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Modeling Supply and Demand Dynamics in Energy Systems Planning

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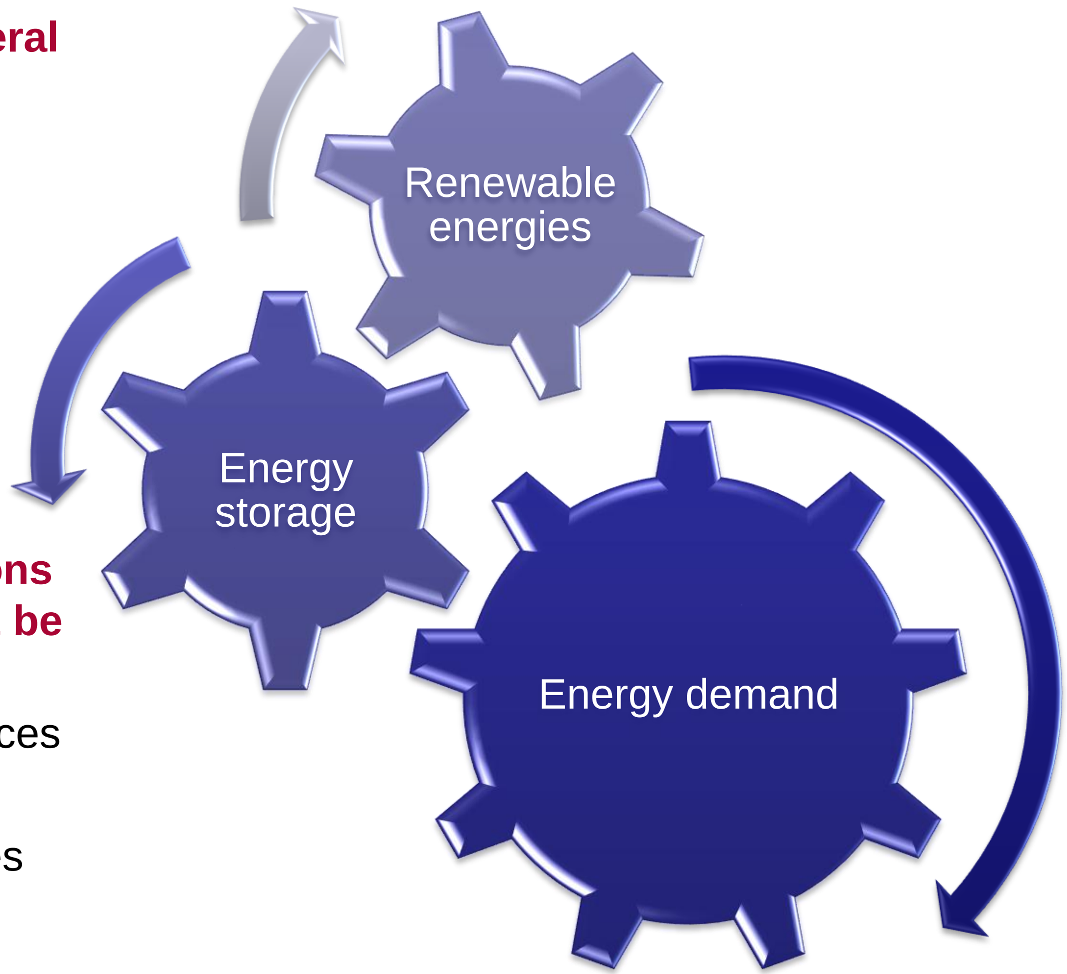
Planning Future Energy Systems

To design sustainable energy, several options must be considered:

- Renewable resources
- Energy storage
- Consumer behavior
- Energy efficiency
- Alternative transportation fuels (biofuels, electricity, others)

To design effectively, the interactions between the possible options must be accounted for:

- Intermittency of renewable resources
- Evolution of energy consumption
- Impact of energy efficiency policies
- Charging of electric vehicles



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Available Tools

Tool	Type						
	Simulation	Scenario	Equilibrium	Top-down	Bottom-up	Operation optimisation	Investment optimisation
AEOLIUS	Yes	–	–	–	Yes	–	–
BALMOREL	Yes	Yes	Partial	–	Yes	Yes	Yes
BCHP Screening Tool	Yes	–	–	–	Yes	Yes	–
COMPOSE	–	–	–	–	Yes	Yes	Yes
E4cast	–	Yes	Yes	–	Yes	–	Yes
EMCAS	Yes	Yes	–	–	Yes	–	Yes
EMINENT	–	Yes	–	–	Yes	–	–
EMPS	–	–	–	–	–	Yes	–
EnergyPLAN	Yes	Yes	–	–	Yes	Yes	Yes
energyPRO	Yes	Yes	–	–	–	Yes	Yes
ENPEP-BALANCE	–	Yes	Yes	Yes	–	–	–
GTMax	Yes	–	–	–	–	Yes	–
H2RES	Yes	Yes	–	–	Yes	Yes	–
HOMER	Yes	–	–	–	Yes	Yes	Yes
HYDROGEMS	–	Yes	–	–	–	–	–
IKARUS	–	Yes	–	–	Yes	–	Yes
INFORSE	–	Yes	–	–	–	–	–
Invert	Yes	Yes	–	–	Yes	–	Yes
LEAP	Yes	Yes	–	Yes	Yes	–	–
MARKAL/TIMES	–	Yes	Yes	Partly	Yes	–	Yes
Mesap PlaNet	–	Yes	–	–	Yes	–	–
MESSAGE	–	Yes	Partial	–	Yes	Yes	Yes
MiniCAM	Yes	Yes	Partial	Yes	Yes	–	–
NEMS	–	Yes	Yes	–	–	–	–
ORCED	Yes	Yes	Yes	–	Yes	Yes	Yes
PERSEUS	–	Yes	Yes	–	Yes	–	Yes
PRIMES	–	–	Yes	–	–	–	–
ProdRisk	Yes	–	–	–	–	Yes	Yes
RAMSES	Yes	–	–	–	Yes	Yes	–
RETScreen	–	Yes	–	–	Yes	–	Yes
SimREN	–	–	–	–	–	–	–
SIVAEL	–	–	–	–	–	–	–
STREAM	Yes	–	–	–	–	–	–
TRNSYS16	Yes	Yes	–	–	Yes	Yes	Yes
UniSyD3.0	–	Yes	Yes	–	Yes	–	–
WASP	Yes	–	–	–	–	–	Yes
WILMAR Planning Tool	Yes	–	–	–	–	Yes	–

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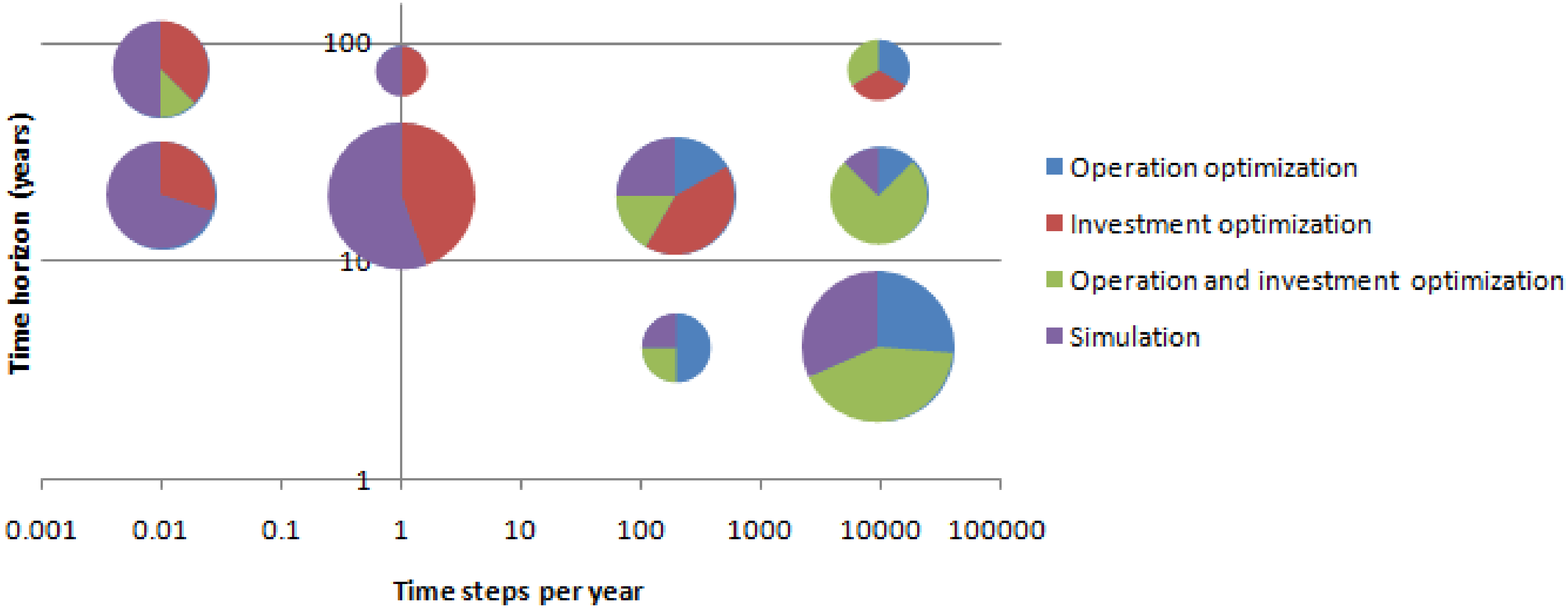
Analysis of energy planning tools

Analysis of 84 energy models showed that:

- Simulation and Invesment optimization models are generally used for simulation of medium and long-term case studies with low resolution
- Operation optimization and Operation and investment optimization models are generally applied to case studies with higher time-resolution than 1h.



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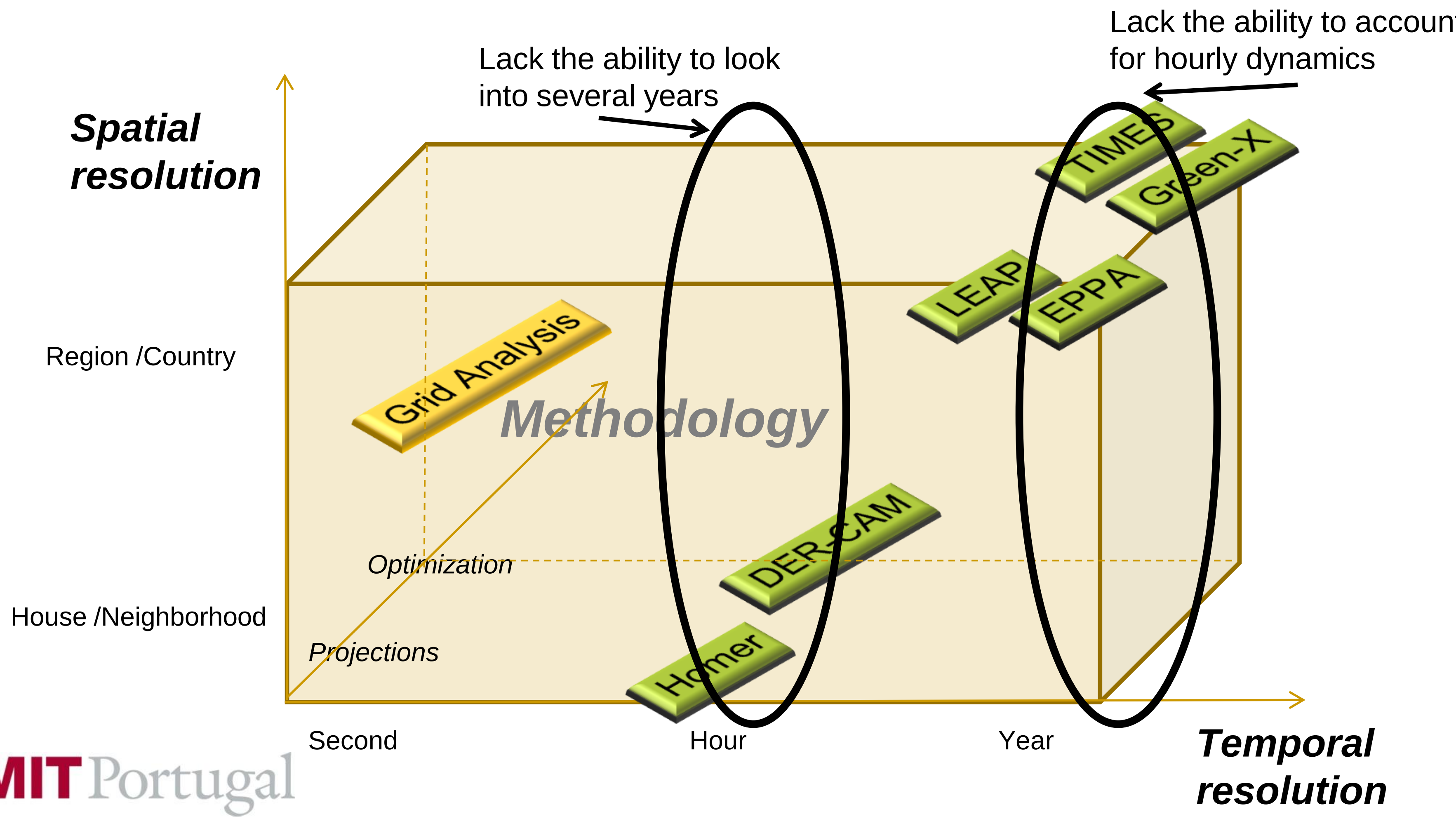
Modeling gaps

Tools have very different scopes, resolution and algorithms.



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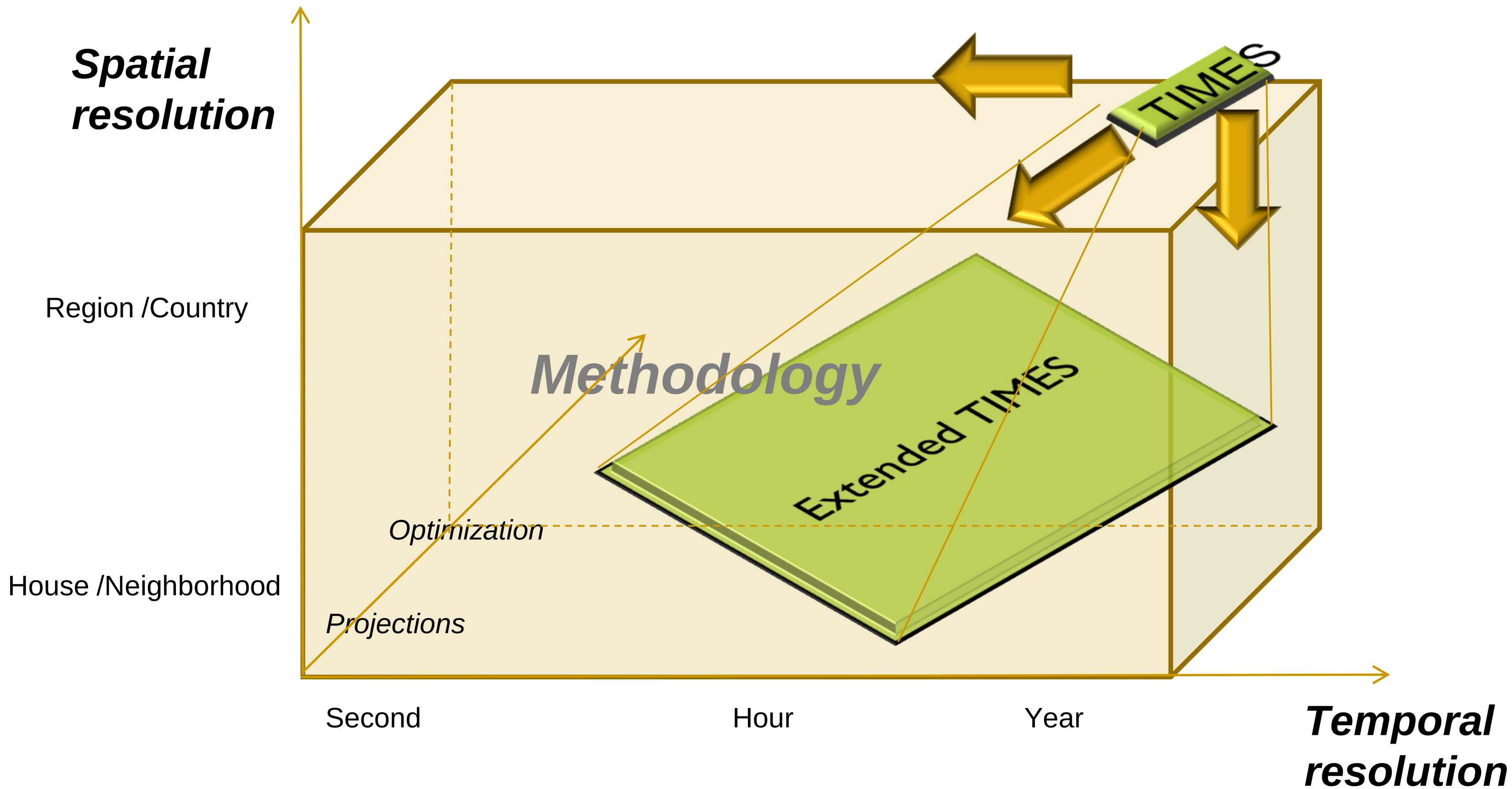
Research goal



TIMES-MARKAL

TIMES-MARKAL is an energy-economy-environmental model developed under the International Energy Agency's "Energy Technology Systems Analysis Programme".

It is a bottom-up optimization model with the following characteristics:

- It does multi-year optimization (computes the least cost path of an energy system for the specified time frame), but does not have to run every year
- Can be used at the global, multi-regional, national, state/province or community level
- The number and lenght of time slices are defined by the user, within three levels (seasonal (or monthly), weekdays/weekends, hour of the day), with the user being able to choose what degree of resolution to give to each process
- Can test a series of policy options, such as CO_2 constraints, taxes or subsidies

TIMES model Inputs/outputs

Inputs

Demand
- Drivers
- Demand curves
- Sectorial demand
- Energy services consumption

Supply
- Existing energy sources
- Potentials
- Imports
- Costs
- Availability of resources
- Storage

Policy
- Taxes
- Subsidies
- Limitation on installed capacities

Techno-economic
- Commodity transformation technologies: electricity generation, services consumption
- Costs
- Efficiencies

Outputs

Installed capacities for each supply and demand technologies, energy fluxes, final energy prices, total system cost, GHG emissions

Modeling dynamics in TIMES

The models being developed are new applications of TIMES, as they try to include some supply and demand dynamics, with higher than usual time resolution.

Each model is divided into 288 time periods of the year:

- 4 seasons
- 3 days per season (Saturday, Sunday and weekday)
- **24h per day** ⟶ **Main new feature**

Supply dynamics were included in the wind, hydro and geothermal resources, as different periods have different availabilities

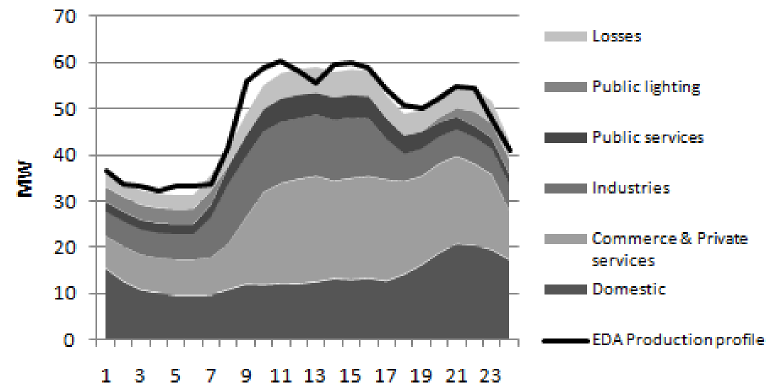
11 different sectors for electricity demand, with the domestic sector divided in 9 subsectors. Each sector and subsector has a different load curve for each day.

Three models have been built using TIMES: São Miguel, Flores and Portugal (CCS, Waves)

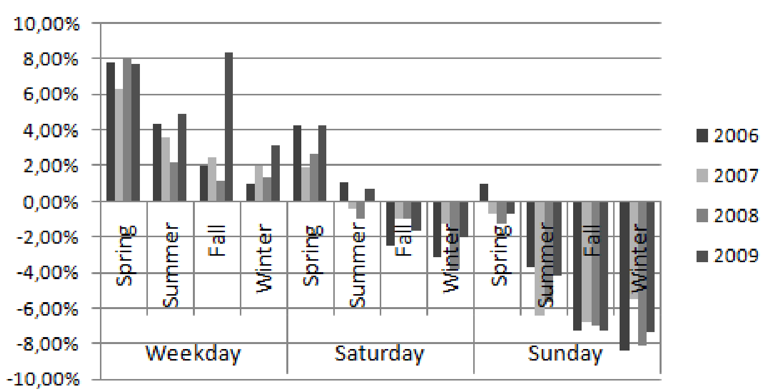
Modeling São Miguel island with TIMES

The reconstructed load curves show that the model is able to estimate with some accuracy the evolution of the demand curve through the years.

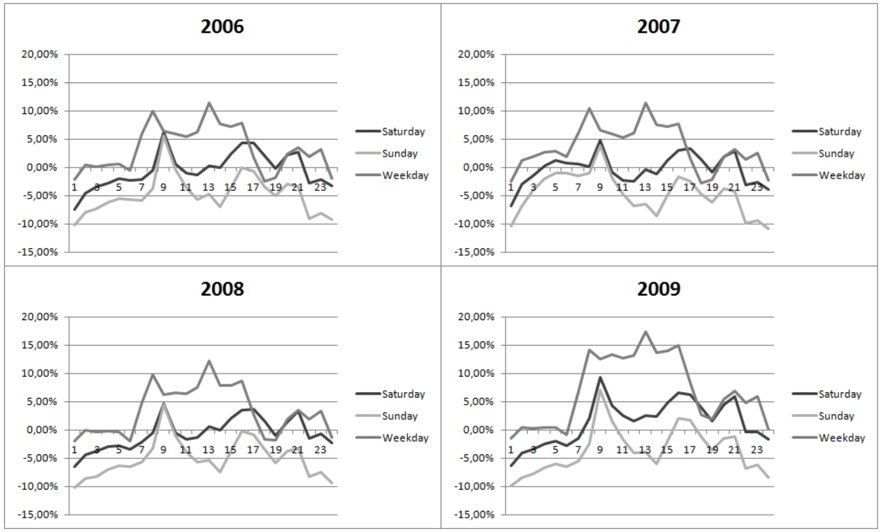
Some problems still exist in the model as weekdays are usually overestimated and Sundays are underestimated.



Reconstructed load curve



Average relative error for each day



Average relative error for each hour of each type of day

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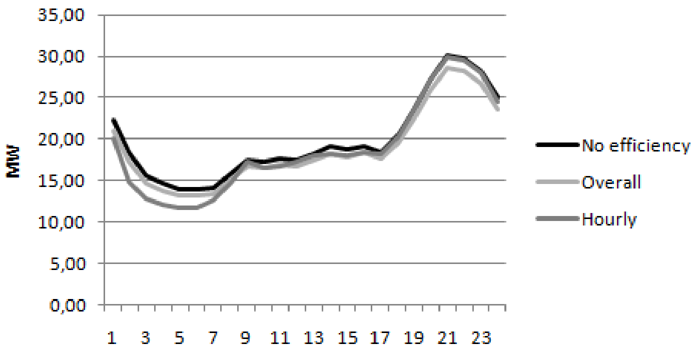
Modeling São Miguel island with TIMES

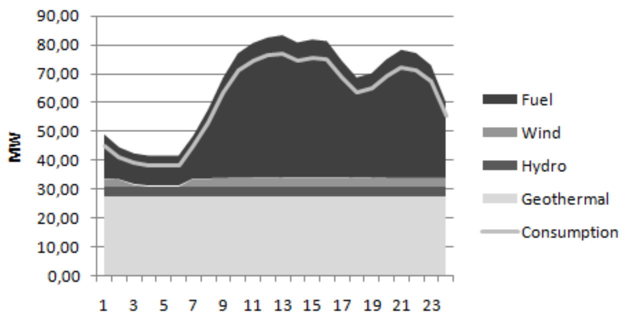
Modeling the impact of eliminating standby power:

- Reduction of 5% in each hour of domestic consumption (Overall scenario)
- Different hours have different reduction potentials (Hourly scenario)



Different scenarios for the domestic curve in 2015

	Wind power installed [MW]	Electricity produced from wind energy [GWh]
Overall	15.27	29.65
Hourly	9.81	18.49



Electricity production for a specific day in 2015, for the Hourly scenario

Even with the lower installed capacity, some wind turbines would not be able to produce electricity during the night.

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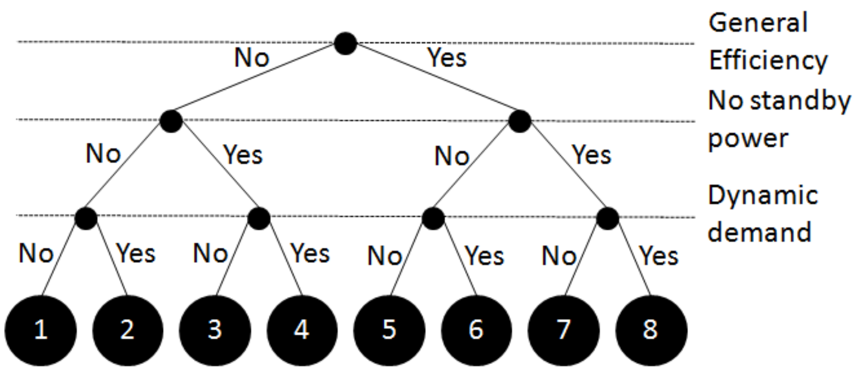
Modeling Flores island with TIMES

Scenario based approach to study different future energy options:

- **General efficiency**
  - If there is an increase in overall energy efficiency, demand growth is reduced to 50% of what it would have been using a linear trend
- **No standby power**
  - Gradually eliminate stand-by power (starting in 2011 and disappearing completely by 2015). Stand-by power is estimated to account for 5% of the electricity consumed in the domestic sector in Portugal
- **Dynamic demand**
  - Gradually enable washers, dryers and dish washing machines to be operated remotely by the grid operator when it is more convenient. Start of introduction in 2013, with all machines having this capability by 2018.



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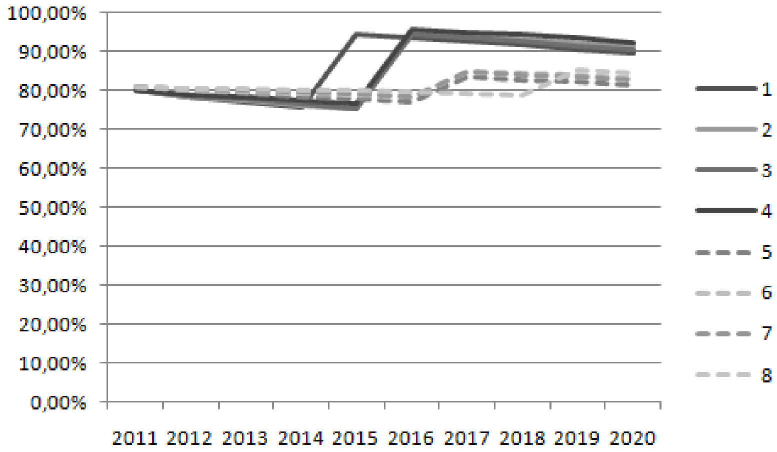
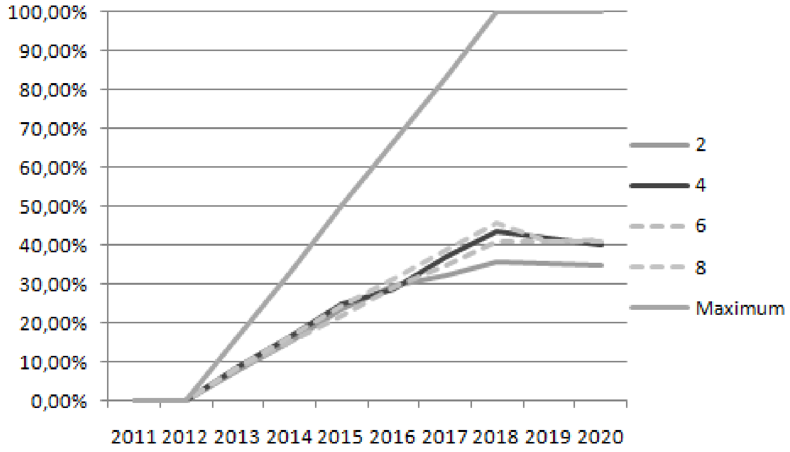
Modeling Flores island with TIMES

Higher demand growths lead to larger investments in renewable energies, thus allowing a higher penetration of renewable energies.

The load shifting capabilities were used to increase the capacity factors of the installed renewables, and postpone the need to install more generation capacity.



Penetration of renewables



Fraction of load shifted

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Comparison with other modeling methodologies – Flores case study (Gustavo+Vitor)

Comparison between three methodologies for modeling 1 year:

- Dynamic: 8760 hours (ENERGYPLAN)
- Semi-Dynamic: 288 time-periods (applied in TIMES)
- Integral: 9 time-periods (methodology of LEAP)

Goal: compare the losses on renewable energy production captured by each methodology

Resource	Installed Power 2008 (kW)	Scenario A 2020	Scenario B 2020	Scenario C 2020	Scenario D 2020
Diesel	2,700	2,700	2,700	2,700	2,700
Total Fossil	**2,700**	**2,700**	**2,700**	**2,700**	**2,700**
Hydro	1,480	1,480	1,480	1,480	1,480
Wind	600	600	600	600	600
New Hydro	0	0	600	1,200	1,200
New Wind	0	500	1,000	1,500	2,200
Total Renewable	**2,080**	**2,580**	**3,680**	**4,780**	**5,480**
TOTAL	**4,780**	**5,280**	**6,380**	**7,480**	**8,180**
TOTAL / Peak	**2.49**	**1.61**	**1.94**	**2.28**	**2.49**
Renewable / Peak	**1.08**	**0.79**	**1.12**	**1.46**	**1.67**

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Comparison with other modeling methodologies – Flores case study

Energy Supplied by Renewables

Scenarios	Integral	Dynamic	Semi-dynamic
Scenario A	33.9%	33.9%	34.0%
Scenario B	48.5%	48.0%	48.6%
Scenario C	63.0%	58.9%	62.6%
Scenario D	72.9%	63.9%	71.1%

Energy not used (KWh)

Scenarios	Integral	Dynamic	Energy wasted kWh (Semi-dynamic)
Scenario A	0.00	10	0
Scenario B	0.00	95,977	148
Scenario C	0.00	832,764	111,351
Scenario D	0.00	1,874,367	424,675

> 600 kW wind capacity

Scenarios	Waste in % of Demand (Integral)	Waste in % of Demand (Dynamic)	Waste in % of Demand (Semi-dynamic)
Scenario A	0.00%	0.00%	0.00%
Scenario B	0.00%	0.46%	0.00%
Scenario C	0.00%	4.03%	0.54%
Scenario D	0.00%	9.08%	2.06%

Scenarios	Emissions tCO2 (Integral)	Emissions tCO2 (Dynamic)	Emissions tCO2 (Semi-dynamic)
Scenario A	3,411	3,411	3,406
Scenario B	2,661	2,685	2,654
Scenario C	1,911	2,119	1,930
Scenario D	1,397	1,866	1,491

Methodological thinking

In order to reduce the computational complexity of the problem, the proposed methodology consists in the use of two different tools.

Medium-term model

- Multi-year optimization of investments in renewable energies
- Some hourly dynamics
- Detailed description of energy consumption:
  - Across different sectors
  - Different types of energy carriers
- Capable of understanding the evolution of the system:
  - Economic growth
  - Fuel prices
  - Energy demand

Test feasibility of the results, one year at a time

Short-term model

- Hourly optimization of electricity production for one year, taking into account:
  - Start-up costs and efficiencies for thermal engines
  - Variability of renewable resources
    - Solar
    - Wind
    - Hydro
  - Fuel prices
  - Demand profiles
  - Dynamic demand options (EVs, others)
- Optimization of use of energy storage systems

Introduction of restrictions for optimization of investments

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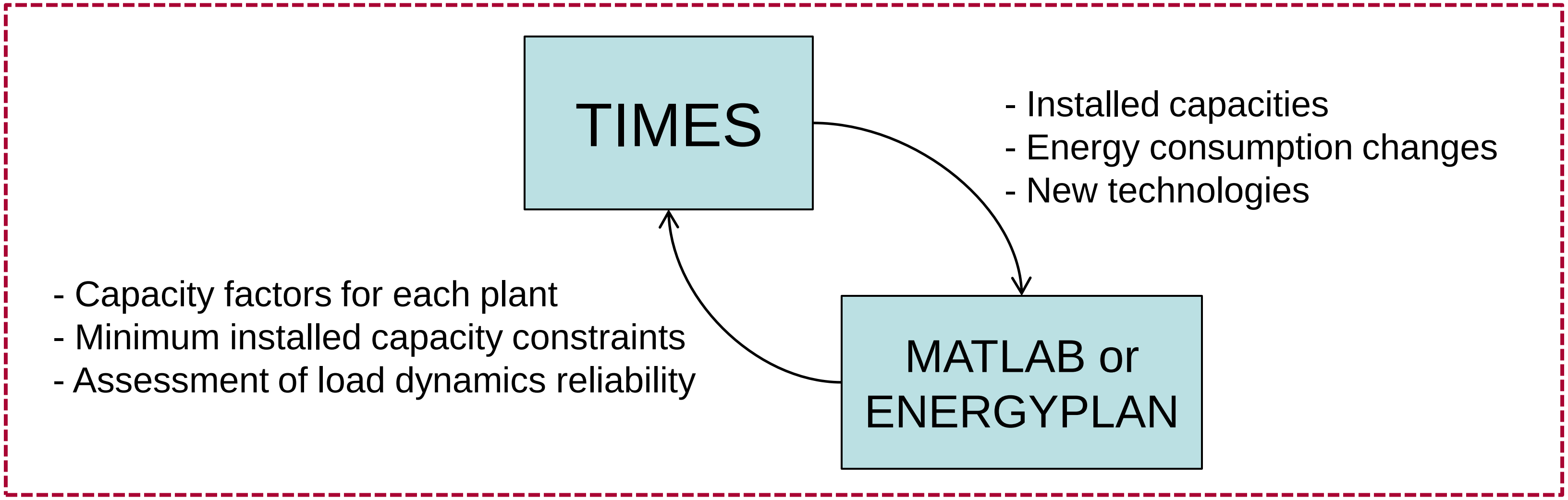
Methodological thinking

TIMES (4 seasons, 3 days, 24h) + Short-time model for key years



- Scenarios for capacities that can be installed (including storage technologies)
- More robust results regarding power system operation reliability and security

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Short-term model for S. Miguel

MATLAB model being developed by Gonçalo Pereira (MSc)

Inputs

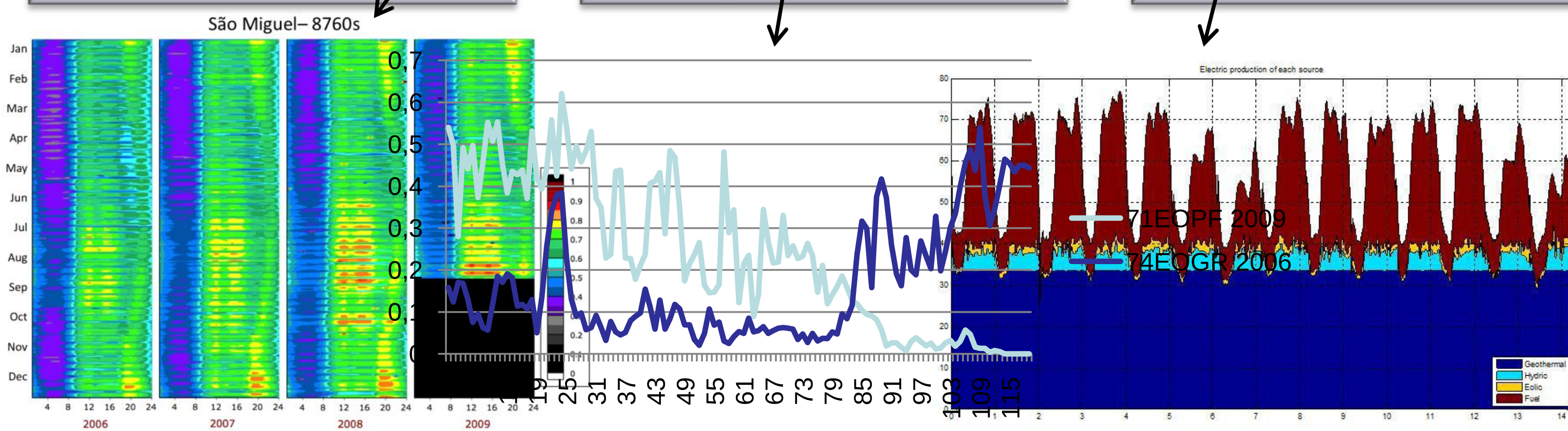
- Installed capacities for electricity generation by source
- Energy storage size and capacity
- Overall electricity demand growth

Data generation

- Electricity demand curve for the whole year
- Hourly availability for each renewable resource
  - For wind energy, historical hourly capacity factors for other islands are used

Optimization outputs

- Electricity production by source
- Charge and discharge of energy storage unit



Application of current methodology to SM

The proposed methodology was tested using the São Miguel TIMES model.

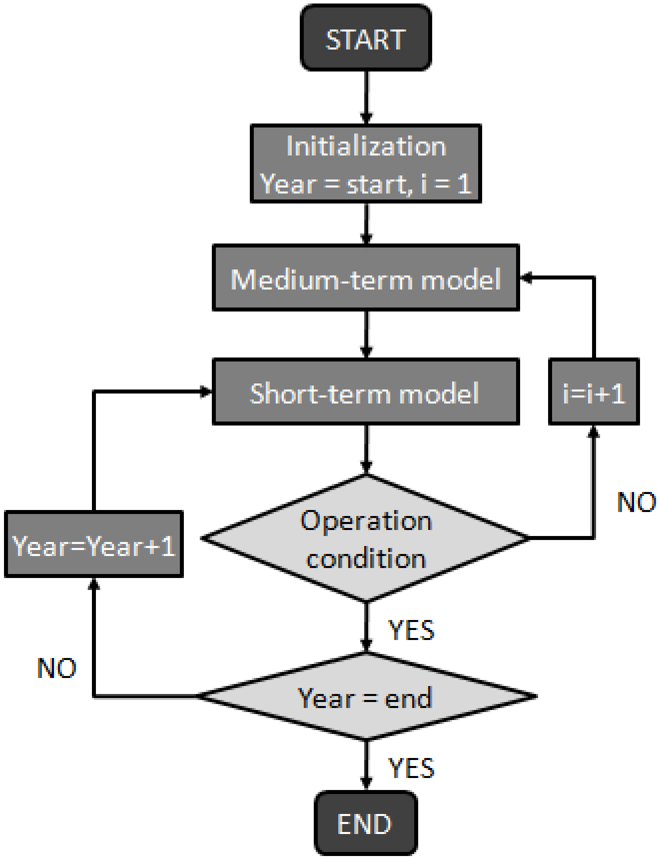
The model had to make two decisions:

- When should the 2 x 10 MW Geothermal facilities be installed
- What amount of wind energy should it install and when

The methodology was applied separately for the two decisions.

Operation conditions:

- Geothermal: the plant must have a capacity factor of 90% or higher for at least 95% of the time.
- Wind: the wind turbines produce at least 90% of the nominal capacity factor.



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Application of current methodology to SM

Total installed capacity of wind energy after each TIMES iteration.

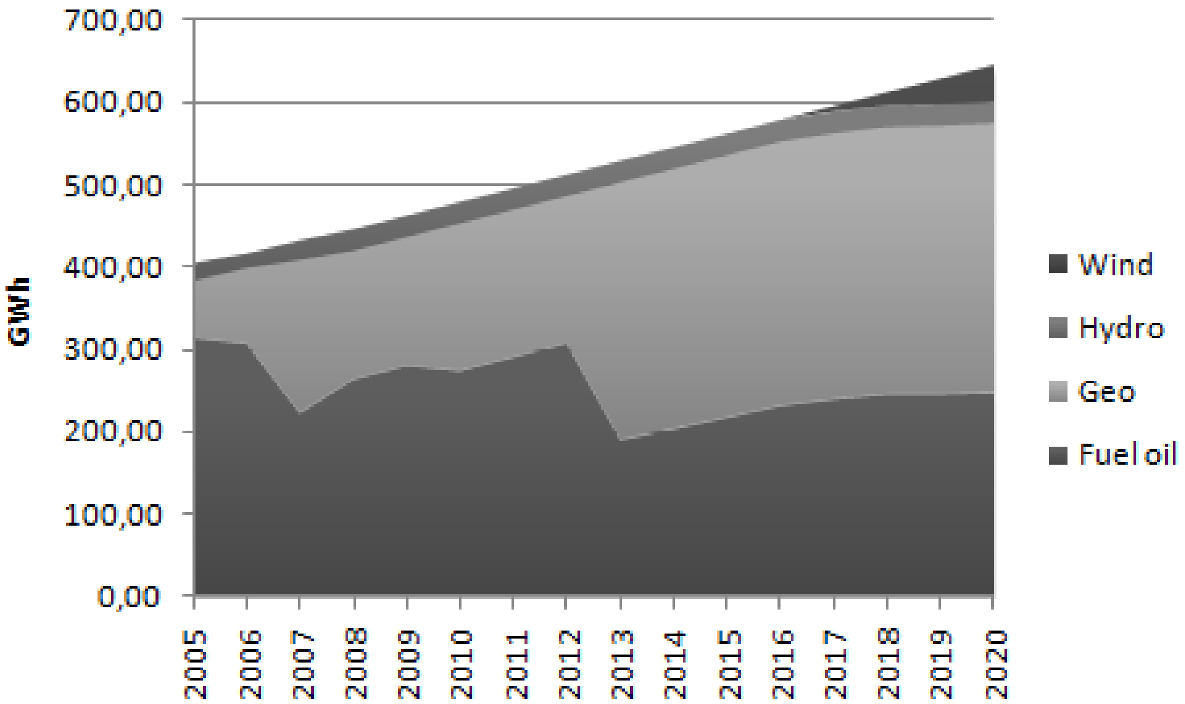
Some notes:

- TIMES processing is the first iteration of TIMES, without any constraint.
- Iteration 1 is the last iteration of the Geothermal decision process, and the first of the Wind decision process.
- Iteration 10 was the last iteration of the Wind decision process.

Iteration	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
TIMES processing	0.0	0.0	0.0	0.0	0.0	0.0	3.5	8.3	16.3	23.3
1	9.7	28.7	28.7	28.7	28.7	30.5	30.5	30.5	30.5	30.5
2	9.7	12.2	26.3	26.3	27.3	29.9	29.9	29.9	29.9	29.9
3	9.7	12.2	15.4	16.9	27.3	29.9	29.9	29.9	29.9	29.9
4	9.7	9.9	9.9	9.9	27.3	29.9	29.9	29.9	29.9	29.9
5	9.7	9.9	9.9	9.9	9.9	29.9	29.9	29.9	29.9	29.9
6	9.7	9.9	9.9	9.9	9.9	9.9	28.7	28.7	28.7	28.7
7	9.7	9.9	9.9	9.9	9.9	9.9	13.5	27.0	27.0	27.0
8	9.7	9.9	9.9	9.9	9.9	9.9	13.5	14.8	14.8	22.3
9	9.7	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	22.3
10	9.7	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9

Application of current methodology to SM

Results for the iteration TIMES processing



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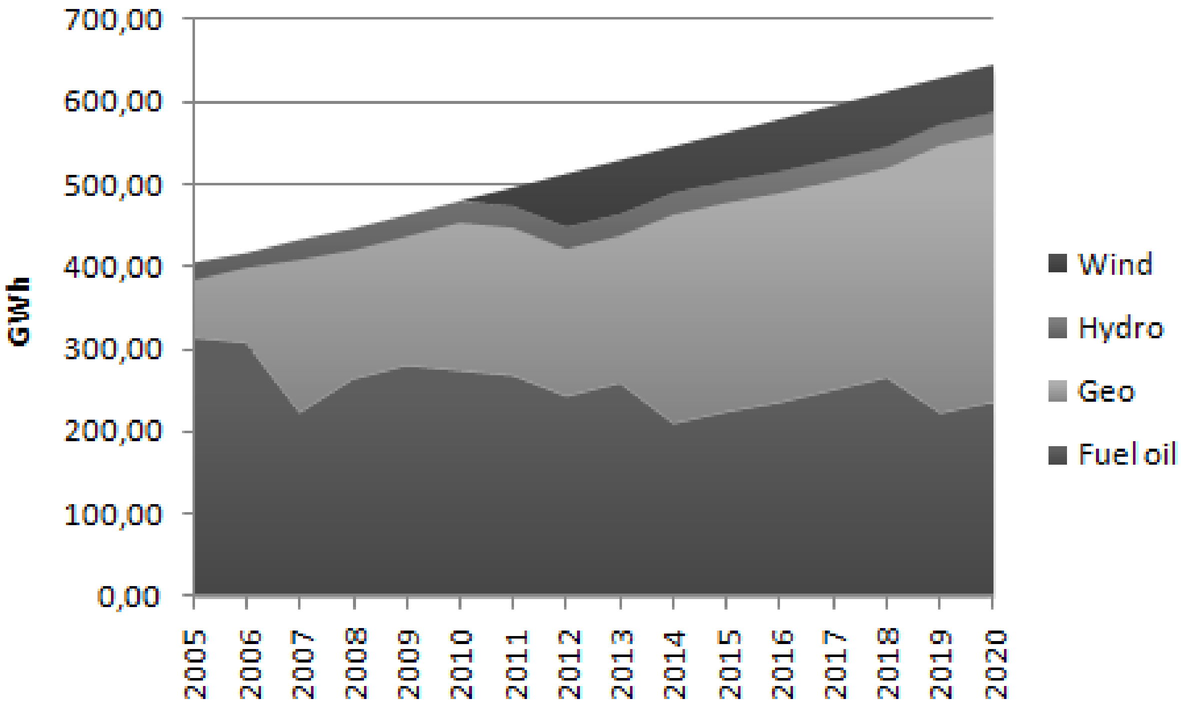
Application of current methodology to SM

Results for iteration 1



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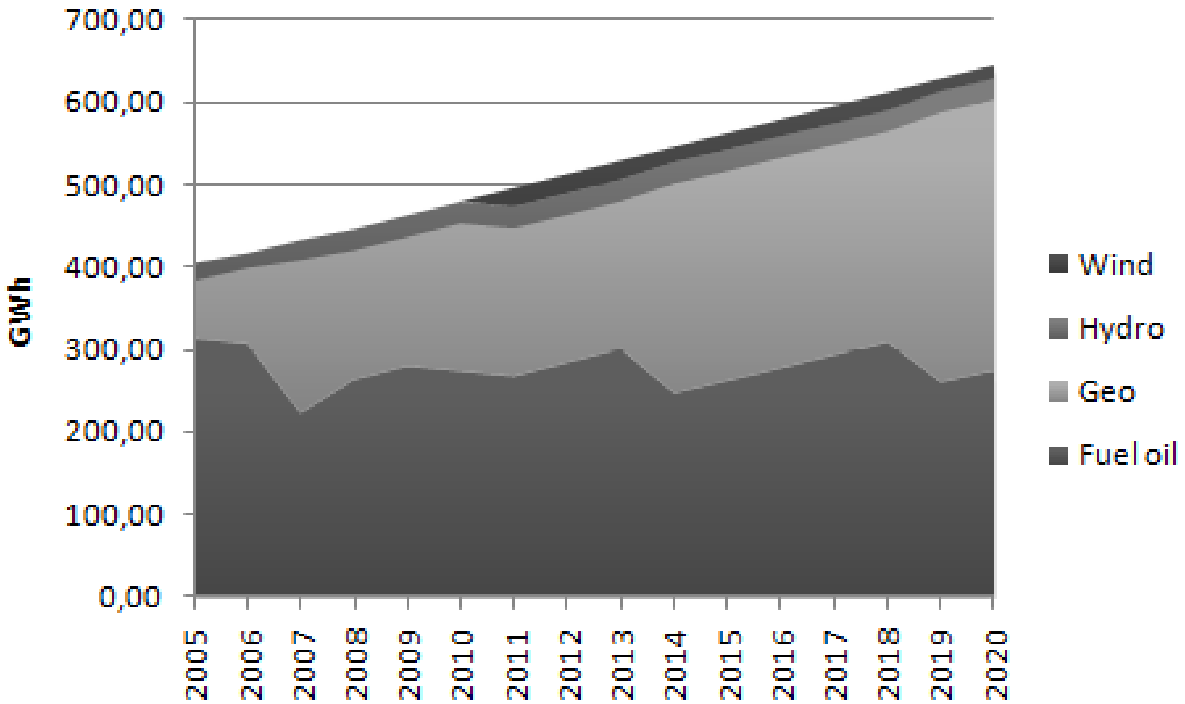
Application of current methodology to SM

Results for iteration 10



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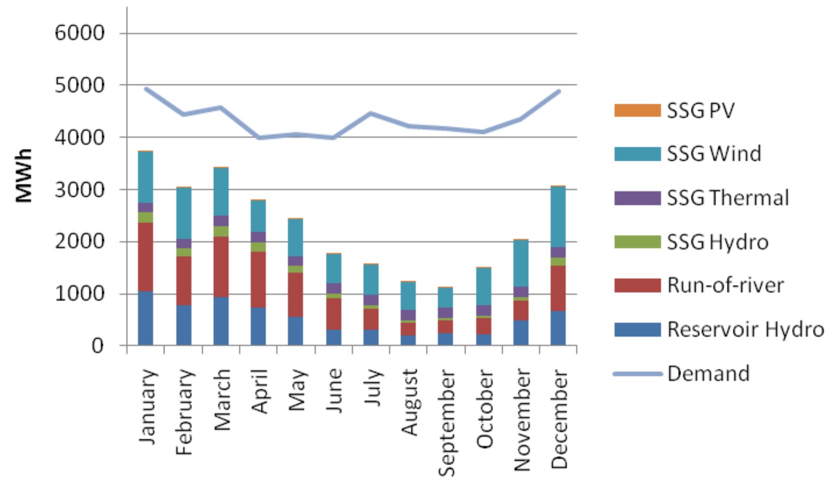
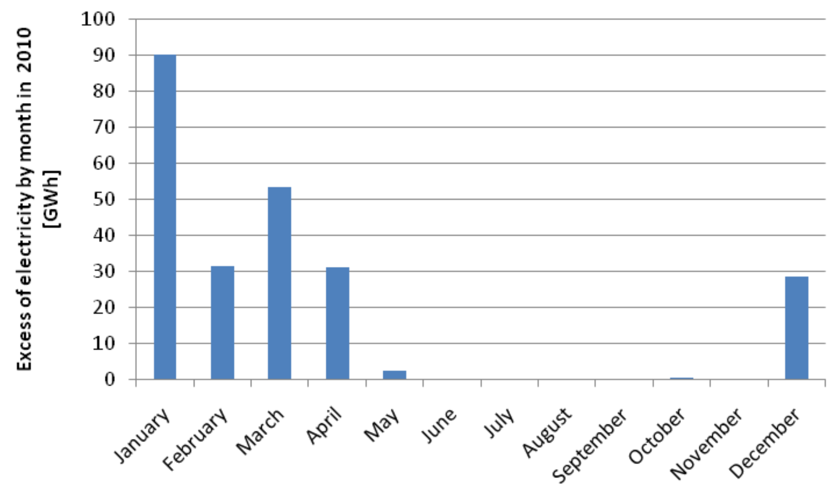
Application of current methodology to Portugal

- In 2010, renewables produced ~50% of all the electricity in Portugal
- Some periods during the Winter time had excesses of renewable electricity
- The investment in renewable generation capacity should be analysed with high temporal resolution





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Application of current methodology to Portugal

MW	2005	2006	2007	2008	2009	2010
Coal	1776	1776	1776	1776	1756	1756
Oil	1909	1909	1877	1877	1878	1822
Natural Gas	2166	2166	2166	2166	2992	3829
Large Hydro	4582	4582	4578	4578	4578	4578
Thermal Status Producers	1166	1295	1365	1424	1610	1698
Hydro Status Producers	333	365	374	385	395	410
Wind Status Producers	891	1515	2048	2662	3357	3705
Solar Status Producers	0	0	13	53	95	122
Wave Status Producers	0	0	0	2	2	2

MW	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Large Hydro	4524	5231	5231	5476	6467	7489	8394	8712	8798	8798
Small Hydro	457	503	503	550	550	600	650	650	700	750
Wind onshore	4928	5600	5600	5600	6100	6100	6100	6600	6800	6800
Wind offshore	0	0	0	0	25	25	25	25	25	75
Solar	258	340	465	590	720	860	1005	1160	1325	1500
Wave	5	5	10	35	60	75	100	125	175	250

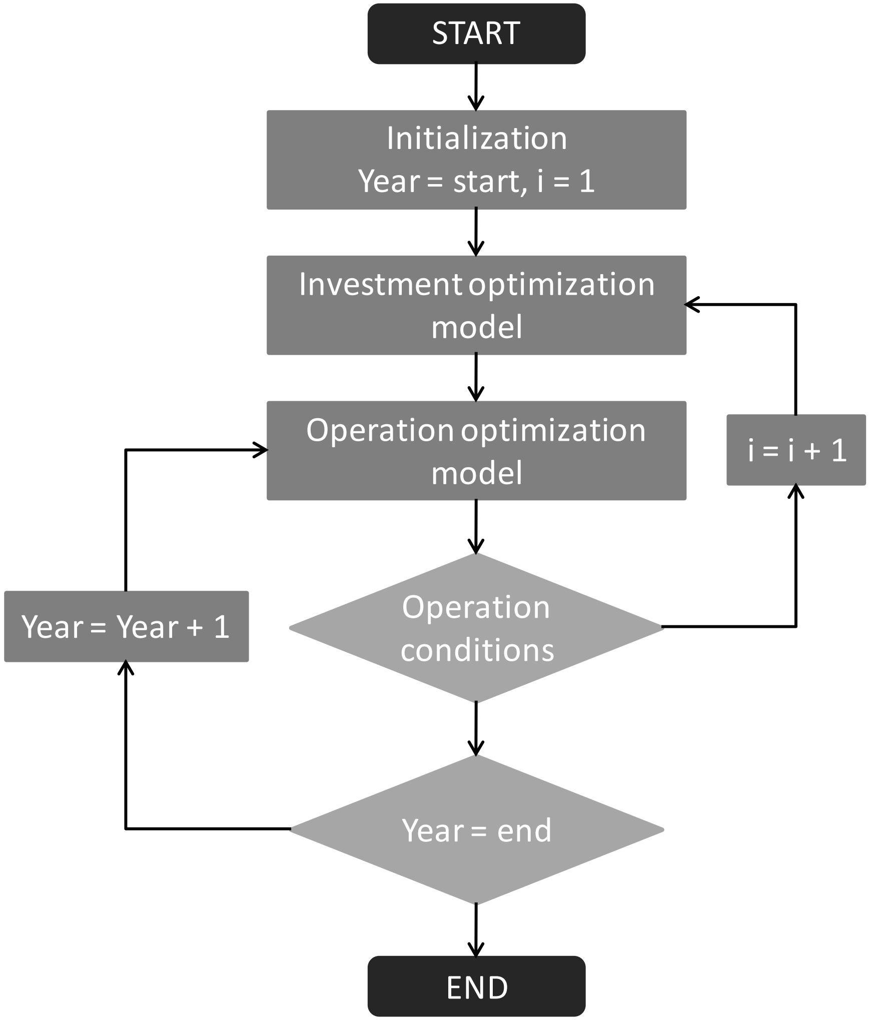
Application of current methodology to Portugal

Application of methodology with TIMES and EnergyPLAN.

- Time horizon of 2005-2050.

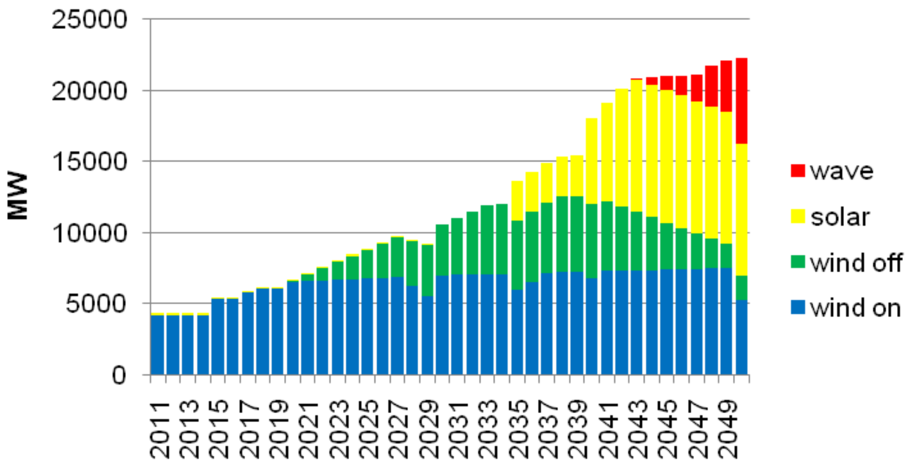
Mainland Portugal case study

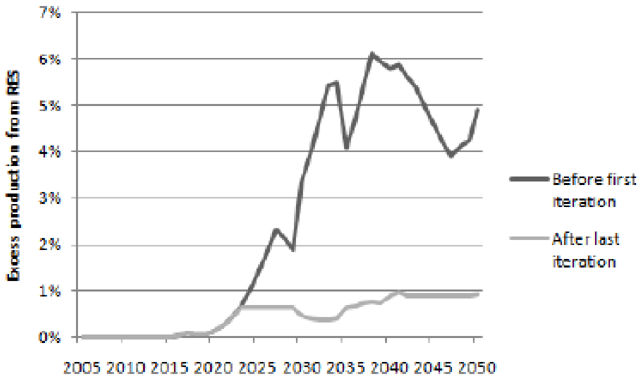
- Operation conditions:
  - *Maximization of renewable energy penetration such that the last installed MW produces at least 90% of its potential capacity factor*
- 2 scenarios concerning installed capacity for hydro pump storage (Current capacity of 1036 vs expected capacity of 4302)
- Assumed gradual reduction of CO_2 emissions to ~30% of 2005 levels in 2050



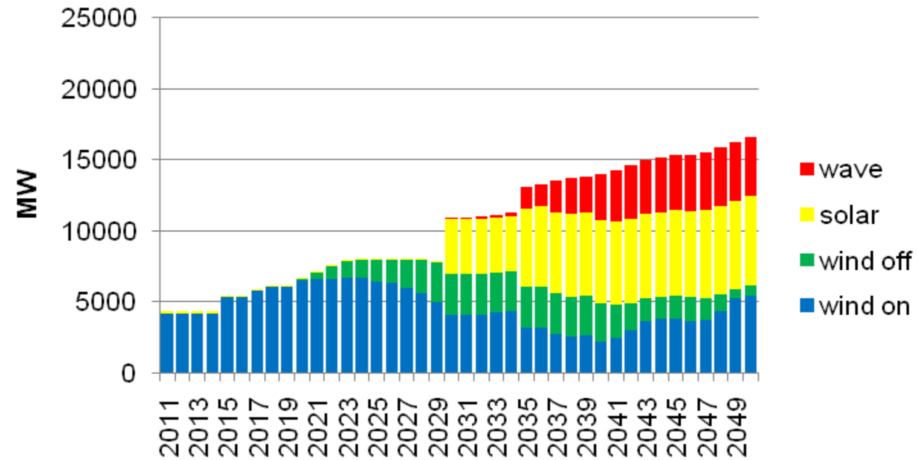
Application of current methodology to Portugal

1st iteration





Last iteration



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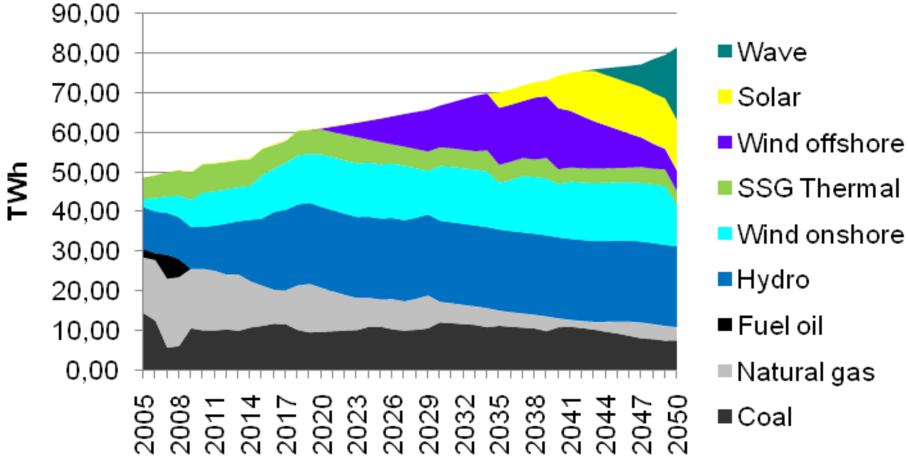
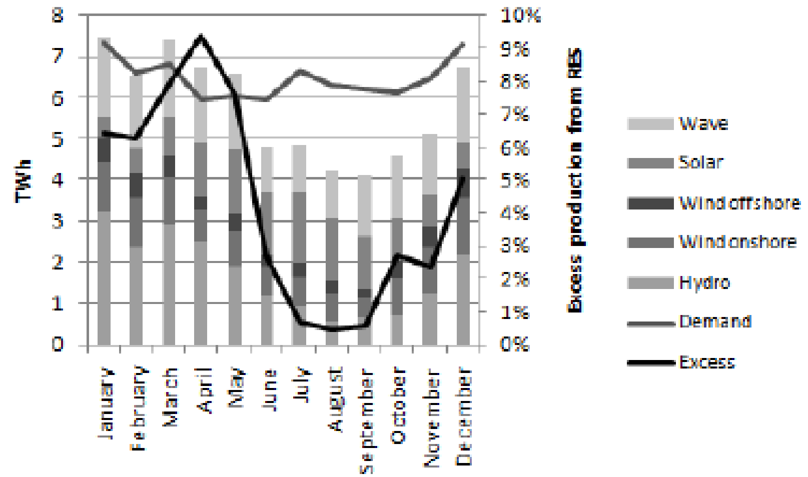
Application of current methodology to Portugal

1st iteration





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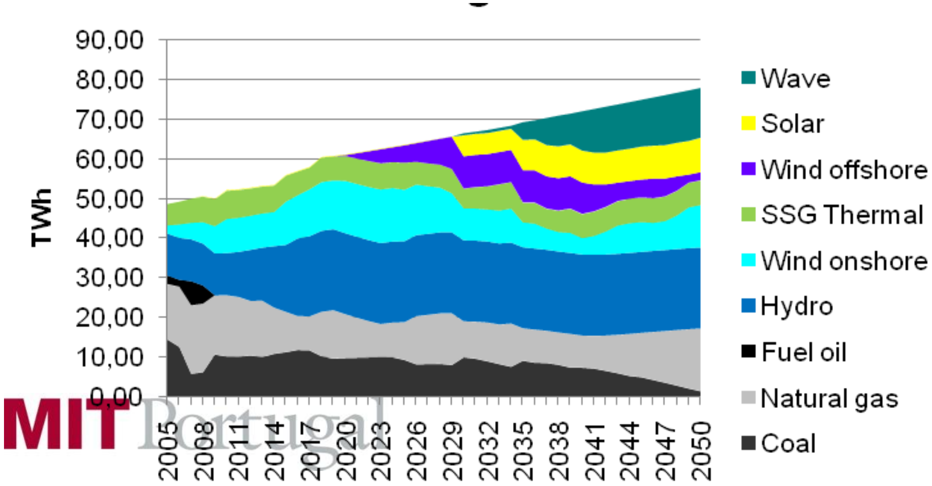
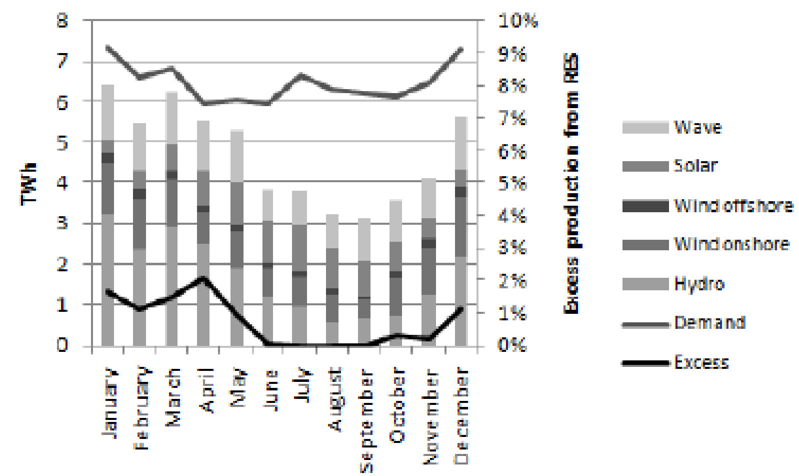
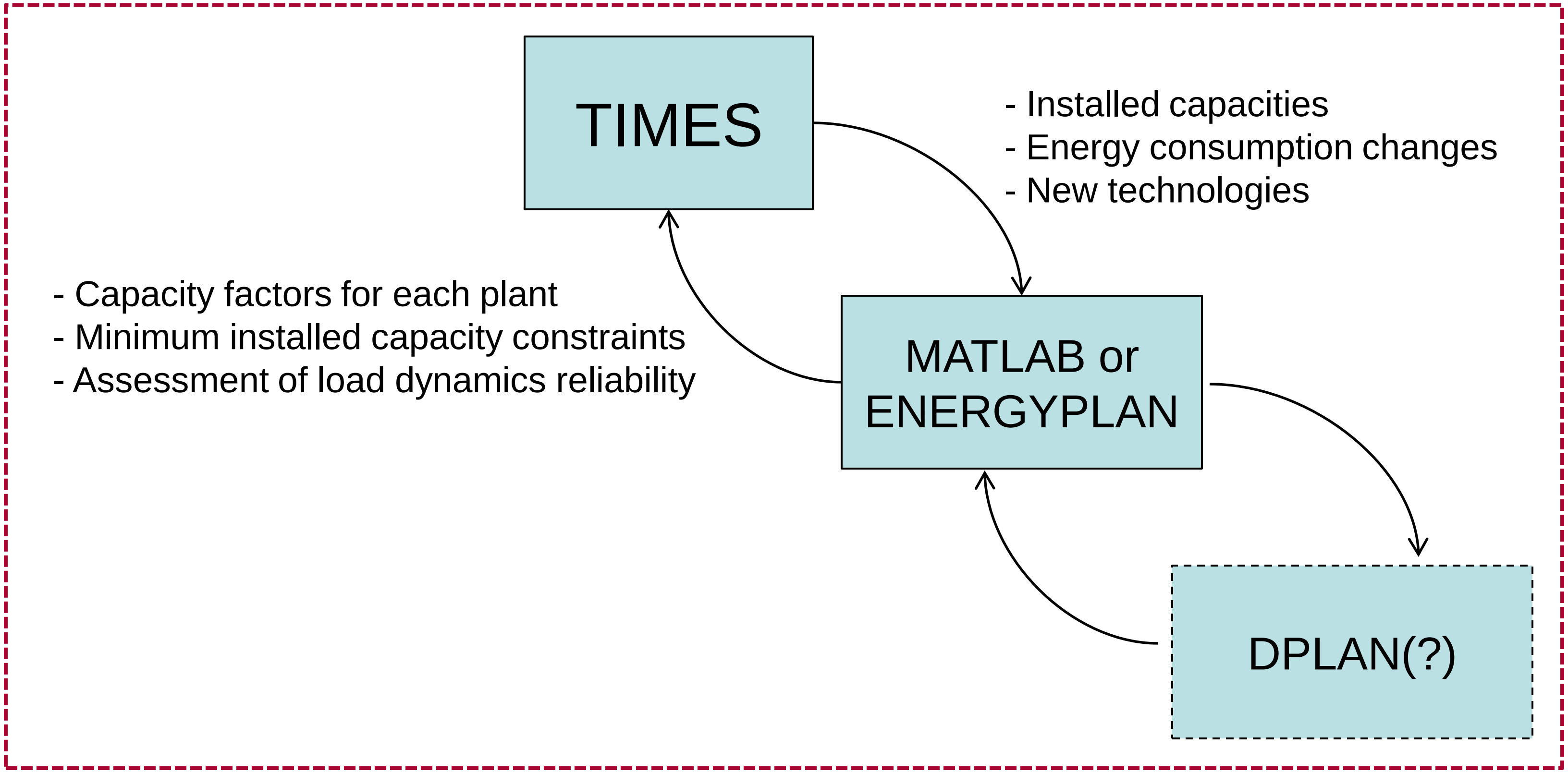




Next Methodological Step

TIMES (4 seasons, 3 days, 24h) + Short-time model for key years

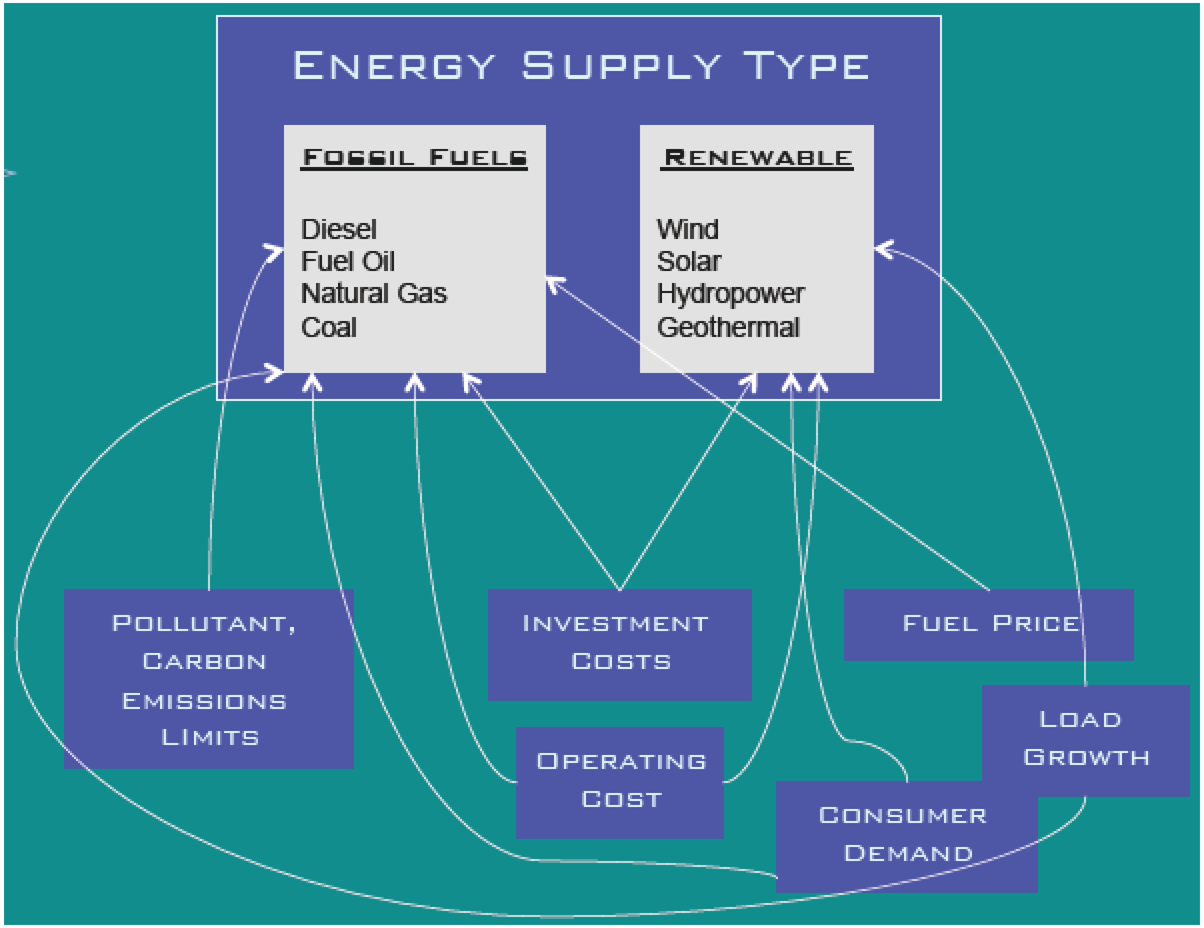


Other ideas going on:

NODES (João Claro, João Sousa)

Wind forecast using soft-computing

Flexible Networked System Design Under Uncertainty: A Case Study in Long-Term Energy Planning



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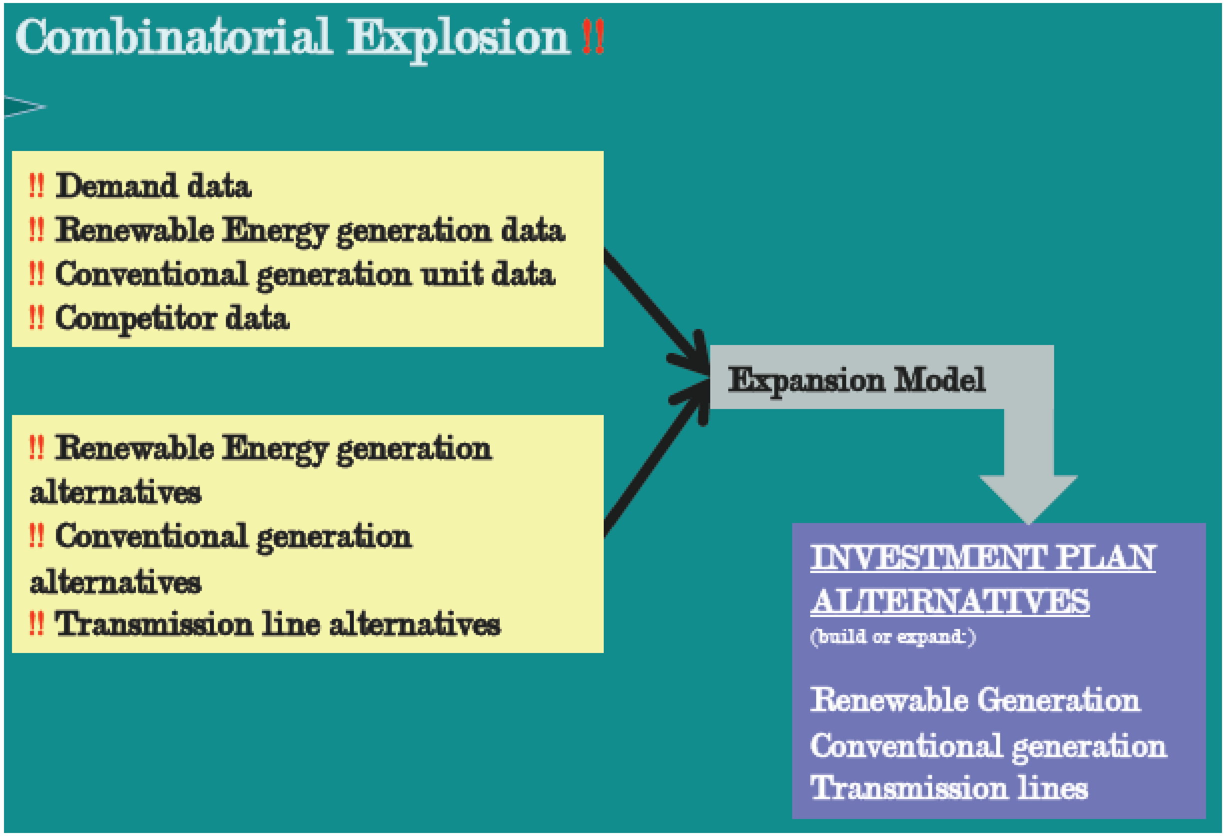
Flexible Networked System Design Under Uncertainty: A Case Study in Long-Term Energy Planning



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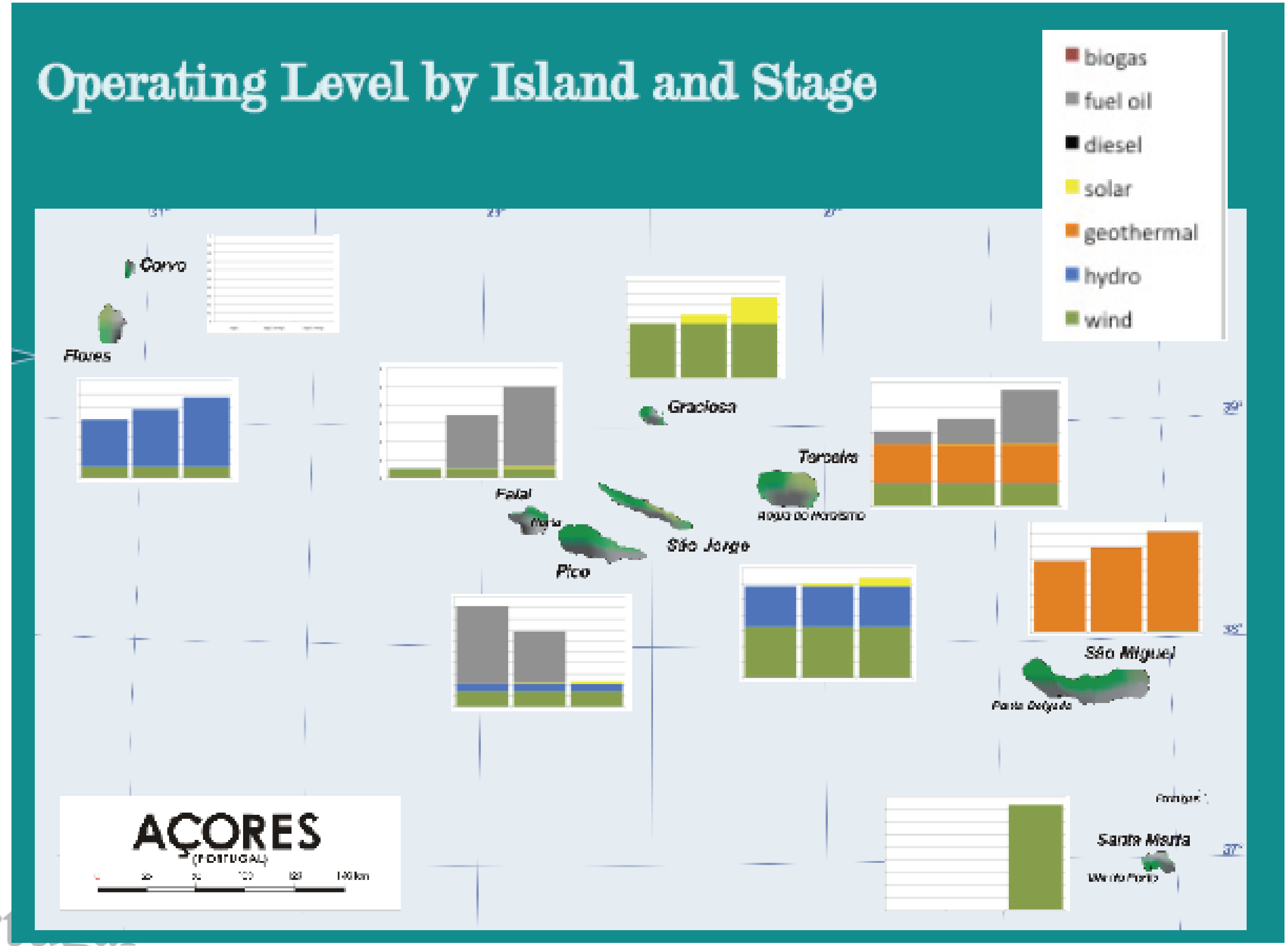
Flexible Networked System Design Under Uncertainty: A Case Study in Long-Term Energy Planning



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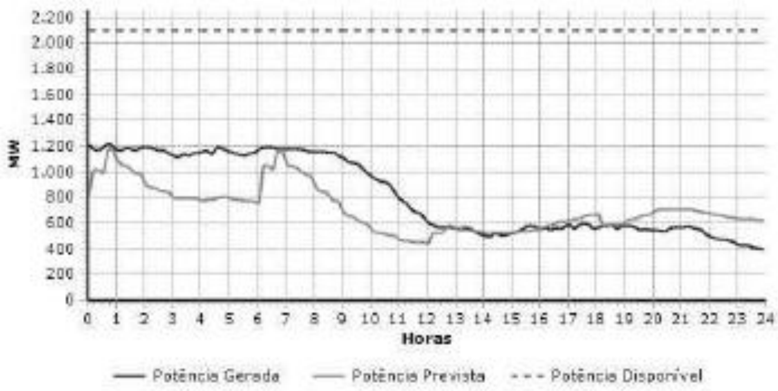
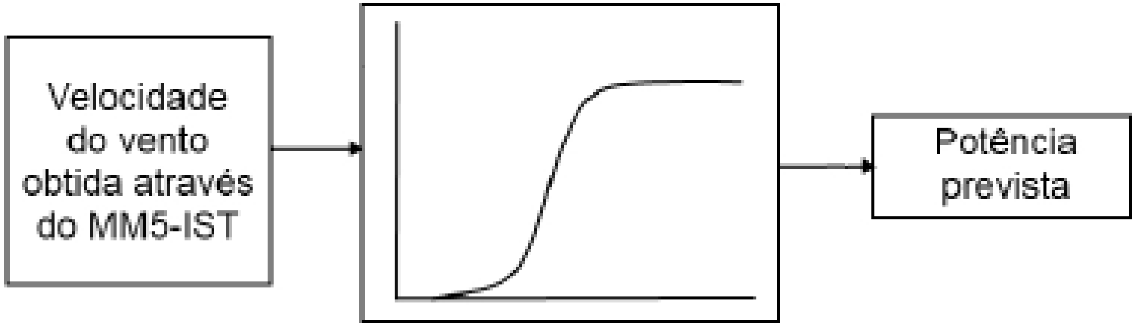
Wind forecasting using sof-computing

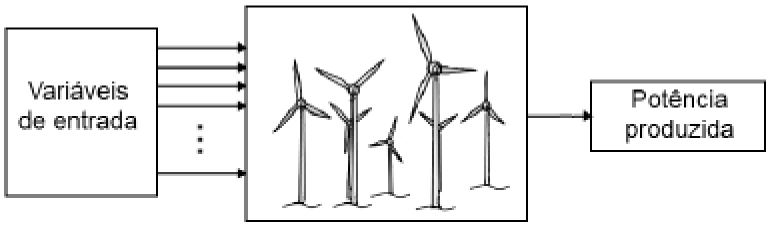


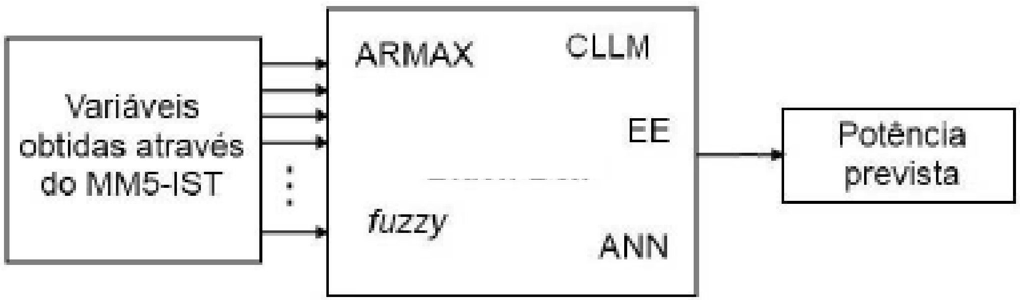
(a) 15 de Maio de 2010.

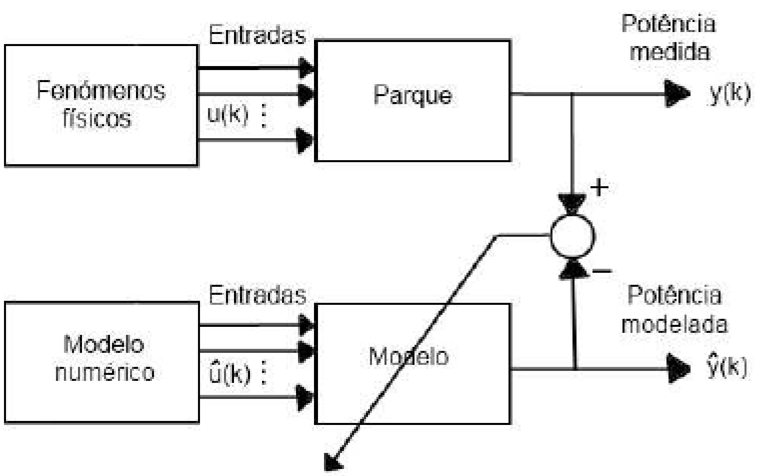
(b) 1 de Julho de 2010.



Wind forecasting using soft-computing







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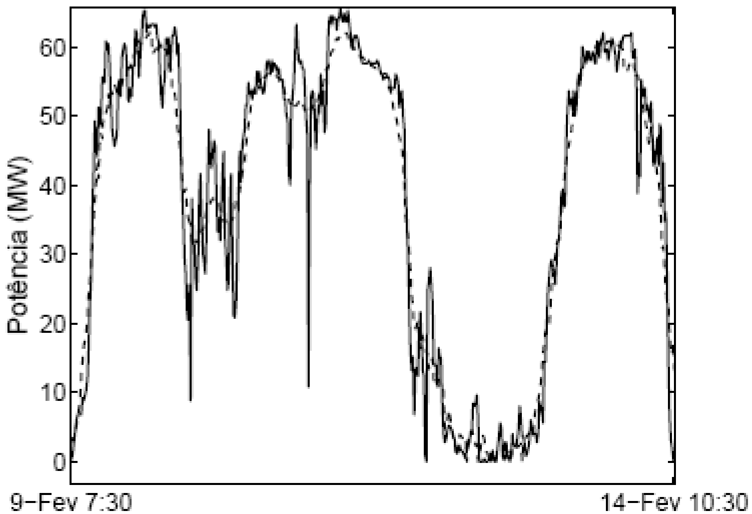
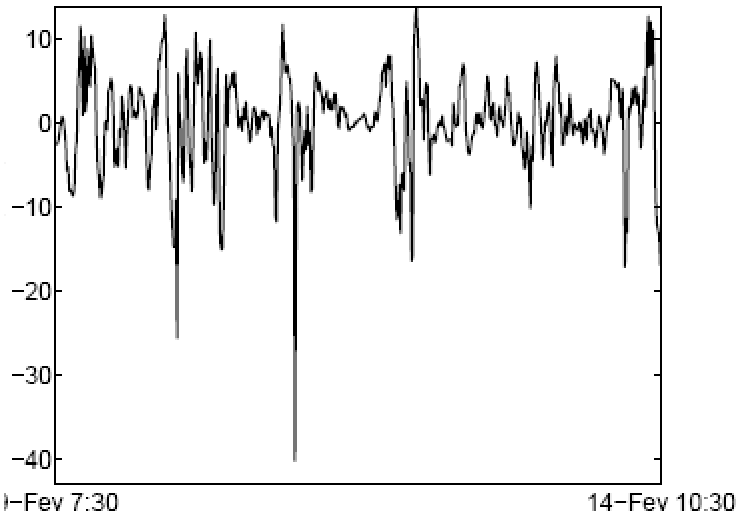


(a) Resposta.



(b) Resíduo.