Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

RES-TMO

interreg Oberrhein Rhin Supérieur

Fonds européen de développement régional (FEDER)
Europäischer Fonds für regionale Entwicklung (EFRE)

Cuban's Energy Strategy into 2030:

General Design Features towards a Sustainable Transition

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EPFL

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UNIVERSIDAD NACIONAL DE COLOMBIA SEDE BOGOTÁ

Why Cuba?

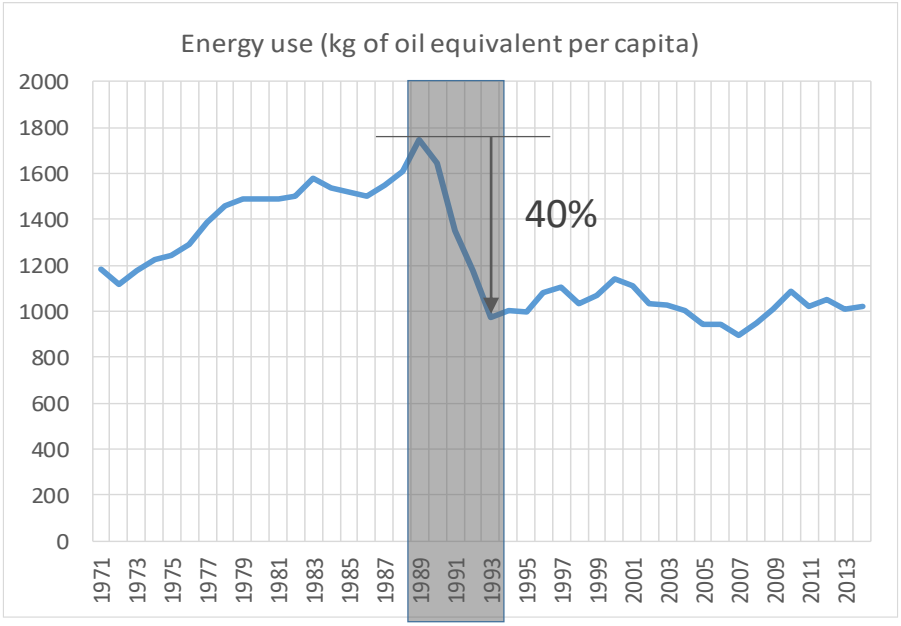
Cuba is an Island under Embargo

1959: The Cuban socialist revolution succeeds.

The American trade embargo and the support of Soviet Union are set up.

1991: Soviet subsidies and trade exchanges are stopped.

In **4 years**, **the energy consumption** has fallen by more than **40%**, GDP by 35%, industrial production by 80% and foreign trade by 75%.



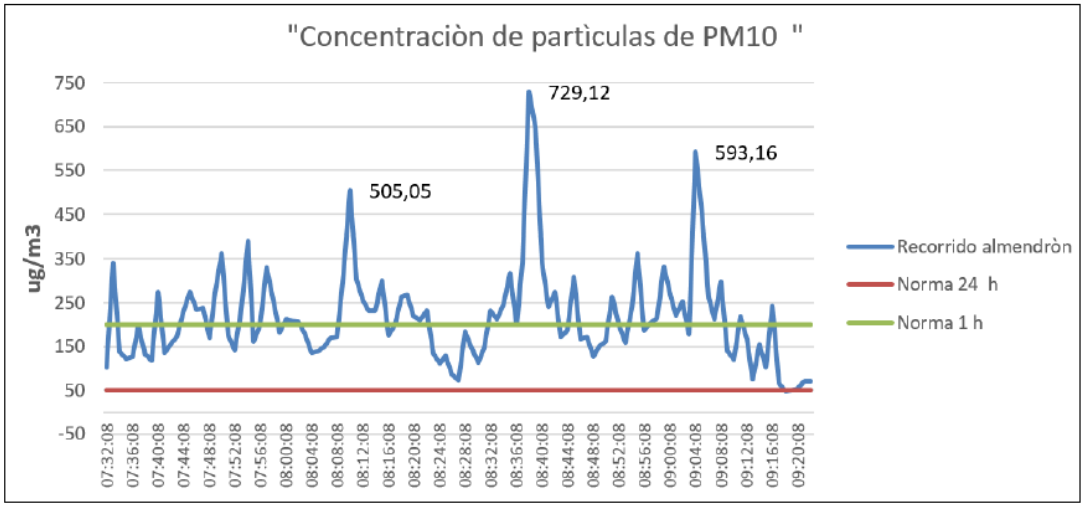
What are the Embargo Implications ?

The Cuban inhabitants had to deeply change their life style to adapt to the new conditions , in all sectors of activity.

What are the Embargo Implications ?

Slow renewal of technologies

Obsolete technologies generate environmental problems: example of air quality



Air Quality Study

Air Quality Study: Emissions

Emissions from industrial and energy sectors

The emission factors for the industries had already been estimated using measures by the Cuban Ministry of Energy (Cubaenergia).

Stacks

Air Quality Study: Emissions

Emissions from the transport sector

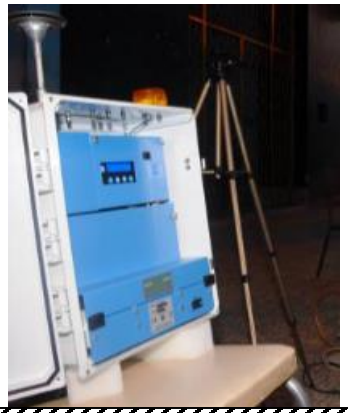
1'000'000 US$

Emission factors for vehicles were not estimated using measurements.

A measurement campaign have ben organized in the framework of our project.

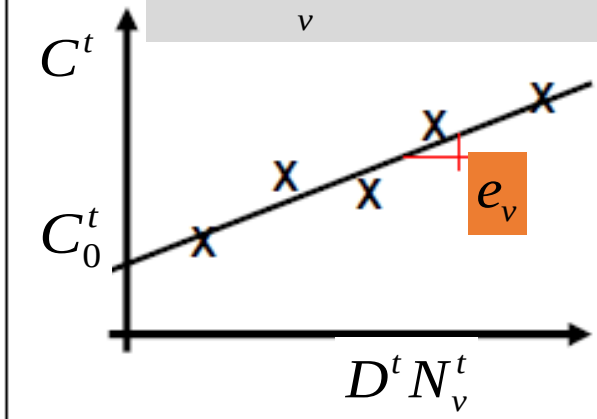
15'000 US$

Measurements of concentrations



Traffic counting

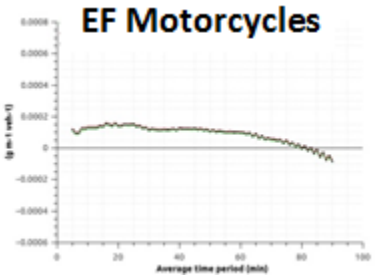
$$C^t = \sum_v D^t N_v^t e_v + C_0^t$$

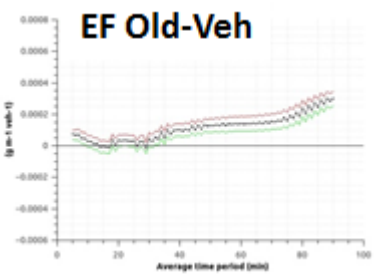


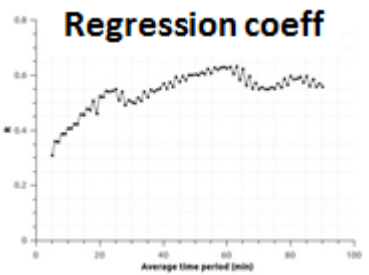
Bulk emission factors

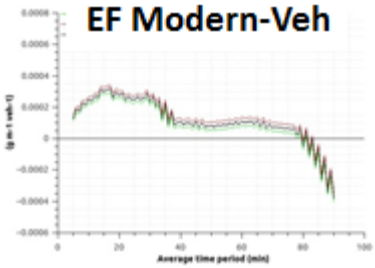
Belalcazar, L., C., O. Fuhrer, M. D. Ho, E. Zarate and A. Clappier, 2009: Estimation of road traffic emission factors from a long term tracer study, *Atmos. Environ.*, **43**, 5830-5837.

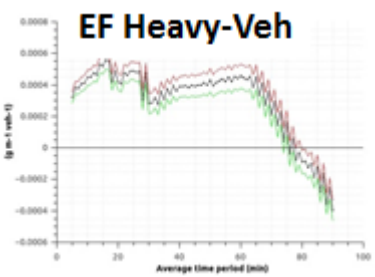
Air Quality Study: Emissions

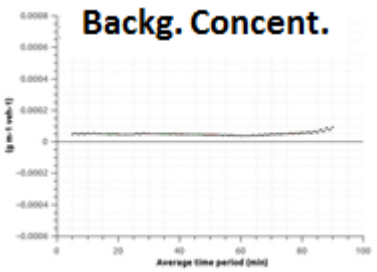












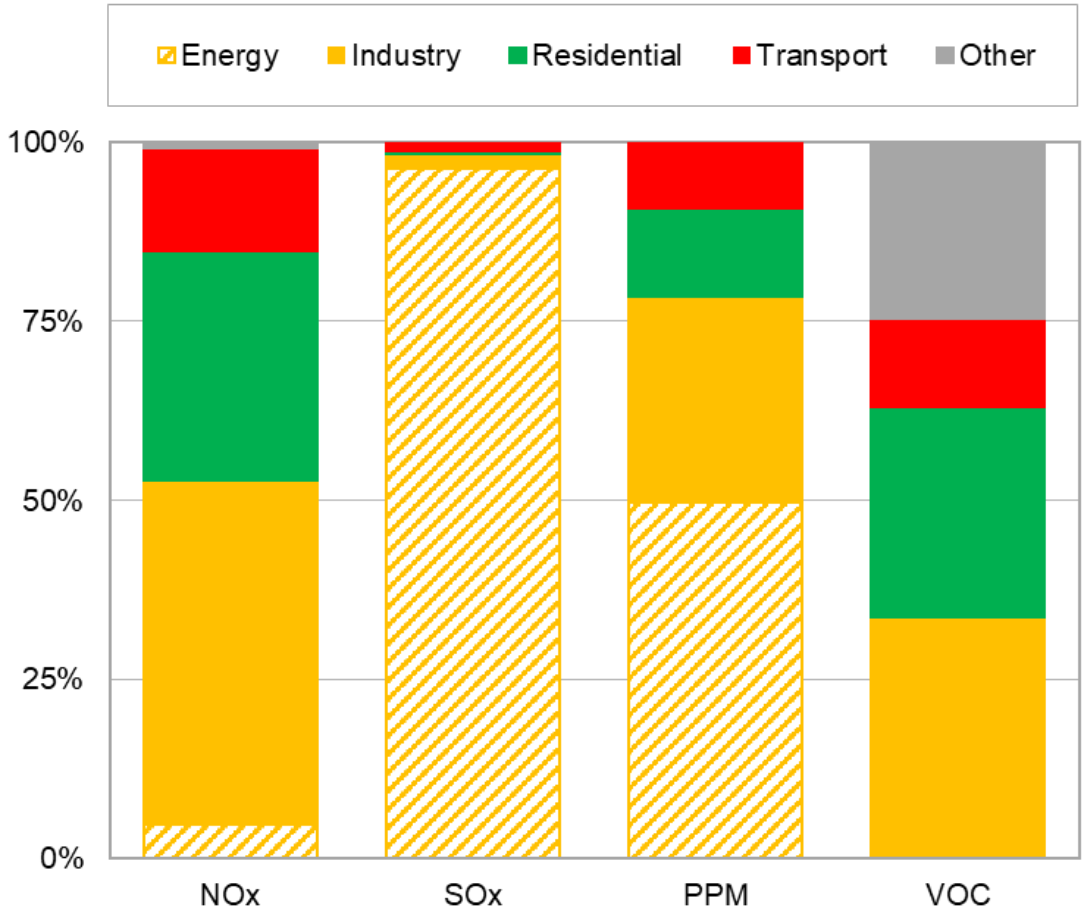
	Emissions (mg/km)	Std. Dev 95% Confid	Emis. (mg/km/pers)	Concent. (µ/m3)
Motorcycles	111.8	2.7	**55.9**	4.4
Modern vehicles	91.3	11.2	22.8	9.6
Old vehicles	124.2	18.5	31.1	**26.7**
Bus	**413.8**	**31.25**	3.5	14.9

1. Identification of time-averaging

2. Principal Component Regression (PCR) instead of **Multi Linear Regression (MLR)**

Madrazo, J., and A. Clappier, 2018: Low-cost methodology to estimate vehicle emission factors, *Atmos. Pollu. Reas.*, **9**, 322-332.

Air Quality Study: Emissions



Madrazo, J., A. Clappier, L. Belalcazar, O. Cuesta, H. Contreras, F. Golay, 2018: Screening differences between a local inventory and the Emissions Database for Global Atmospheric Research (EDGAR), *Science of the Total. Environ*., **631-632**, 934-941

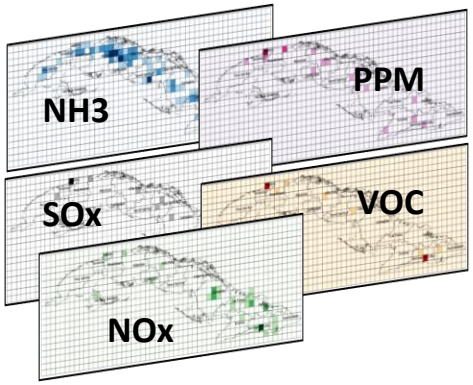
Air Quality Study: Numerical Simulations

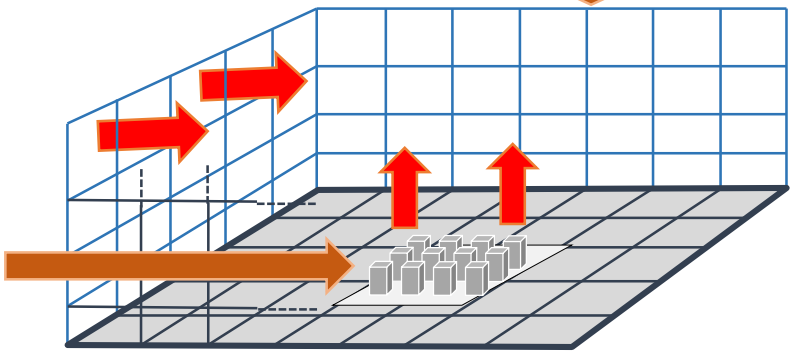
Meteorological fields

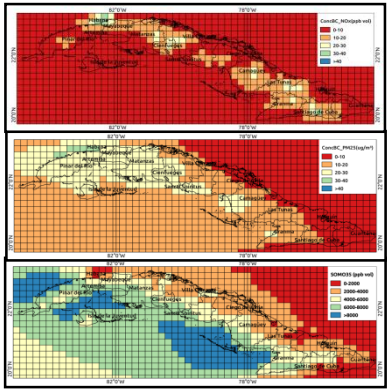
WRF

Several days

Emission Inventory







Air Quality Model

CHIMERE

Concentrations

Few minutes

Set of scenarios results

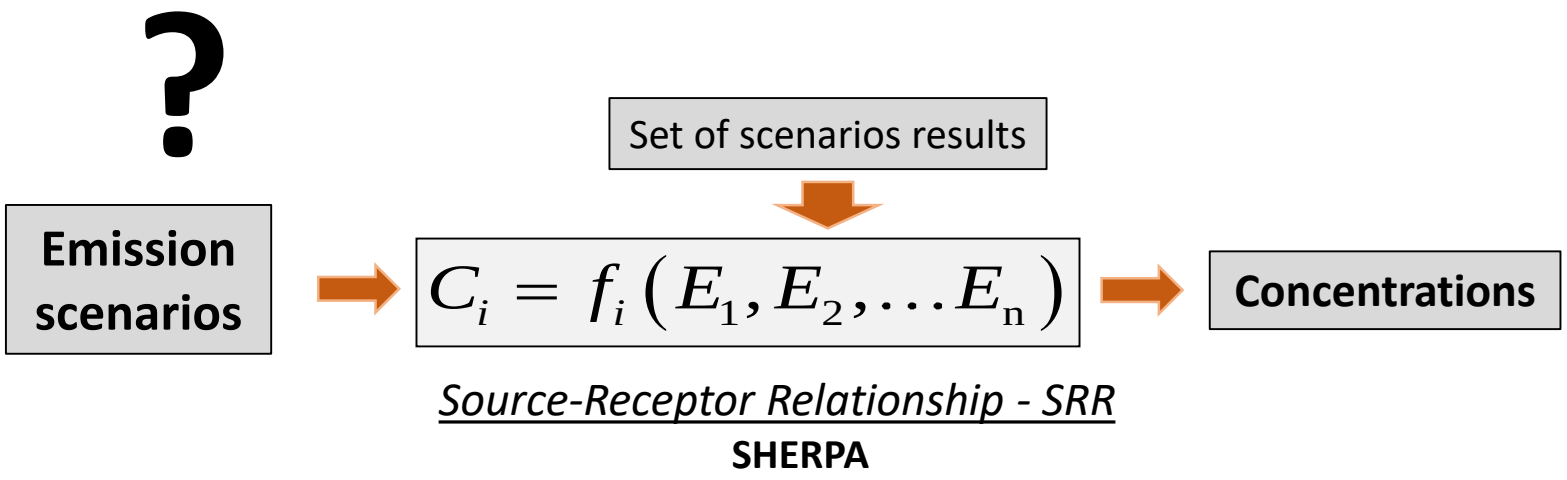
Emissions → $C_i = f_i\left(E_1, E_2, \ldots E_n\right)$ → **Concentrations**

Source-Receptor Relationship - SRR

SHERPA

Thunis, P., B. Degraeuwe, E. Pisoni, M. Trombetti, E. Peduzzi, C.A. Belis, J. Wilson, A. Clappier and E. Vignati, 2018: PM2.5 source allocation in European cities: A SHERPA modelling study, *Atmos. Environ.*, **187**, 93-106.

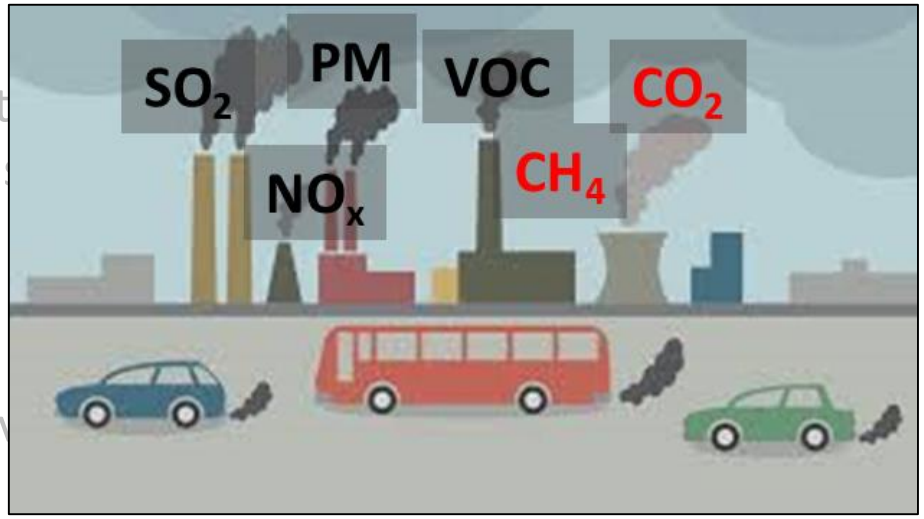
Air Quality Study: Abatement Strategies



Design of Strategies

Why should Air Quality, Climate and Energy Strategies be coordinated?

- Air quality and Climate issues both arise from our energy usage (fossil fuels)
- Although air qualit to co-benefits, there are exception
- Decision makers hav



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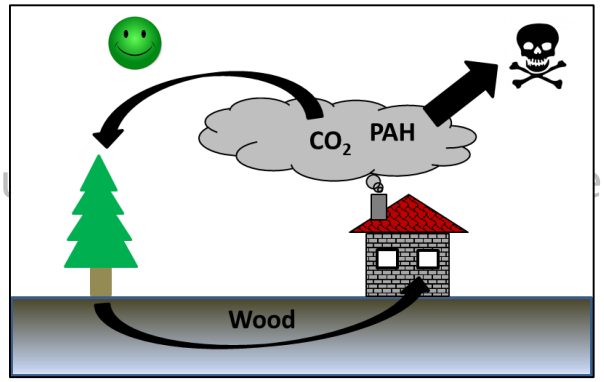
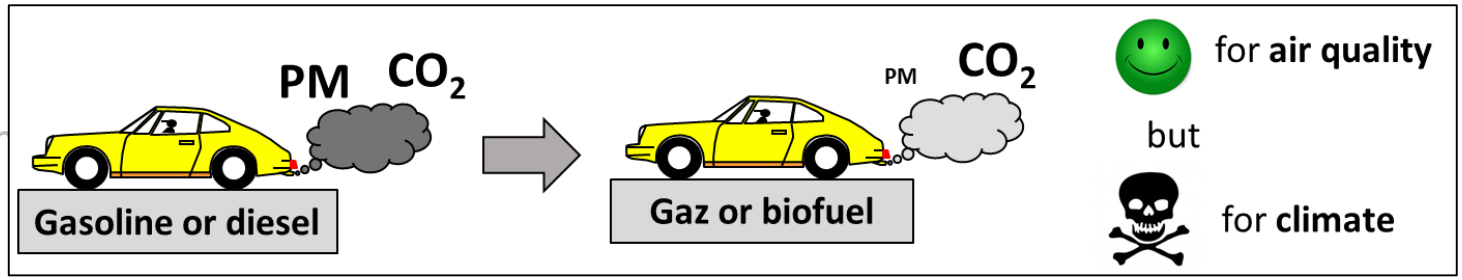


- Air quality and Climate issu … ergy usage (fossil fuels)
- Although air quality and climate measures generally lead to co-benefits, there are exceptions.
- Decision m …



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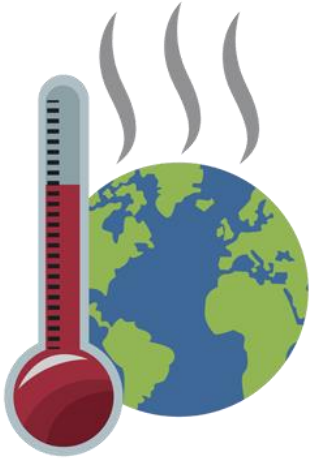
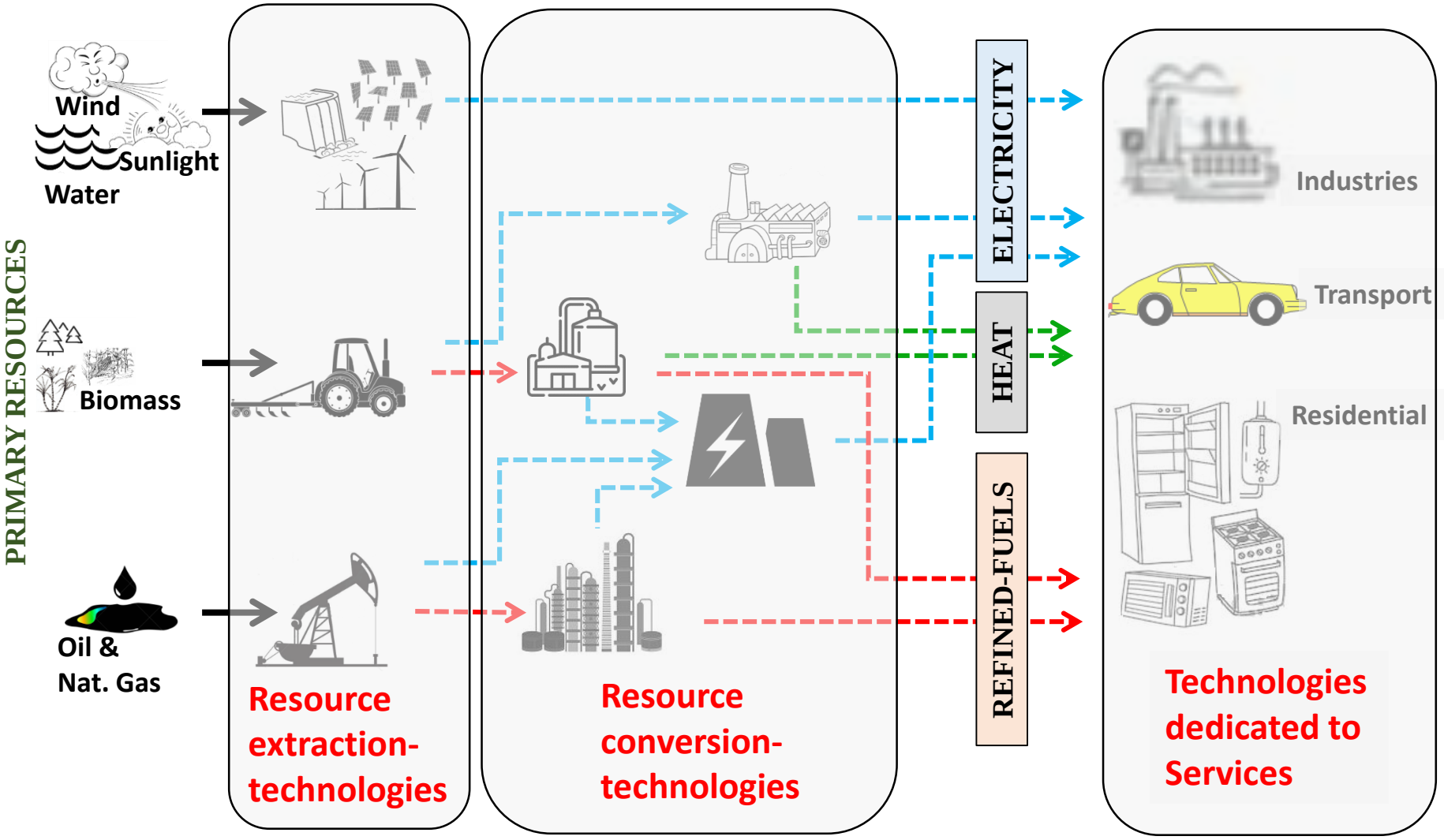


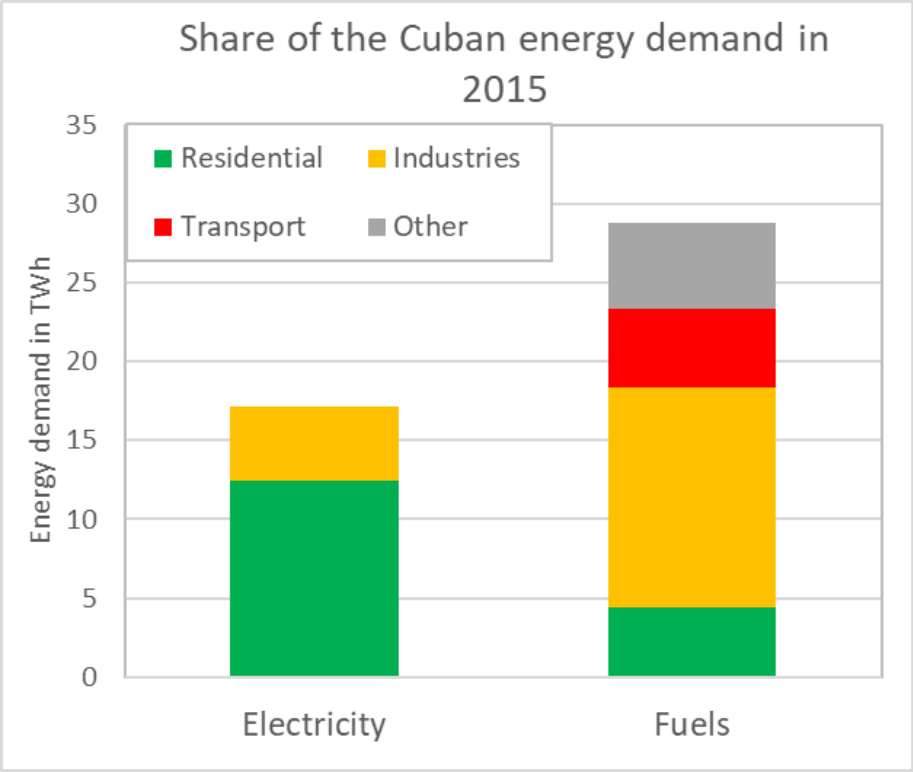
- Alt … lity ar … s
  the … ons.

- Decision makers have their own agenda.

Energy and Technologies



Cuban Energy Demand in 2015



	Electricity	Fuels	**Total**
Residential	27%	10%	**37%**
Industries	10%	30%	**41%**
Transport	0%	11%	**11%**
Other	0%	12%	**12%**
Total	**37%**	**63%**	**46 TWh**

The residential demand is shared between **private buildings (65%)** and **public buildings (45%)**.

Cuban Energy Resources Used in 2015

TOTAL (TWh)	98.7
Water	0.05%
Solar	0.03%
Wind	0.03%
Biomass	18.2%
Domestic_NGas	6.0%
Domestic_Oil	33.2%
Imported_Oil & Sub	42.5%

Ressources

Demand

Cuban Energy Resources Used in 2015

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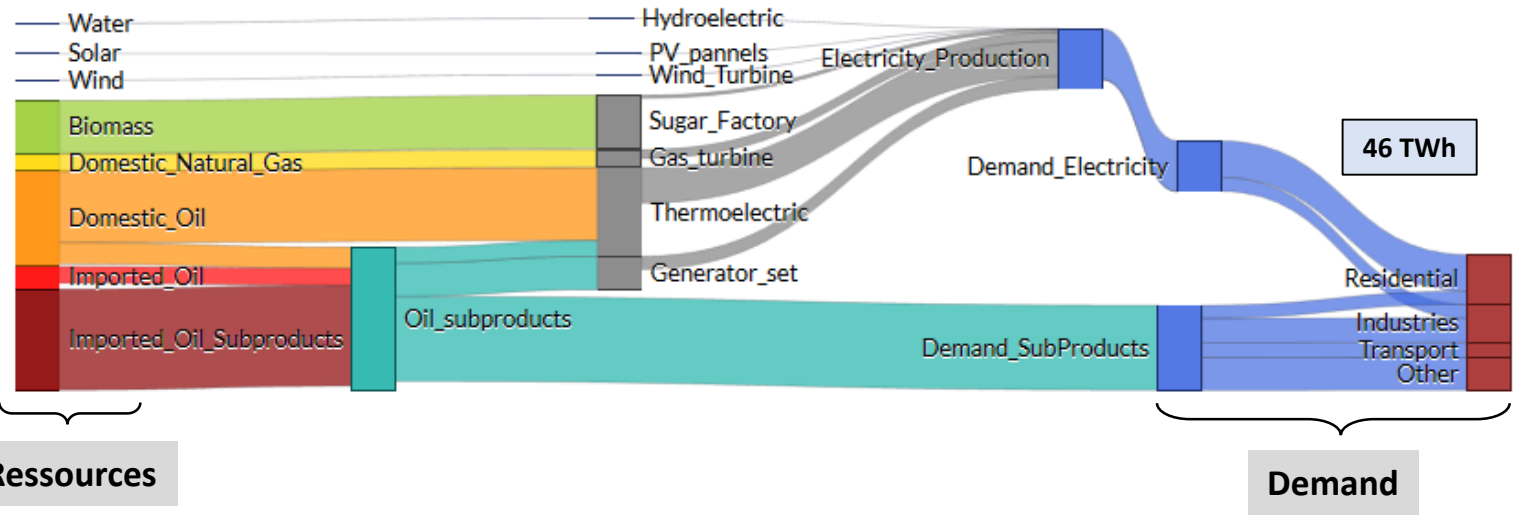
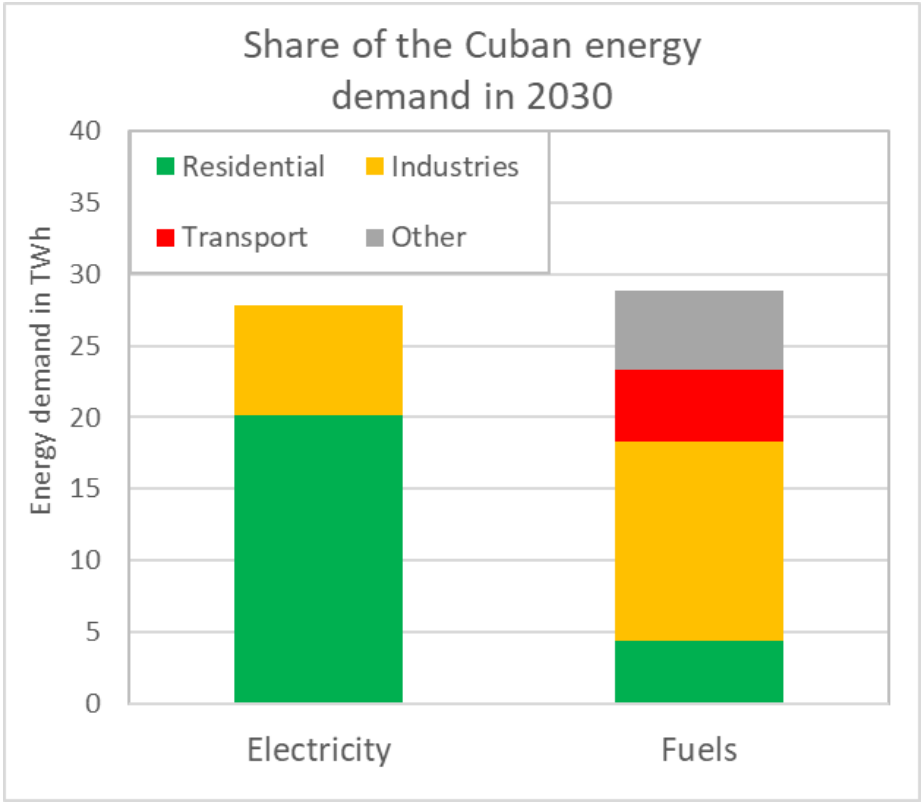


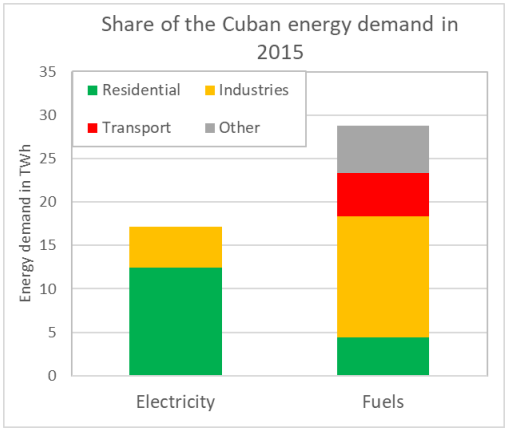
- In 2015, energy imports were still important with a share of 42.5% (i.e. 41.9 TWh).
- The share of wind and solar energy combined was only 0.06%.

« Official » Demand Forecast for 2030

Cuban authorities estimate that the **electricity consumption will increase by 3.28% a year** until 2030. During this period fuel consumption is expected to stagnate. The total energy demand should therefore increase from 46 TWh in 2015 to 56.7 TWh by2030.

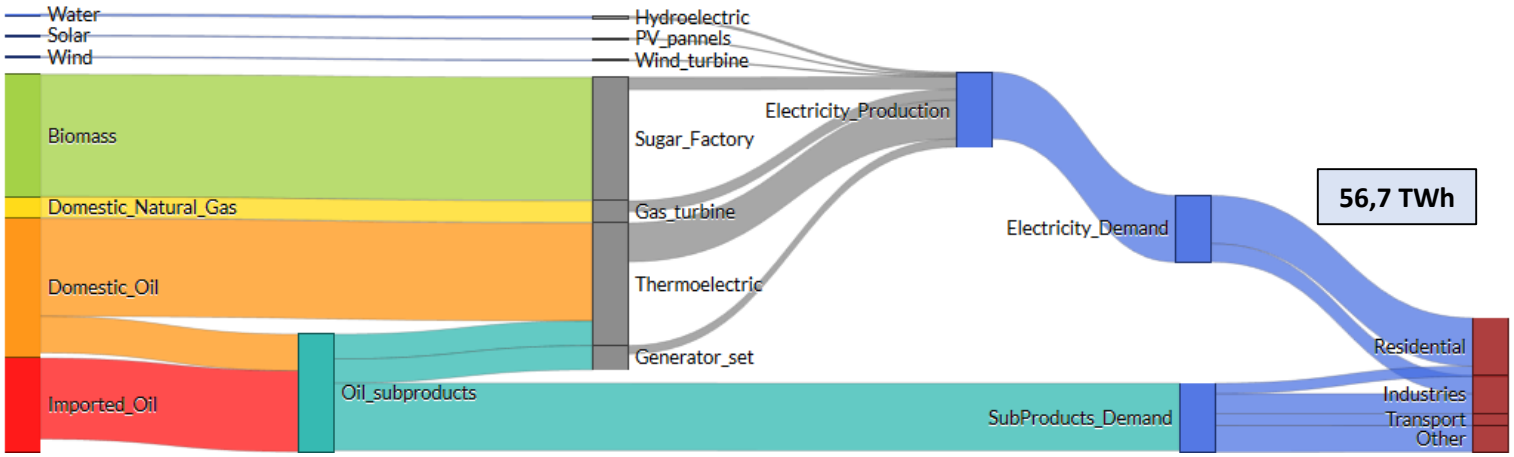


	Electricity	Fuels	**Total**
Residential	36%	8%	**43%**
Industries	13%	25%	**38%**
Transport	0%	9%	**9%**
Other	0%	10%	**10%**
Total	**49%**	**51%**	**56,7 TWh**



« Official » Strategy for 2030

TOTAL (TWh)	160
Water	0.6%
Solar	0.3%
Wind	0.3%
Biomass	32.2%
Domestic_NGas	5.6%
Domestic_Oil	36.3%
Imported_Oil & Sub	24.6%

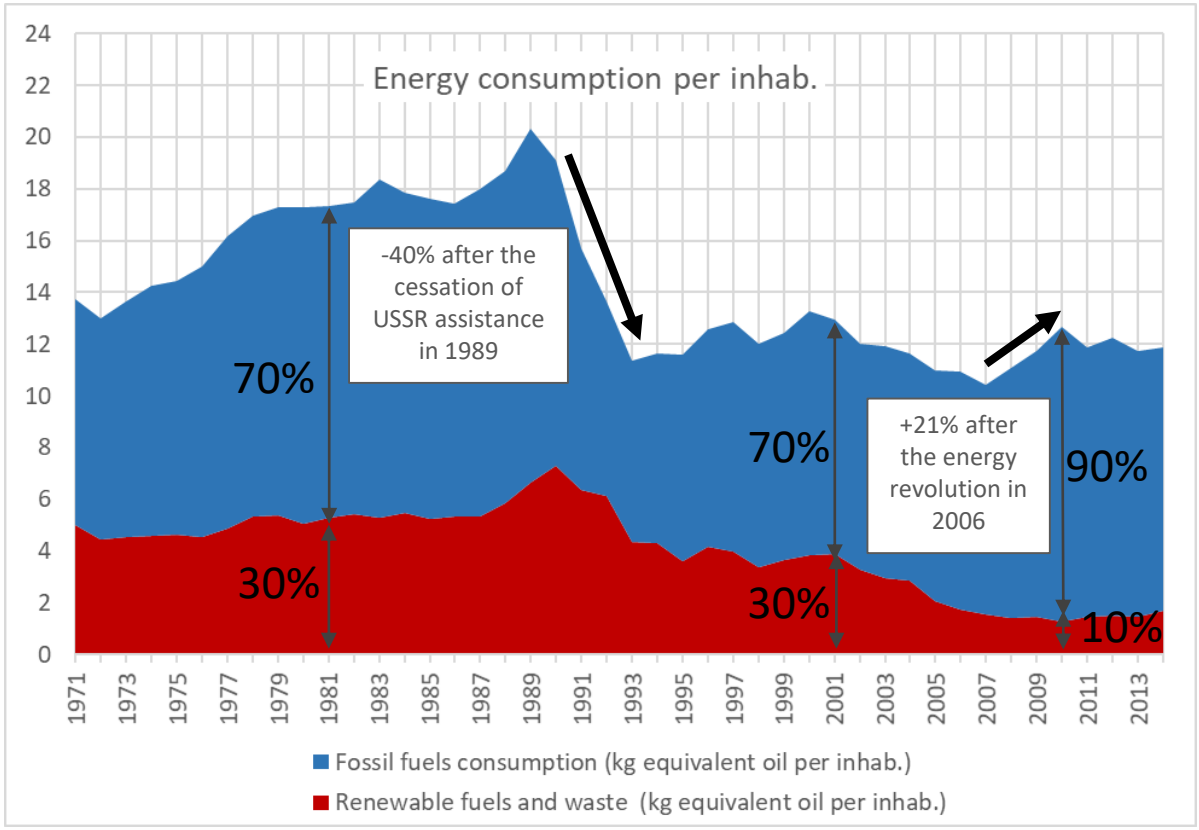


- **Decrease energy imports** from 41.9 to 39.4 TWh.
- **Increase the exploitation of fossil resources** from 32.8 to 58.1 TWh for oil and from 5.9 to 9 TWh for gas.
- **Increase the production of renewable energy** from 18 to 51.5 TWh **for biomass** and from 0.1 TWh to 2 TWh for solar, wind and hydro

The Facts behind Political Strategies…

In 2006 Cuba started its **"Energy Revolution"**. The goal was to increase energy efficiency and increase the share of renewable energy but:

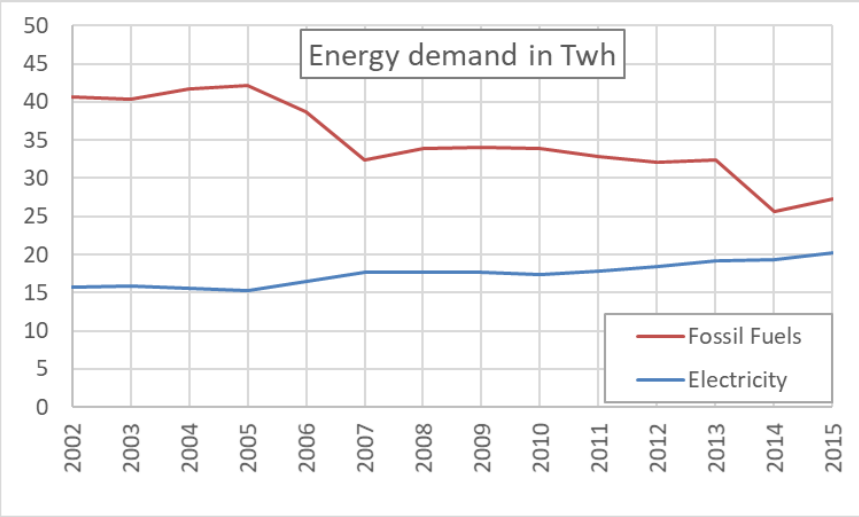
- the energy revolution is followed by a 21% **increase in energy consumption** until 2010,
- the **share of renewable decreases** from 30% in 2001 to around 10% in 2010.



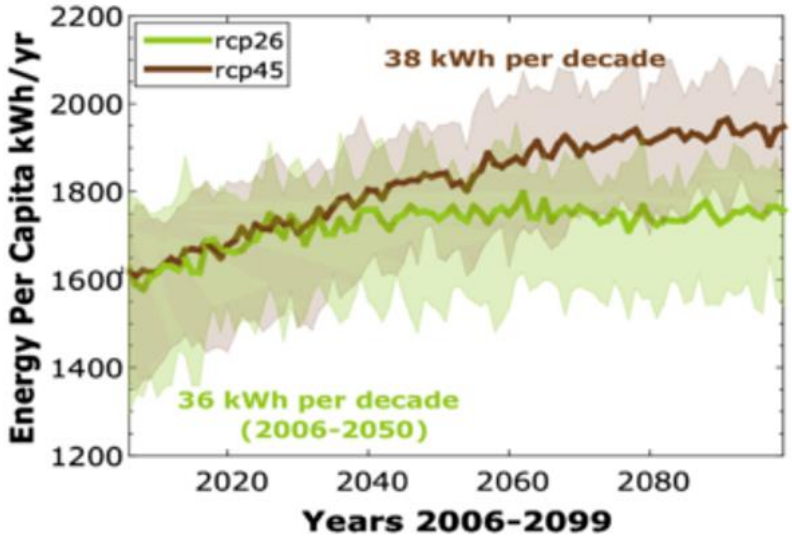
Rather Optimistic Forecasts

- Cuban authorities likely **overestimated their energy production capacities**, for the biomass as well as for the oil extraction.

- Cuban authorities **underestimated the electric demand.** The increase in 2015 was 4.8% instead of the foreseen 3.28%. The large impact of climate change foreseen over the Caribbean region that will increase the needs for air conditioning (tourism) is not accounted for.



Forecast of energy consumption in the Caribbean region

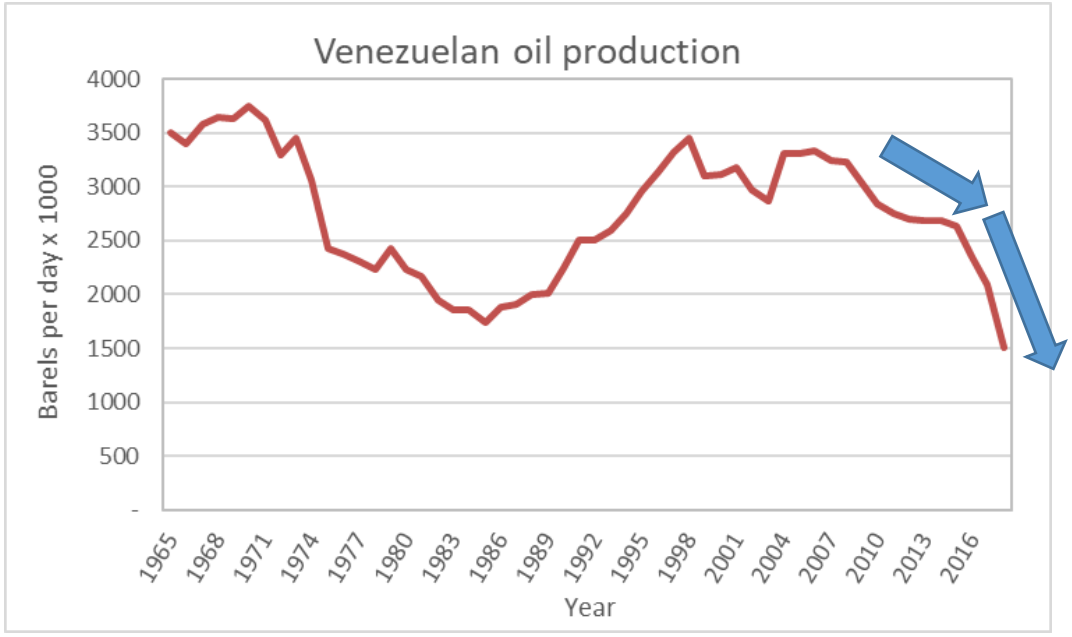


Issues Related to the Energy Supply

In 2005 Cuba concludes a treaty with Venezuela (TSP- Tratado de Comercio de los Pueblos) to **exchange in the field of medical goods, education and oil** between the two nations.


Fidel Castro and Hugo Chavez

Venezuela faced unprecedented economic difficulties and has seen its oil production decline drastically. It is no longer able to provide Cuba, presumably since 2015.



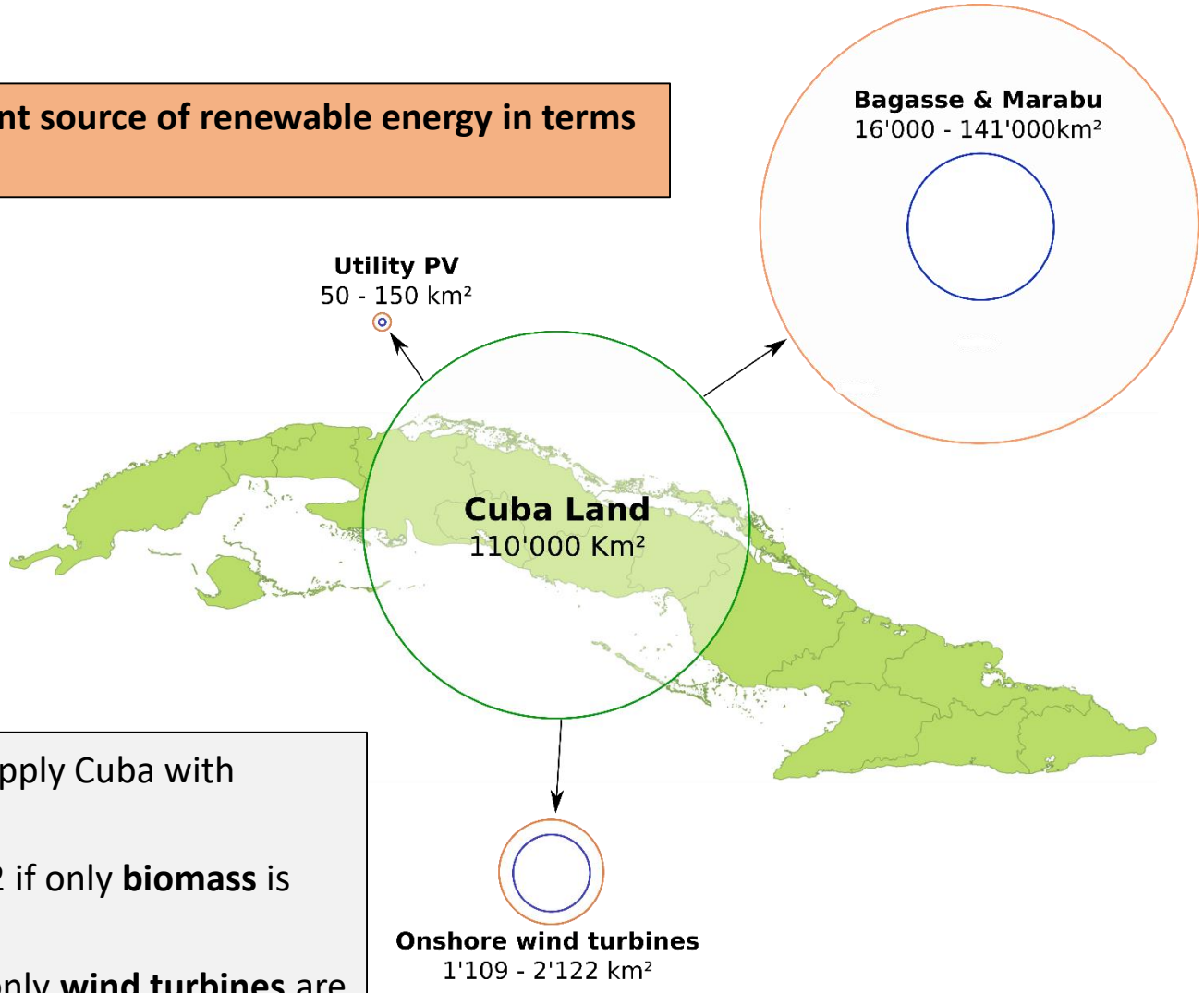
Available Resources

Available ressources	Annual potential (TWh)	Reserves (years)
Oil and gas	15,1 - 20,9	155
Biomass (Bagasse)	1,7 - 6,5	-
Biomass (Marabu)	2,5 - 26,6	-
Hydroelectricity	0,99	-
Wind	2,4 - 28,2	-
Solar	24.433	-

Solar power, if operated over the entire surface of the country**, would provide more than 1,400 times the electricity needs of 2015.**

The different Renewable Energies

Biomass is not the most efficient source of renewable energy in terms of land use.



The land surface necessary to supply Cuba with electricity by 2030:

- from 16,000 to 141,000 km2 if only **biomass** is used (bagasse and marabu),
- from 1'109 to 2'122 km2 if only **wind turbines** are used (on shore only),
- from 50 to 150 km2 if only **solar panels** are used.

Alternative Scenarios

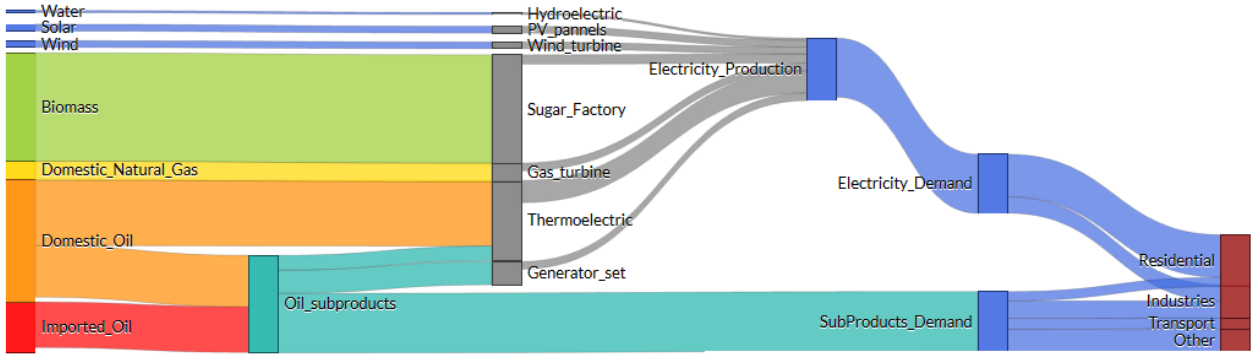
We considered alternative energy scenarios that allow for:

- A potential **increase of the energy offer**,
- A **reduction of the importations** with an **increased share of renewables.**
- A **reduction of the impact on the environment**.

Alternative Scenarios

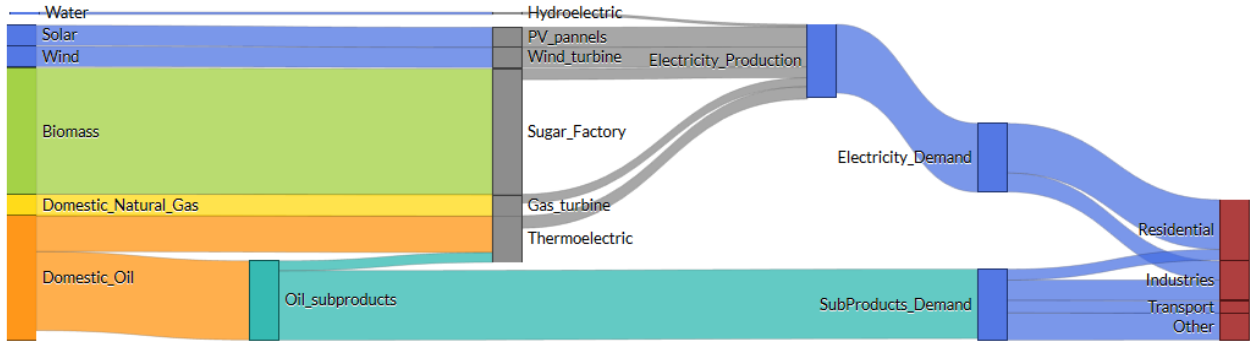
20% of electricity is produced by solar and wind

TOTAL (TWh)	151.5
Water	0.7%
Solar	2.6%
Wind	2.6%
Biomass	34.0%
Domestic_NGas	5.9%
Domestic_Oil	38.4%
Imported_Oil & Sub	15.8%



50% of electricity is produced by solar and wind

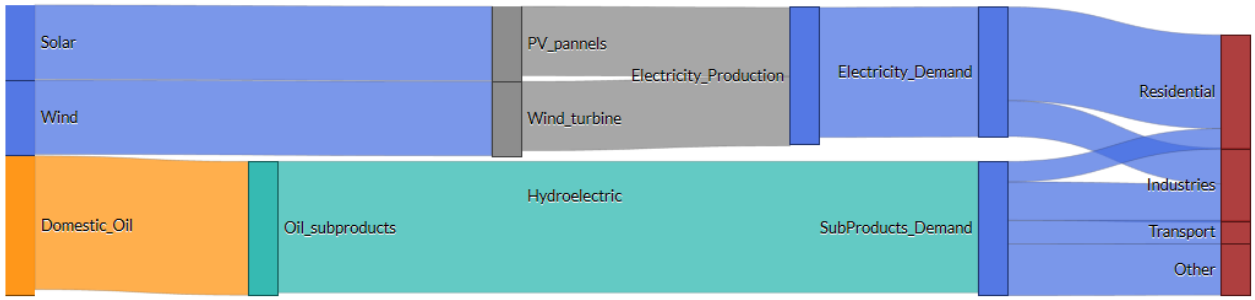
TOTAL (TWh)	128.9
Water	0.8%
Solar	6.4%
Wind	6.4%
Biomass	40.0%
Domestic_NGas	7.0%
Domestic_Oil	39.6%
Imported_Oil & Sub	-



Demand: 56,7 TWh

100% of electricity is produced by solar and wind

TOTAL (GWh)	62
Water	-
Solar	25.8%
Wind	25.8%
Biomass	-
Domestic_NGas	-
Domestic_Oil	48.4%
Imported_Oil & Sub	-



Alternative Scenarios

		2015	Scenarios 2030			
			Official	20%	50%	100%
Ressources (TWh)	**Total**	**98,7**	**160,0**	**151,5**	**128,9**	**62,0**
	Water	0,05	1,0	1,0	1,0	0
	Solar	0,03	0,5	4,0	8,2	16,0
	Wind	0,03	0,5	4,0	8,2	16,0
	Biomass	18,0	51,5	51,5	51,5	0
	Cuban natural gas	5,9	9,0	9,0	9,0	0
	Cuban brut oil	32,8	58,1	58,1	51,0	30,0
	Imported fuels	41,9	39,4	23,9	0	0
Criterias	Energy security	1,00	0,83	0,52	0,00	0,00
	Sutainability of the ressources	1,00	1,16	1,00	0,68	0,35
	Air quality	1,00	1,07	1,01	0,93	0,84

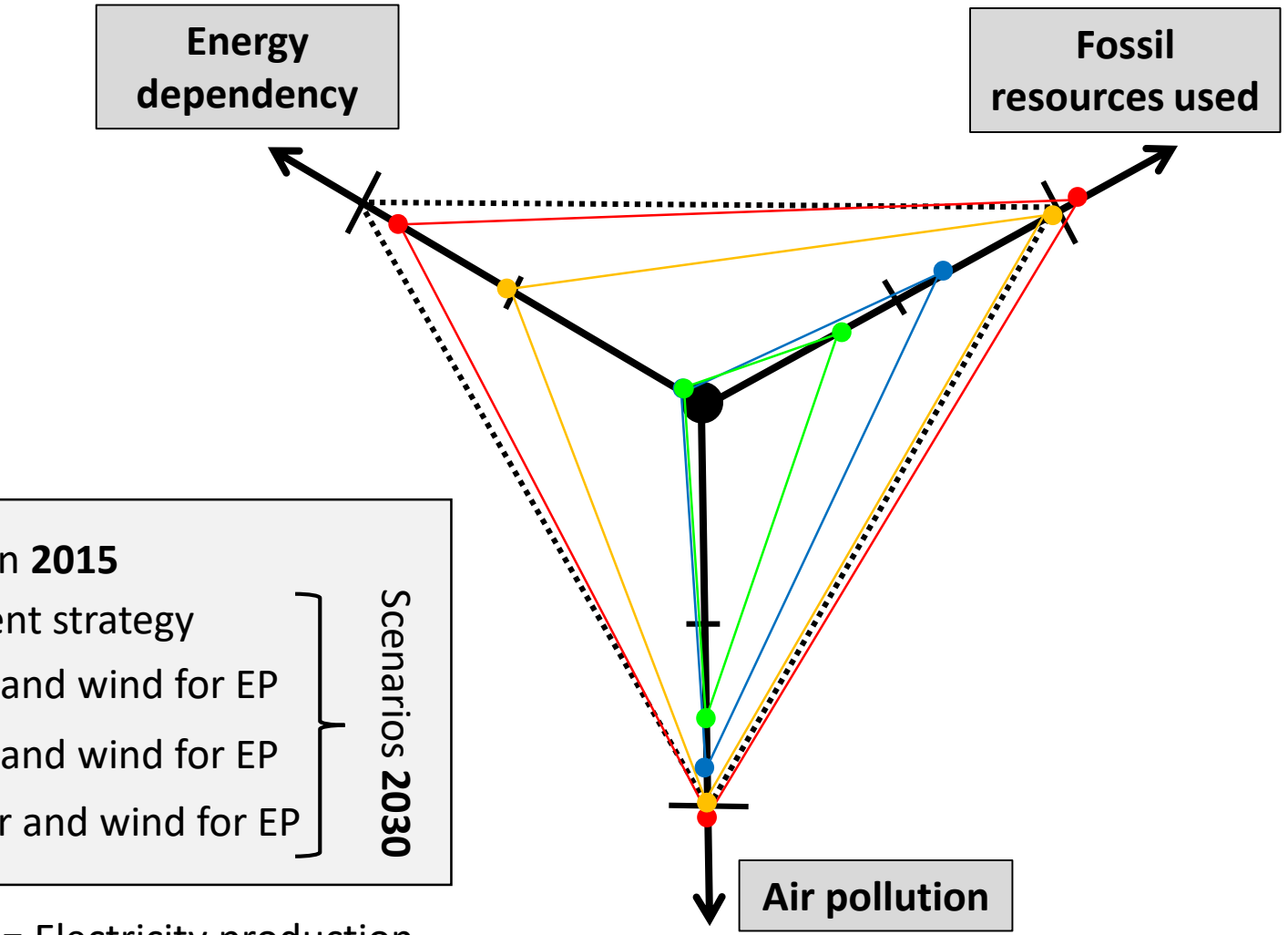
Indicators:
0 = best possible situation
1 = situation in 2015

The increased share of solar and wind energy in the Cuban energy mix would allow to:

- **Improve energy efficiency**. The resources needed to supply 56.7 TWh in 2030 decrease from 160 to 62 TWh.
- **Reduce the country dependency**. Energy imports would decrease and even disappear when at least 50% of the electricity is produced by solar and wind.
- I**ncrease the sustainability** of the resources with a higher share of renewables.
- I**mprove air quality**. Less fuel and biomass are burned leading to reduced levels of pollution.

Alternative Scenarios

Cuban energy mix



EP = Electricity production

Conclusions

- Strategies should be **integrated** (from energy demand to energy resources) and **address several objectives** at the same time (environmental like air quality and climate but also geopolitics like energy supply) .
- Preference to domestic resources increases economic stability…
- …as will do renewable energy in the near (!) future…


TERIMA KASIH

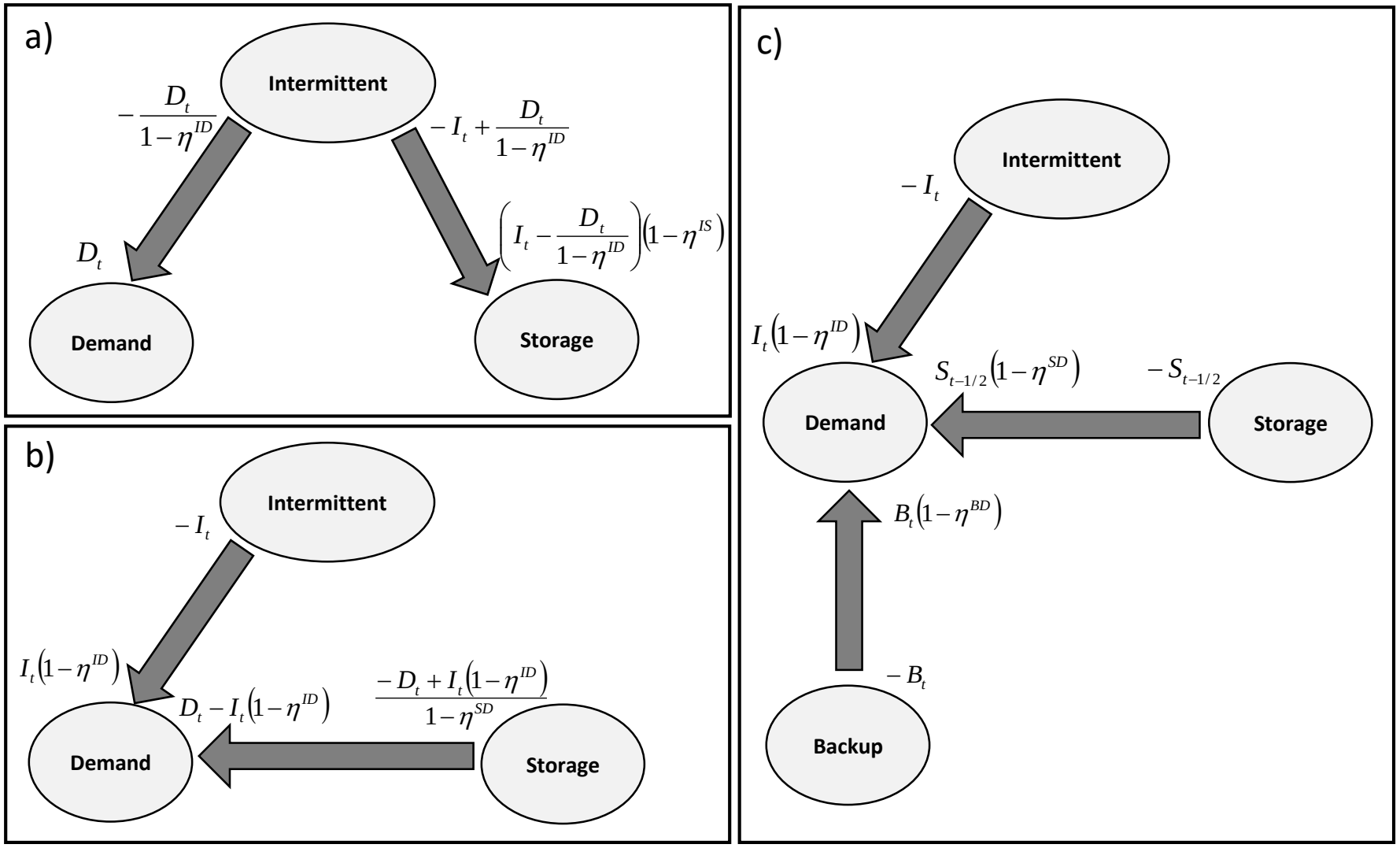
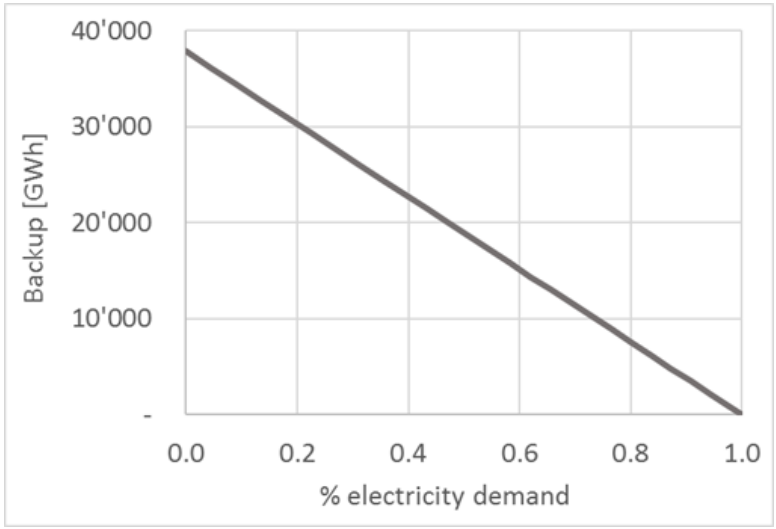
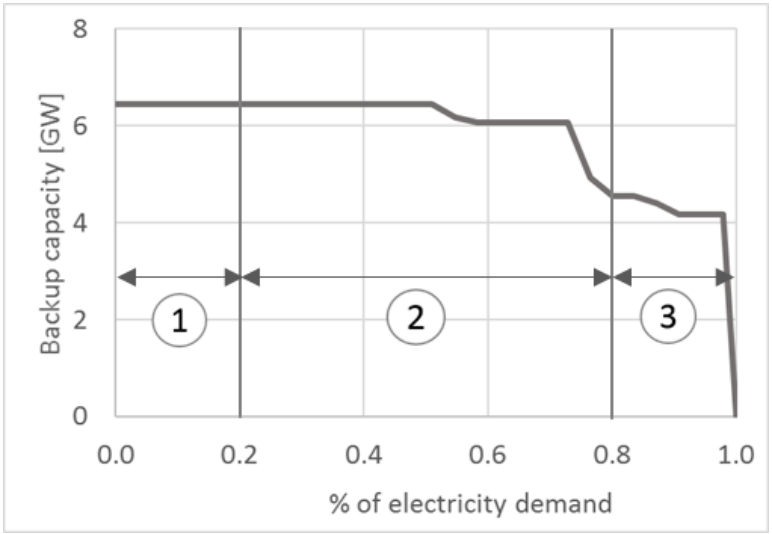
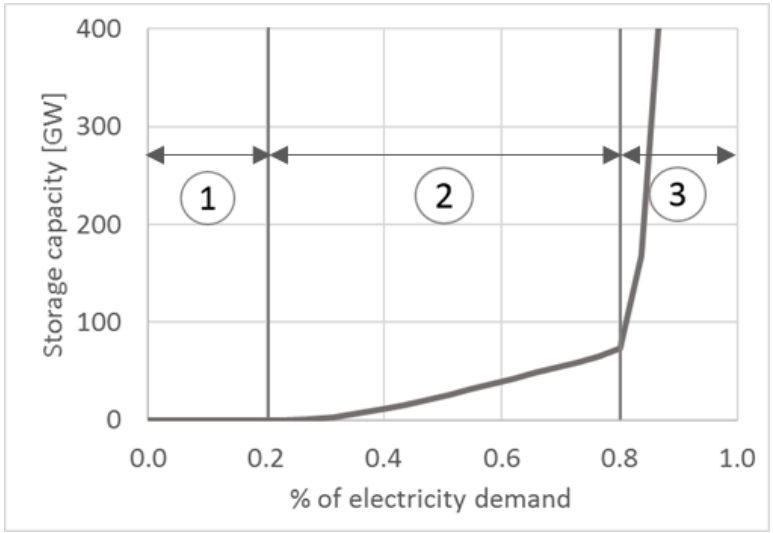


Figure X: Energy fluxes between the intermittent sources, the storage, the demand and the backup: a) the intermittent sources provides enough energy to fulfill entirely the demand, b) the storage completes the intermittent sources to supplies the demand, c) intermittent sources and storage are not sufficient to power entirely the demand, it is necessary to use a backup energy source.


40'000
30'000
20'000
10'000
-
Backup [GWh]
0.0
0.2
0.4
0.6
0.8
1.0
% electricity demand

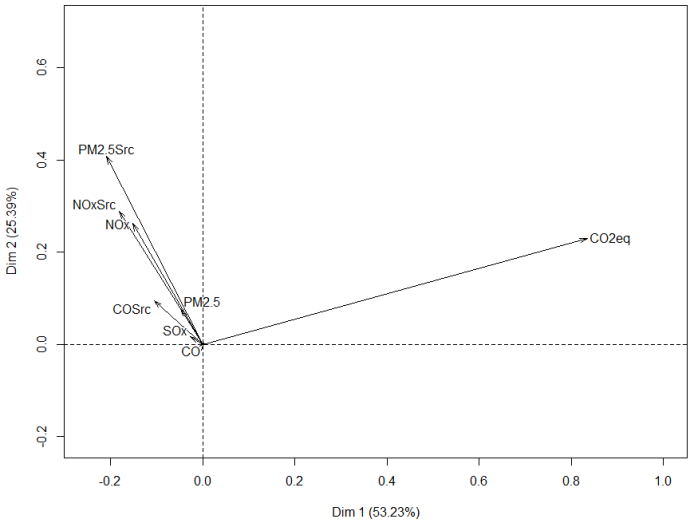

8
6
4
2
0
Backup capacity [GW]
1
2
3
0.0
0.2
0.4
0.6
0.8
1.0
% of electricity demand

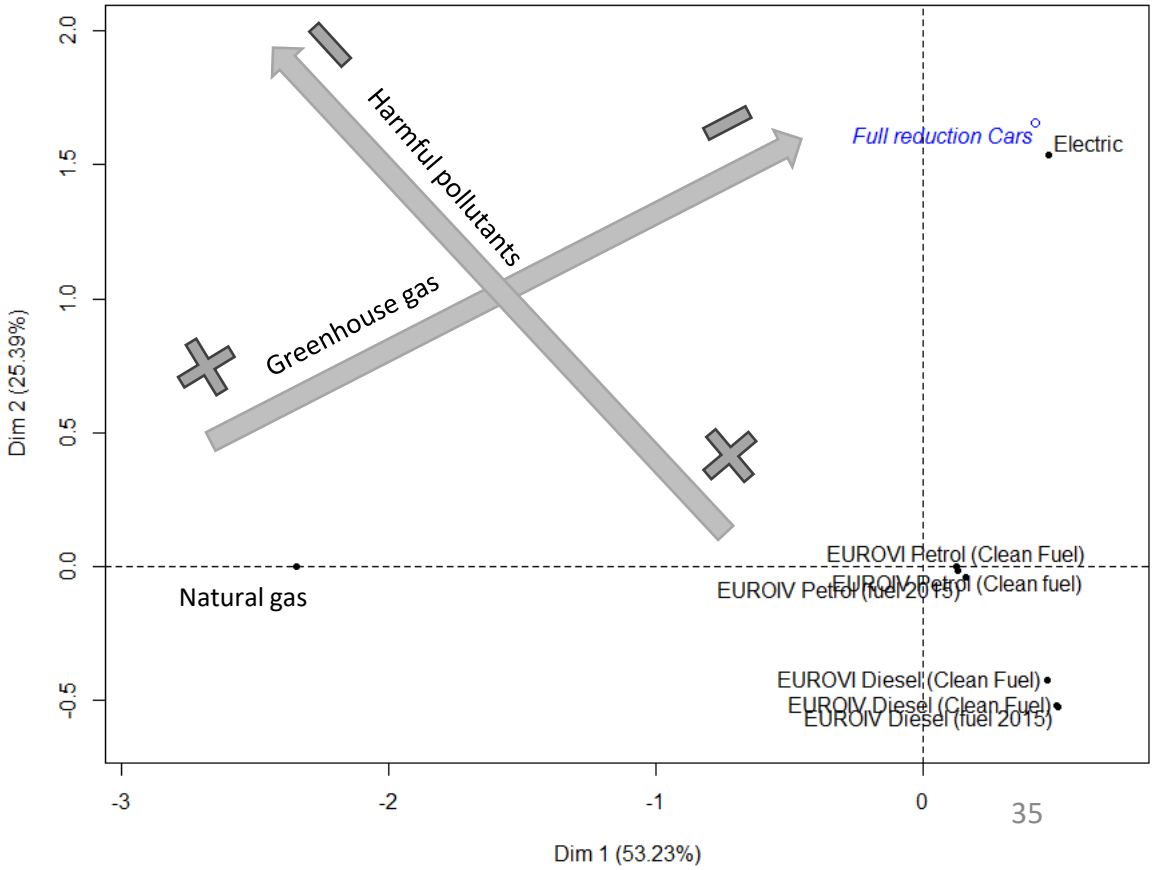

400
300
200
100
0
Storage capacity [GW]
1
2
3
0.0
0.2
0.4
0.6
0.8
1.0
% of electricity demand

Multiple Objectives

Private cars in Bogota (Colombia)

Direct emissions + Emissions resulting from resource production for CO, NO_x, SO_2, PM and Greenhouse gas (CO_2 equivalent)

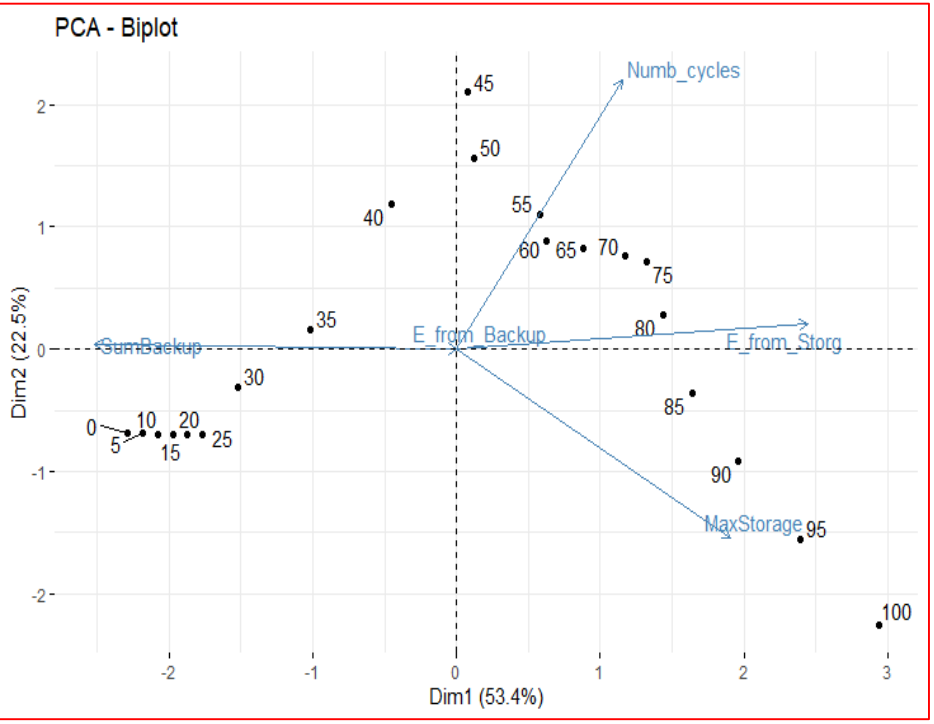




70% of Colombian electricity is hydroelectricity

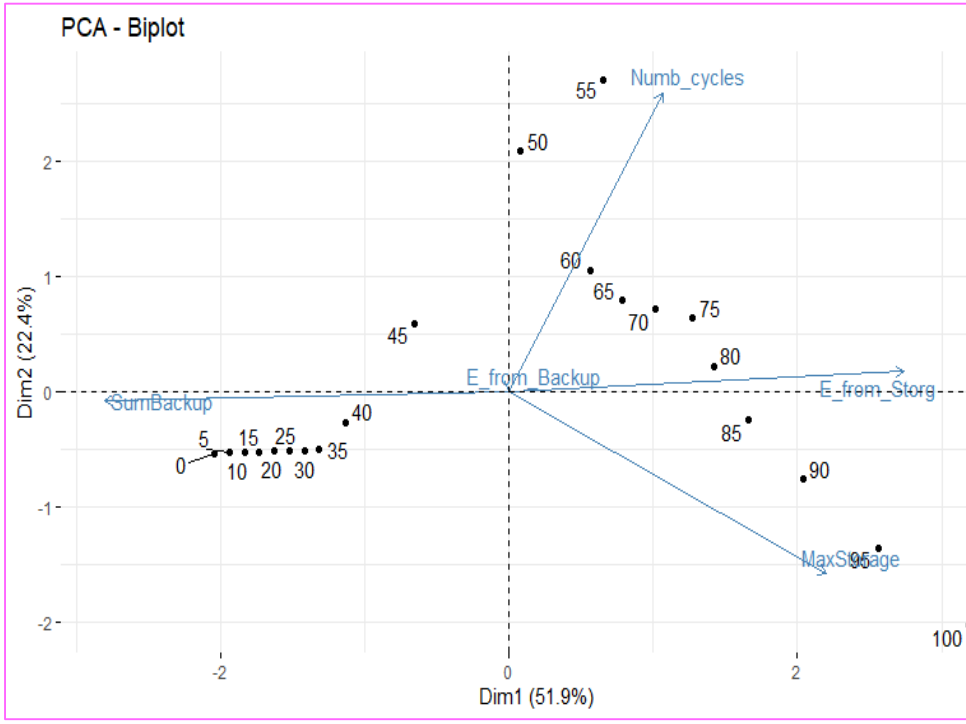
0-100% InterPec scenario

0% SolarWind



	MaxStorage	Numb_cycles	E_from_Storg	SumBackup	E_from_Backup
MaxStorage	1.0	-0.1	0.6	-0.7	NA
Numb_cycles	-0.1	1.0	0.5	-0.4	NA
E_from_Storg	0.6	0.5	1.0	-0.9	NA
SumBackup	-0.7	-0.4	-0.9	1.0	NA
E_from_Backup	NA	NA	NA	NA	1

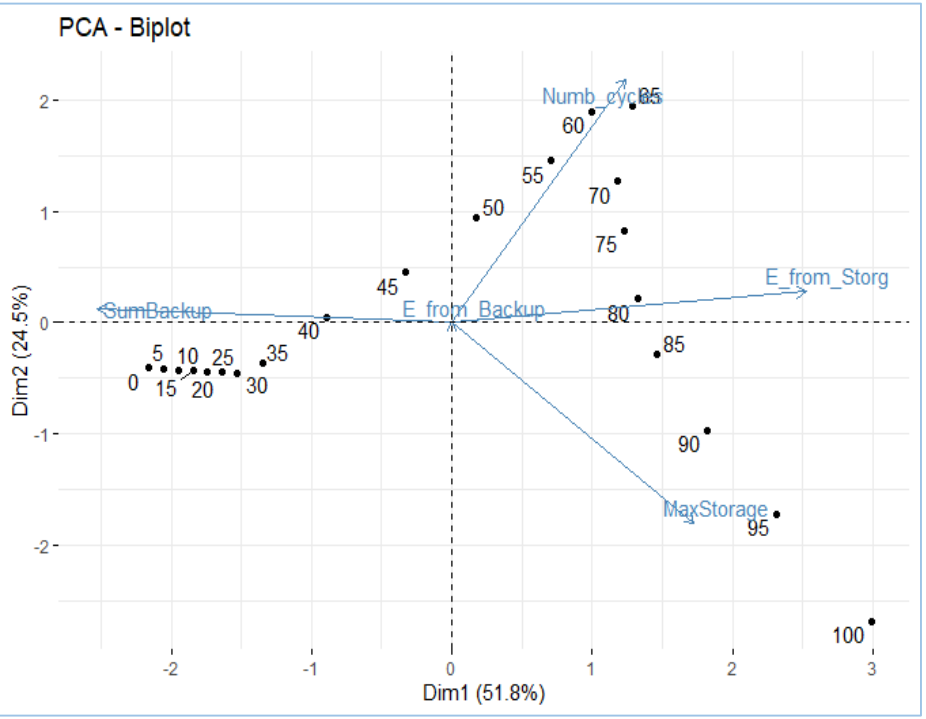
25% Solar



	MaxStorage	Numb_cycles	E_from_Storg	SumBackup	E_from_Bac
MaxStorage	1.0	-0.1	0.6	-0.7	
Numb_cycles	-0.1	1.0	0.4	-0.4	
E_from_Storg	0.6	0.4	1.0	-0.9	
SumBackup	-0.7	-0.4	-0.9	1.0	
E_from_Backup	NA	NA	NA	NA	

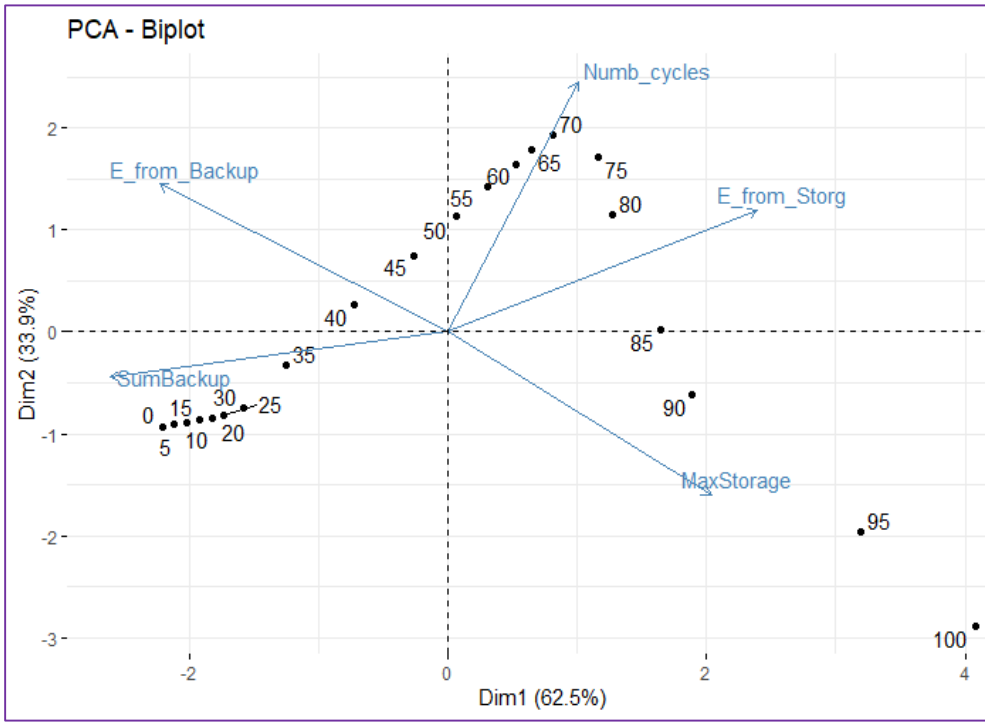
0-100% InterPec scenario

50% SolarWind



	MaxStorage	Numb_cycles	E_from_Storg	SumBackup	E_from_Backup
MaxStorage	1.0	-0.2	0.5	-0.6	NA
Numb_cycles	-0.2	1.0	0.5	-0.4	NA
E_from_Storg	0.5	0.5	1.0	-1.0	NA
SumBackup	-0.6	-0.4	-1.0	1.0	NA
E_from_Backup	NA	NA	NA	NA	1

75% Solar



	MaxStorage	Numb_cycles	E_from_Storg	SumBackup	E_from_Backup
MaxStorage	1.0	-0.2	0.4	-0.6	-0
Numb_cycles	-0.2	1.0	0.7	-0.5	0
E_from_Storg	0.4	0.7	1.0	-0.9	-0
SumBackup	-0.6	-0.5	-0.9	1.0	0
E_from_Backup	-0.9	0.2	-0.5	0.7	1