6th International Conference on Smart Energy Systems
6-7 October 2020
#SESAAU2020

… towards a Trentino energetically autonomous with 0 carbon emissions …

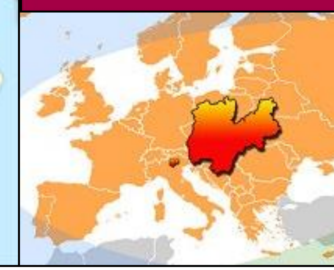
A cost-optimized approach in regional decarbonisation:
the integrated and dynamic energy modelling of the Province of Trento (Italy)

Presenter: Diego Viesi (Fondazione Bruno Kessler – Italy)

Powered by

The Autonomous Province of Trento

Country	Italy
Region	Trentino-Alto Adige/Südtirol
Province	Autonomous Province of Trento
Capital	Trento (118,542)
N. Municipalities	175
Area	6,212 km^2
Population - total	539,898
Population - density	87 inh/km^2



In Italian: Provincia Autonoma di Trento (PAT)

Beyond 2020: a new Provincial Energy Environmental Plan

- Agenzia provinciale per le risorse idriche e l'energia (APRIE) — Policymaker
- Università degli Studi di Trento (UNITN) — University
- Fondazione Bruno Kessler (FBK) — Research Center
- Fondazione Edmund Mach (FEM) — Research Center

A DEDICATED WORKING GROUP

In Italian: Piano Energetico Ambientale Provinciale (PEAP)

Interreg Alpine Space IMEAS

Case study for the IMEAS project

The **IMEAS** project (Integrated and Multi-level Energy Model for the Alpine Space) supports public administrations, energy agencies and others involved in **planning sustainable energy policies**, promoting an integrated approach and common tools that, through the construction and strengthening of skills, and the sharing of good practices, can indicate the measures to be implemented in the Alpine Space for an efficient and low-carbon energy model.

Among the project activities, the **Autonomous Province of Trento** (PAT) is the pilot area for Italy to test new methodologies for regional energy planning.

STARDUST Enlightening european cities

Case study for the STARDUST project

STARDUST is an EU Horizon 2020 Smart Cities project, which brings together advanced European cities, thus forming into a constellation of “innovation islands” – exemplary models of **smart, highly efficient, intelligent and citizen-oriented cities**.

Among the project Lighthouses, the city of Trento will promote actions for the **energy refurbishment** of three towers (new envelope, PV, GSHP, advanced monitoring), to support **electric mobility** (new vehicles, new charging points, planning and impacts on the electricity network), for **ICT** (sensor network, participation portal, smart points)

Decarbonisation goals of the European Union

ENERGY AND CLIMATE EU GOALS

- 2020: - 20% CO_2 emissions compared to 1990
- 2030: - 40% CO_2 emissions compared to 1990
- 2050: from -80% to -100% CO_2 emissions compared to 1990

CLIMATE

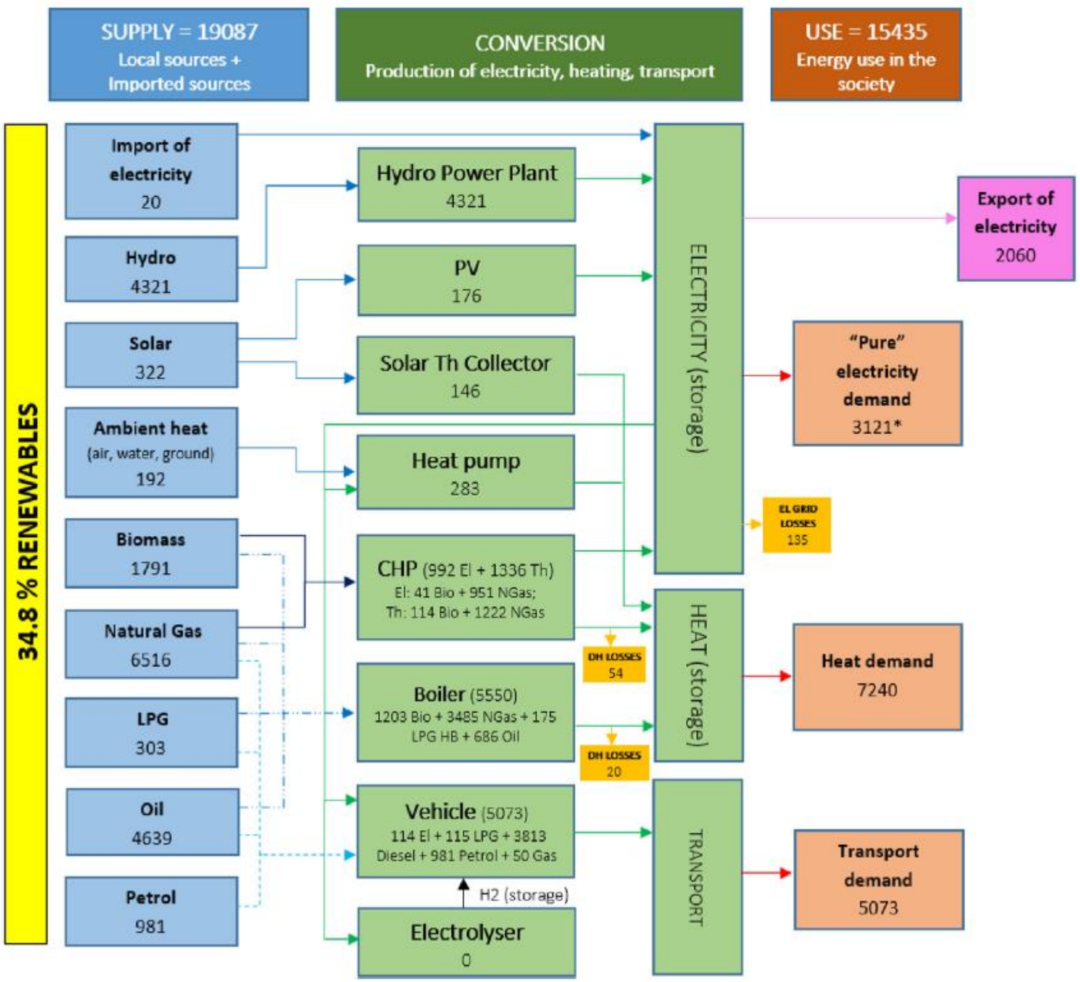
Is it possible to achieve these goals in the PAT? Using which technologies? What are the costs?

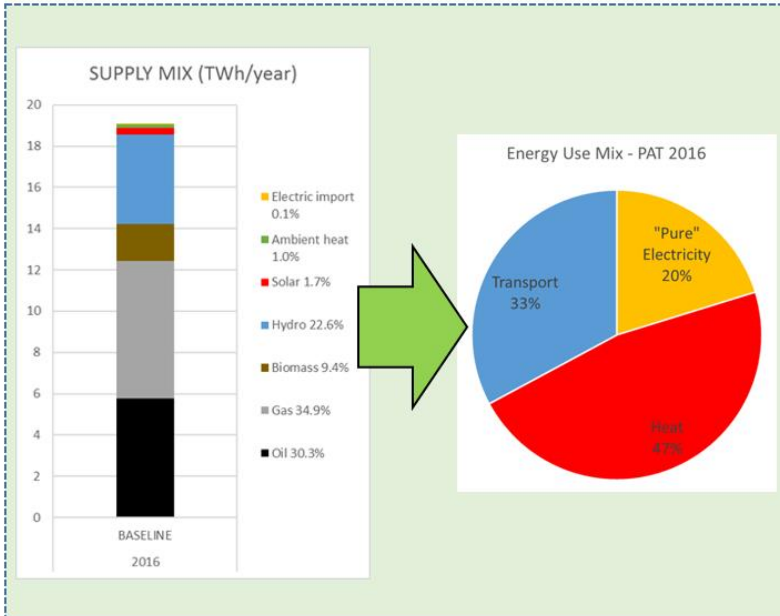
REFERENCE SCENARIOS (REF): maintain the same current technological mix

VS

LOW CARBON SCENARIOS (LC, LC+): promote greater energy efficiency and use of renewable sources

Baseline PAT 2016: Energy flow chart (GWh)





* "Pure" electricity demand doesn't include electricity consumption for heat and transport counted in the corresponding sectors.

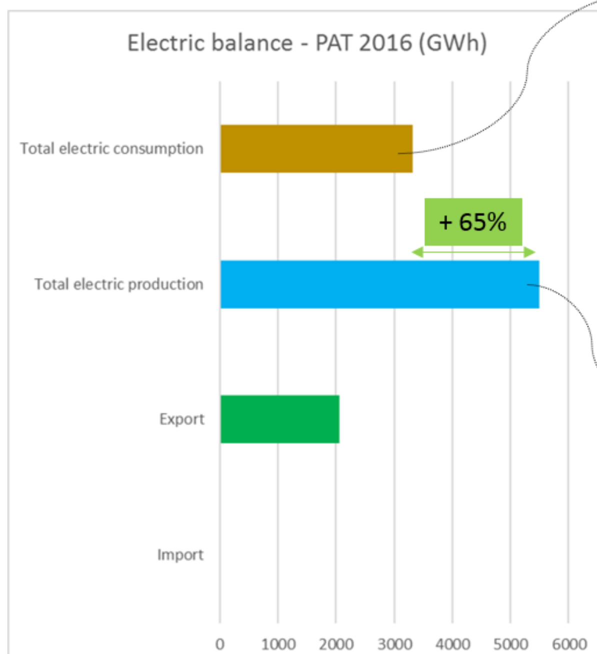
Electric balance PAT 2016

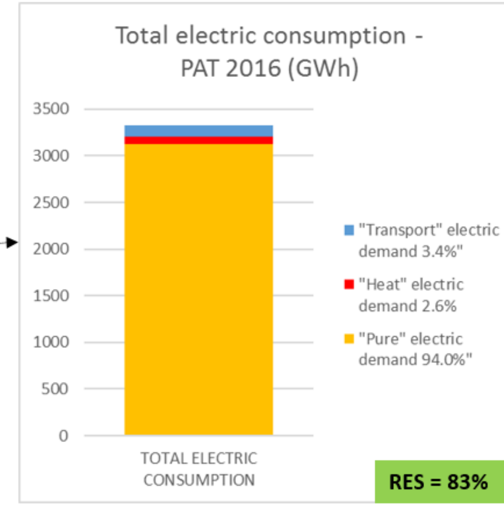
	2016 (GWh)	Data source
CONSUMPTION		
"Pure" electricity	3121	Terna
"Heat" electricity	87	GSE, ENEA
"Transport" electricity	114	Terna
TOTAL	**3322**	
PRODUCTION		
Hydroelectric (normalized)	4321	GSE
PV	176	Terna
CHP biogas	19	Terna/APRIE
CHP/DH solid biomass	22	APRIE
CHP/DH gas	105	AIRU
CHP/industrial gas	846	Terna
TOTAL	**5489**	
IMPORT/EXPORT		
Export	**2060**	**EnergyPLAN**
Import	**20**	**EnergyPLAN**

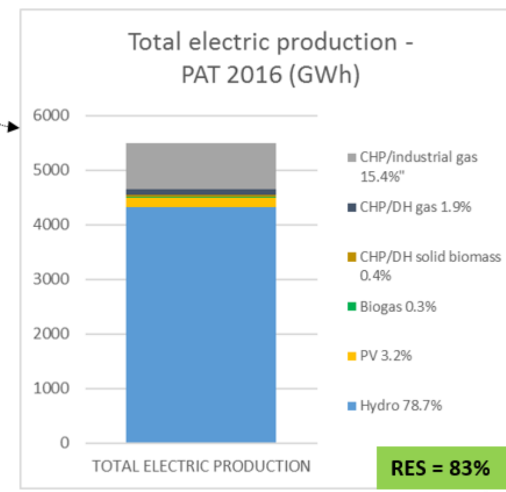
PRODUCTION = 165% CONSUMPTION

RENEWABLE PRODUCTION = 83%

RENEWABLE CONSUMPTION = 83%





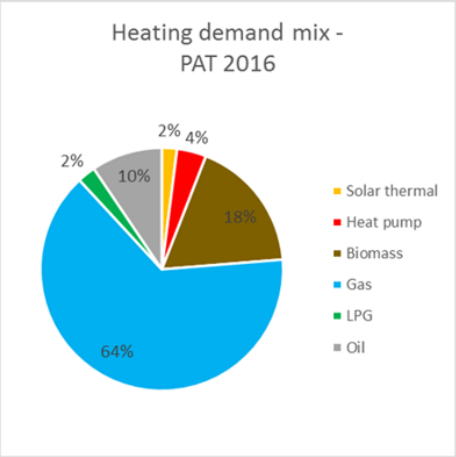


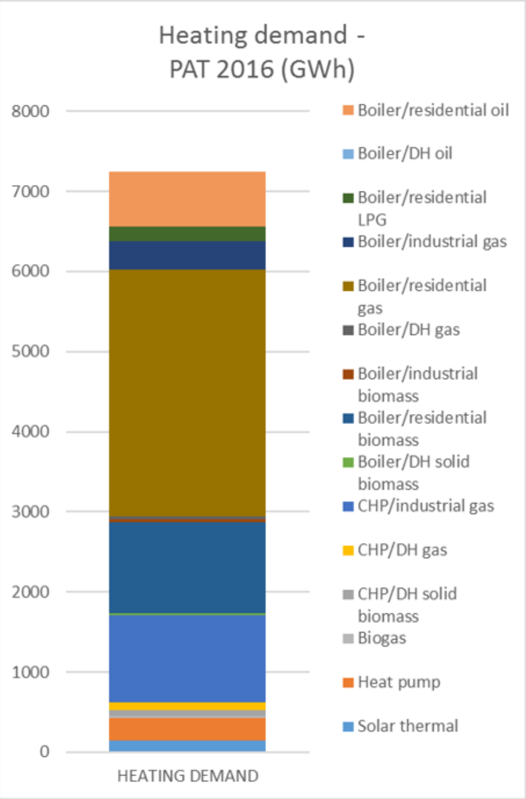
Heating demand PAT 2016

	2016 (GWh)	Data source
Solar thermal	146	GSE
Heat pump	283	GSE, ENEA
CHP biogas	24	Terna/APRIE
CHP/DH solid biomass	68	APRIE
CHP/DH gas	103	AIRU
CHP/industrial gas	1087	Terna
Boiler/DH solid biomass	23	APRIE
Boiler/residential biomass	1132	AIEL
Boiler/industrial biomass	41	GSE
Boiler/DH gas	39	AIRU
Boiler/residential gas	3079	MISE
Boiler/industrial gas	355	MISE
Boiler/residential LPG	175	MISE
Boiler/DH oil	4	AIRU
Boiler/residential oil	681	MISE
TOTAL	**7240**	

DISTRICT HEATING = 3%

RENEWABLE HEAT = 24%





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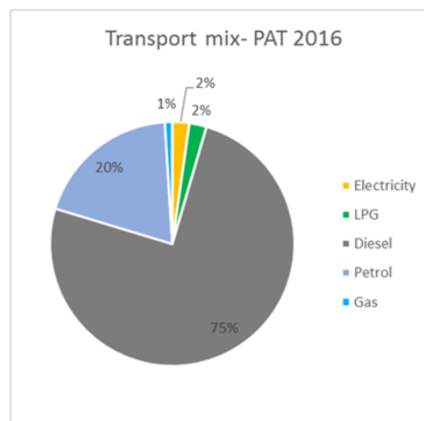
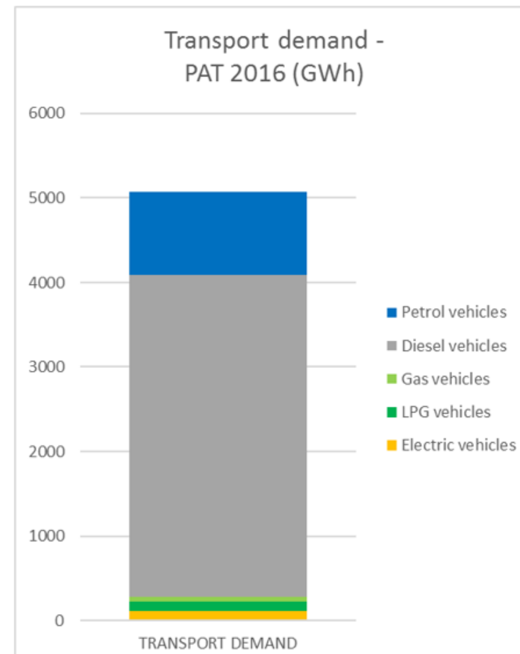
PROVINCIA AUTONOMA DI TRENTO

Transport consumption PAT 2016

	2016 (GWh)	Data source
Electric vehicles	114	Terna
LPG vehicles	115	MISE
Diesel vehicles	3813	MISE
Petrol vehicles	981	MISE
Gas vehicles	50	SERVIZIO COMMERCIO PAT
TOTAL	**5073**	

RENEWABLE TRANSPORT = 2%

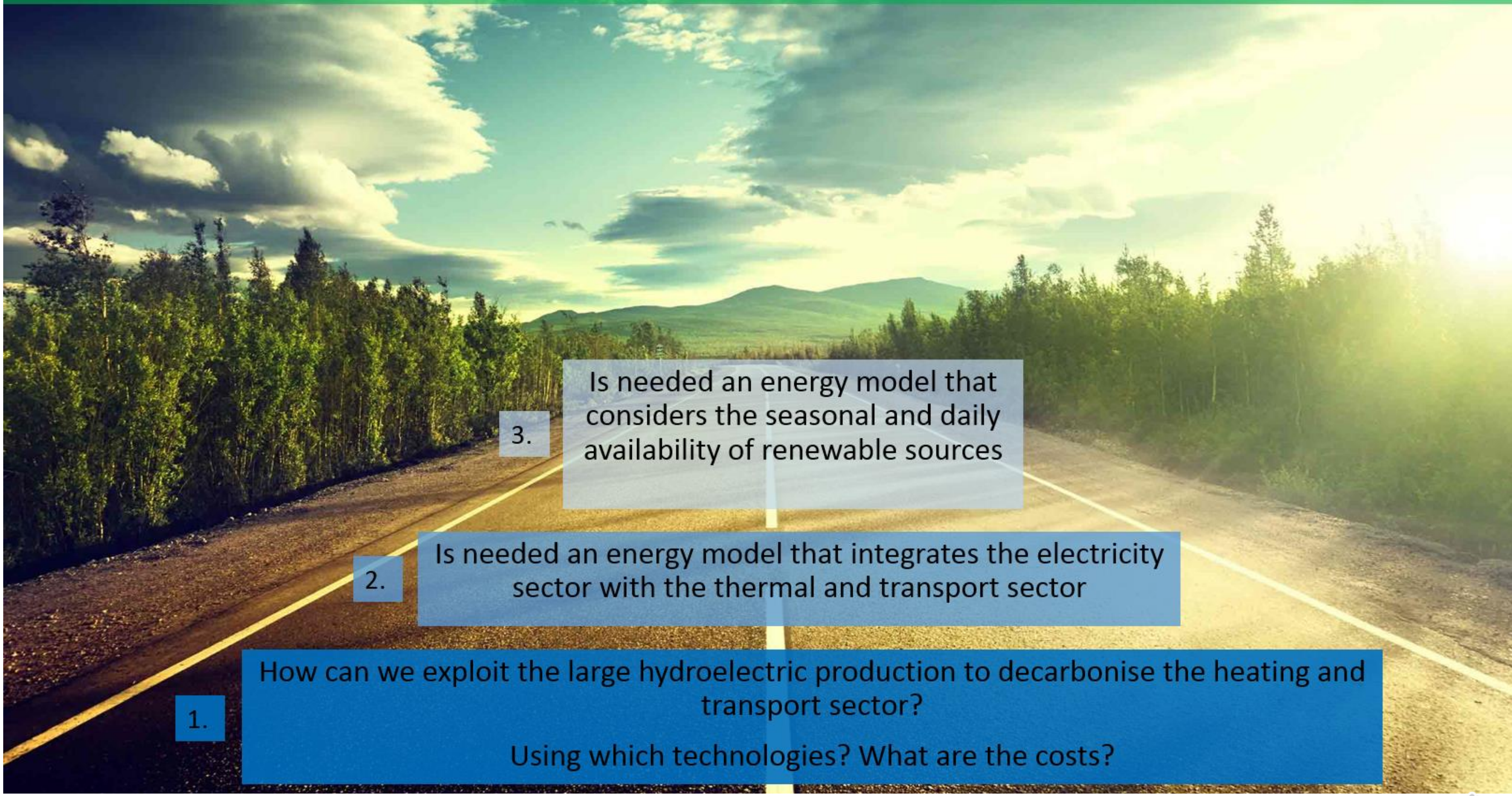




FONDAZIONE BRUNO KESSLER

PROVINCIA AUTONOMA DI TRENTO

... towards a Trentino energetically autonomous with 0 carbon emissions ...



3. Is needed an energy model that considers the seasonal and daily availability of renewable sources

2. Is needed an energy model that integrates the electricity sector with the thermal and transport sector

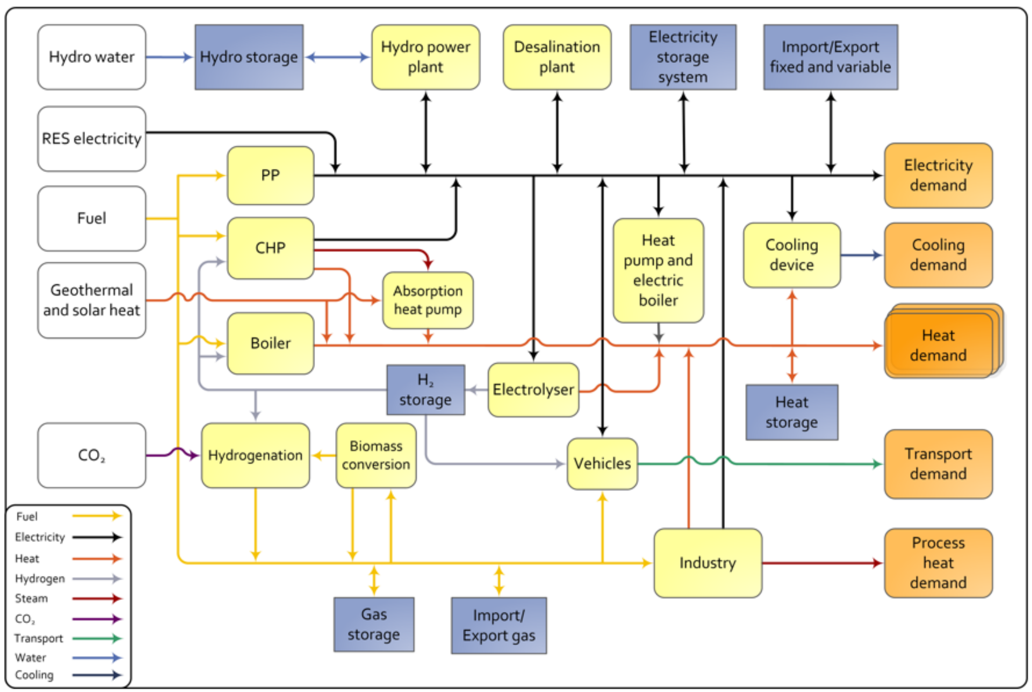
1. How can we exploit the large hydroelectric production to decarbonise the heating and transport sector?

   Using which technologies? What are the costs?

The dynamic & integrated energy model: EnergyPLAN

AALBORG UNIVERSITY DENMARK

- HOURLY ENERGY BALANCE ANALYSIS
- ECONOMIC ANALYSIS
- ENVIRONMENTAL ANALYSIS



INFORMATION REQUIRED:

1) Energy consumption (annual + hourly profiles)
2) Energy production (annual + hourly profiles)
3) Production mix for the national electricity grid
4) Efficiencies (energy production, energy distribution)
5) CAPEX (investment cost)
6) Interest rate (6% in this study)
7) OPEX (maintenance cost)
8) Lifetime
9) Energy carriers cost (annual + hourly profiles only for the national electricity market)
10) CO2 emissions of energy carriers

TIME STEPS:

2016
2030
2050

Technologies and energy carriers considered

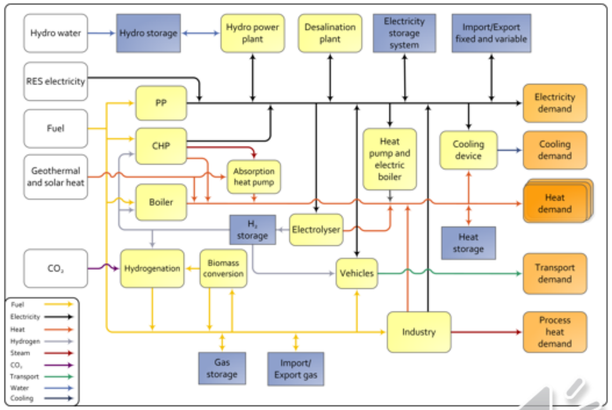
ELECTRICITY PRODUCTION	COGENERATION	THERMAL PRODUCTION	HYDROGEN PRODUCTION	TRANSPORT	STORAGE	BUILDINGS
HYDROELECTRIC	GAS COGENERATOR	GAS BOILER	ELECTROLYZER	ICE VEHICLES (diesel, petrol, LPG, gas)	THERMAL	EFFICIENT ENVELOPE
PV	BIOGAS COGENERATOR	OIL BOILER		HEV VEHICLES	BATTERY	
NATIONAL ELECTRICITY GRID		LPG BOILER		PHEV VEHICLES	HYDROGEN	
		BIOMASS BOILER/STOVE		BEV VEHICLES		
		HEAT PUMP		FCEV VEHICLES		
		SOLAR THERMAL				

TECHNOLOGICAL CHOICES:

- In the model are considered technologies and energy carriers today well known
- Particular attention to energy efficiency and renewable sources
- Of these technologies and energy carriers, the technical, economic and environmental evolution is analyzed in the 2016-2050 period

Use of renewables	(dark green)
Use (partial) of renewables	(light green)
Use of non-renewables	(dark grey)
Use (efficient) of non-renewables	(light grey)
Energy efficiency	(yellow)

EnergyPLAN



Hourly profiles: production, demand, electricity market

	Data source and methodology
"Pure" electric consumption	HOURLY PROFILE: Terna - Transparency Report (hourly data Trentino-Alto Adige/Südtirol 2016).
Hydroelectric production	MONTHLY PROFILE: Hydro Dolomiti Energia (monthly data PAT 2007-2016). HOURLY PROFILE: Terna - Transparency Report (hourly data Trentino-Alto Adige/Südtirol 2010-2016).
PV production	HOURLY PROFILE: PVGIS - Trento Typical Meteorological Year (TMY) 2007-2016.
Individual Heating	*SUBDIVISION OF CONSUMPTION: SH, HSW (23% of SH), cooking (10% of SH):* solar thermal, heat pumps, Boiler/residential biomass, Boiler/residential gas, Boiler/residential LPG, Boiler/residential oil; *industrial processes:* CHP biogas, CHP/industrial gas, Boiler/industrial biomass, Boiler/industrial gas. *HOURLY PROFILE: SH:* profile of the hourly heating degree days using the hourly temperature data from PVGIS - Trento TMY 2007-2016; *HSW:* UNI EN 15316-3-1:2007 (Table A.2); *cooking:* FBK hypothesis; *industrial processes:* constant.
District Heating	*SUBDIVISION OF CONSUMPTION: SH, HSW (23% of SH), cooking (10% of SH):* CHP/DH solid biomass, CHP/DH gas, Boiler/DH solid biomass, Boiler/DH gas, Boiler/DH oil. *HOURLY PROFILE: SH:* profile of the hourly heating degree days using the hourly temperature data from PVGIS - Trento TMY 2007-2016; *HSW:* UNI EN 15316-3-1:2007 (Table A.2); *cooking:* FBK hypothesis.
Solar thermal	HOURLY PROFILE: Hourly data of radiation and temperature from PVGIS - Trento TMY 2007-2016; use of the optical and thermal efficiency parameters of a standard flat solar panel.
Transport consumption	DAILY PROFILE: PAT 2016 traffic data (PAT Servizio Gestione Strade). HOURLY PROFILE: 2016: FBK supply profile hypothesis for ICE vehicles and electric trains; 2030 and 2050: FBK supply profile hypothesis for ICE vehicles, HEV, PHEV (fuel), FCEV, electric train + FIF* charging profiles for PHEV (el) and BEV.
Electric market	HOURLY PROFILE: 2016: Prezzo Unico Nazionale (PUN) 2016 (Gestore dei Mercati Energetici - GME); 2030 and 2050: average PUN 2013-2017 (GME).

*FIF: Fuelling Italy's Future – author: Transport & Environment (2018)

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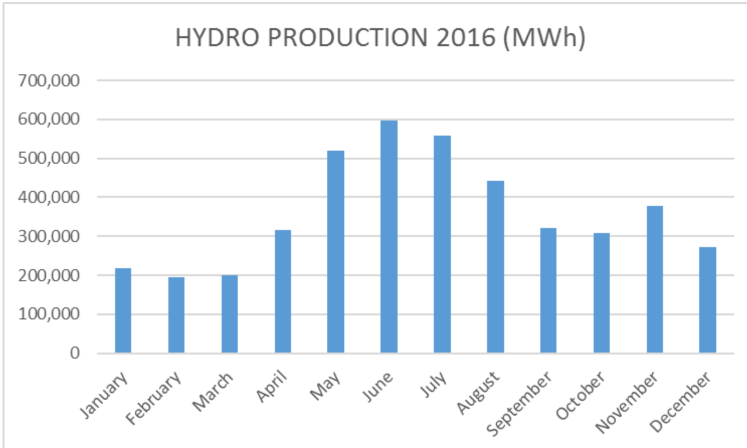

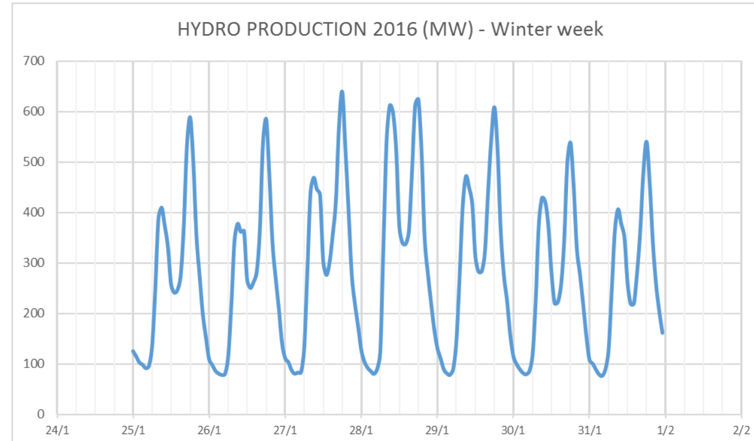

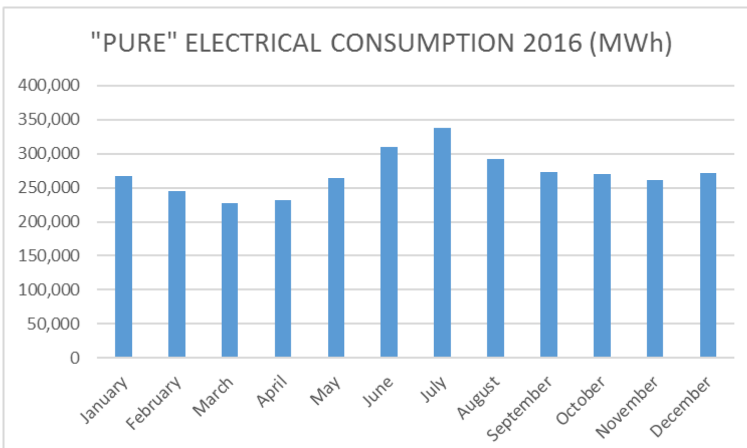

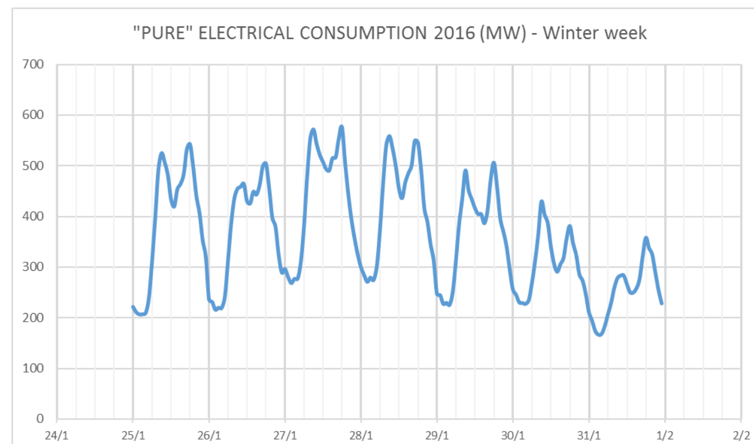

… same work for: PV production, individual heating consumption, district heating consumption, solar thermal production, transport consumption, national electricity market

Baseline PAT 2016 – EnergyPLAN analysis

SUPPLY (TWh/year) = 19.09

PRIMARY ENERGY CONSUMPTION (TWh/year) = 17.05

RES share (% SUPPLY) = 34.8

CO_2 emission (Mt/year) = 2.89

Input PEAP_PAT_REF_2016_DH_v10.txt

The EnergyPLAN model 12.0

Electricity demand (TWh/year): Flexible demand 0.00
Fixed demand 3.25 Fixed imp/exp. 0.00
Electric heating + HP 0.09 Transportation 0.12
Electric cooling 0.00 Total 3.45

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.31	0.00	0.31
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.31	0.00	0.31

Photo Voltaic	174 MW	0.18	TWh/year	0.00	Grid
Wind	0 MW	0	TWh/year	0.00	stabili-
Wind	0 MW	0	TWh/year	0.00	sation
River Hydro	0 MW	0	TWh/year	0.00	share
Hydro Power	1622 MW	4.32	TWh/year		
Geothermal/Nuclear	0 MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	63	111	0.29	0.51	
Heat Pump	0	0			3.00
Boiler		42		0.90	
Group 3:					
CHP	0	0	0.00	0.00	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Condensing	0		0.42		

Heatstorage: gr.2: 0 GWh gr.3 0 GWh
Fixed Boiler: gr.:38.4 Per cent gr.0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.00
Gr.3:	0.00	0.00

Regulation Strate(Technical regulation no. 1
KEOL regulation 00000000
Minimum Stabilisation share 0.00
Stabilisation share of CHP 0.00
Minimum CHP gr 3 load 300 MW
Minimum PP 0 MW
Heat Pump maximum share 0.50
Maximum import/export 9999999 MW
DisPEAP PAT el grid price 2016.txt
Addition factor 0.00 EUR/MWh
Multiplication factor 1.00
Dependency factor 0.00 EUR/MWh pr. MW
Average Market Price 43 EUR/MWh
Gas Storage 0 GWh
Syngas capacity 0 MW
Biogas max to grid 0 MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficien elec.	The
Hydro Pump:	0	0	0.80	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	

CAES fuel ratio: 0.000

(TWh/year)	Coal	Oil	Ngas	Bioma
Transport	0.00	4.96	0.00	0.00
Household	0.00	0.82	4.04	1.56
Industry	0.00	0.00	0.00	0.00
Various	0.00	0.00	0.00	0.00

Output

District Heating

	Demand: Distr. heating MW	Production: Solar MW	Waste-CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Balance MW
January	96	0	0	0	81	0	0	14	0	0
February	69	0	0	0	56	0	0	13	0	0
March	51	0	0	0	39	0	0	12	0	0
April	31	0	0	0	21	0	0	10	0	0
May	10	0	0	0	3	0	0	6	0	0
June	9	0	0	0	3	0	0	6	0	0
July	9	0	0	0	3	0	0	6	0	0
August	9	0	0	0	3	0	0	6	0	0
September	9	0	0	0	3	0	0	6	0	0
October	17	0	0	0	9	0	0	7	0	0
November	32	0	0	0	22	0	0	10	0	0
December	85	0	0	0	71	0	0	14	0	0
Average	35	0	0	0	26	0	0	9	0	0
Maximum	153	0	0	0	111	0	0	42	0	0
Minimum	1	0	0	0	0	0	0	1	0	0
TWh/year	0.31	0.00	0.00	0.00	0.23	0.00	0.00	0.08	0.00	0.00

Electricity

	Consumption: Elec. demand MW	Flex.& Transp MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Turbine MW	RES MW	Hydro MW	Geo-thermal MW	Waste-CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp Million EUR	Exp Million EUR
January	358	12	23	0	0	0	0	12	293	0	0	276	0	100	0	189	0	189	0	7
February	352	12	17	0	0	0	0	16	278	0	0	203	0	100	6	123	0	123	0	3
March	305	13	13	0	0	0	0	22	270	0	0	154	0	100	11	126	0	126	0	3
April	322	13	9	0	0	0	0	24	438	0	0	101	0	100	0	220	0	220	0	5
May	354	14	4	0	0	0	0	26	697	0	0	44	0	100	0	394	0	394	0	10
June	430	14	4	0	0	0	0	26	830	0	0	42	0	100	0	450	0	450	0	12
July	453	16	4	0	0	0	0	28	751	0	0	42	0	100	0	347	0	347	0	11
August	392	17	4	0	0	0	0	26	593	0	0	42	0	100	0	249	0	249	0	7
September	380	15	4	0	0	0	0	23	446	0	0	42	0	100	2	114	0	114	0	4
October	363	13	6	0	0	0	0	17	413	0	0	63	0	100	10	121	0	121	0	5
November	363	12	9	0	0	0	0	11	523	0	0	104	0	100	1	255	0	255	0	11
December	364	13	20	0	0	0	0	10	365	0	0	246	0	100	0	225	0	225	0	10
Average	370	14	10	0	0	0	0	20	492	0	0	113	0	100	3	235	0	235	Average price (EUR/MWh)	
Maximum	740	25	35	0	0	0	0	102	1122	0	0	417	0	100	179	860	0	860		
Minimum	110	2	2	0	0	0	0	0	74	0	0	23	0	100	0	0	0	0	43	43
TWh/year	3.25	0.12	0.09	0.00	0.00	0.00	0.00	0.18	4.32	0.00	0.00	0.99	0.00		0.02	2.06	0.00	2.06	1	88

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu	Hydro	Waste	CAES Elc.ly.	BioCon-version	Synthetic Fuel	PV	Wind	Wind	Hydro	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt) Total	Netto
Coal	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	-0.75	-0.75	0.00	-0.26
Oil	-	-	0.00	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	4.96	0.82	-	5.78	-0.19	5.59	1.54	1.49
N.Gas	-	0.31	0.00	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.30	-	6.66	-1.84	4.81	1.34	0.97
Biomass	-	0.14	0.00	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.62	-	1.79	-2.07	-0.28	0.00	0.00
Renewable	-	-	-	-	-	-	-	4.32	-	-	-	-	0.18	-	-	-	0.15	-	-	-	4.64	0.00	4.64	0.00	0.00
H2 etc.	-	0.00	0.00	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	0.45	0.00	0.09	-	-	-	4.32	-	-	-	-	0.18	-	-	-	0.15	4.96	8.73	-	18.88	-4.85	14.02	2.88	2.20

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Baseline PAT 2016 – EnergyPLAN analysis

Energy carriers cost (M€/year) = 1669

Oil cost (M€/year) = 727
Gas cost (M€/year) = 451
Electrical import cost (M€/year) = 1
Total cost imp. energy (M€/year) = 1179

Operating cost (M€/year) = 454

Investment cost (M€/year) = 2143

TOTAL ANNUAL COST (M€/year) = 4266

Output specifications PEAP_PAT_REF_2016_DH_v10.txt The EnergyPLAN model 12.0

District Heating Production

	Gr.1				Gr.2										Gr.3										RES specification				
	District heating MW	Solar MW	CSHP MW	DHP MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Storage MW	Balance MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Storage MW	Balance MW	RES1 Photo MW	RES2 Windc MW	RES3 Wind MW	RES 4-7 MW	Total MW
January	0	0	0	0	96	0	0	81	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	12
February	0	0	0	0	69	0	0	56	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	16
March	0	0	0	0	51	0	0	39	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	22
April	0	0	0	0	31	0	0	21	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	24
May	0	0	0	0	10	0	0	3	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	26
June	0	0	0	0	9	0	0	3	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	26
July	0	0	0	0	9	0	0	3	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	28
August	0	0	0	0	9	0	0	3	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	26
September	0	0	0	0	9	0	0	3	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	23
October	0	0	0	0	17	0	0	9	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	17
November	0	0	0	0	32	0	0	22	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	11
December	0	0	0	0	85	0	0	71	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	10
Average	0	0	0	0	35	0	0	26	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	20
Maximum	0	0	0	0	153	0	0	111	0	0	42	0	0	0	0	0	0	0	0	0	0	0	0	0	102	0	0	0	102
Minimum	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.23	0.00	0.00	0.08	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.18	0.00	0.00	0.00	0.18

Own use of heat from industrial CHP 0.00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =		791
Uranium =	0	
Coal =	0	
FuelOil =	1	
Gasoil/Diesel=	90	
Petrol/JP =	636	
Gas handling =	0	
Biomass =	65	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		451
Marginal operation costs =		0
Total Electricity exchange =		-87
Import =	1	
Export =	-88	
Bottleneck =	0	
Fixed imp/ex=	0	
Total CO2 emission costs =		0
Total variable costs =		1155
Fixed operation costs =		453
Annual Investment costs =		2029
TOTAL ANNUAL COSTS =		3637

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	10	108	0	1715	0	0	1833	0	0	0	0	0	0	1833	1833	0
February	9	75	0	1272	0	0	1356	0	0	0	0	0	0	1356	1356	0
March	8	52	0	971	0	0	1030	0	0	0	0	0	0	1030	1030	0
April	7	28	0	648	0	0	683	0	0	0	0	0	0	683	683	0
May	4	4	0	284	0	0	292	0	0	0	0	0	0	292	292	0
June	4	4	0	268	0	0	276	0	0	0	0	0	0	276	276	0
July	4	4	0	258	0	0	266	0	0	0	0	0	0	266	266	0
August	4	4	0	275	0	0	283	0	0	0	0	0	0	283	283	0
September	4	4	0	279	0	0	286	0	0	0	0	0	0	286	286	0
October	5	12	0	419	0	0	436	0	0	0	0	0	0	436	436	0
November	6	30	0	677	0	0	713	0	0	0	0	0	0	713	713	0
December	9	95	0	1540	0	0	1643	0	0	0	0	0	0	1643	1643	0
Average	6	35	0	717	0	0	758	0	0	0	0	0	0	758	758	0
Maximum	28	148	0	2646	0	0	2821	0	0	0	0	0	0	2821	2821	0
Minimum	0	0	0	102	0	0	106	0	0	0	0	0	0	106	106	0
Total for the whole year TWh/year	0.05	0.31	0.00	6.30	0.00	0.00	6.66	0.00	0.00	0.00	0.00	0.00	0.00	6.66	6.66	0.00

RES Share: 34.1 Percent of Primary Energy 139.7 Percent of Electricity 4.5 TWh electricity from RES 1[illegible]-agosto-[illegible]019 [15:53]

Elaboration of dynamic-integrated-optimized scenarios 2030 and 2050 … goals

EU ENERGY & CLIMATE GOALS

- 2030: - 40% CO2 emissions compared to 1990
- 2050: - 80% CO2 emissions compared to 1990

… potential «TECH RAPID» trajectory

- 2030: - 50% CO2 emissions compared to 1990
- 2050: - 90% CO2 emissions compared to 1990

Scenarios Low Carbon (LC)

Scenarios Low Carbon Plus (LC+)

Elaboration of dynamic-integrated-optimized scenarios 2030 and 2050 … evaluation elements

STARTING POINT:
Current technology mix (Baseline 2016)

→ Analysis of energy flows in the Autonomous Province of Trento, Università degli Studi di Trento, 2019

+

WHERE IS GOING PAT AND ITALY:
Local energy demand trends and technological perspectives

→ **CONSIDERED TRENDS:**

- local energy demand in the electric, thermal and transport sectors
- potential of energy efficiency
- potential of renewable technologies
- potential of sector coupling: thermal electrification (heat pumps), transport electrification (EV)
- use of thermal, electric and hydrogen storage

+

OPTIMIZED SOLUTIONS
EnergyPLAN+MOEA

→ EnergyPLAN+MOEA, Fondazione Bruno Kessler, 2020

+

TECHNOLOGICAL PERSPECTIVES AND OTHER SOCIO-POLITICAL FACTORS
Considered in EnergyPLAN

→ Modification of the optimized solutions with consideration of main technological perspectives and other socio-political factors (consumer choices, regulatory constraints, incentive opportunities)

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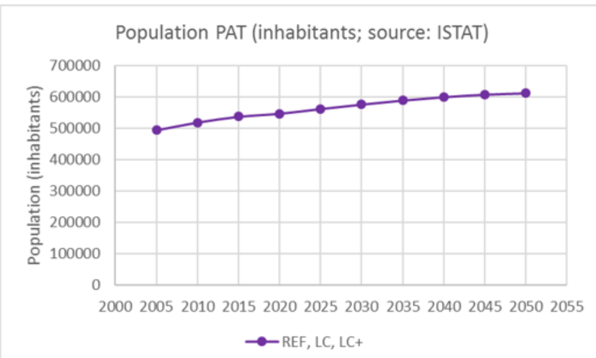
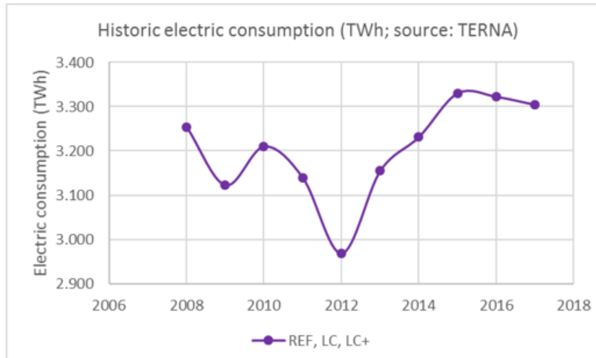
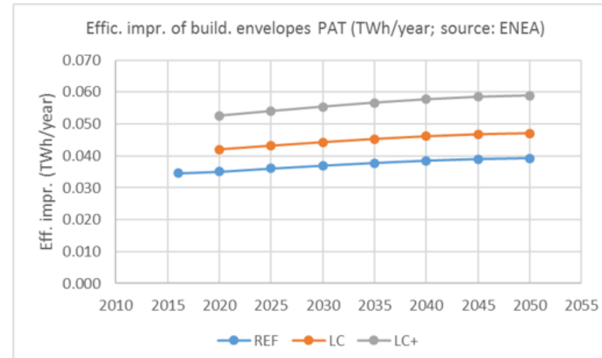
PROVINCIA AUTONOMA DI TRENTO

Energy demand trend

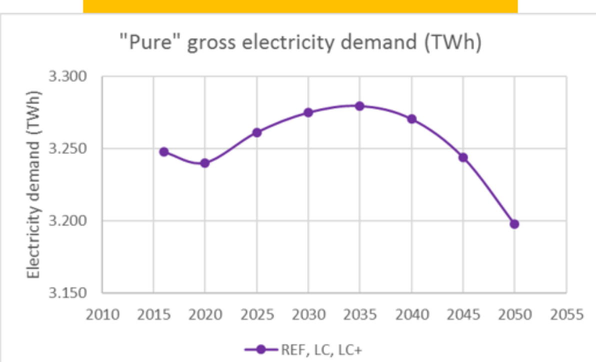
Sector	Trend evaluation elements
"Pure" electric	Population trend (ISTAT), historical electricity consumption trend 2008-2017 (Terna)
Thermal	Population trend (ISTAT), building envelope efficiency trend 2014-2016 (ENEA)
Transport	Population trend (ISTAT)



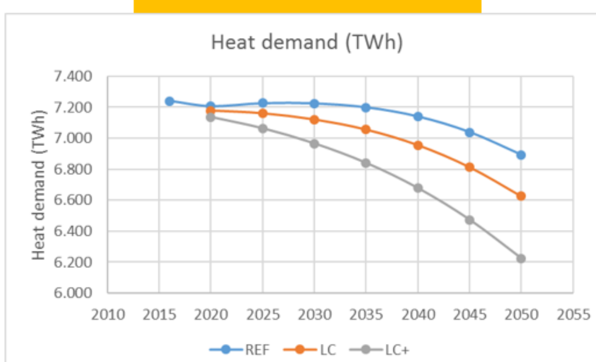




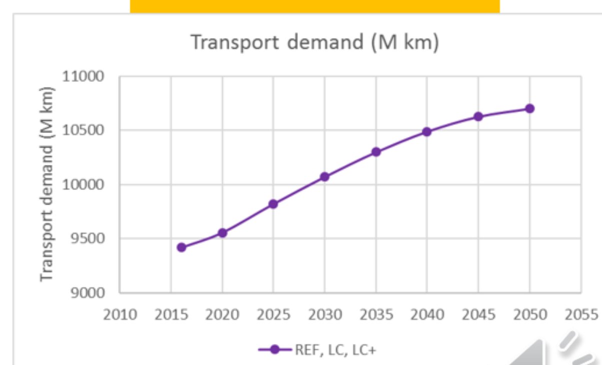
TREND «PURE» ELECTRIC SECTOR



TREND THERMAL SECTOR



TREND TRANSPORT SECTOR



National and local technological perspectives

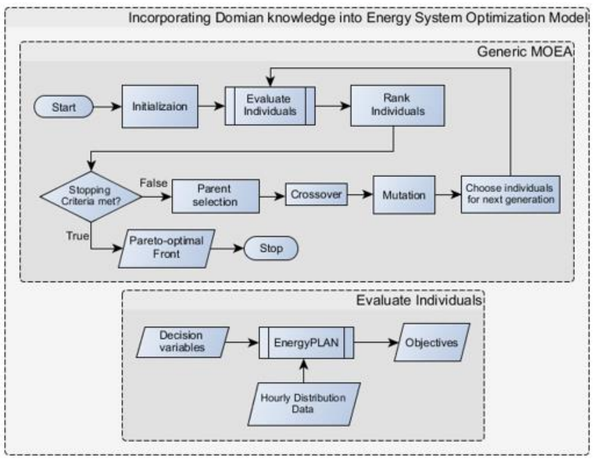
- **REF:** maintain the same technological mix as the Baseline 2016
- **LC, LC+:**
  - ✓ **"Italian National Energy and Climate Plan (NECP)"** (**MISE** 2018): for the hydroelectric, PV, solar thermal, heat pump modeling;
  - ✓ **"Report on tax deductions for the refurbishment of existing buildings"** (**ENEA** 2018): for the implementation of energy efficient building envelopes;
  - ✓ **"Energy Storage Report"** (**POLIMI** 2016): for the introduction of electric batteries as "energy reserve" coupled with PV;
  - ✓ **"Fuelling Italy's Future"** (**Transport & Environment** 2018): for the transport sector modeling;
  - ✓ **FEM scenarios** (**FEM** 2019): for the increase in biogas CHP production;
  - ✓ **PEAP working group considerations** (**APRIE**, **UNITN**, **FBK**, **FEM**, 2018-2019): for the heating sector modeling:
    - "Individual Heating": (I) current political effort to prioritize the reduction of the oil and LPG boilers, (II) current political effort to extend the gas network to some areas currently not supplied, (III) users of biomass boilers are expected to remain constant at 2016 values;
    - "District Heating": the 2016 DH characteristics are expected to remain constant, both in terms of number of users and type of technologies.

Optimized solutions: EnergyPLAN+MOEA

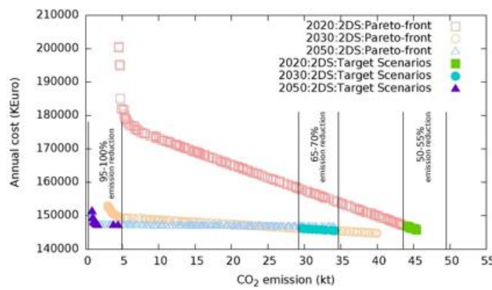
TRENTINO
INNOVATION MADE IN TRENTINO

Which scenarios make it possible to reach CO2 targets <u>at the lowest cost</u>? ...

.. the multi-objective analysis (**<u>minimizing CO2 emission and total annual cost</u>**) and the Pareto front



Case study SEAP Val di Non

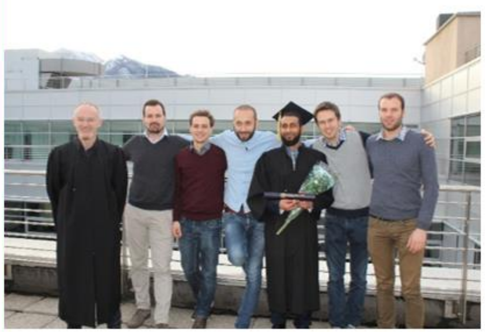


Energy PLAN
Advanced energy system analysis computer model

Newsletter no. 13 - November 2016

New study on combining EnergyPLAN with multi-objective evolutionary algorithms

In a new study by Mahbub et al, the versatility of EnergyPLAN and in particular the ability of EnergyPLAN to be run from other modelling environments is exploited in an automated methodology for generating scenarios, evaluating these according multiple objectives and subsequently generating new scenarios. EnergyPLAN is thus used in an application more commonly associated with investment optimisation models. See http://dx.doi.org/10.1016/j.apenergy.2015.11.042 for further details.



FONDAZIONE BRUNO KESSLER
+
AALBORG UNIVERSITY DENMARK

SCIENTIFIC ARTICLES PUBLISHED BY FBK:

1. Mahbub, M.S., Cozzini, M., Østergaard, P.A. and Alberti, F., 2016. Combining multi-objective evolutionary algorithms and descriptive analytical modelling in energy scenario design. Applied energy, 164, pp.140-151.
2. Mahbub, M.S., Wagner, M. and Crema, L., 2016. Incorporating domain knowledge into the optimization of energy systems. Applied Soft Computing, 47, pp.483-493.
3. Mahbub, M.S., Viesi, D. and Crema, L., 2016. Designing optimized energy scenarios for an Italian Alpine valley: the case of Giudicarie Esteriori. Energy, 116, pp.236-249.
4. Mahbub, M.S., Viesi, D., Cattani, S. and Crema, L., 2017. An innovative multi-objective optimization approach for long-term energy planning. Applied energy, 208, pp.1487-1504.

EnergyPLAN+MOEA: decision variables & boundaries

Technology	2030					2050				
	MOEA LB LC&LC+	LC	LC+	MOEA HB LC	MOEA HB LC+	MOEA LB LC&LC+	LC	LC+	MOEA HB LC	MOEA HB LC+
ELECTRICITY PRODUCTION										
Hydroelectric (TWh)	0			4.673	4.673	0			4.998	4.998
PV (TWh)	0			0.700	0.800	0			1.480	1.860
National electricity grid (TWh)	Calculated by EnergyPLAN, no grid constraints					Calculated by EnergyPLAN, no grid constraints				
COGENERATION (thermal production)										
CHP biogas (TWh)	0			0.038	0.042	0			0.044	0.052
CHP/Indiv gas (TWh)	0			6.888	6.738	0			6.408	6.021
CHP/DH biomass (TWh)		0.067	0.066				0.063	0.059		
CHP/DH gas (TWh)		0.101	0.099				0.094	0.088		
THERMAL PRODUCTION										
Solar thermal (TWh)	0			6.888	6.738	0			6.408	6.021
Heat Pump (TWh)	0			6.888	6.738	0			6.408	6.021
Boiler/Indiv oil (TWh)	0			6.888	6.738	0			6.408	6.021
Boiler/Indiv LPG (TWh)	0			6.888	6.738	0			6.408	6.021
Boiler/Indiv gas (TWh)	0			6.888	6.738	0			6.408	6.021
Boiler/Indiv biomass (TWh)	0			1.384	1.354	0			1.288	1.210
Boiler/DH biomass (TWh)		0.023	0.022				0.021	0.020		
Boiler/DH gas (TWh)		0.038	0.038				0.036	0.034		
Boiler/DH oil (TWh)		0.004	0.004				0.003	0.003		
HYDROGEN PRODUCTION										
Electrolyzer (MW)	Calculated by EnergyPLAN as minimum capacity needed					Calculated by EnergyPLAN as minimum capacity needed				
TRANSPORT SECTOR										
Transport el (Mkm)	0			10071	10071	0			10700	10700
Transport H2 (Mkm)	0			10071	10071	0			10700	10700
Transport petrol (Mkm)	0			10071	10071	0			10700	10700
STORAGE (capacity)										
Thermal storage (GWh)	Considered a capacity of 1 day of average heat demand					Considered a capacity of 1 day of average heat demand				
Battery storage (GWh)	0			2.635	3.022	0			5.522	6.905
Hydrogen storage (GWh)	Considered a capacity of 1 day of average H2 demand					Considered a capacity of 1 day of average H2 demand				
BUILDINGS										
Energy eff. build. env. (TWh)		1.147	1.309				1.364	1.705		

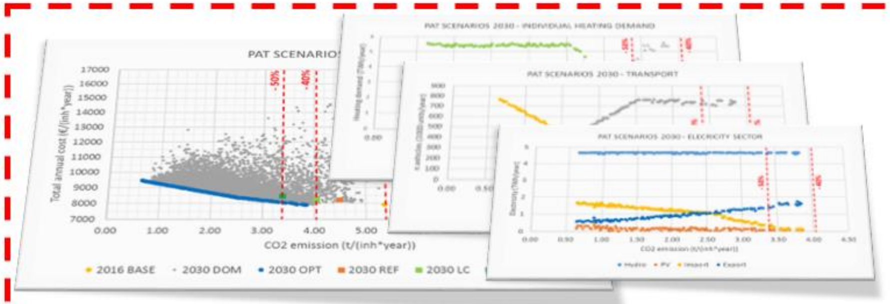
A VERY COMPLEX OPTIMIZATION PROBLEM…

- **14 variable value technologies** (values provided by MOEA, from 0 to max allowed by resource availability, social attractiveness, amplified trends, sector demand)
- **4 linked value technologies** (values calculated by EnergyPLAN: national electricity grid, electrolyzer, thermal storage, hydrogen storage)
- **6 fixed value technologies** (values defined by the PEAP working group considering Baseline 2016 + trends)

24 technologies

RESULTS

STEP1: EnergyPLAN+MOEA



EnergyPLAN+MOEA

Identify "Optimized Solutions"

TECHNOLOGICAL PERSPECTIVES AND OTHER SOCIO-POLITICAL FACTORS

Modification of the optimized solutions with consideration of main technological perspectives and other socio-political factors

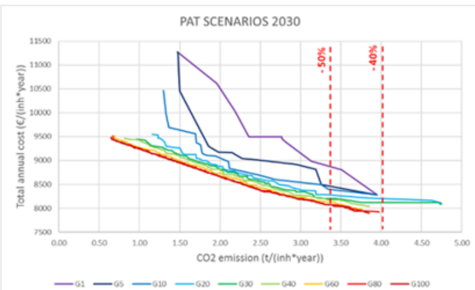
PROVINCIA AUTONOMA DI TRENTO

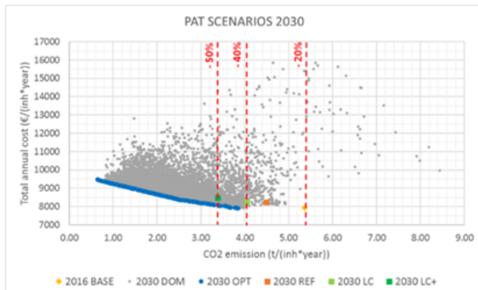
PEAP SCENARIOS LC e LC+

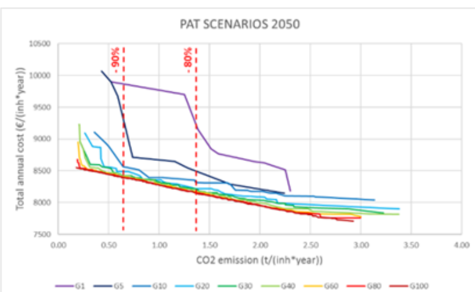
Optimized solutions: EnergyPLAN+MOEA

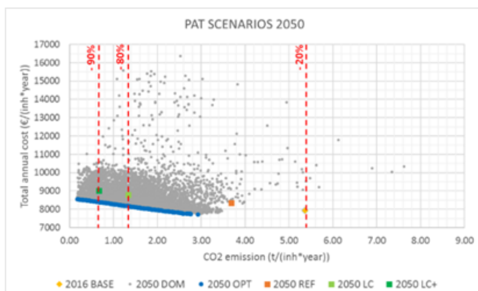
FONDAZIONE BRUNO KESSLER + AALBORG UNIVERSITY DENMARK

A VERY COMPLEX OPTIMIZATION PROBLEM (24 TECHNOLOGIES)…









In order to compare CO2 emission and total annual cost performance between different years, these values are normalized with respect to the number of inhabitants

For each time target:

100 generations to achieve convergence

15000 combinations evaluated

150 optimized solutions constitute the non-dominated Pareto front

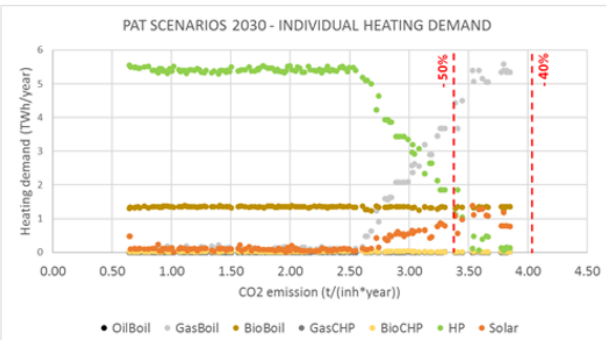
IN TOTAL ASSESSED 30000 COMBINATIONS

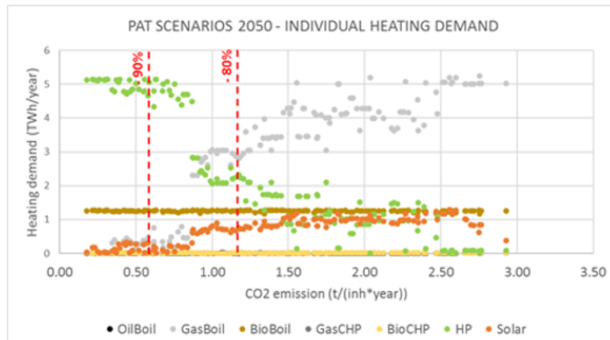
KEY MESSAGES (Optimized Indications)

- **PARETO FRONT SOLUTIONS:** each point on the Pareto front represents a scenario that allows **a CO_2 target to be reached at the lowest possible cost** through an optimal combination of technologies;
- **CO_2 EMISSION vs TOTAL ANNUAL COST:** in 2030 Pareto front scenarios show a reduction in CO_2 emissions between -43 and -90%, compared to the 1990 value, and total annual costs within +0/+20%, compared to the 2016 value; in 2050 reductions in CO_2 emissions between -57 and -97% are combined with total annual costs variations within -3/+8%; technological progress will allow to reach increasingly ambitious CO_2 targets at costs comparable to the current ones

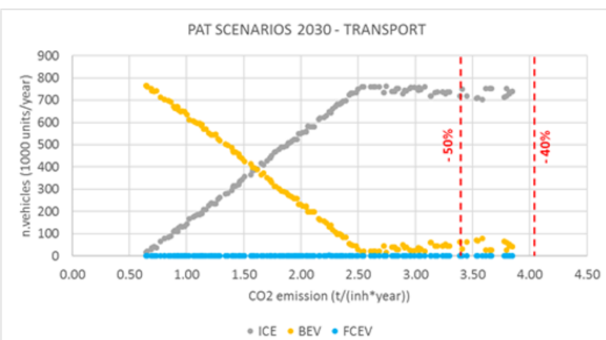
2030 | 2050

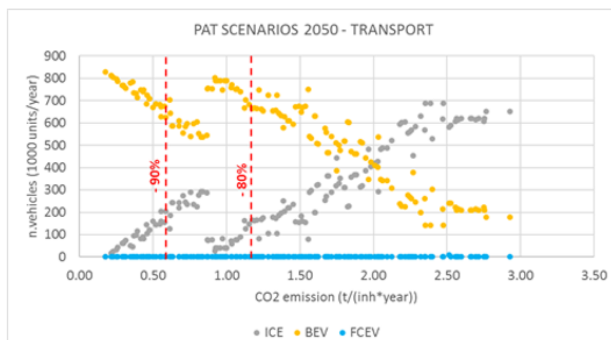
HEATING DEMAND





TRANSPORT





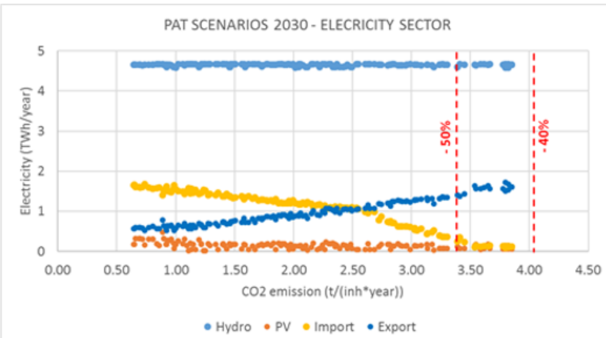
KEY MESSAGES (Optimized Indications)

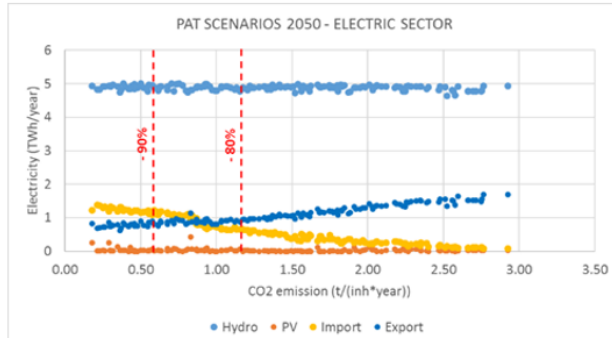
- **INDIVIDUAL THERMAL SECTOR:** maximum attractiveness for biomass boilers at all CO2 values, good for gas boilers and solar thermal only at high CO2 values, incremental for heat pumps moving towards low CO2 values;
- **INDIVIDUAL COGENERATION:** at all CO2 values, good attractiveness for biogas CHP (although in the reduced values of its potential), low for gas CHP;
- **TRANSPORT SECTOR:** good attractiveness for conventional vehicles (ICE) only at high CO2 values, good for BEV only at low CO2 values, low for FCEV at all CO2 values;
- **ELECTRIFICATION AND SECTOR COUPLING:** at low CO2 values the electricity become the most attractive energy carrier, exploiting green production not only for "traditional pure electricity demands" but also in the thermal (heat pumps) and transport (BEV) sectors;
- **DECARBONISATION OF INDIVIDUAL THERMAL SECTOR vs TRANSPORT SECTOR:** to achieve the 2030 decarbonisation goals (between -40 and -50% of CO2 emission), interventions in the thermal sector are more attractive than those in the transport sector;

2030

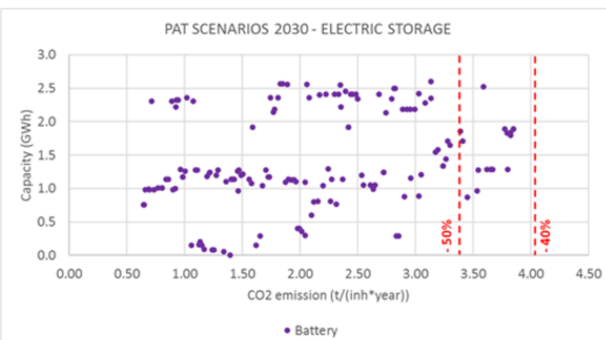
2050

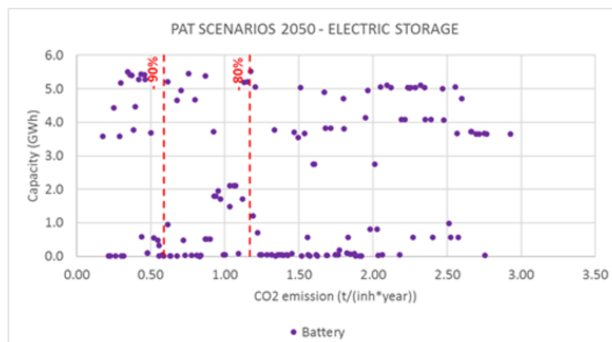
ELECTRICITY SECTOR





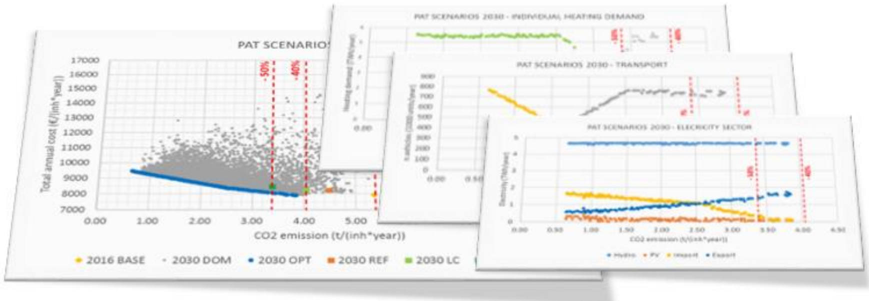
ELECTRIC STORAGE





KEY MESSAGES (Optimized Indications)

- **ELECTRICITY PRODUCTION:** at all CO2 values, maximum attractiveness for hydroelectric production, low for PV;
- **ELECTRIC STORAGE:** the use of electrical storage (batteries) is attractive in many scenarios both in 2030 and 2050;
- **ELECTRICITY IMPORT/EXPORT:** in 2050, the greater availability of hydroelectric power and the greater efficiency of heat pumps and BEV minimize the demand for electric import to achieve high CO2 reductions;
- **LOCAL RES:** at all CO2 values maximum attractiveness for the wide use of local hydro and local biomass, to which is added at low CO2 emission values the wide use of local ambient heat; the attractiveness of local solar is limited to thermal use and up to values of 20% of the total individual thermal demand.



EnergyPLAN+MOEA

Identify "Optimized Solutions"

TECHNOLOGICAL PERSPECTIVES AND OTHER SOCIO-POLITICAL FACTORS

Modification of the optimized solutions with consideration of main technological perspectives and other socio-political factors

STEP2: PEAP SCENARIOS

PROVINCIA
AUTONOMA DI TRENTO

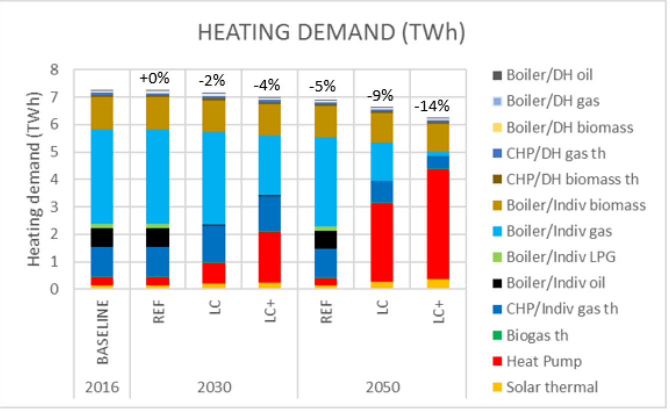
PEAP SCENARIOS LC e LC+

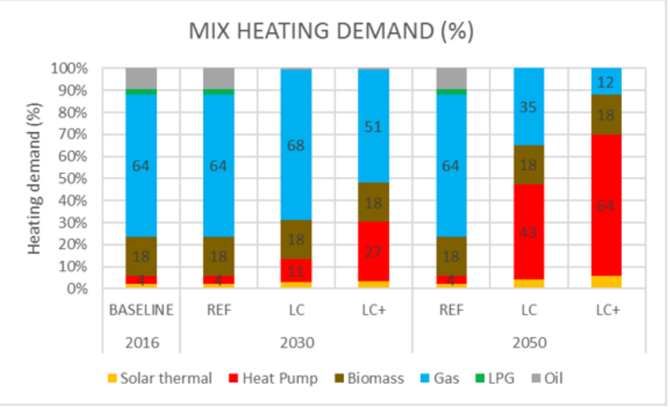
PEAP scenarios: REF vs LC vs LC+

Heating demand

EnergyPLAN analysis — *TECHNOLOGIES*

TWh/year	2016	2030			2050		
	BASELINE	REF	LC	LC+	REF	LC	LC+
ENERGY EFF. BUILD. ENV.	**0.94**	**1.04**	**1.15**	**1.31**	**1.14**	**1.36**	**1.70**
HEATING DEMAND	**7.24**	**7.22**	**7.12**	**6.97**	**6.89**	**6.62**	**6.22**
Solar thermal	0.15	0.15	0.20	0.24	0.14	0.27	0.36
Heat Pump	0.28	0.28	0.76	1.86	0.27	2.86	4.00
CHP biogas th	0.02	0.02	0.03	0.04	0.02	0.04	0.04
CHP/Indiv gas th	1.09	1.09	1.33	1.25	1.04	0.80	0.47
Boiler/Indiv oil	0.68	0.68	0.03	0.03	0.65	0.00	0.00
Boiler/Indiv LPG	0.18	0.17	0.01	0.01	0.17	0.00	0.00
Boiler/Indiv gas	3.43	3.43	3.38	2.18	3.27	1.37	0.15
Boiler/Indiv biomass	1.17	1.17	1.15	1.13	1.12	1.07	1.01
CHP/DH biomass th	0.07	0.07	0.07	0.07	0.07	0.06	0.06
CHP/DH gas th	0.10	0.10	0.10	0.10	0.10	0.09	0.09
Boiler/DH biomass	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Boiler/DH gas	0.04	0.04	0.04	0.04	0.04	0.04	0.03
Boiler/DH oil	0.004	0.004	0.004	0.004	0.003	0.003	0.003





KEY MESSAGES

HEATING DEMAND:

- Decreases thanks to interventions to improve the efficiency of building envelopes
- 2030: - 2% in LC and - 4% in LC+
- 2050: - 9% in LC and - 14% in LC+

INDIVIDUAL HEATING

- Heat pump: from 4% in Baseline 2016 to 11/27% in LC/LC+ 2030 and to 43/64% in LC/LC+ 2050
- Solar thermal and CHP biogas increase slightly
- Biomass boiler stable
- Industrial gas CHP up slightly by 2030 and then decreased to 2050
- Gas boiler stable in LC 2030, down in LC 2050, LC+ 2030 and LC+ 2050
- LPG and oil boilers falling sharply by 2030, absent in 2050

DISTRICT HEATING

- Unchanged (stable 3% of total PAT heat requirement)

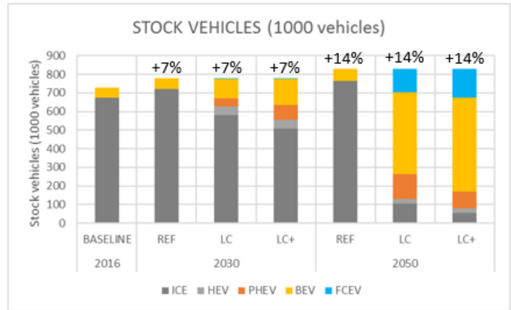
PEAP scenarios: REF vs LC vs LC+

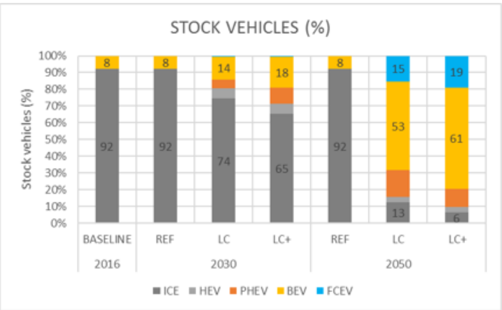
Transport

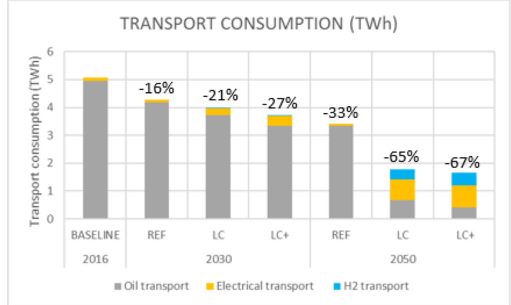
EnergyPLAN analysis *TECHNOLOGIES*

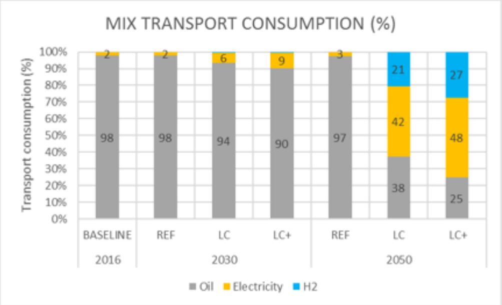
1000 vehicles/year	2016	2030			2050		
	BASELINE	REF	LC	LC+	REF	LC	LC+
STOCK VEHICLES	**730**	**781**	**781**	**781**	**829**	**829**	**829**
ICE (Internal Combustion Engine)	675	721	582	509	766	105	54
HEV (Hybrid Electric Vehicle)			46	48		25	25
PHEV (Plug-in Hybrid Electric Vehicle)			43	77		132	91
BEV (Battery Electric Vehicle)	56	59	106	142	63	440	503
FCEV (Fuel Cell Electric Vehicle)			4	5		127	156

TWh/year	2016	2030			2050		
	BASELINE	REF	LC	LC+	REF	LC	LC+
TRANSPORT CONSUMPTION	**5.08**	**4.27**	**3.99**	**3.72**	**3.42**	**1.79**	**1.66**
Electrical transport	0.12	0.10	0.24	0.35	0.09	0.75	0.79
H2 transport	0.00	0.00	0.02	0.02	0.00	0.37	0.45
Oil transport	4.96	4.17	3.74	3.35	3.33	0.67	0.41









KEY MESSAGES

ENERGY DEMAND:

- Despite increasing stock vehicles, significantly decreases with the transition to electric and hydrogen mobility (but also thanks to increasingly efficient internal combustion vehicles)
- 2030: - 21% in LC and - 27% in LC+
- 2050: - 65% in LC and - 67% in LC+

ELECTRIC AND HYDROGEN MOBILITY

- Electric mobility: from 2% in Baseline 2016 to 6/9% in LC/LC+ 2030 and to 42/48% in LC/LC+ 2050
- Hydrogen mobility: absent in Baseline 2016, on an experimental basis in small captive fleets at 0.4/0.6% in LC/LC+ 2030, at 21/27% in LC/LC+ 2050

PEAP scenarios: REF vs LC vs LC+

Electric system

EnergyPLAN analysis *TECHNOLOGIES*

TWh/year	2016	2030			2050		
	BASELINE	REF	LC	LC+	REF	LC	LC+
GROSS ELECTRICAL CONS.	**3.46**	**3.46**	**3.76**	**4.20**	**3.36**	**5.2**	**5.66**
"Pure" electrical cons.	3.25	3.28	3.28	3.28	3.2	3.2	3.2
"Thermal" electrical cons.	0.09	0.08	0.22	0.54	0.07	0.76	1.07
"Transport" electrical cons.	0.12	0.1	0.26	0.38	0.09	1.24	1.39
ELECTRICAL PRODUCTION	**5.46**	**5.48**	**5.97**	**5.96**	**5.45**	**6.26**	**6.19**
Hydroelectric	4.32	4.32	4.45	4.45	4.32	4.76	4.76
PV	0.18	0.18	0.35	0.40	0.19	0.74	0.93
CHP biogas el	0.02	0.02	0.02	0.03	0.02	0.03	0.03
CHP/Indiv gas el	0.85	0.86	1.05	0.99	0.83	0.64	0.37
CHP/DH biomass el	0.02	0.02	0.02	0.02	0.02	0.02	0.02
CHP/DH gas el	0.08	0.08	0.08	0.08	0.08	0.08	0.07
STORAGE OPERATION	**0.00**	**0.00**	**0.00**	**0.01**	**0.00**	**0.06**	**0.08**
ELECTRICAL IMPORT/EXPORT	**2.04**	**2.05**	**2.24**	**1.79**	**2.11**	**1.07**	**0.54**
Export el	2.06	2.07	2.25	1.82	2.13	1.35	1.19
Import el	0.02	0.02	0.01	0.03	0.02	0.28	0.65

KEY MESSAGES

GROSS ELECTRICITY CONSUMPTION

- Increase due to the increase in heat pumps and electric/hydrogen mobility
- 2030: + 9% in LC and + 21% in LC+
- 2050: + 50% in LC and + 64% in LC+

ELECTRICAL PRODUCTION

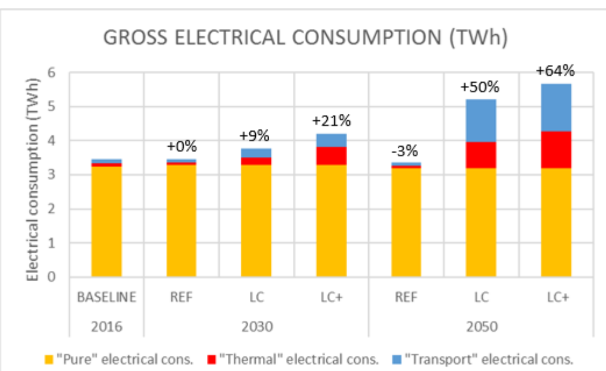
- Significant increase in PV
- Slight increase in hydroelectric and biogas CHP
- Stable CHP district heating
- Industrial gas CHP up slightly by 2030 and then decreased to 2050

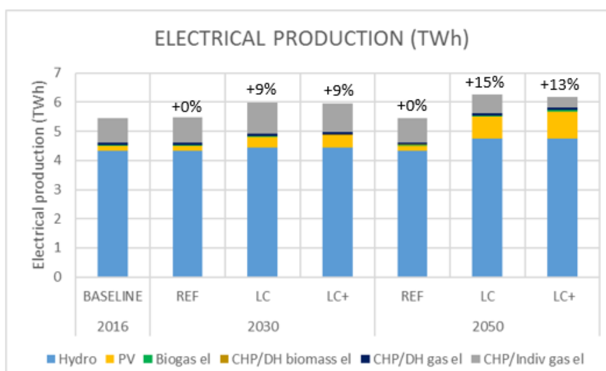
STORAGE OPERATION

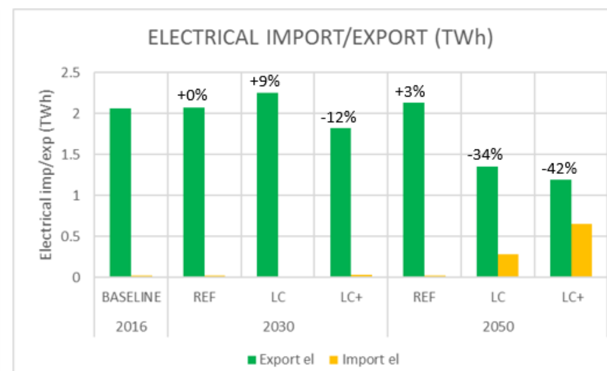
- Storage operation grows as an "energy reserve" coupled to PV thanks to an expected decrease in costs

ELECTRICAL IMPORT/EXPORT

- 2030 (LC, LC+): small variations
- 2050 (LC, LC+): export decrease, import increase







LC (TWh):
2030: RES PROD (4.84) > EL CONS (3.76)
2050: RES PROD (4.9) > EL CONS (4.2)

LC+ (TWh):
2030: RES PROD (5.55) > EL CONS (5.2)
2050: RES PROD (5.74) > EL CONS (5.66)

POSITIVE ENERGY GRID

PEAP scenarios: REF vs LC vs LC+

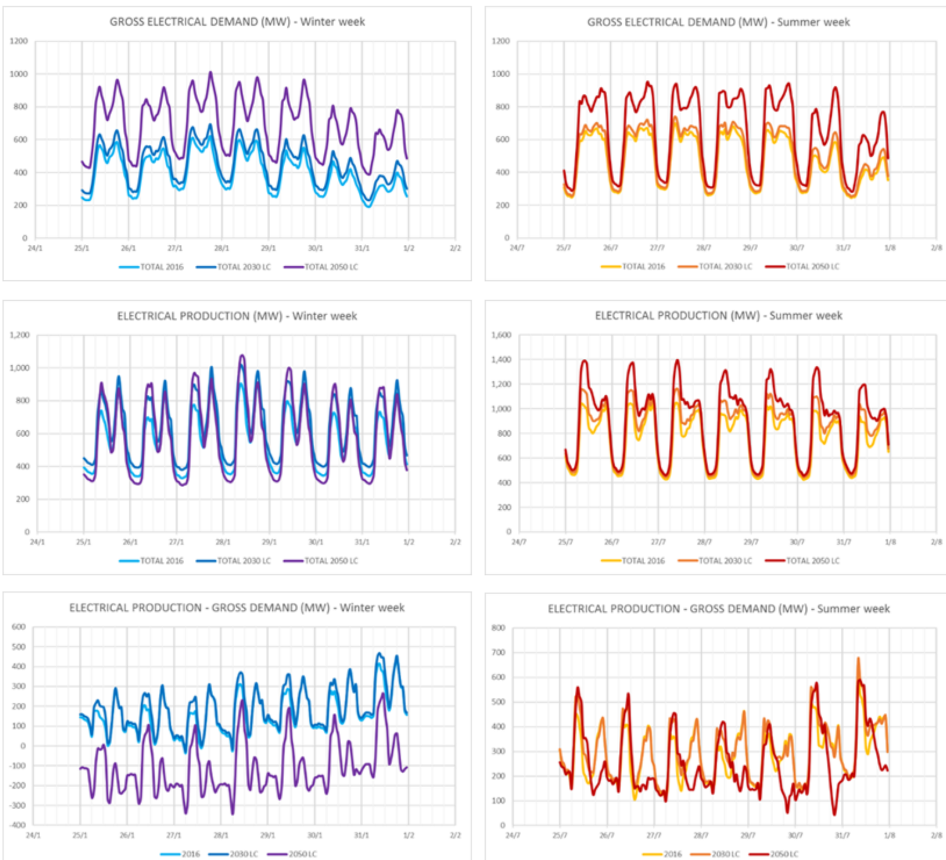
Focus on electric grid: hourly profiles

EnergyPLAN analysis *TECHNOLOGIES*

ELECTRICAL DEMAND

ELECTRICAL PRODUCTION

ELECTRICAL BALANCE



KEY MESSAGES

ELECTRICAL DEMAND

- Important increase related to the electrification of thermal demand and transport.
- Increase more marked in the winter period (higher thermal demand) and in the peaks of thermal demand (HSW, bands 7-8 and 20-21) and charging of electric vehicles (bands 7-11 and 17-21).
- Maximum increase expected in the ranges already critical for "pure" electricity demand (7-11 and 17-20).

ELECTRICAL PRODUCTION

- Small increase: on the one hand PV and hydroelectric productions increase, on the other CHP production decreases.
- Increase more marked in the summer period, corresponding to the greater PV and hydroelectric production, especially in the middle of the day for PV and in bands 7-11 and 17-20 for hydroelectric.

ELECTRICAL BALANCE

- Conditions of marked need for import in the winter, especially in the morning around 6-7 and in the evening around 21, and export in the summer, especially around 11.

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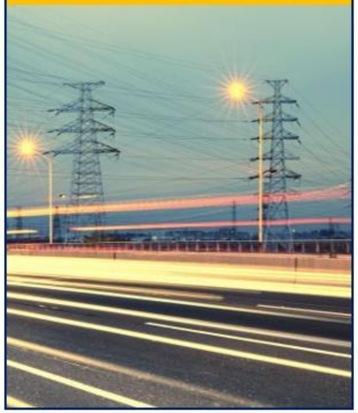
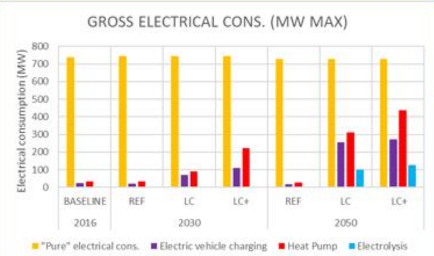
PEAP scenarios: REF vs LC vs LC+

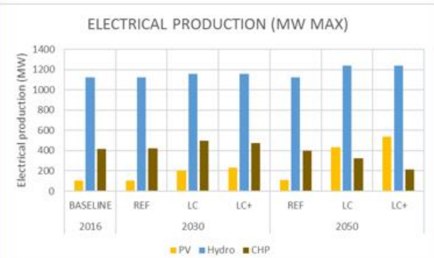
EnergyPLAN analysis *TECHNOLOGIES*

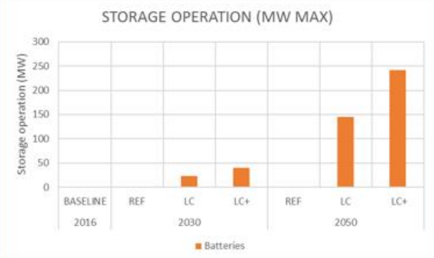
MW MAX	2016	2030			2050		
	BASELINE	REF	LC	LC+	REF	LC	LC+
GROSS ELECTRICAL CONS.							
"Pure" electrical cons.	740	746	746	746	728	728	728
Electric vehicle charging	25	21	71	110	18	256	271
Heat Pump	35	34	90	222	29	313	437
Electrolysis	0	0	5	6	0	102	126
ELECTRICAL PRODUCTION							
PV	102	106	202	232	109	432	540
Hydroelectric	1122	1122	1155	1155	1122	1237	1237
CHP	417	421	500	475	400	324	215
STORAGE OPERATION							
Batteries	0	0	23	40	0	145	242
ELECTRICAL IMPORT/EXPORT							
Export el	860	863	931	884	868	954	995
Import el	179	179	184	211	167	332	506

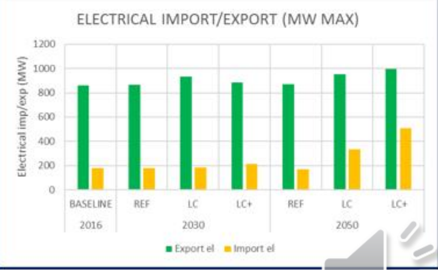
Focus on electric grid: max hourly power











KEY MESSAGES *(comparison MW BASELINE 2016 – LC 2030 – LC 2050)*

GROSS ELECTRICAL CONSUMPTION

- Strong increase in power required for charging electric vehicles (25-71-256), heat pumps (35-90-313) and electrolysis (0-5-102)

ELECTRICAL PRODUCTION

- Strong increase in PV power (102-202-432)

STORAGE OPERATION

- Strong increase in storage operation power (0-23-145)

ELECTRICAL IMPORT/EXPORT

- Increase in power required for export (860-931-954) and for import (179-184-332)

The exchange power with the national grid will have to increase by only 11% between 2016 and 2050
Detailed analysis of grid stability (including voltage and frequency) are recommended, particularly in highly urbanized areas

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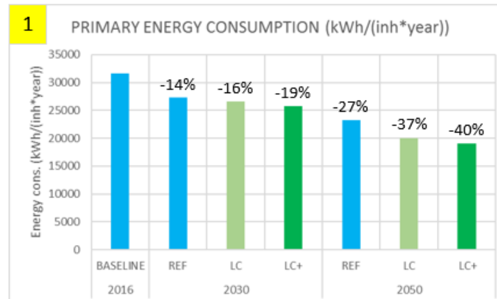
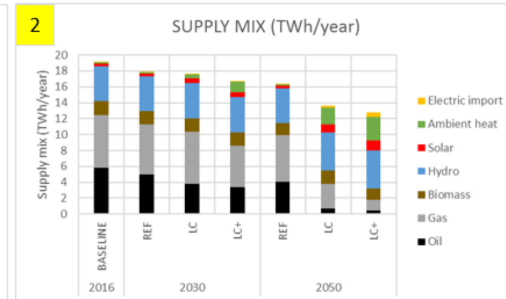
PEAP scenarios: REF vs LC vs LC+

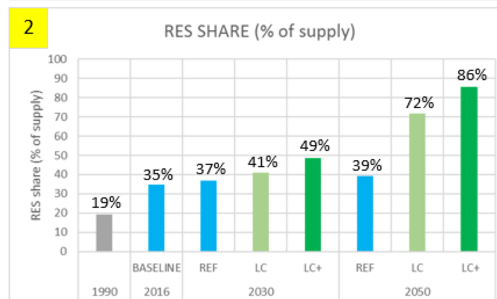
EnergyPLAN analysis

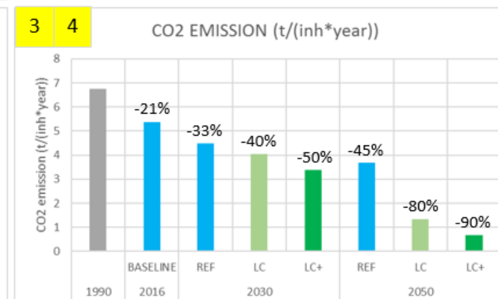
ENERGY CONSUMPTION, RES AND CO2 EMISSIONS

	1990	2016	2030			2050		
		BASELINE	REF	LC	LC+	REF	LC	LC+
ENERGY BALANCE								
SUPPLY (TWh/year)	14.37	19.09	17.84	17.60	16.67	16.35	13.62	12.82
SUPPLY (kWh/inh*year)	32230	35473	30936	30514	28908	26680	22227	20927
Variation 1990 (%)		10.06	-4.01	-5.33	-10.31	-17.22	-31.04	-35.07
Variation 2016 (%)			-12.79	-13.98	-18.51	-24.79	-37.34	-41.01
PRIMARY ENERGY CONSUMPTION (TWh/year)		17.05	15.78	15.35	14.85	14.22	12.30	11.69
PRIMARY ENERGY CONSUMPTION (kWh/inh*year)		31675	27361	26619	25754	23207	20067	19085
Variation 2016 (%)			-13.62	-15.96	-18.69	-26.74	-36.65	-39.75
RENEWABLE ENERGY SOURCES (RES)								
RES Share (% of SUPPLY)	19.1	34.8	36.8	41.2	48.6	39.4	71.7	85.6
CO2 EMISSIONS								
CO2 emission (Mt/year)	3.01	2.89	2.59	2.33	1.95	2.26	0.82	0.41
CO2 emission (t/(inh*year))	6.75	5.36	4.50	4.04	3.37	3.69	1.34	0.67
Variation 1990 (%)		-20.50	-33.34	-40.07	-50.00	-45.31	-80.11	-90.13
Variation 2016 (%)			-16.15	-24.61	-37.11	-31.20	-74.98	-87.58









KEY MESSAGES

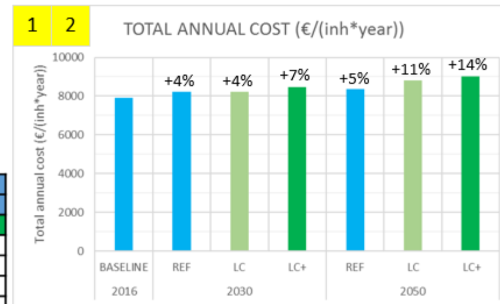
1. Progressive reduction of primary energy consumption due to the use of more efficient technologies. Compared to Baseline 2016 -16/-19% in LC/LC+ 2030 and -37/-40% in LC/LC+ 2050
2. Strong increase in the supply of renewable sources which replace fossil fuels. It reaches 41/49% in LC/LC+ 2030 and 72/86% in LC/LC+ 2050
3. LC scenarios allow achieving the EU Energy and Climate Objectives: -40% at 2030 and -80% at 2050 (compared to 1990)
4. The LC+ scenarios allow to reach the "TECH RAPID" trajectory: -50% at 2030 and -90% at 2050 (compared to 1990)

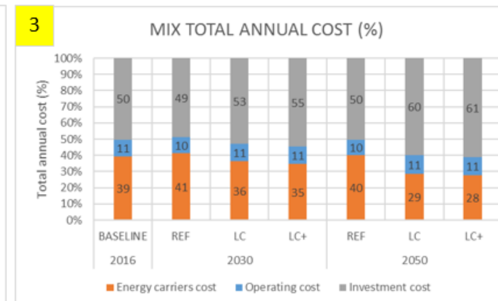
PEAP scenarios: REF vs LC vs LC+

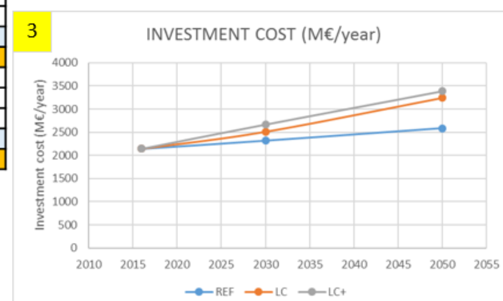
EnergyPLAN analysis

COSTS

	1990	2016	2030			2050		
		BASELINE	REF	LC	LC+	REF	LC	LC+
COSTS								
Energy carriers cost (M€/year)		1669	1953	1727	1701	2042	1541	1531
Oil cost (M€/year)		727	891	574	515	902	95	58
Gas cost (M€/year)		451	556	469	369	636	227	98
Electrical import cost (M€/year)		1	2	1	2	2	25	61
Total cost imported energy (M€/year)		1179	1449	1044	886	1540	347	217
Total cost imported energy (€/(inh*year))		2191	2513	1810	1536	2513	566	354
Variation 2016 (%)			14.71	-17.35	-29.86	14.74	-74.15	-83.83
Operating cost (M€/year)		454	474	506	519	491	611	608
Investment cost (M€/year)		2143	2318	2512	2666	2583	3240	3384
TOTAL ANNUAL COST (M€/year)		4266	4745	4745	4886	5116	5392	5523
TOTAL ANNUAL COST (€/(inh*year))		7926	8229	8228	8473	8350	8801	9014
Variation 2016 (%)			3.82	3.81	6.89	5.34	11.03	13.72







ESTIMATE Δ INVESTMENT COST VS REF

AVARAGE M€/year	2016-2030	2030-2050
LC	97	425
LC+	174	574

public incentives + private investments

KEY MESSAGES

1. REF, LC and LC+ trajectories have similar "total annual cost", close to the Baseline 2016
2. By 2050, an increase in "total annual cost" compared to 2016 is within 11% in LC and 14% in LC+
3. In the LC and LC+ scenarios, investments in building efficiency and renewable technologies increase while spending on imported energy carriers (oil, gas, electricity import) decreases: **THE IMPACT ON THE PAT ECONOMY IS HIGHLY POSITIVE**
4. An analysis of the investment cost shows an annual Δ of the LC and LC+ scenarios compared to the REF of 97/174 M€ in 2016-2030 and 425/574 M€ in 2030-2050: necessary public incentives and private investments gradually increasing as the objectives increase (offset by lower costs for imported energy carriers and benefits for local economy and workforce)

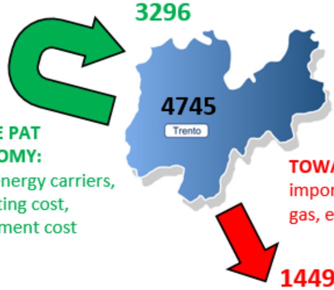
PEAP scenarios: REF vs LC vs LC+

EnergyPLAN analysis

COSTS (M€/year)

REF 2030

3296



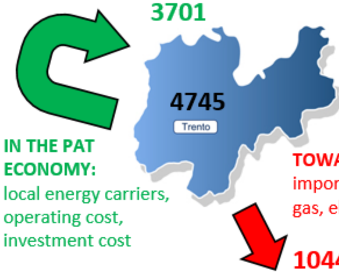
IN THE PAT ECONOMY: local energy carriers, operating cost, investment cost

TOWARDS FOREIGN ECONOMY: imported energy carriers (oil, gas, electrical import)

1449 *31%*

LC 2030

3701



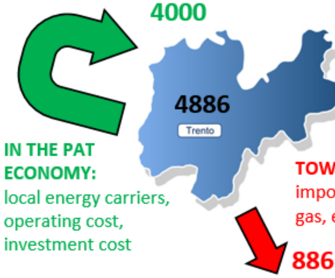
IN THE PAT ECONOMY: local energy carriers, operating cost, investment cost

TOWARDS FOREIGN ECONOMY: imported energy carriers (oil, gas, electrical import)

1044 *22%*

LC+ 2030

4000



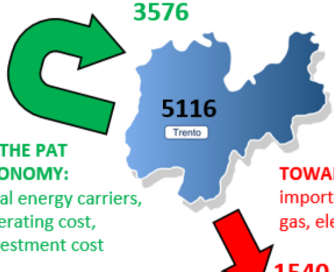
IN THE PAT ECONOMY: local energy carriers, operating cost, investment cost

TOWARDS FOREIGN ECONOMY: imported energy carriers (oil, gas, electrical import)

886 *18%*

REF 2050

3576



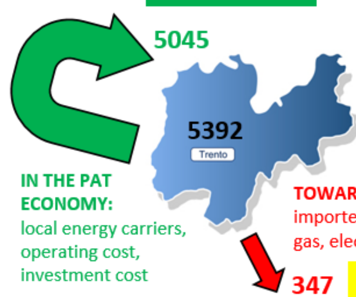
IN THE PAT ECONOMY: local energy carriers, operating cost, investment cost

TOWARDS FOREIGN ECONOMY: imported energy carriers (oil, gas, electrical import)

1540 *30%*

LC 2050

5045



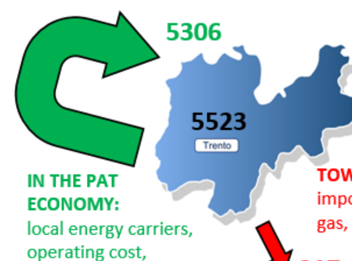
IN THE PAT ECONOMY: local energy carriers, operating cost, investment cost

TOWARDS FOREIGN ECONOMY: imported energy carriers (oil, gas, electrical import)

347 *6%*

LC+ 2050

5306



IN THE PAT ECONOMY: local energy carriers, operating cost, investment cost

TOWARDS FOREIGN ECONOMY: imported energy carriers (oil, gas, electrical import)

217 *4%*

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Integrated and dynamic energy modelling of a regional system: A cost-optimized approach in the deep decarbonisation of the Province of Trento (Italy)

Check for updates

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Sector coupling
Renewable energy
Low-carbon economy

A B S T R A C T

Since the Kyoto Protocol (1997), the European Union has fought against climate change adopting European, national and regional policies to decarbonise the economy. Moreover, the Paris Agreement (2015) calls 2050 solutions between -80% and -100% of greenhouse gas emissions compared with 1990. Regions have an important role in curbing CO2 emissions, and tailor-made strategies considering local energy demands, savings potentials and renewables must be elaborated factoring in the social and economic context. An "optimized smart energy system" approach is proposed, considering: (I) integration of electricity, thermal and transport sectors, (II) hourly variability of productions and demands, (III) coupling the EnergyPLAN software, to develop integrated and dynamic scenarios, with a multi-objective evolutionary algorithm, to identify solutions optimized both in terms of CO2 emissions and costs, including decision variables for all the three energy sectors simultaneously. The methodology is tested at the regional scale for the Province of Trento (Italy) analyzing a total of 30,000 scenarios. Compared to the Baseline 2016, it is identified: (I) the strategic role of sector coupling among large hydroelectric production and electrification of thermal and transport demands (heat pumps, electric mobility), (II) slight increases in total annual cost, +14% for a -90% of CO2 emissions in 2050.

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