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EnergyPLAN + MOEA:

Development of an innovative tool for multi-objective optimization of energy systems

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Introduction

CHALLENGES:

- Increase of energy demand
- Reserve of fossil fuels
- Environmental and Climate Issues
- Integration of Renewable Energy
  - Difficulties:
    - fluctuating behavior
    - limited availability
    - financial obstacles

Aleksandar Rodic © 2007

SOLUTION:

- Integrated energy systems with proper control strategies

Problem

Which optimal Energy System?

- Capacity optimization
- Minimization of objectives (e.g. CO_2 emissions and annual cost)
- Single-objective or Multi-objective optimization problem ?
- Constrained optimization problem

Example:

- Optimal capacities (kW):
  - Wind power
  - Solar power
  - Biomass CHP
  - Gas CHP
- Constraints:
  - Biomass usage <= x (GWh)

→

Multi-objective optimization (example below)

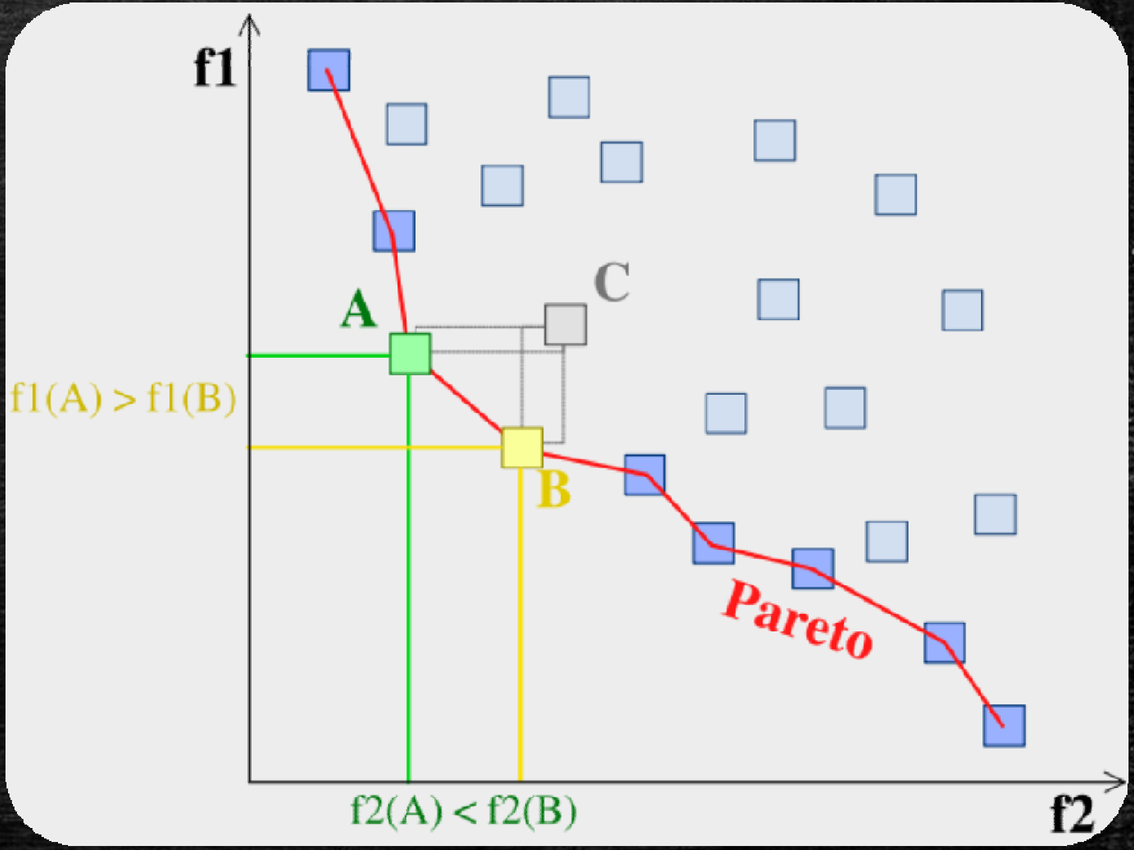
- CO_2 emission (tons)
- Annual cost (euro)

Heterogeneous competences serving a multidisciplinary problem

Energy domain (examples)	**Computer science domain (examples)**
Decarbonisation and energy transition perspective	Multi-objective optimization
Developing proper control strategies	Domain-knowledge integration
Modeling energy scenarios	Stopping criteria
Distributed vs centralized generation	Preferred regional based algorithms

Multi-objective Optimization

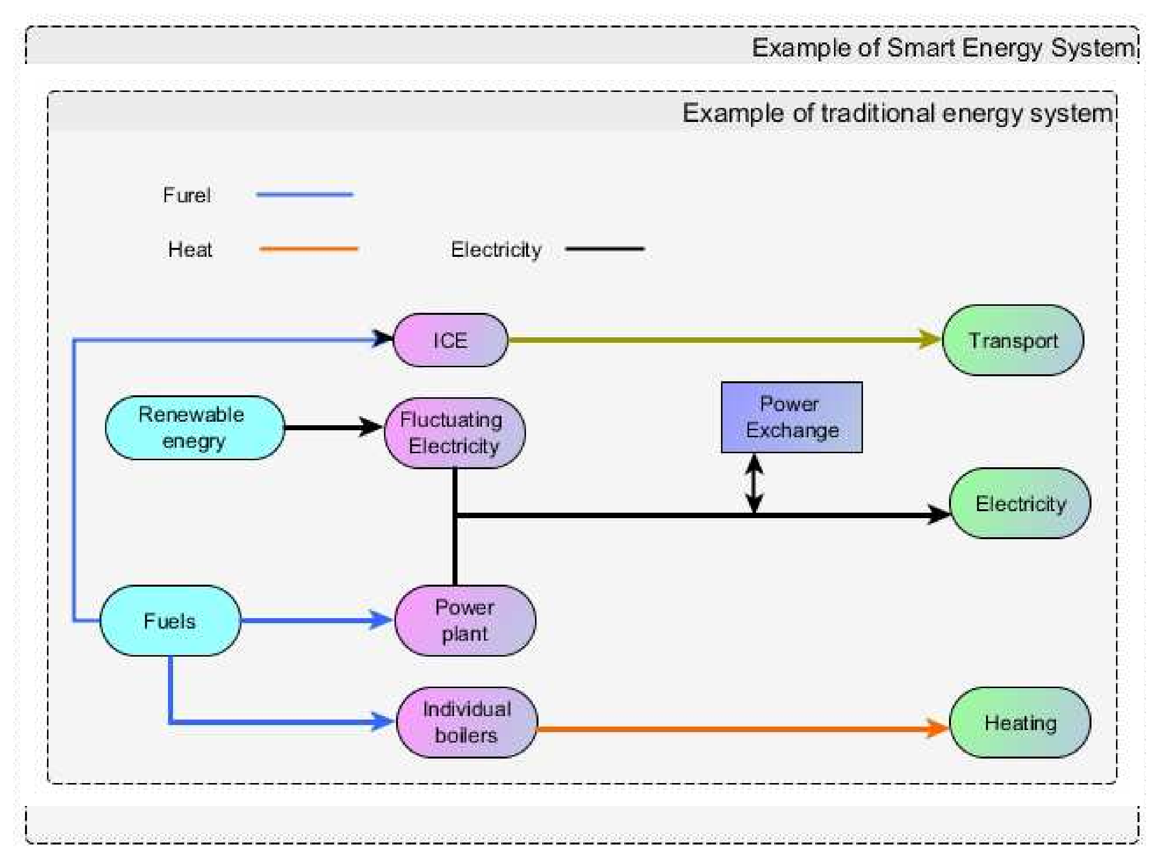
- Have more than one objective
- Often the objectives are conflicting to each others
  - A solution does not typically minimize/maximize all the objectives simultaneously.
- **Pareto-optimal solutions:**
  - Solutions that cannot be improved in any of the objectives without degrading at least one of the other objectives
- **Pareto dominance and Pareto-front**



Main motivation

- No framework for optimize different sectors together
- Manual iterative process
- Time consuming
- No guarantee for finding optimal solutions

Why integrated optimization is important?



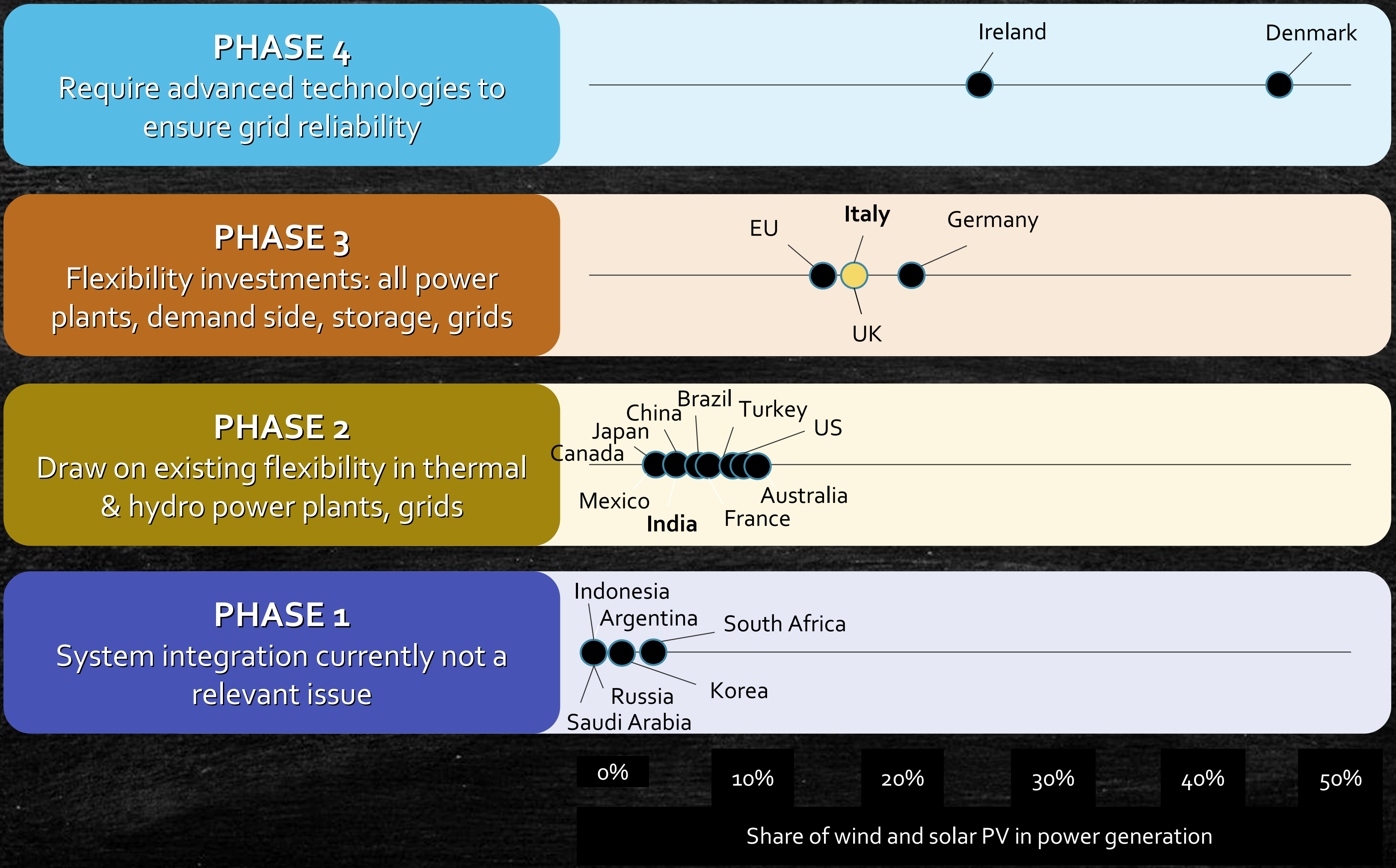
- Traditional System
  - **Mainly based on fossil fuels**
  - **No Interconnection among energy sub-systems**
- Smart Energy System
  - Sector Coupling: interconnection of all major energy sectors
  - New kind of flexibility is added into the system
  - In this architecture more renewable energy could be added

VRES integration phases

1	VRE capacity is not relevant at the all-system level
2	VRE capacity becomes noticeable to the system operator
3	Flexibility becomes relevant with greater swings in the supply/demand balance
4	Stability becomes relevant. VRE capacity covers nearly 100% of demand at certain times
5	Structural surpluses emerge: electrification of other sectors becomes relevant
6	Bridging seasonal deficit periods and supplying non-electricity applications; seasonal storage and synthetic fuels

Source: IEA

Status of VRES



PHASE 4
Require advanced technologies to ensure grid reliability

PHASE 3
Flexibility investments: all power plants, demand side, storage, grids

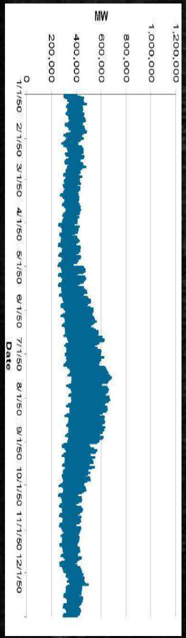
PHASE 2
Draw on existing flexibility in thermal & hydro power plants, grids

PHASE 1
System integration currently not a relevant issue

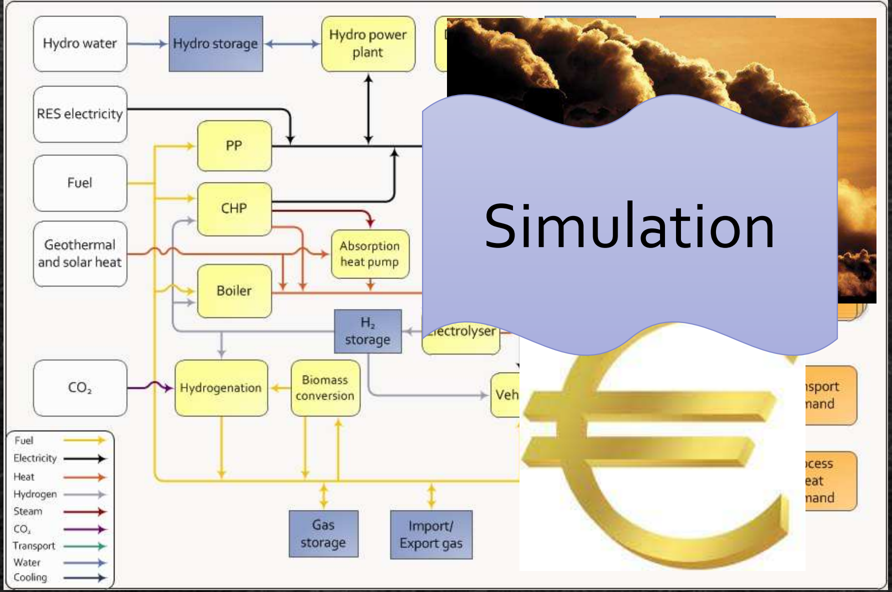
Source: IEA 2016

EnergyPLAN

Developed by AALBORG UNIVERSITY DENMARK

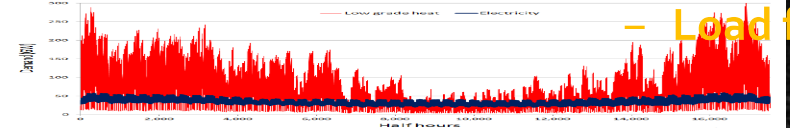


PRODUCTION CAPACITIES



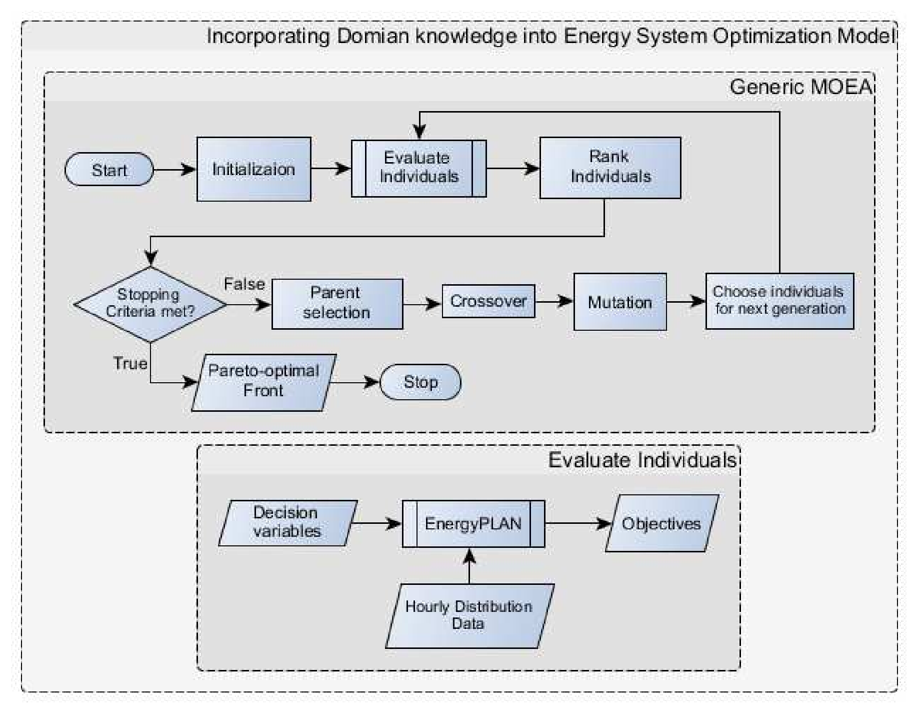
DEMANDS

- Some customized parameters
  - Energy dependency for a region
  - Load following capacity



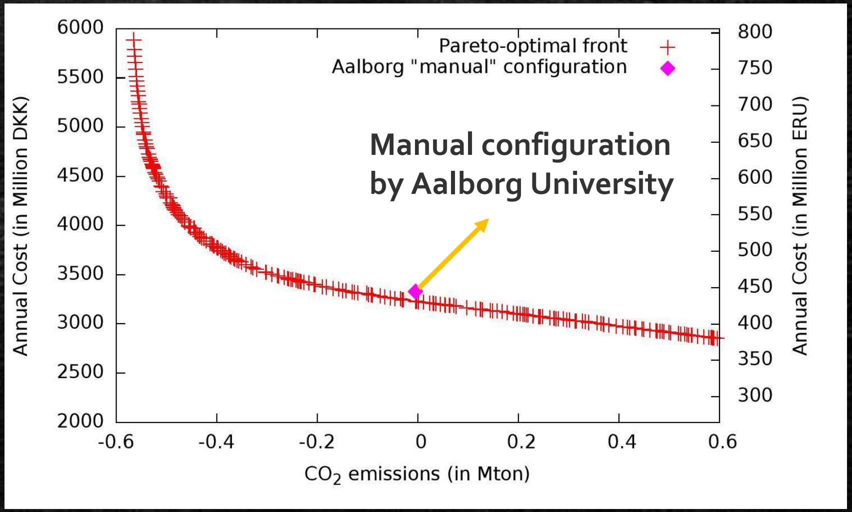
Proposed Framework and results

Integration of Multi-objective evolutionary algorithm with EnergyPLAN



Initial test problem:

- **Energy system optimization of Aalborg municipality**
- **Optimization of on-, off-shore wind, PV, CHP, heat pump capacity in order to minimize CO$_2$ emission and annual cost**



* Combining multi-objective evolutionary algorithms and descriptive analytical modelling in energy scenario design, **Md Shahriar Mahbub**, Marco Cozzini, Poul Alberg Østergaard, Fabrizio Alberti; Applied Energy, 2016

Recognition from Aalborg University as developers of EnergyPLAN + MOEA

AALBORG UNIVERSITY
DENMARK

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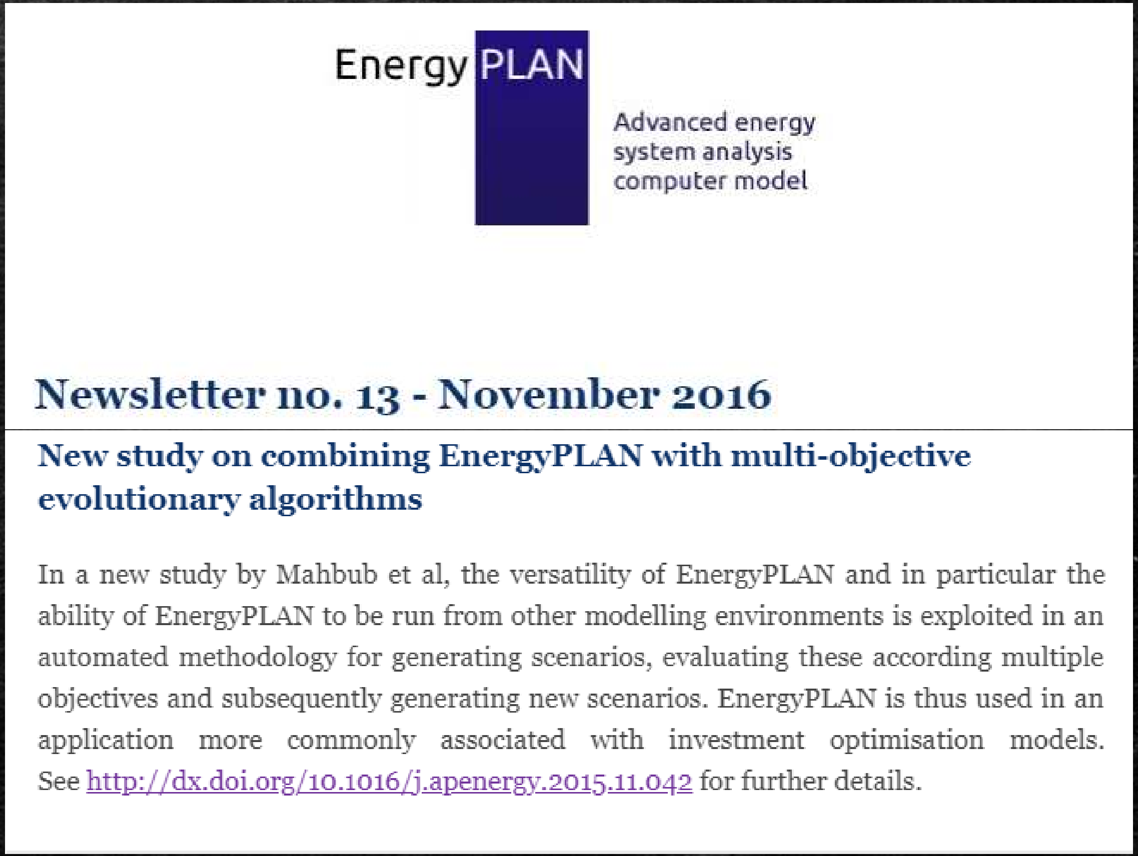


Energy PLAN

Advanced energy
system analysis
computer model

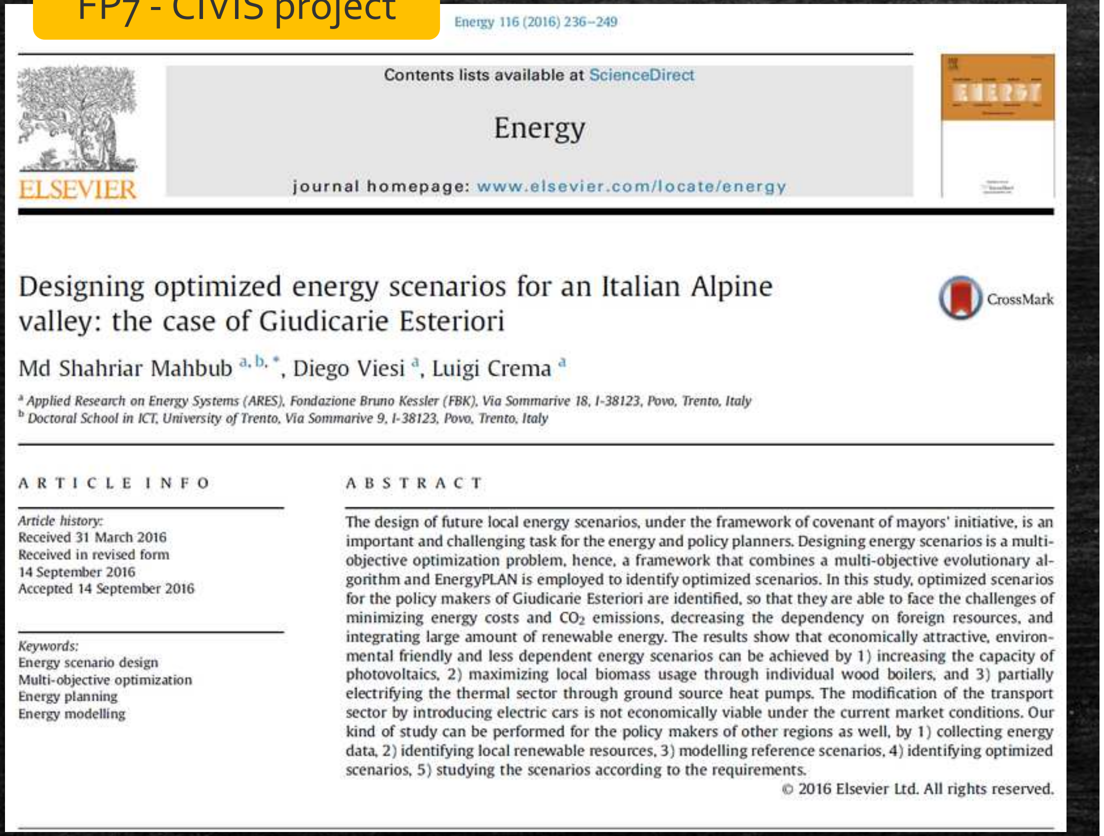
Newsletter no. 13 - November 2016

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.

2 case studies about local communities in the Province of Trento

FP7 - CIVIS project



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Energy

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Designing optimized energy scenarios for an Italian Alpine valley: the case of Giudicarie Esteriori

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A R T I C L E I N F O

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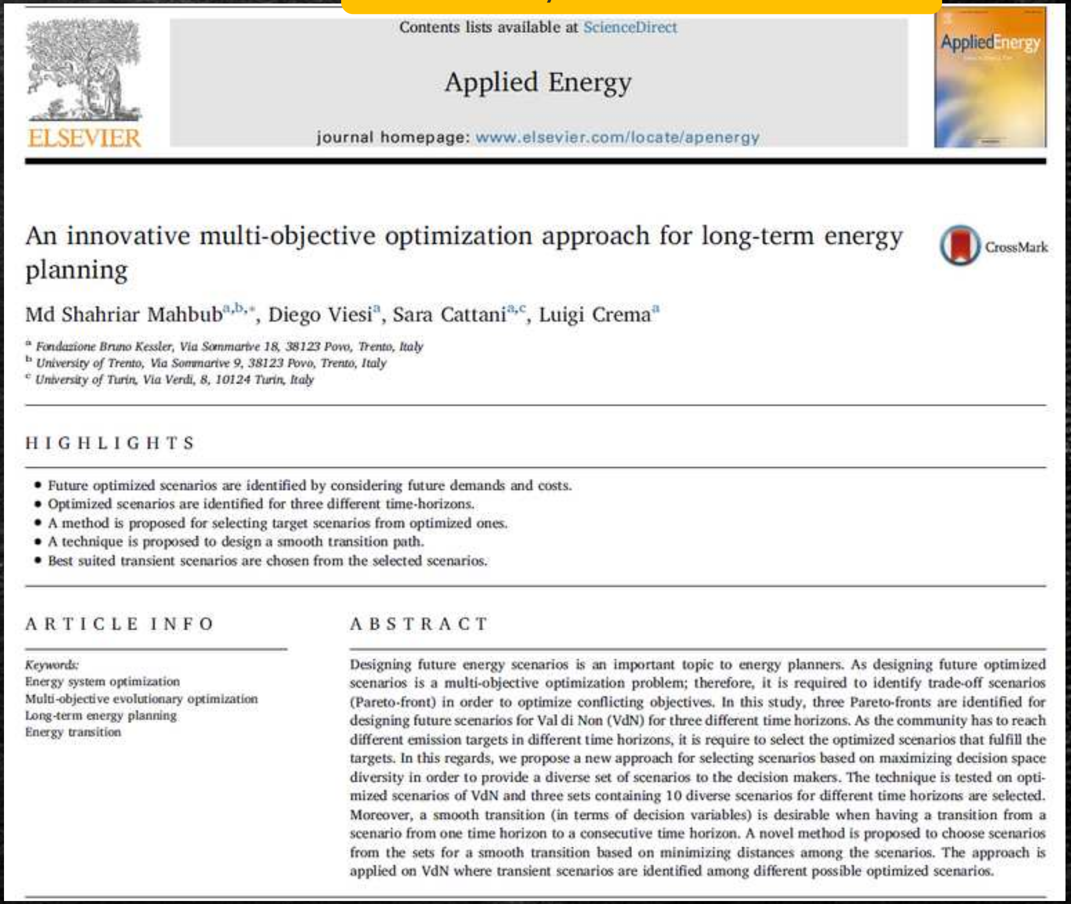
Keywords:
Energy scenario design
Multi-objective optimization
Energy planning
Energy modelling

A B S T R A C T

The design of future local energy scenarios, under the framework of covenant of mayors' initiative, is an important and challenging task for the energy and policy planners. Designing energy scenarios is a multi-objective optimization problem, hence, a framework that combines a multi-objective evolutionary algorithm and EnergyPLAN is employed to identify optimized scenarios. In this study, optimized scenarios for the policy makers of Giudicarie Esteriori are identified, so that they are able to face the challenges of minimizing energy costs and CO_2 emissions, decreasing the dependency on foreign resources, and integrating large amount of renewable energy. The results show that economically attractive, environmental friendly and less dependent energy scenarios can be achieved by 1) increasing the capacity of photovoltaics, 2) maximizing local biomass usage through individual wood boilers, and 3) partially electrifying the thermal sector through ground source heat pumps. The modification of the transport sector by introducing electric cars is not economically viable under the current market conditions. Our kind of study can be performed for the policy makers of other regions as well, by 1) collecting energy data, 2) identifying local renewable resources, 3) modelling reference scenarios, 4) identifying optimized scenarios, 5) studying the scenarios according to the requirements.

Local study on **Val di Non** SEAP



Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

An innovative multi-objective optimization approach for long-term energy planning

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H I G H L I G H T S

- Future optimized scenarios are identified by considering future demands and costs.
- Optimized scenarios are identified for three different time-horizons.
- A method is proposed for selecting target scenarios from optimized ones.
- A technique is proposed to design a smooth transition path.
- Best suited transient scenarios are chosen from the selected scenarios.

A R T I C L E I N F O

Keywords:
Energy system optimization
Multi-objective evolutionary optimization
Long-term energy planning
Energy transition

A B S T R A C T

Designing future energy scenarios is an important topic to energy planners. As designing future optimized scenarios is a multi-objective optimization problem; therefore, it is required to identify trade-off scenarios (Pareto-front) in order to optimize conflicting objectives. In this study, three Pareto-fronts are identified for designing future scenarios for Val di Non (VdN) for three different time horizons. As the community has to reach different emission targets in different time horizons, it is require to select the optimized scenarios that fulfill the targets. In this regards, we propose a new approach for selecting scenarios based on maximizing decision space diversity in order to provide a diverse set of scenarios to the decision makers. The technique is tested on optimized scenarios of VdN and three sets containing 10 diverse scenarios for different time horizons are selected. Moreover, a smooth transition (in terms of decision variables) is desirable when having a transition from a scenario from one time horizon to a consecutive time horizon. A novel method is proposed to choose scenarios from the sets for a smooth transition based on minimizing distances among the scenarios. The approach is applied on VdN where transient scenarios are identified among different possible optimized scenarios.

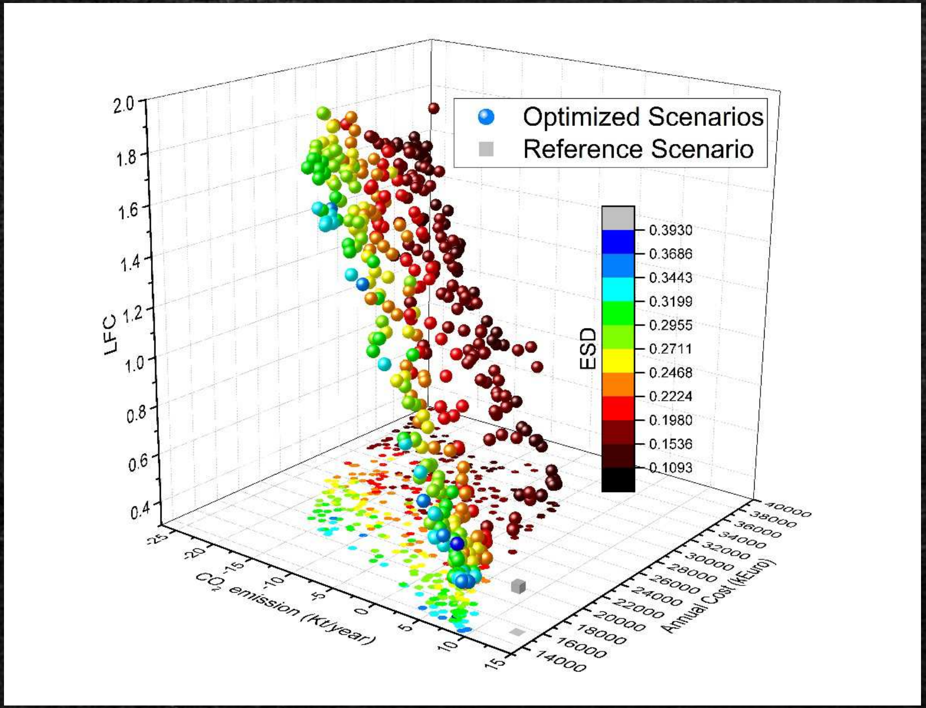
Case Study Giudicarie Esteriori

- Study area: Alpine Valley named Giudicarie Esteriori
- Analyze electricity, thermal and transportation demands
- A reference scenario is modeled (year 2013)
- Four objectives:
  - CO_2 emission
  - Annual cost
  - Load following capacity (LFC)
  - Energy system dependency (ESD)
- Decision variables: oil, gas and biomass individual boiler; individual heat pump; biomass CHP; PV; petrol, diesel and electric car

* Designing of optimized energy scenarios for an "Italian Alpine Valley": the case of Giudicarie Esteriori, **Md Shahriar Mahbub**, Diego Viesi, Luigi Crema, submitted to Energy jounral, review phase

Results for Giudicarie Esteriori

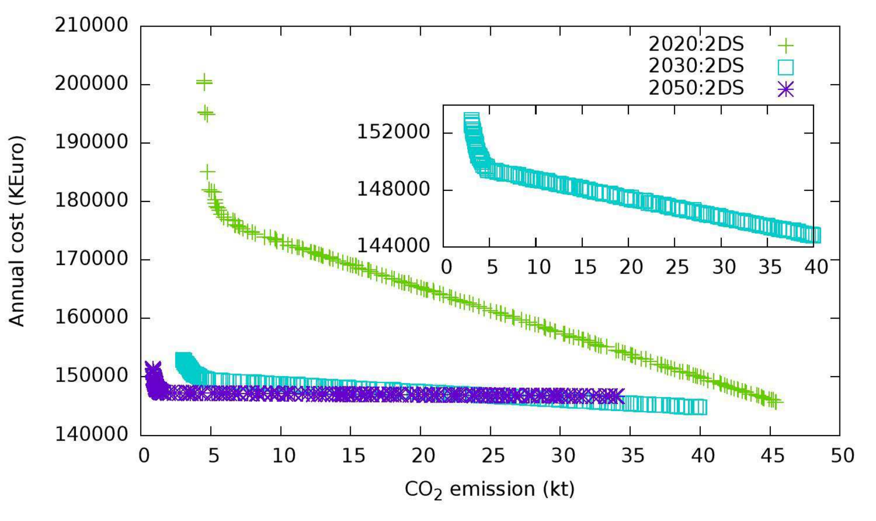
Pareto-front



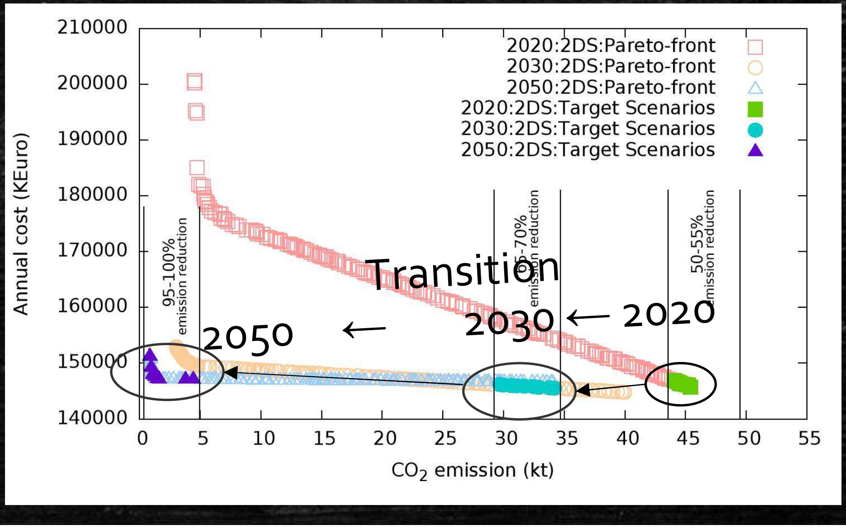
- 401 optimized Scenarios are identified
- Compare to reference scenario
  - Emission: All optimized scenarios
  - Annual cost: 26 are less costly
  - LFC: 54 are better
  - ESD: All optimized scenario
- 13 scenarios are better in all objectives

Case Study Val di Non
approach to transition targets

- Study area: Val di Non
- Three time periods:
  - 2008-2020, 2020-2030 and 2030-2050
- Two objectives: CO_2 emission and annual cost



- Considered different emission targets:
  - 2020: 50-55% emission reduction
  - 2030: 65-70% emission reduction
  - 2050: 95-100% emission reduction
- Selecting scenario within the considered range by using the techniques of maximizing decision space diversity



Future Directions

- Research:
  - Which policies helps to reach optimized scenarios for different time period?

- New case study:
  - Smart Energy Plan for the Autonomous Province of Trento (2021-2050)

List of published papers

- Journal papers:
  1. Combining multi-objective evolutionary algorithms and descriptive analytical modelling in energy scenario design, **Md Shahriar Mahbub**, Marco Cozzini, Poul Alberg Østergaard, Fabrizio Albertia; Applied Energy, 2016.
  2. Incorporating Domain Knowledge into the Optimization of Energy Systems**, Md Shahriar Mahbub**, Markus Wagner, Luigi Crema; Applied Soft computing, June 2016.
  3. Designing of optimized energy scenarios for an "Italian Alpine Valley": the case of Giudicarie Esteriori, **Md Shahriar Mahbub**, Diego Viesi, Luigi Crema, Energy, vol. 116, Part I, December 2016.

- Conference papers:
  1. Improving Robustness of Stopping Multi-objective Evolutionary Algorithms by Simultaneously Monitoring Objective and Decision Space, **Md Shahriar Mahbub**, Tobias Wagner, Luigi Crema; GECCO 15, June 2015, Spain.
  2. Multi-objective optimisation with multiple preferred regions, **M. S. Mahbub**, M. Wagner, and L. Crema, in Australasian Conference on Articial Life and Computational Intelligence (ACALCI). Springer, 2017.
  3. A domain knowledge-based multi-objective evolutionary algorithm for optimizing energy systems, **Md Shahriar Mahbub**, International Conference on Soft Computing, June 2014.

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