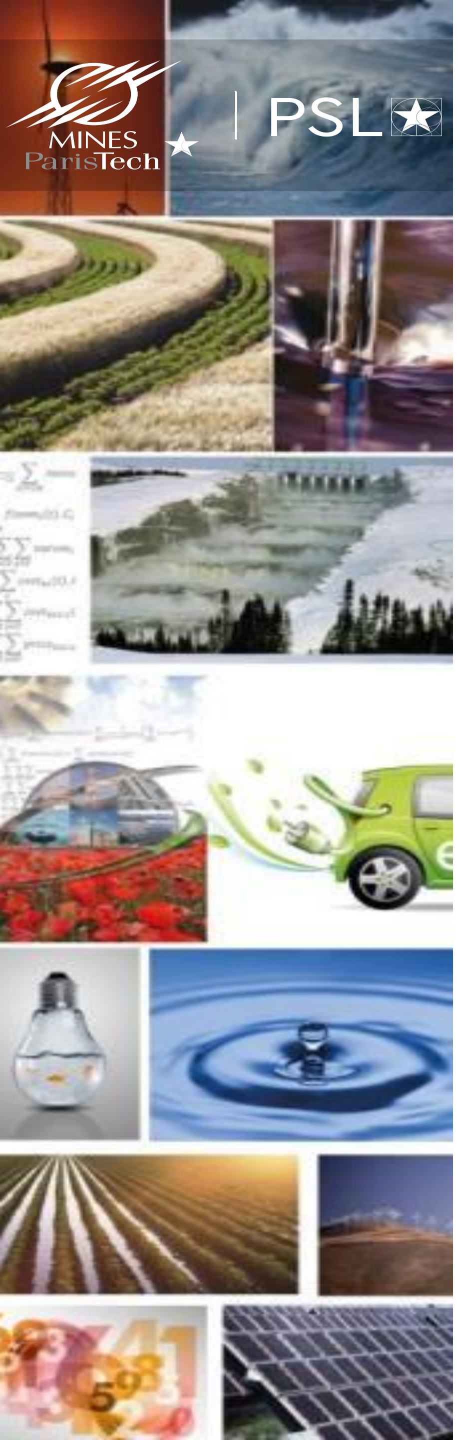


ADEME
Agence de l'Environnement et de la Maîtrise de l'Energie

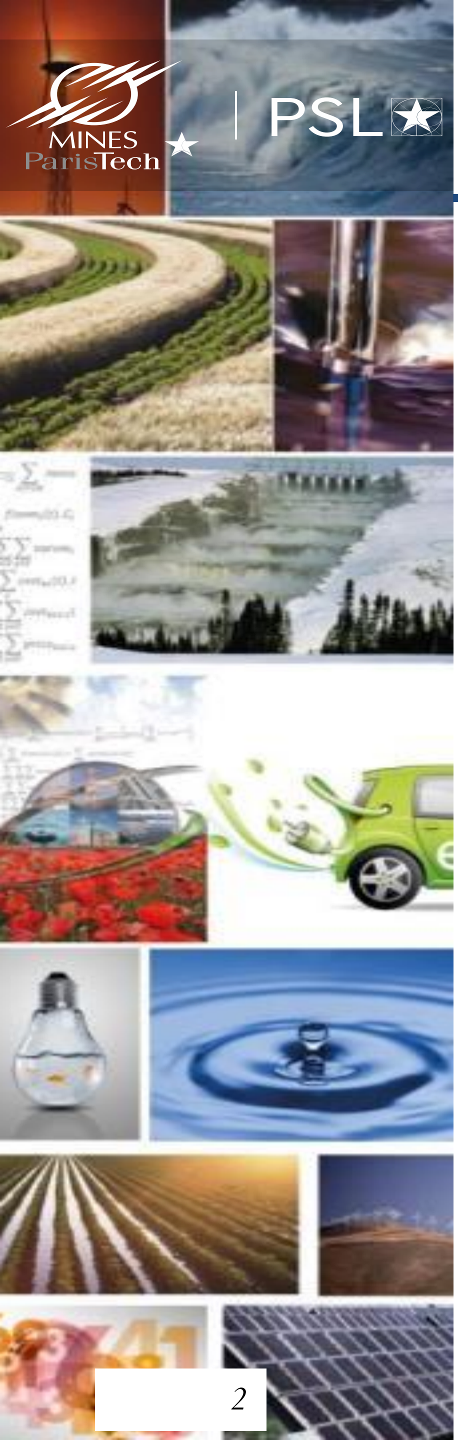
CMA
Centre de Mathématiques Appliquées

ASSESS THE TRANSITION TO A CIRCULAR ECONOMY FOR THE ENERGY SYSTEM:

LONG-TERM ANALYSIS OF THE CASE OF THE SOUTH-EST REGION OF FRANCE

8 June 2021

Carlos ANDRADE, Sandrine Selosse, Nadia Maïzi



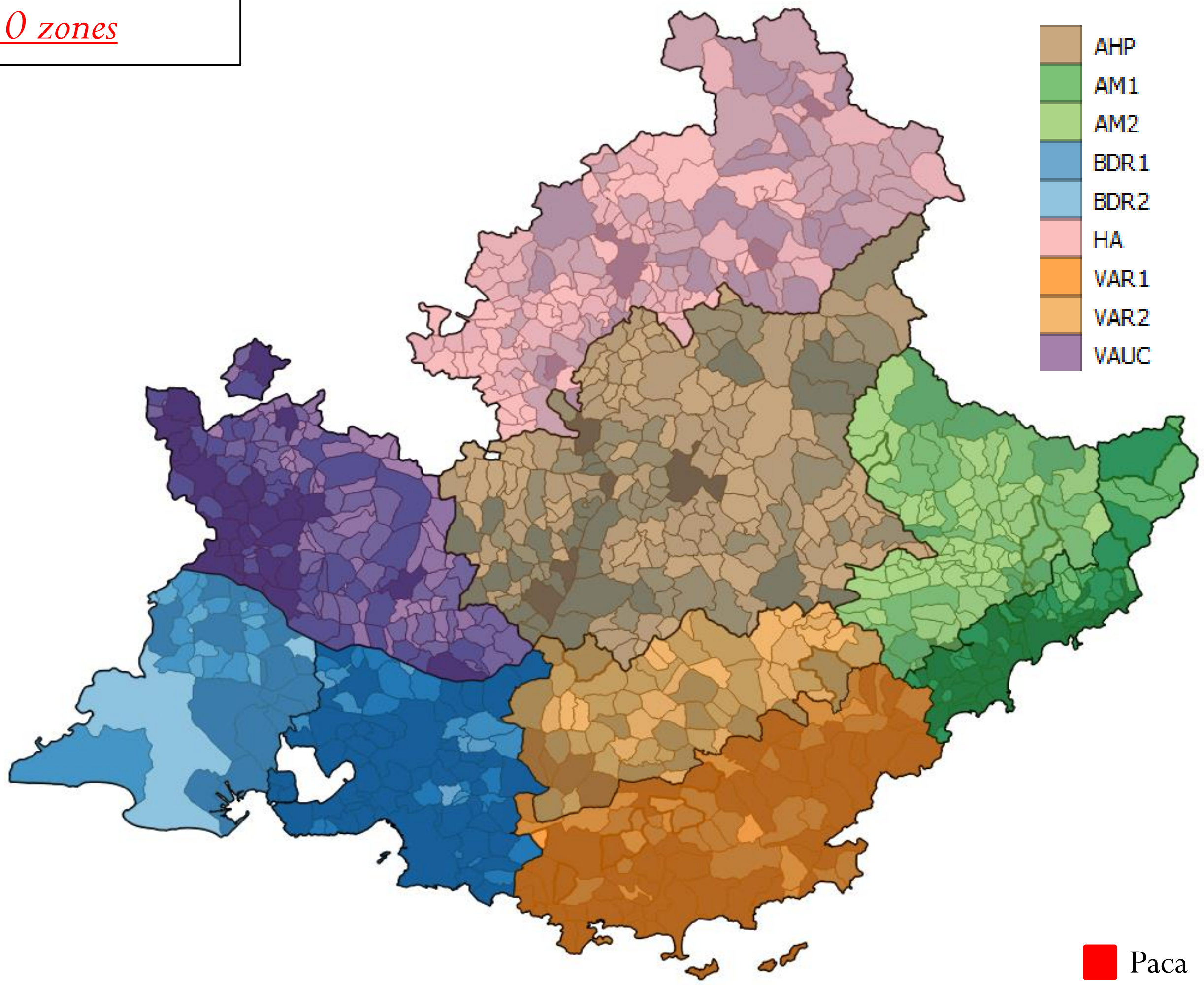
Context

- Objective: Analyze, through a prospective model, the options for low-carbon energy transition and circular economy in the SOUTH PACA region

- Main questions:
  - Integrate circular economy issues into the region's energy system long-term model
  - Evaluate the region's energy-climate policies
    - How to transform the various national guiding documents into regional energy policies?
    - Where and how to develop renewable energy potentials?
    - How the region can contribute to national decarbonisation goals?

Model structure

10 zones



Departments-zones

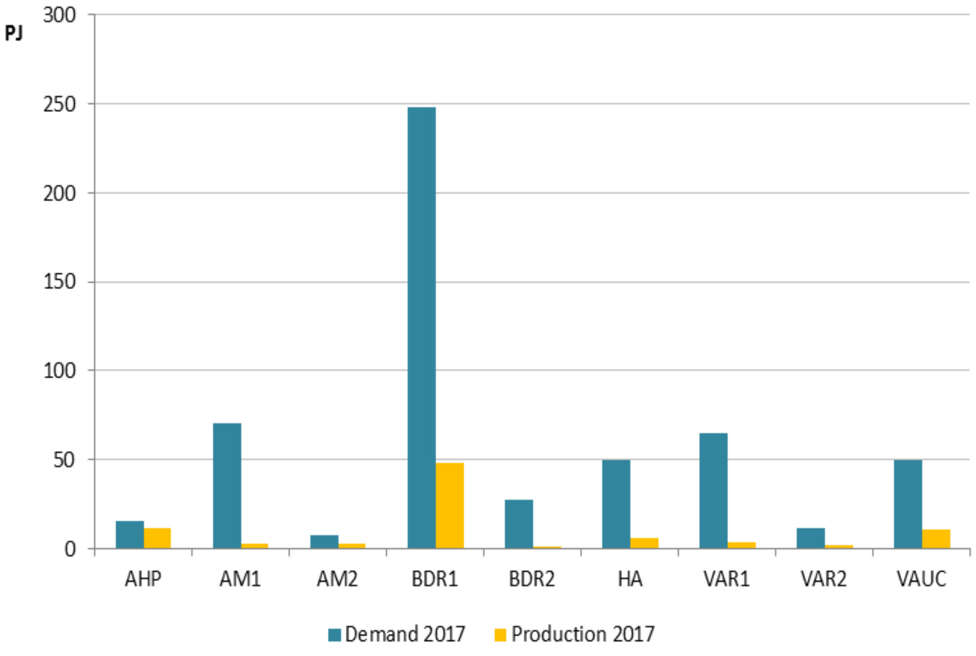
- Electricity production by sector
- Consumption by sector of activity and by type of demand (housing, transport, industry, agriculture)
- Potentials of renewable energies

PACA

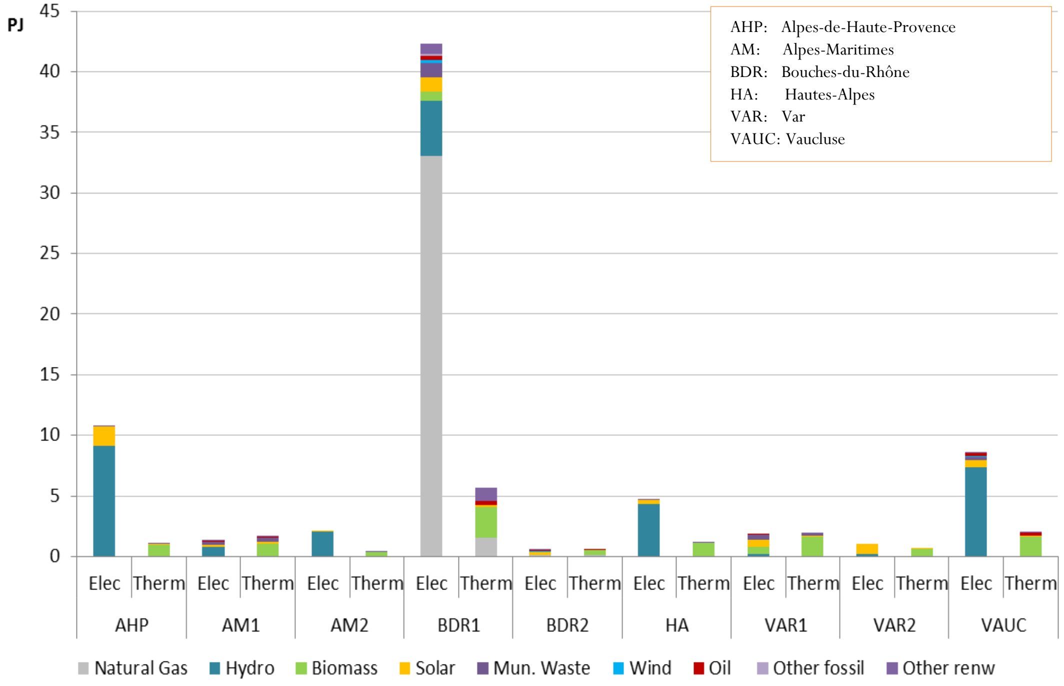
- Power and gas networks
- Energy exchange hub
- Aviation consomption
- Transport consumption (not coming from the PACA region: 15% of the consumption of private vehicles; 22% of heavy goods vehicles)
- Refinery

Final energy production by department of the SUD PACA Region in 2017

Departments' production vs demand

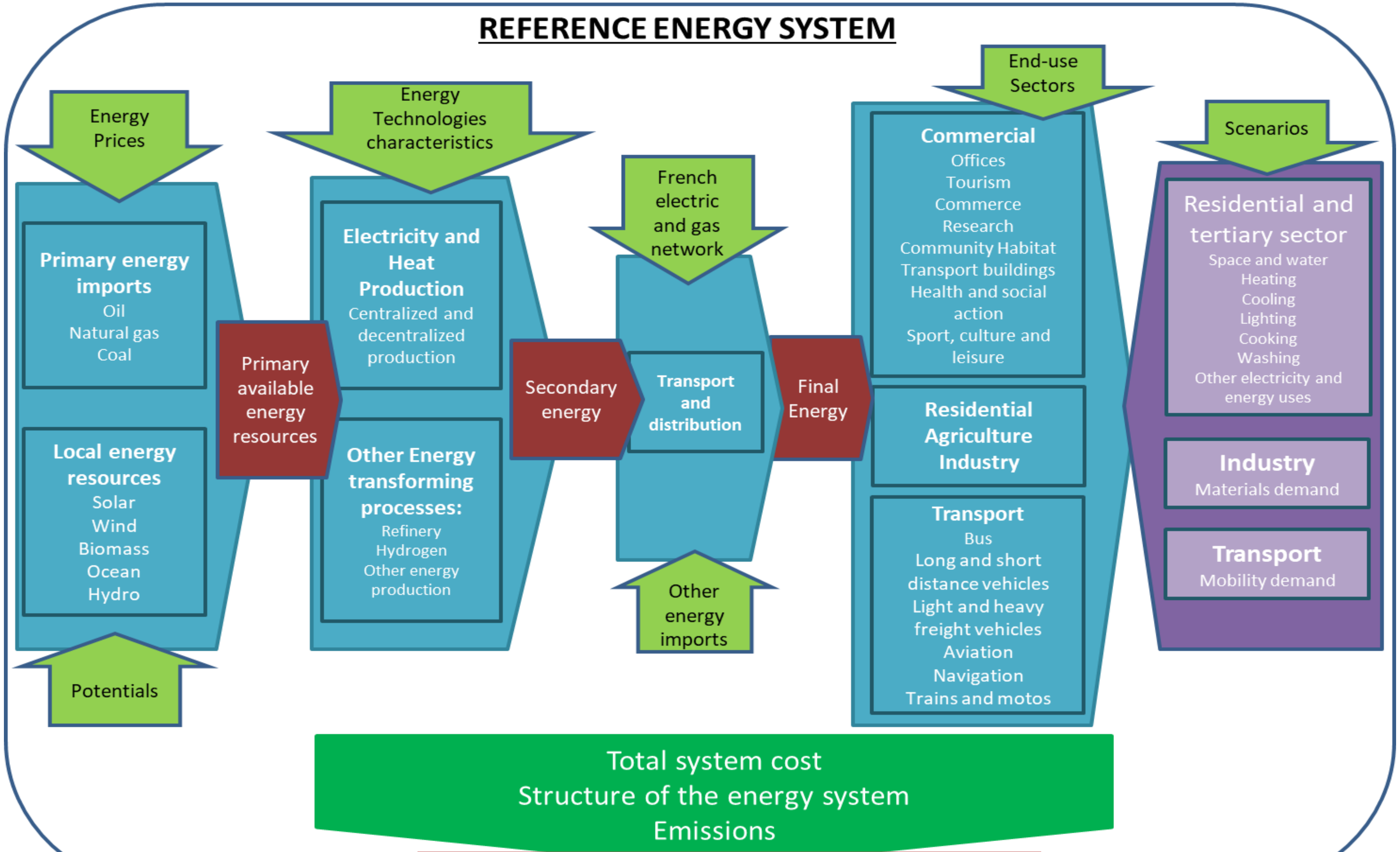


Final energy production

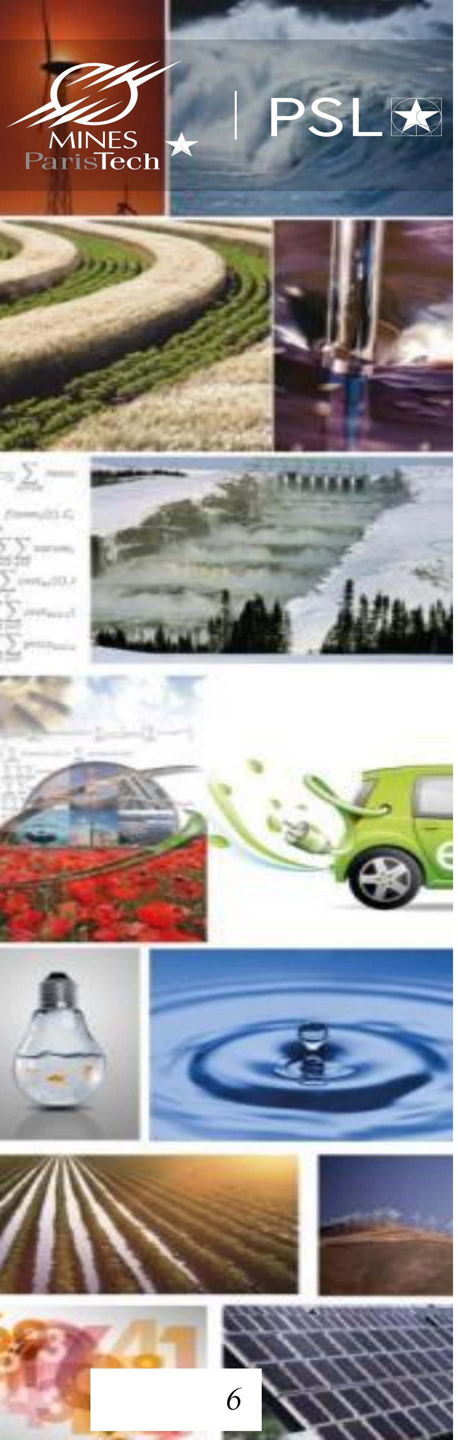


- Low energy production compared to consumption (17% of the demand)
- Energy production mainly comes from fossil fuels (50%)
- Production concentrated in the BDR1 (54%)

TIMES SUD PACA model

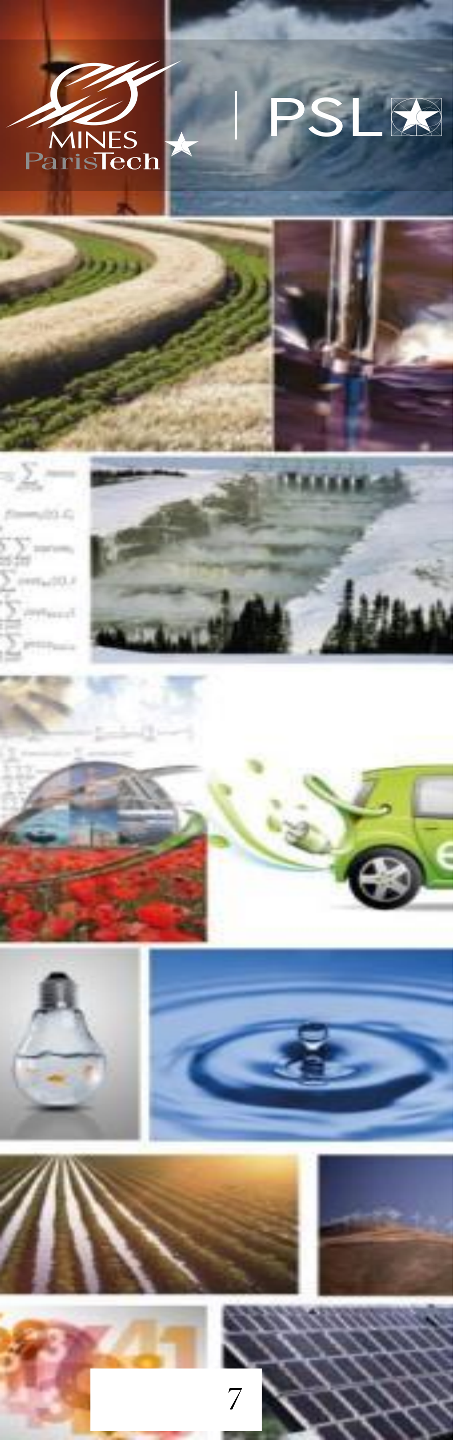


$$NPV = \sum_{r=1}^{R} \sum_{y \in YEARS} (1+d_{r,y})^{REFYR-y} \bullet ANNCOST(r,y)$$



Circular economy

Can be defined as an **economic system** that seeks to contribute to **sustainable development** (cover current needs without compromising those of tomorrow), in particular to **dissociate economic growth from environmental degradation and social inequality**, by **redesigning the way of consuming, of producing**, and how the society relates with the environment and to itself, through the optimal application of the **4 R**'s namely "**reduce, reuse, recycle and recover**", always seeking to **minimize the consumption of resources**, and looking towards producing **zero waste**, with a **systemic approach** at the moment of its deployment at the micro (companies and households), meso (industrial synergies, regions), macro (country and global) and supply chain level (interaction between the previous levels).

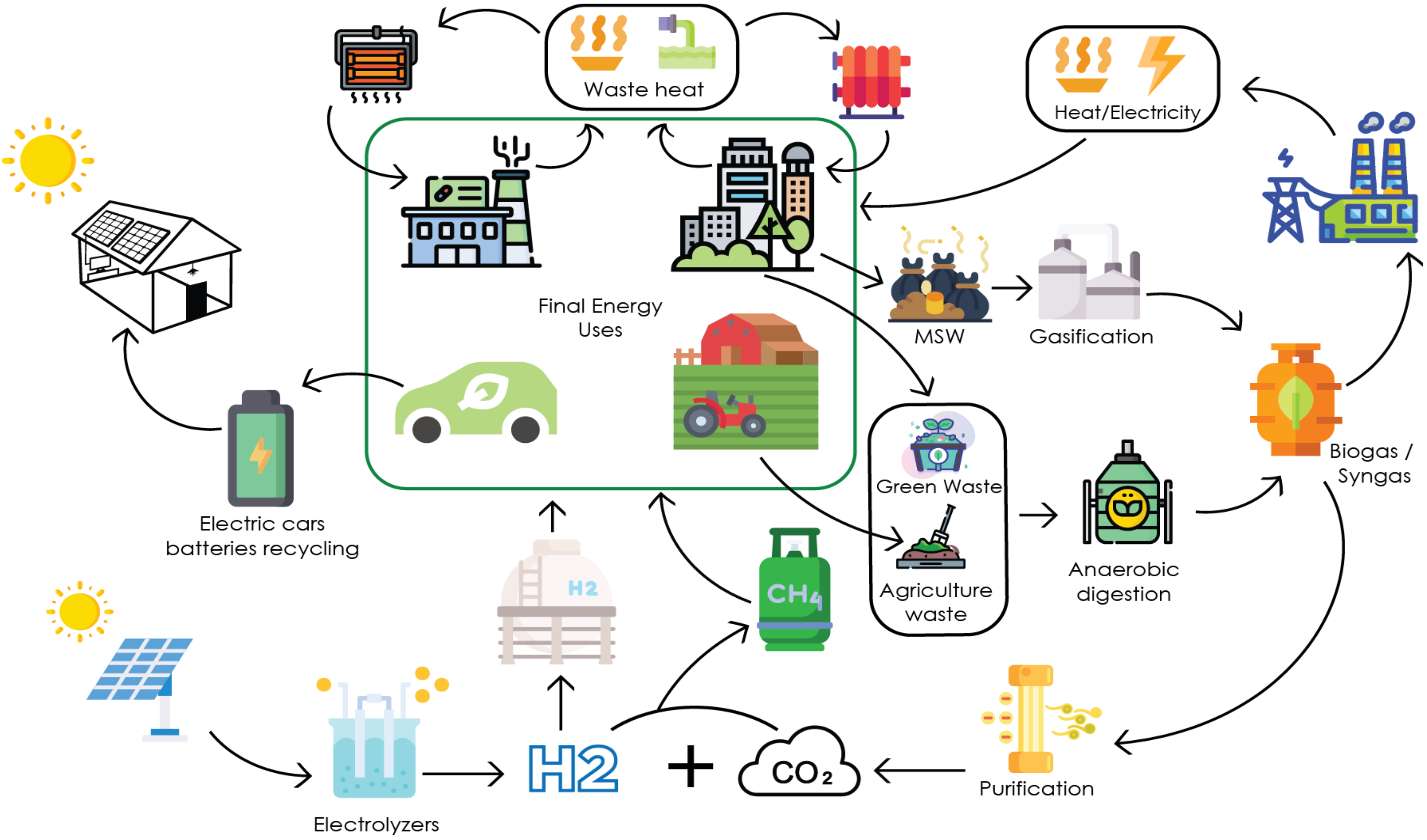


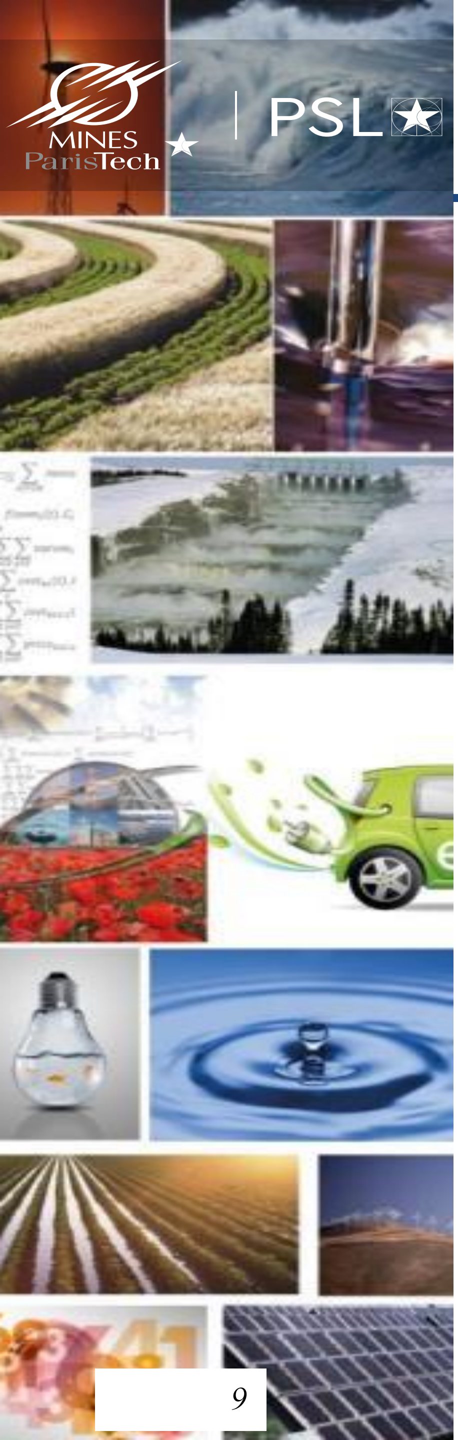
A circular energy system

- Maximize the reuse of resources that otherwise would have been thrown away
- Prioritize the recovery of resources in order to increase the efficiency of the system
- Reduce emissions
- Reuse products by giving them a second life
- Integrate a shift in behavior in terms of how energy is consumed

Type of energy	Potentials (PJ)	Source
Heat recovery from waste water	2.36	Antea Group, 2011
Waste heat from industry	33.1	ADEME, 2017
Waste hydrogen	1.28	ADEME, 2018
Ground photovoltaic	54.81	Cerema Méditerranée, 2019
Roof photovoltaic	92.8	ADEME & Armines PERSEE, 2015
Wind	21.48	Valorem-Conexia Energy, 2010
Geothermal	136.79	BRGM, 2013
Hydraulic	14.73	CEREMA, 2015
Agricultural waste	9.71	Hélianthe, 2015
Green waste	1.36	
Municipal solid waste	13.52	
Waste water sludge	1.52	
Wood	27.73	ADEME, 2018
Total	411.19	

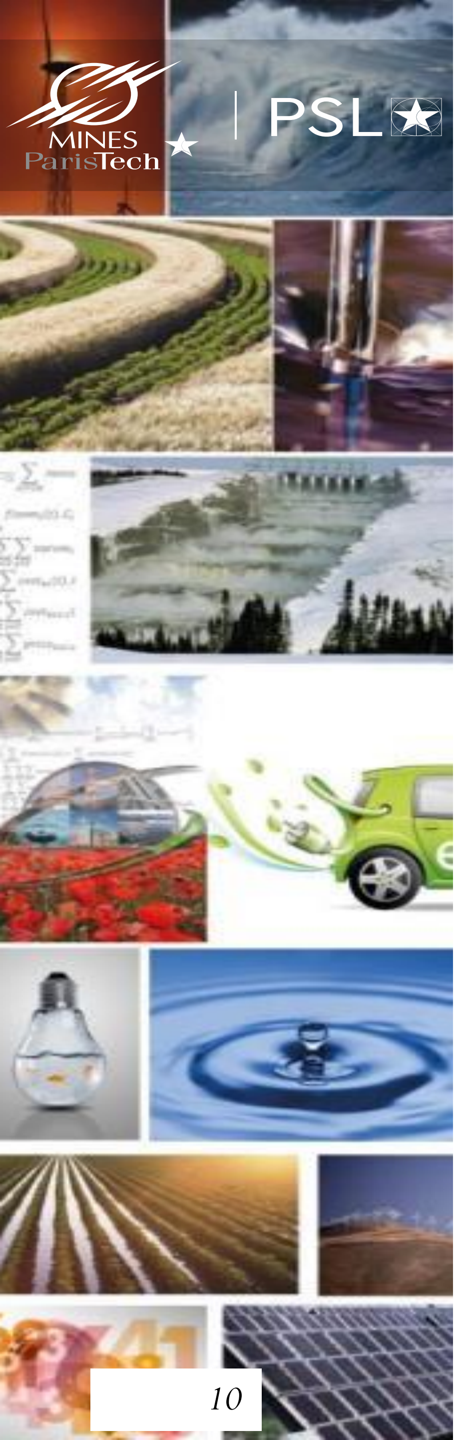
The perspective of the circular energy system for the SUD PACA region



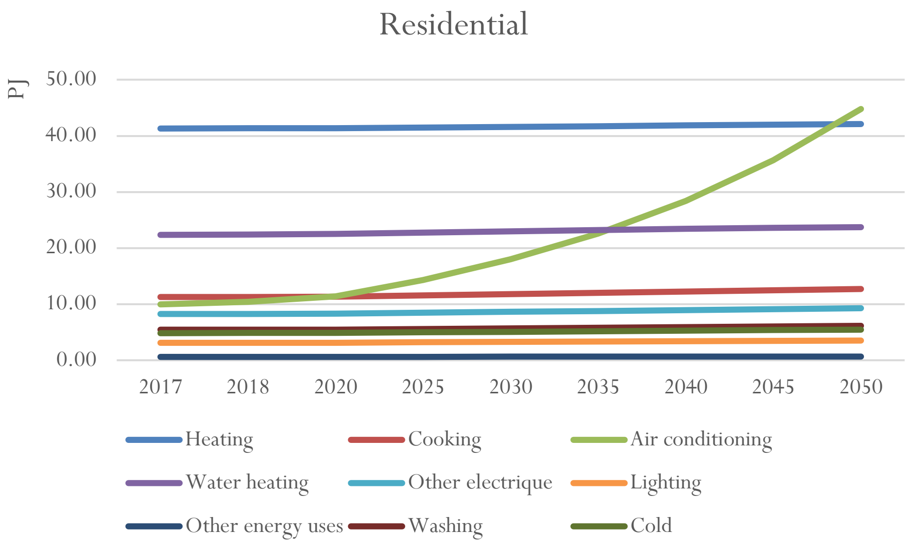


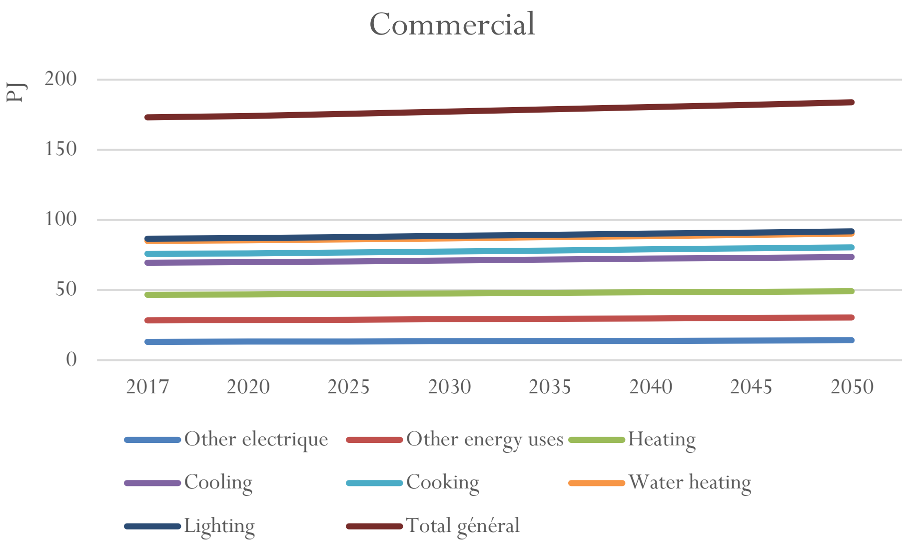
Technological characteristics

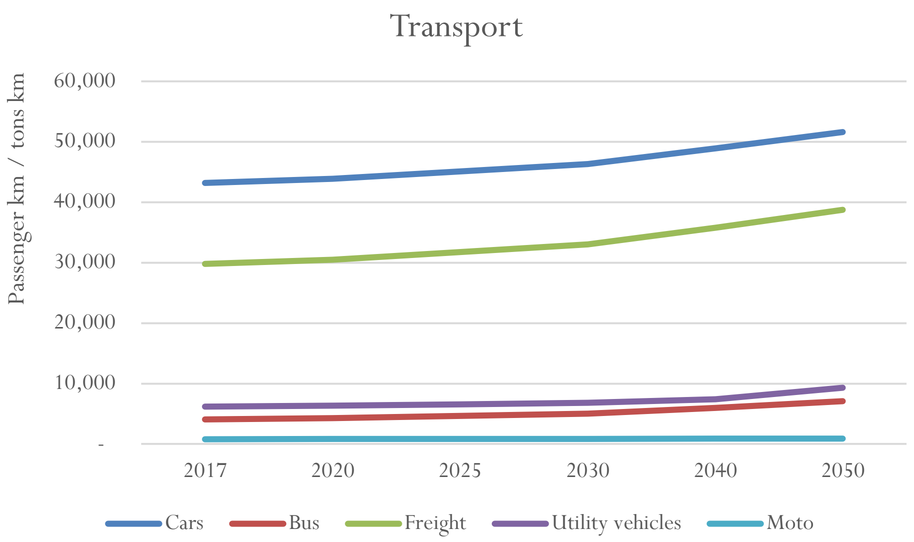
Technologies		Investment cost 2020	Investment cost 2030	Investment cost 2050	Variable Cost 2025	FOM 2025	Source
Electrolysers (€/kW)	Proton Exchange membrane	1500	950	750		45 (M€/GW)	JRC, 2016
	Alkaline large	625	377		0.06	41.5 (M€/GW)	
	Alkaline medium	1779	444		0.06	89.9 (M€/GW)	
	Alkaline small	1940	512		0.90	136.7 (M€/GW)	
	Hydrogen injection	963	933	467			Doudard, 2019
Gasification – Prod. H2 (€/kW)	Centralized - wood/CSR	2453			0.86	122.5182	JRC, 2016
	Decentralized - wood/CSR	3814			1.70	76.2042	
	Biomass reforming	519	519		0.18	20.77 (M€/GW)	
Biogas (€/kW)	Methanization €/MWh				60.00		Doudard, 2019/Ademe, 2018
Biogas/Syngas	Purification	500	450	405			
	Biogas purification (€/t)				9.00		
	Pyrogasification - wood	3000		2500			
	Pyrogasification - CSR (€/MWh)				40.00		
	Methaneur	1519.67418	447	263			
	Biomethane injection	354	267	193			
Energy storage (€/kWh)	H2 - Centralized underground	2.7				0.3 (€/kWh)	JRC, 2016
	H2 - Centralized tank	13				0.8 (€/kWh)	
	H2 - Decentralized tank	7.5				0.4 (€/kWh)	
	Battery - Lead-Acid	176		135			
	Battery - Li-ion	660	224	216			
	Battery - NaNiCl ZEBRA	157		68			

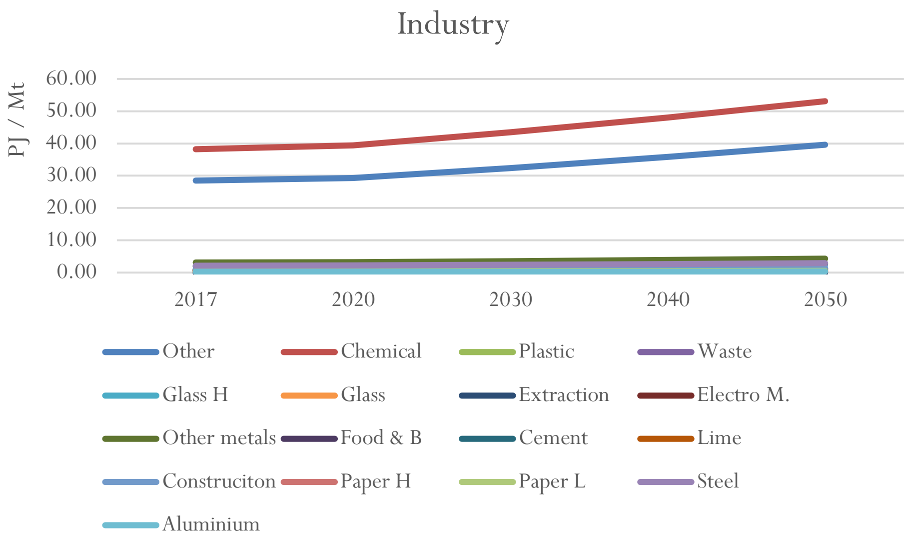


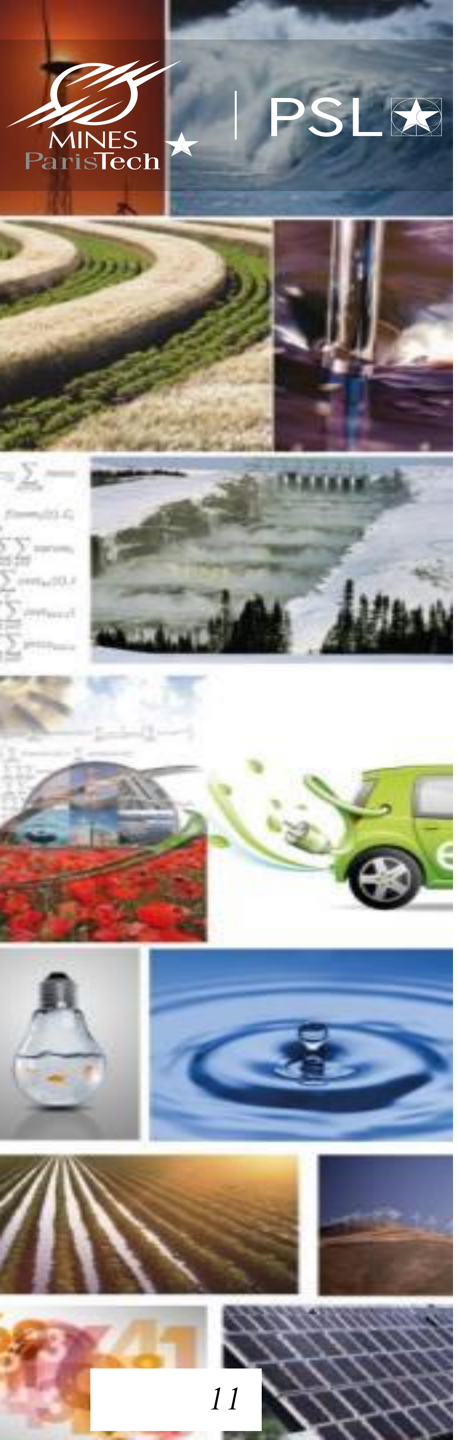
Scenarios – the demand





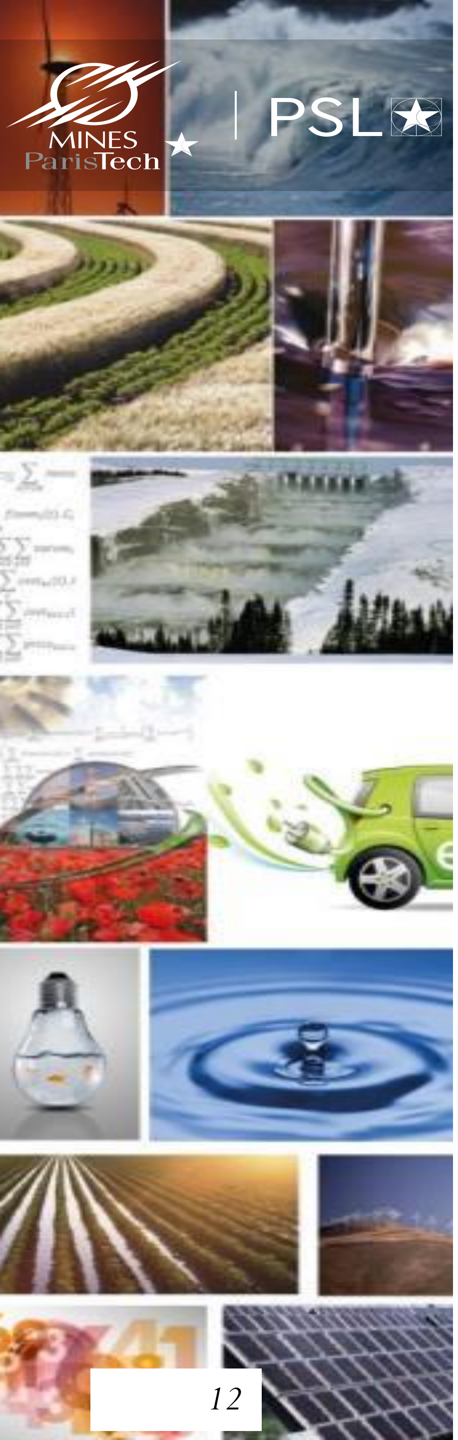






The scenarios

- Reference : This scenario aims to explore the evolution of the energy system according to trends, which take into account policies established in the region and France before the base year
- Sraddet : How the policies proposed by the SUD PACA region will shift the development of the regional energy system
- Circular economy : Evaluate how integrating a circular economy perspective can shift the development of the energy system of the SUD PACA region

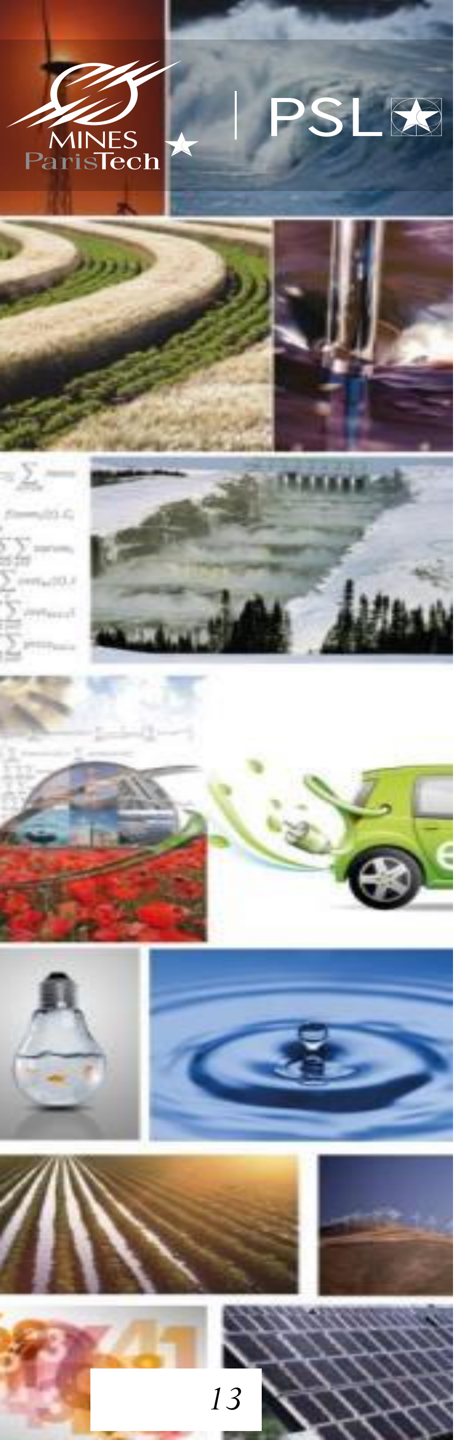


Scenarios - Reference scenario: assumptions for the production sector

This scenario aims to explore the evolution of the energy system according to trends, which take into account policies established in the region and France before the base year

- **<u>Production:</u>** Follows trends from past years
- Electricity from the French electricity grid is reduced by 15% in 2050 (electricity withdrawal trend -3% on average between 2010 and 2017)
- Gas from the gas network can increase by 10% in 2050 (gas consumption 7% higher in 2017 compared to 2007)
- The region can use 21 PJ (20% of gas consumption in 2017) of bio methane from the French gas network in 2050

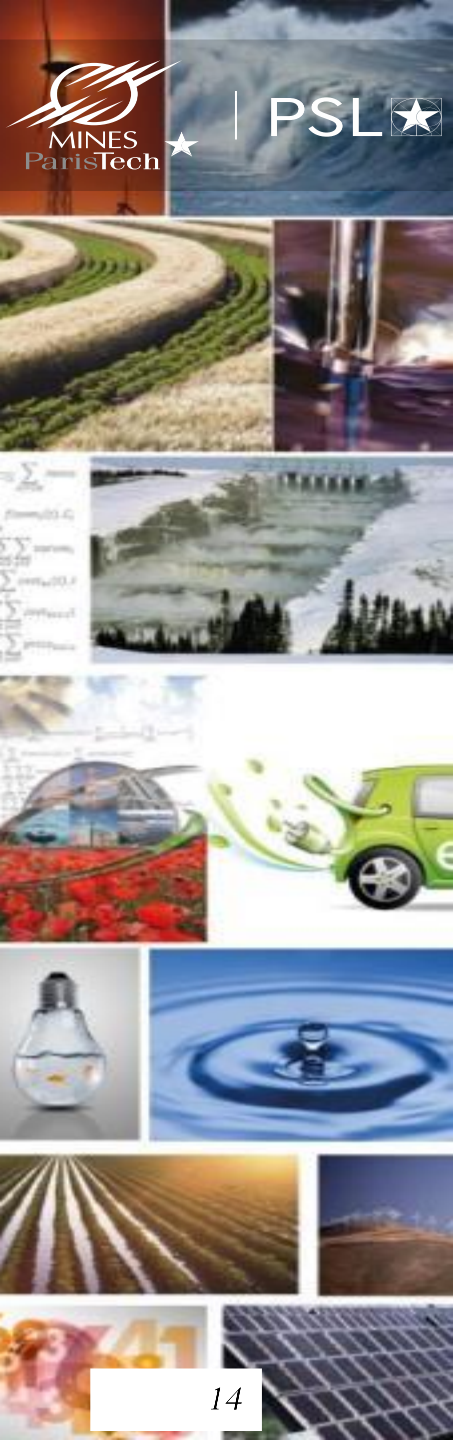
PJ	Energy	2017	Annual growth	2050
Electricity	Biogas	0.84	1.00%	4.90
	Biomass	1.41	0.50%	2.75
	Wind	0.42	0.00%	0.81
	Hydro	28.65	0.10%	35.00
	Waste	1.53	0.00%	2.30
	Solar	5.51	8.00%	127.97
	Fossil	35.54	0.00%	35.54
Thermal	Biomass	9.92	1.00%	14.43
	Heat pumps	17.00	5%	32.68
	Heat Network	1.43	2.00%	5.22
	Solar thermal	0.64	1.00%	0.88
	Fossil	2.32	0.00%	2.32
	Electrique			209.27
	Thermal			57.18



Reference scenario – demand side

- In 2050, building renovation will be developed in 40% for the residential sector, and 30% in the commercial sector
- For the transport sector, natural gas can represent at least 10% of the energy consumption of freight vehicles and buses and 1% for private vehicles
- Personal mobility vehicles can cover 5% of private vehicles mobility demand
- In areas with low consumption, the share of electric vehicles can reach up to 20% of total vehicles in 2050 and it can reach up to 30% for areas with high consumption

P2G PROJECTS			
Jupiter 1000	1 GW	2020	Electrolysers
	0.02 PJ	2021	Methaners
HYGREEN	12 MW	2025	Electrolysers
	435 MW	2030	
Valhydate	7500 t/an	2025	Waste hydrogen valorisation
HynoVAR	7	2030	Hydrogen bus
	404 kg/j	2030	Hydrogen production
HyAMMED	8	2025	Hydrogen freight vehicles



Scenarios – SRADDET: supply assumptions

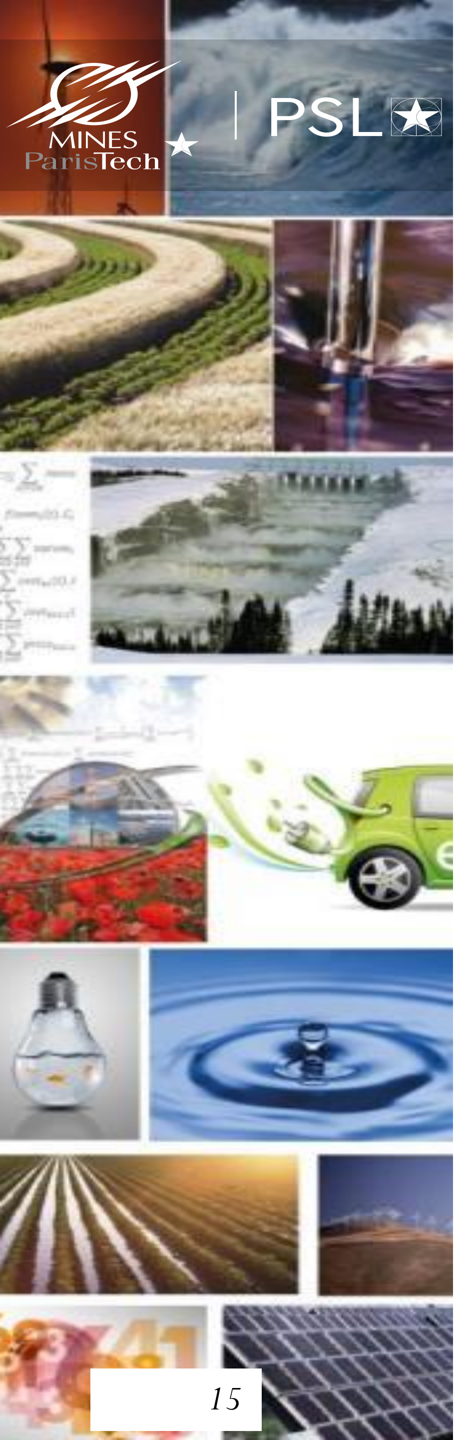
Objective: Analyze the policies proposed by the SUD PACA region

Production:

- Electricity from the French electricity grid is reduced by 50% in 2050
- Gas from the gas network can increase by 10% in 2050
- The region can use 21 PJ (10% of gas consumption in 2017) of bio methane from the French gas network in 2050
- No new fossil power plants

Energy production

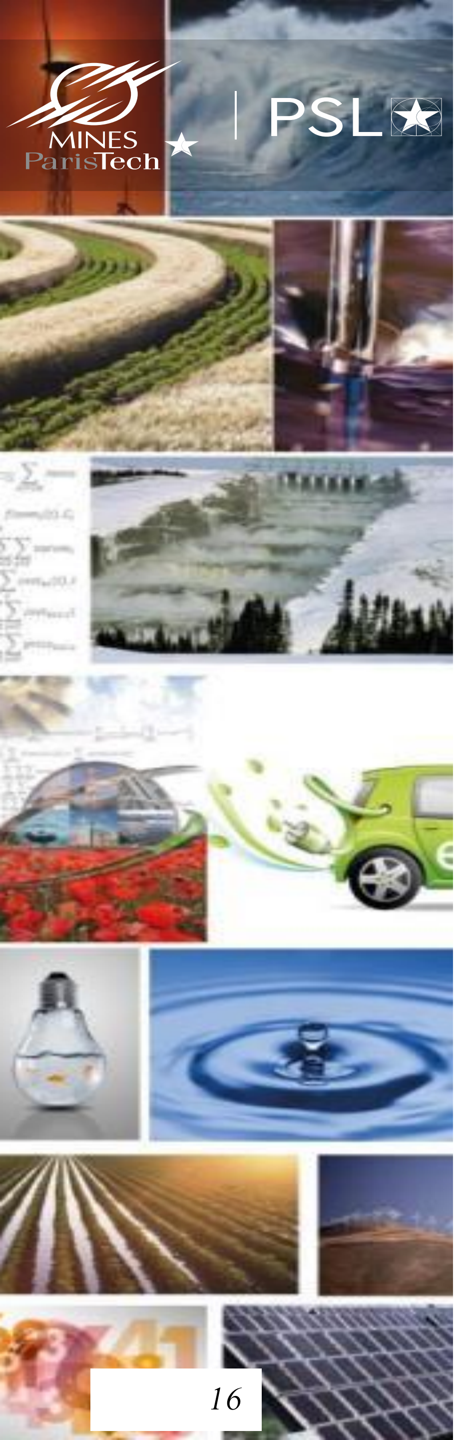
Production (PJ)		2017	2020	2025	2030	2050
Electricity	Biomass	1.41	2.88	4.42	4.42	4.42
	Wind	0.42	0.99	2.21	2.78	5.40
	Hydro	28.65	29.12	31.02	31.02	33.20
	Solar (ground)	5.51	6.27	8.90	6.57	29.47
	Solar (rooftop)	-	1.30	6.47	20.47	78.57
Thermal	Biomass	9.92	6.67	3.79	4.79	9.38
	Methanization	1.73	1.73	2.19	3.60	7.39
	Gasification	-	0.00	2.06	3.60	7.60
	Solar (thermal)	0.62	0.62	1.74	2.21	4.47
TOTAL		48.27	49.57	62.80	79.45	179.90



Scenarios – SRADDET: Demand

- In 2050, building renovation will be developed in 100%
- Personal mobility vehicles can cover up to 15% of cars mobility demand, and buses can cover up to 5% private vehicles mobility demand
- In areas with low energy consumption, the share of electric vehicles can reach up to 40% of total vehicles in 2050 and it can reach up to 50% for areas with high consumption
- People by private vehicle will increase to 1.35 from 2030

Regional hydrogen plan			
		2027	2032
Freight transport	units	100	630
Utilitary vehicles	units	540	2280
Buses	units	86	260
H2 production	tH2/year	16000	28800
Injection into the gas network	tH2/year	3000	5400

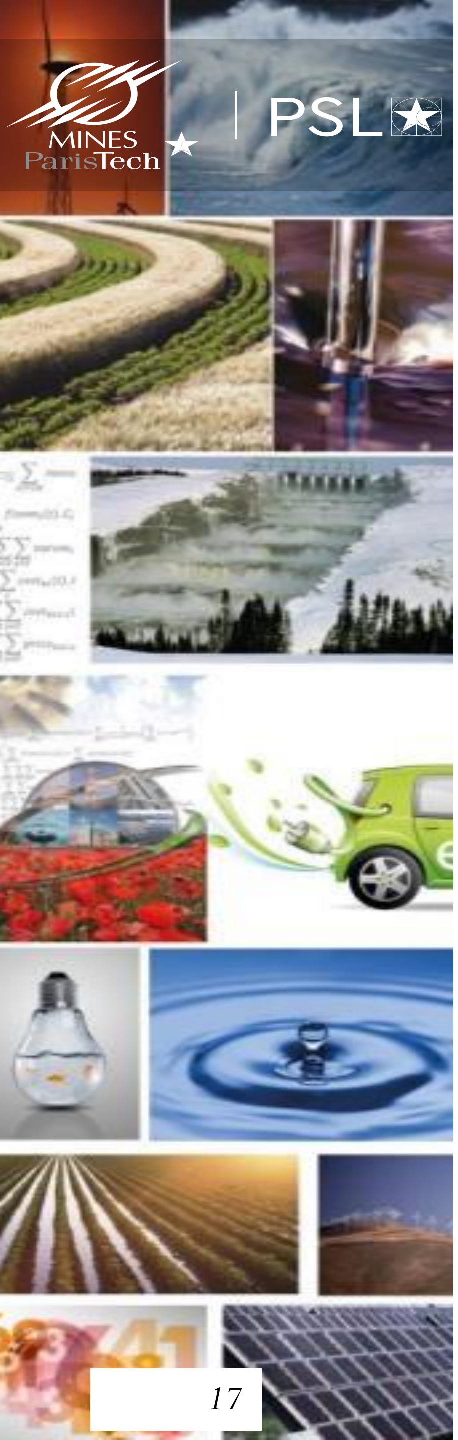


Scenarios – Circular energy system

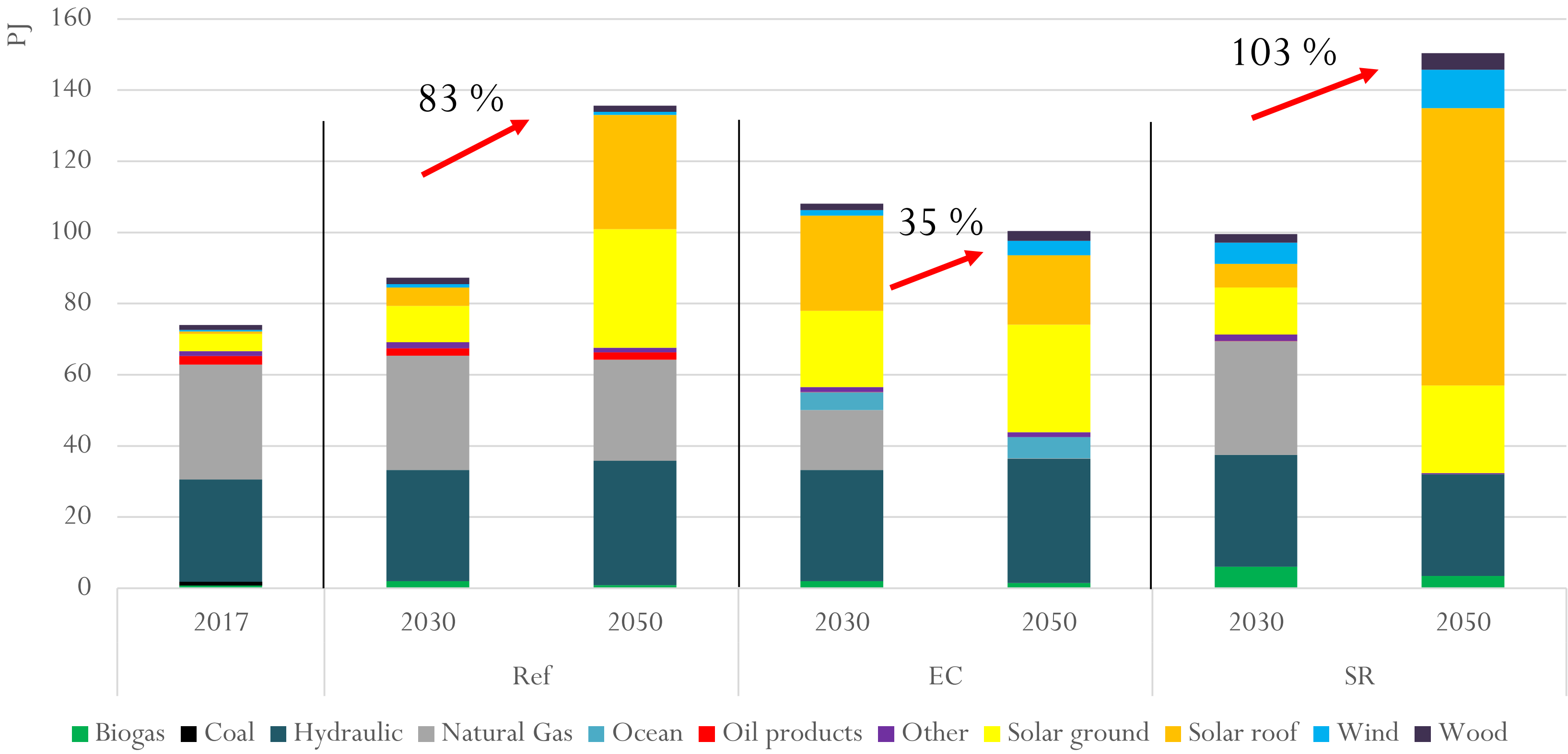
Objective : Evaluate how integrating a circular economy perspective can shift the development of the energy system of the SUD PACA region

Proposed objectives		
100%	Industrial waste heat	
100%	Waste water heat	
100%	Sludge	
100%	Municipal, agriculturae and green waste	
100%	Buildings renovation	
15%	CCU	
Personnes par véhicule particulier	1.70	People by car
Modal shift	Personal mobility vehicles can cover up to 17% of cars mobility demand and buses can cover up to 7% in 2050	
Air heat pumps	15% more than in the reference scenario	
Tidal energy	3 GW	
Wind	3 times the reference scenario	
No new fossil power plants		

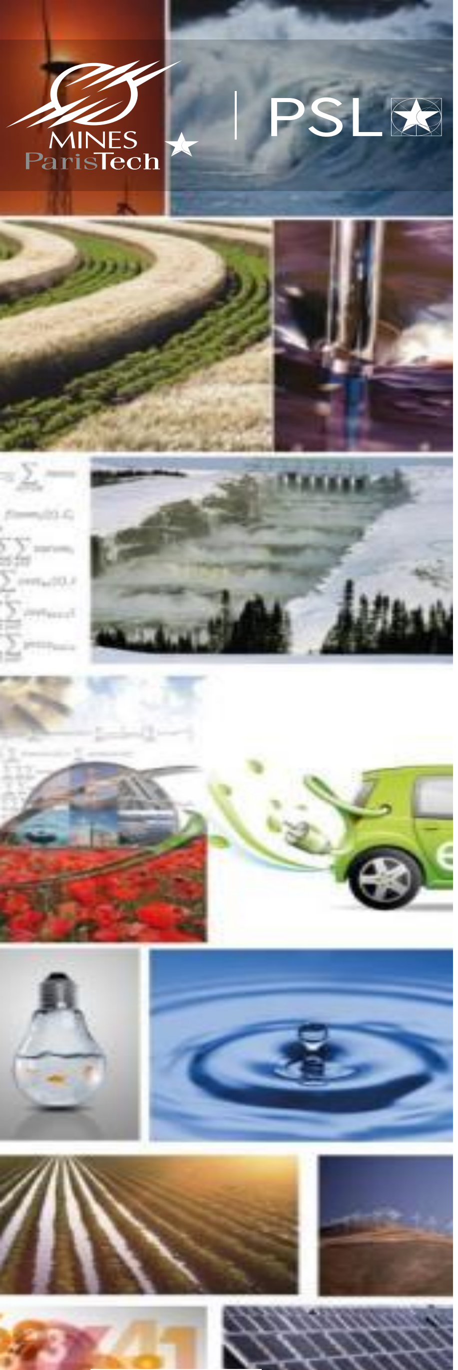
! Includes the regional hydrogen plan



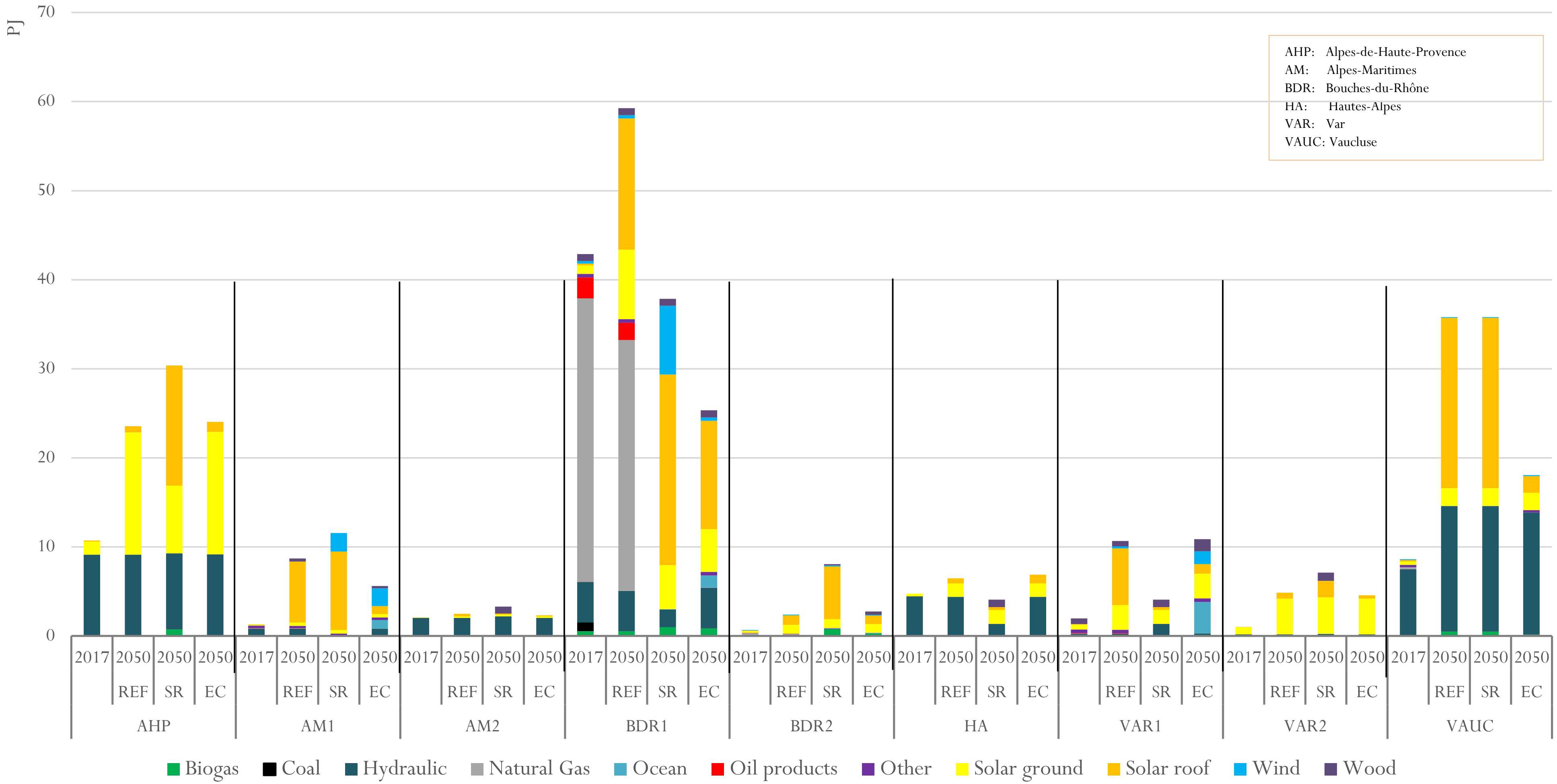
Results – Regional electricity production



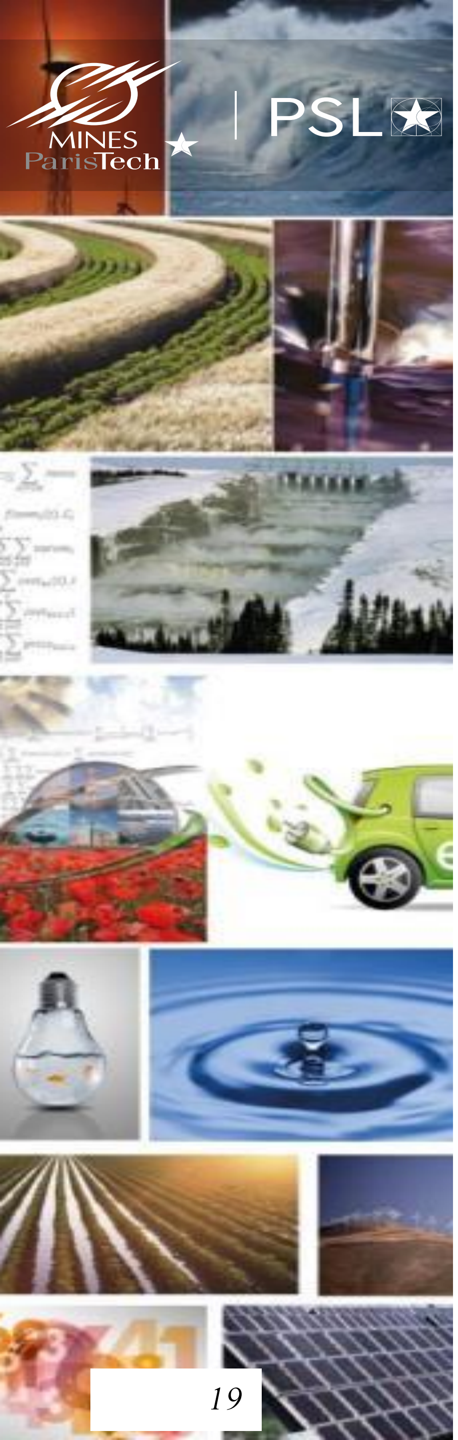
- In 2050 the use of fossil fuels represent 22% of electricity production in the reference scenario, while they account for less than 1% in the SR and CE scenario
- Total power production in 2050 in the CE scenario is the lowest among the studied scenario as it presents a lower electricity demand
- The electricity production achieved in 2050 in the SR scenario complies with a little bit more than 50% of the objectives stablished in the SRADDET



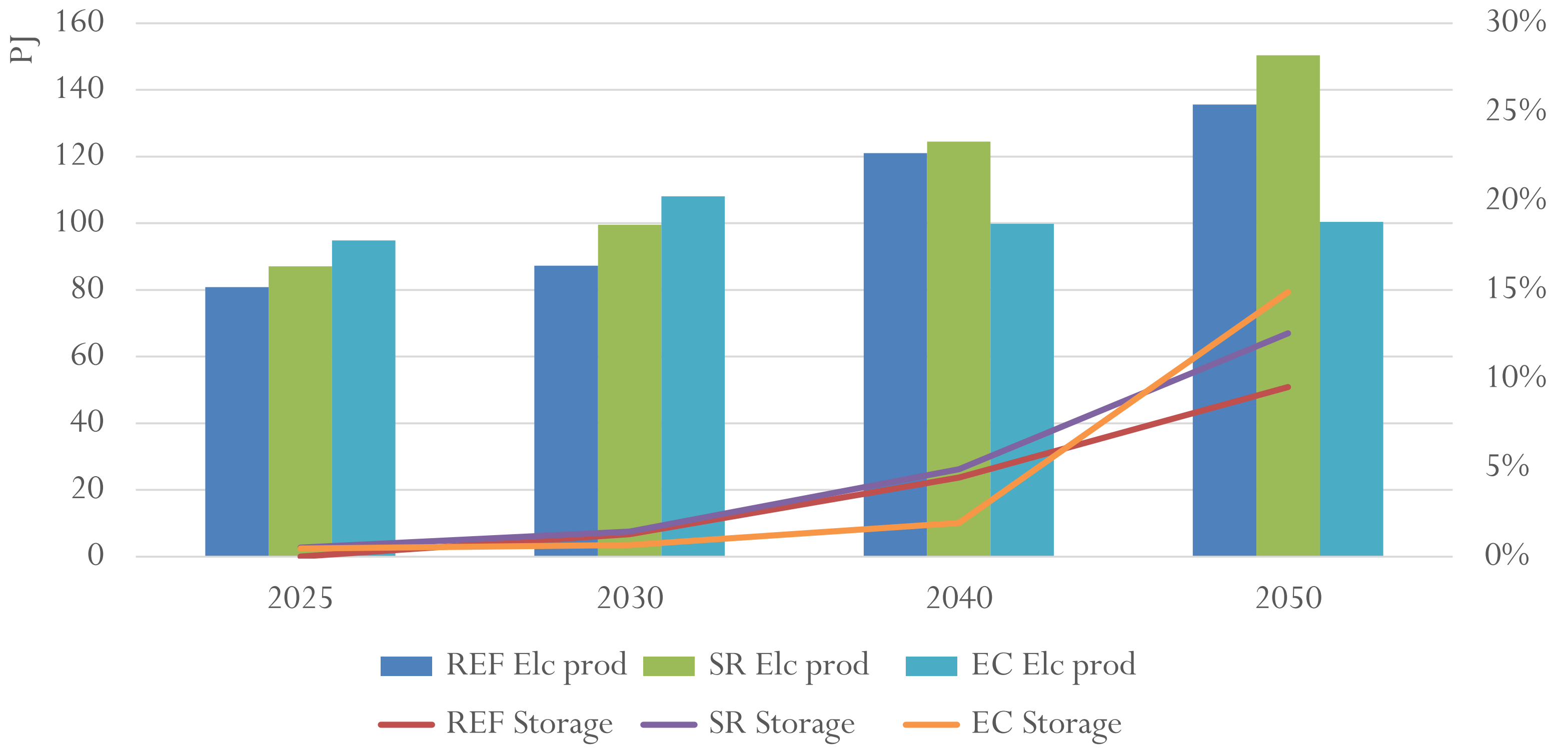
Results – Electricity production by zone



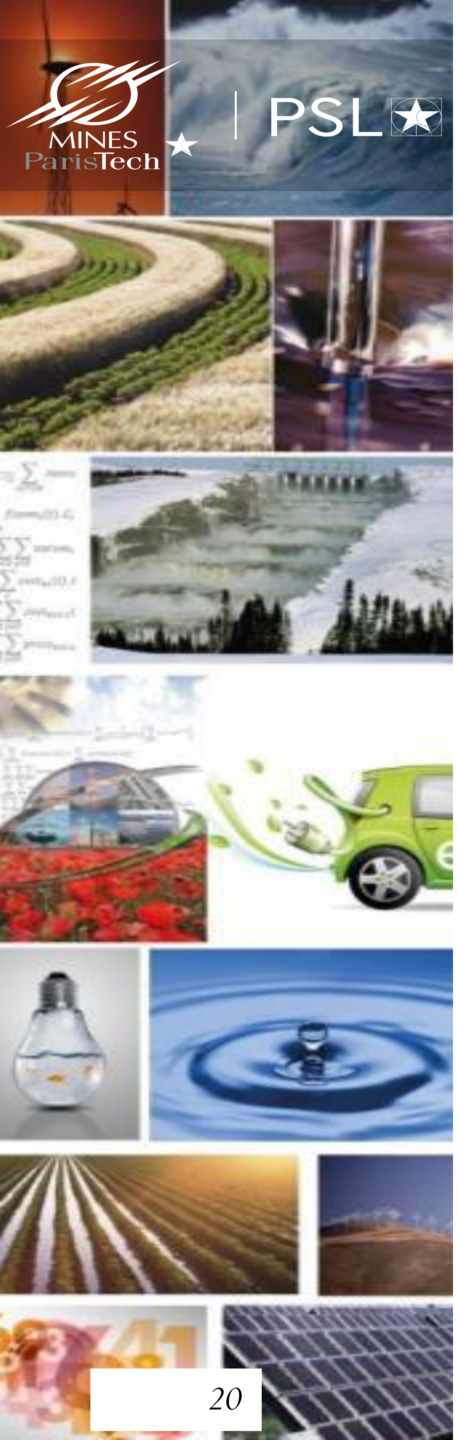
- Electricity production is concentrated in the BDR1 in the reference and SR scenario while it is more distributed among the territories in the CE scenario
- Wind production is developed mainly in the BDR1, while tidal energy is mostly used in the VAR1 zone
- Hydroelectricity is developed mainly in the VAUC zone



Electricity storage

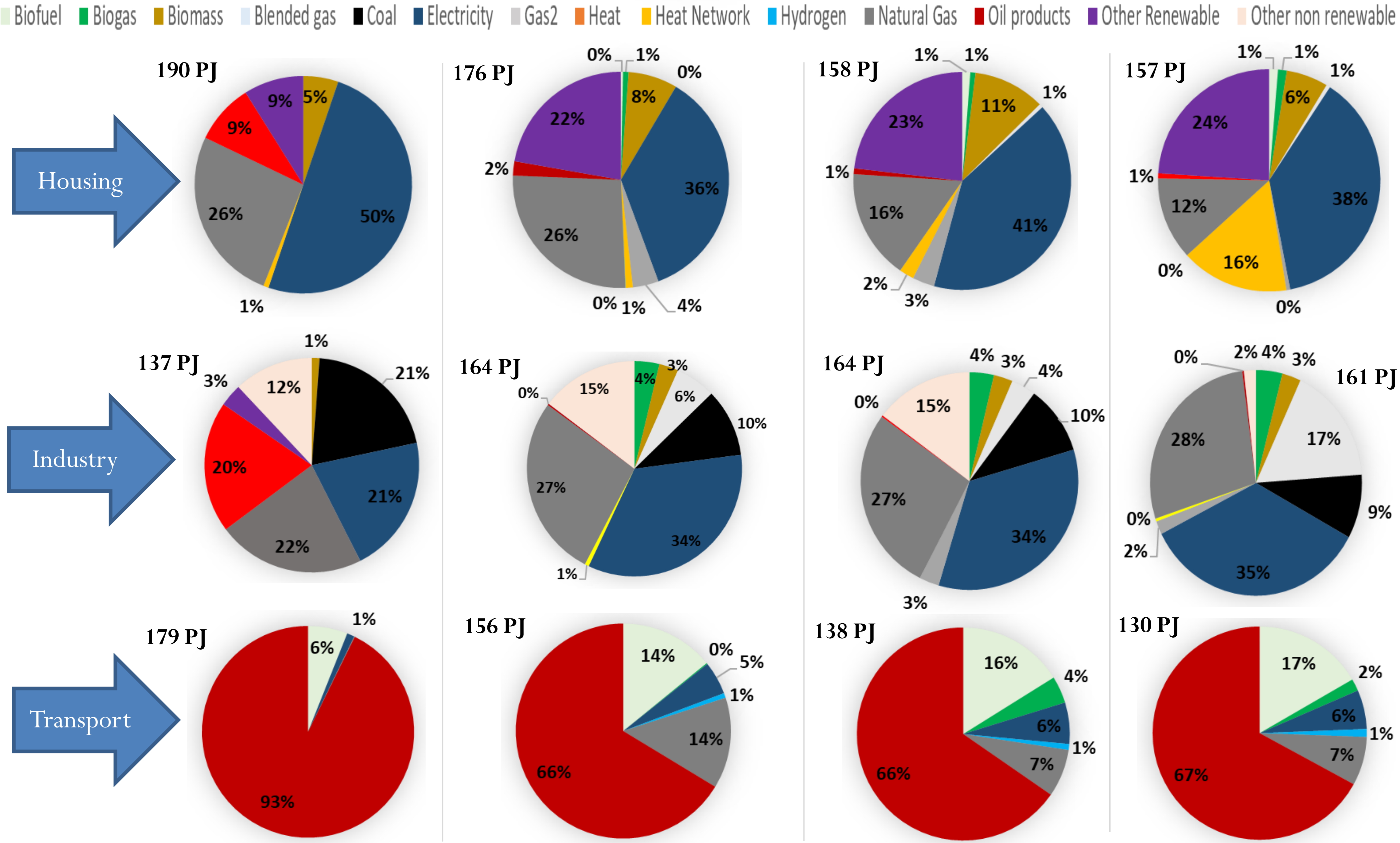


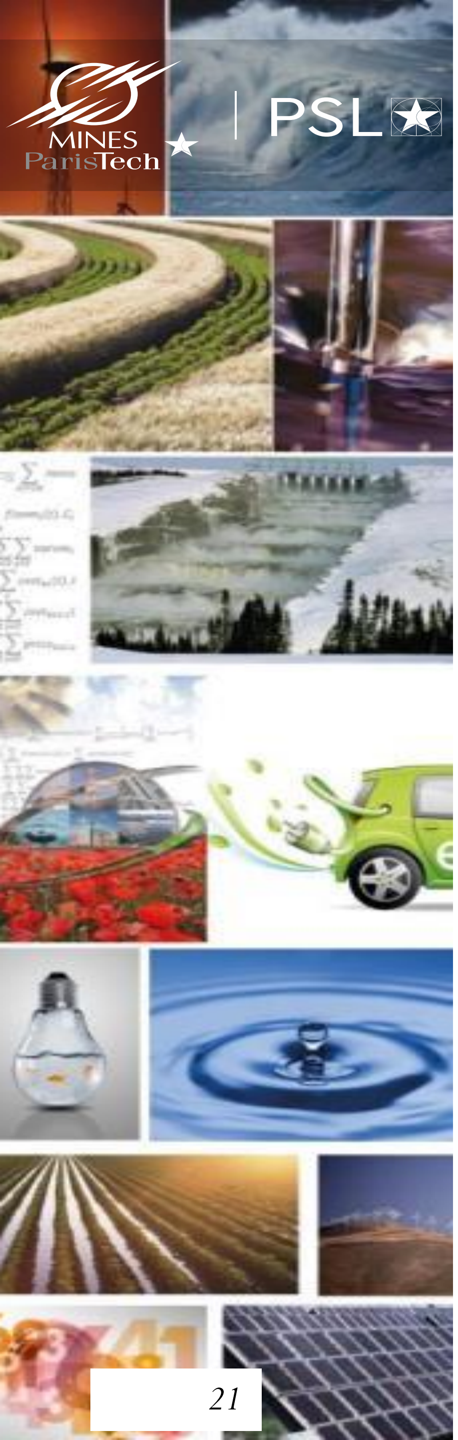
- Hydro storage and batteries have been used to store electricity
- Hydro storage has been developed mainly in the AHP zone
- Batteries have been used mostly in high consuming ares as they have been used to store electricity from roof photovoltaic panels



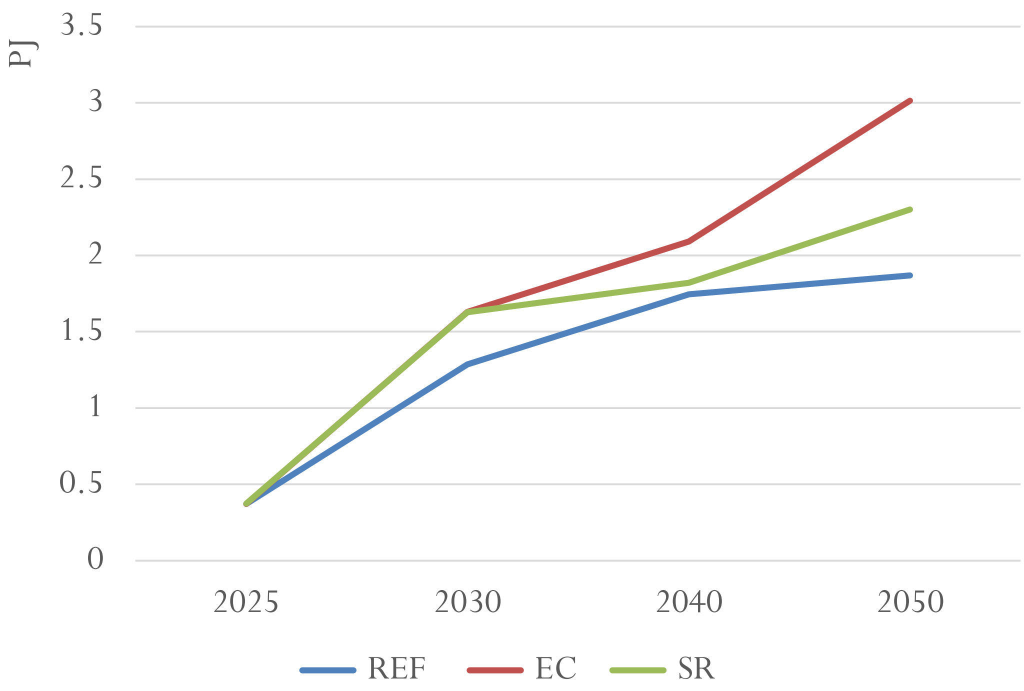
Final energy consumption

2017 | **Reference** | **SRADDET** | **Circular Economy**





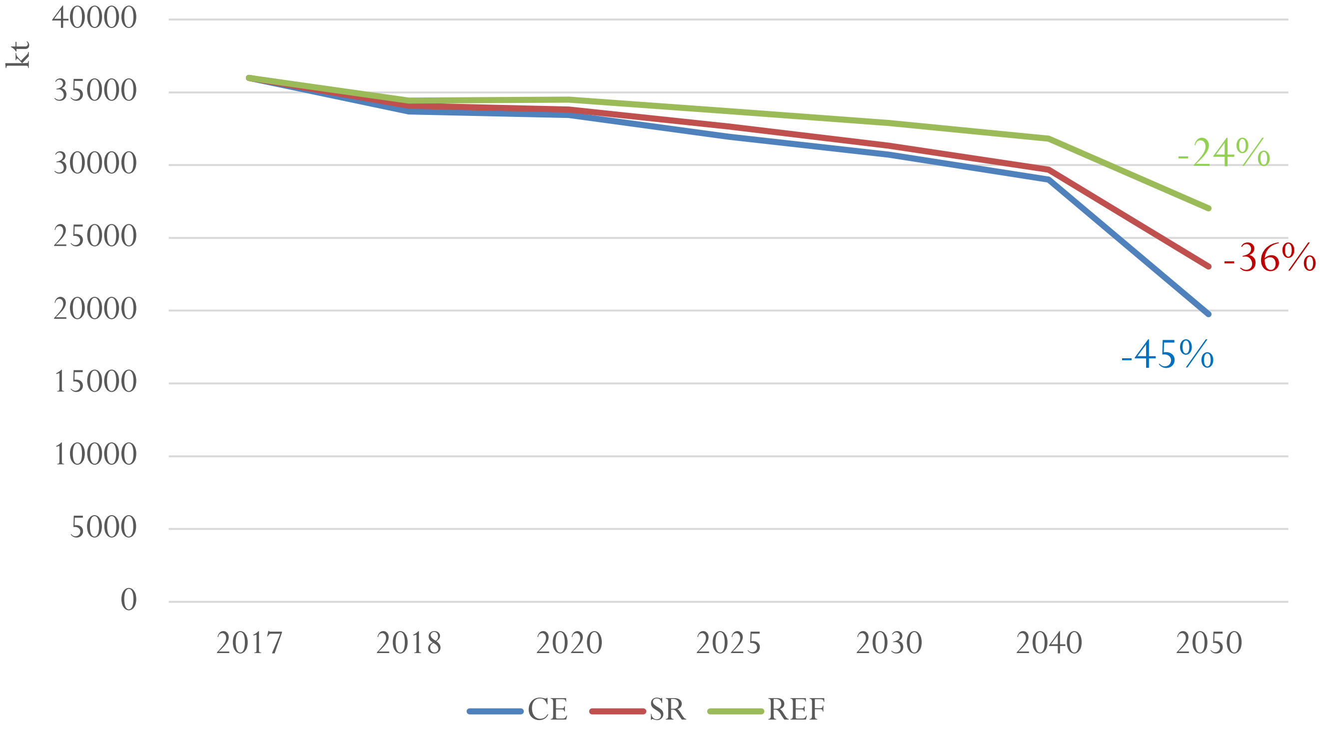
Hydrogen production

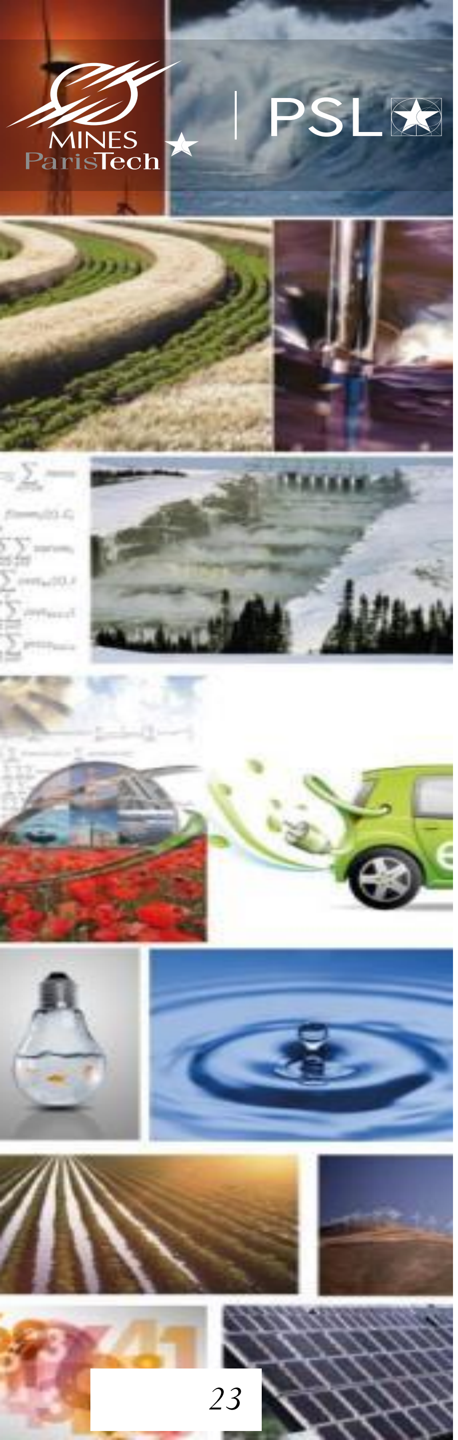


Hydrogen uses in 2050					
REF		SR		EC	
Transport	Injection	Transport	Injection	Transport	Injection
34%	62%	74%	26%	48%	52%

- The most important output of hydrogen is reached in the CE scenario due to the gasification of MSW, which is developed mainly in low consumption areas
- The AHP zone is the greatest producer of hydrogen in all scenarios due to the Hygreen project

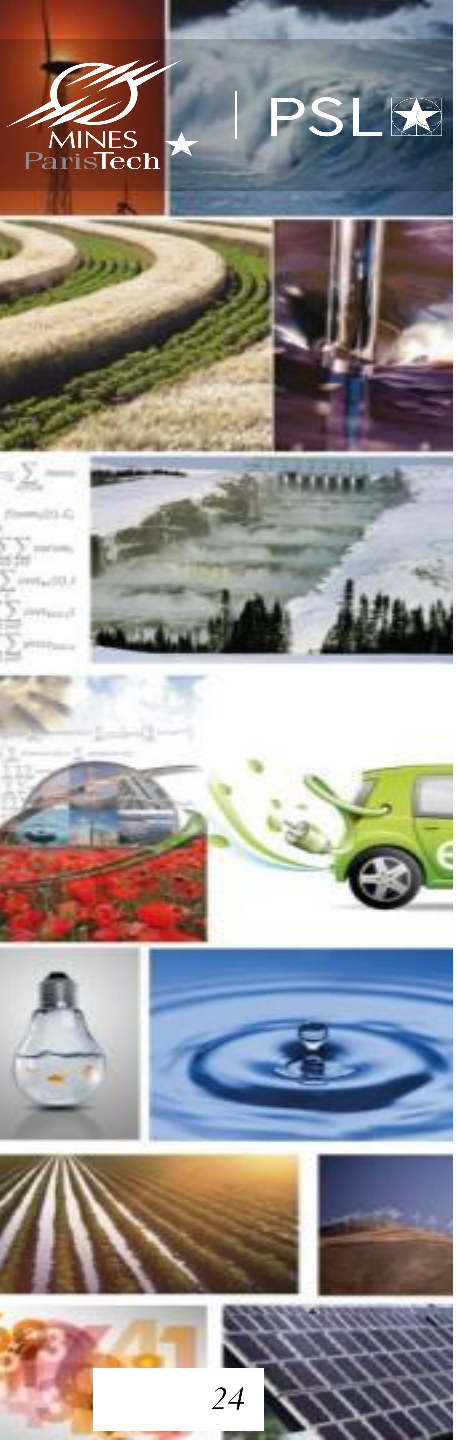
Total CO2 emissions





Conclusion

- The region is in the path towards the decarbonization of its energy system, with the decrease of fossil fuels consumption and the development of clean technologies.
- The recovery of waste heat should be prioritize as it has proven to have a great potential to decarbonize the habitat sector, increasing also the efficiency of the whole system.
- The use of batteries to store roof PV production is key to allow a greater development of the technology
- It is required higher efforts to allow the introduction of clean alternative energies into the transport sector. Supporting the development of an hydrogen market seems key to decarbonize this sector.
- Implementing a CE perspective in the development of an energy system can allow greater environmental results.



THANKS FOR YOUR ATTENTION

Carlos ANDRADE
carlos.andrade@mines-paristech.fr
PhD student
MINES ParisTech, PSL Research University, Center for Applied Mathematics
Thesis co-financed by ADEME and the SUD Provence-Alpes-Côte d'Azur Region and in partnership with Schneider Electric