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Energy from Waste: Generation Potential and Mitigation Opportunity

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SUMMARY The present research proposes a macroeconomic assessment of the role of waste incineration with energy recovery (WtE) and controlled landfill biogas to electricity generation and their potential contribution to a CO2 emission reduction policy, within a recursive-dynamic computable general equilibrium model. From the modelling viewpoint, introducing these energy sectors in such a framework required both the extension of the GTAP7 database and the improvement of the ICES production nested function. We focus our analysis on Italy as a signatory of the GHG reduction commitment of 20% by 2020 wrt 1990 levels proposed by the European Community; the rest of the world is represented by 21 geo-political countries/regions. It is shown that albeit in the near future WtE and landfill biogas will continue to represent a limited share of energy inputs in electricity sector (in Italy, around 2% for WtE and 0.6% for biogas in 2020) they could play a role in a mitigation policy context. The GDP cost of the EU emission reduction target for the Italian economy can indeed be reduced by the 1% when the two energy generating options are available. In absolute terms, this translates into an annuitized value of 87-122 million €.

Keywords: climate change, mitigation, energy from waste

JEL: C68, E27, Q42, Q43, Q54

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1. INTRODUCTION AND BACKGROUND

Sustainable waste management is an issue of increasing importance worldwide. It is widely recognized that the reduction in waste generation both in the production and the final consumption phases and integrated waste management, aimed to a gradual decrease in landfill disposal in favor of materials and energy recovery, can create benefits from social, economic and environmental viewpoints.

Against this background the EU waste strategy (EP, 2008 – art. 4 "Waste hierarchy") establishes the priorities in waste management. First, waste production should be reduced as much as possible through prevention. Then, post-consumption waste generation should be followed by preparation for re-use or recycling. When it is neither possible to prevent waste generation nor recovering material, the preferred option is energy recovery. Only the residual part of waste can be landfilled. Even in this case, landfills must be endowed with biogas collection plants, in order to recover energy and reduce the methane emitted in atmosphere.

Energy from waste can play a role also within a climate change mitigation strategy. Waste is indeed one of the sector present in the Annex A of Kyoto Protocol (UNFCCC, 2007). Albeit its contribution to global greenhouse gas emissions is less than 5% (around 1300 $MtCO_2eq$ in 2005) (IPCC, 2007), moving from uncontrolled landfill to biogas production or energy recovery can decrease emissions and offsets the use of more polluting fossil fuels.

This research assesses the contribution to power generation and CO_2 emission reduction policies provided, in Italy, by energy recovery from waste incineration[1] and biogas production. These are analyzed wihin the framework of the 20% emission reduction policy compared to 1990 level by 2020 proposed by the European Union (EC, 2007) and lately confirmed during the 2009 Copenhagen summit. Analyzing this issue in the Italian context is particulary interesting for at least two reasons: its low share of recycling compared to the EU15 average and the still high share of (unmanaged) landfilled waste may associate high efficiency gains to energy from waste generation. In addition, Italy is amongst the EU countries with the highest dependence on imported energy, and highest abatement costs. It is therefore important to verify the effictive role that an apparently abundant alternative energy source could play. The study benefited from the detailed and updated

[1] In this report, we consider only waste incineration with energy recovery, that indeed represents almost the total of the waste incineration (both with and without energy recovery).

ECOCERVED country database on waste production and management reported by product typology and related shares of disposal/recycling/inceneration, for each of the 110 Italian administrative units (province).

The investigation tool chosen for the analysis is a top-down, recursive-dynamic computable general equilibrium (CGE) model for the world economy: ICES (Eboli *et al.*, 2010), enriched to include waste to energy and biogas production from landfill among the available inputs to the energy sector. Since the beginning of the Nineties, CGE models have been increasingly used for the economic assessment of climate change mitigation policies (see e.g. Burniaux *et al.*, (1992), Waisman (1995), Gottinger, (1998). For an updated review on EU climate policy, Bohringer *et al.* (2009)). Peculiar to this approach is the explicit modelling of international and domestic demand and supply flows linking different industries, and households in the economy. Perfectly flexible prices and rational agents guarantee market clearing and the optimal use of resurces. More interestingly, price changes, induced by say a taxation policy, determine an overall reallocation of demand and supply all over the system which triggers and is influenced by macroeconomic feedbacks. In the context of the present research it is particularly important to link energy demand and supply pattern to the economic cycle, to sectoral dynamics originating flows of supply and demand to and from the energy sectors, to fluctuations in fossil fuel prices. To correctly estimate cost and effectiveness of a given mitigation policy and the role of energy generation from waste it is also fundamental to consider the degree of international coordination, the number and characteristics of the countries involved. All these aspects are taken into account by the present study. And, indeed, albeit the focus of the investigation is Italy, results are presented also for the EU27 and the "rest of the world".

To the best of our knowledge, no similar study has been conducted before especially for Italy. Available assessments in this field are performed mainly in a partial-equilibrium framework confined to the waste sector and without direct reference to the effects on the costs of mitigation policies. In this vein for instance Monni *et al.* (2006) and Delhotal *et al.* (2006) evaluate the costs at the world scale connected to the reduction of CH_4 emissions from waste disposal through a gradual switching from unmanaged landfilling to different waste management options. They conclude that the potential greenouse gases emissions reduction from waste can be the 80% if landfilling were substituted by biogas recovery and thermal processes for waste-to-energy. Monni *et al.* (2006) show also that worldwide a 70% emission reduction from the waste sector could be fostered by a carbon tax of 100

US$/t$CO_2$ eq., but that, interestingly, half of this could be accomplished at negative costs. However, their approach only considers mitigation options within the waste sector, neglecting both a more complex mitigation strategy covering the overall spectrum of energy-intensive sectors and the interaction with the rest of the economic system involving adjustments in economic agents' choices.

Developing a partial equilibrium study for Italy, Bianchi (2008) estimates that an increase of recycling of 15% by 2020 with respect to current level can entail energy savings of 32% and a CO_2 emissions reduction of 17 million tons. This study also quantifies in 3,5 million tons the reduction of CO_2 if energy from waste would replace coal-based power. However, Bianchi (2008) does not analyse the impact on the overall energy sector, nor quantifies the potential contribution of the waste sector to mitigation policy costs.

In what follows, section 2 presents the data used and provides a picture of waste to energy and biogas recovery from landfill in Italy; section 3 briefly describes the ICES model and its improvement; section 4 introduces major findings. Finally section 5 concludes.[2]

2. THE ITALIAN WASTE MANAGEMENT SECTOR: DATA AND HISTORICAL OVERVIEW

Data concerning volumes, technical potentials, emissions from waste incineration, and biogas production in Italy have been collected and elaborated by ECOCERVED[3] The database produced is the most complete and up-to data set available for Italy gathering the information that selected private and public operators in the industrial sector should release in compliance with the Italian regulation (D.Lgs. 152/2006). It covers almost 80% of urban wastes and between the 10% and 50% (depending on the sector) of industrial waste.

In recent years (2002-2006), the volume of wastes used for energy recovery (so-called "R1" category, hereafter WtE) grew in Italy the 27% with a slight slowdown in the last two years. Biogas recovered from landfills increased more considerably (330%); however, that trend was not only due to the diffusion of biogas collection, but also to an increase in number of firms asked to report their own biogas production through the MUD ("Modello Unico di Dichiarazione Ambientale").

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[2] See Bosello *et al.* (2010) for the extended version of the research.

[3] This is an Italian institute devoted to the collection of environmental data on behalf of the main industrial and commerce Italian associations. Since 1996, the ECOCERVED database collects data about waste categories defined in EWC (European Waste Catalogue), keeping also track of waste management options.

table 1, table 2

In 2006, WtE and landfill biogas plants provided respectively 1.02 and 0.31 million tons of oil equivalent (Mtoe) to the Italian power generation sector, contributing a small share of total energy supply (0.7% and 0.2%, respectively). This quota increases if we refer only to the electricity sector: the two sources met respectively 1.9% and 0.6% of energy demand, playing anyway a marginal role compared to traditional fossil fuels.

Therefore, the respective contribution of WtE to total carbon dioxide emissions is also limited: 2.8 million tons of CO_2 (0.58% of the Italian total energy generation or 1.88% of the total electricity generation (ISPRA, 2009)).[4] As emerges crossing IEA (2009a) data on energy volume with ISPRA (2009) data on carbon dioxide emissions, emission intensity of waste incineration is slightly higher than that of natural gas, but lower than that of oil. Biogas is considered a clean energy source since CO_2 emissions resulting from electricity generation are commonly treated as natural organic compounds (like other kind of biomass) and therefore not included in emissions statistics (IPCC, 2007).[5]

3. INTRODUCING WASTE TO ENERGY AND LANDFILL BIOGAS IN THE ICES CGE MODEL

This research uses a recursive-dynamic economic general equilibrium model, developed by the Fondazione Eni Enrico Mattei: ICES (Intertemporal Computable Equilibrium System) (Eboli *et al.*, 2010).[6]

It relies upon the GTAP7 database (Narayanan and Walmsley, 2008) reporting all the economic flows and market exchanges among productive sectors and economic agents within all economic systems in a specific year. Those data are organised in the form of input

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[4] GHG emissions imputable to the overall waste management are much higher: in 2006, they amounted to 18.7 million tons of CO_2 equivalent.

[5] It is important to notice that biogas collection and the resulting use in power generation can greatly contribute to climate change mitigation, reducing the methane (CH_4) emissions in atmosphere from uncontrolled landfills; as known, methane has a much higher global warming potential than CO_2 and represents the most serious environmental concern in waste management.

[6] Detailed information on the model can also be found at the ICES web site: http://www.feem-web.it/ices.

output tables derived from countries' social accounting matrices in 2004 for 113 countries/regions and 57 productive sectors, plus households and government.

Dynamics in the model are originated by an endogenous investment process, based on the equalization of expected rate of return to capital, linking inter-temporally capital stocks in different periods.

As standard in CGE model, in ICES each sector interacts with the others as any change in relative prices, induced by technology or policy shocks reallocates production factors, intermediate inputs and goods across markets in order to maximize producer and consumer revenues.

For this study, ICES details the world into 22 geo-political countries/regions, among which Italy, linked by international trade flows of capital, goods and services (table 3, left-side). For expositional convenience, and according to the purpose of this work, the results will be shown only for Italy, the EU 27 and a "Non-EU" rest of the world aggregate.

The sectoral detail (table 3, right-side) represents, in addition to the electricity sector, energy and carbon intensive industries, since they are directly affected by the development of WtE and biogas production and by mitigation policies; the sector "Oth_ind" is a bundle of non-energy intensive productive sectors.

table 3

In this formulation, ICES introduces WtE and biogas among those sectors providing inputs to electricity generation. This involved an extension of the database and a change in the model specification with reference to the production function of electricity.

Figures 1a and 1b compare the old and the new ICES production trees respectively. The energy composite is now enriched by two additional non electric input: waste to energy and landfill biogas which are also two new economic sectors selling their output to the electricity sector. [7] Waste to energy appears in the first non electric top nest, landfill biogas in the bottom "non coal" nest. The assumption is that landfill biogas is closer to natural gas and thus a closer substitute for the (non-coal) fossil fuel bundle. Waste to energy is on the contrary an easier substitute for the fossil fuel basket as a whole and a more difficult one with single non-coal fossil fuels. The quite low value of the substitution elasticity set in both nests (0.05 and 0.125 for biogas and WtE, respectively) is based on qualified judgments

[7] The electricity sector in GTAP7 also includes heat and heat/electricity cogeneration.

from Italian experts and verified that it was also consistent with the development of both energy generation processes expected in the baseline.[8]

Figure 1

In the GTAP 7 database, the value of input demanded by the electricity sector does include purchases of WtE and landfill biogas; however, these are not disentangled.

The first step is thus to single them out. In the case of Italy, demanded Mtoe of WtE derive from ECOCERVED and the average cost of waste treatment for incineration from Consonni *et al.* (2005). Values for other countries/regions have been estimated using IEA (2009a, b) and Consonni *et al.* (2005). For landfill biogas, unit costs have been estimated according to the outcomes of the CASES project, while quantity demanded according to Eurobserver (2009) for EU countries and IEA (2009a, b) for non-EU countries.

A similar procedure has been used to allocate input demand by the two new sectors. That of WtE has been disentangled from the input demand of the electricity sector; that of landfill biogas from the input demand of the gas distribution sector replicating in demand shares those of sectoral production. For both WtE and landfill biogas input demand is mainly made of capital and labour (Consonni *et al.*, 2005, Sue Wing, 2008), with a minor contribution of public services, transport, electricity used to produce WtE before the combustion process and a small residual of intermediates from “other industries” (UN, 2002; European IPPC Bureau, 2006b, Enea, 2006).

[8] A sensitivity analysis has been performed increasing by up to 5 times the substitution elasticities of both WtE and landfill biogas with other energy generation technologies in the ICES production nest. On the one hand, these are the key parameters driving the development of the two sources in the baseline and in the policy case; on the other hand, it is highly uncertain, basically lacking of estimates used as reference in the top-down literature.

As long as the elasticities are doubled or tripled no detectable changes are shown. For higher values, some changes are indeed experienced, not in the baseline trends of the two energy generation technologies, but on their potential to reduce policy costs. In general higher substitution elasticity is associated to a reduced cost saving opportunity provided by the technology. This may appear counter intuitive, but is in fact perfectly understandable considering that the mitigation policy reduces energy use, including that of WtE and landfill biogas. The higher the elasticity, the less the use of WtE and landfill biogas decreases in the policy case and the closer it is to the baseline case. Therefore, the benefits offered by the two policies also decrease as we compute them contrasting policy costs when their use is free against policy cost when their use is fixed at the baseline levels (see section 4).

4. RESULTS

The period chosen for the investigation is 2007-2020.[9] In this time-frame the technological assumptions embodied in the model remain sufficiently stable. More importantly, the final year represents a significant corner stone for the EU mitigation strategies. As a matter of fact, in 2020 the third trading period of European *Emission Trading System (EU-ETS)* will come to an end and also 2020 is the deadline to meet the target for the 20% reduction of GHG emissions with respect to the level of 1990 (European Commission, 2007).

In order to consider the uncertainty in future economic dynamics, two reference scenarios are proposed: one "optimistic" and the other "prudential".

In each scenario, the effects of the 20% EU mitigation policy are assessed. It is assumed that the policy is implemented cost-efficiently (that is at minimum cost), using an EU emission allowances trading system which grants the best allocation of abatement effort across countries and sectors. Coherently with the EU regulation, this exercise assumes that WtE and biogas production do not participate directly to the emission trading scheme. Nevertheless, they are indirectly involved in the mitigation policy as part of the productive mix and as possible substitutes of other energy sources.

4.1 THE REFERENCE SCENARIOS

In the optimistic scenario, Italian and EU economies grow the 2.8% and 2.5% per year, respectively (Figure 2). In Italy, carbon dioxide emissions increase yearly the 0.5% (Figure 3). Energy production from waste incineration and biogas increases at a rate of 1.27% and 0.75%, respectively (Figures 4 and 5). This increase is consistent with the trend in national energy demand (+0.64% per year) and with the long-run pattern of fossil fuel prices, which increase the competitiveness of alternative sources.

In the prudential scenario, the annual GDP growth is around 1.4% and 1.2% in Italy and EU, respectively (Figure 2). Emissions in Italy grow annually of 0.3% (Figure 3). WtE production increases annually at a rate of 0.88%, whereas biogas decreases slightly of 0.2% per year (Figures 4 and 5), assuming a gradual reduction of waste destined to landfill.

In both scenarios we assumed that oil prices double in the reference period (in prudential scenario, the increase is slightly lower).

[9] Note that the model simulates the period 2004-2020. Nevertheless, we worked to replicate the historical trend (GDP, emission, fossil fuels' prices and so on) for the period 2004-2007.

figure 2, figure 3, figure 4, figure 5

The energy input mix of the electricity sector changes marginally in both scenarios (Figure 6): WtE slightly increases its share from 1.9% in 2007 to 2.1% in 2020 in the optimistic scenario and to 2.0% in the prudential scenario; biogas share remains roughly constant to 0.6% in both scenarios. This pattern is similar to the European trend (Figure 7) that is characterized by a more intensive use of coal (mainly in East-European countries and Germany) and a lower use of natural gas.

figure 6, figure 7

4.2. WASTE TO ENERGY AND LANDFILL BIOGAS IN A MITIGATION POLICY CONTEXT: IMPLICATIONS FOR ENERGY PRODUCTION

The EU mitigation commitment implies a reduction of CO_2 emissions amounting to -20% with respect to 1990 by 2020. In the cost-efficient setting this imposes Italy, an emission reduction of the -18.9% and -16.1% compared to business-as-usual (-5.6% and -5.1% with respect to 1990) in the optimistic and prudential scenarios, respectively (Figure 8). In 2020, the price of carbon allowances in the EU settles at around 47 and 39 €. Implementation costs in Italy range between the 1.1% and 0.9% of GDP (Figure 9), slightly below the European average.

figure 8, figure 9

The Non-EU block, which includes all the countries not taking part to the emission reduction effort, experiences a moderate GDP increase (0.2% and 0.1%). This is the well known *leakage effect*: goods produced where environmental regulation is softer are less costly and consequently more competitive in international market. It generates an increased demand and a resulting benefit for more polluting exporting countries.
This partially neutralizes the effectiveness of the European mitigation policy (Figure 8): in 2020, in front of a EU reduction of 1,319 and 1,096 million tons of CO_2, the rest of the world increases its emissions by 579 and 436 million tons of CO_2, with a leakage effect of about 40%. It is important to highlight that such a high leakage comes from the pessimistic hypothesis of not even small emission reduction commitment in Non-EU countries.

Consequent to the mitigation policy, total energy demand in Italy shrinks (-16.1% and -13.7% respectively in the optimistic and prudential scenarios); the reduction in electricity demand (-26.1% and -22.7%) is even stronger like that of energy sources required for domestic power production (Figure 10). The demand reduction affects more severely carbon intensive inputs: coal (-48.1% and -43.8%), oil (-20% and -17.4%), natural gas (-26.8% and -22.4%).

figure 10

Against this background, even if WtE and landfill biogas are not directly involved in mitigation efforts and biogas is commonly considered a clean productive factor, demand of both decreases (-17.7% and -14.8% in the first scenario and -15.8% and -13% in the second one). Indeed, the aggregate effect of overall demand contraction is dominant on substitution effect among energy inputs.

The energy mix in electricity sector shows an increase in WtE and biogas shares (however, in absolute values the percentage change is lower), a substantial constant contribution of natural gas and a clear substitution effect between coal and oil (Figure 11).

figure 11

4.3. WASTE TO ENERGY AND BIOGAS IN MITIGATION POLICY CONTEXT: IMPLICATIONS FOR THE POLICY IMPLEMENTATION COSTS

Which could be the impact of energy production from waste and biogas on the costs of the mitigation policy? In other words, by how much the presence of these two technological options for power generation can facilitate the achievement of the mitigation targets? This can be assessed by comparing the overall costs of the mitigation policy when countries are and are not free to adjust the use of the two technologies in response to the policy. Operationally, the latter case translates in constraining countries subjected to the policy to use WtE and biogas at their baseline levels. The difference between policy costs with free or "freezed" WtE and biogas defines the value of the additional flexibility provided by the two options.[10]

[10] A similar concept is that of "option value" applied by Leimback *et al.* (2010) which relates to the introduction of specific technologies in the energy mix. It is defined explicitly as the contribution provided by a non-traditional energy source to cost reduction in achieving a policy target. In our case

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Table 4 shows that the flexibility associated to WtE in Italy is not negligible: 122 and 87 million euro yearly in the optimistic and prudential scenarios, respectively. This means that the possibility to include WtE in the technological portfolio could save the 1% of the total policy cost. In absolute terms, as a comparison, the value of neglecting the contribution of WtE is much lower than that of natural gas. But this is not surprising: we can expect that the more relevant an energy source and the corresponding technology in power generation are, the more important are their role in the mitigation policy and therefore their flexibility value. Natural gas has indeed a paramount role as primary energy source and in electricity generation. It can be however more interesting to compare the two generation technologies at "equivalent energy contribution" – in the specific freezing natural gas utilization for the same amount of energy generated by WtE -. In this case, the latter in fact shows a higher flexibility value.

Finally, policy cost saving associated to biogas is extremely small (0.3 and 0.1 million euro every year), which is due to its marginal role in power generation.

Table 5 and 6 allow some comparison with and within the EU. In Italy, the value to give up to WtE and biogas is higher than the EU-27 average which is influenced by the New Member Countries performance where the role of the two inputs is lower. The Italian data is instead lower than, but comparable with, the average value of France, Germany, Spain and UK, chosen for their similar economic system.

table 4, table 5, table 6

4. CONCLUSIONS

This research assessed the possible development of Waste to Energy (waste incineration with energy recovery) and landfill biogas used for electricity generation and their potential cost-saving contribution to a CO_2 emission reduction policy in Italy.

From the energy generation point of view, in the medium term WtE and landfill biogas will remain a minor share of energy inputs for the electricity sector (around 2% for waste incineration and 0.6%). While waste incineration could nonetheless show interesting growth rates (18% - 12% in the period 2007-2020), biogas collection could gradually diminish in a scenario with slow growth rate and decreasing use of waste landfilling (-3.2% in period 2007-2020).

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however the situation is rather peculiar as total electricity use, and accordingly also that of energy from waste is reduced by the policy.

Even though considering the marginality of these two sectors, WtE could play a role in a mitigation policy context. The policy costs that could be saved because of the flexibility provided by the possibility to produce electricity also from wastes, corresponds to 1% of the total policy costs or to 87-122 million € each year in absolute terms.

It is worth to point out that, even if WtE and biogas are not directly involved in mitigation efforts and biogas is commonly considered a clean productive factor, the demand of both decreases (-17.7% and -14.8% in the first scenario and -15.8% and -13% in the second one). In this case the aggregate effect of overall demand reduction is dominant on substitution effect among energy inputs.

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APPENDIX. THE ICES MODEL

As in all CGE models, ICES makes use of the Walrasian perfect competition paradigm to simulate market adjustment processes, although the inclusion of some elements of imperfect competition is also possible. Industries are modeled through a representative firm, minimizing costs while taking prices as given. In turn, output prices are given by average production costs. The production functions are specified via a series of nested CES functions. Domestic and foreign inputs are not perfect substitutes, according to the so-called "Armington" assumption (Figure A1).

A representative consumer in each region receives income, defined as the service value of national primary factors (natural resources, land, labor, capital). Capital and labor are perfectly mobile domestically, but immobile internationally. Land and natural resources, on the other hand, are industry-specific. This income is used to finance three classes of expenditure: aggregate household consumption, public consumption, and savings. The expenditure shares are generally fixed, which amounts to saying that the top-level utility function has a Cobb-Douglas specification.

Public consumption is split in a series of alternative consumption items, again according to a Cobb-Douglas specification. However, almost all expenditure is actually concentrated in one specific industry: non-market services.

Private consumption is analogously split in a series of alternative composite Armington aggregates. However, the functional specification used at this level is the Constant Difference in Elasticities form: a non-homothetic function, which is used to account for possible differences in income elasticities for the various consumption goods (Figure A2).

Investment is internationally mobile: savings from all regions are pooled and then investment is allocated to achieve equality of expected rates of return to capital. In this way, savings and investments are equalized at the world, but not at the regional level. Because of accounting identities, any financial imbalance mirrors a trade deficit or surplus in each region.

The recursive-dynamic engine for the model can replicate dynamic economic growths based on endogenous investment decisions. As standard in the CGE literature the dynamic is recursive. It consists of a sequence of static equilibria (one for each simulation period which in the present exercise is the year) linked by the process of capital accumulation. As investment decisions, which build regional capital stocks are taken one year to the other, i.e. not taking into account the whole simulation period, the planning procedure is “myopic”. Two factors endogenously drive investment and its international allocation: the equalization of the expected rate of return to capital and the international GDP differentials. In other words, a country can attract more investment and increase the rate of growth of its capital stock when its GDP and its rate of return to capital are relatively higher than those of its competitors.

Table 1 - Waste used for incineration with energy recovery (2002-2006)

Year	Tons
2002	3,096,965
2003	3,599,050
2004	4,134,659
2005	4,027,931
2006	3,921,904

Fonte: Ecocerved (MUD 2003-2007)

Table 2 - Landfill biogas used for energy recovery (2002-2006)

Year	Tons
2002	119,883
2003	167,841
2004	307,902
2005	411,934
2006	515,966

Fonte: Ecocerved (MUD 2003-2007)

Table 3 - Regional and sector details in the ICES model

Countries/Regions
Austria
Belgium
CzechRep
Denmark
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Netherlands
Poland
Portugal
Spain
Sweden
UnitKingdom
RoEU
USA
EEFSU
RoA1
RoW

Productive Sectors
Agricolture
Coal
Oil
Natural Gas
Oil_Pcts
WtE
Landfill Biogas
Electricity
Paper
Minerals
Chemicals
Iron_Steel
Transport
Oth_ind
Market Services
Public services

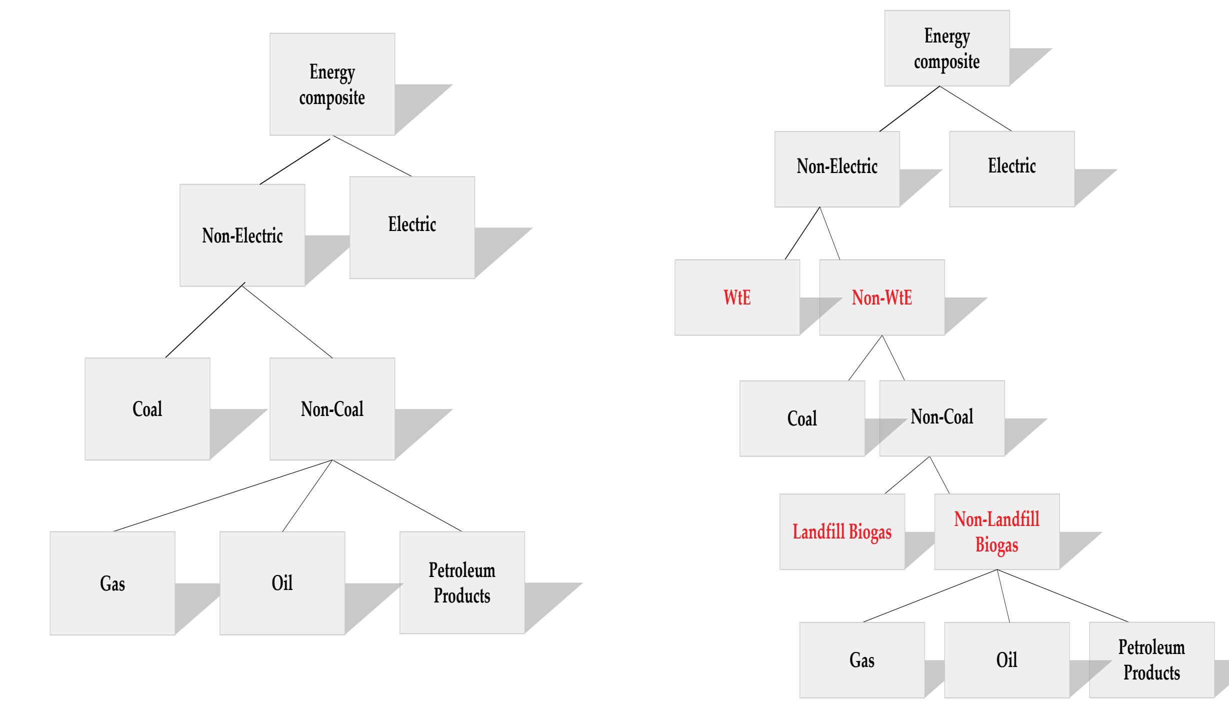

Figure 1a – The GTAP-E energy nest | Figure 1b – The ICES energy nest

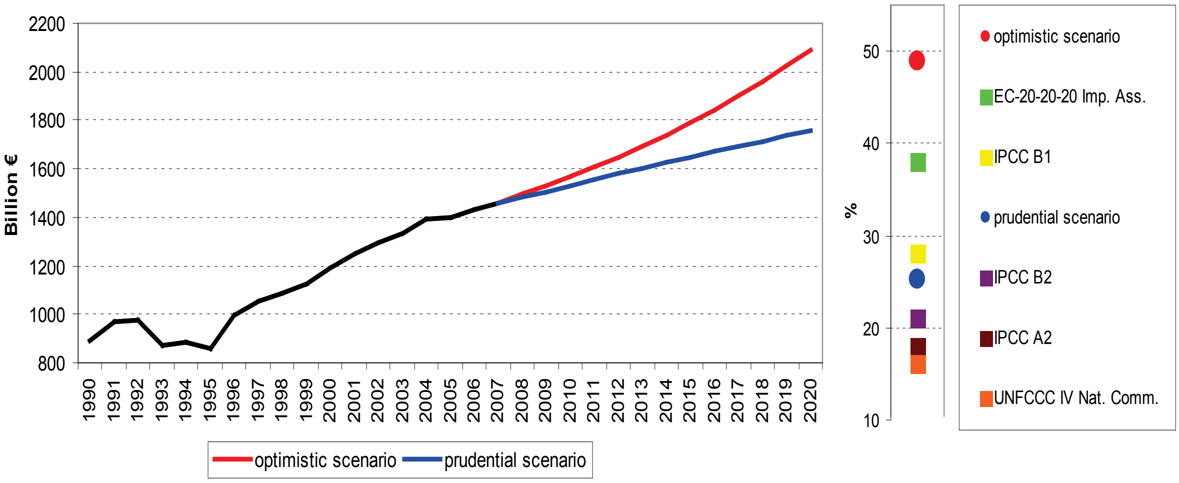

Figure 2 - GDP Italy: historical and projected trends in the optimistic and prudential scenarios (left) and comparison with other sources (2005-2020 growth rates) (right)

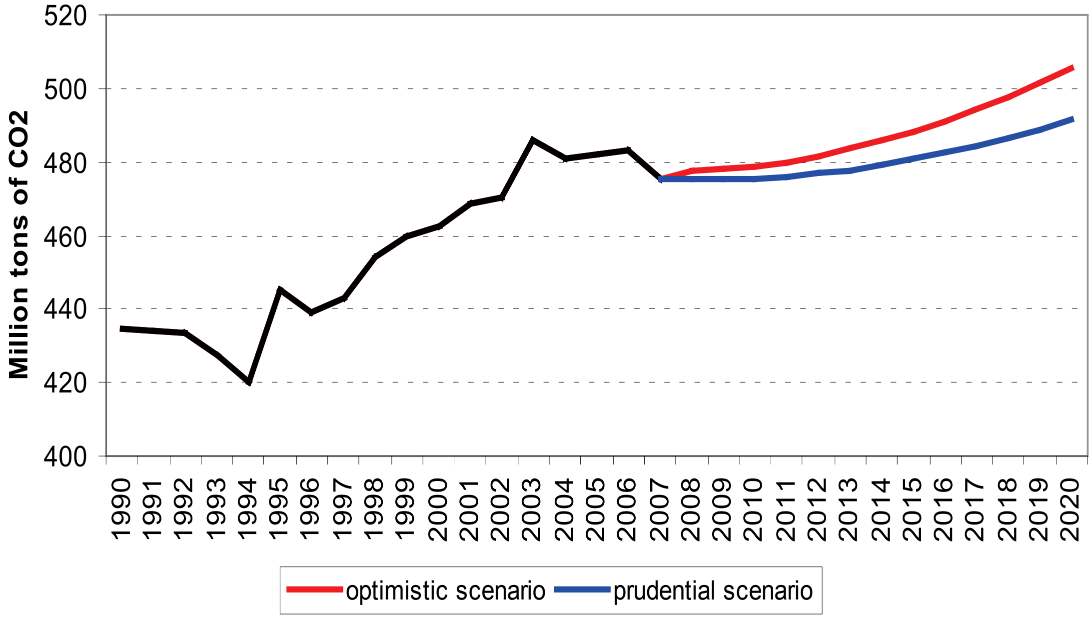

Figure 3 – CO_2 emissions Italy: historical and projected trend in the optimistic and prudential scenarios

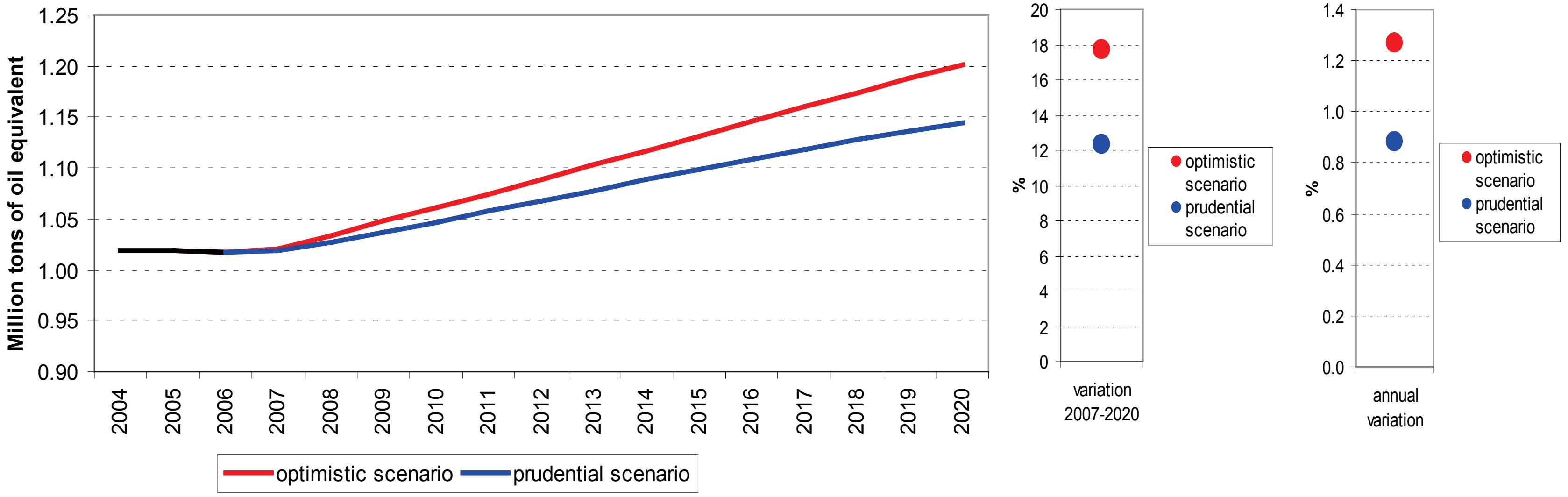

Figure 4 - WtE Italy: historical and projected trend in the optimistic and prudential scenarios. Absolute value (left), % variation 2007-2020 (center) and % annual variation (right)

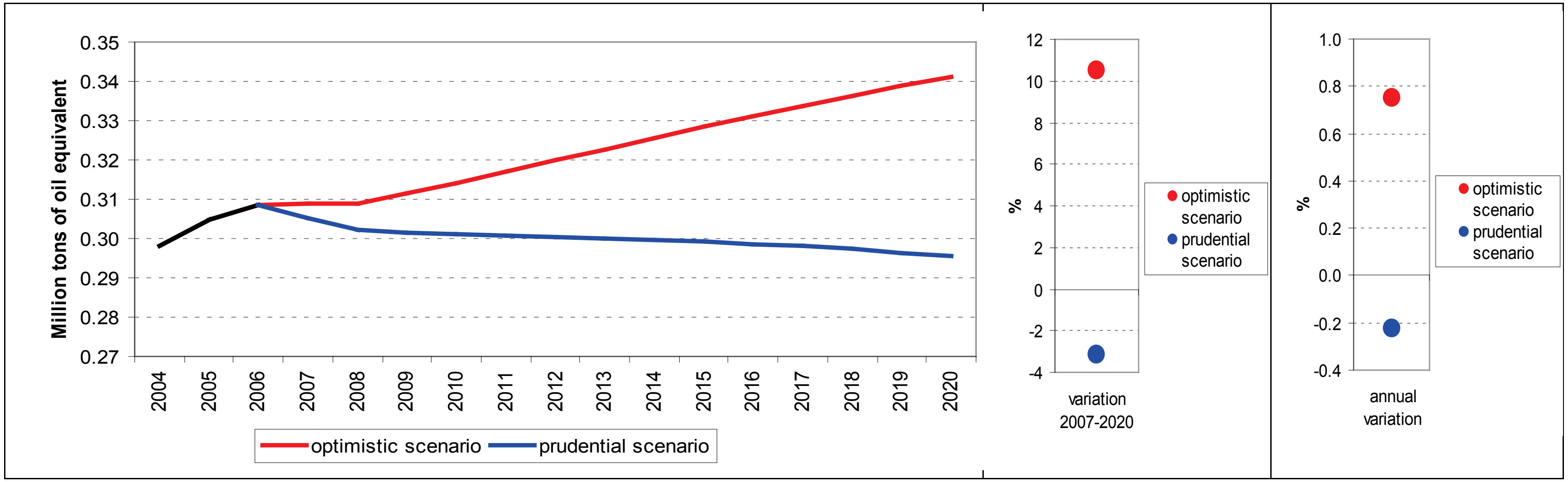

Figure 5 - Biogas Italy: historical and projected trend in the optimistic and prudential scenarios. Absolute value (left), % variation 2007-2020 (center) and % annual variation (right)

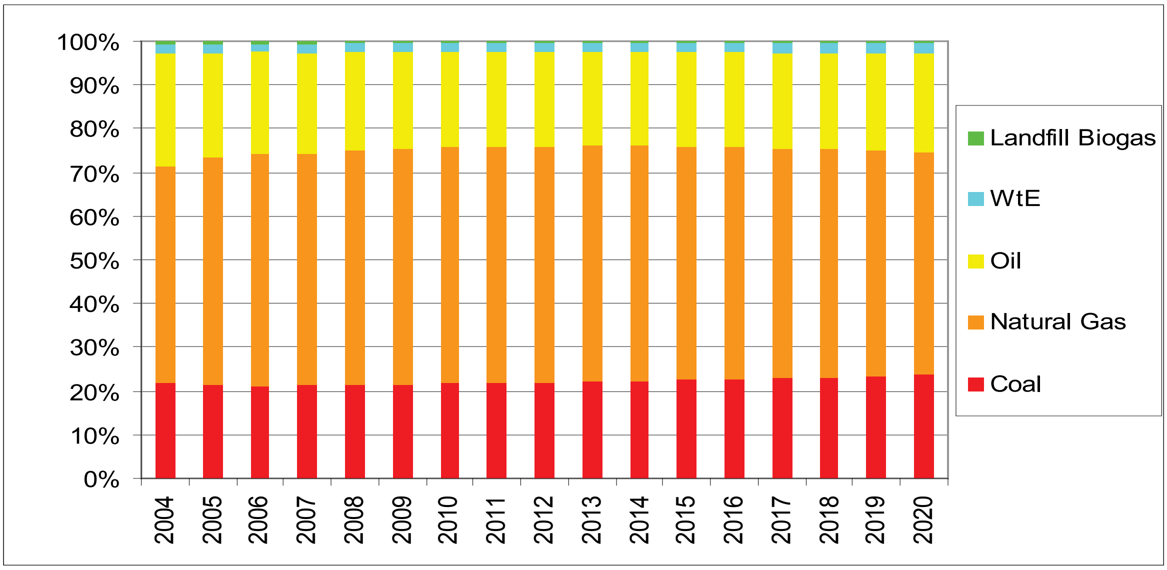

Figure 6 – Energy mix of power sector demand in Italy – Prudential scenario

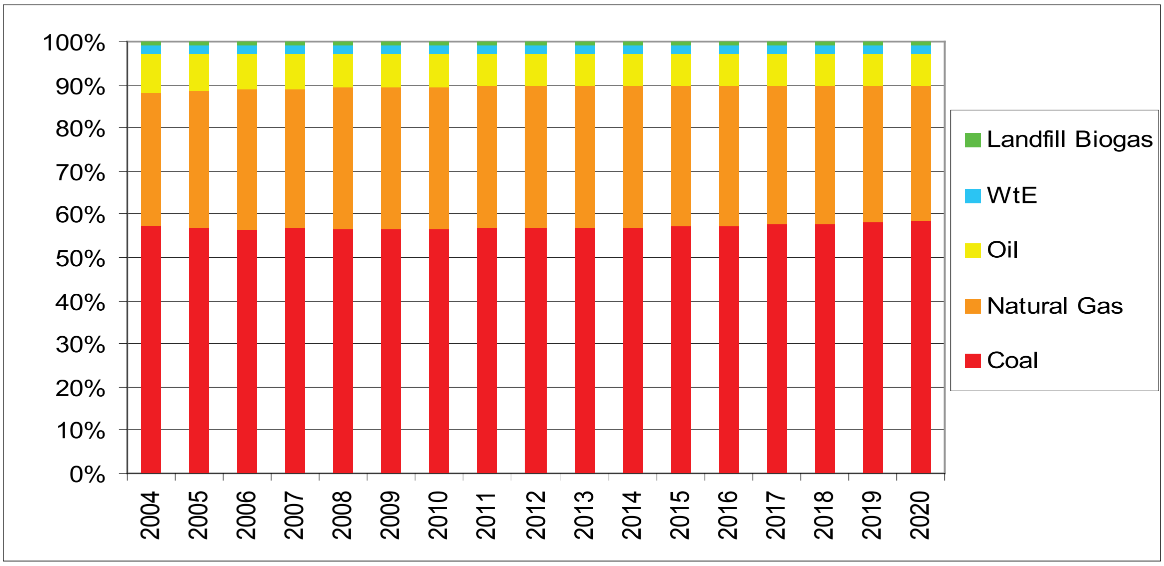

Figure 7 - Energy mix of power sector demand in EU27 – Prudential scenario

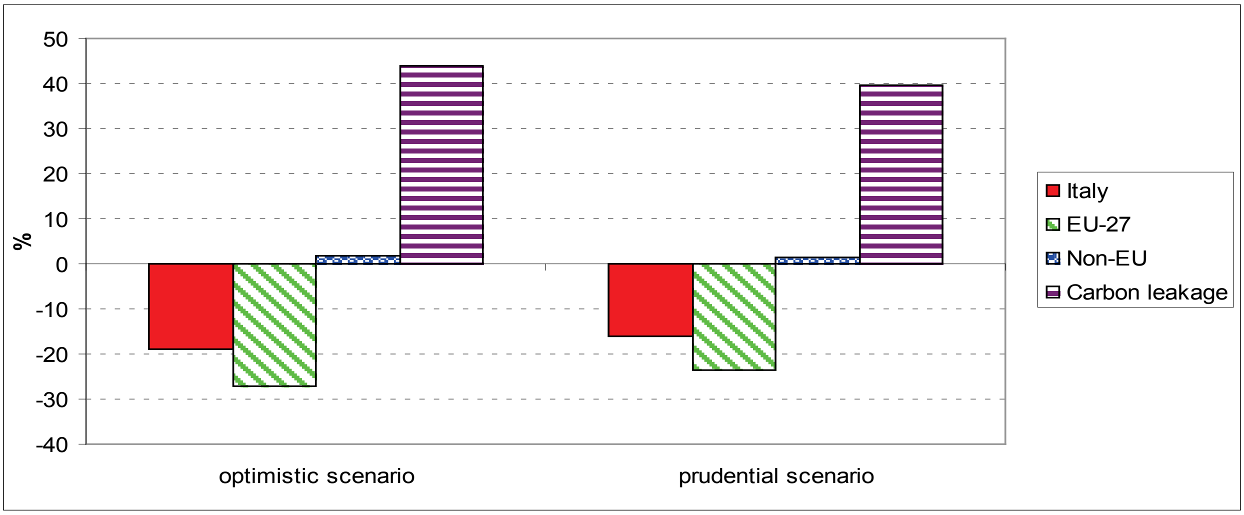

Figure 8 – Impact of mitigation policy on CO_2 emissions in 2020 (% change wrt reference scenarios)

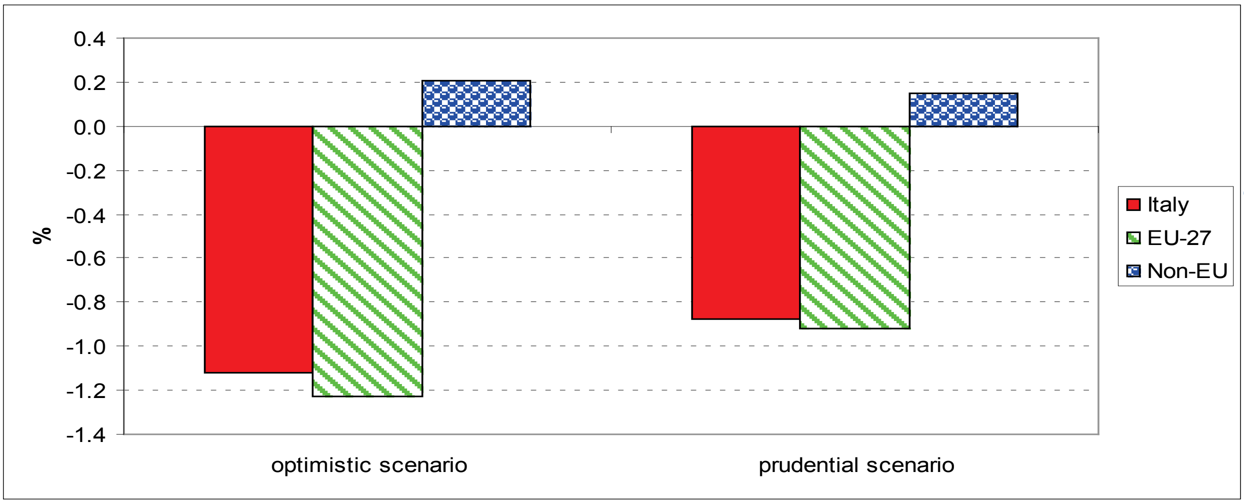

Figure 9 - Impact of mitigation policy on GDP in 2020 (% change wrt reference scenarios)

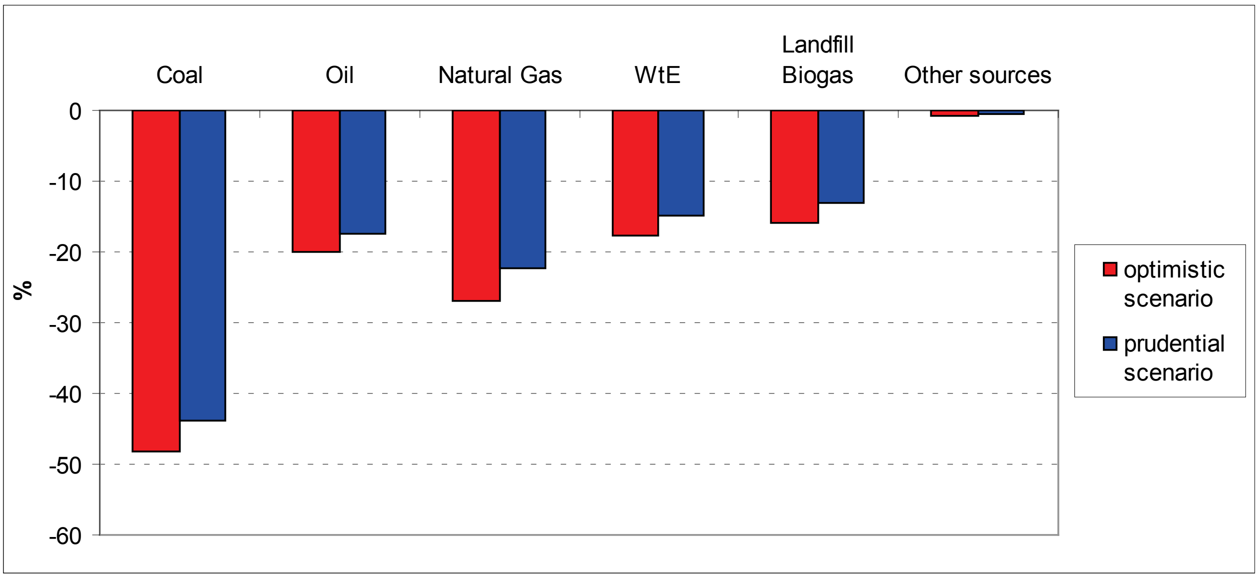

Figure 10 - Impact of mitigation policy on energy mix for power purpose in 2020 (% change wrt reference scenarios)

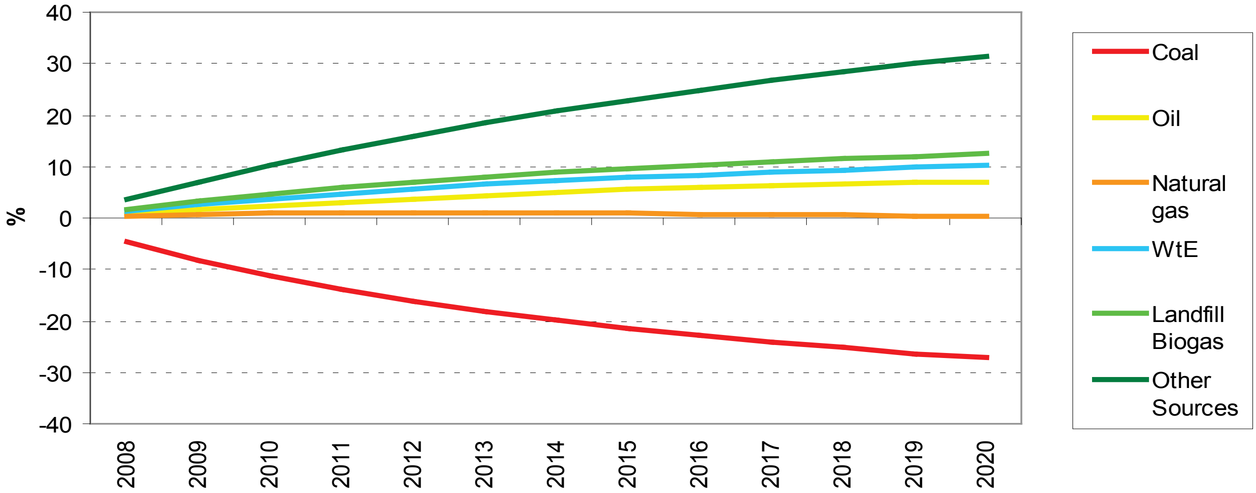

Figure 11 - Impact of mitigation policy on energy mix for power purpose (% change of shares)

Table 4: Flexibility values (2009 Mln €) for different technologies given a reduction in CO_2 emissions by 20% in 2020 compared to 1990 levels: Italy

	2007-2020 (discount rate 3%)		Annuitized	
	Optimistic scenario	Prudential scenario	Optimistic scenario	Prudential scenario
WtE	1269	907	122	87
Landfill Biogas	3	1	0.3	0.1
Natural gas (“energy equivalent” to Waste to Energy)	905	440	90	45
Natural gas*	29962	20702	2889	1984

* Only for electricity sector

Table 5: Flexibility values (2009 Mln €) for different technologies given a reduction in CO_2 emissions by 20% in 2020 compared to 1990 levels: EU 27 aggregate

	2007-2020 (discount rate 3%)		Annuitized	
	Optimistic scenario	Prudential scenario	Optimistic scenario	Prudential scenario
Waste to Energy	513	364	49	35
Biogas from landfill	1.5	1.2	0.15	0.12
Natural gas (“energy equivalent” to Waste to Energy)	368	228	36	23
Natural gas*	8427	5778	811	553

* Only for electricity sector

Table 6: Flexibility values (2009 Mln €) for different technologies given a reduction in CO_2 emissions by 20% in 2020 compared to 1990 levels: France, Germany, Spain and UK aggregate

	2007-2020 (discount rate 3%)		Annuitized	
	Optimistic scenario	Prudential scenario	Optimistic scenario	Prudential scenario
Waste to Energy	1933	1410	184	134
Biogas from landfill	8	6	0.8	0.6
Natural gas (“energy equivalent” to Waste to Energy)	1366	895	134	88
Natural gas*	27030	18983	2598	1815

* Only for electricity sector

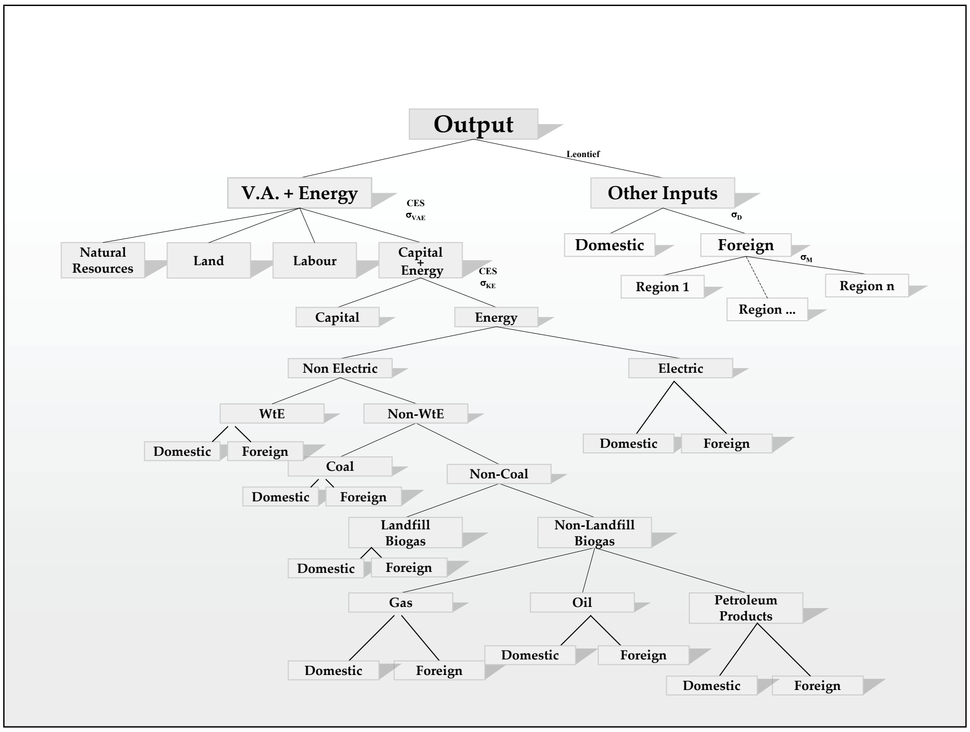

Figure A1. Nested tree structure for industrial production processes of the ICES model

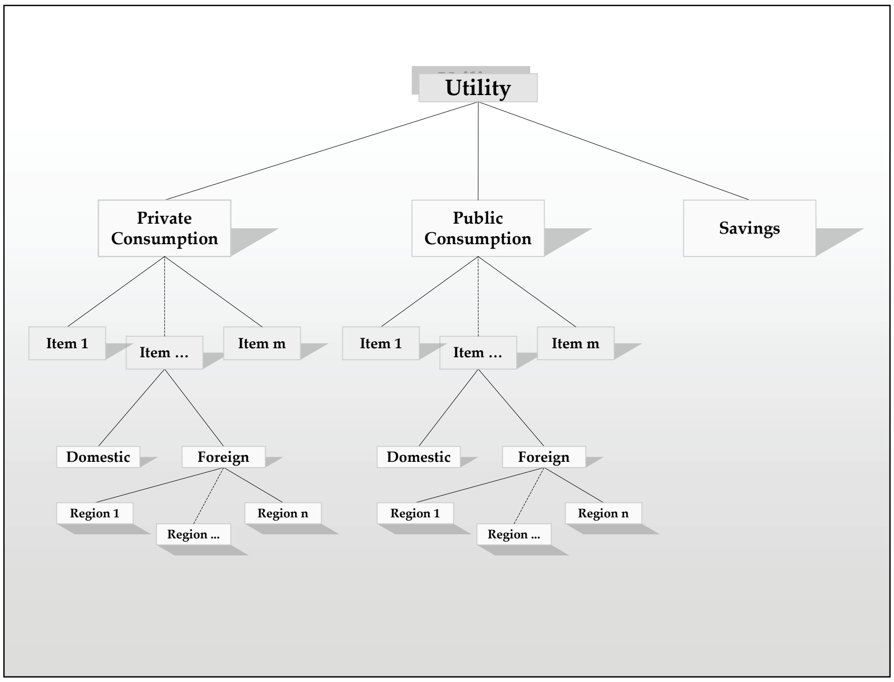

Figure A2. Nested tree structure for final demand of the ICES model