Energy from Waste:
Generation Potential, Mitigation Opportunity and Option Value

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Abstract

Climate change and waste management represent two challenges for sustainable development. As known, global warming will affect welfare worldwide through many categories of impact. Landfilling, especially if uncontrolled, often a preferred option as apparently cheap, can deteriorate the environment, originate dangerous pollution sources and arise social tension through the well known NIMBY syndrome.

To reduce antropogenic impact on climate change one main instrument is carbon efficiency improvement implying to increase the share of non-GHGs intensive energy sources in energy production and consumption processes.

When referring to non fossil fuels, the main focus is usually on nuclear and Renewable Energy Sources (RES): wind, solar, hydro and biofuels.

However, there are other important sources that may have a role to tackle climate change and limit other negative environmental problems while exploiting useful resources. This is the case of wastes. After the reduction in waste generation, the so-called integrated waste management may create important benefits from the social, the economic and the environmental viewpoints allowing to recovering either material or energy.

The present research proposes a macroeconomic assessment of impacts of Waste to Energy (WtE) (i.e. waste incineration with energy recovery) and of controlled landfill biogas to electricity generation and their potential contribution to a CO_2 emission reduction policy, within a computable general equilibrium framework. To our knowledge, this is the first time that this has been done.

We focus our analysis on Italy as a signatory of the GHG reduction commitment of 20% proposed by the European Community to be achieved by 2020 and confirmed once again at the Copenhagen summit organised by UNFCCC in December 2009. However, the rest of the world is also represented with a detail of 21 geo-political countries/regions.

To introduce WtE and landfill biogas for electricity generation, the GTAP 7 database and its production tree have been extended appropriately.

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 European 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 option value of 87-122 million €.

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). Its contribution to global greenhouse gas emissions is less than 5% (around 1300 $MtCO_2eq$ in 2005) (IPCC, 2007). However, 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.

The investigation tool chosen is a top-down, recursive-dynamic computable general equilibrium model for the world economy: ICES. Its production structure has been enriched including waste to energy and biogas production from landfill among the available inputs to the energy sector. Peculiar to this approach is the ability to capture macroeconomic feedbacks which are determinant to the final results. Indeed energy demand and supply are tightly linked to the pattern of the economic cycle, to sectoral dynamics originating flows of supply and demand to and from the energy sectors, to fluctuations in fossil fuel prices. Moreover, cost and effectiveness of internationally coordinated mitigation policies are strongly influenced by the number and charactristics of the participants. All this is taken into account.

The focus of the investigation is Italy, but international relations are considered: 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. Available assessments in this field are performed mainly in a partial-equilibrium, framework confined to the waste sector. In this vein for instance Monni *et al.* (2006) and Delhotal *et al.* (2006). They conclude that the potential greenouse gases emissions reduction from waste can be the 80% if landfilling were substituted with biogas recovery. 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$/$tCO_2$, eq., but that, interestingly, half of this could be accomplished at negative costs

Also at the national level studies are developed in a partial equilibrium framework and confined to the waste sector, disregarding wider implication for the energy sector and for the economic system as a whole. For example, Bianchi (2008) estimates that an increase of recycling of 15% by 2020

[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).

with respect to present may 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. 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. This is an important disclaimer: this database is the most complete and up-to date information set available for Italy collecting all the information that private and public operators in the industry declared complying with the Italian regulation (D.Lgs. 152/2006). Since 1996, the ECOCERVED database collects data about waste categories defined in EWC (European Waste Catalogue), keeping also track of waste management options. Coverage is almost 80% of urban wastes, it varies between the 10% and 50% across sectors for industrial waste.

In Italy, the volume of wastes used for energy recovery (so-called "R1" category, hereafter WtE) grew by 27% in the period 2002-2006 (from 3.1 to 3.9 million tons (Table 1)). It fell slightly in the last two years. Biogas recovered from landfills increased more considerably (Table 2); however, that trend was not only due to the diffusion of biogas collection, but also to an increase in number of firms asked to declare their own biogas production through the MUD ("Modello Unico di Dichiarazione Ambientale").

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)

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.

Thereby, the respective contribution to total carbon dioxide emissions is also limited: 2.8 million tons of CO_2 (0.58% of the Italian total or 1.88% of the electricity generation total (ISPRA, 2009)) from waste incineration with energy recovery[2]. 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).[3]

Data for Rest of the EU and other macro-regional aggregates have been obtained integrating IEA (2009a, b), EUROBSERVER (2009) and European IPPC Bureau (2006a, b).

3. Introducing waste to energy and landfill biogas in the ICES CGE model

This research uses a dynamic-recursive economic general equilibrium model, developed by the Fondazione Eni Enrico Mattei: ICES (Intertemporal Computable Equilibrium System) (Eboli *et al.*, 2009).[4] It relies upon the GTAP7 database replicating all observed market flows in 2004 as reported by countries' social accounting input-output matrices.

Dynamics in the model are originated by an endogenous investment process, based on the equlization of expected rate of return to capital, linking intertemporally 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 together 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.

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

[3] 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.

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

Table 3 - Regional and sector details in the ICES model

Countries/Regions	Productive Sectors
Austria	Agricolture
Belgium	Coal
CzechRep	Oil
Denmark	Natural Gas
Finland	Oil_Pcts
France	WtE
Germany	Landfill Biogas
Greece	Electricity
Hungary	Paper
Ireland	Minerals
Italy	Chemicals
Netherlands	Iron_Steel
Poland	Transport
Portugal	Oth_ind
Spain	Market Services
Sweden	Public services
UnitKingdom	
RoEU	
USA	
EEFSU	
RoA1	
RoW	

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.

The new ICES production tree is represented in Figure 1b (figure 1a reports the “old” production nest). The energy composite is now enriched by two additional non electric input: waste to energy and landfill biogas. The former appears in the first non electric top nest, the latter 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.

Waste to energy and landfill biogas are also two new economic sectors selling their output to the electricity sector.

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

Thus, firstly we estimated them. For WtE we used for Italy Mtoe of energy produced from Ecocerved and the average cost of waste treatment for incineration provided by Consonni *et al.* (2005). Values for other countries/regions have been estimated using IEA (2009a, b) and Consonni *et al.* (2005). For landfill biogas, cost information have been gathered from the outcomes of the CASES project while information on quantity have been collected by Eurobserver (2009) for EU countries and IEA (2009a, b) for non-EU countries.

These values were then subtracted from the value of total demand of the electricity sector.

A similar procedure has been used to attribute input supply to the two sectors. That of WtE has been disentangled from input demand of the electricity sector; that of landfill biogas from input demand of the gas distribution sector. The shares replicate the shares of the value in production. For both sectors input demand is constituted mainly of capital and labour (Consonni *et al.*, 2005), (Sue Wing, 2008), a minor part of public services, transport and other industries (UN, 2002; European IPPC Bureau, 2006b) and of electricity used to produce WtE before the combustion process (Enea, 2006).

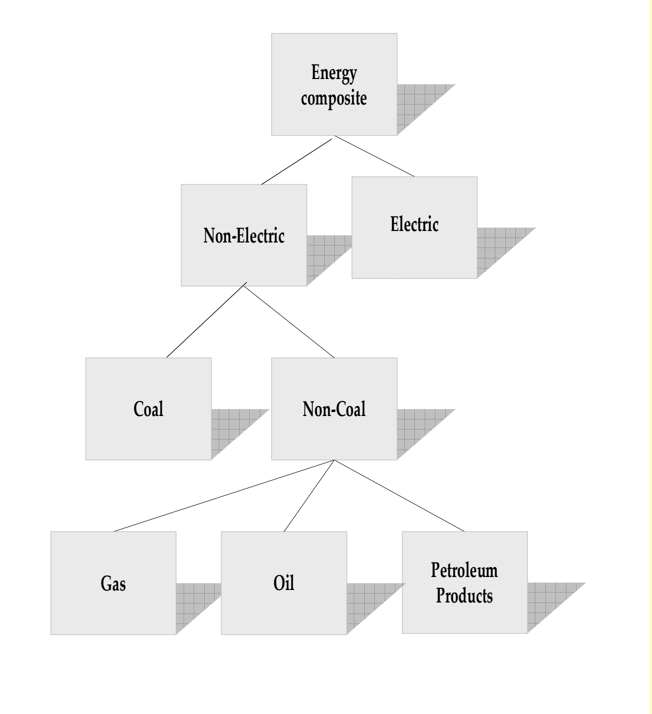

Figure 1a – The GTAP-E energy nest

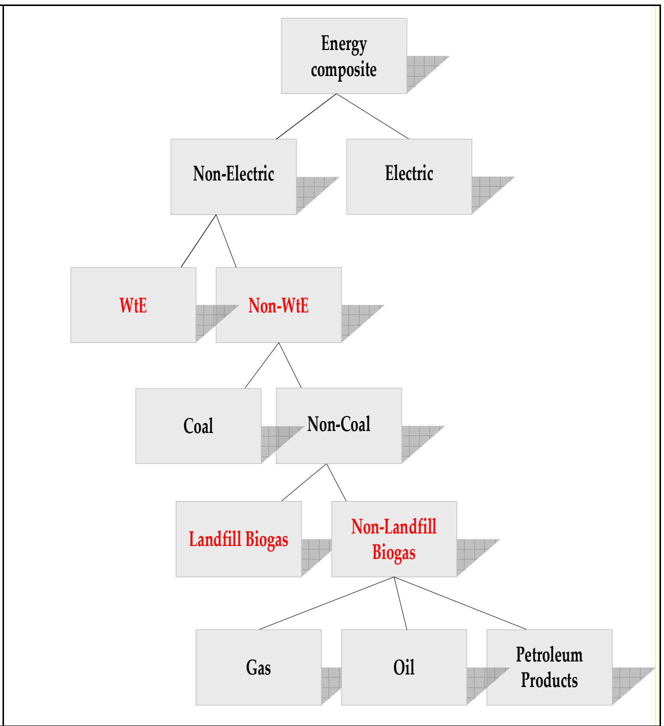

Figure 1b – The ICES energy nest

4. Results

The period chosen for the investigation is 2007-2020[5]. 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

[5] Note that the model simulates the period 2004-2020. We expressly worked to replicate the historical data when available, usually for the period 2004-2007.

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).

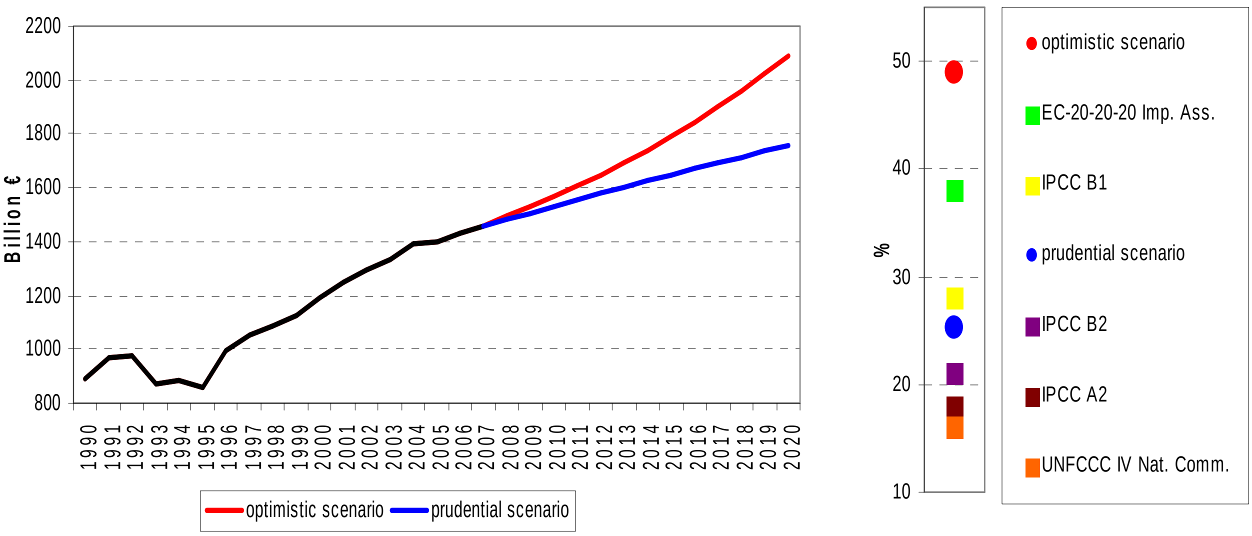

Figure 2 - GDP Italy: historical and projected trends in the optimistic and prudential scenarios (left) and comparison with other sources (2005-2020 growth rates) (right)

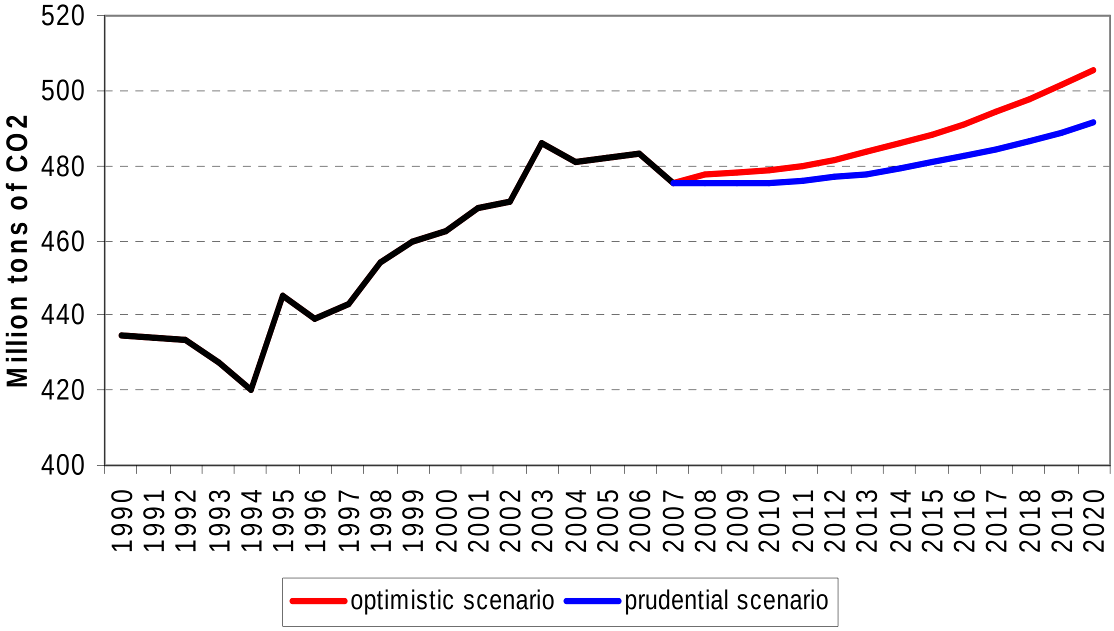

Figure 3 – CO_2 emissions Italy: historical and projected trend in the optimistic and prudential scenarios

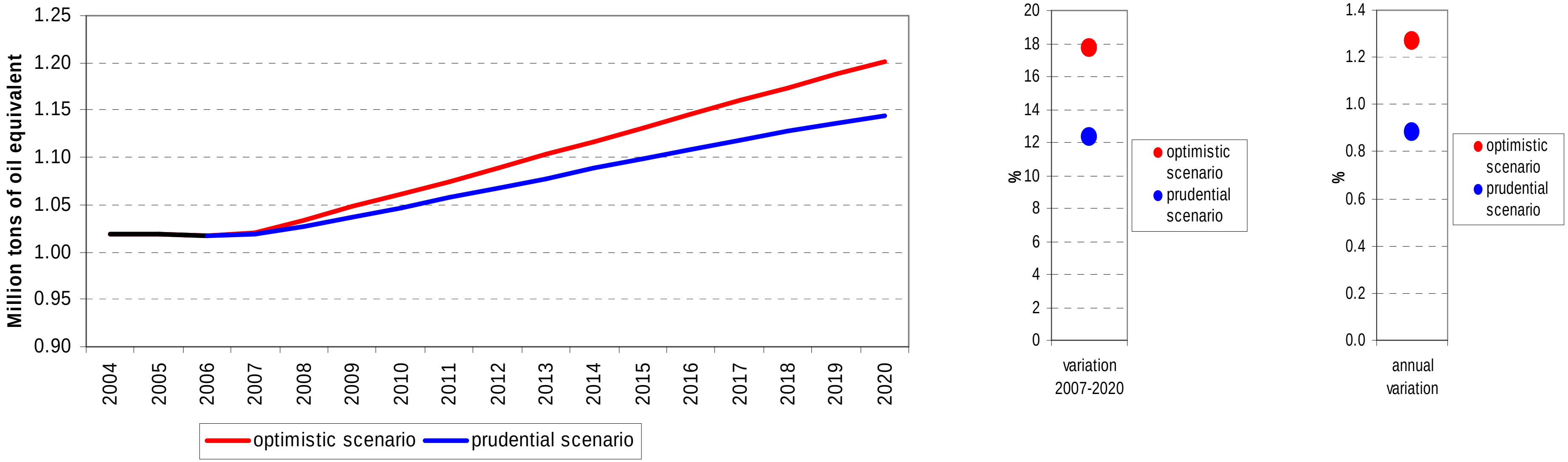

Figure 4 - WtE Italy: historical and projected trend in the optimistic and prudential scenarios. Absolute value (left), % variation 2007-2020 (center) and % annual variation (right)

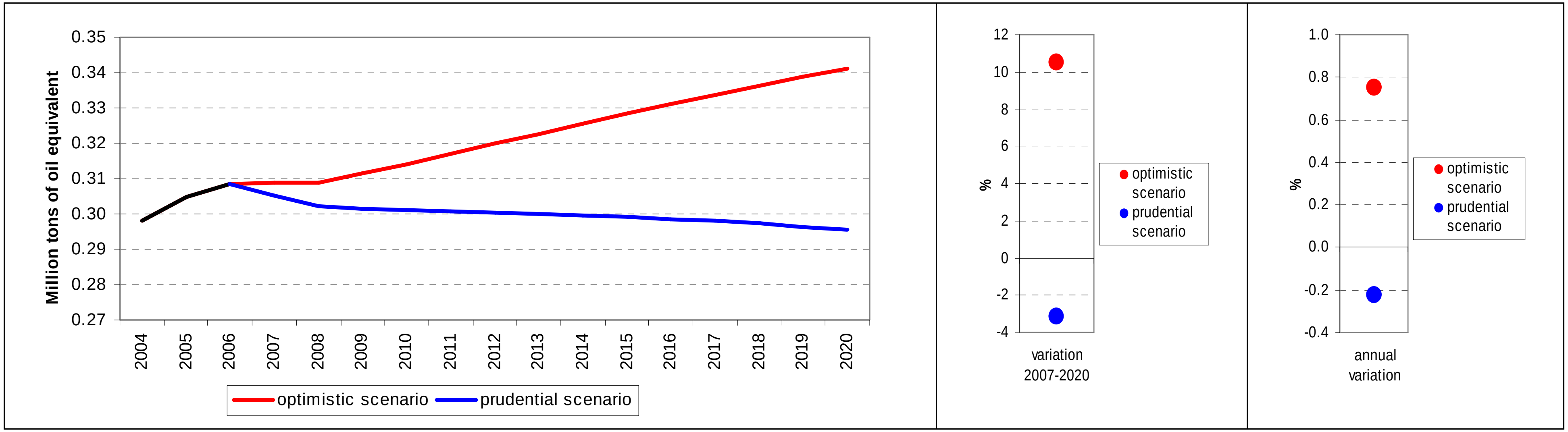

Figure 5 - Biogas Italy: historical and projected trend in the optimistic and prudential scenarios. Absolute value (left), % variation 2007-2020 (center) and % annual variation (right)

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.

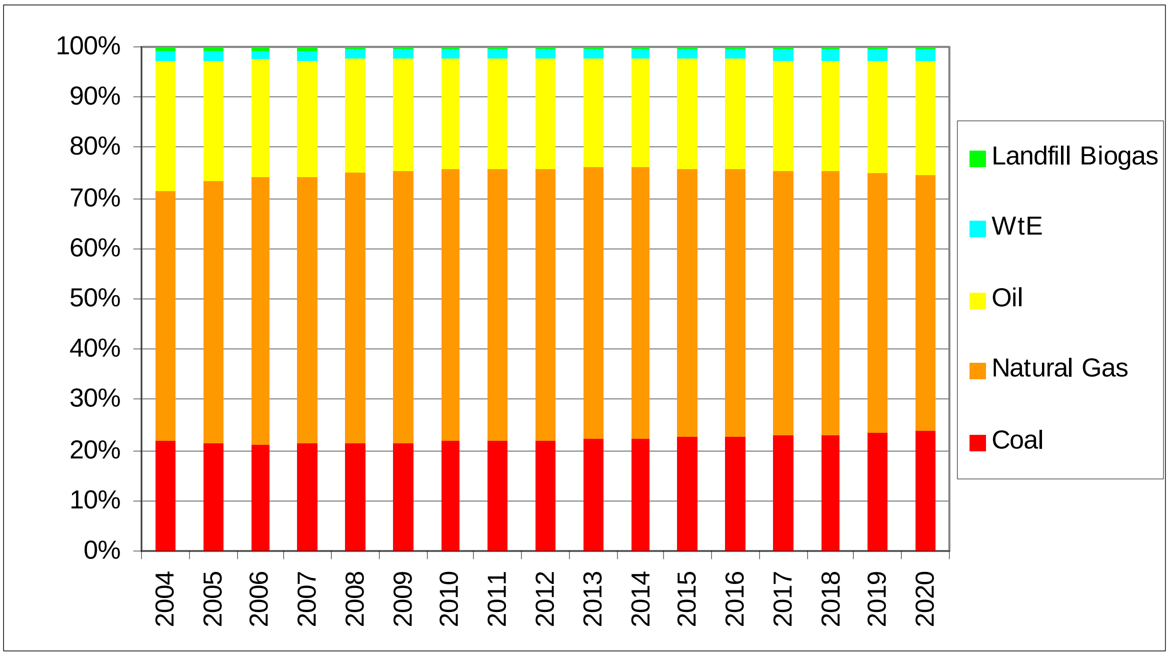

Figure 6 – Energy mix of power sector demand in Italy – Prudential scenario

This pattern is similar to the European trend (Figure 7) that is however characterized by a more intensive use of coal (mainly in East-European countries and Germany) and a lower use of natural gas.

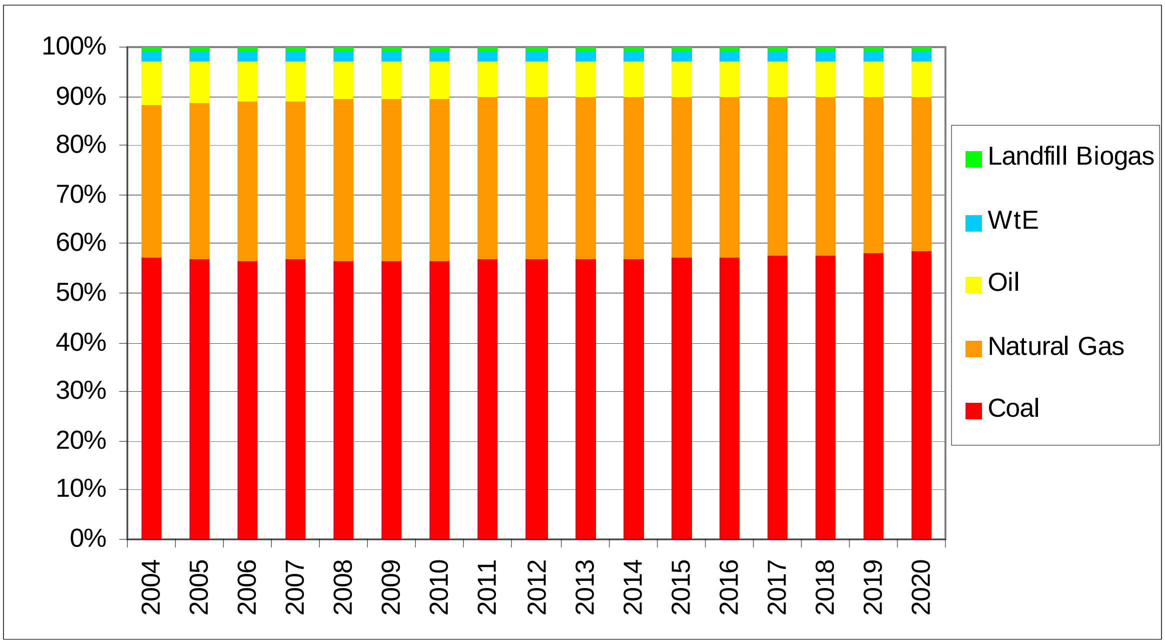

Figura 7 - Energy mix of power sector demand in EU27 – Prudential scenario

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. 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 *carbon leakage effect*: goods produced where environmental regulation is softer are less costly and consequently more competitive in international market. This 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.

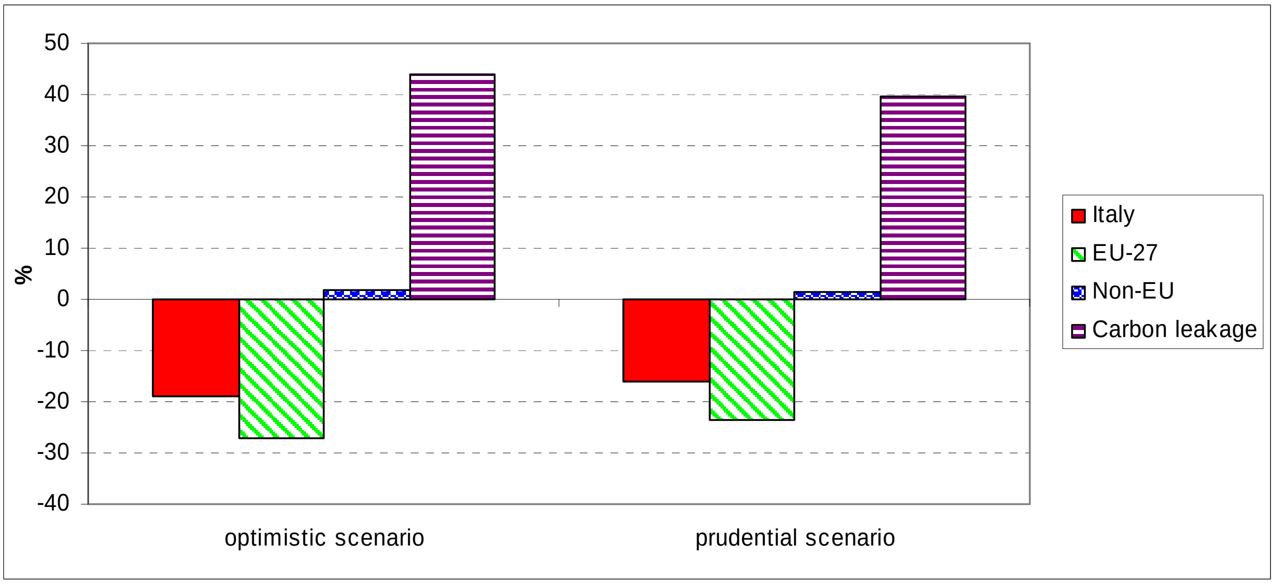

Figure 8 – Impact of mitigation policy on CO_2 emissions in 2020 (% change wrt reference scenarios)

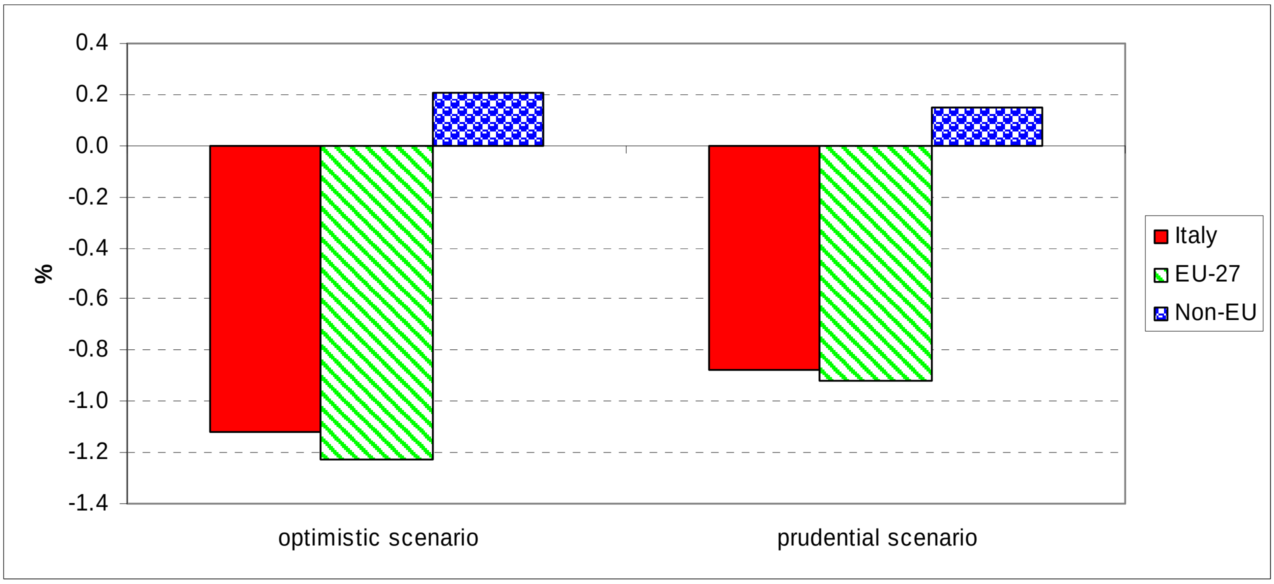

Figure 9 - Impact of mitigation policy on GDP in 2020 (% change wrt reference scenarios)

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%).

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.

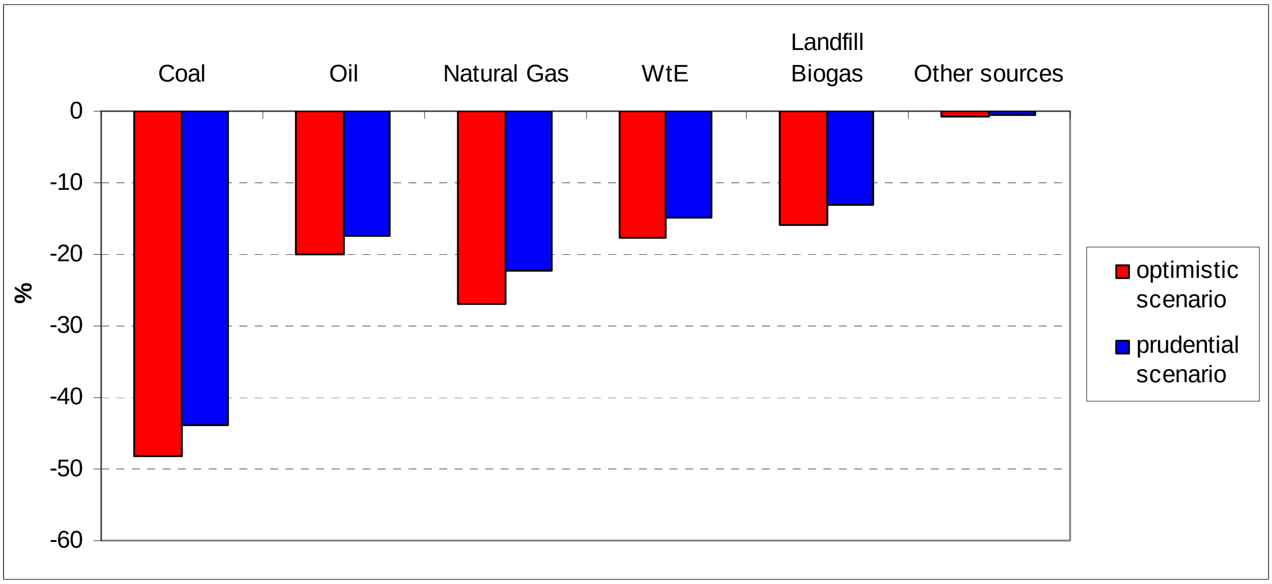

Figure 10 - Impact of mitigation policy on energy mix for power purpose in 2020 (% change wrt reference scenarios)

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).

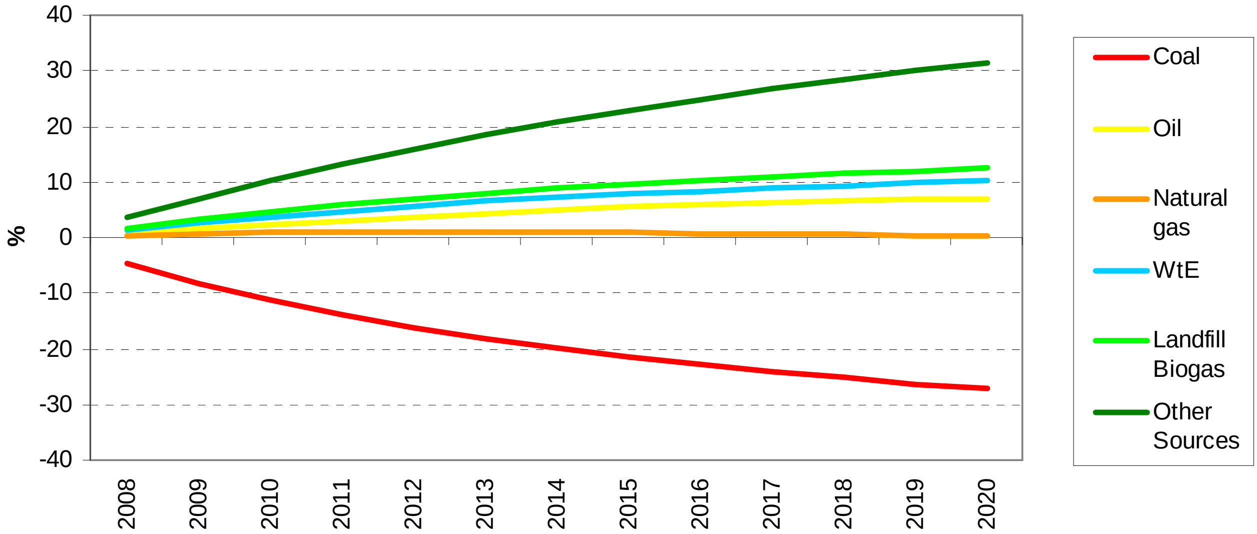

Figura 11 - Impact of mitigation policy on energy mix for power purpose (% change of shares)

4.3. Waste to energy and biogas in mitigation policy context: implications for the policy implementation costs

But 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 an "option value" for the two options.
Table 4 shows that the option value for 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. The option value of WtE is also 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 option value. Natural gas has indeed a paramount role as primary energy source and in electricity generation. Nevertheless, when the two options are compared, at "equivalent energy contribution" - namely freezing natural gas utilization for the same amount of energy generated by WtE - the latter shows a higher option value. Benefits (option value) associated to biogas is extremely small (0.3 and 0.1 million euro every year), but this is due to its marginal role in power generation.

Table 5 and 6 finally allow some comparison with the EU. In Italy option value of WtE and biogas is higher than the EU-27 average which is decreased by 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 and productive system.

Table 4: Option 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%)		Annualized	
	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: Option values (2009 Mln €) for different technologies given a reduction in CO_2 emissions by 20% in 2020 compared to 1990 levels: EU 27 average

	2007-2020 (discount rate 3%)		Annualized	
	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: Option 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 average

	2007-2020 (discount rate 3%)		Annualized	
	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

5. 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).

Even though considering the marginality of these two sectors, WtE could play a role in a mitigation policy context. Its option value, or said differently 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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