

# IEA Bioenergy

## Task 36

### Integrating energy recovery into solid waste management

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## Energy recovery from renewable content of waste: incentives and methodology for analysing biogenic content of mixed waste

### Topic 1 - Policy Support Final Report

**Contractor** IEA Bioenergy Task 36

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01	22/05/2012	12002353	Revision of Chapter 1 and Chapter 2 in accordance with IEA task 36
02	30/10/2012	12003964	Final Report

## FORWARD

This report was supported by the International Energy Agency (IEA) Bioenergy Task 36, which is a collaborative agreement examining the integration of energy into solid waste management. The overall aim of the work was to understand how policy makers incentivise energy from non-fossil biogenic waste through renewable incentive schemes, what evidence is required to prove biogenic origin and how this evidence can be obtained.

The work was undertaken in two phases: the first of these reviewed European and National policy on renewable energy incentives, in order to understand how they apply to waste to energy (WtE), including supporting actions such as “green certificates” and their implications for WtE. The second part of the work reviewed the methodologies available to measure the biogenic or renewable content of waste, which may be eligible for support through renewable energy incentives.

The objectives of the work were therefore:

1. To overview of policies and instruments applied or proposed in Europe to promote and support energy from renewable sources;
2. To review technical and economical assessment of the methodologies currently available to quantify the renewable energy from mixed fuels treated at WtE plants, (i.e. fuels containing a biomass and a fossil fraction), such as MSW and industrial wastes.

Chapter 1 of the Report provides the delivery “*summarising current EU and National RES Policy, including supporting action and implication for WtE*” while Chapter 2 delivers a “*Review on existing methodologies for the quantification of the renewable fraction of mixed fuels (including MSW and industrial waste*” and a “*Final report on methodologies for biogenic content of waste*”.

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A special thank to Roberto Guandalini (RSE) and Guido Cerletti (RSE) for their scientific and technical contribution towards the assessment of the biogenic content of waste treated in some italian WTE plants

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## EXECUTIVE SUMMARY

This report is part of an overall aim of IEA Bioenergy Task 36 to provide technical support to Policy Makers to allow a common basis for decisions on supporting actions, including incentives, to be adopted for the implementation policy on renewable energy that may affect waste to energy (WtE). The overall objective of this study is to analyse the technical problems associated with European and National Renewable Energy Source (RES) policies, including incentives such as “green certificates” and their implications for WtE plants.

This work was focused on two of the objectives: firstly, an overview of policies and instruments applied or proposed in Europe to promote and support energy from renewable sources, and how energy from waste-to energy plants is included in these instruments; and secondly, a technical and economical assessment of the current methodologies available to quantify the renewable energy in mixed fuels<sup>1</sup> treated at WtE plants. This report concentrates on European incentives as these are the most advanced policy instruments relevant to countries participating in Task 36. The implications of this work are relevant, however, elsewhere, where policy makers wish to incentivise renewable energy, including energy generated from the renewable fraction of mixed waste.

Financing tools applied at country and EU level, are instruments aimed at supporting RES and alleviating project risks; renewable energies have much lower operating costs (no fuel costs for most technologies) but proportionately higher capital costs. The policies are mainly directed at lowering capital costs by reducing technology, plant and construction costs, or covering generating costs through revenues. Even if relatively low EU financial instruments are available, Member States play a major role in supporting RES energy through national support schemes aimed at reducing capital costs and/or covering generating costs through revenues.

With regard to the RES-E (renewable electricity) sector, feed-in tariffs, feed-in premiums and quota obligations are the main instruments applied in EU 27 countries to support renewable electricity although on a national basis more than one scheme may be applied. Investment grants are currently the main support for most RES heating and cooling (RSE-T) technologies in Europe; obligations (rather a regulatory than a financial instrument) are applied in Spain and Germany. This situation is evolving in some European countries, for example support schemes for heating and cooling have also been introduced in national legislation on RES (UK) or under discussion (Italy) for the same purpose.

WtE is recognised by most EU Governments as having a role as a RES, but the rules for its status as a RES and financial support vary across Europe. Evidence to the existence of numerous different national support regimes (investors and other market operators thus have to deal with a wide range of

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<sup>1</sup> In this report mixed fuels for WtE refers to fuels containing a biomass and a fossil fraction, such as MSW and industrial wastes

differences, in regulations), which supports the conclusion that more effective selection and coordination of financing tools at national and EU level is one main need. In addition there are indications that there is a legal link between financial support and mandatory biomass sustainability criteria in Europe (see the new UK legislation on RO and RHI incentives). This should not affect WtE as waste is generally regarded as sustainable according to the RES Directive.

Instruments designed to promote and support RES-E, and where available RES-H too (e.g. The Green Certificate system in Italy; the Renewable Obligation (RO) and the Renewable Heat Incentive (RHI) in UK), are substantially linked and applied to the biomass (biodegradable) fraction of fuels.

Operators of eligible WtE plants are generally required to demonstrate the renewable content of their feedstock in order to show the renewable contribution to the total net energy (i.e. electricity) generated. This means they have to quantify the share of electricity due to the biogenic content of fuels (“ $E_{\text{biogenic}}$ ”), based on accepted methodologies.

Regulations in charge in some European countries allow WtE plants to adopt a “simplified” approach, even if for specific wastes only (usually MSW, and solid recovered fuels (SRF), if derived from MSW) whose composition is well monitored on a national basis for other purposes (e.g. waste management or emission trading). In this case, the  $E_{\text{biogenic}}$  generated can be calculated by applying a “default percentage share” or a “deemed renewable content” (legally recognised as energy from renewable source) to the total net energy (electricity) produced. This is useful as it avoids the large cost, time and labour of the WtE plant operators having to apply a waste sampling and characterization plan to monitor samples at the plant. WtE plant operators may still choose to develop a sampling and characterisation plan for their waste if treating MSW or SRF with an higher biogenic content or, by necessity, if treating other mixed wastes outside the typical composition.

Currently no existing national rule identifies one unambiguous reference method for WtE plants to measure the  $E_{\text{biogenic}}$ . There are two reasons for this. Waste feedstocks used for heat and power generation in the EU may vary widely in composition. In addition the methodologies for measuring the biogenic content are either lacking or not sufficiently mature (from both an operational or economic viewpoint). In general national legislation mainly refers to those methodologies considered the most mature: manual sorting analysis and the selective dissolution analysis. These methodologies are, supported by EU standard (e.g. the CEN/TS 15440), already used on field. These need a representative sample of the solid mixed wastes treated in the plant. This is also true for the alternative method, based on a pre-combustion Carbon-14 analysis, which is included in some national legislations (e.g. Italy), referring to the available standard method described in the CEN/TS 15440. The Carbon-14 method, has a lower level of field application at WtE plants, probably due to its requirement for more specialised laboratory analysis and related costs.

A post-combustion application of the  $^{14}\text{C}$  method has also been developed, which allows the determination of the biogenic content of the treated waste by measuring the  $^{14}\text{C}$  content in flue gas samples by mass and by energy. This technique investigates the partition of the biogenic and fossil  $\text{CO}_2$  in the flue gas emitted by the WtE plant and appears to be a direct and quite simple way to assess the biogenic and fossil contribution to the total net energy produced (as for other purposes such  $\text{CO}_2$  trading schemes). Flue gases are generally sampled automatically and continuously or frequently at a plant during normal operation, from locations where gases have been uniformly mixed (so that they are representative of the mixed fuel burned). This approach avoids limits associated with both the manual sorting and the selective dissolution methods, as the need to produce and convert to  $\text{CO}_2$  representative samples of solid wastes as required when a pre-combustion Carbon-14 method is applied (i.e. on SRF samples). Sampling and analytical requirements results now in a whole cost per sample higher than that assessed for both the selected dissolution and  $^{14}\text{C}$  method applied to solid sample. The post-combustion  $^{14}\text{C}$  measure has been tested and compared to the mature methods mentioned above and the results appear to be in a good agreement with outputs from the selective dissolution of solid waste samples.

The post combustion  $^{14}\text{C}$  measure is currently receiving increasing attention from National Authorities of EU Member States and there seems to be general agreement to consider this methodology as the best available method – also useful in the future as “reference” method – to assess the whole biogenic fraction of energy produced in a WtE plant. Up to now the method has not been widely accepted or mentioned in national regulations, due to the need of a large validation process on field. Few standardised procedures (e.g. ASTM D6866; ISO/DIS 13833) are available based on the  $^{14}\text{C}$  measure in the flue gas  $\text{CO}_2$  which allow an assessment of the biogenic fraction mainly on a mass basis.

An intensive effort has been recently made in Italy, resulting in a proposal (now under public consultation) for an Italian national standard based on this method. It allows the final conversion of the biomass content measured on a mass basis into biogenic energy and takes into account the energy spent for water evaporation (water in MSW and SRF is mainly associated to the biogenic fraction) so that a net value of renewable energy can be obtained. This is a first in European legislation.

Furthermore a modelling approach based on a mass and energy balance was recently implemented (software tools are available in Italy and Austria) and tested on some WtE plants (MSW and SRF plants, mainly). This approach appears to be quite promising in terms of: performance (due to an observed good correlation with results achieved by applying the selective dissolution and the  $^{14}\text{C}$  methods); costs, being waste sampling & analysis-free (it uses as input waste reference data from literature and plant operational data usually recorded in a WTE plant); feasibility, allowing the on-line monitoring of the biogenic energy produced by a WTE plant.



## GLOSSARY

<b>AMS</b>	Accelerated Mass spectrometry
<b>BI</b>	Beta Ionisation
<b>CEN</b>	European Standards Agency
<b>CV</b>	Calorific value
<b>EEA</b>	European Environment Agency
<b>EFTA</b>	European Free Trade Association
<b>ISO</b>	International organisation for standardisation
<b>Ktoe</b>	Thousand tonne oil equivalent
<b>MSW</b>	Municipal Solid Waste
<b>Mtoe</b>	Million tonne of oil equivalent
<b>NREAP</b>	National Renewable Energy Action Plan
<b>PS</b>	Proportional Scintillation
<b>RES</b>	Renewable Energy Source
<b>RES-E</b>	Electricity from Renewable Energy Source
<b>RES-T</b>	Thermal energy from Renewable Energy Source used for cooling and heating
<b>RDF</b>	Refuse derived fuel
<b>ROCs</b>	Renewable Obligation Certificates (in UK)
<b>SDE</b>	Subsidies Duurzame Energie (NL renewable electricity support scheme)
<b>SRF</b>	Solid Recovered Fuel
<b>TGC</b>	Tradable Green Certificate for electricity generated.
<b>WtE plant</b>	Waste-to-Energy plant

## **1 CURRENT EU AND NATIONAL RES POLICY INCLUDING SUPPORTING ACTION AND IMPLICATION FOR WTE**

This Chapter gives an overview of the status and perspectives of energy production from renewable sources in Europe, policies and incentives currently in force to promote and support it, at an EU and Member States level, with a focus on the waste-to energy sector. The focus on European legislation reflects participation in Task 36 and that legislation in Europe is relatively mature.

### **1.1 STATUS AND PERSPECTIVES OF ENERGY PRODUCTION FROM RENEWABLE SOURCES IN EUROPE**

Under the Directive 2001/77/EC [*EU Directive 2001/77/EC*] and the Directive 2003/30/EC [*EU Directive 2003/30/EC*] national indicative targets were introduced with the aim of achieving an EU share of renewable energy in electricity generation of 21% and of renewable energy replacing fossil road transport fuels of 5.75%, by 2010.

Neither of these EU targets were met [*EU COM(2011)31*], because only a few Member States (fig. 1.1) achieved their 2010 targets for renewable energy in electricity generation (Denmark, Germany, Hungary, Ireland, Lithuania, Poland and Portugal) and in transport (Austria, Finland, Germany, Malta, Netherlands, Poland, Romania, Spain and Sweden) [*EU SEC(2011) 130*]. Due to this inadequate rate of progress a change in EU policy was introduced by the adoption of the Directive 2009/28/EC [*EU Directive 2009/28/EC*], commonly referred to as the Renewable Energy Directive. This Directive covers energy consumption as a whole, including heating and cooling. It lays down legally binding national targets to achieve a 20% EU share of renewable energy by 2020, introduces legal requirements for Member States to prepare National Renewable Energy Action Plans (NREAPs) and proposes reform of planning regimes and development of electricity grids.

Based on an analysis of Member States' NREAPs<sup>2</sup>, the European Commission [*EU COM(2011)31*] concluded that the new policy approach is “*starting to pay off*”, if all national production forecasts are fulfilled (Austria, Bulgaria, Czech Republic, Denmark, Germany, Greece, Spain, France, Lithuania, Malta, Netherlands, Slovenia and Sweden are planning to exceed their own targets) the overall share of renewable energy in the EU will exceed the 20% target in 2020. This shows an expected total renewable energy consumption (gross final energy consumption) of combined States more than double compared to 2005 (from 103 million tonne oil equivalent, Mtoe, in 2005 to 217 Mtoe in 2020); the electricity sector is expected to account for 45%, the heating sector for 37% and the transport sector for 18% of the total increase.

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<sup>2</sup> NREAPs: National Renewable Energy Action Plans

The European Commission [EU COM(2011)31] highlighted some main needs to meet the 2020 RES target (see: Box 1), all regarded as relevant barriers to achieving the full potential of RES, (including WtE) in Europe.

	Electricity					Biofuels				
	2008 share (%)	2010 target (%)	2010 NREAP (%)	recent growth	progress made	2008 share (%)	2010 target (%)	2010 NREAP (%)	recent growth	progress made
Austria	65.1	78.1	69.3	😊	😞	7.1	5.75	6.8	😊	😊
Belgium	4.6	6	4.8	😊	😊	1.2	5.75	3.8	😊	😞
Bulgaria	9.4	11	10.6	😊	😊	0.2	5.75	1.7	😞	😞
Cyprus	0.3	6	4.3	😊	😞	2.1	2.5	2.2	😊	😊
Czech Rep.	5.2	8	7.4	😊	😊	0.2	5.75	4.1	😞	😞
Denmark	26.1	29	34.3	😊	😊	0.3	5.75	1.0	😞	😞
Estonia	2.1	5.1	1.7	😊	😞	0.0	5.0	0.0	😞	😞
Finland	27.2	31.5	26.8	😊	😞	2.2	4.0	5.7	😊	😊
France	14.4	21	15.4	😊	😞	5.6	7.0	6.4	😊	😊
Germany	14.0	12.5	17.4	😊	😊	6.2	5.75	7.3	😞	😊
Greece	9.7	20.1	13.3	😊	😞	1.0	5.75	1.7	😞	😞
Hungary	5.3	3.6	9	😊	😊	3.9	5.75	3.7	😊	😊
Ireland	11.2	13.2	20.4	😊	😊	1.2	4.0	3	😊	😞
Italy	16.6	22.5	19	😞	😞	2.3	5.75	3.5	😊	😊
Latvia	38.7	49.3	44.7	😞	😞	0.9	5.75	4	😊	😞
Lithuania	4.9	7	8	😊	😊	4.0	5.75	4	😊	😊
Luxemburg	3.6	5.7	4	😞	😞	2.0	5.75	2.1	😊	😊
Malta	0.0	5	0.6	😞	😞	0.0	1.25	2.8	😞	😞
Netherlands	7.5	9	8.6	😞	😊	2.5	4.0	4.1	😞	😊
Poland	4.3	7.5	7.5	😊	😊	3.3	5.75	5.8	😊	😊
Portugal	33.3	39	41.4	😊	😊	2.4	10.0	5	😊	😊
Romania	28.1	33	27.5	😊	😞	2.8	4.0	5.8	😊	😊
Slovakia	17.1	31	19.1	😊	😞	6.3	5.75	4.1	😊	😊
Slovenia	30.0	33.6	32.4	😊	😞	1.5	3.0	2.6	😊	😞
Spain	23.3	29.4	28.8	😊	😊	1.9	5.83	6	😊	😞
Sweden	53.6	60.0	55	😊	😊	6.3	5.75	7.4	😊	😊
UK	5.4	10	8.6	😊	😞	2.0	3.5	2.6	😊	😊

Source: Eurostat 2008 and Member States NREAPs

**Figure 1.1 - Member States progress in developing renewable energy.** The smilies reflect actual progress towards the target, based on Eurostat statistics; key to "smiley" grades: progress made (toward target): red 0-33%, yellow, 34-66% green 67-100%; recent growth (on 2008) red ≤ 0 percentage point change, yellow > 0 – 1 percentage point change, green > 1 percentage. NREAP: national Renewable Energy Action Plan [Source: EU SEC(2011) 130 final, 2011]

**Box 1 Main needs to meet the 2020 EU RES target [EU COM(2011)31]**

improve infrastructural investments;  
streamline complex authorisation and planning procedures;  
remove non-cost barriers to the growth of renewable energy;  
promote R&D for plant technology improvement and investment cost reduction;  
work for an effective selection and coordination of financing tools at national and EU level, depending on the state (maturity) of technology and project development, without altering the competitiveness of the market, with a predictable and transparent way of adapting support levels so as to avoid "stop and go" policies or political calls for retroactive changes to conditions (such as in certain photovoltaic markets recently).

### 1.1.1 The RES-T sector

In the past only modest market development was experienced in the past in the heating and cooling sector (RES-T) due to a lack of adequate support actions in most Member States.

The EU Commission data based on NREAPs [EU COM(2011)31], indicates that biomass is expected to remain the main renewable source (fig. 1.2). To achieve this, the EC highlights the need for a combination of National Support schemes, R&D and investment in infrastructure (e.g. the pellet industry, biomass boiler technology, co-firing and biofuels refineries).

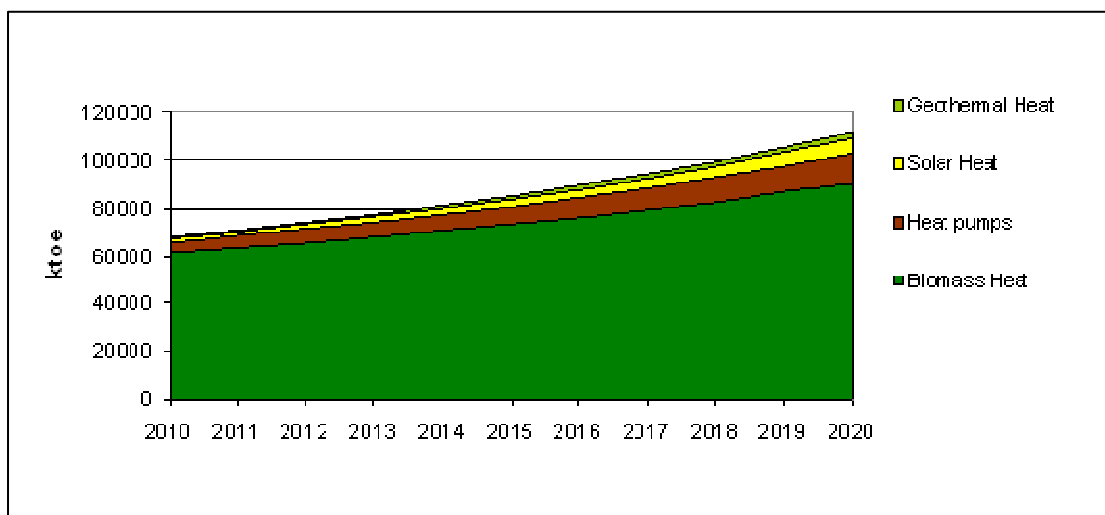


Figure 1.2 - Expected development of renewable energy in the heating&cooling sector [Source: EU COM(2011)31]

### 1.1.2 The RES-E sector

With reference to the electricity sector (RES-E), from 2000 to 2010 (fig. 1.3) a whole increment in gross production of 220.850 GWh was observed for the whole EU15 zone (2000: 380.258 GWh; 2010: 601.108 GWh), mainly due to a growth of solar (+119.414 GWh) and biomass (+ 75.956 GWh) generation (accounting in 2010 for a 24% and 18%, respectively, of the total EU 15 RES-E production). The proportion of RES-E on total electricity (gross) EU15 production changed from a 15% (2000) to a 21% (2010)[GSE, 2011].

In 2010 the RES-E mix showed a different composition within EU15 countries (fig. 1.4), with the whole biomass source resulting mainly involved in northern European countries such as Belgium (63% of RES-E mix), Netherland (63% of RES-E mix), United Kingdom (46% of RES-E mix), Finland (45% of RES-E mix) [GSE, 2011].

The analysis released by the European Commission [EU COM(2011)31] indicates that the RES-E sector will account for about a 37% of the EU electricity mix covered with renewable sources by 2020. The expected contribution of renewable sources to the whole growth of the RES-E sector from 2010 to 2020 is described in fig. 1.5 [EU COM(2011)31].

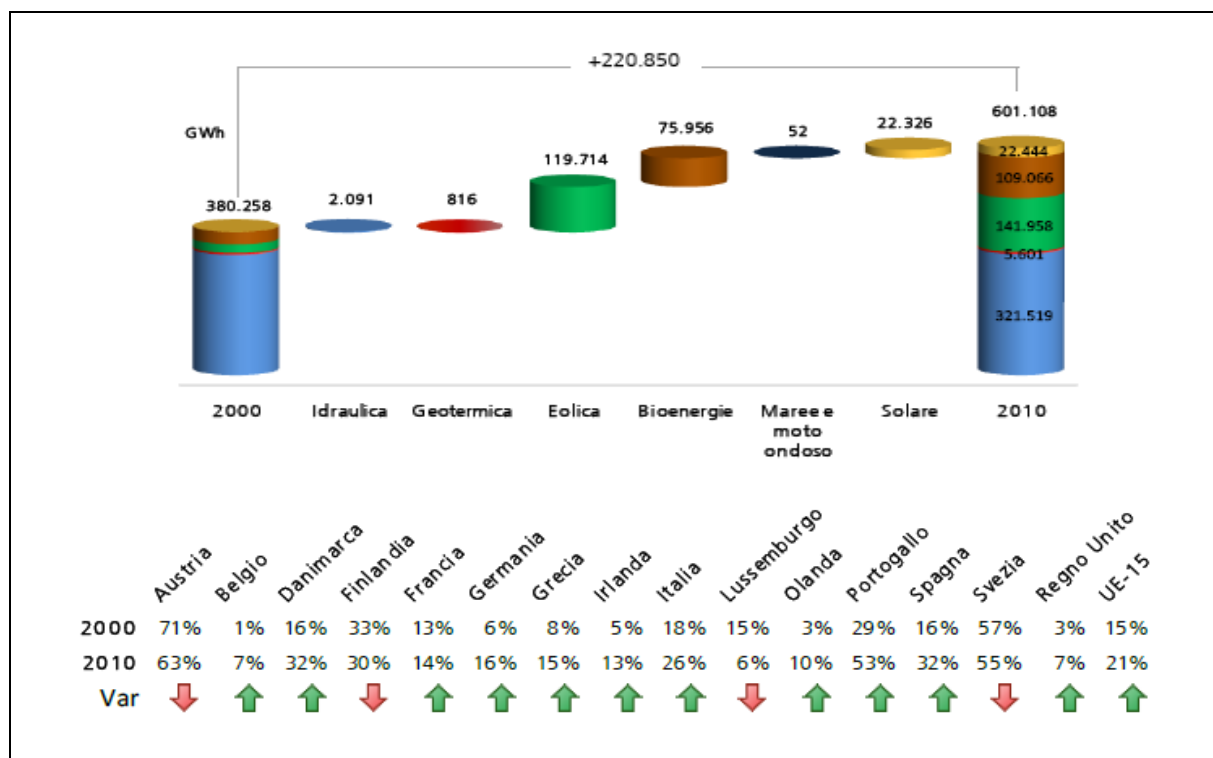


Figure 1.3 - Change of RES-E (gross) production in the whole EU15 zone from 2000 to 2010, total and per source: blu:hydro; red: geothermal; yellow: solar; black: tide, wave; green: wind; brown: biomass) - 2000 and 2010 values (%) of the incidence of RES-E on Total (gross) production of electricity in the EU15 zone [Source: GSE , 2011]

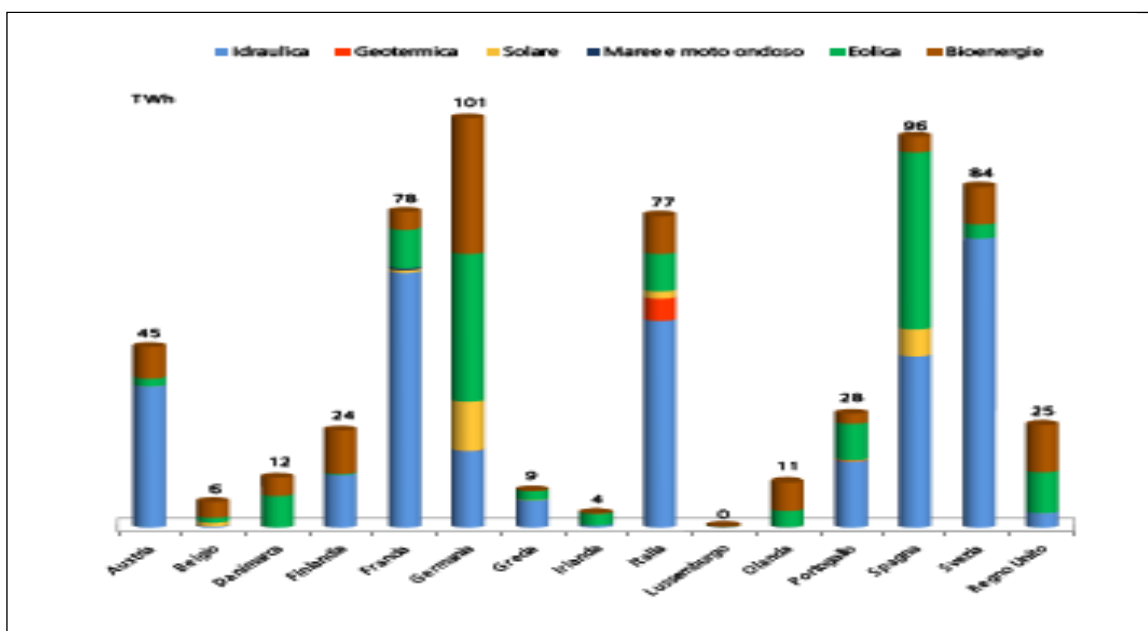


Figure 1.4 - Year 2010: gross RES-E mix in the EU15 countries; source; blu: hydro; red: geothermal; yellow: solar; black: tide, wave; green: wind; brown: biomass [Source: GSE, 2011]

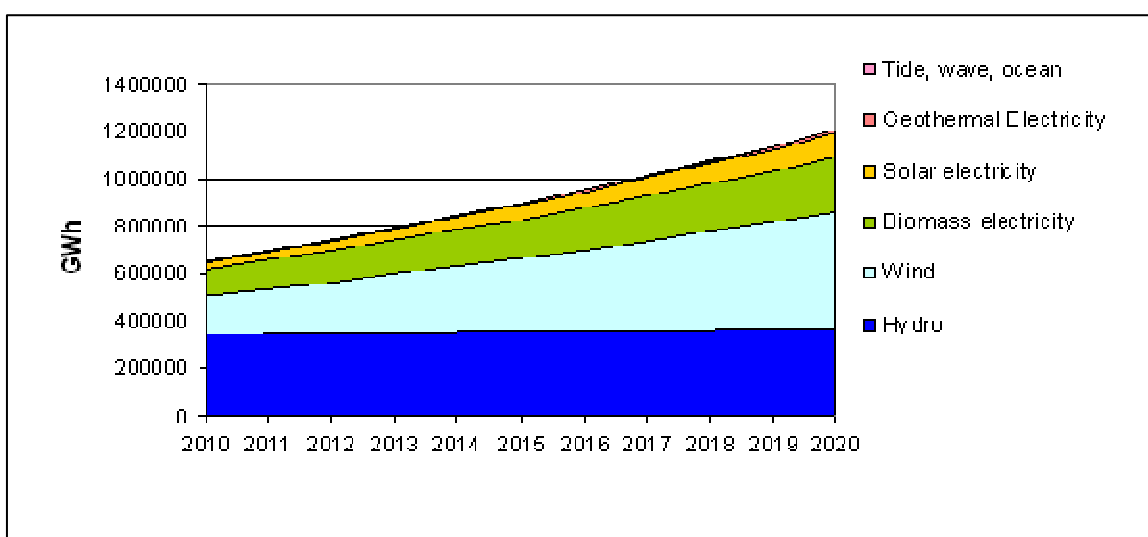


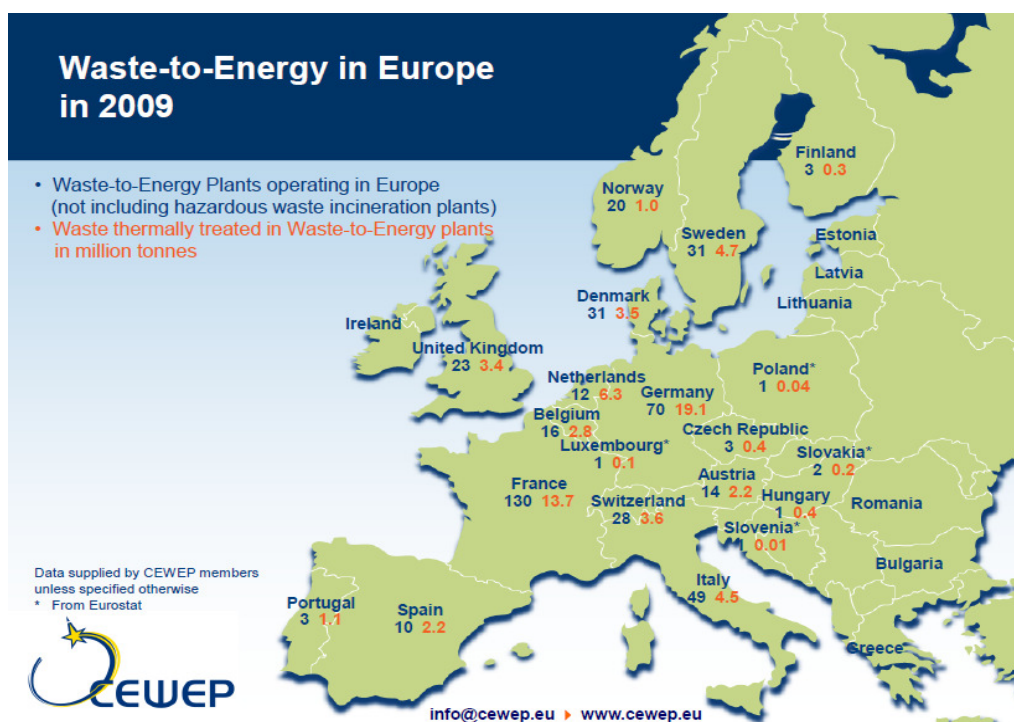
Figure 1.5 - Expected development of renewable energy in the electricity sector [Source: EU COM(2011)31, 2011]

### 1.1.3 The Waste-to-Energy (WtE) sector

All previous figures refer to the renewable energy achievable from biomass as a whole, without specifying the relative contribution of its components, bio-waste in particular. Summary figures on both WtE operating plants and/or amount of renewable energy produced in Europe can be really obtained

from different sources: from CEWEP<sup>3</sup> through its on line data and publications [CEWEP, 2010 a-g], to the EurObserv'Er<sup>4</sup> through an on-line Renewable Municipal Waste Barometer and the published Country Reports [CEWEP, 2010 a-g], the Member State's NREAPs or their overall analysis [Teckenburg Eva et al, 2011] produced within the Intelligent Energy Europe project "RE-Shapping"<sup>5</sup>. For both the items, update summary data from the above mentioned sources generally refer to the year 2009. Information on if and how much (%) energy produced in WtE plants is recognised and supported as renewable, can be derived from some of these sources (e.g. Member State's NREAPs ; CEWEP Country Reports), as discussed later.

As fig. 1.6 shows [CEWEP, 2012] EU Member States differ in both the number of operating WtE plants and the total amount of waste (MSW, SRF) thermally treated, reflecting a different management ways of the overall municipal waste produced as reported in fig. 1.7 (the figure includes an update to 2010 of the waste management in each country).



**Figure 1.6 – The 2009 map of the waste-to-energy situation in EU 27 countries [Source: CEWEP, 2012]**

<sup>3</sup> CEWEP: Confederation of European Waste-to-Energy Plants; it represents about 363 Waste-to-Energy Plants across Europe (www.cewep.eu)

<sup>4</sup> Euroserv'Er: l'Observatoire des Energies Renouvelables (www.euroserv-er.org)

<sup>5</sup> Intelligent Energy Europe project RE- Shapping: Shaping an effective and efficient European renewable energy market (www.reshaping-res-policy.eu)



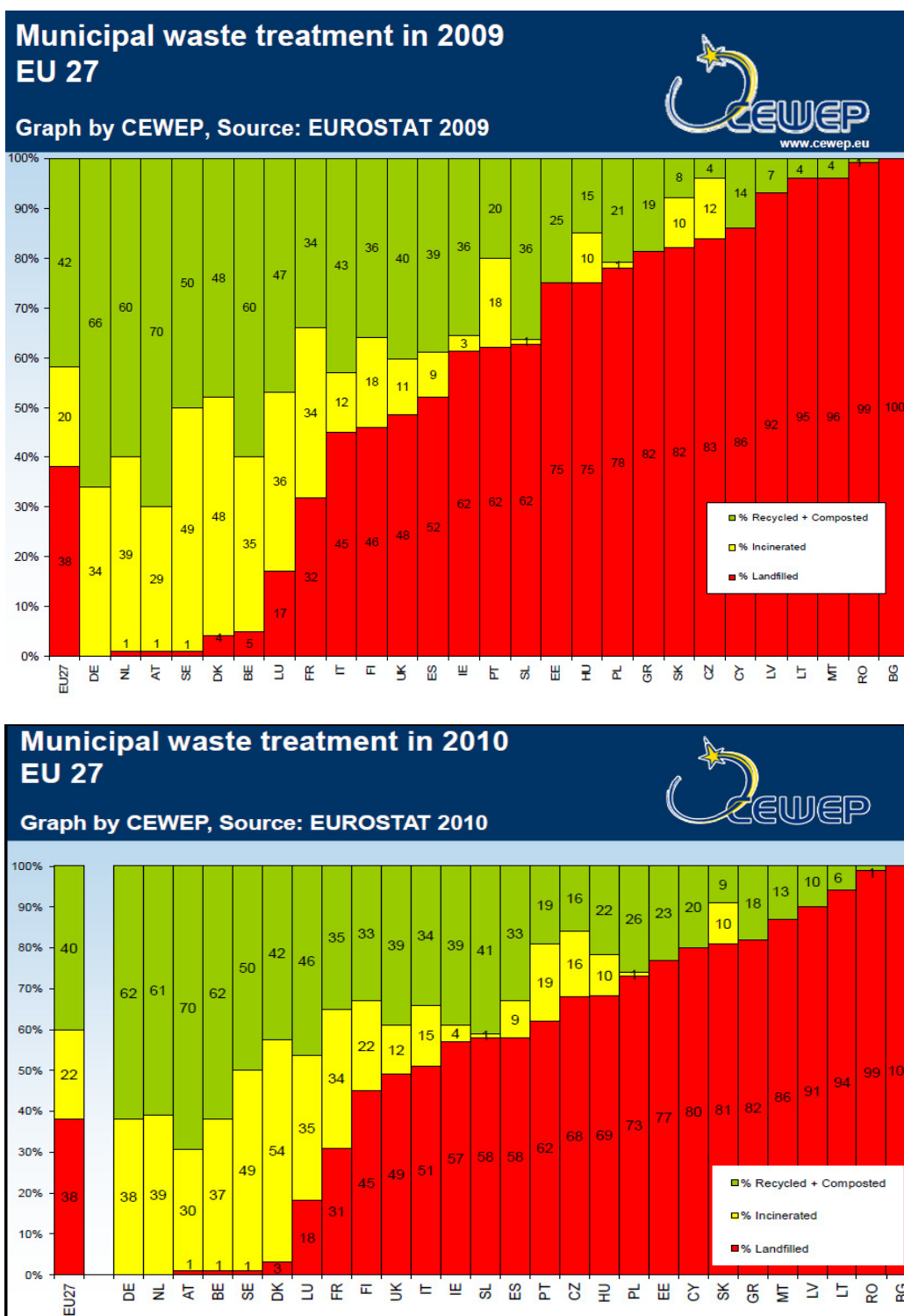


Figure 1.7 – Percentage of municipal waste recycled and composted, incinerated and landfilled in EU 27 countries in 2009 and 2010 [Source: CEWEP, 2012]



Referring to the year 2009, in the European Union [*Eurobserv'Er, 2010*] incineration of MSW resulted in a total primary energy production of 7738.4 ktoe (this value doubles if all municipal waste are considered), a total gross electricity production of 15376.3 GWh and a total heat production in the transformation sector<sup>6</sup> of 1949.2 ktoe. Country data in fig. 1.8 (primary energy production), fig. 1.9 (gross electricity production) and fig. 1.10 (heat production) clearly show that a different degree of development of the WtE sector occur in EU Member States [*Eurobserv'Er, 2010*].

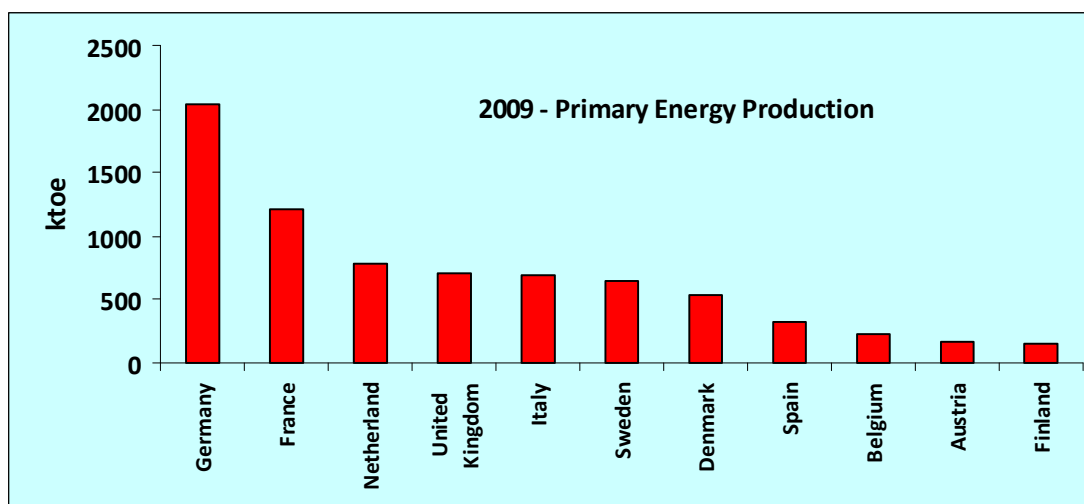


Figure 1.8 – Total primary energy production from renewable municipal waste combustion in some EU member States: year 2009 [Source: Erobserve'Er, 2010]

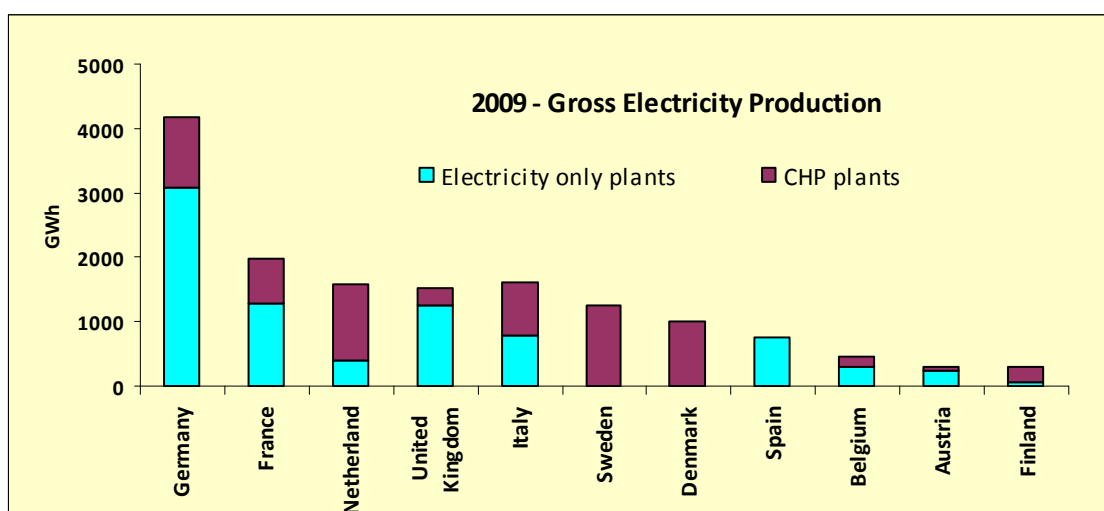
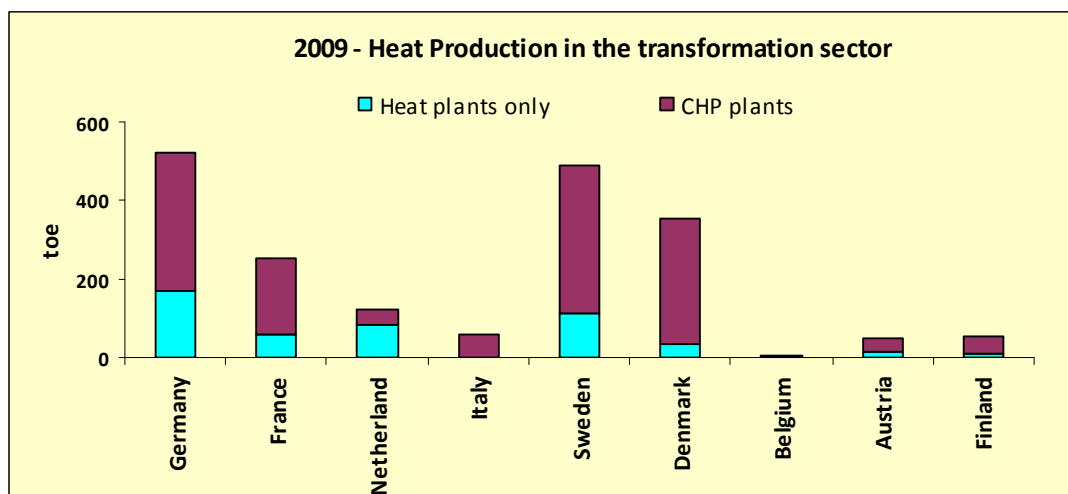


Figure 1.9 – Total gross electricity production from renewable municipal waste combustion in some EU member States: year 2009 [Source: Erobserve'Er, 2010]

<sup>6</sup> Heat sold to district heating networks



**Figure 1.10 – Total heat production (transformation sector) from renewable municipal waste combustion in some EU Member States: year 2009 [Source: Erobserve’Er, 2010]**

A similar summary figure for bio-waste was produced by the Intelligent Energy Europe project RE-Shaping [Teckenburg *et al*, 2011], which also included a comparison between gross electricity production from bio-waste and from biomass (solid and liquid), based on 2009 Renewable Energy Country Profiles (tab. 1.1). About the 2009 renewable heat production, a comparison between grid-biomass and no-grid biomass (tab. 1.2) can be derived only, from the same source [Teckenburg *et al*, 2011].

**Table 1.1 – Gross electricity production from biowaste, solid and liquid biomass and biogas (ktoe) in some EU Member States municipal: year 2009 [Source: Teckenburg *et al*, 2011]**

2009	Gross Electricity production		
	Bio-waste	Biogas	Biomass
	ktoe	ktoe	ktoe
Austria	26	55	286
Belgium	40	40	229
Denmark	88	28	189
Finland	25	3	723
France	170	73	110
Germany	358	1080	936
Italy	139	150	243
Netherlands	135	79	305
Spain	85	45	184
Sweden	90	3	862
United Kingdom	130	481	304

**Table 1.2 - Renewable Heat production in 2009: a comparison between the grid- and the non-grid biomass source (ktoe) in some EU Member States [Source: Teckenburg et al, 2011] – na: data not available**

2009	Heat production		
	Bio-waste	Biomass grid	Biomass non-grid
	ktoe	ktoe	ktoe
Austria	na	584	2832
Belgium	na	36	784
Denmark	na	984	1117
Finland	na	1231	4154
France	na	84	10056
Germany	na	900	7147
Italy	na	164	1498
Netherlands	na	164	492
Spain	na	0	3770
Sweden	na	2709	5072
United Kingdom	na	0	882

For WtE in Norway (an EEA<sup>7</sup> and EFTA<sup>8</sup> Member State, not entering the European Union), data published by Avfall Norge Association<sup>9</sup> refer to a total of about 1.1 Mt of wastes incinerated in 2009 in Norwegian WTE plants (19 operating plants) - of which MSW accounts for a 60% - resulting in an energy production of 1.26 TWh as heat to district heating (about 50% of the total production of district heating in Norway), followed by 0.50 TWh (steam to industry) and 0.11 TWh (electricity to the grid).

Statistics available at the website of Statistic Norway<sup>10</sup> show a lower dimension of waste combustion in Norway for the same year (2009): a total amount of c.a. 0.99 Mt, of which c.a. 0.85 Mt is household waste, increasing to 1.16 Mt (total waste incineration) and 0.91 Mt (household waste incineration) in 2010.

With respect to energy generation, refuse incineration is confirmed as the most important input in the Norwegian district heating production, by Statistic Norway too, but according to this data source a net heat production from refuse incineration of c.a. 1.3 TWh was obtained in Norway (it means a 36% of the 3.6 TWh reported as total net production of district heating), which increased in 2010 to around 1.6 TWh (32% of a total net production of district heating of about 4.8 TWh).

<sup>7</sup> EEA: European Environment Agency

<sup>8</sup> EFTA: European Free Trade Association; an intergovernmental organisation set up for the promotion of free trade and economic integration to the benefit of its four Member States: Iceland, Liechtenstein, Norway and Switzerland

<sup>9</sup> Data kindly provided by the Norway Member of the IEA Task 36 Mr. Michel Becidan

<sup>10</sup> Data available at the website of Statistic Norway: [www.ssb.no](http://www.ssb.no)

## **1.2 FINANCING RENEWABLE ENERGY IN EUROPE**

### **1.2.1 Summary**

This section reviews the mechanisms and tools available for support for renewable energy in the EU and Norway, indicating where WtE is eligible for such support and the conditions for support. The first section provides an overview of support for Renewable Energy; and this is followed by a country by country analysis. At the end of the section the information on support for WtE plants is summarised in a table.

This review concentrates on the EU, although there are renewable energy support schemes outside of Europe. The analysis reflects the participating countries in Task 36 and provides an indication of the typical ways in which WtE is supported as part of renewable energy policy.

### **1.2.2 A general overview on mechanisms and tools available in EU Member States**

Renewable energies often have much lower operating costs (no fuel costs for most technologies) but proportionately higher capital costs compared to conventional alternatives. This makes capital investment costly and as a result support schemes for renewable energy (both heat and electricity) have been introduced in the EU.

Technology-specific investment costs (data referred to the year 2009) for RES-E and RES-T plants (fig. 1.11-1.12) were assessed within the project “*Financing Renewable Energy in the European energy market*” commissioned by the European Commission [*de Jager D et al, 2011*]. The de Jager et al analysis uses the Green-X database (which provides detailed information on current cost for investment, operation & maintenance, fuel and generation and potentials for RES technologies in Europe).

The results show that the cost of developing WtE is relatively high, reflecting the need for air pollution control equipment; and the efficiency of conversion low compared to conventional bioenergy schemes. However, the plants are relatively large-scale and the feedstock attracts a gate fee, which effectively covers the cost of the plants over plant lifetime, which contrasts to other bioenergy plants, where the feedstock has to be bought. Consequently Government target efforts mainly at lowering the capital costs by reducing technology, plant and construction costs, or covering generating costs through revenues.

As described below different financial mechanisms and tools - aimed at promoting RES and alleviating project risks - have been made available at both the EU level and the Member States level. Most Governments only include the renewable energy content of WtE schemes within their incentives although the way in which renewable energy content is specified differs.

RES-E sub-category	Plant specification	Investment costs	O&M costs	Efficiency (electricity)	Efficiency (heat)	Lifetime (average)	Typical plant size
		[€/kW <sub>e</sub> ]	[€/kW <sub>e</sub> *year]	[t]	[t]	[years]	[MW <sub>e</sub> ]
Biogas	Agricultural biogas plant	2550 - 4290	115 - 140	0.28 - 0.34	-	25	0.1 - 0.5
	Agricultural biogas plant - CHP	2765 - 4525	120 - 145	0.27 - 0.33	0.55 - 0.59	25	0.1 - 0.5
	Landfill gas plant	1350 - 1950	50 - 80	0.32 - 0.36	-	25	0.75 - 8
	Landfill gas plant - CHP	1500 - 2100	55 - 85	0.31 - 0.35	0.5 - 0.54	25	0.75 - 8
	Sewage gas plant	2300 - 3400	115 - 165	0.28 - 0.32	-	25	0.1 - 0.6
	Sewage gas plant - CHP	2400 - 3550	125 - 175	0.26 - 0.3	0.54 - 0.58	25	0.1 - 0.6
Biomass	Biomass plant	2225 - 2995	84 - 146	0.26 - 0.3	-	30	1 - 25
	Cofiring	450 - 650	65 - 95	0.37	-	30	-
	Biomass plant - CHP	2600 - 4375	86 - 176	0.22 - 0.27	0.63 - 0.66	30	1 - 25
	Cofiring - CHP	450 - 650	85 - 125	0.2	0.6	30	-
Biowaste	Waste incineration plant	5500 - 7125	145 - 249	0.18 - 0.22	-	30	2 - 50
	Waste incineration plant - CHP	5800 - 7425	172 - 258	0.14 - 0.16	0.64 - 0.66	30	2 - 50
Geothermal Electricity	Geothermal power plant	2575 - 6750	113 - 185	0.11 - 0.14	-	30	5 - 50
Hydro large-scale	Large-scale unit	850 - 3650	35	-	-	50	250
	Medium-scale unit	1125 - 4875	35	-	-	50	75
	Small-scale unit	1450 - 5750	35	-	-	50	20
	Upgrading	800 - 3600	35	-	-	50	-
Hydro small-scale	Large-scale unit	975 - 1600	40	-	-	50	9.5
	Medium-scale unit	1275 - 5025	40	-	-	50	2
	Small-scale unit	1550 - 6050	40	-	-	50	0.25
	Upgrading	900 - 3700	40	-	-	50	-
Photovoltaics	PV plant	2950 - 4750	30 - 42	-	-	25	0.005 - 0.05
Solar thermal electricity	Concentrating solar power plant	3600 - 5025	150 - 200	0.33 - 0.38	-	30	2 - 50
Tidal stream energy	Tidal (stream) power plant - shoreline	5650	145	-	-	25	0.5
	Tidal (stream) power plant - nearshore	6825	150	-	-	25	1
	Tidal (stream) power plant - offshore	8000	160	-	-	25	2
Wave energy	Wave power plant - shoreline	4750	140	-	-	25	0.5
	Wave power plant - nearshore	6125	145	-	-	25	1
	Wave power plant - offshore	7500	155	-	-	25	2
Wind onshore	Wind power plant	1125 - 1525	35 - 45	-	-	25	2
Wind offshore	Wind power plant - nearshore	2450 - 2850	90	-	-	25	5
	Wind power plant - offshore: 5...30km	2750 - 3150	100	-	-	25	5
	Wind power plant - offshore: 30...50km	3100 - 3350	110	-	-	25	5
	Wind power plant - offshore: 50km...	3350 - 3500	120	-	-	25	5

Figure 1.11- RES-E plants: economical and technical specifications. [Source: de Jager D et al, 2011].

RES-H sub-category	Plant specification	Investment costs	O&M costs	Efficiency (heat) <sup>1</sup>	Lifetime (average)	Typical plant size
		[€/kW <sub>heat</sub> ] <sup>2</sup>	[€/kW <sub>heat</sub> *yr] <sup>2</sup>	[t]	[years]	[MW <sub>heat</sub> ] <sup>2</sup>
<b>Grid-connected heating systems</b>						
Biomass district heat	Large-scale unit	350 - 380	16 - 17	0.89	30	10
	Medium-scale unit	390 - 420	17 - 19	0.87	30	5
	Small-scale unit	475 - 550	20 - 22	0.85	30	0.5 - 1
Geothermal district heat	Large-scale unit	800	50	0.9	30	10
	Medium-scale unit	1200 - 1500	55	0.88	30	5
	Small-scale unit	2000 - 2200	57 - 60	0.87	30	0.5 - 1
<b>Non-grid heating systems</b>						
Biomass non-grid heat	log wood	255 - 340	6 - 10	0.75 - 0.85*	20	0.015 - 0.04
	wood chips	340 - 610	6 - 10	0.78 - 0.85*	20	0.02 - 0.3
	Pellets	390 - 530	6 - 10	0.85 - 0.9*	20	0.01 - 0.25
Heat pumps	ground coupled	900 - 1100	5.5 - 7.5	3 - 4 <sup>1</sup>	20	0.015 - 0.03
	earth water	650 - 1050	10.5 - 18	3.5 - 4.5 <sup>1</sup>	20	0.015 - 0.03
Solar thermal heating & hot water supply	Large-scale unit	400 - 420 <sup>2</sup>	5 - 7 <sup>2</sup>	-	20	100 - 200
	Medium-scale unit	540 - 560 <sup>2</sup>	7 - 9 <sup>2</sup>	-	20	50
	Small-scale unit	900 - 930 <sup>2</sup>	13 - 15 <sup>2</sup>	-	20	5 - 10

**Remarks:** <sup>1</sup> In case of heat pumps we specify under the terminology "efficiency (heat)" the seasonal performance factor - i.e. the output in terms of produced heat per unit of electricity input  
<sup>2</sup> In case of solar thermal heating & hot water supply we specify under the investment and O&M cost per unit of m<sup>2</sup> collector surface (instead of kW). Accordingly, expressed figures with regard to plant sizes are also expressed in m<sup>2</sup> (instead of MW).

Figure 1.12 - RES-H plants: economical and technical specifications. [Source: de Jager D et al, 2011].

### 1.2.2.1 Supporting schemes at the EU level

EU supports for RES are relatively low; in the period 2007-2009 EU funds spent amounted to around € 9.8 billion (€3.26bn/a), made up of:

- loans and assistance from the European Investment Bank (€8.4bn),
- the European Economic Recovery Plan (€565m),
- the "Intelligent Energy Europe" Programme, co-funding analysis and policy research in renewable energy (€110m),
- the EU Structural and Cohesion Funds for projects and demonstrations of renewable energy (€499m),
- the EU R&D Framework Programme (€250m),
- venture capital or loan guarantees from EIP GIF (€151M),
- loans from the European Bank for Reconstruction and Development (€140M).

In addition, at the EU level a new source is the "NER 300 programme" (established under the Emissions Trading Directive 2003/87/EC), supporting (co-funding) demonstration of CCS and innovative renewable project at commercial scale (€4.5 billion of co-funding, matching funding from industry and Member States).

A reorientation of EU budget priorities is expected [EU SEC(2011) 131] in terms of developing new instruments to support RES energy in Europe, but also of a more focused use of existing instruments such as: the Structural Funds and Cohesion Funds (2007-2013) planned support for renewable energy activities of about €4.8 billion; the European Agricultural Fund for Rural Development (EAFRD), which can also include renewable energy projects (e.g. stimulation of biomass production through energy crops or forestry); and the European budget for research and technology development.

### 1.2.2.2 Supporting schemes at the Member State level

At a Member State level *National Support schemes reducing capital costs* (see: Box 2) and *National Support schemes covering generating costs through revenues* (see: Box 3) are the main mechanisms to support energy from renewable sources.

With regards to the latter, historically the Feed-in tariff mechanism was the main choice, applied by most of the Member States (France, Germany, Spain, Greece, Ireland, Italy, Luxembourg, Austria, Hungary, Portugal, Bulgaria, Cyprus, Malta, Lithuania, Latvia and Slovakia), also with a technology-based differentiation, although (i.e. Cyprus and Estonia) a common feed-in tariff for all technologies is used too.

Usually the level of tariff is based on future expectations of the generation cost of renewable electricity (so that when these turn out lower than expected, producers may receive a windfall profit); is regularly

reviewed (to adjust the system to the latest available generation cost projections and to stimulate technology learning); and guaranteed for a limited time period (approximately 15-20 years, allowing recovery of investments, but avoiding windfall profits over the lifetime of the plant).

In tariff systems, RES generators do not sell the electricity generated on the power market (a single buyer, e.g. the TSO, fulfils this role), so that they are generally less involved in adjusting production according to market (i.e. electricity demand) and this can result in a disadvantage in terms of market compatibility. Compared to feed-in premiums, the tariff system offers long-term certainty of receiving fixed level support, so lowering investment risks. Capital costs for RES investments in countries with an established tariff systems have, as a result, been significantly lower than where other instruments introducing higher risks of future returns on investments are used (the weighted average cost of capital is reported as higher in countries with quota obligations, compared to tariff-based systems).

**Box 2 - National Support schemes reducing capital costs**

- ▶ Grants, taxpayer funded aid, often for innovative demonstration projects
- ▶ R&D grants, grants, often for research into innovative, immature technologies
- ▶ Public loans, cheaper access to capital due to public funds used to bear greater risk
- ▶ Equity funds, private medium risk investors, expecting relatively high returns, for later stage of projects and more mature technologies, and investment periods of 3-5 years
- ▶ Venture capital, private equity investment for financing technology innovation, with active involvement of the fund managers in the project
- ▶ Mezzanine funds, loans that take more risk than normal debt but less risk than equity, expecting relative short term and variable but high return
- ▶ Guarantees, compensating payment to a lender or an investor in case of payment default by a project developer
- ▶ Contingent grants or loans, support converted into a loan when a project turn out to be successful or treated as a grant the project encounters financial difficulties

**Box 3 - National Support schemes covering generating costs through revenues**

- ▶ Regulated prices (feed in tariffs), giving energy producers a fixed financial payment per unit of electricity/heat produced from renewable sources, often differentiated by technology and phased out
- ▶ Regulated premiums (feed in premiums), giving energy producers a fixed financial payment per unit of electricity/heat produced from renewable energy sources for the green value; the producer receiving the market price for the physical energy
- ▶ Quota/certificates, a minimum share or quota of renewables in the electricity, transport fuel or heating fuel mix is imposed which can be met either through physical production (i.e. biofuels) or through purchasing "green certificates" (virtual) rather than physical energy
- ▶ Fiscal incentives, tax exemptions or tax credits for investments in renewable energy projects
- ▶ Tenders, a government call for tender for a renewable energy project often specifying capacity/production/technology/site, the winner generally granted a long term power purchasing agreement at a competitive price.



The Feed-in premium system is the main support mechanism in Denmark and the Netherlands, while Spain, Czech Republic, Estonia and Slovenia allow a choice between feed-in tariffs and premiums for a selection of technologies. In Italy it is used for solar power generation.

RES generation is remunerated through two separate components: one coming from the sale of electricity to be fed into the grid (exposed to demand/supply fluctuations) and the other one is the premium for the electricity generated or fed into the grid, paid by transmission system operators or other national entities. The level of the premium is based on future expectations regarding the generation costs of renewable electricity and the average electricity market revenues. Time limits and a regular review of cost projections, adjusting premium based on these projections are applied in some countries such as Denmark and the Netherlands.

In premium systems, the renewable electricity producer participates in the wholesale electricity market. The advantage is that producers of renewables are stimulated to adjust their production according to the evolution of the market (i.e. electricity demand). The premium system provides a secure additional return for producers, but does not offer protection against the electricity price risk, which results in less certainty for investors compared to the feed-in tariff.

The Treadable Green certificates (TGCs) and Quota obligation system are currently in force in some European countries (Belgium, Italy, Sweden, United Kingdom, Poland and Romania), whose governments impose a minimum share of renewable electricity on suppliers (or consumers or producers), increasing over time, with financial penalties if obligations are not met.

As in the feed-in premium system, RES generation is remunerated through two components: sale of electricity and treadable renewable certificates (TGCs) that certify generation of a given quota of RES which are combined with obligations. Such TGCs are issued directly to producers by a national entity (e.g. GSE, in Italy, OFGEM, in the United Kingdom, SvK in Sweden).

Under current national legislation, some parties engaged in the electricity business are required to surrender a number of TGCs proportional to the amount of electricity they have managed, generated, sold, imported or dispatched. Obligated parties are held to purchase TGCs and to guarantee one of the two remuneration components to RES producers. Italy is the only country that identifies RES producers and importers as obliged parties, while in the other countries such obligation falls on electricity suppliers.

This support mechanism is often introduced in combination with other systems (e.g. feed-in tariffs) for small-scale projects or specific technologies. Belgium offers minimum tariffs for each technology as an alternative to the revenues from the TGCs trade and the electricity market price. Italy offers feed-in tariffs for small-scale applications below 1 MW and the United Kingdom started to make feed-in tariffs



available for small-scale applications in spring 2010. Tradable certificates represent the value of the renewable electricity at a certain time. Furthermore, certificate prices are subject to other market influences (e.g. market power prices). Uncertainty about current and future price of certificates increases financial risks and can have a negative impact on the willingness to invest.

Because producers do not only sell their electricity on the market, but also their certificates, the risk on the certificate market is added to the risk on the electricity market. This uncertainty increases the level of risk premiums and cost of capital; these costs are usually transferred to consumers, so that the societal costs of renewable electricity support are usually higher than under feed-in tariff and premium systems.

Depending on the design, quota obligations tend to stimulate the development of lower-cost technologies; this is particularly the case for quota obligation systems that are technology-neutral and do not make a distinction between renewable energy options. Depending on the specific market and resource conditions, less mature technologies would best be supported under a quota obligation system with technology or band specifications.

The Tender support instrument is not largely used in Europe, some Member States apply it to specific projects/technologies (e.g. wind off-shore in Denmark). Tax incentives and investment grants represent the dominating policy measure in Finland and in Malta; they are also used as supplementary support (i.e. in the Netherlands) to the economic viability of RES projects.

### 1.2.2.3 The RES-H sector

The RES-H sector has only recently received attention from policy makers and very few incentives have been introduced in the past by Member States (tab. 1.3) including investment grants, tax exemptions, financial incentives and premiums, with a degree of deployment largely depending on country and technology [de Jager D et al, 2011].

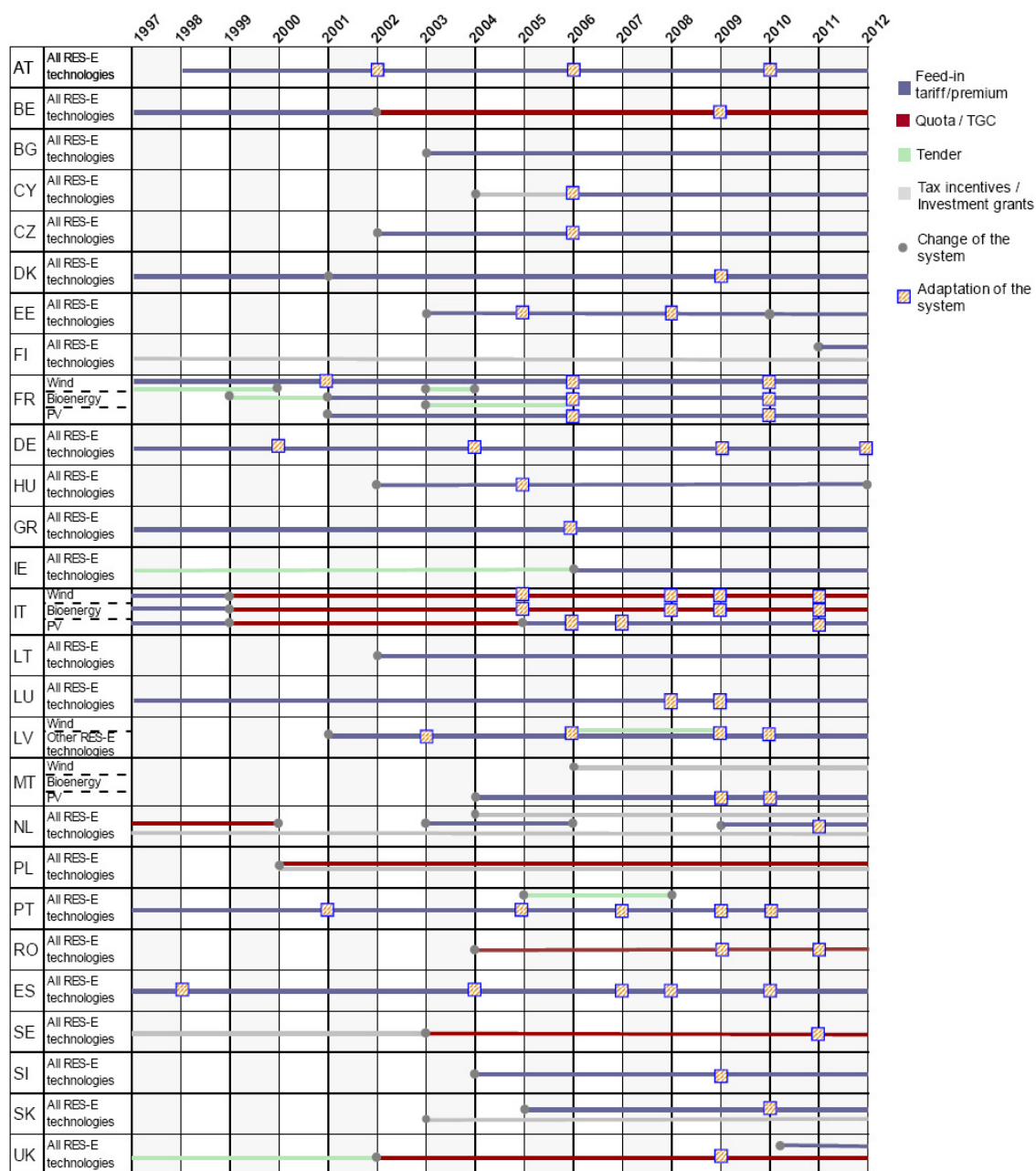
**Table 1.3 - RES-H sector: Overview on the main support schemes applied on a national basis ●=established support schemes ★= support schemes recently introduced or under discussion [Source: de Jager D et al, 2011].**

SUPPORT SCHEME	AT	BE	BG	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE
<i>Investments Grants</i>	●	●	●	●	●	●		●		●	●	●	●	●
<i>Tax exemptions</i>	●	●					●				●	●		
<i>Financial Incentives</i>			●			●		●			●			
SUPPORT SCHEME	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	UK	
<i>Investments Grants</i>		●	●	●	●	●	●	●		●	●	●	●	
<i>Tax exemptions</i>	●	●				●				●			●	
<i>Financial Incentives</i>	★							●					★	

The main support is in the form of investment grants and tax exemptions, available in Member States for most RES-T technologies. Financial incentives, such as soft loans, are less common. RES based district heating has received relatively little attention from Member States with the exception of Austria, Finland, Hungary and Lithuania. Obligations are applied in Spain and Germany, but they are rather a regulatory than a financial instrument. Something is now in progress in some European countries with regard to financial supports already introduced in the national legislation on RES (UK) or under discussion (Italy) for the same purpose.

#### **1.2.2.4 The RES-E sector**

Mechanisms to support renewable electricity (RES-E sector) were introduced as early as 1997, mainly starting with the feed in tariff/premium system, and then implemented and/or changed over time in a different way depending on Member State, as depicted in fig. 1.13. Member States' legislations generally provide for more than one RES-E support scheme (tab. 1.4), but the feed-in tariff, the feed-in premium and the quota obligation are really the main operating instruments (fig.1.14) in the EU 27 zone [de Jager et al 2011; Teckenburg Eva et al, 2011].



**Figure 1.13 - Evolution of RES-E support instruments. [Source Teckenburg et al, 2011]**

Table 1.4 - RES-E: details of support schemes applied on a national basis.[Source: de Jager D et al, 2011].

SUPPORT SCHEME	AT	BE	BG	CY	CZ	DE	DK	EE	ES	FI	FR	GR	HU	IE
<i>FIT</i>	●	●	●	●	●	●		●	●		●	●	●	●
<i>Premium</i>					●		●	●	●					
<i>Quota Obligation</i>		●												
<i>Investments</i>		●		●	●					●		●	●	
<i>Tax exemptions</i>		●							●	●		●		
<i>Fiscal Incentives</i>			●			●		●						
SUPPORT SCHEME	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	UK	
<i>FIT</i>	●	●	●	●	●			●			●	●	●	
<i>Premium</i>						●					●			
<i>Quota Obligation</i>	●						●		●	●			●	
<i>Investments</i>		●	●	●	●								●	
<i>Tax exemptions</i>				●		●	●			●		●	●	
<i>Fiscal Incentives</i>					●	●	●				●			

**Main RES-E support instruments in the EU-27**

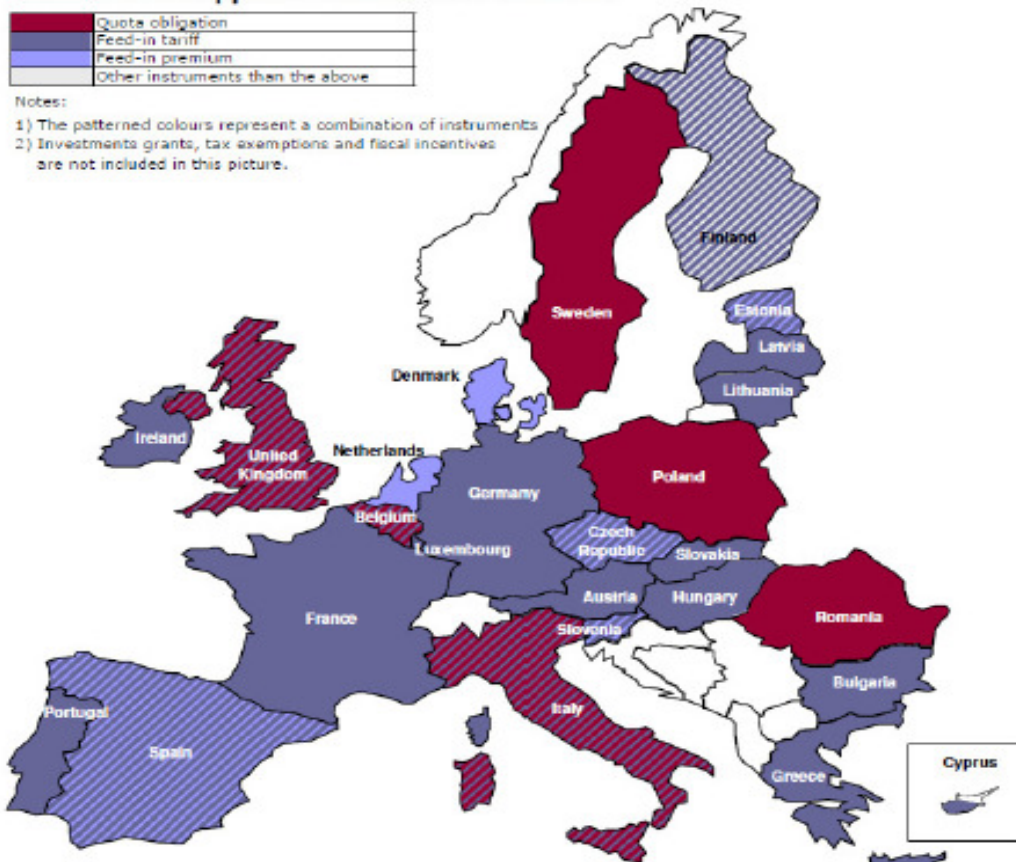


Figure 1.14 - RES-E: main support instruments applied in the EU 27 zone. [Source: de Jager D et al, 2011].

### **1.2.3 Renewable energy from waste is supported in Europe**

There are a number of differences between EU countries regarding the treatment of renewable energy from waste (MSW and SRF). Details are provided below for a number of individual EU Member States (Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Spain, Sweden, United Kingdom).

This section examines to what extent renewable energy (electricity and, for some countries, thermal energy too) from the biodegradable fraction of waste (MSW and SRF) is recognised as renewable and eligible for RES support schemes in charge in each country.

#### **1.2.3.1 Austria**

The support policy for energy from renewable sources in the electricity sector in Austria is provided through the Green Electricity Act [*Austria NREAP, 2010*]; the current legal situation is based on the Green Electricity Act of 2002 and following amendments [*Austria, 2002*].

The main promotional instrument to support electricity from RES in Austria is a feed-in tariff system set out in the Green Electricity Act and the regulations related to offering technology-specific incentives with purchase obligation. The purchase and selling of green electricity is administered by the settlement centre OeMAG<sup>11</sup>.

Regarding eligibility for financial support: according to the Green Electricity Act the following restrictions are in charge: electricity generated from spent liquors, meat-and-bone meal, sewage sludge or waste is not eligible, except when the waste contains a high proportion of biogenic substances. In addition power generation plants must be at least 60% efficient i.e. it is linked to the use of the heat. The required efficiency may be increased by order if the increase is deemed economically reasonable; plants fuelled by solid biomass are ineligible unless measures were taken to prevent particulate matter emissions.

A given operator of a plant fuelled by solid or liquid biomass or biogas is entitled to the purchase of all electricity exported to the grid and to the payment of the tariff applicable on the date on which the contract was concluded, for 15 years starting on the date on which the plant is put into operation. The amount of tariff is determined for each source of energy by the Minister of Economy, Family and Youth. For the Biomass renewable source it fall into the range 10 – 14.98 €/kWh .

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<sup>11</sup> OeMAG: [www.oem-ag.at](http://www.oem-ag.at)

### 1.2.3.2 Belgium

In Belgium the Federal Authority and the Flanders, Wallonia and Brussels Capital Regions have set up systems based on tradable certificates, largely similar, but with certain specific features (fig. 1.15) to support electricity production from renewable sources, included that from bio-waste incineration [Belgium NREAP, 2010; CEWEP, 2010 b].

Characteristics	Federal Authority	Flemish Region	Walloon Region	BCR
Issuing body	CREG	VREG	CWAPE	Brugel
Eligible technologies	Offshore wind energy	All*	All*	All*
Accounting unit for green certificates	Produced MWh	Produced MWh	Avoided CO <sub>2</sub> emissions <sup>9</sup>	Avoided CO <sub>2</sub> emissions <sup>10</sup>
Period for which certificate is granted	Entire service life of installation	Entire service life of installation	15 years	10 years
Number of certificates granted	1 certificate/ produced MWh	1 certificate/ produced MWh	Number of certificates/variable saved TCO <sub>2</sub> according to technology	Number of certificates/variable saved TCO <sub>2</sub> according to technology
Duration of certificate life (banking)	5 years	5 years	5 years	5 years
Fine (EUR/lacking certificate)	/	125 <sup>11</sup>	100	100
Who has to fulfil the quota obligation?	/	Suppliers	Suppliers and DSO	Suppliers
Guaranteed minimum prices	Variable according to technology	Variable according to technology	Identical	/
Duration of benefits under guaranteed minimum price scheme	20 years (offshore wind energy) or 10 years (other installations)	10 years (except photovoltaic, 20 years <sup>12</sup> )	15 years	/
Recognition of certificates	Federal, Flemish, Walloon and Brussels certificates	Flemish certificates	Walloon certificates	Brussels and Walloon certificates

\* Except offshore wind energy (federal competence) and with certain variants according to the Regions. By way of example, quality CHP units are eligible under the green certificate schemes organised by the Walloon Region and the Brussels Capital Region, while they benefit from a specific scheme in the Flemish Region.

<sup>9</sup> By general principle, a green certificate corresponds to a quantity of 456 kg of avoided CO<sub>2</sub>. However, for certain technologies multiplying factors are applied. Thus a green certificate is only granted if the electricity production chain generates a minimum carbon dioxide saving of 10% compared to carbon dioxide emissions, as defined and published annually by CWAPE, from conventional electricity generation by modern reference installations.

<sup>10</sup> By general principle, a green certificate corresponds to a quantity of 217 kg of avoided CO<sub>2</sub>. However, for certain technologies multiplying factors are applied.

<sup>11</sup> EUR 100 per lacking certificate as of 2015.

<sup>12</sup> 15 years for installations established from 1 January 2013 onwards.

**Figure 1.15 - Belgium: main characteristics of the systems of tradable green certificates applied by the the Federal Authority and the Flanders, Wallonia and Brussels Capital Regions. [Source: Belgium NREAP, 2010].**

Both Federal Authority and Regions introduced investment support schemes, including a tax deduction mechanism applied to the generation of energy from waste incineration and the use of gas from anaerobic fermentation of waste [Belgium NREAP, 2010]. No regulation providing targets or obligations



regarding the use energy from renewable sources in the heating and cooling sector exist in Belgium, although a support programme for heating is reportedly under consideration in the Flemish and the Walloon Regions, [*Belgium NREAP, 2010*].

### **1.2.3.3 Denmark**

Electricity generated from MSW is recognized as renewable in Denmark and supported under a green certificate scheme. As reported by CEWEP [*CEWEP, 2010 a*], there are no subsidies available for RES-H from waste, even if there is a support for district heating.

There has been a long history of support for district heating in Denmark. According to the NREAP local authorities must authorise projects for possible collecting heating supplies.<sup>12</sup> The Danish Heat Supply Act contains the framework for the expansion of collective district heating, including heat based on renewable energy; and many WtE plants are an important supply of heat for district heating.

As a result of these policies, only 25% of the energy generated by WtE in Denmark is electricity; 75% is heat [*Danish Energy Agency 2005*]; many incinerators are key installations contributing to district heating (see the Danish District Heating Association<sup>13</sup> for further information). As reported in the website of the Danish Energy Agency<sup>14</sup>, in 2007, 19.3% of district heating came from renewable waste. There are also general taxes on incineration of waste, to encourage recycling, but biomass waste is exempt. Currently the biodegradable part is regarded as renewable. This fraction is deemed to be 58.8% of waste.

### **1.2.3.4 Finland**

Energy from biowaste is not recognized and economically supported in Finland [*CEWEP, 2010 c; Finland NREAP, 2010*].

### **1.2.3.5 France**

With regards to WtE in France, 50% of energy from municipal solid waste incineration is recognized as renewable [*Cewep, 2010 d*]. As reported in the website of Ministry of Sustainable Development<sup>15</sup>, according to the Order of 2 October 2001 [*France, 2001*] such renewable energy benefits in France from a feed-in-tariff of 4.5 - 5 eurocents/kWh plus an energy efficiency premium between 0 and 0.3 eurocents/kWh. The time limit for eligibility is 15 years (the same is true for biogas; 20 years for other biomass such as non-fossil vegetable or animal material, animal wastes or residues from their

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<sup>12</sup> According to the Danish NREAP, around 40 % of the gross final energy consumption for domestic heating comes from district heat and about 65 % of consumption for heating of commercial premises comes from district heating in Denmark

<sup>13</sup> Danish District Heating Association: <http://dbdh.dk>

<sup>14</sup> Danish Energy Agency: <http://www.ens.dk/EN-US/SUPPLY/HEAT>

<sup>15</sup> French Ministry of Sustainable Development: [www.developpement-durable.gouv.fr](http://www.developpement-durable.gouv.fr)

transformation biomass); no limits for eligibility concerning the installed plant capacity results for WtE plants (for biomass an installed plant capacity not exceeding 12 MW is required). No specific supporting instruments are applied to renewable heat from biowaste [Cewep, 2010 d].

In France, the provisions relating to the support of electricity generation from renewable sources is within the scope of Law No. 2000-108 of 10 February 2000 [France, 2000 a], on the modernization and development of public service electricity. Electricity from renewable sources is promoted through a price regulation system based on a feed-in tariff and tax benefits, and through subsidies on a regional level. Electricity suppliers (EDF and private suppliers) and distribution grid operators are obligated to conclude agreements on the purchase of and payment for electricity, at a price fixed by an order, with the operators of systems that generate electricity from renewable energy sources.

In general, all renewable energy generation technologies are eligible for the feed-in tariff mechanism. Through specific Orders (arrêtés) time and power limits for eligibility as tariff levels (guaranteed minimum payments, which may be increased by a premium, depending on the amount of electricity exported and intended to reflect the degree to which this electricity helped achieve the national energy targets), have been introduced per renewable source.

#### **1.2.3.6 Germany**

About 50% of energy generated in Waste (MSW)-to-Energy and refuse derived fuel (RDF) plants is recognised as renewable in Germany [CEWEP, 2010 e].

Based on the Renewable Energy Sources Act – EEG [Germany, 2012 a] a feed-in tariff mechanism (a fixed tariff plus bonus, based, for example, on the technology used) is the main support mechanism applied in Germany to support energy (electricity) from renewable sources. According to the Energy Sources Act and to the Biomass Ordinance-BiomasseV [Germany, 2012 b] no advantages or subsidies are applied to electricity (and heat) from the biogenic fraction of MSW and SRF [German NREAP, 2010] although they are in place for energy from other biogenic sources, such as biogas and solid biomass.

However, district heating networks that are supplied with heat from renewable energy sources (including the biogenic portion of MSW) can receive funding within the framework of the Market Incentive Program (MAP), providing at least 50% of the heat is supplied from renewable energy sources. This program supports the construction and development of a heating network supplied by renewable sources. The funding is up to a maximum of 1.5M Euro, but the grid must have a minimum average heating value of 500kWh/year per meter of pipeline [German NREAP, 2010].



### 1.2.3.7 Italy

Electricity derived from the biodegradable fraction of mixed wastes (MSW and SRF derived from MSW only) is legally recognised as renewable, accounting for a 51% average percentage. This reference value was derived based on statistical data on municipal solid waste composition produced in Italy (mainly from the results of manual sorting analysis) and substantially confirmed by results obtained analyzing MSW and SRF with the selective dissolution method and the  $^{14}\text{C}$  analysis.

RES-E from MSW and SRF (but also from other biogenic wastes, residues and biomasses) is eligible for supporting schemes (e.g. the All-inclusive feed-in tariff scheme - this feed in tariff is labelled in Italy TO: Tariffa Omnicomprensiva), the Quota Obligation and Green Certificate (GC) scheme (GC is labelled in Italy "CV") according to the Italian legislation on renewables in charge [*Italy Ministerial Decree, 2008; Italy Legislative Decree, 2011*],.

The all-inclusive feed-in tariff scheme (TO) is a new national support scheme producers can choose (as an alternative to the quota obligation scheme) if meeting the following requirements: use of RES (excluding the solar); nominal real power not exceeding 1 MW (200 kW for on-shore wind plants); and commissioning after 31 Dec. 2007. This scheme has a 15-year duration and is differentiated on the basis of the type of source used, granting for biodegradable waste (as for biogas and other biomass) an all-inclusive feed-in rate of 28 ¢cent/kWh [*Italy Law 99, 2009*].

The GC scheme is based on the legislation which requires producers and importers of non-renewable electricity to inject a minimum quota of renewable electricity into the power system every year. GCs represent proof of compliance with the renewable quota obligation. Each GC is conventionally worth 1 MWh of renewable electricity. GCs are valid for three years (those issued in respect of electricity generation in a given year (reference year) may be used towards compliance with the obligation also in the following two years). To fulfil their obligation, producers and importers may inject renewable electricity into the grid or purchase an equivalent number of GCs from green electricity producers.

GCs are tradable instruments granted (for a 15-year duration) to renewable-energy power plants which have been commissioned before 31 December 2012, according to the Legislative Decree approved in 2011 [*Italy Legislative Decree, 2001*]. The number of certificates issued is proportional to the electricity generated by the plant/system and is calculate by multiplying the net annual production (MWh) of supported renewable energy (Incentivated Energy: IE). IE value depends on the type of project (new, reactivated, upgraded, renovated system/plant) and the annual net energy produced by a plant – for a renewable source-specific coefficient (K: 1.3 for biodegradable wastes).

With regards to the Italian GCs market [*GSE, 2010; GSE, 2011b*], the GSE offer price for GCs was 113.10 €/MWh and 105.28 €/MWh, values calculated as difference between the reference price of 180 €/MWh

[Italian Law 11, 2007] and the average annual value of the sale price of electricity (66,90 €/MWh in 2010 and 74,72 €/MWh in 2011). While the GCs withdrawal price recognized by GSE was 87.38 €/MWh (2010) and 82.12 €/MWh (2011).

Only if qualified as RES-E plant (“IAFR plant”) by GSE (the national publicly-owned company promoting and supporting renewable energy sources) under the IAFR Technical Procedure [*Italy Ministerial Decree 2007*], hybrid fuels fed plants (upgraded/repowered, totally or partially renovated, reactivated or new) can be admitted to the green certificates or to the all-inclusive feed-in tariff schemes.

Producers (WtE IAFR plants) asking for this financial support are required to detail how they assess (by weight and energy) the biogenic fraction of the treated wastes (sampling and characterization procedures have to comply with available technical specifications and standards) and calculate the number of GCs they are asking for.

According to the regulations [*Italy Ministerial Decree, 2008*], producers can advantage of a “simplified” procedure which allows them to calculate the amount of RES-E produced annually by applying a fixed (default) “renewable” share to the total net electricity produced, without need of evidence about waste composition and its biogenic fraction.

In reality this means that if the RES-E is from MSW and SRF (derived from MSW) only, it is legally possible to assume that 51 % of the total net electricity produced from the combustion of these two wastes is renewable (due to the biodegradable fraction occurring in the waste) and so eligible for incentives [*Italy Ministerial Decree, 2008*].

It can be noted that with the above mentioned 2011 Decree [*Italy Legislative Decree, 2001*] an in-depth review of the national RES-E supporting system (mainly of the GC mechanism, substantially moving toward a feed-in-tariff scheme) has been started in Italy. Implementation is expected in 2012, detailing the structure of the new supporting scheme (to be applied to qualified plants commissioned after 31 December 2012).

News is also expected regarding the simplified procedure for the quantification of the RES-E generated (based on a fixed share of biogenic content per source) WtE IAFR plants can use if fed with some wastes (such as SRF but also some non-hazardous and hazardous industrial wastes). As in UK, the new RES scheme will introduce a supporting system for RES-H and these financial supports will be linked to mandatory biomass sustainability criteria in compliance with recommendations on this matter coming from the European Commission [*EUCOM(2010)11*].

### 1.2.3.8 Netherlands

In the Netherlands the renewable content of waste is defined on an annual basis from statistics on the composition of MSW collected in the Netherlands; this percentage value is used for both subsidies and national statistics on renewable energy. An average biogenic content in the municipal waste of 48% was assessed in 2008 [Cewep, 2010g] which increased to 51% in 2009.<sup>16</sup>

In the Netherlands a new RES support system, Subsidies Duurzame Energie (SDE), was introduced in 2008, resembling the old MEP (Milieukwaliteit Electriciteitsproductie) mechanism under which Dutch producers feeding renewable electricity into the public grid received a fixed fee per kWh depending on technology for a guaranteed period of ten years; MEP subsidised costs for renewable electricity generators through a premium on top of the electricity price for the extra “green” costs of renewable generation.

The original SDE scheme – to be financed through a levy on the consumer electricity bills - was reviewed and replaced in 2010 by the SDE+ scheme, effective from January 2011.

The SDE+ scheme grants a bonus payment to the producers of renewable energy to compensate for the difference between the wholesale price of electricity from fossil sources and the price of electricity from renewable sources. The bonus is paid for a period of up to 15 years.

The scheme is basically a feed-in-premium system which differs depending on the technology, but which is also linked too to the wholesale price for electricity allowing price adjustment depending on the electricity price. In this way base prices are guaranteed for the full support period of a project but the feed-in-premium will vary annually depending on the wholesale price for electricity (when it is high, a low subsidy is required; when it is low additional funding is needed).

The SDE+ scheme [ECN, 2011] is mainly focused on short term implementation of renewable energy (up to 2020) and applied to newly constructed installations only. Funds available are no longer distributed in such a way as to provide an individual budget for each technology. There is a single budget for all technologies and subsidies are made available in 4 stages or sequential subsidy rounds, used to encourage competition among technologies, with the level of subsidy increasing with stage (fig. 1.16).

A maximum reference price is determined in each round starting, in the first one with a call for technologies that have the lowest subsidy; it is followed by three rounds for technologies requiring higher levels of subsidy. Subsidies are allocated on a "first come, first serve" basis: applicants applying at a later stage run the risk of being rejected due to a lack of funds. This means that in general, the SDE+ scheme gives an advantage to those applying for lower subsidies and at an early stage of the allocation process.

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<sup>16</sup> Data kindly provided by Mr. Timo Gerlagh, NL Energy and Climate Change Agency, Utrecht

The maximum basic subsidy and the eligible technologies differ at each stage and is calculated annually by the Ministry of Economic Affairs, Agriculture and Innovation after consultation with the Minister of Finance. In addition, the Ministry sets the annual correction value by which the basic subsidy will be reduced.

The regulation on the categorisation of sustainable energy generation (RAC 2011) provides information on the eligible technology categories and on the calculation of subsidies under the SDE+ scheme [Netherlands, 2011 b]. A "free" category was introduced in the SDE+ scheme, open for technologies that require higher funding (e.g. PV, offshore wind, geothermal energy) or other projects (e.g. manure digestion, thermal conversion of biomass < 10 MW), which is useful for generators that expect to realize projects with less subsidy than implied from the reference prices for the applied technology.

Phase	I	II	III	IV
Electricity: Maximum base price per phase	9 €/kWh	11 €/kWh	13 €/kWh	15 €/kWh
Biogas: Maximum base price per phase	79 €/Nm <sup>3</sup>	97 €/Nm <sup>3</sup>	114 €/Nm <sup>3</sup>	132 €/Nm <sup>3</sup>
Base price per technology	Sewage treatment plants, electricity from landfill gas or bio gas (6.0 €/kWh and 28.7 €/Nm <sup>3</sup> )			
	Waste incineration plants (6.2 €/kWh)			
	Hydro power > 5m (7.2 €/kWh)			
	Sewage treatment plants and landfill biogas (28.7 €/Nm <sup>3</sup> )			
	Biogas fermentation (78.3 €/Nm <sup>3</sup> )			
	Free category (9 €/kWh or 79 €/Nm <sup>3</sup> )	Onshore wind (9.6 €/kWh)		
		Manure co-digestion biogas (83.1 €/Nm <sup>3</sup> )		
		Free category (11 €/kWh or 97 €/Nm <sup>3</sup> )	Biomass >10 MW (12.1 €/kWh)	
			Hydro power < 5m (12.3 €/kWh)	
			Free category (13 €/kWh or 114 €/Nm <sup>3</sup> )	All fermentation electricity (13.4 €/kWh)
				Free category (15 €/kWh or 132 €/Nm <sup>3</sup> )

**Figure 1.16 - Netherlands: price scheme under the feed-in-premium SDE+ scheme applied to RES-E [Source: Teckenburg et al, 2011].**

Energy from waste incineration (see: fig. 1.11) is eligible for the SDE+ scheme and the amount received depends on energy efficiency (waste incineration must have an energy efficiency of at least 22%; higher efficiencies give rise to a relatively higher reference price (technology base price) and subsidies) [IEA, 2008; Frontier Economics Europe, 2011; Netherlands NREAP, 2010]. No advantages/subsidies for RES-H from waste are mentioned in the SDE+ supporting system.

A tax deduction scheme (EIA: Energy Investment Allowance or Investeringsaftrek) has also been introduced in the Netherlands. This tax benefit (which may be combined with the SDE premium)

enables entrepreneurs based in the Netherlands to write off investments in renewable energy systems against tax. The level of funding depends, among other things, on the source of energy and the type of system used. All technologies are eligible, except for geo`thermal energy and electricity from biogas. The Energy List [*Netherlands, 2011 b*], published by the Dutch Energy Agency and updated on an annual basis, sets out which investments in renewable energy are eligible. The amount of tax credit may be up to 41.5% of the total investments made in renewable energy or energy-efficiency technologies within one year.

#### **1.2.3.9 Norway**

According to the Norwegian Biomass Action Plan [*Norway, 2008*], 50% of energy produced in combustion plants treating MSW is considered to be from the biodegradable fraction of mixed waste (RES-E). The same percentage value (reference year: 2008) is reported in the country report produced by CEWEP [*Norway Cewep, 2010*], although CEWEP points out that this value can vary in the range 46-53%.

Surveys<sup>17</sup> to evaluate the renewable fraction of MSW (burnt in 19 Norwegian WTE plants) were carried out by the Avfall Norge Association (in 2006 and 2010) with the main goal to assess the level of renewability of Norwegian WTE plants, in view of its inclusion in a renewable energy support system (Green Certificate scheme). With respect to the MSW treated in 2009, 52% of electricity produced by the WTE plants investigated was assessed as renewable, deriving from the biodegradable fraction of the waste.

Norwegian policy for RES support was, until recently, mainly based on investment grants covering various business areas (wind power projects, district heating projects also facilitating the use of bio-energy and waste, energy efficiency in industry and building projects) and managed by the state-owned company Enova.<sup>18</sup>

At the end of 2011, the Norwegian Government incorporated the EU RES Directive [*EU Directive 2009/28/EC*] into the EEA Agreement and signed an agreement with Sweden to establish a common Green Certificates Market (from the beginning of 2012 to 2035). The common Norway-Sweden Green Certificate scheme is based on the existing Swedish scheme.

Of total energy consumption in Norway (228 TWh in 2008) 70% is in the form of electricity [*Norway, 2012*] (mainly because of higher use of electricity for household heating occur in Norway compared to other European countries). Electricity generation in Norway is mainly from hydropower: in 2010 total electricity generation in Norway was around 123.6 TWh of which 117.1 TWh was from hydro power,

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<sup>17</sup> Data provided by the Norway Member of the IEA Task 36, Mr. Michel Becidan

<sup>18</sup> ENOVA: the Norwegian National Energy Agency owned by the Royal Norwegian Ministry of Petroleum and Energy (MPE)

5.6 TWh from thermal power and 0.9 TWh from wind power [Norway, 2012]. To reach the national goal – a renewable energy share of 67.5% by 2020 and carbon-neutrality country by 2030 - it is assumed that there will be a significant expansion of wind energy capacity. However, as there is a key principle of non-discrimination between technologies included in the Norway-Swedish agreement hydropower and bio-power (including bio-waste) could receive financial supports under the new mechanism [Norway, 2009, 2010, 2011].

#### **1.2.3.10 Spain**

The Spanish National Renewable Energy action plan [Spain NREAP, 2010] indicates that 50% of energy generated from the combustion of MSW and SRF is recognised as renewable.

In Spain RSE-E legislation prioritises economic stability. Electricity from renewable sources is promoted through a *Special Regime* (that provides for higher remuneration than under the *Ordinary Regime in charge in the country established by a royal decree* [Spain Royal Decree 661, 2007; Spain NREAP, 2010]).

All technologies are generally eligible for the *Special Regime*, although there may be exceptions [Spain Royal Decree 661, 2007]. A technology-specific capacity limit is considered: if the market cap set by the government for the respective system type is reached, additional electricity generated will not be eligible for subsidies (key principle: biomass from energy crops, agricultural or gardening waste, residues from forest and woodlands and agricultural residues, waste from industrial plants are eligible for subsidies until the total capacity reaches 1371 MW). A system-specific capacity limit is also included: this means all systems that generate electricity from renewable sources and whose installed capacity does not exceed 50 MW are eligible for support. Systems where capacity exceeds this limit are not eligible.

Plants that use MSW or other residues are eligible [Spain Royal Decree 661, 2007; Spain NREAP, 2010]. Electricity generators including WtE plants choose between two options: a guaranteed feed-in tariff (Tarifa regulada) and a guaranteed feed-in-premium (Prima de referencia) (furthermore, investments in systems and equipment required for the generation of electricity from renewable sources may be deducted from tax). All system operators need to be registered in the Official Register of systems kept by the Ministry of Industry, Tourism and Trade [Spain Royal Decree 661, 2007]).

The feed-in tariff scheme really allows a choice between two remuneration alternatives for the amount of energy delivered to the grid: a Guaranteed feed-in tariff and a Variable feed-in tariff. The first one is a state-regulated minimum tariffs (Tarifa regulada), different for each technology; the later involves the open electrical energy market, so that the remuneration is the market price (or freely negotiated price), supplemented by a specific premium for each renewable technology area. Feed-in tariffs are paid for the operational period, from the date of commissioning of the system, but with a reduction after a certain



period of operation (15 years for biomass). The remuneration paid for renewable electricity includes specific amounts for each renewable area, as established by royal decree [*Spain Royal Decree 661, 2007*]. According to last revision (January 2012) of the royal decree,<sup>19</sup> for the technology area “energy from waste” a differentiation is made between WtE plants in term of:

- plants mainly treating MSW (guaranteed feed-in tariff: 5.36 eurocents/kWh; guaranteed premium; 2.75 eurocents/kWh);
- plants mainly treating other wastes (guaranteed feed-in tariff: 5.36 eurocents/kWh; guaranteed premium; 2.30;
- plants taking no more than 50% of MSW (guaranteed feed-in tariff: 3.83 eurocents/kWh; guaranteed premium; 2.75).

#### **1.2.3.11 Sweden**

The Swedish National Renewable Energy Action Plan [*Sweden NREAP, 2010*] indicates that energy from combustion of MSW and SRF is 50% renewable based on a study conducted in 2008 on behalf of the Swedish Energy Agency. This study showed that the biogenic content can vary between 50-60 %.

However, in accordance with Swedish regulations, energy from the biogenic fraction of waste, even if recognised as renewable, does not qualify (is not considered eligible) for the Green Certificates scheme<sup>20</sup> [*Swedish Energy Agency, 2010; Sweden NREAP, 2010; CEWEP, 2010 f*]. However, sorted waste wood (pre-sorted or separated) is and biogas derived from waste water treatment or biogenic waste digestion is considered as biomass fuel, which means a producer can get certificates if the biogas is used to generate electricity.

Consequently the Green Certificate scheme Sweden does not incentivise the combustion of MSW [*Schüßler, 2011*], although the renewable content of WtE is included in the Swedish targets.

#### **1.2.3.12 United Kingdom**

With regard to the mass burn technology, a deemed value for *fossil fuel* content of 50% has been established in the UK (increasing as recycling increases to 60% in 2013 and 65% in 2018) for MSW only.

The UK Renewables Obligation Order defines the level of support that is offered to renewable energy. For each MWh of renewable energy Renewable Obligation certificates (ROCs) are awarded, on a banded basis [*DECC 2011 a*].

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<sup>19</sup> Available at the website: [www.boe.es](http://www.boe.es)

<sup>20</sup> This is the most important incentive for renewable energy in Sweden: one certificate corresponds to 1 MWh and is granted for a 15 year period per plant, subject to a ceiling of 2035.

Updated criteria for the eligibility of energy from waste (tab. 1.5) is provided on the DECC<sup>21</sup> and Ofgem<sup>22</sup> web sites.

**Table 1.5 - Eligibility of energy derived from waste. [Source: DECC, 2012]**

Type of Generating station	Mixed waste	Waste that is purely biomass	Energy crops, agricultural waste and forestry
Incineration	Ineligible	Eligible <sup>1</sup>	Eligible <sup>1</sup>
Pyrolysis, gasification and anaerobic digestion	Eligible for the biomass fraction of waste	Eligible <sup>1</sup>	Eligible <sup>1</sup>
Combined Heat and Power (CHP)	Eligible for the biomass fraction of waste produced as good quality CHP 2	Eligible <sup>1</sup>	Eligible <sup>1</sup>
Co-firing	Ineligible	Eligible <sup>1</sup> (There are no restrictions on the amount of co-firing a generator can undertake. However, suppliers can only meet 10% of their obligation from co-fired ROCs.)	Eligible <sup>1</sup>

**1 :** Subject to a maximum fossil-derived energy content of 10%. CHP stations must be accredited under the CHP Quality Assurance scheme to be eligible. For schemes that are fully compliant with the Good Quality benchmark, they receive ROCs on the electricity generated from the biomass fraction of the waste. For schemes that are partially compliant, this is scaled back depending on their efficiency. Only stations first commissioned or re-equipped on or after 1 January 1990 (except micro-hydro and co-firing stations) are eligible. All stations must be located within the UK, its territorial waters or the Continental Shelf. The RO has been approved by the EU Commission and all eligible generation can expect to benefit from it. If a generating station receives or applies for a grant then it is the responsibility of the grantor of any additional aid - over and above that available through the RO, including banded ROCs - to ensure that there is a need to provide additional support and that the state aid cumulation rules are respected, this includes giving guidance on how ROC income is to be treated in determining the level of support. All RDAs and other public bodies making grants for the deployment of renewables generation have been made aware of their duties and should refer any questions about the level of support available under state aid rules to the State Aids unit in BIS in the first instance.

WtE is only eligible for support if it is associated with Good Quality Combined Heat and Power or generated using advanced conversion technologies, such as pyrolysis, gasification and anaerobic digestion plants. This means that mass burn incineration plants generating power only are not supported. ROCs are only awarded on submission of evidence of renewable content. For MSW the deemed value is 50%, falling to 40% and then 35% as detailed above, providing the operator can demonstrate that the waste is typical MSW. For any other, operators must be able to demonstrate that it is similar in composition to MSW or else prove the biogenic (renewable) content of the waste (this applies, for

<sup>21</sup> DECC: UK Department of Energy and Climate Change: [www.decc.gov.uk](http://www.decc.gov.uk)

<sup>22</sup> Ofgem: UK Office of the Gas and Electricity Markets: [www.ofgem.gov.uk](http://www.ofgem.gov.uk)



example, to SRF). If the MSW has been pre-processed, operators have to demonstrate that the fossil fuel portion of the waste is unlikely to exceed 50%.

Resubmission and proof that the fuel remains typical of MSW is required on an annual basis. Operators may claim lower fossil fuel content than 50%, but will have to undertake a full sampling programme to demonstrate the component analysis of the waste fuel and the biodegradable fraction in each component of the mixed waste.

When a combustion of high biomass content waste occurs, if the energy content of the waste can be demonstrated as >90% from biomass then the power is eligible for RO as pure biomass. For more details on the eligibility of waste, SRF and biomass and the required fuel measurements see Ofgem “*Renewables Obligation: Fuel measurement and sampling guidance*” [Ofgem, 2011].

The UK is now starting to introduce a link between financial supports and mandatory biomass sustainability criteria [DECC, 2010; DECC, 2011a; DECC, 2011b; Ofgem2011], aligning with recommendations on this matter coming from the European Commission [EUCOM(2010)11]. On this matter the Statutory Consultation on the Renewables Obligation Order (ROO) 2011 [DECC, 2011 a] includes a proposal for: a minimum 60% GHG emission saving relative to fossil fuel (equating to 285 kg CO<sub>2</sub>/MWh or lower).

In addition the UK has introduced an incentive scheme for renewable heat, the Renewable Heat Incentive (RHI) scheme. Under this heat from solid biomass contained in municipal waste will also be considered eligible for the RHI in UK [DECC, 2011 b]. Eligible waste feedstock for combustion, gasification and pyrolysis will be limited to solid biomass from municipal solid waste (MSW), including solid recovered fuel (SRF) if derived from MSW containing no more than 10 per cent fossil fuel (an extension of eligibility to SRF from waste streams other than municipal solid waste is in progress).

In addition, other wastes where at least 90% of their energy content is comprised of solid biomass will receive support. Examples of such wastes include waste wood and residues from the paper manufacturing industry. Plant operators who burn MSW will receive the biomass tariff, adjusted pro-rata for the solid biomass content of their waste. Analysis on the possibility of a dedicated tariff for MSW is underway and DECC will consider introducing a specific tariff from 2012, providing sufficient evidence is available.

**Summary of the eligibility of MSW combustion in WtE plants for support in selected European countries (Data extracted from NREAPs and other sources, as cited above).**

Country	Eligibility conditions	Deemed value of biogenic content of MSW.*
Austria	Waste is not eligible unless the biogenic content is high and the efficiency of the plant reaches 60%	
Belgium		None
Denmark	Electricity from MSW recognised as renewable and supported by green certificates. No support scheme for heat, but district heating receives support. There is an incineration tax, but biomass waste is excluded.	58.8%
Finland	Not eligible	None given
France	Biogenic content of MSW eligible for feed-in Tariff, which includes an efficiency premium	50%. This is expected to decrease by 2020.
Germany	No funding for electricity only WtE plants, but district heating networks can receive funding providing at least 50% of the fuel is from renewable sources and the grid has a minimum average value of 500kWh/y/m pipeline.	Renewable content of MSW and RDF is deemed to be 50%
Italy.	WtE plants are eligible for Green Certificates if operators detail how they assess the biogenic fraction of the waste; alternatively the deemed value can be assumed for MSW and SRF derived from MSW	51%
NL	WtE plants are eligible under the SDE+ scheme, providing their efficiency is 22%. Higher efficiencies are rewarded at a higher rate.	51%
Norway	Renewable content of waste is eligible for Green Certificates for renewable electricity.	Renewable content of MSW was measured as 50% (range 46-53%) but in 2009 the deemed renewable content of MSW was set at 52%.
Spain		50% (MSW and SRF from MSW) 59% for industrial waste (includes reclaimed wood); 59% for paper industry waste.
Sweden	WtE is not eligible for Green Certificate for electricity generated.	50% (range 50-60%) (2010)
UK	Mass burn incineration is not eligible for support under the Renewables Obligation unless heat is also generated. Advanced conversion technologies (as defined in the Renewables Obligation) are eligible for support.	50% (to 2013) decreasing to 40% (from 2013) and 35% in 2018.
<b>Summary</b>	Most countries in Europe accept that the biodegradable part of MSW is renewable, but not all include this fraction in their renewables incentives. Most countries provide a deemed value for renewable content based on the biogenic content of MSW, calculated from sampling of MSW at national level.	Deemed values vary from 50-58.8%. Some countries will re-examine this figure as recycling increases; some countries have already set decreasing levels related to recycling targets..

\* This is derived from national statistics unless otherwise stated.

## **2 METHODOLOGIES FOR THE QUANTIFICATION OF THE BIOGENIC CONTENT OF MIXED FUELS**

As reported in Chapter 1, EU incentives to promote and support renewable electricity and heat (e.g. The Green Certificate system in Italy; the Renewables Obligation (RO) and the Renewable Heat Incentive (RHI) in UK), are substantially linked to the biomass (biodegradable) fraction of fuels feeding the plant. In addition the introduction of emissions trading means that it is important to understand the emissions from plants using waste derived fuels that are due to the fossil component of the waste and the renewable component of the waste.

According to the 2009 European Renewable Energy Source Directive [EU Directive 2009/28/EC], renewable energy means *energy from renewable non-fossil sources, namely .....biomass, .....*, where specifically biomass is defined as *the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste.*

In the framework of the RES Directive and for the specific purpose of this discussion, the term “*biodegradable fraction*” means in practical terms something different from its common scientific sense: “*material capable of undergoing biological anaerobic or aerobic decomposition under conditions naturally occurring in the biosphere*”.

In reality it is synonymous with the more appropriate terms “*biogenic fraction*” (*material produced by living organisms in natural processes but not fossilised or derived from fossil resources*) or “*biomass fraction*” (*material of biological origin excluding material embedded in geological formation or transformed to fossil*), which identifies the renewable component of the fuel, based on criteria relating to formation and origin of the material (also used to denote its CO<sub>2</sub>-neutral nature for emissions quantification and trading). Some plastics derived from fossil materials are really biodegradable but cannot be considered as a biogenic or biomass fraction due to their origin; very lignin-rich woods biodegrade slowly but they are a biogenic or biomass fraction of the fuel [CEN/TR 14980; CEN/TS 15440].

As a consequence, eligible WtE plants are usually required to demonstrate the renewable contribution the wastes give to the total energy generated. This means that they have to quantify the share of E<sub>biogenic</sub> that can be ascribed to the biogenic content of the fuel, based on accepted methodologies.

Regulations in force in some European countries allow the WtE plants to adopt a “simplified” approach for specific wastes (MSW and solid recovered fuel, if derived from MSW), whose composition is traditionally well monitored on a national basis for other purposes (such as waste management; emission trading).

The  $E_{\text{biogenic}}$  value produced can be calculated by applying a “default percentage share” (legally recognised as energy from renewable source) to the total net energy (electricity) produced. This means that expensive time and labour costs for the routine monitoring of the renewable energy content of MSW going to energy plants can be avoided.

Many European countries have proposed default or ‘deemed’ values for the renewable content of MSW. For Example, a default share (51%) of RES-E is deemed in Italy and in Netherland, while the UK RO legislation has deemed a value of 50% (although evidence of proof of the type of waste is required). Some proposals are currently under discussion in Italy, aimed to the extension of the “51% default value” to other non-hazardous industrial mixed wastes, if they have a composition similar to MSW.

Similarly, work is in progress in some European Countries (e.g. Italy) in order to extend the default shares approach to industrial hazardous and non-hazardous wastes (e.g. health care hazardous waste, end life tyres) whose nature/composition makes it impossible, or at least problematic, to perform a waste sampling and/or a waste characterization to assess their biogenic content. Studies are in progress on this matter to support decision makers [Martignon, 2010; Martignon, 2011].

WtE plants may opt to use the deemed value but, when processing MSW or solid recovered fuel with a higher biogenic content or wastes of different nature than MSW, they maybe/are required to apply a full sampling and characterization plan to determine the real share of  $E_{\text{biogenic}}$  produced. However this is complicated because none of the existing national rules is able to identify in an unambiguous way the biogenic content of the mixed fuels, due to the lack or the poor degree of maturity/feasibility of the experimental methodologies available for this purpose.

In this chapter we will examine the methodologies available to determine the renewable content of waste:

- The first section examines methods that are already established and for which there are accepted standards
- The second section discusses methods that are being developed and the standards that are being proposed
- The final section discusses alternative methods that are being examined to understand their potential and their practical use.

It should be noted that the issue of biogenic content of waste is a relatively new problem, related to measurement of carbon emissions and demonstration of renewable content for renewable incentives. Therefore much of the work in this area is relatively recent and this is why some methodologies are still under development.

## 2.1 AVAILABLE STANDARD METHODS

National regulations often refer to the most mature available methodologies, the manual sorting analysis and the selective dissolution method, both of which need to be performed on a representative sample of the wastes feedstock for the plant.

These methods are described in European and international standards, although often not covering all the types of waste really used in common practice (i.e. CEN/TS 15440 for SRF).

In addition the  $^{14}\text{C}$  analysis of representative samples of waste is considered by some national regulation (e.g. in Italy), which refer to available standards (e.g. CEN/TS 15440). However, this methodology is not yet widely applicable due to the present lack of expertise available.

The three above mentioned methods differ in the approach of assessing of the biogenic content.

### 2.1.1 The manual sorting method

The manual sorting method involves physical (manual) steps for identification and sorting of all the waste components and their allocation into a defined number of biomass and not biomass (fossil, inert) fractions (tab. 2.1).

**Table 2.1 - Categorization of waste components for a manual sorting analysis of waste according to CEN/TS 15440 [Source CEN/TS 15440]**

Waste fraction	Characterized as a	Considered as
Biological waste	Biomass fraction	100% biomass
Paper/cardboard	Biomass fraction	100% biomass
Wood residue	Biomass fraction	100% biomass
Tissue	Biomass fraction	100% biomass
Fabric	Mixed fraction containing mostly biomass	50% biomass
Leather/rubber	Mixed fraction containing mostly biomass	80% biomass
Glass	Inert fraction containing mostly contamination of biomass	100% inert
Stone	Inert fraction containing mostly contamination of biomass	100% inert
Fines (nominal top size < 10 mm)	Inert fraction containing mostly contamination of biomass	50% biomass
Soft plastic	Non biomass fraction	100% fossil
Rigid plastic	Non biomass fraction	100% fossil
Carpet/mats	Mixed fraction containing mostly non biomass	100% fossil
Iron & not ferrous metals	Inert fraction containing mostly contamination of not biomass	100% inert

In reality this method uses waste characterization methodologies (typically applied to MSW) which were developed and largely used (and still are) in the sampling of waste at national level. Examples

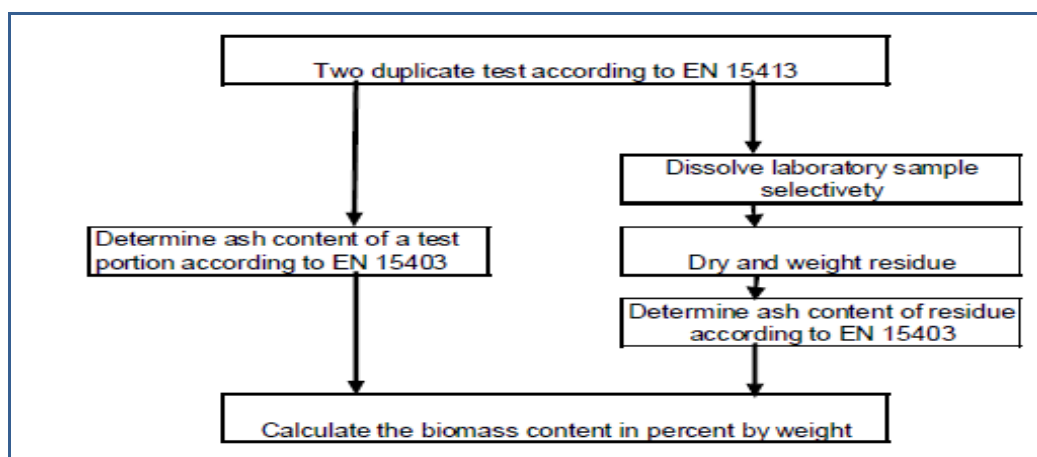
include as the methods produced by IPLA<sup>23</sup> in Italy or by ERRA<sup>24</sup> and ADEME<sup>25</sup> in France [IPLA, 1992; IPLA, 1998; ADEME, 1993; ERRA, 1993]., which were originally aimed at assessing the fractions present in municipal solid waste (paper, plastic, food residues, etc.) and monitoring their change over time in response to changes in the local way to manage the waste collection system.

The aim of such assessments was related to understanding improvements in waste management or recycling. This objective is quite different to the estimation of the biogenic content of the waste; and it allows assessment of biogenic content only by mass of each fraction based on the biogenic content of each fraction.

### 2.1.2 The selective dissolution method

The selective dissolution method [Cuperus et Van Dijk, 2002; Cuperus et al, 2005; Staber et al, 2008; Severine et al, 2010] provides an estimation of the biogenic content based on the assumption that complete biodegradation of biomass materials and non-biodegradation of all of the non-biomass materials occurs in laboratory test conditions (using treatment with a mixture of concentrated sulphuric acid and hydrogen peroxide. The assumption is that the solid sample selectively dissolves and the non-biomass to remain in the residue).

According to the available standard method for SRF [CEN/TS 15440] the waste sample is weighed before and after selective dissolution and the result (biogenic content by weight) corrected for carbonates by measuring the ash content before and after dissolution (fig. 2.1).



**Figure 2.1 - Selective dissolution method for biomass content in SRF, expressed in percentage by weight. [Source: CEN/TS 15440]]**

<sup>23</sup> IPLA: Istituto per le Pianta da Legno e l'Ambiente

<sup>24</sup> ERRA: European Recovery and Recycling Association

<sup>25</sup> ADEME: Agence de l'Environnement et de la Maîtrise de l'Energie

The CEN/TS 15440 method also includes standardised procedures aimed at determining the calorific values of the whole sample and the non-biomass fraction (fig. 2.2) and calculation of the biomass by energy content (% by net or gross calorific value). The calorific value and the required ash content of both sample and residue are then determined according to standardised methods [CEN/TS 15400, CEN/15430].

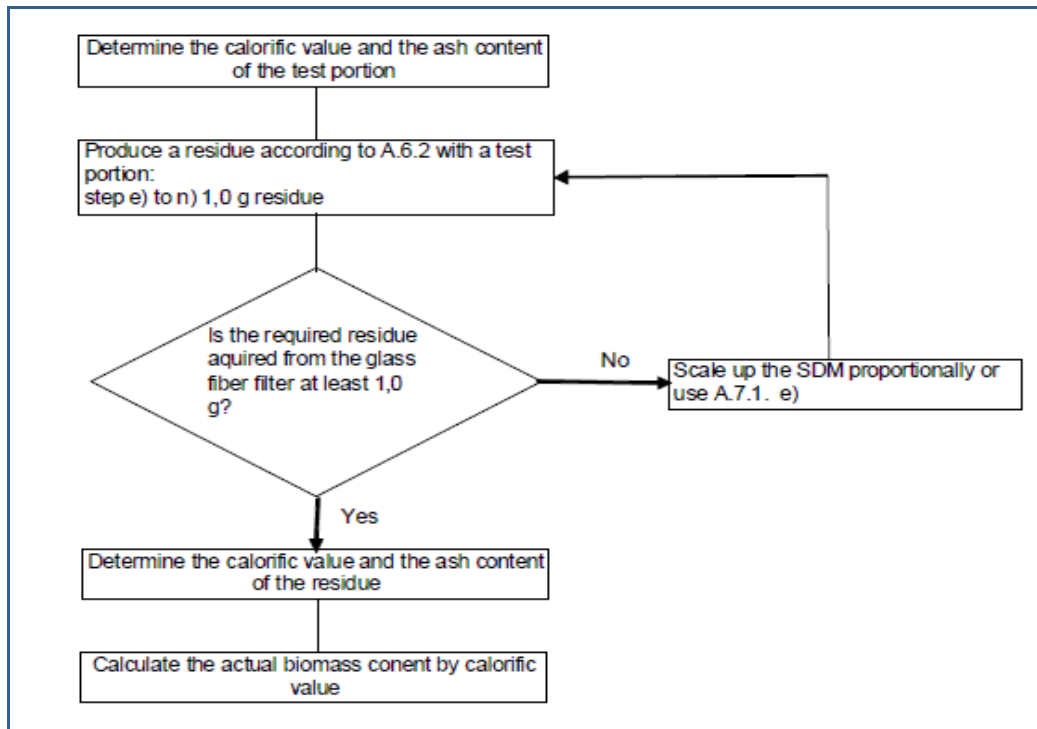


Figure 2.2 - Determination of calorific value of the biomass and non biomass fraction. [Source CEN/TS 15440]]

### 2.1.3 The radiocarbon method

The  $^{14}\text{C}$  method is based on a measurement of the  $^{14}\text{C}$  content (modern or biogenic carbon, C ) of the waste, assuming it is proportional to the amount of biomass. Carbon, an essential element for life, has two stable isotopes ( $^{12}\text{C}$  and  $^{13}\text{C}$ ) and one natural occurring radioactive isotope ( $^{14}\text{C}$ ) which decays ( $\beta$ -) to stable  $^{14}\text{N}$  with a half-life of 5,730 years.  $^{14}\text{C}$  is continuously reintegrated in living processes (fig. 2.3) where it shows a constant concentration with time while the organism is living. After death  $^{14}\text{C}$  concentration (activity) decreases with time such that fossil fuels (although of biogenic origin) have no  $^{14}\text{C}$  content, because the  $^{14}\text{C}$  has completely decayed. The level of  $^{14}\text{C}$  in materials, including the waste (MSW, SRF, etc.), is therefore related to the ratio of its biogenic and fossil fractions.



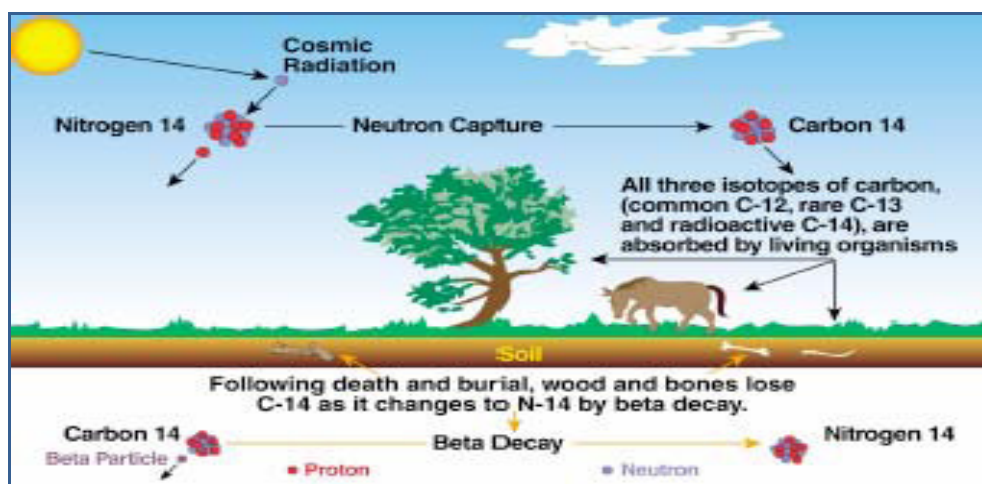


Figure 2.3 - The  $^{14}\text{C}$  cycle. [Source Ciceri et al, 2009]

The  $^{14}\text{C}$  method been investigated and described since the 1950s for different research fields (e.g. atmospheric carbonaceous gases and aerosols; food authenticity research, etc.) and is largely considered to be supported by a stronger scientific basis than the other two methods considered above [Clayton et al, 1955; Simon et al, 1968; Currie et al, 1994; Zondevan etd Mejer, 1996; Stuiver et al, 1998; Levin et Hesshaimer, 2000; Kneissl, 2001; Levine et al., 2003; Levin et Kromer, 2004; Lewis et al, 2004; Noakes et al., 2005; Norton et Devlin, 2006; Hamalainen et al, 2007; Fellner et al, 2007; Staber et al, 2008; Reinhardt et al, 2008; Mohn et al, 2008; Fellner et Rechberger, 2009; Palstra et Meijer, 2010].

The specification outlined for the  $^{14}\text{C}$  method included in CEN/TS 15440 requires first a complete combustion of the solid sample to convert the C present in the sample into  $\text{CO}_2$  in such a way as to be able to comply with the requirements of the subsequent  $^{14}\text{C}$  measurement. This measurement can be made by using three different instrumental techniques:

- PS (proportional scintillation) counting;
- BI (beta ionisation);
- AMS (accelerated mass spectrometry).

The method allows calculation both by weight and biogenic energy content of the waste.

These calculations take into account the specific need for correction of the  $^{14}\text{C}$  content of biomass to account for the so called “bomb effect”. This is the increase of  $^{14}\text{C}$  concentration in the atmosphere following the above-ground hydrogen bomb experiment during the 1950s and '60s, with respect to the pre-1950s natural equilibrium (fig. 2.4) or the “dilution” effect due to the intensive use of fossil fuel in the past century that effectively modified the  $\text{CO}_2$  concentration in the atmosphere. For this purpose, a

default value of 112 pMC<sup>26</sup> for biomass is suggested by CEN/TS EN 15440. This is a useful correction when information on waste composition is not available. This figure is based on studies on compositions, age and measured pMC values of individual waste components. It will be used until 2013, when a revision of such correction factor is expected. This “reference” value, strictly refers to solid recovered fuel, but can be taken for other waste, such as MSW.

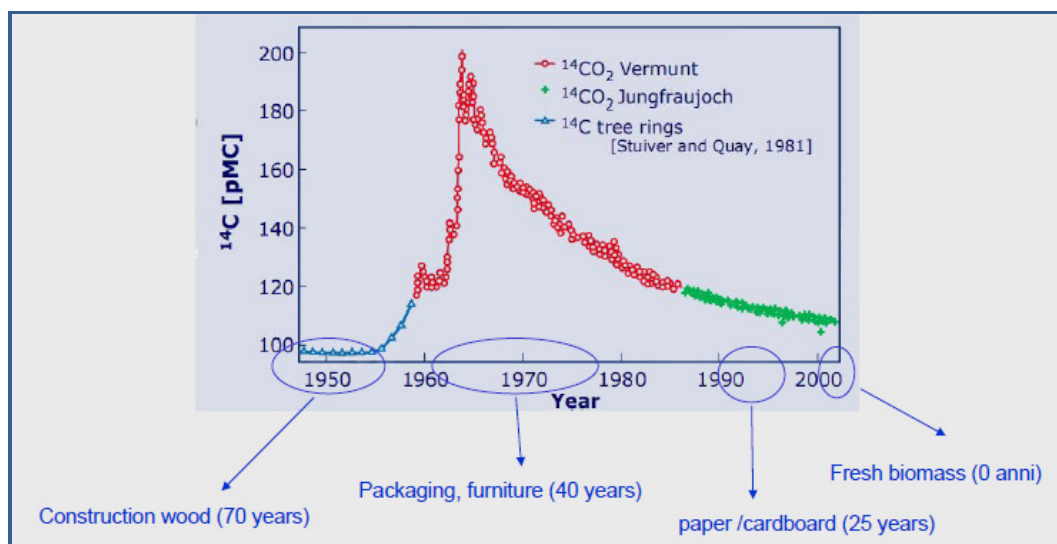


Figure 2.4 - Radiocarbon activity due to the so called “bomb effect” [Source: Ciceri et al, 2009]

A further correction that is taken into account is that related to the so-called isotopic fractionation effect (i.e. small variations in carbon isotope ( $^{12}\text{C}$ ,  $^{13}\text{C}$  and  $^{14}\text{C}$ ) ratios naturally occurring in biomass, depending on its origin). For high precision pMC measurements the  $^{14}\text{C}/^{12}\text{C}$  and  $^{13}\text{C}/^{12}\text{C}$  isotopic ratios have to be determined; a maximum error of about 1% is estimated (for SRF) by CEN/TS EN 15440.

## 2.2 FEASIBILITY AND FIELD APPLICABILITY OF THE AVAILABLE METHODS

The degree of feasibility and real field applicability of the above methods is related to both operational aspects and waste origin and composition.

### 2.2.1 Manual sorting method

The method requires that the waste (in the case of this standard, solid recovered fuel) is made up of discrete particles of which a representative manual separation is possible: EN 15440 recommends a minimum particle size over 1cm. The method gives as a result a by weight measure of the biogenic

<sup>26</sup> pMC is “post-modern carbon”: this is a relative measurement, which is expressed as an index relative to the  $^{14}\text{C}$  content in the atmosphere pre 1950 when atomic bomb testing began [Source: Fuglsang et al 2011]

content. To translate this into a by energy value, either laboratory analysis (CV, moisture content, ash) of the selected waste fraction should be performed or an estimation based on literature reference value of the energy content per selected fraction has to be done.

Although it is simple to apply and only uses low cost equipment, the number of samples required means the overall test is time consuming. In addition it is highly susceptibility to human error or personal judgement. Correct application of the method requires an assessment of the sorting precision by means of a very complicated procedure which includes a confirmation test using the selective dissolution method. Furthermore, if composite materials occur in a waste – materials whose biogenic (e.g. paper) and non-biogenic (e.g. plastics and metals) cannot be easily or completely separated by hand, a mistaken final result for the biogenic content can be obtained.

### 2.2.2 Selective dissolution method

This method can give false analytical results if specific components occur in the waste in significant quantities. Most biomass material shows 100% biodegradability, but deviations have been observed for some biomasses, which are only partially dissolved under the operational test condition.

Similarly, most non-biomass material shows 0% biodegradability but some fossils materials can result in a partial dissolution, producing false positive analytical results (see: tab. 2.2. for some of these problems).

**Table 2.2 - Some examples of components potentially giving false results with the Selective Dissolution (SD) method**  
[Source: REA, 2007]

<b>Natural rubber</b>	Is 100% biomass but if analyzed according the SDM it can result as 84% biomass only
<b>Frying fat</b>	Is 100% biomass but if analyzed according the SDM it can result as 41% biomass only
<b>Wool</b>	Is 100% biomass but if analyzed according the SDM it can result as 82% biomass only
<b>ECOPLA</b>	Is 100% biomass but if analyzed according the SDM it can result 0% biomass
<b>Nylon, polyurethane</b>	Are not biomass but SDM but if analyzed according the SDM they can result as over 95% biomass
<b>Coal</b>	Is not biomass but hard coal analyzed according to the SDM can result ad 43.5% biomass and lignite as 93% biomass

### 2.2.3 Pre-combustion $^{14}\text{C}$ method

This method requires pre-treatment of a solid sample (in a calorimetric bomb, in a tube furnace, in a laboratory scale combustion apparatus) to convert carbon in the solid sample into gaseous  $\text{CO}_2$  for the subsequent  $^{14}\text{C}$  measurement.

The method requires the application of analytical techniques (as mentioned above) with instruments usually available only at well-equipped and specialist laboratories.

#### **2.2.4 Waste sampling**

The availability of a representative sample of the solid waste is a common requirement for all of the above methods.

Sampling should be performed according to existing standards and technical specifications (e.g. EN/TS 15442; EN/TS 15443; EN/TS 15413 for SRF; EN/TS 14778, EN/TS 14779, EN/TS 14790, for solid recovered fuels and biomass products), and requires room for treatment and storage that may not be available at the plant.

The size of representative waste samples can, as a result, be very large and preparation can involve manual and/or mechanical operation, which, if not correctly performed, can affect how representative the final analytical result is. Furthermore, samples must be representatively reduced into a few grams or even less before the final chemical analysis.

#### **2.2.5 Requirements for the WtE plant**

As mentioned in the previous Chapter, according to regulations in force in specific countries (e.g. in Italy), WtE plants applying for RES incentives (e.g. green certificates) have to demonstrate that the waste is collected and analyzed for biogenic content using proper sampling and analytical characterisation standards, to allow the local competent authority to validate the procedure.

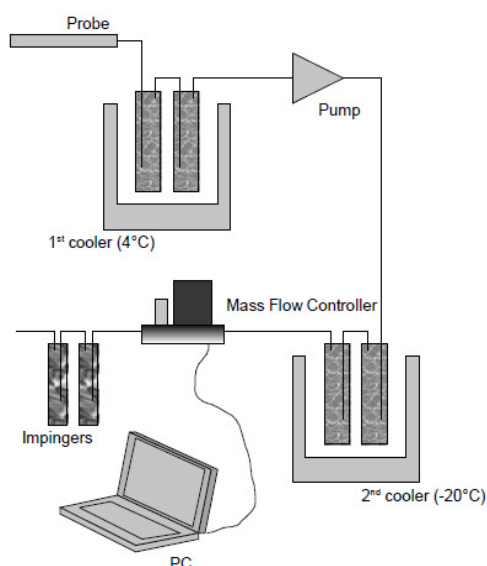
These requirements can be onerous and costly and may outweigh the incentive for renewable energy generation.

### **2.3 METHODS IN ADVANCED STATE OF DEVELOPMENT**

#### **2.3.1 The post-combustion $^{14}\text{C}$ method**

A post combustion  $^{14}\text{C}$  method is now under development in some countries as at ISO level. It allows investigation of the partitioning of biogenic and fossil  $\text{CO}_2$  in the flue gas from a WtE plant and is used mainly for the  $\text{CO}_2$  trading schemes. However, Ofgem, the UK regulator, has recently issued a letter to say that it will consider evidence using this method and provided forms to be completed by those wishing to use the method [Ofgem, 2012]. This method links the biogenic carbon content of the waste to the concentration (or the activity) of the  $^{14}\text{C}$  in the  $\text{CO}_2$  generated during waste combustion, under the assumption that fossil carbon produces a  $^{14}\text{C}$  free  $\text{CO}_2$  and modern (biogenic) carbon, produces  $\text{CO}_2$  at the current  $^{14}\text{C}$  level.

Flue gases are usually automatically sampled (continuously or at selected time intervals) in the stack from a sampling point where emission can be assumed uniformly mixed. In recent years the post-combustion  $^{14}\text{C}$  method as applied to plant flue gases emissions received increasing attention from European and some national Authorities. The American Society for Standard and Materials (ASTM) has already published a standard [ASTM D6866] to be applied to stationary source emissions; while at ISO level [ISO/DIS 13833] a similar standard is in progress. The two methods refer to the existing standard for sampling flue gases from stationary source emissions (ASTM D 7459 and CEN 13528). The sampling, performed using specific adsorbing solutions (NaOH or KOH), produces a representative sample of small size and gas sampling can be carried out automatically (fig. 2.5), allowing to reduce the cost of sampling, as shown in [Ciceri et al., 2009].



**Figure 2.5 - The flue gas sampling equipment developed by RSE in Italy [Source: Ciceri et la, 2009]**

The application of such a methodological approach significantly reduces the uncertainty limits associated with both the manual sorting and the selective dissolution methods and avoids the need to produce and convert into  $\text{CO}_2$  individual representative samples of the waste as required by the  $^{14}\text{C}$  method mentioned in the EN 15440.

A similar method has been recently proposed in Italy and adopted as UNI<sup>27</sup> standard method (UNI/TS 11461:2012).

According to the technical specification, two different sampling solutions, depending on the final instrumental analytical technique applied, can be used to collect the emitted  $\text{CO}_2$ . In particular if the final  $^{14}\text{C}$  analysis is performed by AMS (Acceleration Mass Spectrometry) the use of 2 M KOH is

<sup>27</sup> UNI: Ente Nazionale Italiano di Unificazione, member of the European Committee for Standardisation (CEN)

proposed; if the final  $^{14}\text{C}$  analysis is performed by Proportional Liquid Scintillation counting, the  $\text{CO}_2$  is trapped in an ethanol amine mixture such as Carbosorb ®, that can be directly submitted to analysis without any further treatment of the sample, except for addition of the scintillation.

Information about how to correct measured data for both the “bomb effect” and the isotopic fractionation effect previously mentioned, as well as for the effect due to  $\text{CO}_2$  dilution during sample collection (due to the air used in the combustion process), are included too.

One of the main advantages of the proposed method is that it also defines how to calculate (fig. 2.6) the renewable energy ( $E_{\text{bio}}$ ) from the by mass-result of the  $^{14}\text{C}$  analysis.  $E_{\text{bio}}$  is calculated, as reported in fig. 2.6, according to the method developed by the UK Renewable Energy Association, which assumes the ratio of calorific value/C in the biogenic and fossil fraction of the waste is constant [REA, 2007].

**Energy from biomass ( $E_{\text{bio}}$ ):**

$$E_{\text{bio}} = \frac{A \times C_{\text{rin}}}{B + [(A - B) \times C_{\text{rin}}]}$$

**A** = Reference value of the PCI/C ratio [MJ/kg] for the biogenic fraction of the mixed fuel  
**B** = Reference value of the PCI/C ratio [MJ/kg] for the fossil fraction of the mixed fuel  
 **$C_{\text{rin}}$**  = Renewable C content in the mixed fuel as determined according to the  $^{14}\text{C}$  method

**Figure 2.6 - Equation proposed by REA and adopted by the Italian technical specification UNI prE0209B460 to calculate the renewable fraction of energy ( $E_{\text{bio}}$ ) produced by mixed fuels, based on the  $C_{\text{rin}}$  content measured at plant emission]**

Default values for the A and B parameters of the equation (fig. 2.6) have been proposed by REA, to be applied for a simplified assessment of  $E_{\text{bio}}$  for MSW only. Reviewed default values are included in the standard method proposed in Italy based on a larger waste dataset (the original REA default values were derived from data collected in the past related to UK municipal wastes only) and use a more detailed and larger number of individual biogenic and non-biogenic fractions potentially occurring in MSW (as well in some industrial waste normally burnt in WtE plants).

According to the Italian technical specification, energy lost for water evaporation during the combustion of wet waste materials is quantified too, in order to obtain a more correct value of the net renewable energy produced by the plant (the largest part of the water in MSW and solid recovered fuel being mainly associated with the biogenic fraction).

The standardised method proposed in Italy aroused great interest at the level of national stakeholders but also of international standardisation bodies; in particular its suggestions on how to calculate the biogenic fraction by energy will be taken into account in the review process of “ the ISO/DIS 13833 “Stationary



source emissions - Determination of the ratio of biomass (biogenic) and fossil-derived carbon dioxide - Radiocarbon sampling and determination”, in progress within the ISO/TC 146/WG 26<sup>28</sup>.

### 2.3.2 The mass and energy balance model

A further interesting approach to the biogenic content of wastes is the “mass and energy plant balance model” [Fellner et al, 2007].

This method allows derivation of the renewable energy produced through an iterative numerical solution of a system of balance equations (fig. 2.7) generally including a: total mass balance equation, an ash balance equation, a carbon balance equation, an oxygen and a CO<sub>2</sub> balance equation, a water balance equation and an energy balance equation.

The method requires knowledge of both waste variables - such as the elementary chemical composition (C, H, O, N and S) of the fossil and the biogenic material (as dry and ash free mean values and standard deviations) - and plant variables (fig. 2.8).

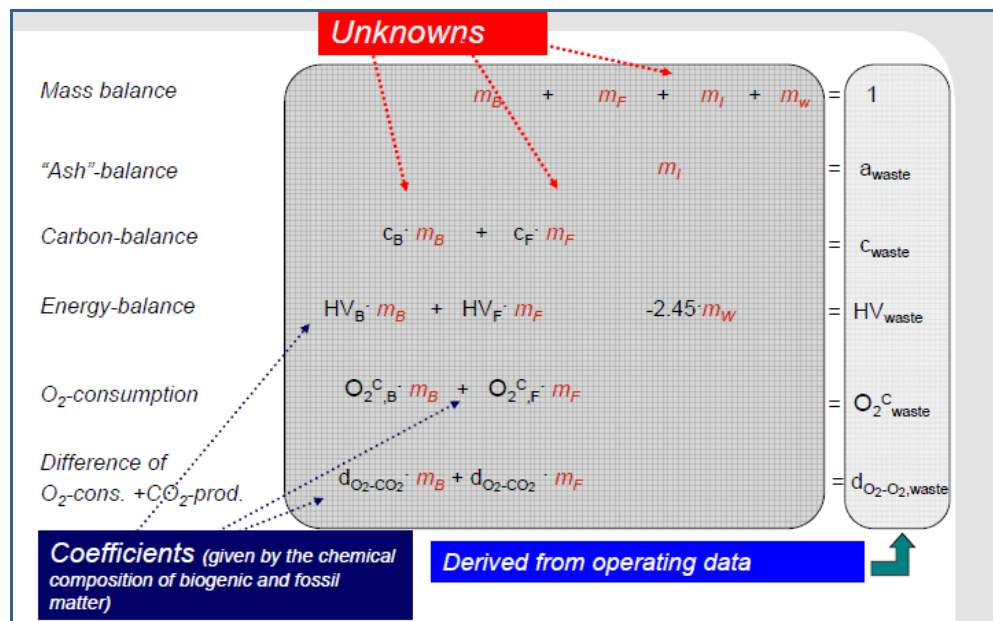
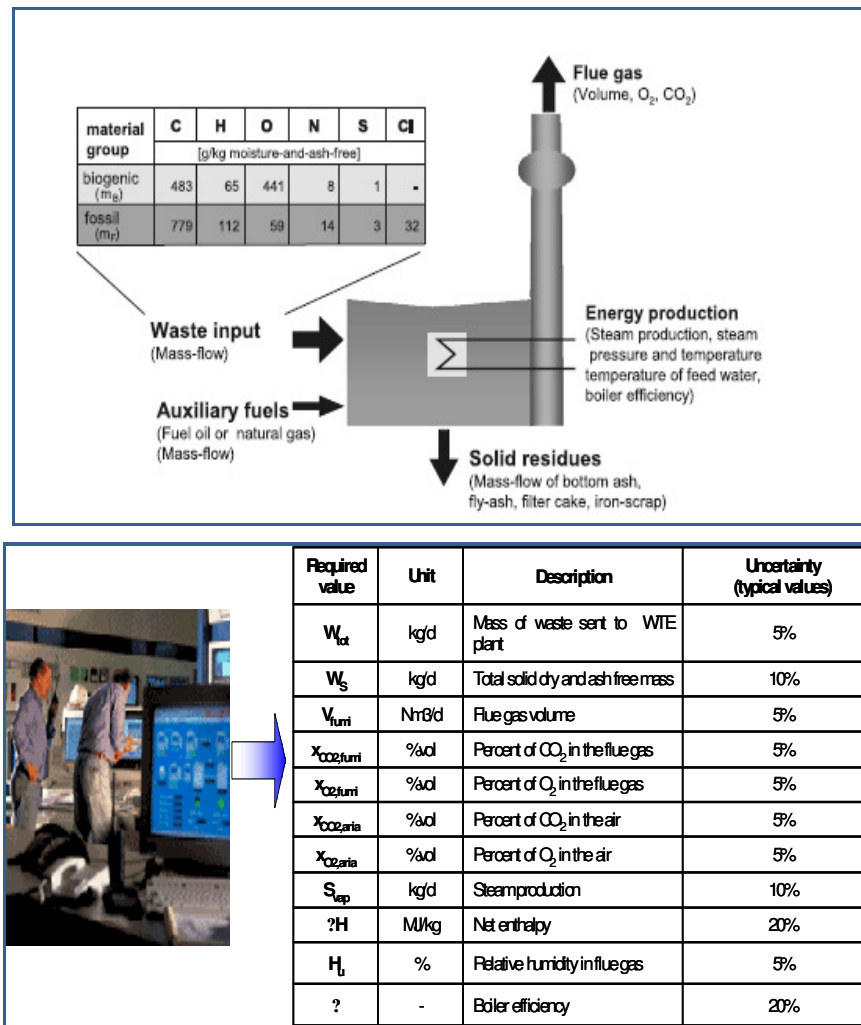


Figure 2.7 - Schematic view of mass and energy balance equations considered by the mass and energy plant balance model [Source: Rechberger, 2010]

<sup>28</sup> ISO/TC 146 "Air Quality" SC 1 "Stationary Source Emission" Committee (and related CEN/TC 264 mirror Committee), Working Group (WG) 26 "Biomass and fossil derived CO<sub>2</sub>"





**Figure 2.8- Waste and plant variables considered by the mass and energy plant balance model [Source: Rechberger, 2010; Guandalini, 2010]**

Usually, reference data taken from literature are used, but literature data can be substituted in the model by more specific information, where available.

Plant variables required by the model are related to operational plant data, usually measured periodically (e.g. any hour or half-hour). Uncertainty for this method depends on the accuracy of the sensors and on the measurement methods. Values are usually taken as mean value with an associated standard deviation.

Although not yet recognized by the national regulations for the purpose of RES-E financial support (as for the post-combustion <sup>14</sup>C method), the mass and energy plant balance model seems quite promising due to some general advantages such as:

- waste data are achievable from literature (no additional sampling and supplemental chemical analyses generally required);

- the plant operating data, required by the model, are usually already measured and recorded by a WtE plant for other purpose (e.g. the compliance with environmental emission standards);
- the model can be applied on line in a WtE plant, without the need of a lot of hardware equipment, providing the renewable amount of electricity produced by the plant;
- some software packages based on the mass and energy plant balance model are now available in Europe. A software tool based on the mass and energy plant balance model was developed and tested (fig. 2.9) on some WtE plants in Austria [Rechberger, 2010]. A similar (free) software tool labelled OBAMA (Optimized Balance Method Application) (fig. 2.10) was developed in Italy by RSE as part of the Electric System Research (RdS) activities [Guandalini, 2010].

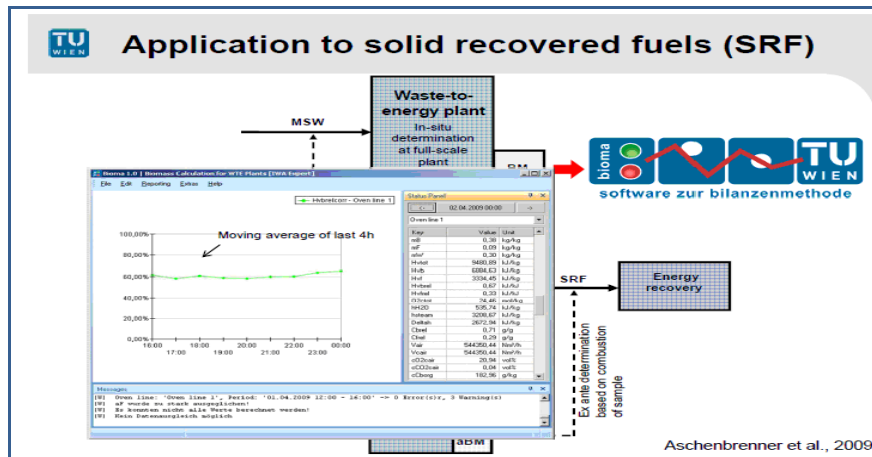


Figure 2.9 - Software tools based on the mass and energy plant balance model developed in Austria [Source: Rechberger, 2010]



Figure 2.10 - Software tools based on the mass and energy plant balance model, developed in Italy [Source: Guandalini, 2010]

Nevertheless, limitations and/or need for further studies have been evidenced in presence of some wastes. For example, in the case of End of Life Tyres (ELT) the mass and energy balance model was not able to discriminate between biogenic and fossil components (e.g. natural and synthetic rubber), due to the similar chemical composition of the two matrixes. In fact one of the basic criteria of the method is the different stoichiometry of the oxidation reaction of the biogenic fraction of the waste compared to the fossil fraction. Low accuracy of data due to plant and instrumentation failures can affect the model's performance. Furthermore, the integration of the model software with the specific waste combustion control and data recording system working in a WtE plant can take some time, but appears generally to be straight forward. Other aspects, such as the role of some inorganic reactions and their effects on the results, the different water content of biogenic and fossil fractions, have to be taken into account in the model in the future to reach better applicability to a wider range of WTE plants.

### 2.3.3 Performances of methods in advanced state of development

The post-combustion  $^{14}\text{C}$  measurement has been investigated on WtE and power plants in a number of comparative test [Fichtner, 2007; Raber, 2003. Hämäläinen et al. 2007; Mohn et al., 2008; Reinhardt et al., 2008; Staber et al., 2008; CEN/TR 15591; Palstra and Mejer, 2010 and has shown good agreement with existing standards methods, particularly with the selective dissolution analysis. All Authors stated that the manual sorting method seems to produce higher biomass content value compared to the other methods (an overestimation of the actual ratio between the biogenic and the fossil fraction of the mixed fuel).

The mass and energy plant balance model also performed well when applied to MSW at different WtE plants in Europe, showing a good agreement with consolidated methodologies (EN 15440) for the assessing of the biogenic fraction of the energy produced at the plant. The results from comparison tests between the  $^{14}\text{C}$  post-combustion method and the mass and energy balance model, at three different WtE plants (MSW) in Switzerland [Mohn et al., 2008] showed that there is a good agreement between the methodologies.

Results of field tests performed in Italy by RSE at WtE plants treating MSW (see: fig. 2.11; fig. 2.12) or SRF produced from MSW (see: fig. 2.13) as at a dedicated WtE plant (see: fig. 2.14) treating HCWs (health care waste) [Cipriano et al, 2007; Ciceri et al, 2009; Ciceri et al 2010; Martignon and Ciceri, 2012], provide evidence supporting these evaluations.

All field tests included the post-combustion  $^{14}\text{C}$  method, performed according to the new Italian standard (UNI/TS 11461:2012) and the plant mass and energy balance model, which the OBAMA tool developed by RSE is based on; really a wrong performance of the OBAMA model occurred when it

was applied to the SRF-WtE plant (mainly due to the inadequate quality of the available WtE plant data), so that results are not reported in fig. 2.13.

Manual sorting analysis was applied to both the municipal solid waste collected at MSW-WtE plants (fig. 2.11 and fig. 2.12) and the CER 180103, the main waste treated at the HCW-WtE Plant (fig. 2.14), according to the methodology developed in Italy by IPLA [IPLA, 1992; IPLA, 1998]. The methodology allows an assessment of the biogenic content of waste by mass (M, wt%), based on the %weight of the selected fractions identified as biomass or not biomass (fossil, inert) in the waste. The M (mass) wt% value reported in fig. 2.11 and fig. 2.12 was obtained by analysing samples of MSW treated at the WtE plants during the test. A “*theoretical*” manual sorting assessment, was the only feasible option at the HCW-WtE Plant (fig. 2.14). Due to the very high risk for human and environment health of CER 180103, handling operations (as needed to produce a solid waste sample or to analyse it) are prohibited by law at a plant; so that a reference composition of CER 180103, as achievable from literature for Italian health care facilities, was used. The result by mass from a manual sorting analysis is generally expressed on a wet basis ( $Mwt\%_{ar}$ ), as we report in fig. 2.12 and fig. 2.14. Data reported in fig. 2.11 represent a preliminary attempt to “normalize” values from different methodologies, by converting the  $Mwt\%_{ar}$  value in a  $Mwt\%_{daf}$  value, based on knowledge of the ash content (about 22% of the total waste weight; this parameter was not measured in the solid samples collected during field tests on WtE plants 2 and 4). Finally, the biogenic content by energy was derived (for all test cases) by applying reference data for calorific value for each selected fraction to the by mass result from manual sorting analysis.

A selective dissolution analysis and a pre-combustion  $^{14}C$  analysis, according to EN 15440, were applied to samples of solid recovered fuel collected at the SRF-WtE plant (see: fig. 2.13), as standard methods to assess their biogenic content.

Generally, in this field test reasonable agreement between the post combustion  $^{14}C$  and the mass and energy balance model (OBAMA tool) was achieved in the assessment of the renewable energy content of mixed wastes (not only for MSW or SRF, but also when a specific industrial waste such as that labelled by CER code 180103 was examined). A similarly reasonable agreement was achieved between the post combustion  $^{14}C$  and the selective dissolution methods, when these were compared. The results presented here also confirm the lower performance of the manual sorting method for estimating the biogenic content of the wastes tested in this work, particularly when for HCW-HI, strongly dependent on reference data.

WTE plant 1

Installed power MWe 84,4 Authorized treatment ton/y 810000

Combustion technology Moving Grate Feeding mix MSW + other industrial wastes During field campaign feeded with MSW only

Manual sorting

$M_{bio}$	$wt\%_{daf}$	67	
$E_{bio}$	$\%_{daf}$	50	uncertainty 30%

Post-combustion<sup>14</sup>C (LSC)

$M_{bio}$	$wt\%_{daf}$	50	
$E_{bio}$	$\%_{daf}$	33	uncertainty 24%

OBAMA model

$M_{bio}$	$wt\%_{daf}$	47	
$E_{bio}$	$\%_{daf}$	32	uncertainty 6%

Figure 2.11 - Comparison of existing standard methods and methods in advanced state of development for the assessment of the biogenic content of mixed fuels. Test Case 1: Italian WtE plant mainly fed with MSW ( $wt_{bio}\%$ : biogenic content by mass; LSC: liquid scintillation counting; ar: value expressed on a wet base, eg: as received; daf: value expressed on a dry and ash free base) [Source: Martignon and Ciceri, 2012]

<b>WTE plant 3</b>		Installed power MWe 10,5	Authorized treatment ton/y 870000
		Combustion technology Moving Grate	Feeding <b>MSW</b> + other industrial wastes
		During field campaign feeded with MSW only	
		<u>day 1</u>	<u>day 2</u>
<b>Manual sorting</b>			
$M_{bio}$	$wt\%_{ar}$	<b>62,1</b>	<b>58,9</b>
$E_{bio}$	$\%_{ss}$	<b>49,2</b>	<b>44,2</b>
<b>Post-combustion<sup>14</sup>C (AMS)</b>			
$C_{bio}$	$wt\%_{daf}$	<b>56,2</b>	<b>62,1</b>
$E_{bio}$	$\%_{daf}$	<b>45,7</b>	<b>51,2</b>
<b>OBAMA model</b>			
$M_{bio}$	$wt\%_{ar}$	<b>40,7</b>	<b>39,9</b>
$E_{bio}$	$\%_{daf}$	<b>47,6</b>	<b>51,7</b>

Figure 2.12 - Comparison of existing standard methods and methods in advanced state of development for the assessment of the biogenic content of mixed fuels. Test Case 3: Italian WtE plant mainly fed with MSW ( $wt_{bio}\%$ : biogenic content by mass;  $C_{bio}Wt\%$ : biogenic C content by mass; AMS: accelerated mass spectrometry; ar: value expressed on a wet base; ss: value expressed on a dry base; daf: value expressed on a dry and ash free base;) [Source: Martignon and Ciceri, 2012]

<b>WTE plant 2</b>		Installed power	MWe 9,3	Authorized treatment	ton/y 75000	
		Combustion technology	Fluidized bed	Feeding	CSS + other industrial wastes	
		During field campaign feeded with CSS from MSW only				
				<u>day 1</u>	<u>day 2</u>	<u>day 3</u>
<b>Selective dissolution</b>		M <sub>bio</sub>	wt% <sub>daf</sub>	58,8	56,3	55,0
		C <sub>bio</sub>	wt% <sub>daf</sub>	46,1	43,5	42,5
		E <sub>bio</sub>	%	na	na	na
<b>Pre-combustion<sup>14</sup>C (LSC)</b>		M <sub>bio</sub>	wt% <sub>daf</sub>	67,0	72,7	67,2
		C <sub>bio</sub>	wt% <sub>daf</sub>	57,9	61,0	54,9
		E <sub>bio</sub>	% <sub>daf</sub>	51,9	55,1	48,9
<b>Post-combustion<sup>14</sup>C (AMS)</b>		M <sub>bio</sub>	wt% <sub>daf</sub>	54,3	55,0	53,6
		C <sub>bio</sub>	wt% <sub>daf</sub>	41,8	42,5	41,8
		E <sub>bio</sub>	% <sub>daf</sub>	36,1	36,6	36,1
<b>(LSC)</b>		M <sub>bio</sub>	wt% <sub>daf</sub>	na	57,1	58,9
		C <sub>bio</sub>	wt% <sub>daf</sub>	na	44,6	46,3
		E <sub>bio</sub>	% <sub>daf</sub>	na	38,7	40,4

Figure 2.13 - Comparison of existing standard methods and methods in advanced state of development for the assessment of the biogenic content of mixed fuels by mass. Test Case 3: Italian WtE plant mainly fed with CSS (wt<sub>bio</sub> %: biogenic content by mass; C<sub>bio</sub>Wt%: biogenic C content by mass; AMS: accelerated mass spectrometry; LSC: liquid scintillation counting; ar: value expressed on a wet base; daf: value expressed on a dry and ash free base;) [Source: Martignon and Ciceri, 2012]

WTE plant 4

Installed power MWt 15

Authorized treatment ton/y 20000

Combustion technology Rotary kiln

Feeding Health Care Wastes

During field campaign feeded mainly with CER 180103

Manual sorting

Calculated reference value CER 180103

$M_{bio}$	wt% <sub>ar</sub>	45,0		
$E_{bio}$	% <sub>ss</sub>	34,1		

Post-combustion<sup>14</sup>C

(AMS)

	<u>day 1</u>	<u>day 2</u>	<u>day 3</u>	
$C_{bio}$	wt% <sub>daf</sub>	24,3	24,8	21,9
$E_{bio}$	% <sub>daf</sub>	23,4	23,8	21,0

(LSC)

$C_{bio}$	wt% <sub>daf</sub>	26,2	26,8	25,3
$E_{bio}$	% <sub>daf</sub>	25,1	25,7	24,3

OBAMA model

	<u>average 3 days</u>			
$M_{bio}$	wt% <sub>ar</sub>	25,8		
$E_{bio}$	% <sub>daf</sub>	24,3		

Figure 2.14 - Comparison of existing standard methods and methods in advanced state of development for the assessment of the biogenic content of mixed fuels by mass. Test Case 4: Italian WtE plant mainly fed with HCW-HI (CER 180103) (wt<sub>bio</sub> %: biogenic content by mass; C<sub>bio</sub>Wt%: biogenic C content by mass; AMS: accelerated mass spectrometry; LSC: liquid scintillation counting; ar: value expressed on a wet base; ss: value expressed on a dry base; daf: value expressed on a dry and ash free base) [Source: Martignon and Ciceri, 2012]



## **2.4 NEW METHODS IN DEVELOPMENT**

### **2.4.1 Calorimetric test**

A new calorimeter technique (Calorimetric test C-Tech by C-Tech Innovation Ltd) aimed at providing an indication of the biogenic content of waste as it enters the combustion chamber, is reported currently under development and validation in the UK for an on line/real time application on WTE plants. This project has received support from the Government Departments, Defra and DECC.

The technique seems to be able to differentiate between fossil and biogenic plastic in mixed plastic samples; it could also be used on black bag samples, once appropriate look up tables have been prepared; the equipment needs for the technique are minimal, but it will require technicians to interpret the data.

### **2.4.2 Image analysis methodology**

In UK, a project of CERT Cranfield University has been supported by DEFRA, DECC under the SBRI programme for novel techniques to monitor the biogenic content of waste of the Technology Strategy Board. This work is focused on the development and testing of an image analysis methodology to examine the physical composition of waste, without the need for manual handling [Wagland and al, 2012].

The equipment was designed to sit on top of a conveyor belt to enable imaging of the waste input to the combustion chamber. The imaging is linked to a database on the density of waste components and its 2 D image, allowing an estimate of the physical composition of the waste. This can then be subsequently linked to  $^{14}\text{C}$  analysis allowing an estimation of the biogenic content of the waste, which can be related to its physical components.

The method can be used for solid recovered fuel, providing it is calibrated for this waste first. A good correlation of the methodology with other methods for determining the physical composition of waste is reported. Further work was funded to allow calculation of the energy value of the waste biogenic content, by using the calculated biogenic content obtained from the  $^{14}\text{C}$  analysis.

### **2.4.3 Thermogravimetric analysis**

Some applications of thermogravimetric analysis (TGA) to the characterization of mixed wastes (i.e. tyres) are reported in literature [Della Vedova et al, 2011; Heikkinen et al, 2004; Moilanen, 2006; Rimez et al, 2008], and considered potentially useful to identify and quantify (by weight) components (including biomass) occurring in a waste used for energy recovery.



## 2.5 ECONOMIC CONSIDERATIONS

An attempt has been undertaken to derive preliminary and indicative only unit costs (€/sample) for the methods described above for routine use at a WtE plant.

Both sampling - a necessary operational step, which is both labour and cost expensive, depending on the nature of the sample (type of solid waste; flue gas emission) and technical specifications applied to perform it - and laboratory analysis, have been considered as influencing factors, under the following assumptions:

- A minimum daily commitment of a mean of 1 dedicated person (individual unit cost: 60 €/hour/people) was assumed for the sampling step when the post-combustion  $^{14}\text{C}$  method (on flue gas samples) is applied for an incidence of sampling of about 480 €/day was assessed. This effort can be significantly reduced by applying automatic sampling methods;
- When a selective dissolution or a pre-combustion  $^{14}\text{C}$  method approach are applied on solid waste samples, a minimum daily commitment of 1 dedicated person (individual unit cost: 60 €/hour/people) was assumed, so that a whole incidence of sampling of about 480 €/day was assumed. It is difficult to reduce this cost because the sampling cannot be completely done automatically;
- In the case of the manual sorting method, the same daily commitment as above was applied to field (plant) samples for collection only. To this we need to add the cost of the analytical step, including the subsequent operations (manual identification, separation and weight of waste components), which result in extra time-related costs. A single run cost in the range 900-1200 €/sample was assumed for the “analytical step”;
- All the analytical steps have been assumed to be carried out by an external laboratory and include costs of producing a test sample from the laboratory sample collected in the field at the plant and/or for any sample pre-treatment required before analytical step;
- In the case of the measurement of the biogenic content by the selective dissolution method, a range of unit costs of 150-250 €/sample was assumed.
- For the  $^{14}\text{C}$  method (both on solid and gaseous samples), the assumed range of unit cost was 300-400 €/sample, if based on proportional scintillation analysis (PSM), and 250-500 €/sample if based on accelerated mass spectrometry (AMS).
- An indicative unit cost in the range of 100-200 €/sample was assumed for the general, physical and chemical characterization of the waste sample (LCV, moisture content, elementary composition: C, H, N, O, Cl, S, ash content).

In summary, the manual sorting method was assessed to be the most expensive of those currently available for the assessment of the biogenic content of waste (tab. 2.3) , followed by the post-combustion  $^{14}\text{C}$  method. Both the  $^{14}\text{C}$  method applied on solid samples and the selective dissolution method resulted in a lower whole unit cost.

As estimate of the cost of the mass balance method of EUR 5000/y/facility was obtained from Professor Rechberger of TUWien. This applies to the use of the BIOMA software,<sup>29</sup> developed at TUWien (Rechberger, Personal communication). BIOMA produces 6-hour mean values up to yearly mean values.

**Table 2.3 - An indicative comparative analysis of the whole unit cost of the manual sorting, the selective dissolution, the pre-combustion and the post-combustion  $^{14}\text{C}$  approaches for the measure of the biogenic content of mixed wastes**

<b>Manual sorting method</b>		
	(€/sample) min	<b>1380</b>
	(€/sample) max	<b>1680</b>
<b>Selective dissolution method</b>		
	(€/sample) min	<b>630</b>
	(€/sample) max	<b>730</b>
<b><math>^{14}\text{C}</math> method (solid waste)</b>		
<b>Biogenic fraction analysis (PSM method)</b>	(€/sample) min	<b>780</b>
	(€/sample) max	<b>880</b>
<b>Biogenic fraction analysis (AMS method)</b>	(€/sample) min	<b>730</b>
	(€/sample) max	<b>980</b>
<b><math>^{14}\text{C}</math> method (flue gases)</b>		
<b>Biogenic fraction analysis (PSM method)</b>	(€/sample) min	<b>780</b>
	(€/sample) max	<b>880</b>
<b>Biogenic fraction analysis (AMS method)</b>	(€/sample) min	<b>730</b>
	(€/sample) max	<b>980</b>

<sup>29</sup> <http://iwr.tuwien.ac.at/ressourcen/downloads/bioma.html>.

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