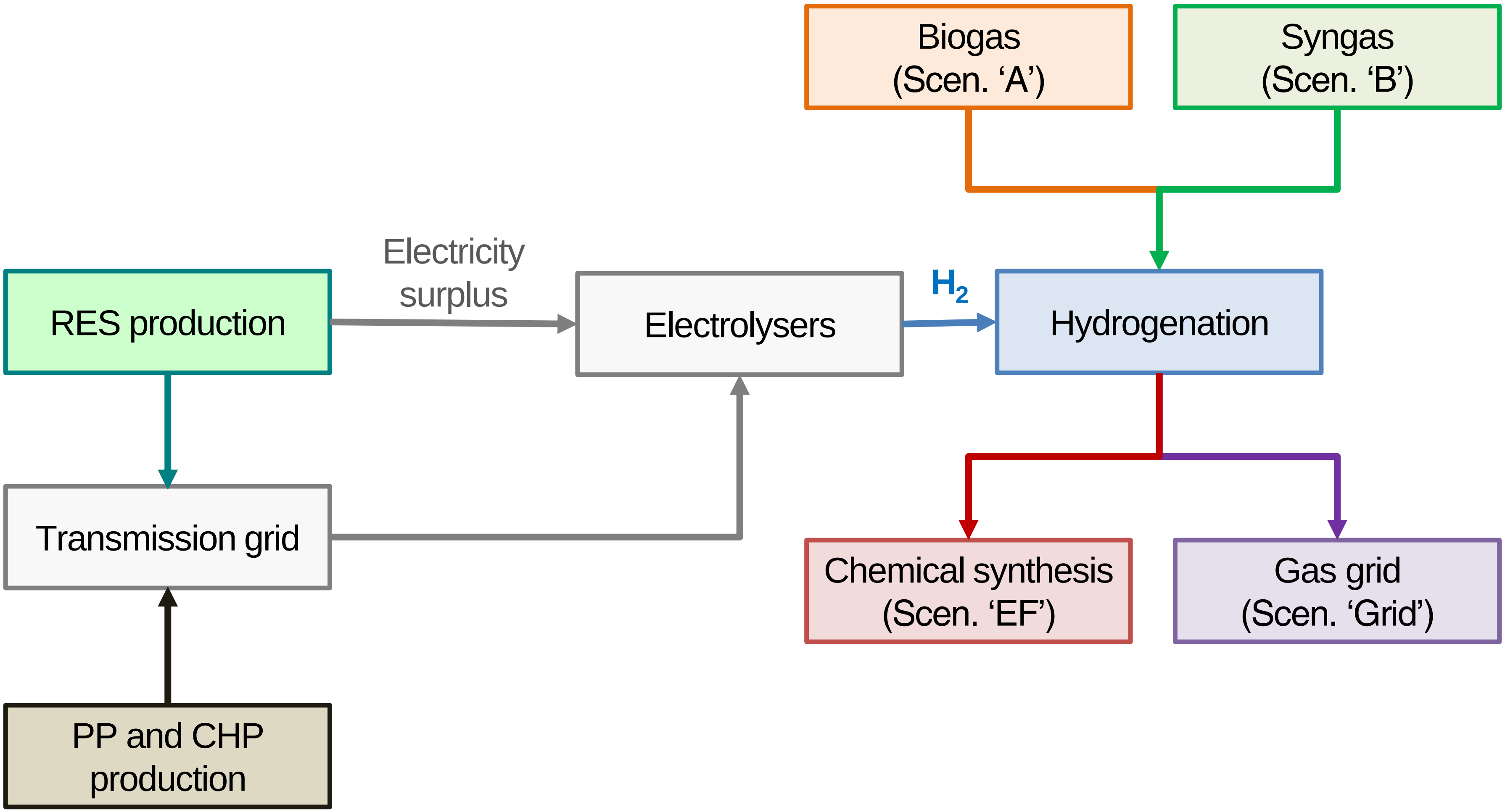
Electrification of fossil-fuel dependent sectors (e.g. individual heating and transport introducing heat pumps and electric vehicles)



Power-to-hydrogen (P2H)

- RES power to run electrolysers and obtain H_2
- *Synthetic gas/biogas hydrogenation and liquid fuel via chemical synthesis*

Energy scenarios including P2H



Energy scenarios including P2H: assumption

P2H scenarios assumption

1. Electrolysers have been designed with an efficiency equal to 0.73* and an installed capacity equal to double the average power required to guarantee the annual hydrogen production for syngas/biogas hydrogenation processes estimated on the amount of electrofuel needed.

2. Electrofuel production is assumed to gradually increase with EV penetration until a complete replacement of fossil fuel in the heavy transport.

3. In “Grid” scenarios the amount of syngas injected in the gas grid corresponds to the syngas required for electrofuel production in the equivalent “EF” alternative.

*H. Lund, Renewable energy systems: a smart energy systems approach to the choice and modeling of 100% renewable solutions, 2nd ed. American Press, 2015

Implementing P2H scenarios: assumption

P2H process parameters: gasification, hydromethanation and chemical synthesis

Gasification[1]	
Parameter	**Efficiency**
Steam share	0.95
Steam efficiency	0.94
Cold gas efficiency	0.90

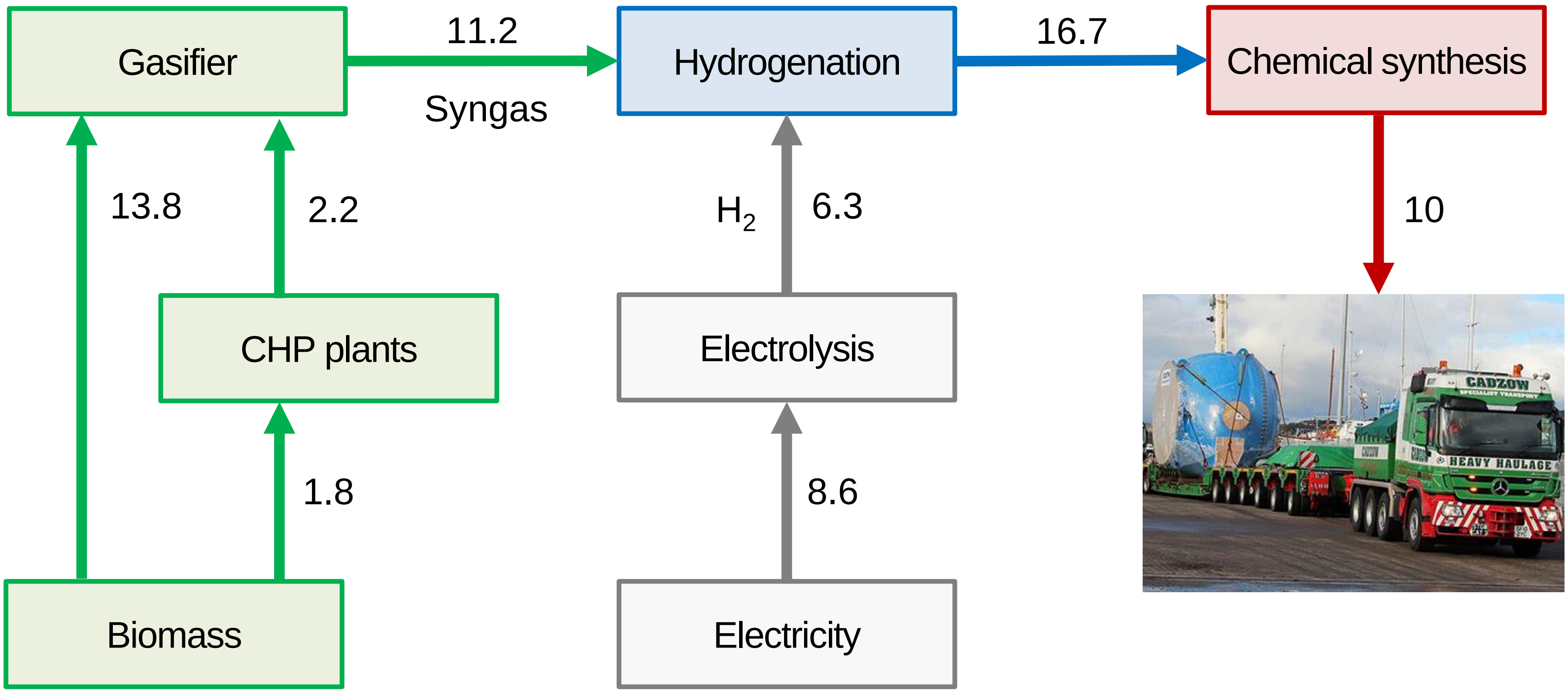
Hydromethanation[1]		
Method	**Efficiency**	**Hydrogen share**
Biogas hydrogenation	0.94	0.52
Syngas hydrogenation from biomass gasification	0.95	0.36

Fuel chemical synthesis	
Parameter	**Efficiency**
Gas-to-liquid (GTL)	0.6[2]÷0.8[3]

[1]H. Lund, Renewable energy systems: a smart energy systems approach to the choice and modeling of 100% renewable solutions, 2nd ed. American Press, 2015
[2]A. De Klerk, Fischer-Tropsch Refining, Wiley-VCH, 2011
[3]Energy efficiency for methanol synthesis, I. Ridjan, Integrated electrofuels and renewable energy systems, Aalborg University, PhD thesis 2015

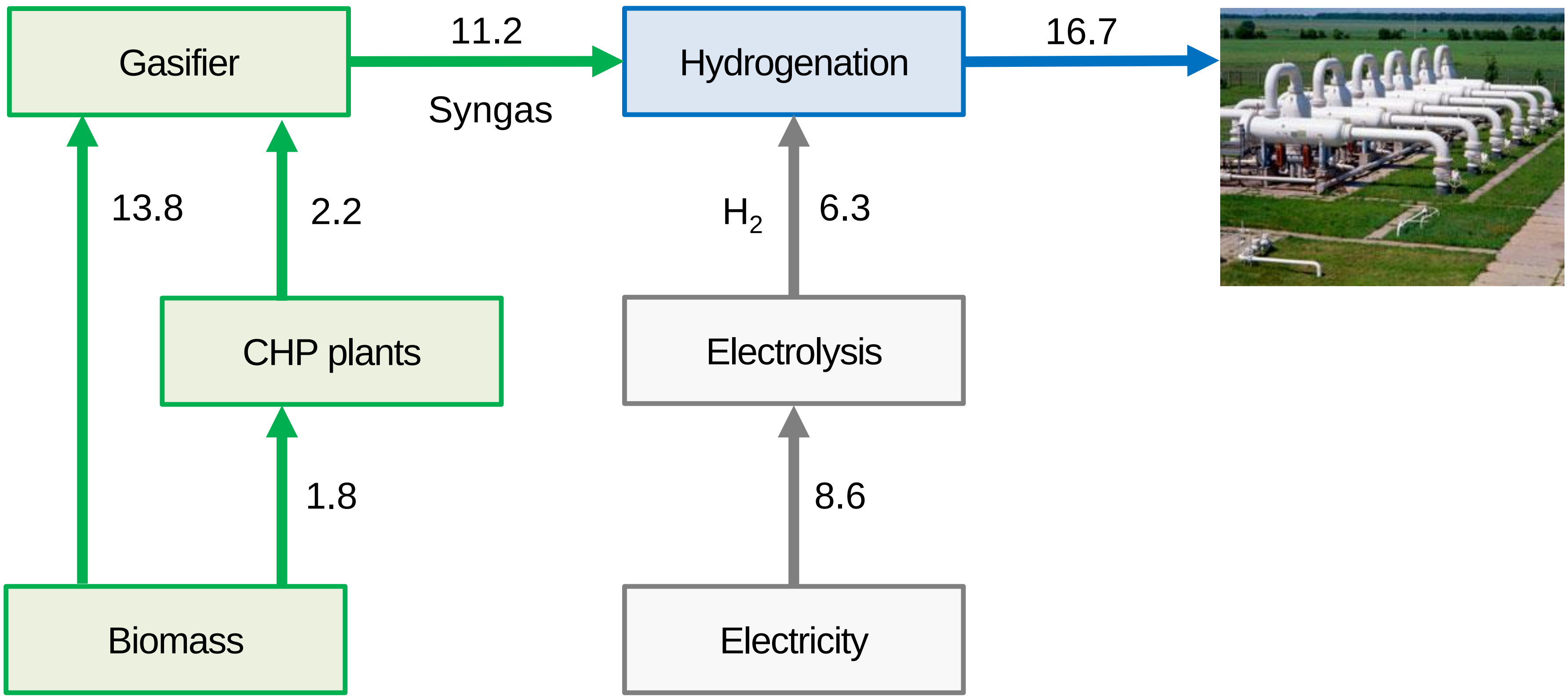
Energy scenarios including P2H: Energy Flow

Energy flow for Scenario B - EF



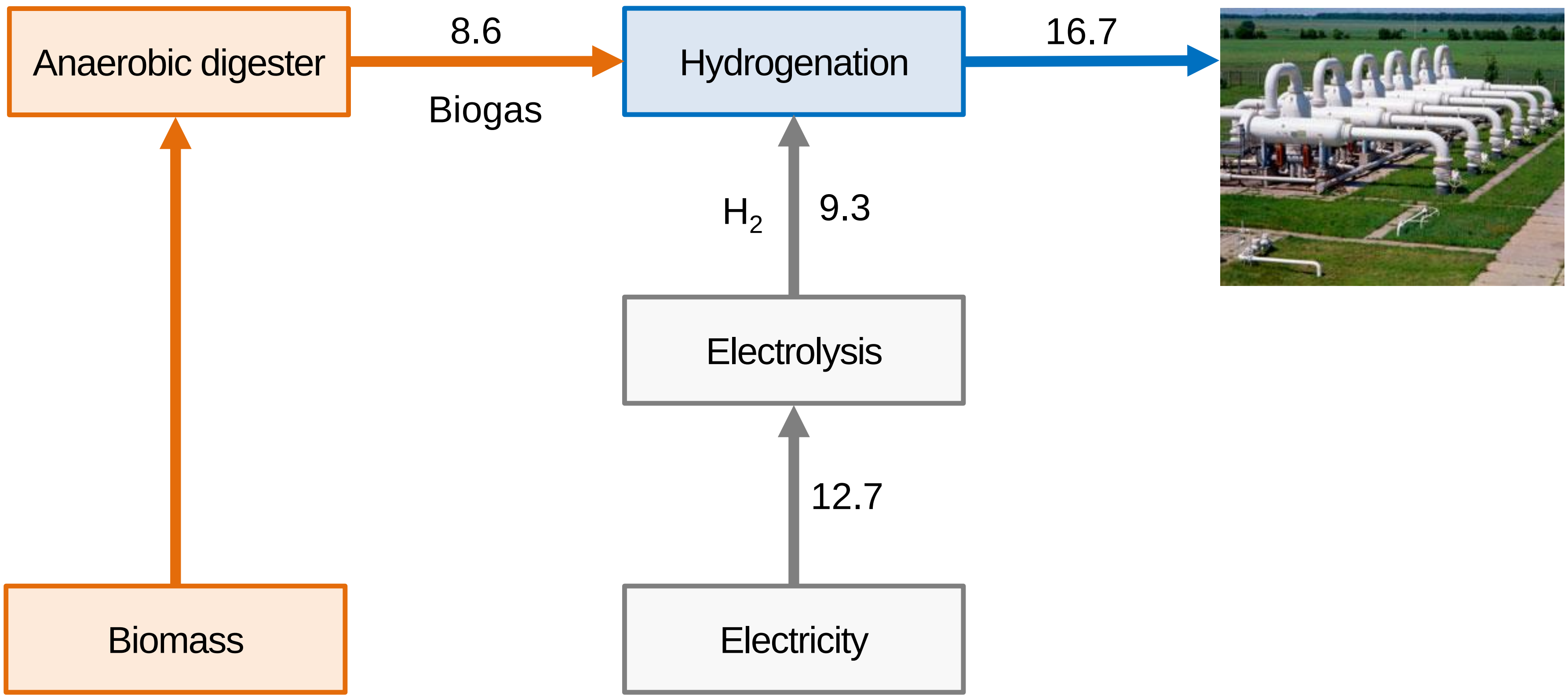
Energy scenarios including P2H: Energy Flow

Energy flow for Scenario B - Grid



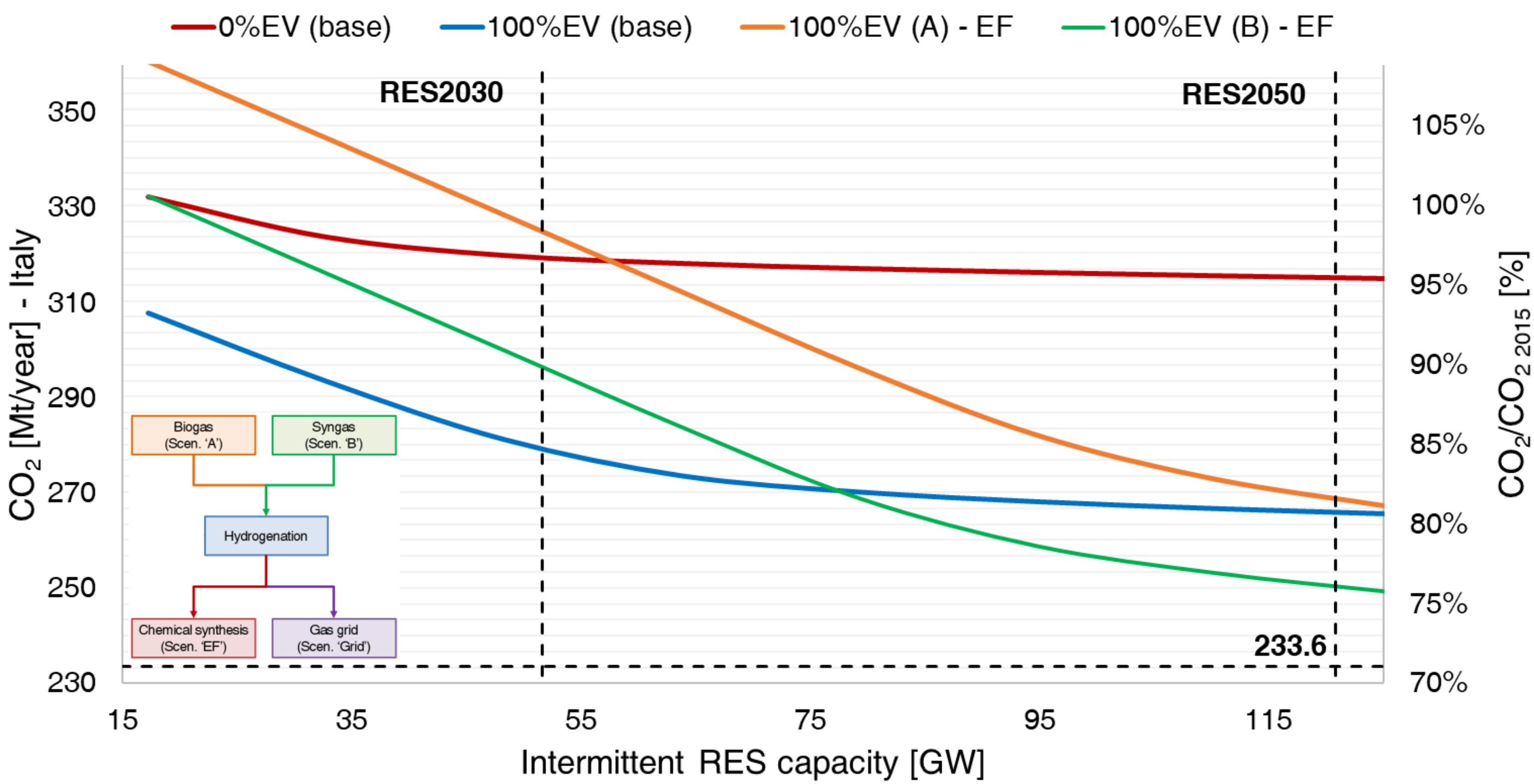
Energy scenarios including P2H: Energy Flow

Energy flow for Scenario A - Grid



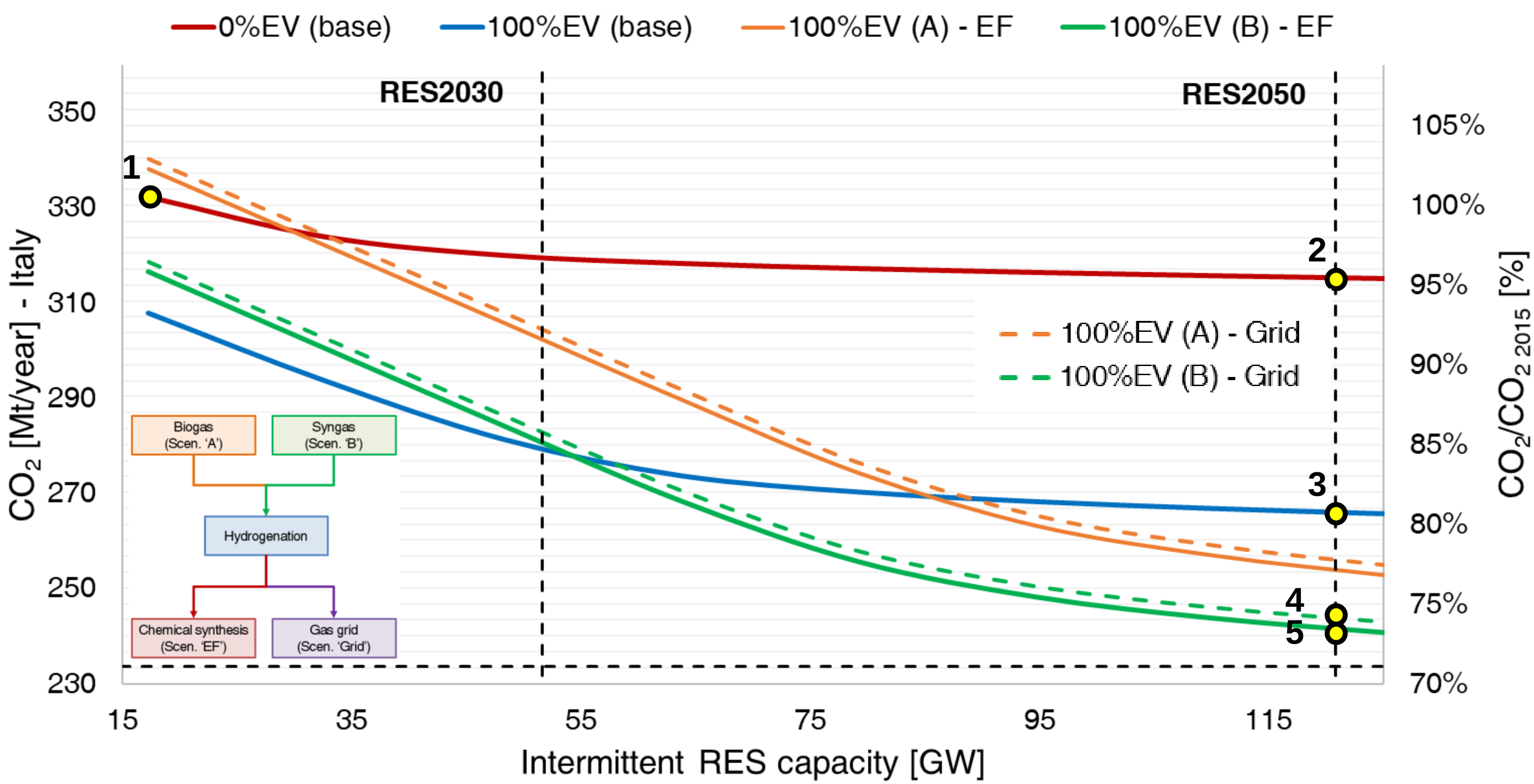
Energy scenarios including P2H: CO_2 emissions

CO_2 emissions at 60% GTL efficiency (e.g. fuel synthesis via Fischer-Tropsch)



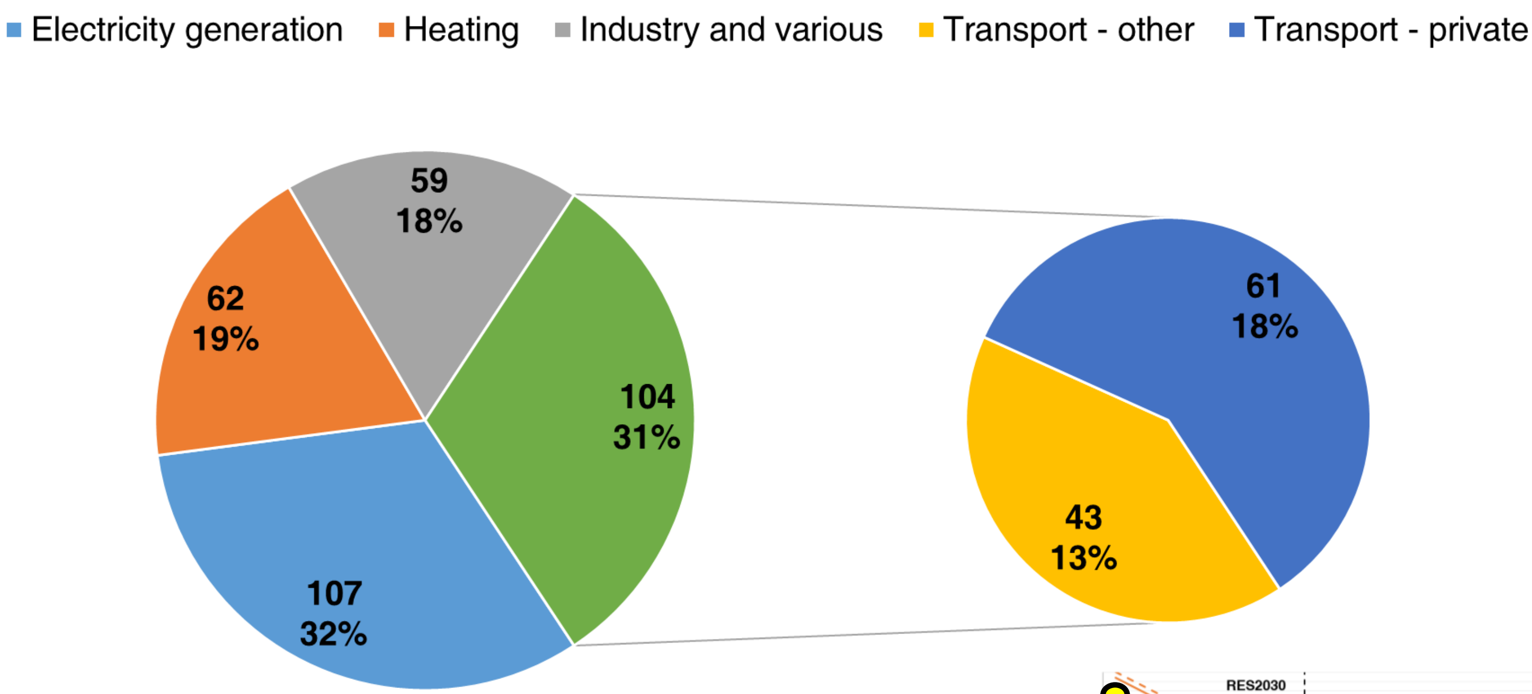
Energy scenarios including P2H: CO_2 emissions

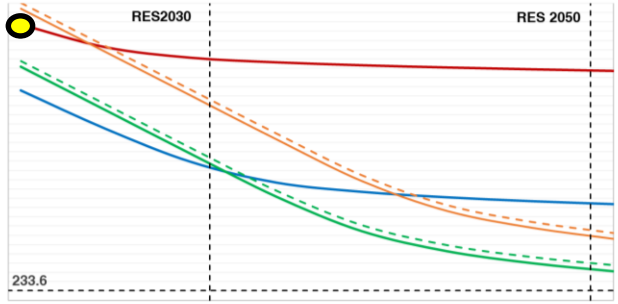
CO_2 emissions can be reduced almost down to 2030 reduction target at 100% EV for scenario B – EF when electrofuels are produced via more efficient processes (e.g. hydrogenated syngas to methanol synthesis)



CO_2 emissions at different scenarios

1: Emissions by sector in Italy at RES2015 and 0%EV – 332 Mt CO_2

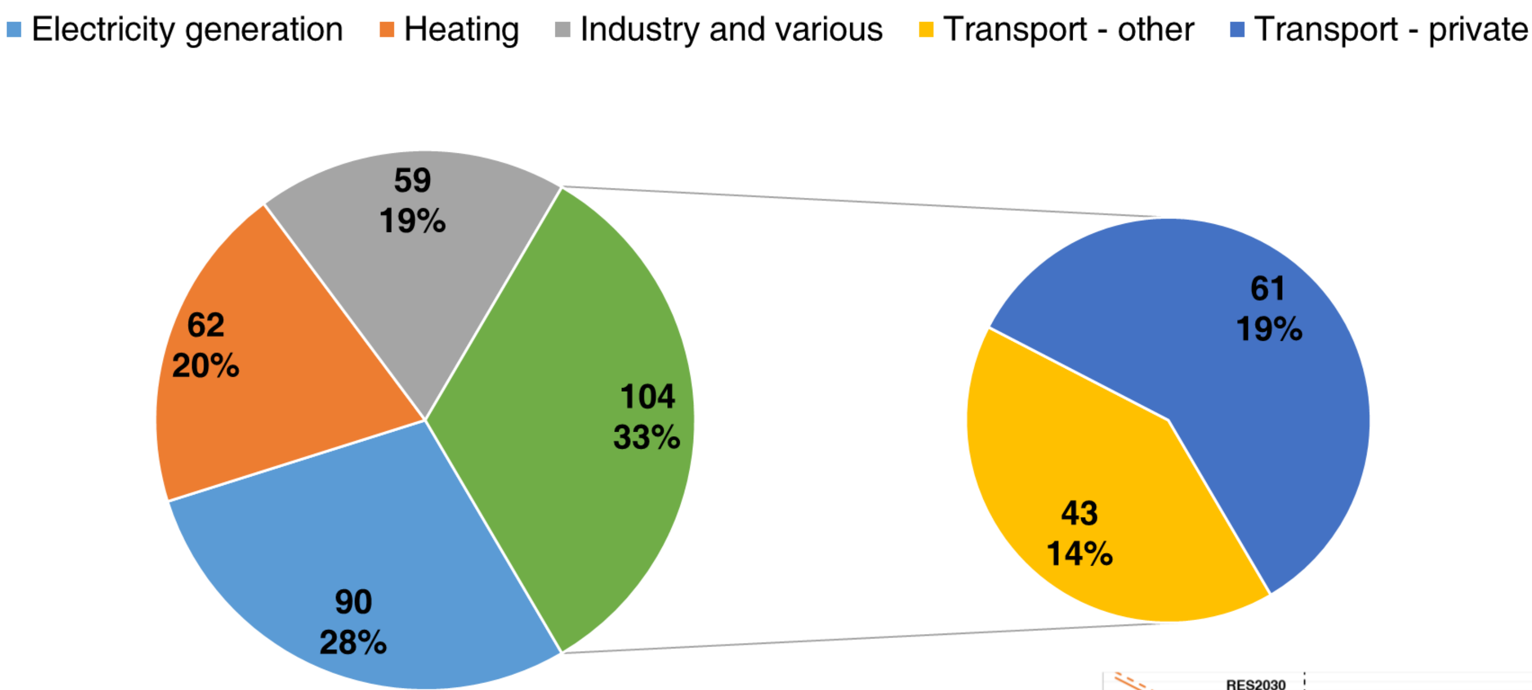


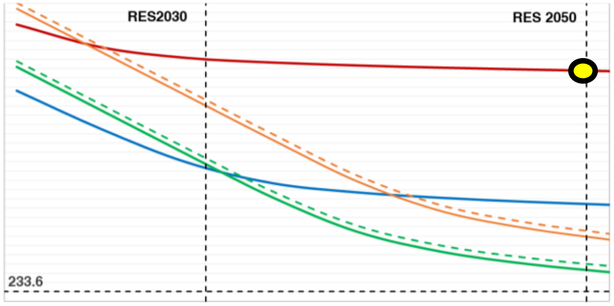


Consumption data from TERNA and IEA annual report, emission factors assigned according to IPCC guidelines

CO_2 emissions at different scenarios

2: Emissions by sector in Italy at RES2050 and 0%EV – 315 Mt CO_2 (-5%)

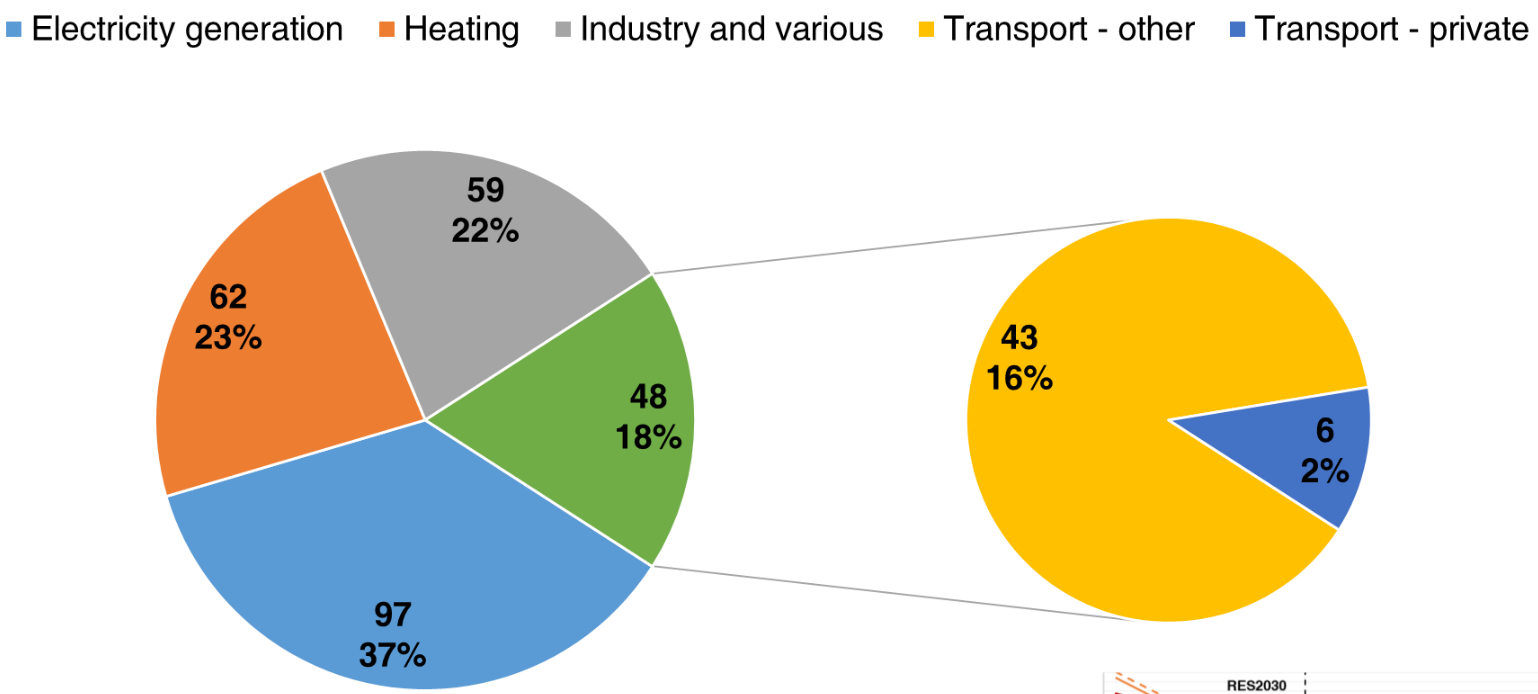


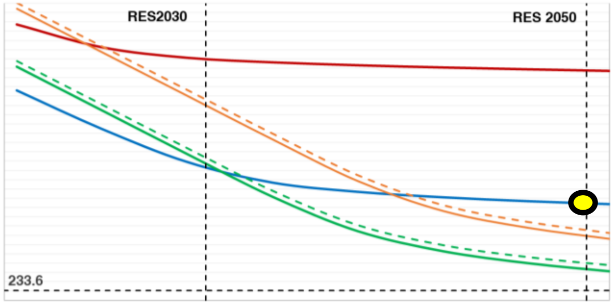


Consumption data from TERNA and IEA annual report, emission factors assigned according to IPCC guidelines

CO_2 emissions at different scenarios

3: Emissions by sector in Italy at RES2050 and 100%EV – 266 Mt CO_2 (-20%)

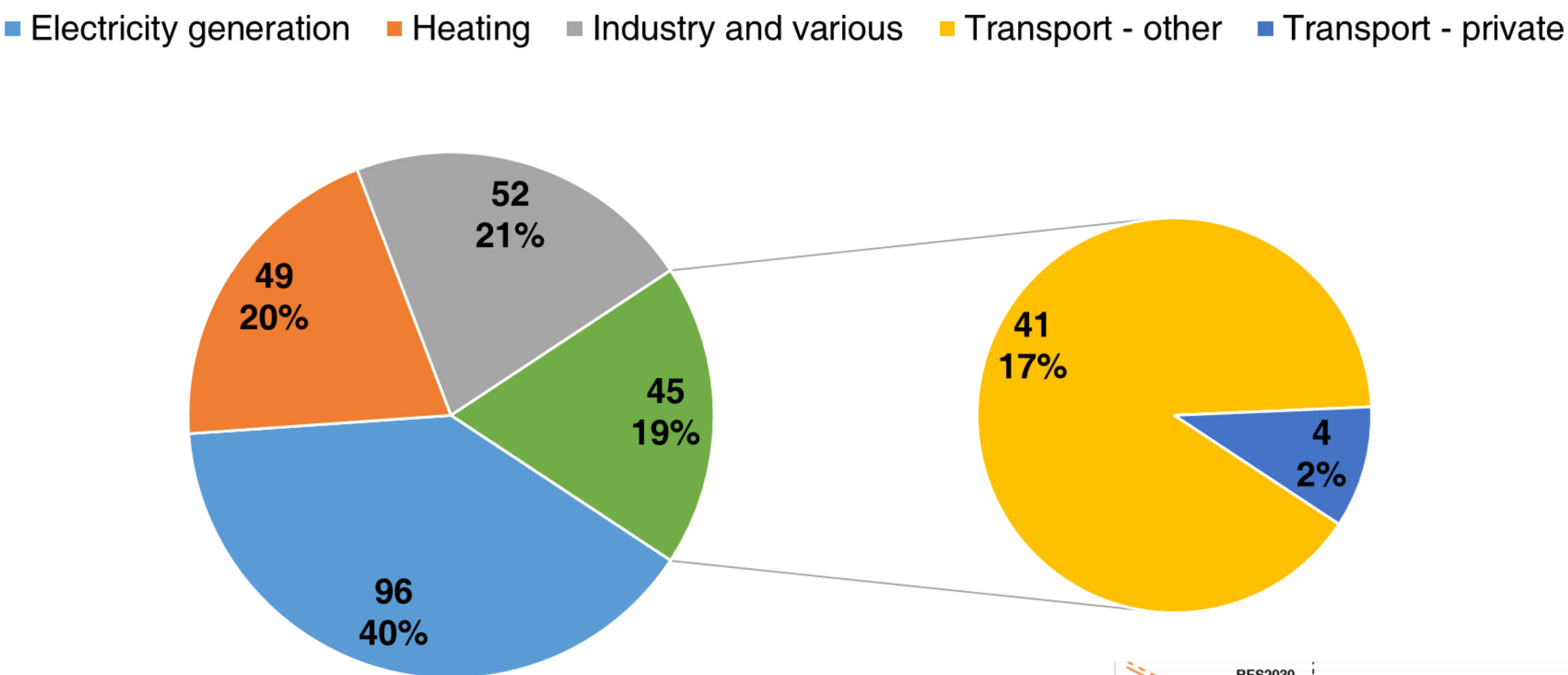


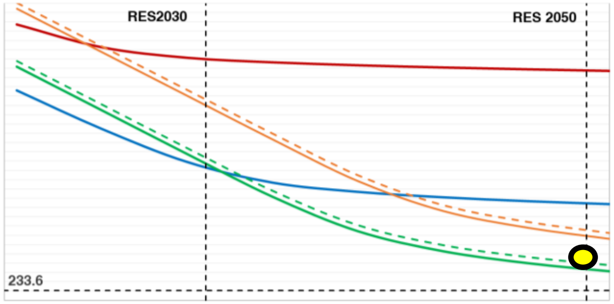


Consumption data from TERNA and IEA annual report, emission factors assigned according to IPCC guidelines

CO_2 emissions at different scenarios

4: Emissions by sector in Italy at RES2050 and 100%EV (B) - Grid – 243 Mt CO_2 (-27%)

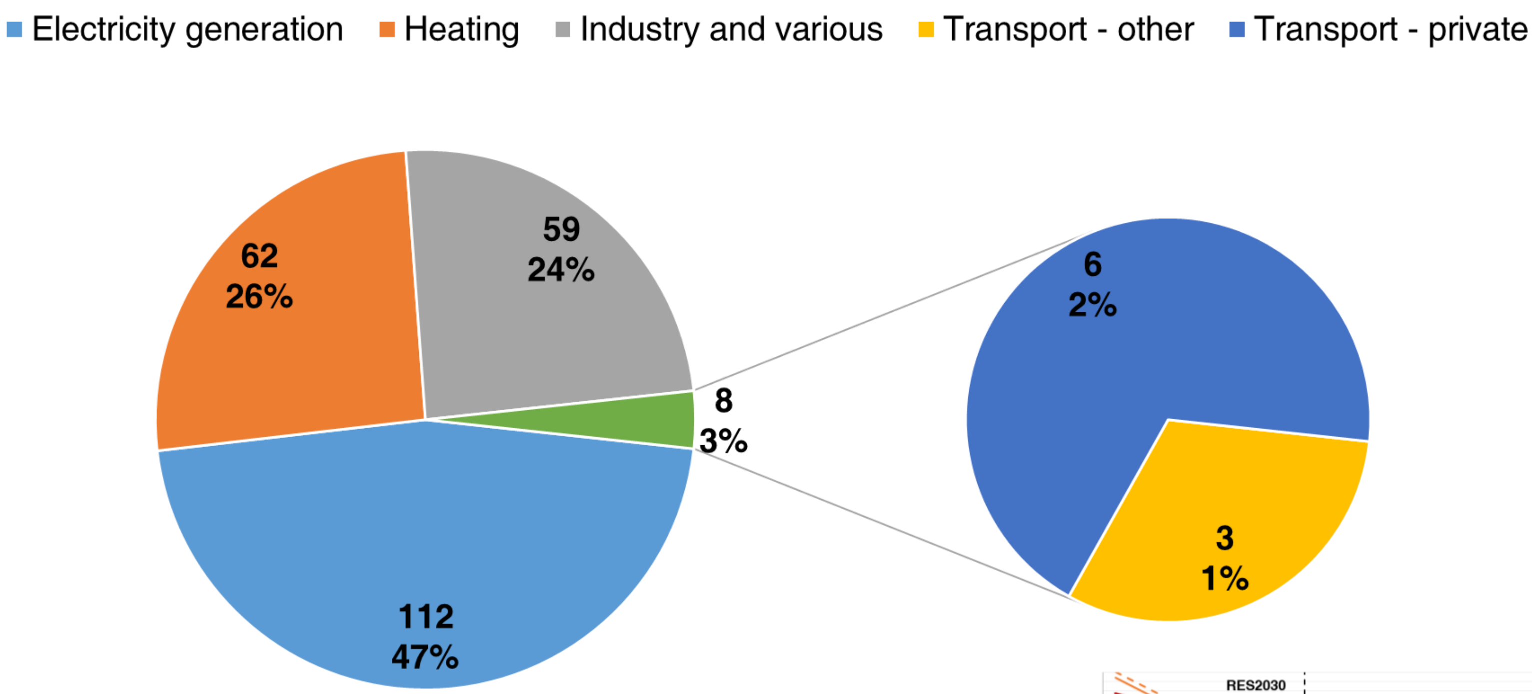


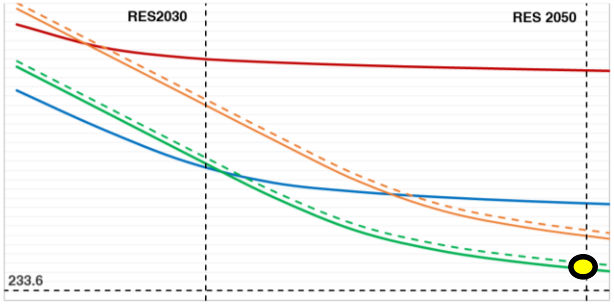


Consumption data from TERNA and IEA annual report, emission factors assigned according to IPCC guidelines

CO_2 emissions at different scenarios

5: Emissions by sector in Italy at RES2050 and 100%EV (B) - EF – 241 Mt CO_2 (-28%)





Consumption data from TERNA and IEA annual report, emission factors assigned according to IPCC guidelines

Energy scenarios including P2H: costs variation

Variable (as in fuel) costs reduction mitigates investment costs increase. When EV price equals conventional cars total costs increase is mainly due to higher RES installed capacity (24%). If the considered electrofuel is methanol, additional investment costs should be considered to adapt heavy-duty fleet.

	Costs variation at RES2050					
	0%EV	**20%EV**	**40%EV**	**60%EV**	**80%EV**	**100%EV**
ΔC_t[%]						
EV (B) – EF (20% price reduction)	24.3%	29.9%	35.4%	41.3%	46.8%	52.7%
EV (B) – EF (conventional car price)	24.3%	24.2%	24.0%	24.2%	24.0%	24.1%
ΔC_i[%]						
EV (B) – EF (20% price reduction)	39.7%	50.1%	60.6%	71.1%	81.6%	92.0%
EV (B) – EF (conventional car price)	39.7%	41.5%	43.4%	45.3%	47.2%	49.0%
ΔC_v[%]						
EV (B) – EF	-6.2%	-10.3%	-14.6%	-17.8%	-22.1%	-25.5%

Energy scenarios including P2H: conclusions

Conclusions and future developments

1. The impact of P2H technology in high RES penetration scenarios characterized by increasing EV share for private transportation has been assessed.

2. Different end uses for hydrogen within the energy system have been explored for the Italian case.

3. Hydrogenation of biogas from anaerobic digestion plants provides higher CO_2 emissions than syngas hydrogenation.

4. When:
   - RES capacity is set to 2050 level
   - EV completely replace conventional vehicle fleet for private transportation
   - syngas allows fossil fuel replacement for heavy transport via electrofuels

   CO_2 emissions can be reduced by 28% with respect to 2015 level

5. Future developments should include electrification of other energy sector options as well as further potentials for synergies among sectors under a Smart Energy System perspective.

Thanks for your attention