Paths towards the future:

a system dynamic analysis of the Italian energy system

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Abstract

The target assigned by the Kyoto Protocol to Italy (1990-2010: - 6.5% emissions of GHGs) pushes the Italian energy system towards radical changes. The interventions addressed by the Government have given rise to a great debate. In order to get a clearer comprehension, the paper proposes a two-fold analysis. Its aims are: to generate information about Italy's energy and environmental future; to verify how far Italy is from its Kyoto target. Such targets are met by means of a scenario and sensitivity analysis based on system dynamics (differential equations). Exploring different hypotheses on the sector growth rates, fuel shares and energy intensities, 27 scenarios are built. The main conclusion is that very strong, and probably unfeasible, efforts are necessary in order to meet the Kyoto target.

Italy basic energy characteristics

The essential characteristics of the Italian energy system can be derived by Tab. 1 and Fig. 1 which show the evolution of the fuel shares in the years 1960-1997 and the total primary energy supply (TPES) by sector in 1997 (all the article data are from IEA, Paris and ISTAT, Rome).

	1960	**1975**	**1985**	**1990**	**1997**
Coal	18%	5%	10%	10%	7%
Oil	47%	75%	64%	60%	58%
Gas	14%	15%	21%	26%	30%
Renewables	21%	5%	5%	4%	5%

Tab. 1: 1960-1997, fuel shares

In spite of the expansion of gas in the last years, oil is still the fundamental fuel of the national economy, while coal is characterised by a decreasing trend and renewable sources are around 5%. In less than 40 years, the TPES increased almost four times. The energy and transport energy consumption shares increased in the years while the industry and households ones decreased, and in 1997 (last IEA data available) they consumed around 60% of Italy primary energy.

In regard to the fuel shares of each sector, basic information are provided in Fig. 2 which shows the key role of oil in the energy and transport sectors, while gas is important in residences and industry. The coal share is negligible in all the sectors but energy (15.2%) and industry (7.6%). Renewable sources have some relevance in the energy sector (11.5%) and in residences (3.6%).

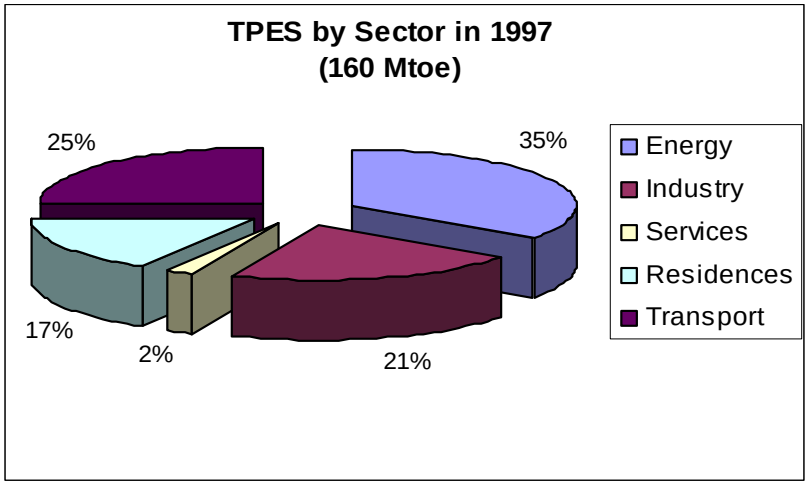

Fig. 1 – Italy Total Primary Energy Supply (TPES) by Sector, in 1997

The TPES expansion, the oil dominion and the increasing role of the energy and transport sector are reflected in the CO_2 trend which increased almost four times in thirty years (1960-1990). The picture for the year 1997 is given by Fig. 3 which shows the key role of energy and transport sectors.

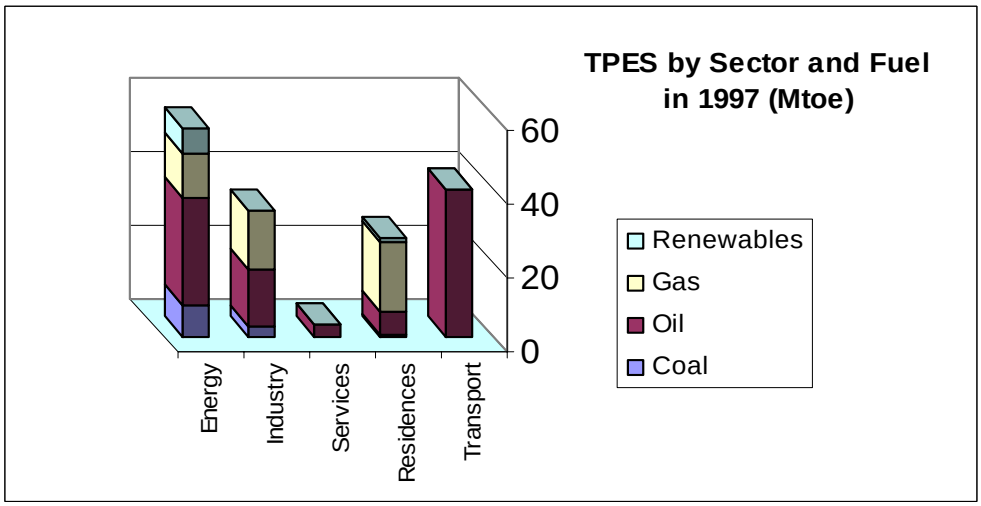

Fig. 2 – Italy fuel composition by Sector, in 1997

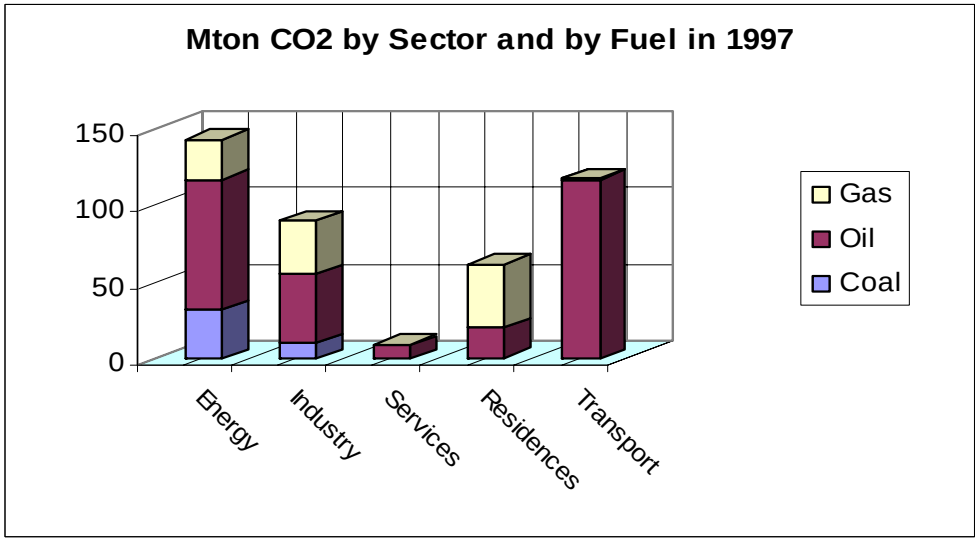

Fig. 3 – Italy CO_2 emissions by Sector and Fuel, in 1997

Will this situation be modified? Is it possible a deep change in Italy energy characteristics so that, through improvements in energy efficiency and changes in the fuel shares, a substantial CO_2

emissions reduction will be obtained? How far Italy is from its Kyoto target (-6.5%), if such a target had to be met only by means of domestic actions? These are some questions to which the following simulations will try to answer.

Model

In order to study the future energy consumption by sector, the CO_2 emissions potential reduction, and the role of energy intensity and fuel shares, a system dynamic model of the Italian energy system has been built. It splits the national economy into five sectors: energy, industry, services and agriculture, residences, transport. Its main characteristics can be derived, for a generic sector, by Fig. 4.

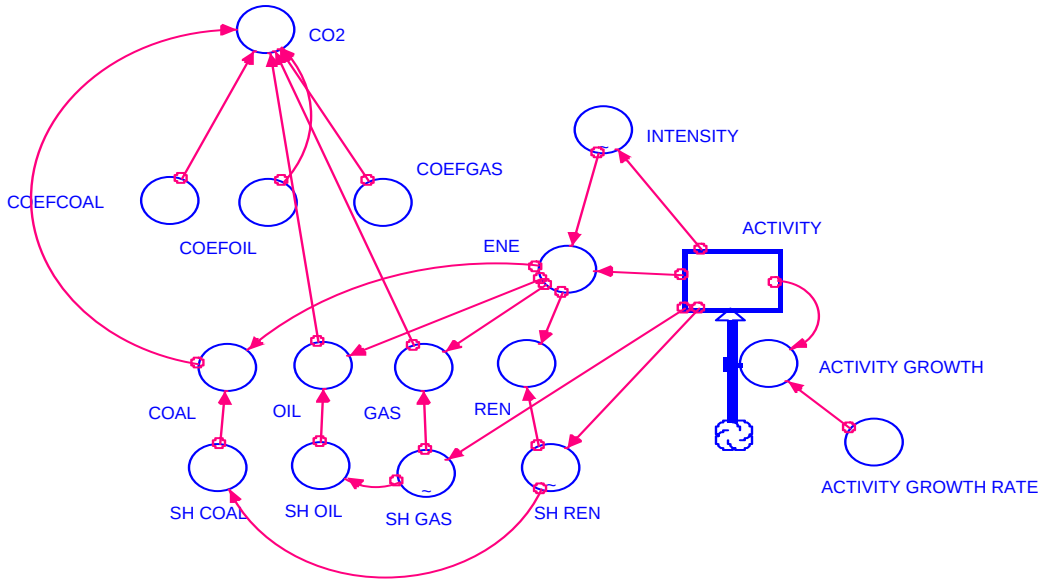

Fig. 4: Model framework for a generic sector

Energy consumption (ENE) is derived multiplying the activity level (ACTIVITY) by energy intensity (INTENSITY). The single fuel consumption (COAL, OIL, GAS, REN) is the product of the total energy consumption (ENE) by the single fuel shares (SHCOAL, SHOIL, SHGAS, SHREN). Finally, CO_2 emissions are derived multiplying the single fuel consumption by the CO_2 coefficients (COEFCOAL, COEFOIL, COEFGAS). The activity level is synthesised by traditional indicators: added value, for the energy, industry, services and agriculture sectors; population, for residences; passenger-km and ton-km, for the transport sector. For simplicity reasons, the assumption that energy intensity and fuel shares are linked is not explicitly made, even if some scenarios are implicitly built on it. Flexibility is a model quality, which is built with the “ithink” software. The model allows to make simulations on the sectors growth rate (ACTIVITY GROWTH RATE), energy intensity and the fuel shares. In particular, the growth rate can be easily regulated by means of a simple device (Fig. 5), while the trend of the energy

intensity and fuel shares versus the activity level can be simply drawn (Fig. 6 and Fig. 7). As far as the fuel shares are concerned, substitution between gas and oil, renewable sources and coal are hypothesised: this means that, according to a scenario, if the gas and renewable shares grow (with the growing level of activity) the oil and coal shares decreases. In the case of service and agriculture, the transport sector and residences, since the coal share is zero or very low, the expansion of gas and renewables implies a decrease in the only oil share.

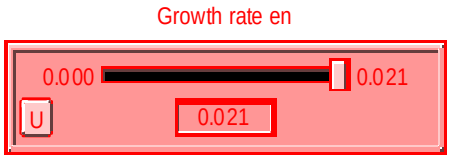

Fig. 5 - Growth rate regulator

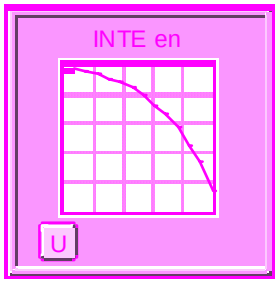

Fig. 6 - Energy intensity regulator

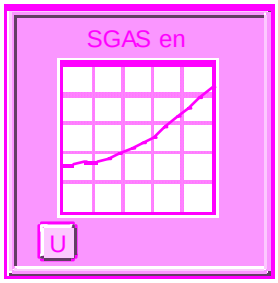

Fig. 7 - Fuel share regulator

Simulation logic

The scenario analysis is carried out, for the period 1997-2010, on energy intensity and fuel shares. Decreases in energy intensity reflect, to some extent, improvement in energy efficiency, while changes in the fuel shares allow to study the country future fuel mix. The scenario assumptions are the following (Tab. 2):

• ***Energy Intensity***	**Constant (C)** as in 1997	**Weakly** **Decreasing (W)**	**Strongly** **Decreasing (S)**
• ***Fuel Shares***	**Constant (C)** as in 1997	**Yellow (Y):** expansion of gas and renewables	**Green (G):** strong expansion of gas and renewables

Tab. 2: Scenario assumptions

As far as energy intensity is concerned, apart from the Constant scenario, decreases, which grow in the years as 2010 is approached, are generally assumed. On average, the improvements (decreases) are in the range 0.5%-2% per year. In regards to fuel shares, the starting point is the year 1997 (Tab. 3). The Yellow and the Green scenarios assume, in each sector, expansions of gas and renewables which increase in the years and reach their maximum values in 2010.

	Coal	**Oil**	**Gas**	**Renewables**
Energy	15.3%	51.6%	21.6%	11.5%
Industry	7.6%	45.1%	46.6%	0.7%
Services and Agr.	0%	96.1	3.9%	0%
Residences	0,5%	24.6%	71.3%	3.6%
Transport	0%	99.3%	0.7%	0%

Tab. 3: Fuel shares by sector in 1997

This reflects a sort of increasing returns to scale in their expansion, as well as the tightness of the Kyoto target as time approaches to 2010. More precisely, the fuel shares in 2010, that is at the end of the fuel change paths, are the following:

	Coal	**Oil**	**Gas**	**Renewables**
Energy	7.2%	38.6%	34.6%	19.6%
Industry	6.6%	26.5	65.2%	1.7%
Services and Agr.	0%	91.2%	6.8%	2%
Residences	0.5%	12.1%	81.3%	6.1%
Transport	0%	94.8%	4.2%	1%

Tab. 4: Fuel shares by sector in the Yellow Scenario

	Coal	**Oil**	**Gas**	**Renewables**
Energy	3.7%	19.2%	54%	23.1%
Industry	5.6%	7.9%	83.8%	2.7%
Services and Agr.	0%	79%	17%	4%
Residences	0.5%	6%	86.3%	7.2%
Transport	0%	90.3%	7.7%	2%

Tab. 5: Fuel shares by sector in the Green Scenario

The maximum expansion rates are in the transport sector where the gas share increases up to ten times (Green Scenario) and renewable reach 2%, their share being zero in 1997. In the other cases, the gas and renewable share increases are less intense, even if it must be stressed that both scenarios assume radical changes in the fuel shares (e.g. doubling of renewable in the energy and residential sectors, triple values in the industry sector, very strong expansion in services and agriculture).

		Fuel shares		
		Constant	**Yellow**	**Green**
Energy intensity	**Constant**	CC	CY	CG
	Weakly Decreasing (W)	WC	WY	WG
	Strongly Decreasing (S)	SC	SY	SG

Tab. 6: Scenario combinations

Given such scenarios for fuel shares and energy intensity, their combination is showed in Tab. 6. Naturally, because very probably decreases in energy intensity and fuel mix greening occur jointly, the scenario combinations WY and SG are characterised by a high degree of coherence. Finally, for each scenario, sensitivity analysis is carried out by varying the activity level growth rate per year (Tab. 7).

	Business as Usual (B):	**High (H):**	**Low (L):**
• ***Activity level growth rate***	as the average of the period 1990-1997	B + 40%	B - 40%

Tab. 7: Activity level growth rates

This means that any of the nine scenario combinations is studied under three different assumptions concerning the activity level increase, so that 27 possible scenarios emerge.

Simulations results

In order to simplify the result interpretation, this paragraph will separately focus on CO_2 emissions, fuel shares, energy consumption and trajectories.

a) CO_2 Scenarios

The results for the three hypothesised activity levels are given in Figs. 8, 9, 10.

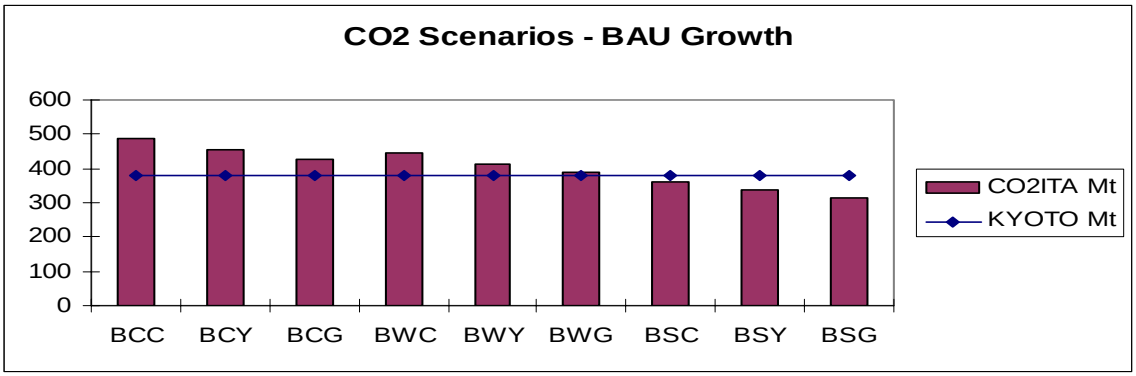

Fig. 8 – Italy CO_2 emissions in 2010 in the BAU Growth Case

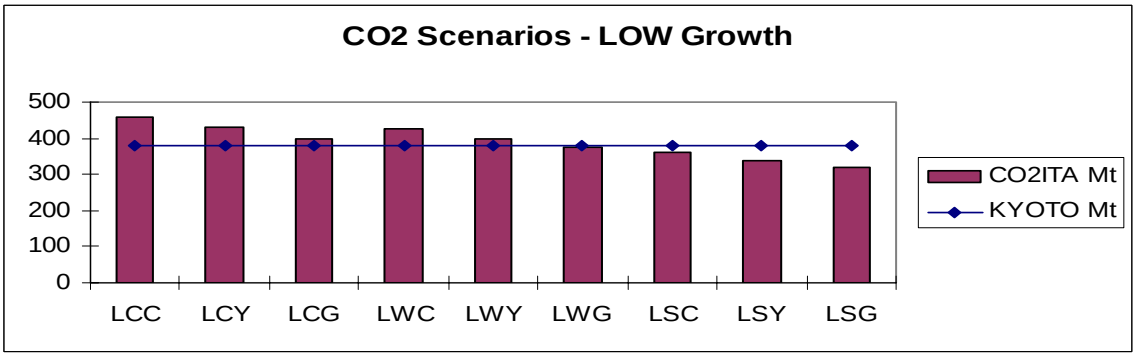

Fig. 9 – Italy CO_2 emissions in 2010 in the LOW Growth Case

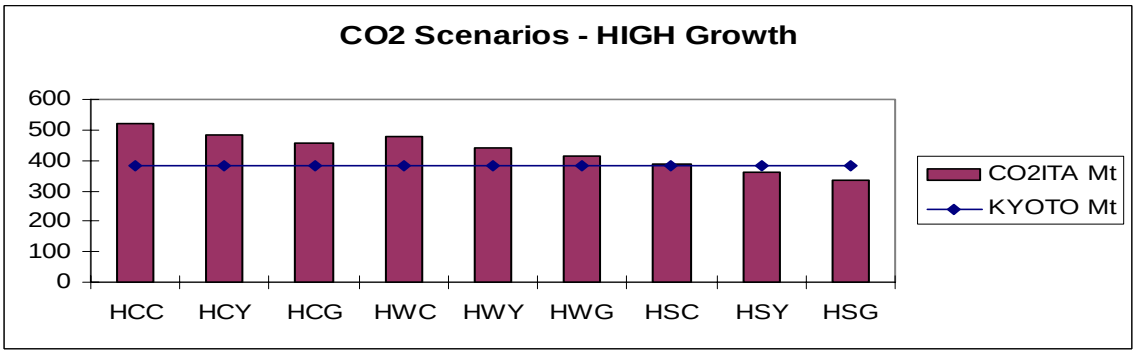

Fig. 10 – Italy CO_2 emissions in 2010 in the HIGH Growth Case

It is possible to see that the Kyoto target is not met in 18 out of 27 considered cases. The virtuous combination of a strongly decreasing energy intensity (S) with expansion or strong expansion of

gas and renewables (Yellow or Green scenario) always allows to meet the Kyoto target. This occurs also in the HIGH growth case, where the HSC scenario (which assumes unchanged fuel shares, C) is very close to the target, too. It is worth noting that the hypothesised strong decreases of energy intensity in all the sectors play a more important role in meeting the Kyoto target that the greening of the fuel mix. In fact, apart from the LWG scenario, in spite of such a greening (Yellow or Green Scenario), the system is not able to reach the target when energy intensity either keeps constant in the years (C case) or weakly decreases (W).

b) Fuel Share Scenarios

The changes in the fuel shares are represented, for the BAU growth scenario, in Fig. 11, the other two cases (LOW and HIGH growth) being characterised by the same fuel shares.

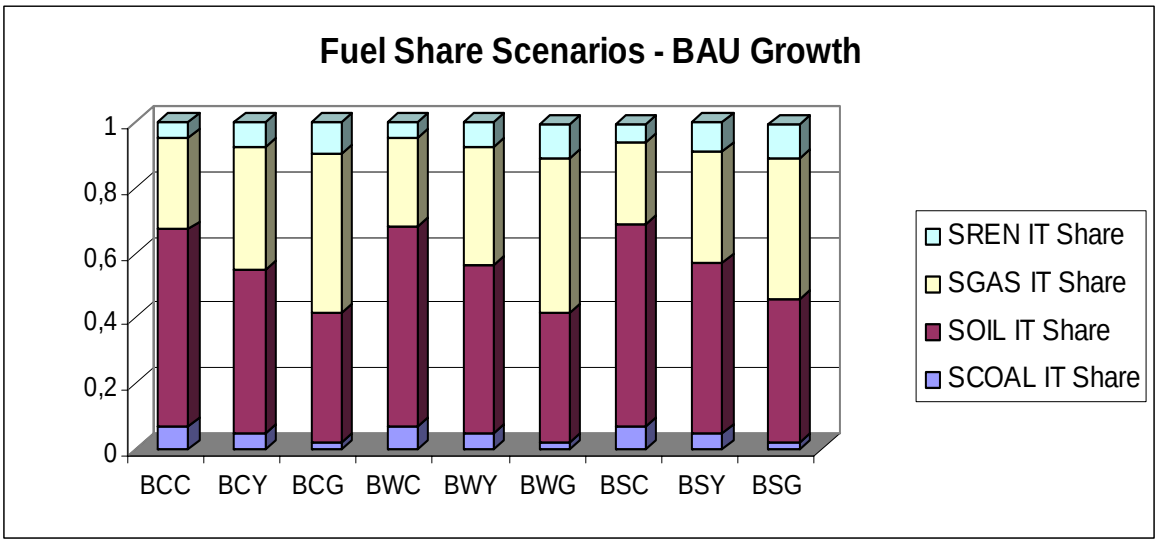

Fig. 11 – Italy Fuel Shares in 2010 in the BAU Case

In the two scenarios (Y and G), the fuel shares are around the following values: coal, 5% and 2%, versus 7% in 1997; oil, 51% and 38% versus 58% in 1997; gas, 36% and 48% versus 30% in 1997; renewables, 8% and 10% versus 5% in 1997. In other words, the Green scenario assumes that the ambitious EU target, concerning the renewable sources doubling, is met and that very strong increases in gas consumption occur. In regard to this, it is useful to compare the assumed expansion of gas and renewables in 13 years (since 1997 to 2010), with the real trend occurred in the last 12 years for which IEA data are available (since 1985 to 1997). While gas is characterised by deep penetration in the energy system (+ 9%), renewables do not change. On the contrary, in both the Yellow and Green Scenario renewables grow (Y: + 3%, G: + 5%), while gas expansion is, in the Yellow (+ 6%) and in the Green scenario (+18%), respectively lower and greater than

real historical expansion. Thus, a careful reflection must be done regarding the feasibility of the scenario assumptions, especially with reference to renewables.

c) Energy Scenarios

Primary energy consumption is given, by sector and in the case of BAU growth, in Fig. 12.

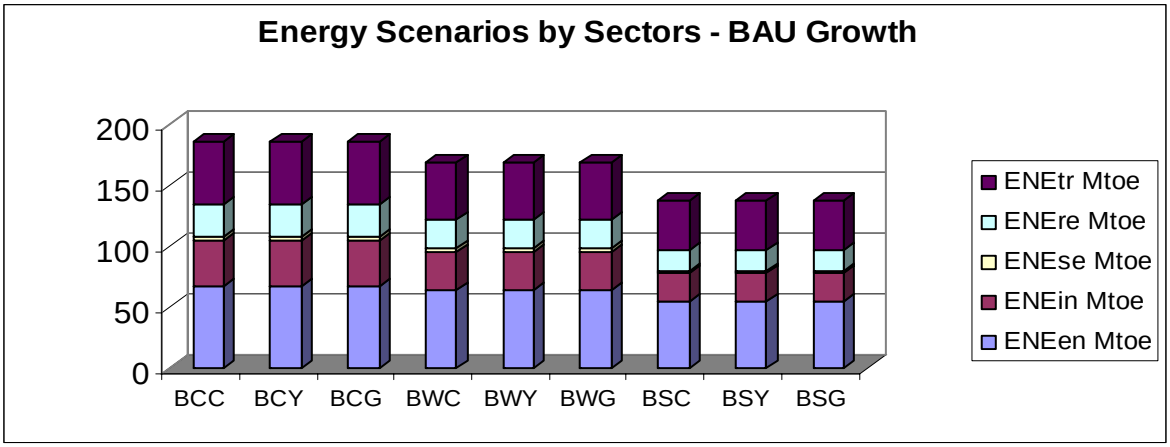

Fig. 12 – Italy Primary Energy Consumption in 2010 in the BAU Case

The sectors weight do not significatively change if energy intensity and fuel mix vary, while the different improvements in energy intensity (decreases) strongly influence primary energy consumption. In fact, a strongly decreasing energy intensity (S scenario) generates a total energy consumption which is lower than the 1997 one, also in the HIGH growth case (146 versus 160). On the contrary, in the W scenario (energy intensity weakly decreasing), the total energy consumption is always higher that the 1997 one, also in the LOW growth case (162 versus 160). Nevertheless, as it was shown above, even if only in the three strongly decreasing energy intensity scenarios (S) energy consumption in 2010 is lower than the one in 1997, CO_2 emissions meet the Kyoto target in 8 cases, and this means that the fuel mix can play a very important role.

d) Energy and CO_2 trajectories

It is important to note that, even if this article focuses on 2010, the model is able to calculate the whole trajectory since 1997 to 2010 for around 50 variables (activity level, sector CO_2 emissions, fuel shares, energy consumption, etc.). Thus, it generates, for 27 scenarios and 14 years, more than 15.000 pieces of information. As an example of the trajectory that the economy follows in meeting the Kyoto target, CO_2 emissions and primary energy consumption are shown in the BSG scenario case (BAU growth-Strongly decreasing energy intensity-Green fuel mix, Fig. 13). In this case, the decrease in CO_2 emissions becomes to be significative since the 8^{th} year, that is since 2004, and this means that, due to the model assumptions (increasing improvements in energy

intensity and expansions of gas and renewables in the last years) the target is met by means a strong effort implemented in the last six years.

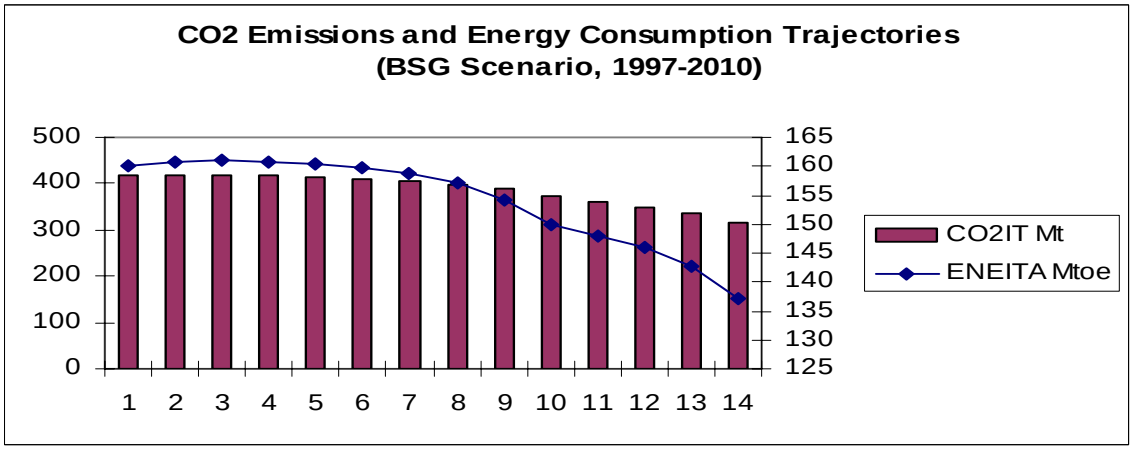

Fig. 13 – BSG Scenario - Italy CO_2 emissions and Primary Energy Consumption Trajectories (1997-2010)

As an example of failure in meeting the target, here the HWY scenario (HIGH growth-Weakly decreasing energy intensity-Yellow fuel mix) is proposed (Fig. 14).

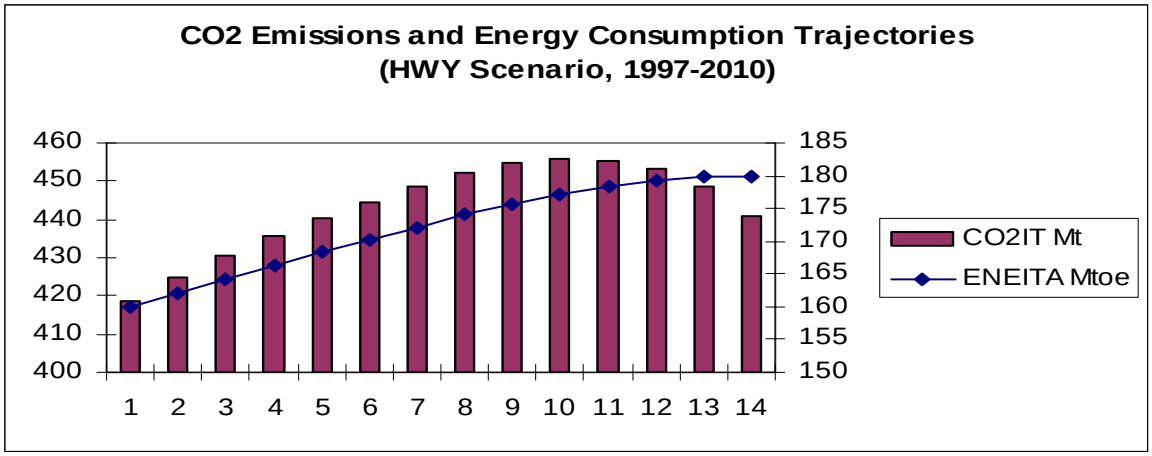

Fig. 14 – HWY Scenario - Italy CO_2 emissions and Primary Energy Consumption Trajectories (1997-2010)

In this case, the strong growth in the activity level pushes energy consumption and CO_2 emissions, particularly in the first years, and even if the decrease in energy intensity and the expansion of renewables and gas generate a decrease in CO_2 emissions since the 11th year (2007), this is not sufficient.

Conclusions

The basic results of the scenario analysis are summarised in Fig. 15. Within each activity level growth (LOW, BAU, HIGH), movements towards north-east (stronger decreases in energy intensity and greater fuel mix greening) are both desirable and difficult. The simulation results showed that only 9 out 27 scenarios allow to meet the Kyoto target (they are marked with the

symbol K). Apart from a case (LWG), they always occur when there are strong decreases in energy intensity (S scenarios). In all the other situations, even if the fuel share changes substantially (strong expansion in renewables and gas, G scenarios) the target is not met.

Activity level growth / *Energy Intensity*		*Constant*	*Yellow*	*Green*
HIGH Growth	*Strongly decreasing*	HSC	HSY^{K}	HSG^{K}
	Weakly decreasing	HWC	HWY	HWG
	Constant	HCC	HCY	HCG
BAU Growth	*Strongly decreasing*	BSC^{K}	BSY^{K}	BSG^{K}
	Weakly decreasing	BWC	BWY	BWG
	Constant	BCC	BCY	BCG
LOW Growth	*Strongly decreasing*	LSC^{K}	LSY^{K}	LSG^{K}
	Weakly decreasing	LWC	LWY	LWG^{K}
	Constant	LCC	LCY	LCG

Fuel mix greening

Fig. 15 – Scenario synthesis

In order words, energy intensity emerges as the key force in bringing the system towards the target. Thus, the key question is: are energy intensity improvements equal to 1.5%-2% per year feasible? Certainly, further scientific investigation is needed, but Italy's past experience shows that, apart from the case of industry (see Cozzi L. and Di Giulio. E. 1999), such improvements are absolutely extraordinary and cannot be held for long periods. The consequence of such a negative answer is that the use of the Kyoto mechanisms (ET, JI, CDM) becomes unavoidable for Italy.

Basic references

- Contaldo M., Tosato G.C. 1998, "Sistema energetico nazionale e opzioni di riduzione delle emissioni di gas serra" , Conferenza Nazionale sulle Strategie per uno Sviluppo Sostenibile (Roma, novembre 1997).
- L. Cozzi and E. Di Giulio 1999, "Determinants of CO_2 growth in Italy: a Laspeyres index analysis", 1999 ECEEE Summer Study, Mandelieu, France.
- L. Cozzi and E. Di Giulio 1999, "Developed countries facing the Kyoto constraint", 22nd Annual IAEE Conference, Rome, June 9-12.
- IEA 1999, "Energy balances of OECD countries: 1996-1997", OECD/IEA, Paris.
- IEA 1999, "Energy policies of IEA countries", OECD/IEA, Paris.
- Ministero dell'Ambiente 1998, "Linee guida per le politiche e misure nazionali di riduzione delle emissioni dei gas serra", in Staffetta Quotidiana, 17 ottobre.

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