New insights from econometric data: an Extended Exergy Analysis (EEA) of the Italian System, 2013-2017

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Aim of this work

- To introduce a novel approach to Extended Exergy Analysis (EEA);
- To apply the method to the Italian society, analysing a time-window of 5 years (2013-2017);
- Tom analyse the results in order to get useful insights fora comparison between the exergy destruction of a Country and its GDP;

The method is based on the exploitation of a massive and patchy dataset (data mining).

The problem: what does «sustainable growth» actually mean?

- ✓ The progressive lack of primary resources is driving politicians, economists and public awareness toward the acknowledgment of the necessity of a *sustainable* growth paradigm;

- ✓ In 1987 the "Brundtland Commission" of the United Nations formally coined the term *sustainable development* in the report named "Our Common Future" as:

"development which meets the needs of the present without compromising the ability of future generations to meet their own needs".

It sounds attractive but…is it suitable for a accurate and rigorous application?

The problem: what does «sustainable growth» actually mean?

"development which meets the needs of the present without compromising the ability of future generations to meet their own needs".

- ✓ **What** are actually the ***needs*** of the present?
- ✓ **How**, in concrete terms, is it possible to pursue the purpose?

Is there any means to assess whether we are moving in the right direction?

Exergy

- ✓ the energy conservation law is a fundamental tool for the purposes of a thermodynamic analysis: indeed the first step of any system analysis consists in performing an energy balance;
- ✓ The shortcomings of an energy balance approach are related to the fact that it assigns the same "value" to every form in which energy flows through the system;

Exergy is defined as the maximum theoretical useful work obtained when a system S is brought into thermodynamic equilibrium with the environment by means of processes in which S interacts only with the environment

Energy vs Exergy Analysis

- ✓ A historical -or cultural- barrier forces analysist to deal with "***First Law analyses***", completely neglecting the natural degradation along the paths of energy conversion, transportation and final use;
- ✓ This limitation can be overcome by using an ***exergy analysis,*** that is considering the actual amount of energy that can be used for real;
- ✓ To the present day the exergy methods are the basis for a multitude of studies performed on industrial systems and countries*;
- ✓ Although considerable progress has been made in this field, too many factors are neglected when one considers the exergy balances of a whole country: the so-called "***externalities***" (Labour, Capital, Environmental Costs) are not explicitly included in a traditional Exergy Analysis;

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Extended Exergy Analysis (EEA)

- ✓ Against this background, the algorithm of Exergy Analysis was extended taking into account the «externalities» leading toward two different approaches: a second-law based accounting method in terms of either monetary costs (**Thermo-Economics**) or primary exergy costs (**EEA**);

- ✓ In EEA, the exergy cost of a commodity is computed treating the energy carriers, the whole supply-chain, labour, capital and remediation costs in terms of their embodied primary exergy, thus eliminating the monetary cost from the picture;

- ✓ EEA has been successfully applied to different societies** proving to be a good, rigorous and consistent sustainability indicator;

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Extended Exergy Analysis (EEA)

✓ The rationale behind the EEA method is to assign equivalent exergy values to the externalities:

$$\dot{E}E_L = \alpha \dot{E}_{in}$$

$$\dot{E}E_K = \beta \dot{E}E_L = \alpha\beta \dot{E}_{in}$$

β=M2/S

α<1, β econometric factors depending on the society being considered

✓ The Extended Exergy of a generic commodity is computed as

$$EEAc = CExCm + CExCe + EEL + EEk + EEenv$$

the CExC, Cumulative Exergy Content, being the "cost" of a physical asset is expressed only in terms of its physical exergy content, considering the whole supply-chain, *from the cradle to the grave (Szargut)*

Extended Exergy Analysis (EEA)

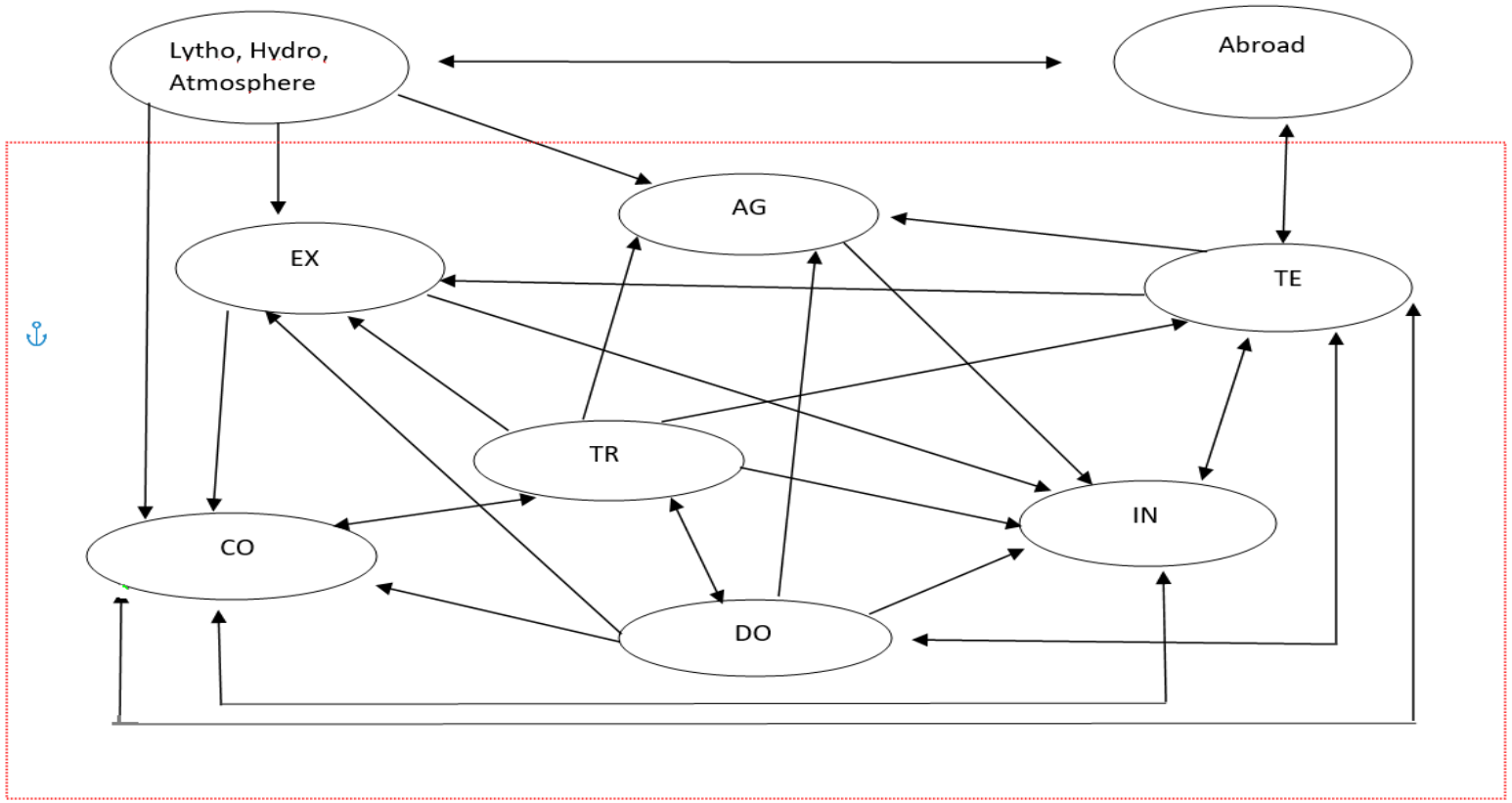
The System-Country is subdivided in 7 Sectors:

- Domestic (DO): power-consuming activities for survival and growth of human population;
- Extractive (EX): involves the processes of mining and quarrying;
- Conversion (CO): includes energy conversion, heat and power plants, oil refineries, other refinery and base chemistry industries;
- Industrial (IN): includes all of the manufacturing activities which generate added-value to raw materials;
- Transportation (TR): covers transportation services, commercial and private;
- Tertiary (TE): includes commercial, financial and all the service sector (Government, Schools, Police, etc.);
- Agricultural (AG): Harvesting, forestry, husbandry, fishing;

✓ Different types of exergy streams are exchanged among the different sectors, each sector “destroying” part of the exergy inflow

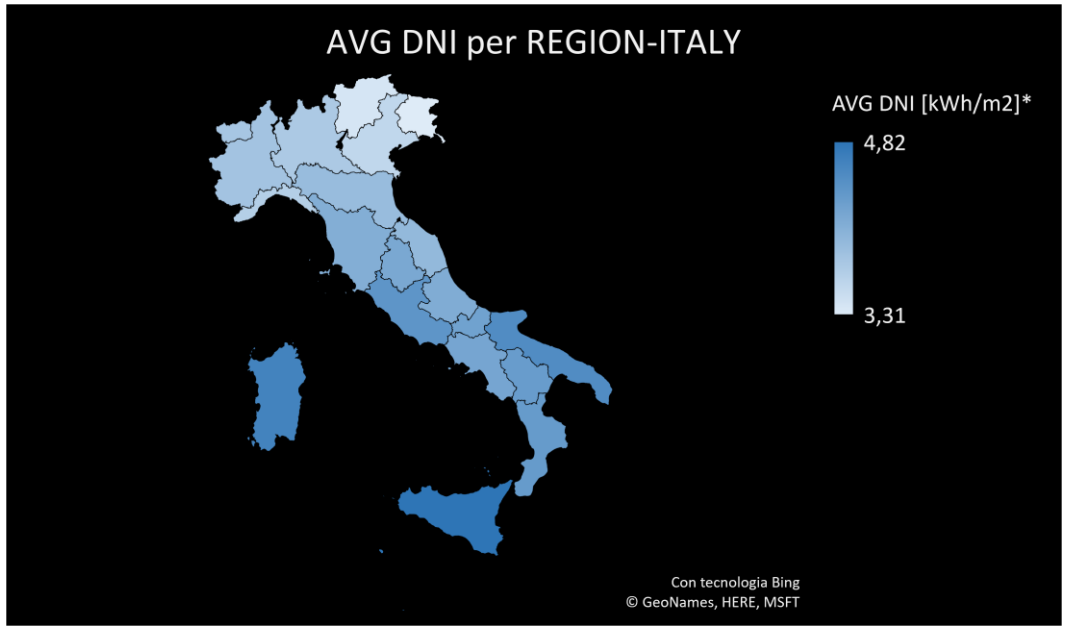
✓ the aim of the analysis is in fact the calculation of the rate of exergy destruction and the identification of their causes, so as to gather information useful for the optimization of a single sector or a whole.

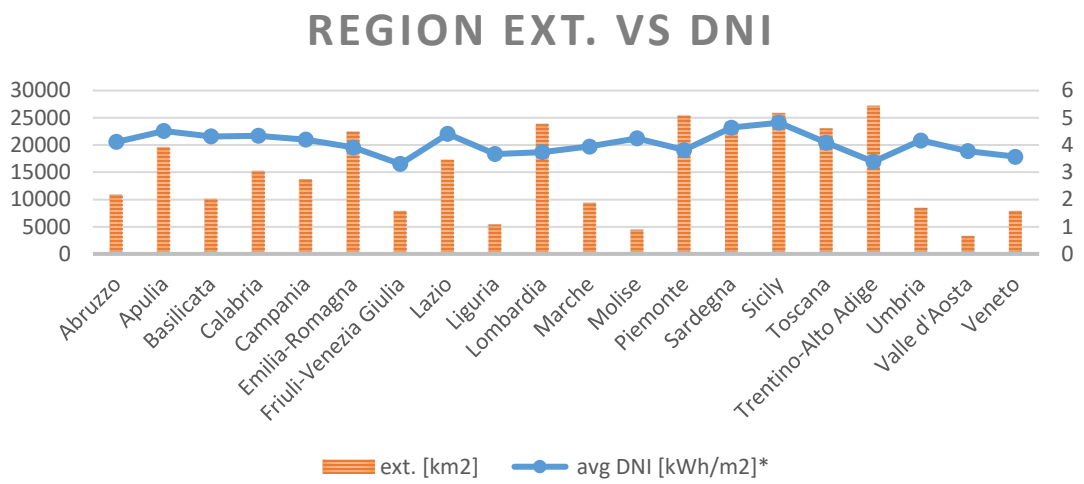
The Method: the EEA streams network



The Method: Collecting Data

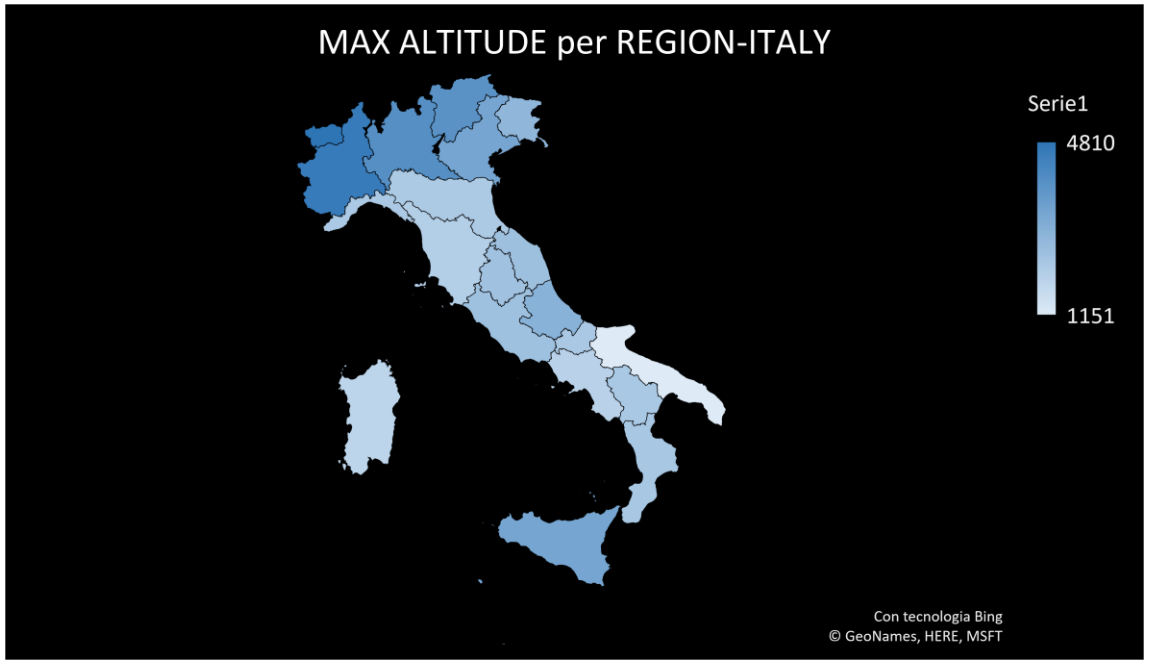
Solar Exergy

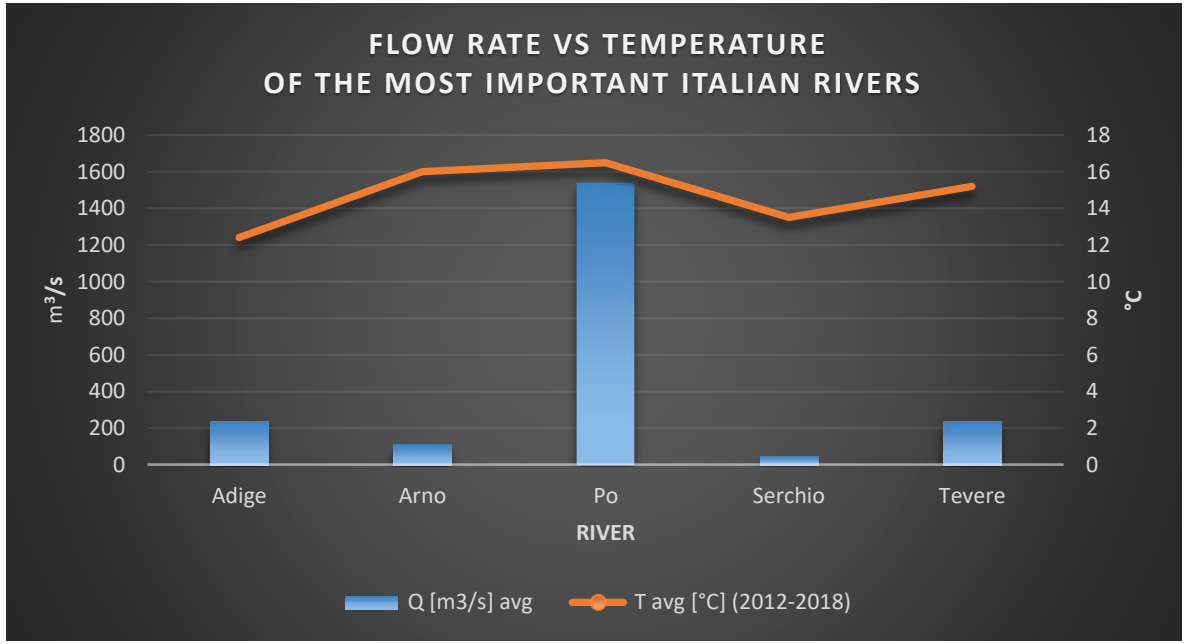




The Method: Collecting Data

Hydraulic Exergy Potential





The Method: Collecting Data

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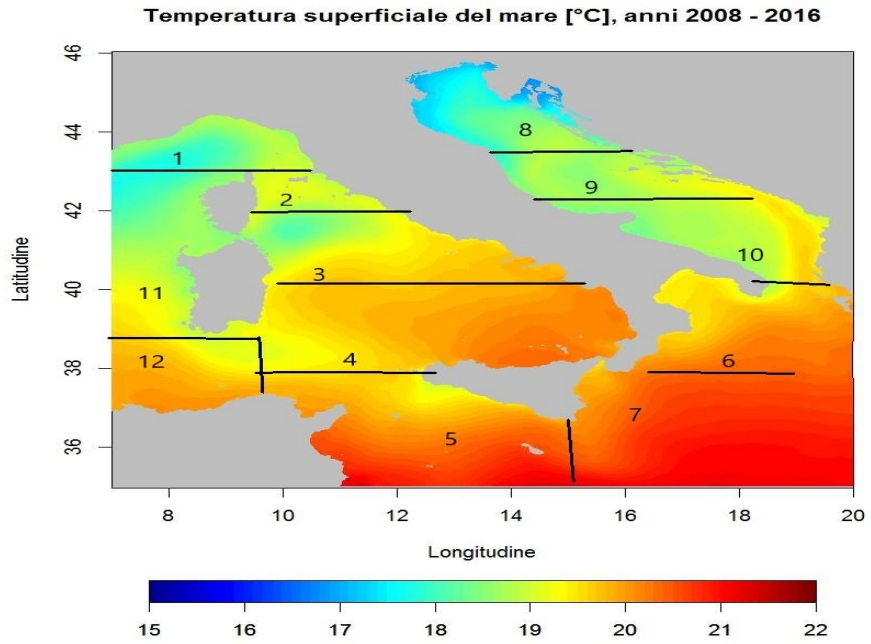


	Sea	T_0 [°C]
1	Ligure	18,5
2	Tirreno sett.le	19,4
3	Tirreno cent.le	19,8
4	Tirreno merid.le	20,3
5	Stretto di Sicilia	20,5
6	Ionio sett.le	20
7	Ionio merid.le	20,8
8	Adriatico sett.le	17,8
9	Adriatico cent.le	18,5
10	Adriatico merid.le	18,8
11	mare di Sardegna	19
12	Canale di Sardegna	19,7
	avg [K]	292,575

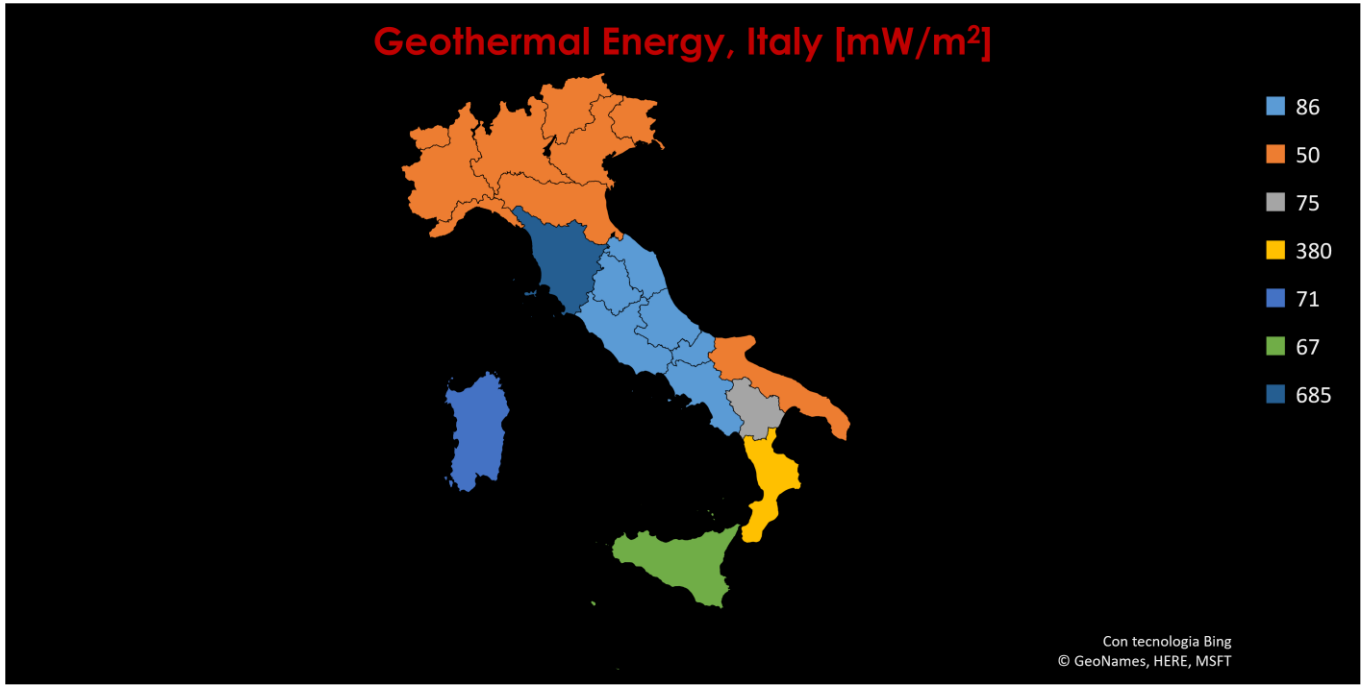
The Method: Collecting Data

Hydraulic Exergy Potential

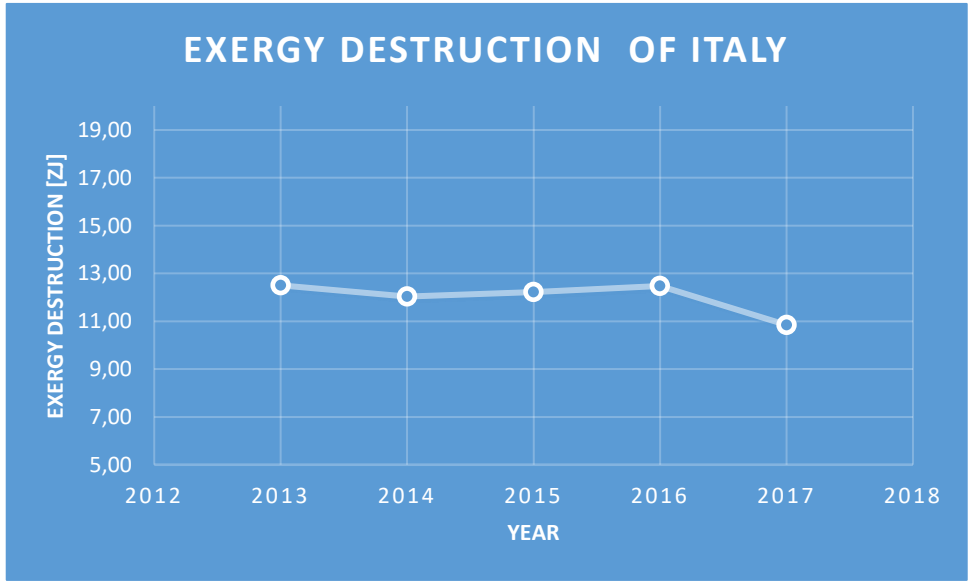
River	Q [m^3/s] avg	T avg [°C] (2012-2018)	et[kJ/kg]	e_z [kJ/kg]	ew [kJ/kg]	Ew [GW]
Tevere	240	**15,20**	**25,40**	**13,80**	**39,20**	**9,40**
Serchio	46	**13,50**	**35,69**	**14,72**	**50,41**	**2,32**
Po	1540	**16,50**	**17,59**	**19,62**	**37,21**	**57,23**
Arno	110	**16,00**	**20,61**	**16,23**	**36,83**	**4,05**
Adige	235	**12,40**	**42,34**	**15,21**	**57,55**	**13,51**
AVG	484	288,45 [K]				

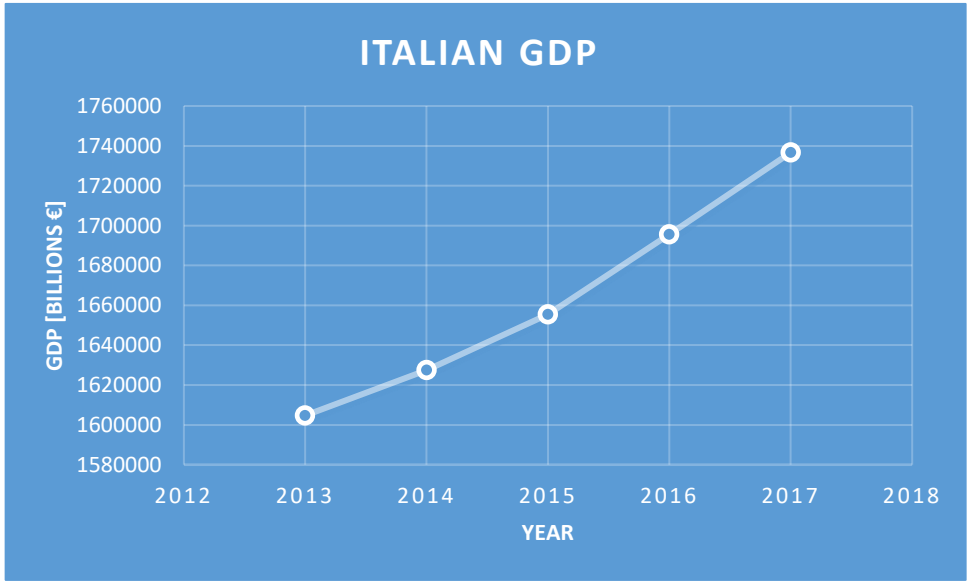
The Method: Collecting Data

Geothermal Exergy

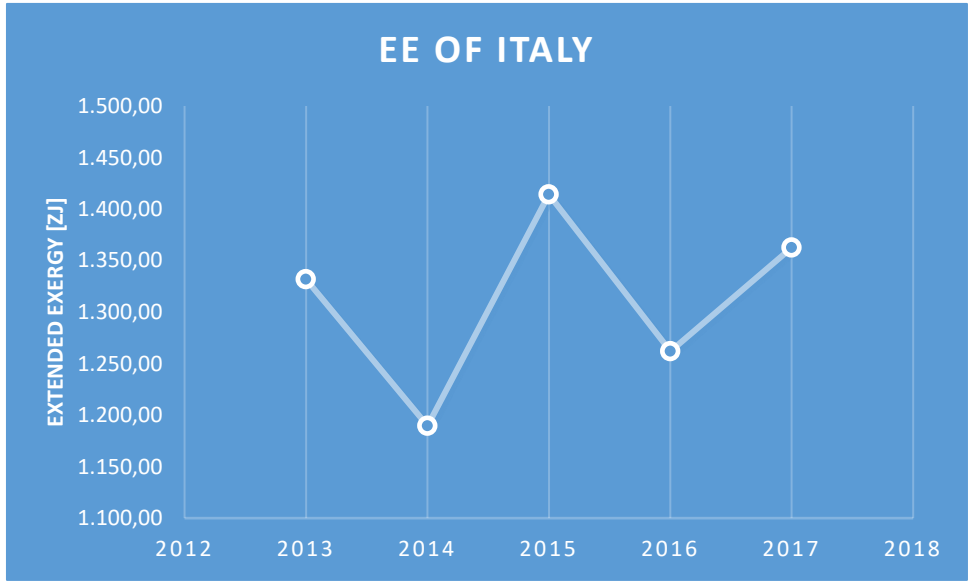


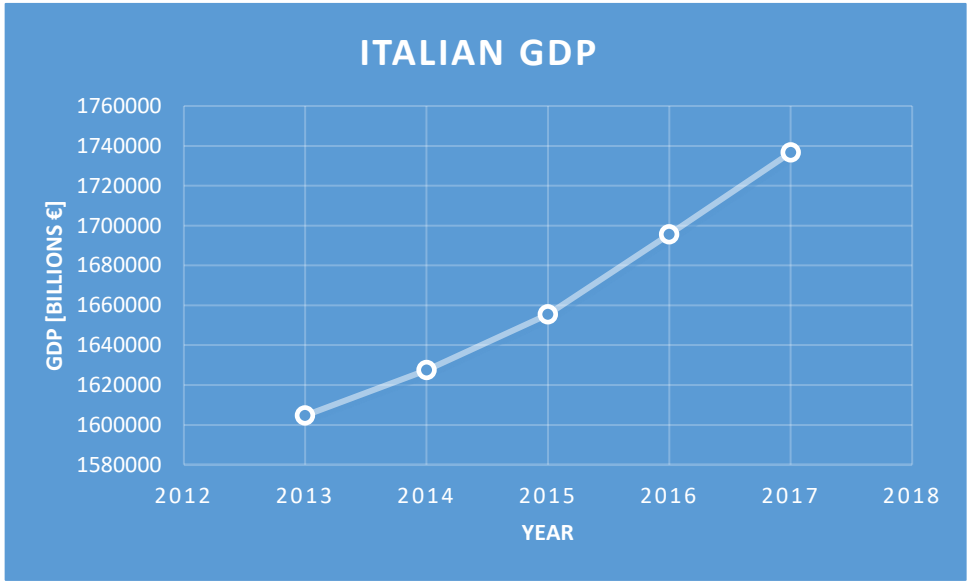
Results and Discussion





Results and Discussion





Conclusions

- An Extended Exergy Analysis of the Italian system was conducted over a period of five years, 2013-2017;
- An innovative data validation and reconciliation procedure was implemented to assure the full congruency of the data prior to the actual analysis.
- The Italian society is divided in the usual 7 sectors, plus the Environment and a virtual sector ("Abroad") that accounts for the import/export of materials and energy fluxes;

Conclusions

- The two econometric coefficients α and β were calculated for each year, as well as the specific extended exergy of Labour ee_L and of Capital, $ee_{K;}$
- The exergy destruction in the system is compared with the GDP along the observation window, and it is demonstrated that the two are not correlated.

Thank you for your attention