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Primary Energy Methodologies Applied to Portugal

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[1] *Lisboa E-Nova - Agência Municipal de Energia e Ambiente de Lisboa* is Lisbon's Municipal Energy and Environment Agency (website http://www.lisboaenova.org).

Abstract

Primary energy methods perform substitutions of certain energy flows. We review the different methods to derive the valuation criteria implicit in the substitutions performed.

We then introduce the Time Reference Valuation (TRV). This method uses the criterion of valuing all primary energy flows (fossil and renewable) as the separate delivery of electricity and heat, with the efficiency at a given reference year.

This valuation removes the trend due to changes in the electric system, and has two main applications: to evaluate the remaining trend in primary energy use, and to establish a baseline for assessing changes occurring in the electric system.

We apply the current methods and the TRV method to Portugal from 1994 to 2009, comparing the results obtained and illustrating the two main uses of the TRV method.

Keywords: Primary Energy, Renewable Energy, Power Plants, Combined Heat and Power.

Sumário

Os métodos de energia primária realizam substituições de certos fluxos energéticos. Revemos os diferentes métodos para obter os critérios de valorização implícitos nas substituições realizadas.

Introduzimos então a Valorização com Referência no Tempo (VRT). Este método utiliza o critério de valorizar todos os fluxos de energia primária (fósseis e renováveis) como o fornecimento separado de electricidade e calor, com a eficiência de um dado ano de referência.

Esta valorização remove a tendência devida a mudanças no sistema eléctrico, e tem duas aplicações principais: avaliar a restante tendência no uso de energia primária, e estabelecer valores de referência para avaliação das mudanças que ocorrem no sistema eléctrico.

Aplicamos os métodos existentes e o método VRT a Portugal de 1994 a 2009, comparando os resultados obtidos e ilustrando os dois usos principais do método VRT.

Palavras chave: Energia Primária, Energia Renovável, Centrais Térmicas, Cogeração.

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List of Abbreviations

CHP – Combined Heat and Power 2
CSP – Concentrating Solar Power 9
DGEG – Directorate-General of Energy and Geology 1
IEA – International Energy Agency 1
MSW – Municipal Solid Waste 48
NRV – Nominal Reference Valuation 12
OECD – Organisation for Economic Co-operation and Development 1
PV – Photovoltaic 9
toe – tones of oil equivalent 14
TRV –- Time Reference Valuation 12
USEIA – United States Energy Information Administration 4

1 Introduction

1.1 Relevance

In Portugal the proportion of final energy which is delivered as electricity has increased from 17% in 1990 to 23% in 2009, as illustrated in Figure 1.[2]

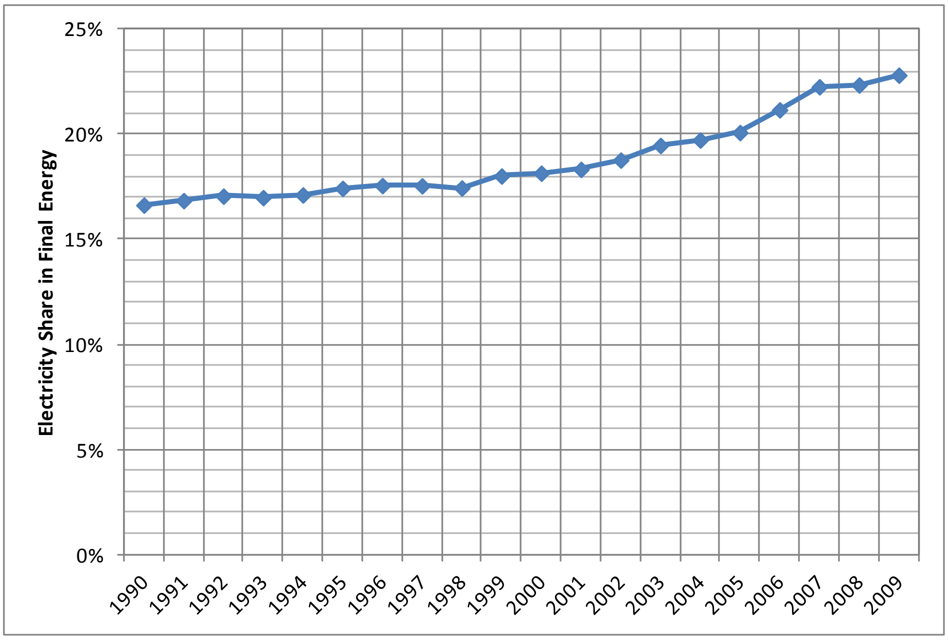

Figure 1 – Electricity Share in Final Energy

In this time period of 1990 to 2009 a significant share of electricity was delivered by hydroelectric power plants, although the actual share varies among years, representing between 11 and 43 % of gross electricity delivery (Figure 2). Wind power plants have been delivering increased shares of electricity, from 0 % in 1990 to 15% in 2009 (Figure 2).

With regard to future trends, the International Energy Agency (hereafter IEA) of the Organisation for Economic Co-operation and Development (hereafter OECD) states that the objectives set for the increase of renewable energies in Portugal are ambitious (OECD/IEA, 2009a, p. 144). The fulfillment of such objectives would lead to increasing quantities of energy delivered with renewable energies instead of fossil fuels.

[2] The figures in this chapter were derived directly from the National Energy Balances of the Directorate-General of Energy and Geology (hereafter DGEG).

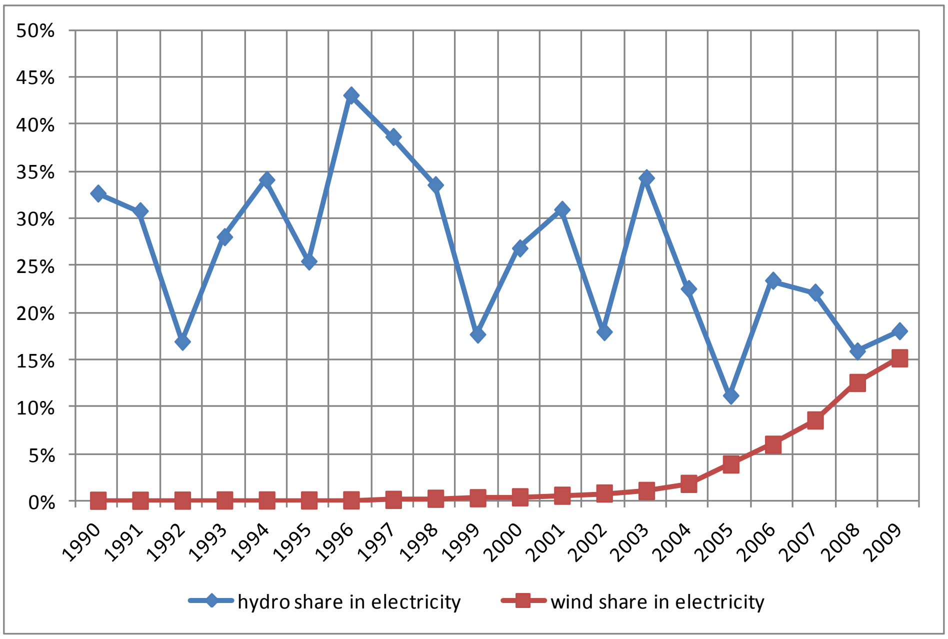

Figure 2 – Shares of Electricity Delivered by Hydro and Wind

Increasing renewable energy in electricity delivery is an example of a supply policy. Other examples are increasing Combined Heat and Power (hereafter CHP) or increasing the efficiency of power plants (which deliver only electricity). On the other hand, demand side policies include for instance increasing the use of efficient domestic appliances or increasing the use of driving behaviors that save fuel. This matter leads us to two aspects that contribute to the relevance of this work.

In first place, by examining how existing primary energy methods deal with the different energy deliveries to the energy sector we clarify how they compare the results of different supply policies. In second place, given that primary energy is used in methodologies for the analysis of demand policies, our examination of the existing primary energy methods also evaluates how different methods analyze demand policies.

Portugal has no relevant fossil fuels reserves and therefore renewable energy is also the only domestic energy.[3] The correct evaluation of its contribution is thus also relevant for energy dependency issues.

The relevance of the study of energy use in general is justified by the correlation between energy use and economic growth (see for instance Brown *et al.*, 2011, and references therein).

Energy intensity is often used to examine such correlation (for the case of Portugal see for instance Amador, 2010). It is computed as the ratio between primary energy and Gross Domestic Product. This ratio is often taken as a measure of how well an economy uses its energy. An examination of the primary energy methods in use contributes to clarify what is being expressed by such a widely used indicator.

[3] No proven reserves of oil, natural gas or coal are indicated for Portugal in BP (2011).

1.2 Motivation

As mentioned above, primary energy methods are relevant for both the study of supply policies and demand policies.

Regarding demand policies, one main application of primary energy values is the analysis of final energy use, e.g. by a given metropolitan area. In this case, the primary energy used by the energy system for delivering electricity is used to express the value of electricity compared to other final energy flows such as fossil fuels (e.g. gasoline).

If $PE_{electricity}{}^{(ES)}$ is the Primary Energy (PE) used by the Energy System (ES) to deliver electricity, $E^{(ES)}$ is all the electricity delivered by the energy system, $E^{(MA)}$ is the electricity used by the Metropolitan Area (MA), then the primary energy used to deliver electricity to the Metropolitan Area, $PE_{electricity}{}^{(MA)}$, is given by:

$$PE_{electricity}{}^{(MA)} = [\, PE_{electricity}{}^{(ES)} / E^{(ES)}] \cdot E^{(MA)} \qquad (1)$$

A decrease in the primary energy used to deliver electricity to the metropolitan area can result from two factors: decreased electricity use by the metropolitan area or decreased primary energy use to deliver electricity (e.g. due an increase in the efficiency of thermal power plants).

For the case of the metropolitan area, there are stakeholders whose acts can impact the energy use by the metropolitan area, but not the energy use by the electric system (e.g. municipal councils). To evaluate the results of their acts on energy use, such stakeholders need to establish the trend in the energy use in the metropolitan area, having removed variations due to the electric system. To answer this need is a main motivation of this work

Regarding supply policies, one main application of values obtained with primary energy methods is the analysis of the energy system. In this case, primary energy values are used to compare different primary energy flows, e.g. renewable primary energy vs fossil fuel primary energy. The stakeholders whose acts can impact the primary energy use in the energy system are interested in such comparisons in order to evaluate the results of their acts (e.g. governments wishing to evaluate the results of a renewable energy policy).

By addressing the need of removing the effect of variations in the electric system, we also provide the means to determine a baseline for the electric system. This baseline is useful to measure the relative importance of savings that are also related to energy policy but that are not due to renewable energy and that appear to receive less attention: savings from efficiency increases in fossil fuel power plants and savings from fossil fuel CHP plants.

1.3 Objectives

This dissertation has the following objectives regarding primary energy methods:

i. analyze the main differences in current methods;
ii. propose an method which removes variations due to the electric system;
iii. apply the methods to Portugal.

The relevance of these objectives is justified by the discussion above presented.

2 Literature Review

When quoting a primary energy value it is essential to identify the method applied, because there are several methods in use.

OECD/IEA (2005, p. 19) and EUROSTAT (2011, pp. 6-7) apply a method in which for all fuels (fossil and renewable) the primary energy is the heat calculated using the calorific value. For concentrating solar, geothermal and nuclear energy (i.e. non-fuel thermal flows), the primary energy is the heat received by the plant (OECD/IEA, 2010a, p. 278; OECD/IEA, 2009b, p. I.4; OECD/IEA, 2005, pp. 21-22).[4] For hydro, wind and solar photovoltaic energy (i.e. non-fuel non-thermal flows), the primary energy is the electricity obtained from the plant (OECD/IEA, 2005, pp. 21-22).

The United States Energy Information Administration (hereafter USEIA) adopts a different procedure for hydro, solar concentrating, solar photovoltaic and wind energy. Using the electricity from such plants, the primary energy is calculated as the heat required to deliver the same electricity but by using thermal power plants (USEIA, 2010, pp. 402-403). The efficiency used in the calculation is the annual average efficiency of fossil fuel power plants.

BP uses USEIA's procedure but considers 38% efficiency for thermal power plants (stated to be the value for a modern power plant) and applies the procedure also to electricity from nuclear, geothermal, biomass and waste energy (BP, 2011, pp. 35-36, 38, 44).

Statistics Netherlands uses the "Renewable Energy Monitoring Protocol Update 2010" (NL Agency, 2010).[5] In this method, for all renewable flows, primary energy is also calculated as the heat required to deliver the electricity by using thermal power plants. The efficiency used is the year's average efficiency of fossil fuel and nuclear power plants.

A fundamental difference of NL Agency's method is that CHP plants using renewable fuels are addressed differently. The primary energy is calculated as the heat required to replace the electricity and the heat from CHP, but by using a power plant and separate heat delivery (NL Agency, 2010, pp. 42-43).

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[4] If the heat received is not know, it is estimated from the electricity delivered by the plants by using an efficiency of 40%, 33% and 10%, respectively for concentrating solar electricity, nuclear electricity and geothermal electricity (OECD/IEA, 2010a, p. 278; OECD/IEA, 2005, p. 138). For geothermal heat, if the heat flow is not known, it is estimated using a heat efficiency of 50% (OECD/IEA, 2009b, p. I.4).

[5] NL Agency (2010, p. 16) refers to an update of the "Energy Saving Monitoring Protocol" to be published. I inquired Statistics Netherlands in 2011 if such update had been published, to which Mr. Ferry Lapré kindly replied indicating that the update was not yet published.

The methods by OECD/IEA and EUROSTAT, USEIA, BP and NL Agency have significant differences in how primary energy is calculated, and the issue received some attention in the literature.[6]

Lightfoot (2007) commented the methodologies for calculating primary energy used by USEIA, IEA and Working Group III of the Intergovernmental Panel on Climate Change (in the Special Report on Emissions Scenarios). The author presented a comparison of the methods, calculated the world primary energy consumption in 2003 with each method, and noticed how the proportion of fossil fuels was different. Lightfoot (2007) considered the different methods as different "scales" and mentioned that there is no right or wrong scale, stressing the need to use the same scale consistently. The author argued that the Special Report on Emissions Scenarios is inconsistent due to the use of different scales for primary energy.

Ó Gallachóir *et al.* (2006) studied the case of Ireland for the period 1990-2003. They determined the primary energy using OECD/IEA and EUROSTAT's method and also by substituting non-fuel renewables by the amount of fossil fuels required to deliver the same electricity in thermal power plants.

This latter calculation was done by the authors for two cases: (i) using the average efficiency of existing fossil fuel power plants ("operating margin" approach) and (ii) using the efficiency of the least cost future fossil fuel power plant - considered to be a combined cycle power plant ("build margin" approach). For the year 2003, the authors concluded that renewable primary energy with the operating and the build margin approaches is respectively 45% and 28% higher than with OECD/IEA and EUROSTAT's method. The authors proceeded to estimate avoided carbon dioxide emissions.

Segers (2008) approached the issue of different primary energy methods from the viewpoint of calculating the proportion of renewable energy. This author considered the following methods: primary energy calculated with OECD/IEA and EUROSTAT's method, primary energy calculated with a substitution method, and final energy.

For the substitution method, the substitution factor presented for electricity from wind, hydro and solar energy was 2.5, based on a typical thermal power plant average efficiency of 40%. Specific substitution factors were also given for biodiesel, biogasoline and solid biomass used in households. For other sources a generic factor of 1 was used

Segers, affiliated with Statistics Netherlands, compared the results for the proportion of renewable energy obtained with the three methods for European Union countries for the year 2005.

[6] The literature search included searching with the keywords "primary energy" both in Web of Science and in Google Scholar. Whilst there are many publications using the concept of primary energy, here we have included specifically publications dealing either with defining or comparing different methods to calculate primary energy.

The author concluded that the proportion of renewable energy calculated using the substitution method does not have the accuracy problems of OECD/IEA and EUROSTAT's method and of final energy method and requires only very limited concessions related to data accuracy and simplicity.

Harmsen *et al.* (2011) approached the issue of primary energy methods focusing on its interaction with Europe's energy savings target. These authors noticed how OECD/IEA's method leads to primary energy savings as power generation from renewable energy increases (e.g. from wind, hydro and solar).

Harmsen *et al.* (2011) pointed out that understanding this influence of OECD/IEA's method is vital for policy makers, but they stated that this could lead to wrong policy targets, given the risks that it may decrease the need for demand side energy saving. The authors defended that savings targets should be expressed in final energy (instead of primary energy).

In the literature it is noticeable that OECD/IEA and EUROSTAT's method is mentioned as "the" primary energy method (e.g. Ó Gallachóir *et al.*, 2006, Segers, 2008, and Harmsen *et al.*, 2011). This illustrates that this particular method is so commonly used that one may think that it is the only method and that there are no other methodological options.

For example, Amador (2010) mentions using OECD/IEA's data, but does not mention using OECD/IEA and EUROSTAT's method. Although this is implicit, not mentioning the method has the appearance that only sources of data are involved, when it is not the case.

Values calculated with primary energy methods have widespread and diverse applications: studying the trends in the use of different energy resources (e.g. Marchetti, 1977 and Devezas *et al.*, 2007), examining CHP systems (e.g. Smith *et al.,* 2011), performing Life Cycle Assessment (e.g. Dodoo *et al.,* 2011), analyzing energy use in buildings (e.g. Airaksinen, 2011), studying the influence of lifestyles in energy use (e.g. Korjenic and Bednar, 2011) or comparing the energy use of vehicles (Åhman, 2001).

In each of these applications, whenever primary energy values are used, also a method for its calculation has to be chosen. In the next chapter, we clarify the choices implicitly made when a particular method is chosen to calculate primary energy.

3 Current Methods

3.1 Definition

When used in the economy, fuels are burned, and the resulting heat is eventually returned to the environment (e.g. as heat losses). Using the fuels' heating value, we determine how much heat is received by the economy when burning fuels. This heat is the primary energy flow from fuels.[7]

However, there are primary energy flows that do not involve burning fuels, e.g. hydraulic, wind and solar energy. Let us notice two aspects of these non-fuel flows.

First, such primary energy flows are real and have one only way of being determined, e.g. the primary energy flow to a wind turbine is the mechanical energy extracted from wind.

Second, for such primary energy flows the real primary energy flow does not refer to heat, and is thus difficult to compare with the heat that fuels can deliver.

Because of this second aspect, the real primary energy flow is not used when comparing different primary energy flows. Instead, a substitute value is used, that expresses how valuable is the real primary energy flow when compared to heat. It is this alternative value that is used when comparing primary energy flows.

In the literature there are different procedures for these substitutions. Hereafter we refer to these procedures as "primary energy valuation methods".[8]

This approach differs from the literature reviewed because we do not consider the usual distinction between a "primary energy method" by OECD/IEA and "substitution methods".[9] In fact, OECD/IEA's method also substitutes some real primary energy flows with other values that express how valuable they are. For example, OECD/IEA substitutes real primary energy from wind (i.e. the mechanical energy extracted from wind) with the electricity obtained from wind.

Although all primary energy valuation methods perform substitutions, the substitutions performed are different. This reflects different implicit valuation options. This work approaches the primary energy methods by observing the substitutions they perform and deriving the implicit valuation options.

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[7] We assume the reader is familiar with the definitions used in energy statistics. Annex 1 presents a review of such definitions (primary and final energy, energy consumption and production, and energy balance).

[8] The idea that a valuation is being performed is explicit in the literature, e.g. in OECD/IEA (2005, 137), which refers to methods "used to value primary energy production", and in Lightfoot (2007), who refers to "different primary energy scales".

[9] OECD/IEA (2005, p. 137) names its method "physical energy content method". The distinction between this method and substitution methods is found in for example in OECD/IEA (2005), NL Agency (2010), Segers, (2008), and Harmsen *et al.* (2011).

This approach does not lead to conclusions for a “right” or “wrong” method, following Lightfoot (2007) and differing from Segers (2008) or Harmsen *et al.* (2001). But besides what Ligthfoot (2007) pointed out, i.e. that comparisons must be made using a same method, we seek to clarify which valuation principles correspond with each method.

3.2 Usefulness

It must be noted that valuing fossil fuels is relevant because fossil fuels are not infinitely available, i.e. they are a scarce resource. Were fossil fuels to be infinitely available, their value would be null.

With primary energy valuation methods, we are also valuing renewable energy (e.g. hydraulic energy). Although such flows are renewable, they are not infinitely available (e.g. hydraulic energy depends on the availability of water). Therefore, it is relevant to establish a valuation of (scarce) renewable primary energy flows relative to heat from (scarce) fossil fuels.

Depending on the purpose to achieve, there are cases where instead of a primary energy valuation method we need to use the real primary energy flows. For example, to assess how much electricity can be obtained from hydraulic energy in a given hydrographic basin, we would be interested in the real primary energy flow and not in its valuation (see for instance Gardel, 1981, pp. 74-81, and MacKay, 2009, pp. 55-56).

However, if we wish to assess whether an energy system is more dependant on fossil fuels or on hydraulic energy, a valuation of hydraulic energy compared to fossil fuel heat is required.

3.3 Valuation Options

Table 1 summarizes the primary energy methods of OECD/IEA (2005, 2010a) and EUROSTAT, USEIA (2010), BP (2011) and NL Agency (2010).

Table 1 – Current Primary Energy Valuation Methods

<table>
<tr><th colspan="3" rowspan="2">Primary Energy Flow</th><th colspan="4">Valuation of Primary Energy Flow[a]</th></tr>
<tr><th>OECD/IEA</th><th>USEIA</th><th>BP</th><th>NL Agency</th></tr>
<tr><td rowspan="4">Fuels</td><td rowspan="2">Fossil Fuels</td><td>To Power Plants</td><td colspan="2" rowspan="4">Fuel Heating Value[c]</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>To CHP[b] Plants</td></tr>
<tr><td rowspan="2">Renewable Fuels</td><td>To Power Plants</td><td>Heat to deliver the electricity at 38% efficiency</td><td rowspan="7">Heat to deliver the electricity and (if relevant) the heat, at the nominal efficiency[e]</td></tr>
<tr><td>To CHP[b] Plants</td><td></td></tr>
<tr><td rowspan="6">Non Fuels</td><td colspan="2">Hydraulic and Wind</td><td rowspan="2">Electricity Heating Value[d]</td><td rowspan="3">Heat to deliver the electricity at the nominal efficiency[e]</td><td rowspan="4">Heat to deliver the electricity at 38% efficiency</td></tr>
<tr><td rowspan="2">Solar</td><td>To PV[b] Plants</td></tr>
<tr><td>To CSP[b] Plants</td><td>Heat from solar energy</td></tr>
<tr><td colspan="2">Geothermal</td><td colspan="2">Heat from geothermal reservoir</td></tr>
<tr><td colspan="2">Net Electricity Import</td><td colspan="2">Electricity Heating Value[d]</td><td>Zero[f]</td></tr>
<tr><td colspan="2">Nuclear</td><td colspan="2">Heat from nuclear energy</td><td>Heat to deliver the electricity at 38% efficiency</td><td>Heat from nuclear energy[g]</td></tr>
</table>

[a] Annex 2 presents the mathematical expressions for the current primary energy valuation methods.

[b] CHP - Combined Heat and Power; PV – Photovoltaic; CSP – Concentrating Solar Power.

[c] For renewable fuels to CHP plants, for BP (2011) the use of the fuel heating value is presumed, given that no special treatment is referred.

[d] Electricity heating value is the heat obtainable from electricity (which is the same as the electricity, given that electricity can be fully converted to heat).

[e] Nominal efficiency denotes the average efficiency of thermal power plants in the same year as the year of the primary energy flow being valued. In this efficiency, USEIA considers only fossil fuel power plants. NL Agency considers both fossil fuel and nuclear power plants.

[f] Presumed, given that BP (2011) mentions that cross-border electricity is not accounted for.

[g] Presumed, given that NL Agency (2010) includes nuclear power plants in the nominal efficiency.

From the viewpoint of the valuations implicit in the substitutions performed, the current methods can be summarized by addressing four main valuation options.

As a **first valuation option**, observe that if we were to consider renewable flows as not valuable, we could adopt a method in which we valued such flows as zero. None of the methods uses this approach, and thus they all consider renewable flows as valuable.[10]

A **second valuation option** regards non thermal renewables, i.e. hydraulic energy, wind energy, and solar energy to photovoltaic power plants. OECD/IEA and EUROSTAT's method gives such flows the value of the electricity obtained. Electricity can be fully converted to heat, and thus the electricity value is the same as the heating value of electricity. This means that, for example for hydraulic energy, the valuation performed is to give the value of heat obtainable from electricity. It can be an interesting option if electricity is to be used mainly for conversion to heat.[11]

Alternatively, realizing that electricity can be used to deliver work instead of heat and that this use can be significant, it can be argued that primary energy from non thermal renewable primary energy can be given a different value to express its usefulness to deliver work. This alternative valuation is performed by USEIA, BP and NL Agency: the primary energy from non-thermal renewables is given the value of the heat that would be required to deliver the same amount of electricity through thermal power plants. The methods differ in the reference efficiency considered for the thermal power plants. USEIA uses the nominal (i.e. yearly average) efficiency of fossil fuel power plants. BP uses a fixed efficiency of 38% (stated to be the efficiency of a modern thermal power plant). NL Agency uses the nominal efficiency of both fossil fuel and nuclear power plants.

As a **third valuation option**, OECD/IEA and EUROSTAT's method gives always the same value to heat, whether it is obtained from a geothermal reservoir or from burning fuels. This valuation option considers that, regardless of the particular technology and primary energy employed, heat can (at least potentially) be equally useful.

Alternatively, we can consider that the usefulness of heat depends on the type of plant to which it is being delivered. This alternative valuation option is followed by BP for all thermal renewables and for nuclear, which are all valued as the heat that would be required to obtain the same electricity but using instead a thermal power plant (with 38% efficiency).

USEIA proceeds as OECD/IEA and EUROSTAT for some of the primary energy flows (i.e. some are valued in the same way as heat from fossil fuels) but as BP for other primary energy flows (i.e. they are valued differently from heat from fossil fuels). This approach is interesting if one wishes to consider that some primary energy forms and technologies can (at least

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[10] According to Molenbroek *et al.* (2011) the approach of using a null value for renewable primary energy is suggested in the standard EN 15603:2008, *Energy performance of buildings - Overall energy use and definition of energy ratings*.

[11] Prof. Delgado Domingos kindly pointed out this reasonable possibility in 2010.

potentially) be used as efficiently as fossil fuel heat, but that other primary energies do not have such a potential. For instance, in USEIA's method geothermal energy is valued by the heat it provides (i.e. with the same value as heat from fossil fuels) but primary energy to solar concentrating power plants is valued differently (i.e. as the heat that would be required to deliver the same electricity).

A **fourth and final valuation option** regards primary energy to CHP plants. OECD/IEA and EUROSTAT's method values such primary energy in the same way as primary energy to power plants. This is an interesting option if we wish to consider that all power plants could potentially be CHP plants. The same valuation is followed by USEIA and by BP.

NL Agency chooses an alternative valuation for renewable fuels used in CHP plants: they are valued as the heat required to separately deliver the same electricity and the same heat.[12] This is an interesting option if we wish to consider that not all plants can potentially be CHP plants. These plants can be more efficient than separately delivering electricity and heat. Therefore, the renewable energy can be considered more useful when delivered to CHP plants than when delivered to power plants.

[12] This requires that a reference efficiency for heat only delivery is defined. See Annex 2 with the mathematical expressions.

4 Proposed Methods

To obtain a method that performs a valuation without the effect of changes in the electric system, we need to introduce two valuation options. To better clarify each of these options, we take a stepwise approach, and begin by introducing a **Nominal Reference Valuation** (hereafter NRV). This method has the following features:

- all primary energy flows to the electric system are valued as the heat required to deliver the amount of final heat and/or electricity obtained with such primary energy flows;
- the efficiency for calculating the heat required to deliver electricity is the nominal efficiency for fossil fuel power plants (i.e. the average efficiency of fossil fuel power plants in the same year as the year of the primary energy flow being valued);[13]
- the efficiency for delivering heat with fuels is the yearly average efficiency for delivering heat with fossil fuels.

This method presents a main difference compared to current methods: all flows to the electric system are substituted.

Thus, it performs substitutions for all renewable primary energy flows to the electric system. This includes: non-fuel non-thermal flows (as USEIA); non-fuel thermal flows (as BP); renewable fuels to power plants (as BP); and renewable fuels to CHP plants (as NL Agency).

But we also perform substitutions for all fossil fuels. This is a main valuation option not followed by current methods: in NRV method, we value all fossil fuel flows to power plants and to CHP plants as the heat required to deliver the same electricity (and the same heat in the case of CHP plants).

We now introduce the **Time Reference Valuation** (hereafter TRV), which as NRV substitutes all primary energy flows to the electric system, but uses different efficiencies:

- for all years the efficiency for calculating the heat required to deliver electricity is a fixed reference efficiency, taken as the nominal efficiency observed in a given reference year;
- for all years the efficiency for delivering heat with fuels is a fixed reference efficiency, taken as the average efficiency for delivering heat with fossil fuels observed in the given reference year.

TRV method presents a main valuation option not followed by current methods or NRV: efficiencies used for the valuation are fixed as those observed at a given reference year. Thus, besides using a fixed efficiency for valuing renewable flows (as BP), with the TRV method we also use a fixed efficiency for valuing fossil fuel flows.

[13] The choice of including nuclear power plants in the reference efficiency depends on whether one considers them as a reference technology comparable to fossil fuel power plants. We consider it is not the case, because many countries do not have nuclear power plants but have fossil fuel power plants (e.g. Portugal). For a country in which nuclear power plants are considered as a reference technology, the method can be adapted simply by including such plants in the nominal efficiency.

Table 2 summarizes the NRV and TRV methods and Annex 2 presents the mathematical expressions.

Table 2 – Proposed Primary Energy Valuation Methods

<table>
<tr><th colspan="3" rowspan="2">Primary Energy Flow</th><th colspan="2">Valuation of Primary Energy Flow</th></tr>
<tr><th>NRV</th><th>TRV</th></tr>
<tr><td rowspan="4">Fuels</td><td rowspan="2">Fossil Fuels</td><td>To Power Plants</td><td rowspan="10">Heat to deliver the electricity and (if relevant) the heat, at the nominal efficiency</td><td rowspan="10">Heat to deliver the electricity and (if relevant) the heat, at the reference efficiency</td></tr>
<tr><td>To CHP Plants</td></tr>
<tr><td rowspan="2">Renewable Fuels</td><td>To Power Plants</td></tr>
<tr><td>To CHP Plants</td></tr>
<tr><td rowspan="6">Non Fuels</td><td colspan="2">Hydraulic and Wind</td></tr>
<tr><td rowspan="2">Solar</td><td>To PV Plants</td></tr>
<tr><td>To CSP Plants</td></tr>
<tr><td colspan="2">Geothermal</td></tr>
<tr><td colspan="2">Net Electricity Import</td></tr>
<tr><td colspan="2">Nuclear</td></tr>
</table>

5 Results

5.1 Methods Applied

The current and proposed methods were applied to Portugal from 1994 to 2009. Annex 2 gives the mathematical expressions used and Annex 3 provides a numerical example of their application.

Regarding NL Agency's method, an adaptation of the method was applied, which consisted in performing only the substitutions indicated in Table 1, and in using always 90% as the reference efficiency for the separate delivery of heat with fossil fuels.

Annex 4 describes this adaptation in more detail, gives the data sources used for Portugal, and describes the implementation of the calculations.

The results are given in the following figures, which include both absolute values in tones of oil equivalent (hereafter toe) and values relative to the total primary energy.

Given that USEIA's method uses OECD/IEA and EUROSTAT's valuation for some energy flows and NL Agency's valuation for others, we refrain from presenting this method in the figures, to improve their legibility.

5.2 Absolute Values

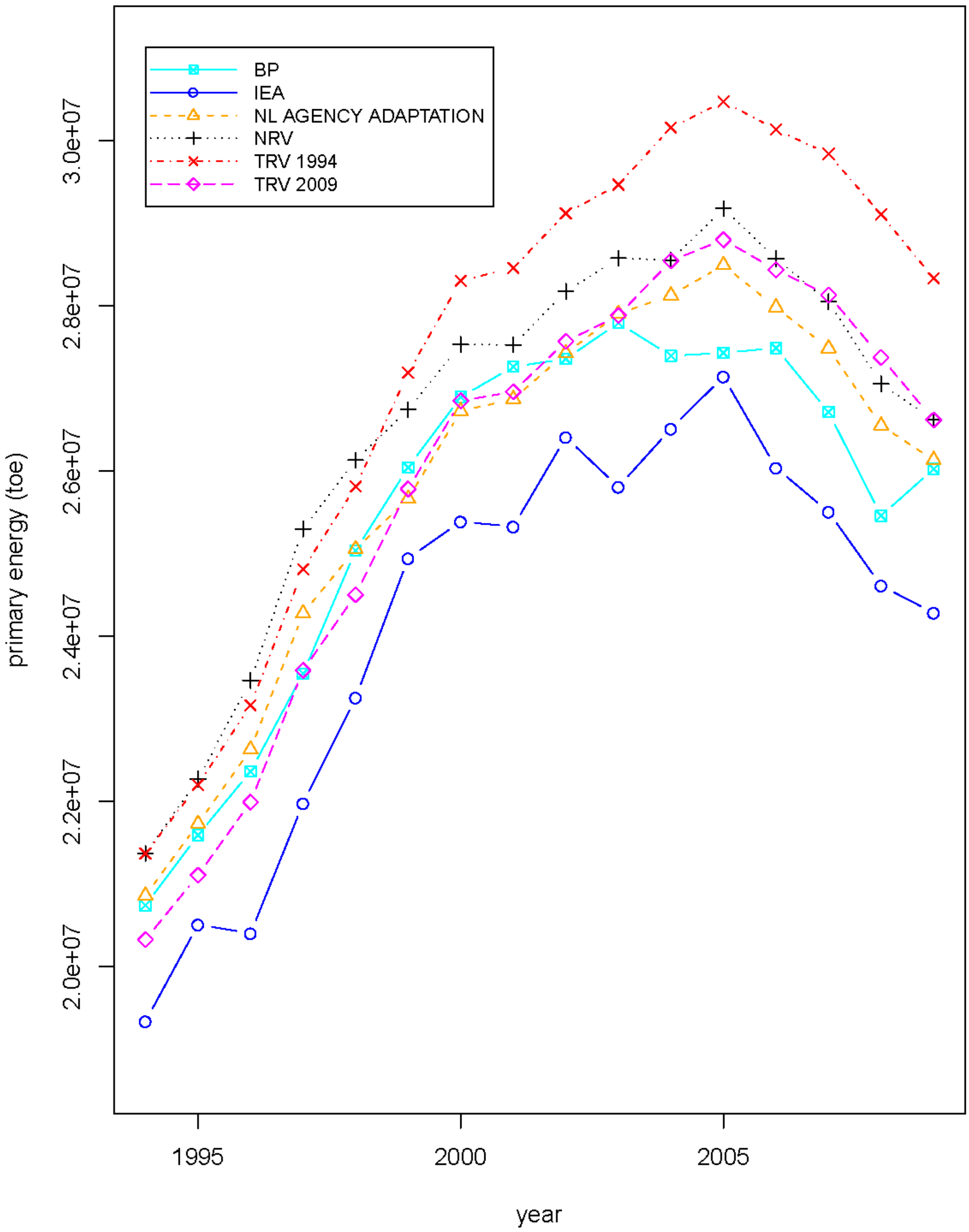

Figure 3 – Total Primary Energy

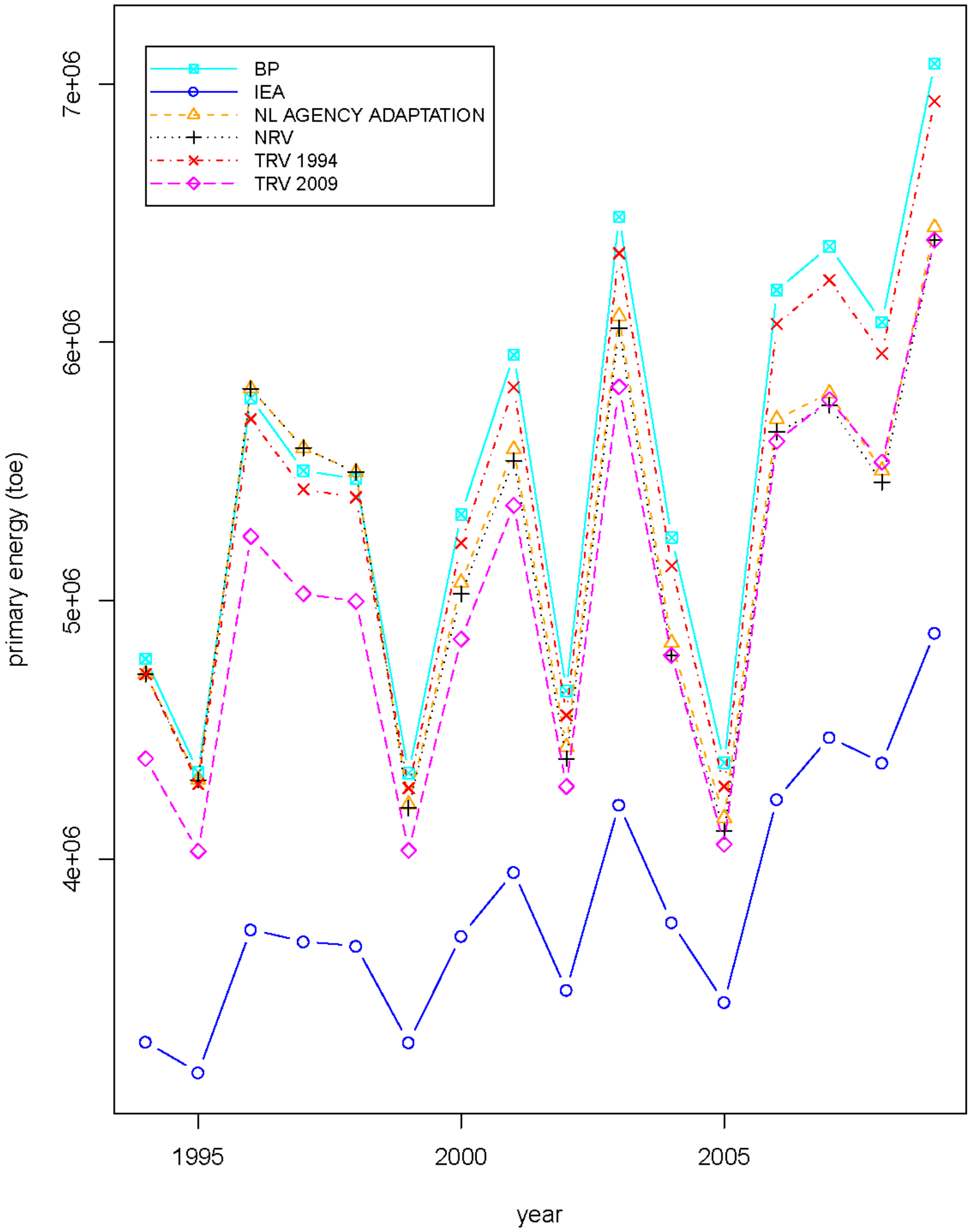

Figure 4 – Renewable Primary Energy

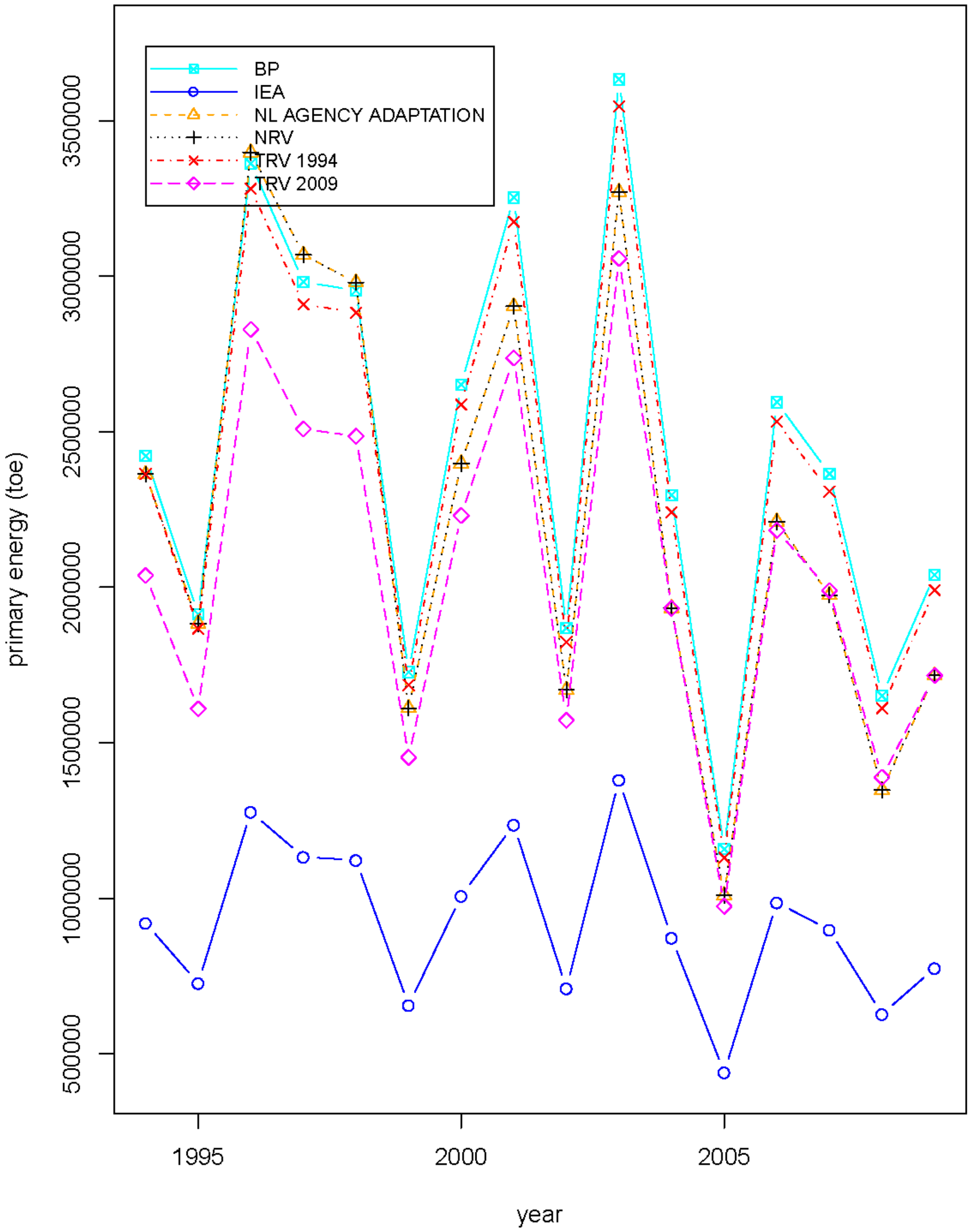

Figure 5 – Hydraulic Primary Energy

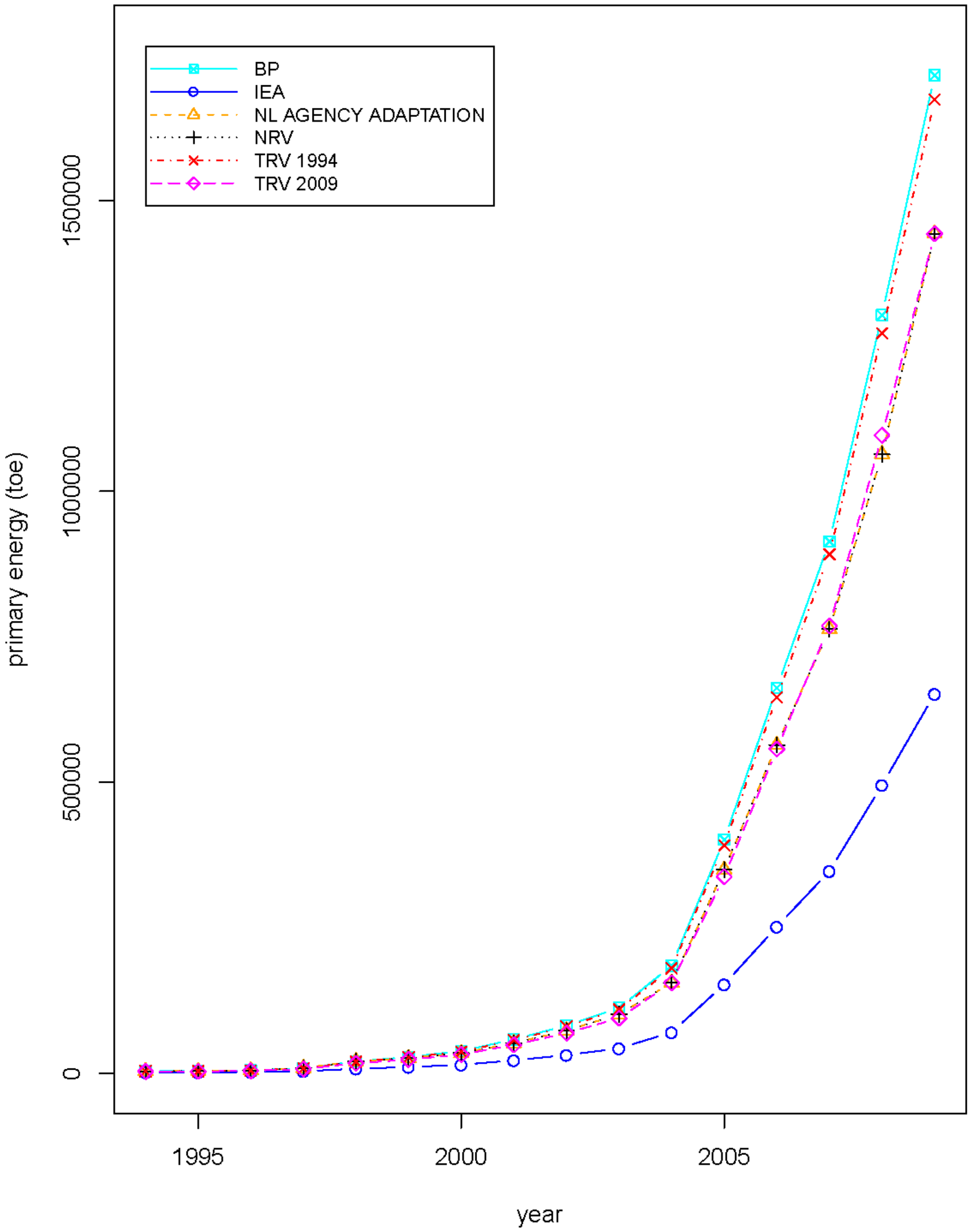

Figure 6 – Wind Primary Energy

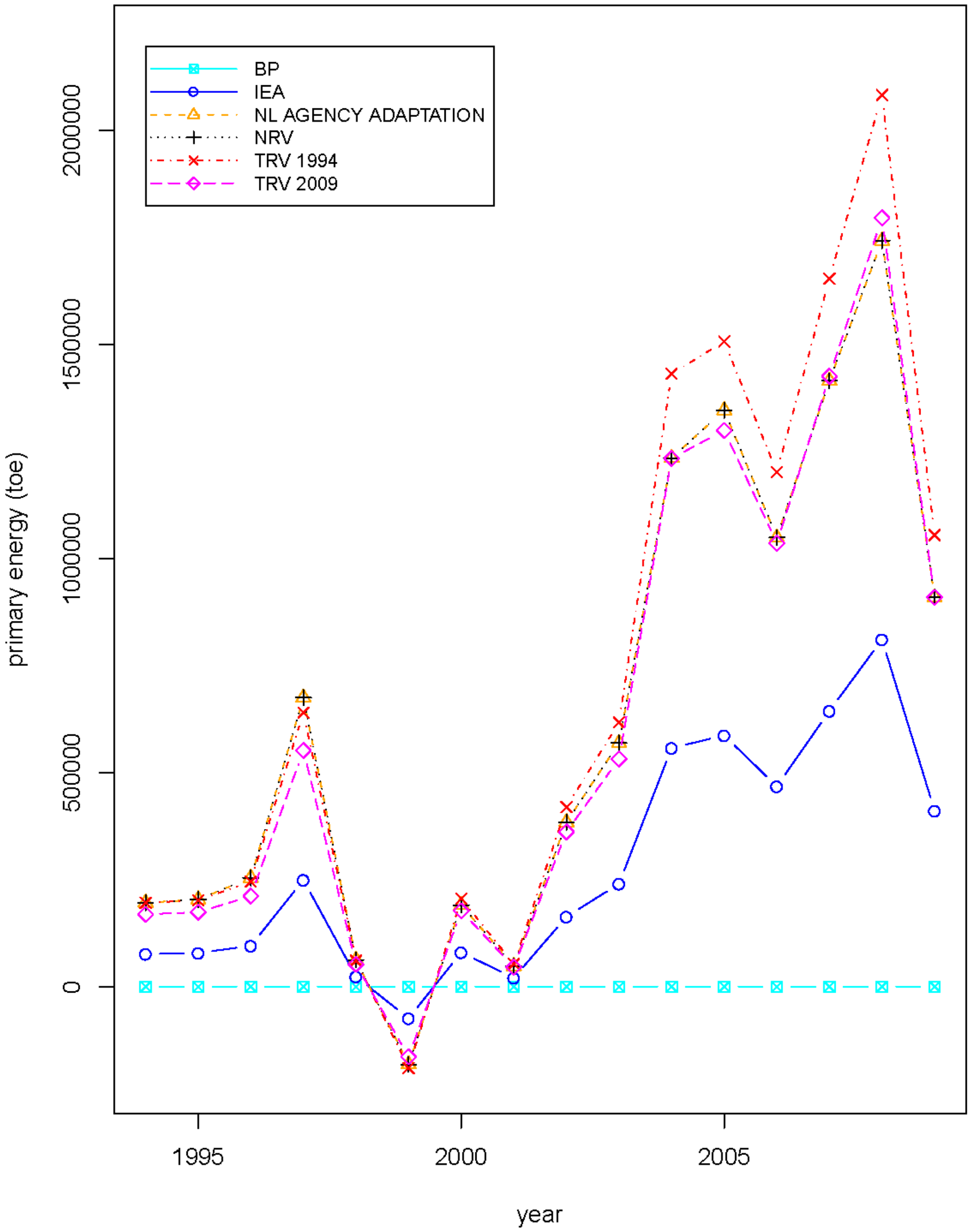

Figure 7 – Net Electricity Imports Primary Energy

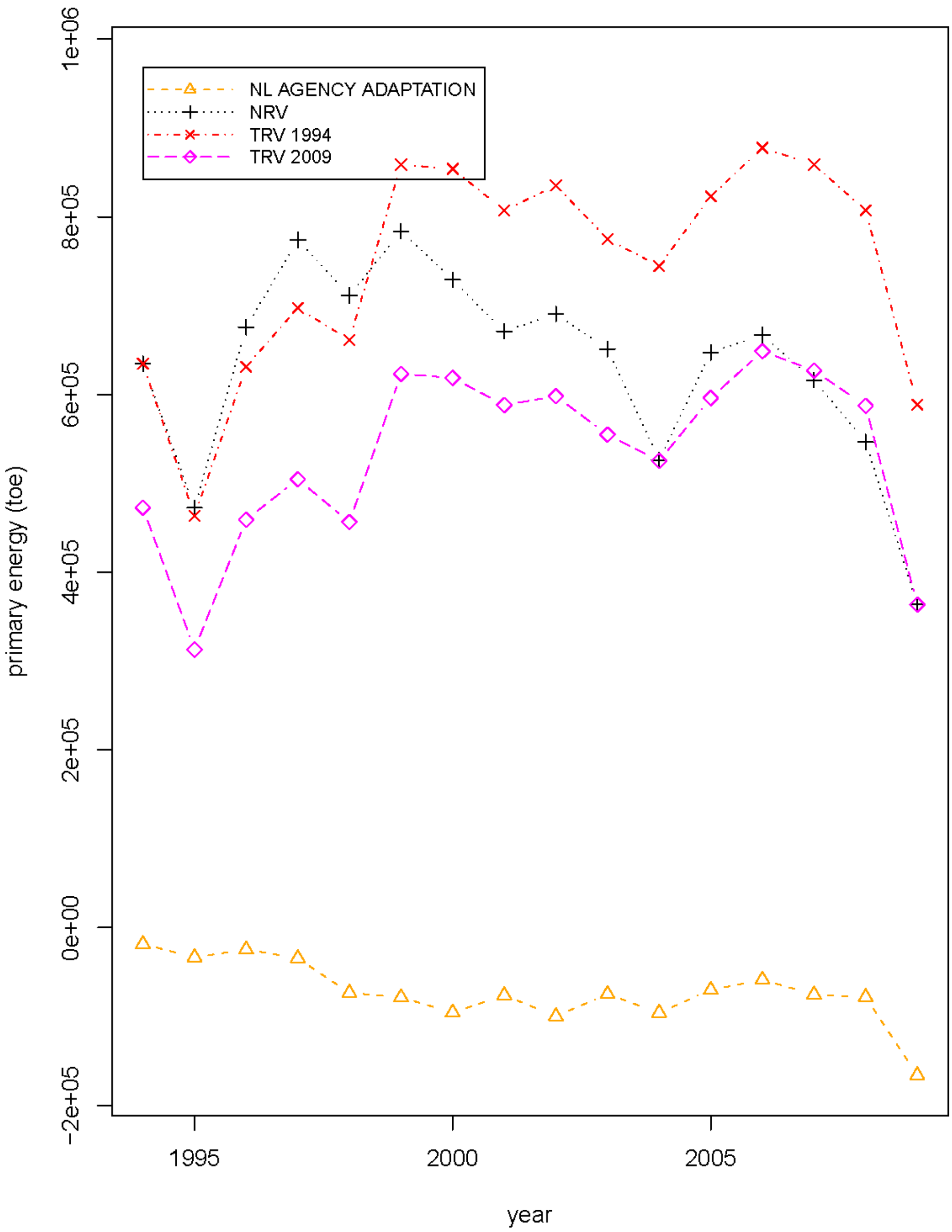

Figure 8 – Primary Energy Savings from CHP

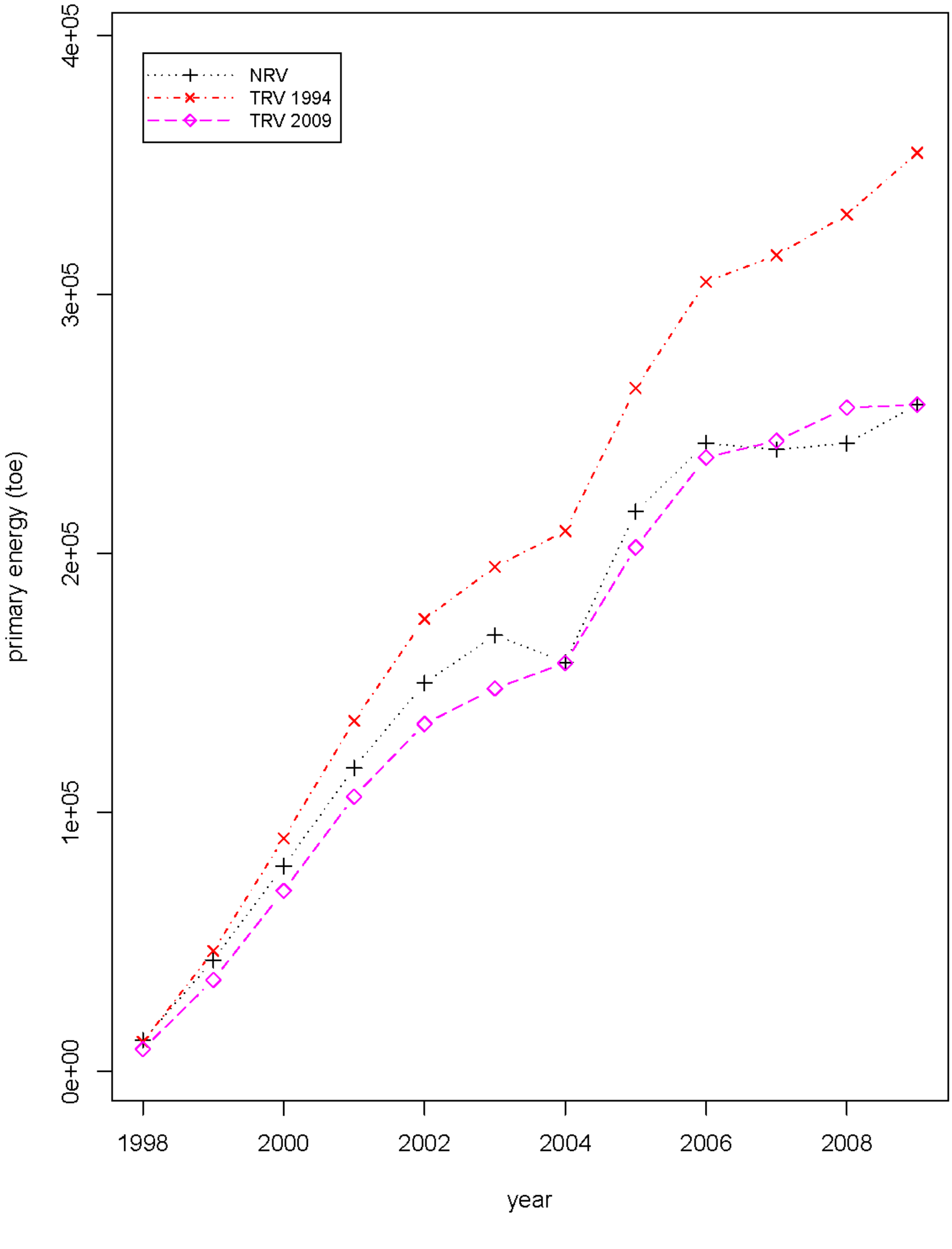

Figure 9 – Primary Energy Savings from Natural Gas CHP

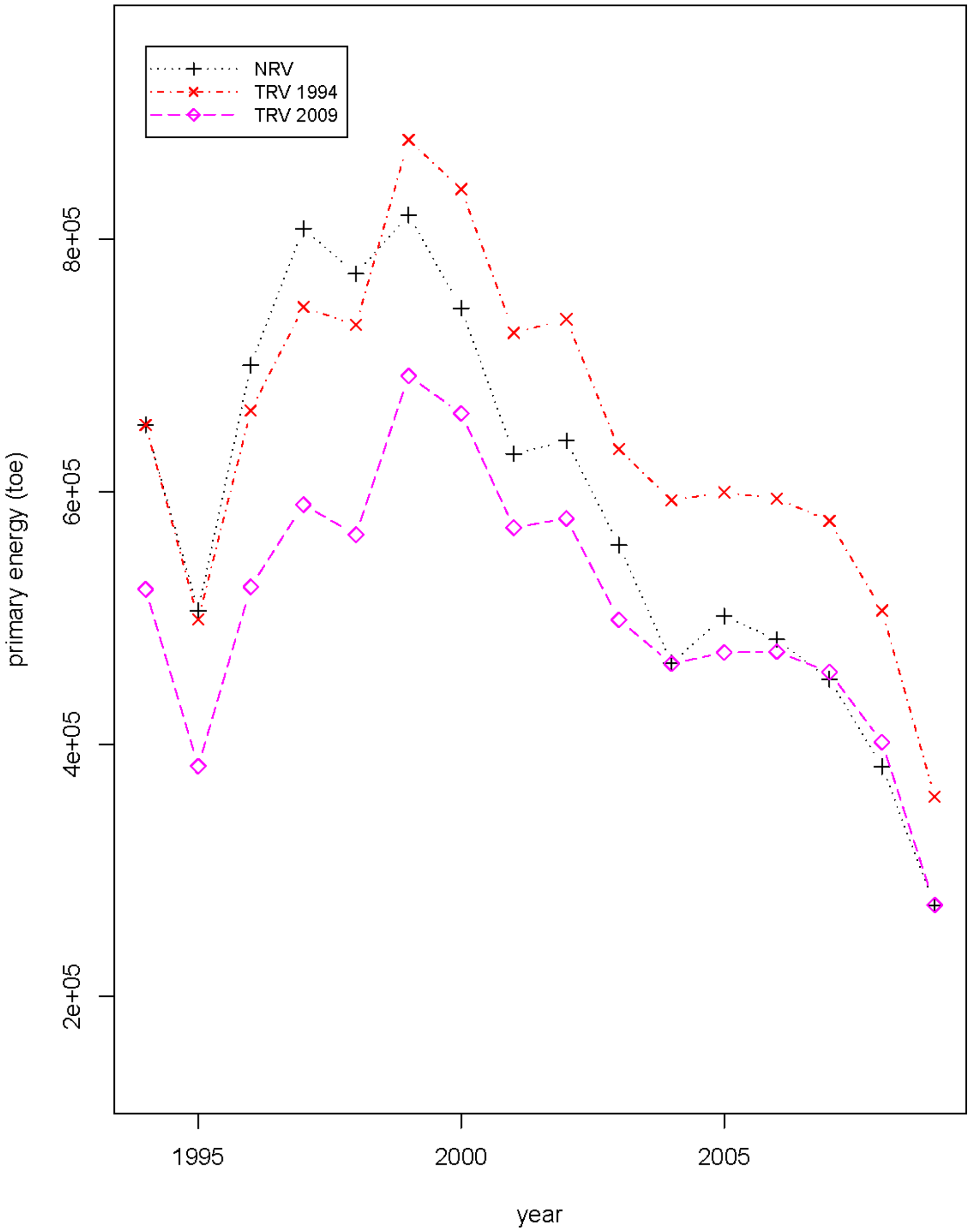

Figure 10 – Primary Energy Savings from Fuel Oil CHP

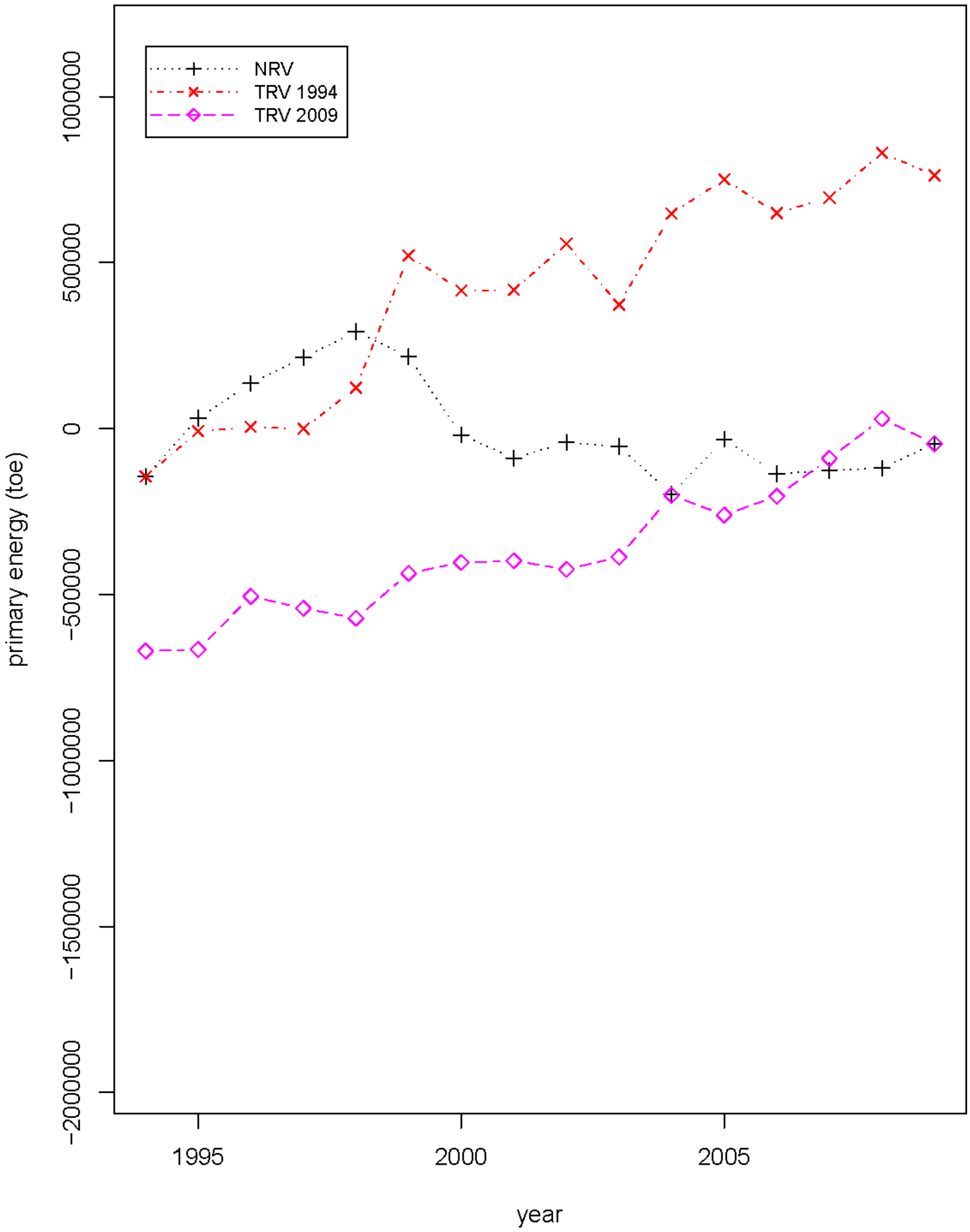

Figure 11 – Primary Energy Savings from Fossil Fuel Power Plants

5.3 Relative Values

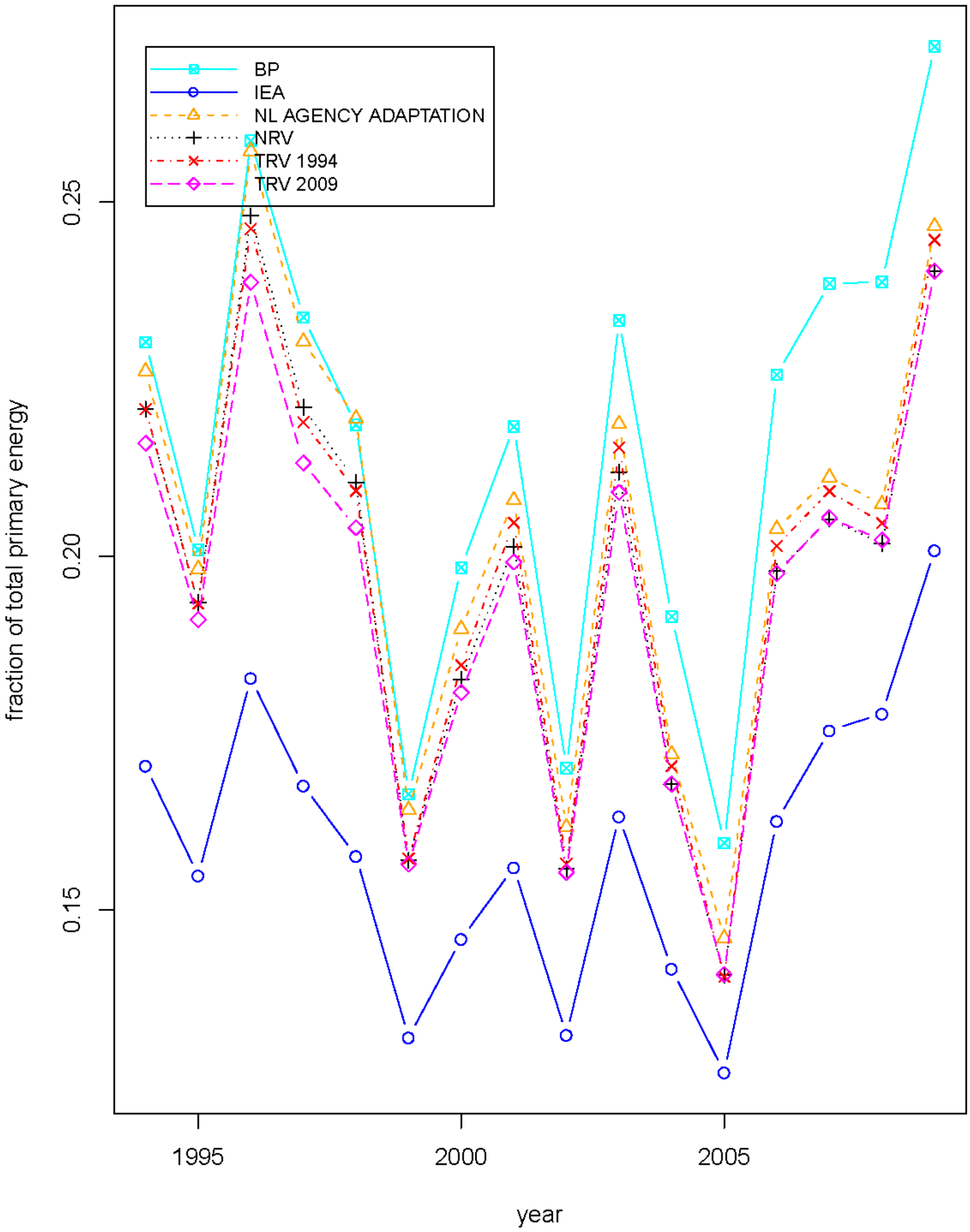

Figure 12 – Proportion of Renewable Primary Energy

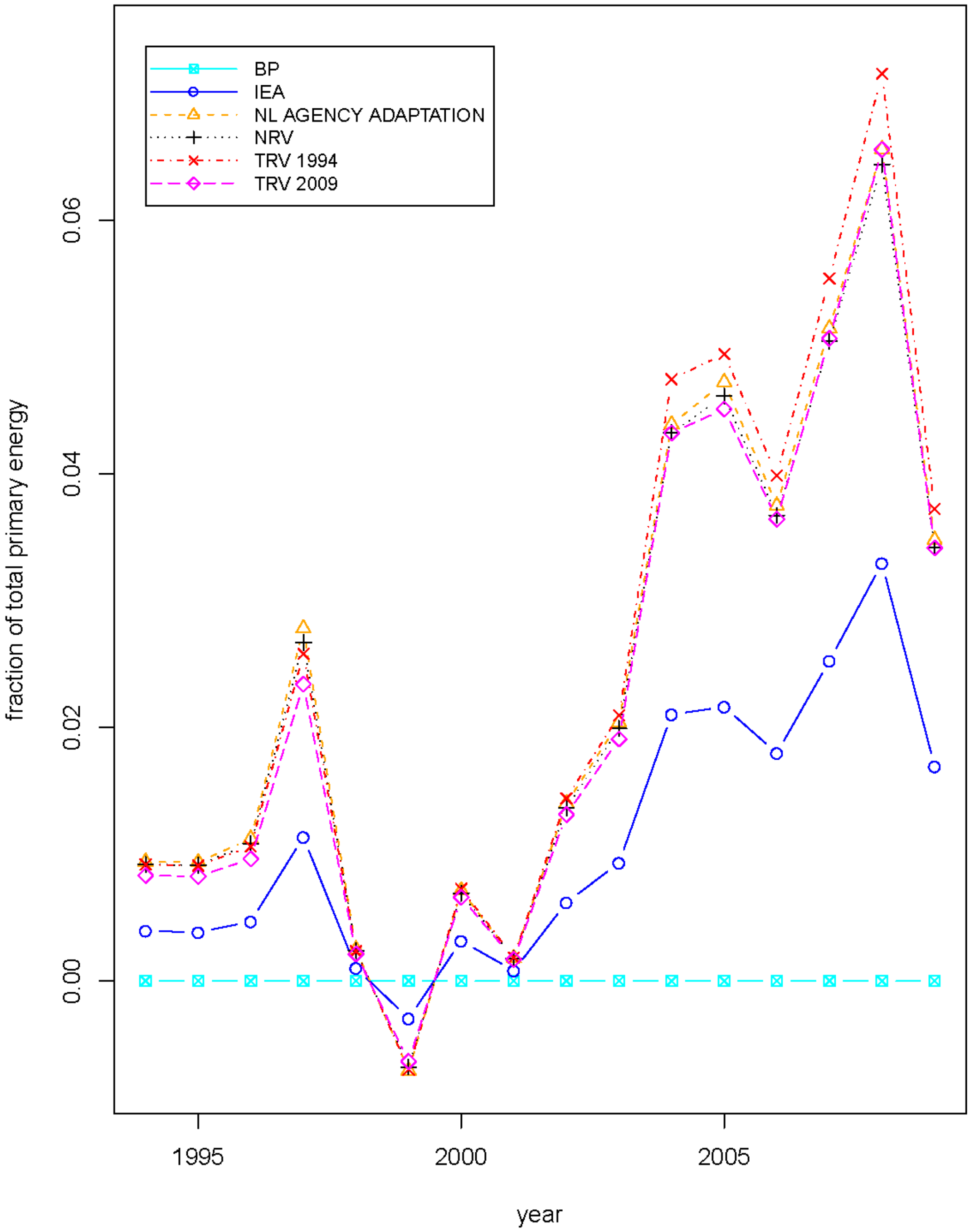

Figure 13 – Proportion of Net Electricity Imports Primary Energy

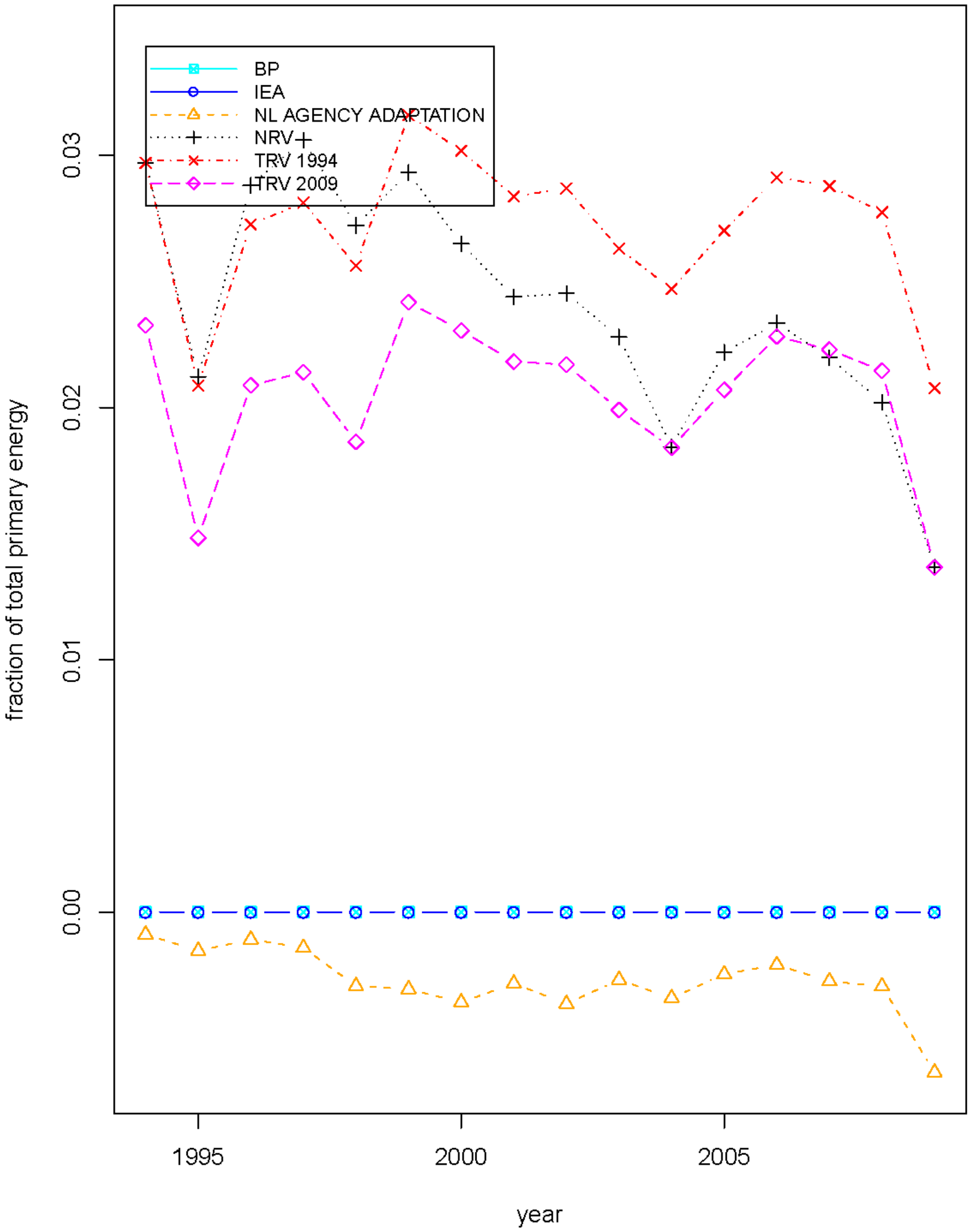

Figure 14 – Proportion of CHP Primary Energy Savings

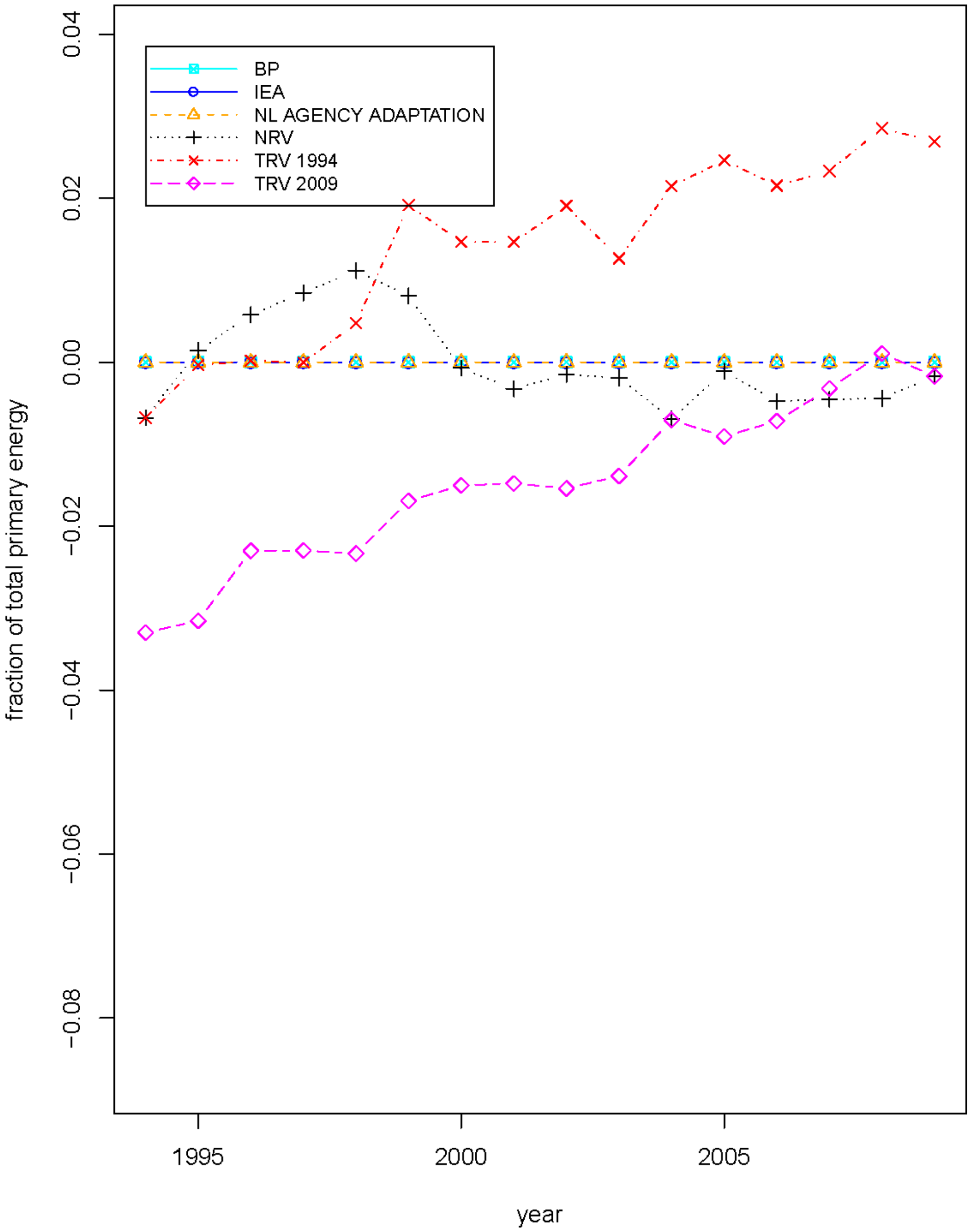

Figure 15 – Proportion of Fossil Fuel Power Plant Primary Energy Savings

6 Discussion

Total primary energy valued with OECD/IEA's method is lower than with any other method (Figure 3). From 2005 to 2009, OECD/IEA's method gives a decrease in total primary energy. With this valuation method, we are unaware if this decrease is due to the electric system or not. We can use TRV 1994 and TRV 2009 methods, which value primary energy with a fixed reference electric system, to realize that the 2005 to 2009 decrease in primary energy also occurs. This means that when we remove the trend associated with the electric system, we observe that the remaining trend is of decreasing energy use.

Renewable primary energy is valued lowest by OECD/IEA's method (Figure 4). Until 2006, the variations in renewable primary energy follow the variations in hydro contribution (Figure 5). Since 2007, the renewable primary energy (Figure 4) varies also due to the increase in the contribution from wind energy (Figure 6). For methods other than OECD/IEA's the variations due to hydro energy are greater than differences in values due to different methods (Figure 5). This illustrates how the variability in the contribution from hydro energy has an important impact in the Portuguese energy system.

Wind energy is more stable than hydro energy and thus it can contribute to stabilize the renewable energy contribution.[14] It may be interesting to observe if in future years the contribution of renewable energy becomes more stable when compared to the past (Figure 4).

Net electricity imports in all methods are higher in recent years, e.g. 2004-2009 when compared to 1994-2003 (Figure 7). The magnitude of the values is comparable to that of, for example, wind energy in recent years (Figure 6). This means that for the Portuguese case accounting for electricity imports and export is as important as accounting for wind energy.

The fact that BP's method doesn't account for traded electricity makes this method less appropriate for the Portuguese case, because of the importance of net electricity imports in this country. For instance, from 2008 to 2009 there is a large decrease in net electricity import which is not accounted for in BP's method (Figure 7). Thus, for total primary energy, BP's method shows an increase from 2008 to 2009 when other methods show a decrease (Figure 3).

Savings from CHP (Figure 8) using NL Agency are slightly negative, which is a result that should be confirmed using more detailed data.[15] When also fossil fuel CHP is accounted for, using the proposed TRV method, the total savings from CHP plants are positive but exhibit a decreasing trend since 2006 (Figure 8).

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[14] For example, from DGEG (2011) the average equivalent production hours from year 2000 to 2010 vary between 2066h and 2470h for wind energy, and between 983h and 3973 for hydro.

[15] In the Portuguese energy balance, the electricity and useful heat obtained from CHP plants is not available for each fuel. It was estimated using mainly IEA data (see Annex 4). It would be important to have more detailed data from DGEG in order to confirm the results obtained for renewable CHP savings.

CHP savings are achieved using mainly two fuels: natural gas and fuel oil. CHP savings using natural gas show a growth trend since this fuel was introduced in 1998 (Figure 9). CHP savings using fuel oil show a decrease trend since natural gas was introduced (Figure 10).

Savings due to the increase in the efficiency of fossil fuel power plants show an increasing trend using the proposed TRV method (Figure 11). Using 1994 as a reference year, the magnitude of the savings is above that of the total savings obtained using CHP (Figure 8).

The **proportion** of renewable primary energy is quite lower in OECD/IEA's method (Figure 12), a result which reproduces what is found in the literature. Here we have given also the proportion of net electricity imports, which for the Portuguese case are quite significant (Figure 13). With the use of the TRV method, we also present the proportion of savings from CHP (renewable and fossil) (Figure 14), and the savings from increasing the efficiency of fossil fuel power plants (Figure 15). These are two ways of saving fossil fuels which can also be impacted by energy policies.

To finalize, we focus on the **most recent year analyzed, 2009, and use the TRV method with 1994 as reference year** to compare the difference contributions to primary energy.

Renewable energy represents 24% of total primary energy (Figure 12). Net electricity imports represent 4% of total primary energy (Figure 13). Savings from CHP plants contribute with 2% of total primary energy (Figure 14). Savings from increases in the efficiency of fossil fuel power plants since 1994 contribute with 3% of total primary energy (Figure 15).

Therefore, in 2009, using the TRV 1994 method, the contribution of primary energy due to renewables is six times the contribution of net electricity imports. The proportion of savings from fossil fuel power plant efficiency increases since 1994 is less than the contribution of net electricity imports. Finally, the contribution from savings due to CHP plants (using renewables and fossil fuels) is less than the contribution from savings due to efficiency increases in fossil fuel power plants since 1994.

7 Conclusion

A first conclusion of the work here presented is that, by examining current methods used in energy statistics to calculate primary energy, we conclude that all methods perform substitutions. For example, in OECD/IEA and EUROSTAT's method the primary energy flow to hydropower plants is substituted with the heat obtainable from the electricity delivered by the hydropower plants. This substitution is neither more nor less hypothetical than other substitutions. But it is different, and it corresponds to a different implicit valuation criteria.

We examined the existing methods from this perspective, naming them primary energy valuation methods, in order to clarify that the actual primary energy flow is not necessarily used. We concluded that the different valuation criteria are: whether to consider that the main use of electricity is heat; whether to consider that the value of heat is different for different technologies; and whether to consider or not that all plants can potentially be CHP plants.

We have also introduced a primary energy valuation method: the Time Reference Valuation (TRV). This method references the electric system to a given year's fossil fuel power plant efficiency, without Combined Heat and Power (CHP).

One interest of this particular method is that it can be used to remove the trend from changing electric systems (as the Portuguese), in order to uncover the remaining trend of energy use.

By referencing the electric system to a base year, the TRV method also has the interest of establishing a baseline against which changes in the electric system can be measured. This baseline can be used to measure the proportion of renewable energy and net electricity imports in total primary energy. But because it has fixed power plant efficiency and no CHP, it can also be used to measure the proportion of primary energy saved by changes in power plant efficiency and by changes in CHP use. These contributions can also save fossil fuels and are also influenced by energy policy.

We applied the different methods to Portugal for 1994 to 2009. With the TRV method, the primary energy decrease from 2005 to 2009 also occurs, meaning that even when one removes the trend of the electric system there is a trend of decreasing energy use. For 2009, the renewable energy is the largest contribution to primary energy, followed by net electricity imports, then by savings from efficiency increases in fossil fuel power plants since 1994, and finally by savings from CHP plants

The proposed TRV method is one valuation option with its specific valuation criteria. It does not replace the existing methods, such as OECD/IEA's. A method will not fit any purpose, and may be more or less adequate depending on how the valuation criteria fit the purpose. The TRV method can be useful when there is a purpose of (i) establishing a baseline to assess savings from various changes in the electric system or (ii) removing the trend due to the electric system changes, in order to examine the remaining trend in energy use.

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Annex 1 – Review of Definitions

Energy Consumption and Production

From the first law of thermodynamics it follows that energy is a conserved quantity. Therefore, in a strict sense, energy is neither produced nor consumed, but it can be transferred through a variety of modes (e.g. heat, mechanical work and electrical work). Energy flows are defined as energy transfers per unit of time.

Although energy is a conserved quantity, from the second law of thermodynamics it follows that in any process entropy must increase. This constrains the energy flows so that work flows can be fully transformed to heat flows, but heat flows cannot be fully transformed to work flows.

Consider the example of a thermal power plant. We implicitly consider:

- a system (the power plant);
- valuable input energy flows (the fuel);
- valuable output energy flows (the electricity);
- other input energy flows (e.g. the air for the combustion)
- other output energy flows (e.g. heat dissipated for cooling)

"Energy consumption" and "energy use" are commonly used to refer to the valuable input flow (the fuel). "Energy production", "energy supply" and "energy delivery" are commonly used to refer to the valuable output flow (electricity).[16]

In this work the expressions "energy use" and "energy delivery" are preferred, simply to avoid mentioning energy as a consumed or produced quantity.

[16] For example, OECD/IEA uses both energy "consumption" and energy "use" (OECD/IEA, 2005, pp. 27, 30), as well as energy "production", "supply" and "delivery" (OECD/IEA, 2005, pp. 22, 147)

Final and Primary Energy

Final energy is usually defined as energy purchased for own use[17] and primary energy is usually defined as energy extracted from the environment.[18]

However, these definitions do not always account for all flows that are considered final energy or as primary energy. For example, in the Portuguese Energy Balances, imported gasoil is considered primary energy (although it is not obtained from the environment) and heat from CHP plants is considered final energy (although it is not necessarily purchased).[19]

To introduce alternative definitions that account for these flows, consider the systems depicted in Figure 16, in which we divide each economy in an energy system and a final system.

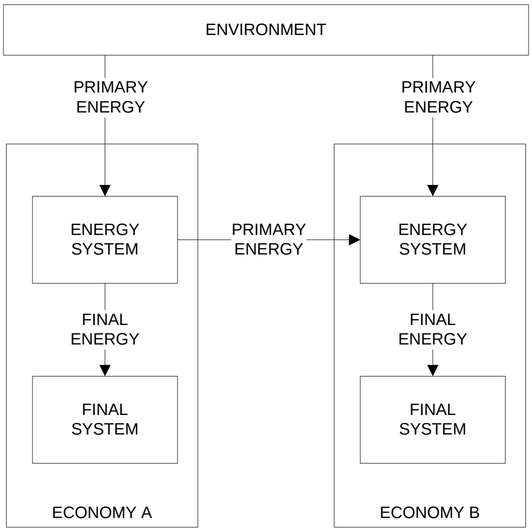

Figure 16 – Systems for Alternative Definitions of Primary Energy and Final Energy

We can define the primary energy of an economy as energy taken from the environment or from other economies' energy systems. For the Portuguese case, we thus account for imported gasoil as primary energy (because it is taken from other economies' energy systems).

We can define the final energy of an economy as energy delivered by its energy system to its final system. For the Portuguese case, we thus account for heat from CHP plants as final energy even if it is not sold (because we consider CHP plants to be part of the energy system).

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[17] For example, Directive 2006/32/EC of the European Parliament and of the Council, of 5 April 2006, defines a "final [energy] customer" as "a natural or legal person that purchases energy for his own end use" (Article 3, n). Other definitions are used, e.g. OECD/IEA (2005, p. 20) defines "final use" as disappearance from energy statistics.

[18] For example, OECD/IEA (2005, p. 18) defines primary energy as "captured directly from natural resources". Other definitions are used, e.g. USEIA (2010, p. 402) defines primary energy as the first form accounted for in a statistical energy balance before any transformation. BP (2011. p. 40) defines primary energy as commercially traded fuels and modern renewables used to deliver electricity.

[19] For another example, see OECD/IEA (2010b, pp. 38), in which the "Total Primary Energy Supply" includes imported oil products, which is not extracted from the environment.

Energy Balance

In country energy statistics, the energy balance is usually defined as an accounting of fuel, heat and electricity flows.[20] The use of this definition has two implicit approaches.

The first implicit approach of the "energy balance" is that only tradable flows are accounted. An economy uses energy flows other than fuels, heat or electricity (e.g. solar radiation is used for photosynthesis in agriculture), but such flows are generally not tradable. Fuels and electricity are generally tradable. Heat flows can be tradable or not. For example, heat delivered to homes by district heating systems is tradable, but heat delivered to homes by solar radiation is not tradable (and thus not included in the energy balance).

The second implicit approach is that the "energy balance" actually includes more data than the balance for the economy as a whole. Balances for subsystems are also presented, e.g. for thermal power plants. Therefore, the "energy balance" presents not only the energy flows of the economy as a whole but also energy flows within the economy.

The expression "energy balance" has wide usage.[21] To follow the literature, it is also used in this work, bearing in mind that we implicitly adopt the two above mentioned approaches.

[20] For example, OECD/IEA (2005, pp. 17, 30 and 135) defines an energy balance to be the presentation of data for fuels, heat and power, analogous to a cash account and expressed in energy units.

[21] Several reference publications actually include "energy balance" in their title, e.g. OECD/IEA (2009b), "Energy Balances of OECD Countries - 2009 Edition", and EUROSTAT (2011), "Energy Balance Sheets 2008-2009 – 2011 Edition".

Annex 2 – Mathematical Expressions

Primary Energy Valuation

An expression to apply a generic primary energy valuation method can be written as:

$$PEV_{mt} = \sum_{j} W_{tj}^{(P)} \alpha_{mtj}^{(P)} + W_{tj}^{(CHP)} \alpha_{mtj}^{(CHP)} + U_{tj}^{(CHP)} \beta_{mtj}^{(CHP)} + Q_{tj}^{(H)} + W_{t}^{(I)} \gamma_{mt}^{(I)} \tag{2}$$

Where

- m identifies the method;
- t identifies the year;
- PEV_{mt} is the Primary Energy Valuation (PEV) using method m at year t;
- j identifies the primary energy flow;
- $W_{tj}^{(P)}$is the electricity from Power (P) plants at year t using flow j;
- $\alpha_{mtj}^{(P)}$is the valuation factor for method m for electricity from Power (P) plants at year t using flow j;
- $W_{tj}^{(CHP)}$is the electricity from Combined Heat and Power (CHP) plants at year t using flow j;
- $\alpha_{mtj}^{(CHP)}$is the valuation factor for method m for electricity from CHP plants at year t using flow j;
- $U_{tj}^{(CHP)}$is the useful heat from CHP plants at year t using flow j;
- $\beta_{mtj}^{(CHP)}$is the valuation factor for method m for heat from CHP plants at year t using flow j;
- $Q_{tj}^{(H)}$is the heat obtainable from flows not used in power plants or in CHP plants;
- $W_{t}^{(I)}$is the net electricity import at year t;
- $\gamma_{mt}^{(I)}$is the valuation factor for net electricity Import for method m at year t;

Flow Primary Energy Valuation

For a given primary energy flow we can write

$$PEV_{mtj} = W_{tj}^{(P)}\alpha_{mtj}^{(P)} + W_{tj}^{(CHP)}\alpha_{mtj}^{(CHP)} + U_{tj}^{(CHP)}\beta_{mtj}^{(CHP)} + Q_{tj}^{(H)} \quad (3)$$

where

- PEV_{mtj} is the flow primary energy valuation using method m at year t for flow j;
- other symbols have the same meaning as above;

and thus

$$PEV_{mt} = \sum_{j} PEV_{mtj} + W_{t}^{(I)}\gamma_{mt}^{(I)} \quad (4)$$

Efficiencies

For thermal power plants, we write

$$\eta_{tj}^{(P)} = \frac{W_{tj}^{(P)}}{Q_{tj}^{(P)}} \quad (5)$$

where

- $\eta_{tj}^{(P)}$ is the (electric) efficiency of thermal power plants at year t using flow j;
- $W_{tj}^{(P)}$ is the electricity from thermal power plants at year t using flow j;
- $Q_{tj}^{(P)}$ is the heat input to thermal power plants at year t using flow j.

We write the nominal efficiency of fossil fuel power plants as

$$\eta_{nom,t}^{(f)} = \frac{\sum_j W_{tj}^{(P)}}{\sum_j Q_{tj}^{(P)}} \quad (6)$$

where j includes only flows used in fossil fuel power plants.

We write the nominal efficiency of fossil fuel and nuclear power plants as

$$\eta_{nom,t}^{(f+n)} = \frac{\sum_j W_{tj}^{(P)}}{\sum_j Q_{tj}^{(P)}} \quad (7)$$

where j includes only flows used in fossil fuel power plants and in nuclear power plants.

For CHP plants, we write:

$$\eta_{tj}^{(CHP)} = \frac{W_{tj}^{(CHP)}}{Q_{tj}^{(CHP)}} \quad (8)$$

- $\eta_{tj}^{(CHP)}$ is the electric efficiency of CHP plants at year t using flow j;
- $W_{tj}^{(CHP)}$is the electricity from CHP plants at year t using flow j;

- $Q_{tj}^{(CHP)}$ is the heat input to CHP plants at year t using flow j;

and

$$\mu_{tj}^{(CHP)} = \frac{U_{tj}^{(CHP)}}{Q_{tj}^{(CHP)}} \tag{9}$$

where

- $\mu_{tj}^{(CHP)}$ is the heat efficiency of CHP plants at year t using flow j;
- $U_{tj}^{(CHP)}$is the useful heat from CHP plants at year t using flow j;
- $Q_{tj}^{(CHP)}$ is the heat input to CHP plants at year t using flow j.

We use $\mu_{nom,t}^{(H)}$ to denote the nominal efficiency for delivering final heat by burning fossil fuels.

Valuation Factors

To provide the valuation factors, we first define certain values used in the different valuation methods.

The electric efficiency for valuation purposes with BP's method is:

$$\eta_{BP} = 38\% \tag{10}$$

For TRV method, we take

$$\eta_{ref}^{(f)} = \eta_{nom,r}^{(f)} \tag{11}$$

Where r is the reference year.

As an electric efficiency for valuation purposes, other methods use either $\eta_{nom,t}^{(f)}$ (USEIA and NRV methods) or $\eta_{nom,t}^{(f+n)}$ (NL Agency method).

For the heat efficiency for valuation purposes, with TRV method the value is fixed as the value observed at the reference year

$$\mu_{ref}^{(H)} = \mu_{nom,r}^{(H)} \tag{12}$$

where again r is the reference year

For the heat efficiency for valuation purposes, other methods (NL Agency and NRV) use the nominal efficiency for heat only delivery $\mu_{nom,t}^{(H)}$.

With these definitions, we give the valuation factors for the current and proposed methods in Table 1.

Table 3 – Valuation Factors for Current and Proposed Methods

<table>
<tr><th colspan="3" rowspan="2">Primary Energy Flow</th><th rowspan="2">Valuation Factor</th><th colspan="6">Expression for the Valuation Factor</th></tr>
<tr><th>IEA</th><th>USEIA</th><th>BP</th><th>NL Agency</th><th>NRV</th><th>TRV</th></tr>
<tr><td rowspan="6">Fuels</td><td rowspan="3">Fossil Fuels</td><td>To Power Plants</td><td>$\alpha_{mtj}^{(P)}$</td><td colspan="4">$1/\eta_{tj}^{(P)}$</td><td rowspan="2">$1/\eta_{nom,t}^{(f)}$</td><td rowspan="2">$1/\eta_{ref}^{(f)}$</td></tr>
<tr><td rowspan="2">To CHP[a] Plants</td><td>$\alpha_{mtj}^{(CHP)}$</td><td colspan="4">$1/\eta_{tj}^{(CHP)}$</td></tr>
<tr><td>$\beta_{mtj}^{(CHP)}$</td><td colspan="4">0</td><td>$1/\mu_{nom,t}^{(H)}$</td><td>$1/\mu_{ref}^{(H)}$</td></tr>
<tr><td rowspan="3">Renewable Fuels</td><td>To Power Plants</td><td>$\alpha_{mtj}^{(P)}$</td><td colspan="2">$1/\eta_{tj}^{(P)}$</td><td>$1/\eta_{BP}$</td><td rowspan="2">$1/\eta_{nom,t}^{(f+n)}$</td><td rowspan="2">$1/\eta_{nom,t}^{(f)}$</td><td rowspan="2">$1/\eta_{ref}^{(f)}$</td></tr>
<tr><td rowspan="2">To CHP[a] Plants</td><td>$\alpha_{mtj}^{(CHP)}$</td><td colspan="3">$1/\eta_{tj}^{(CHP)}$</td></tr>
<tr><td>$\beta_{mtj}^{(CHP)}$</td><td colspan="3">0</td><td>$1/\mu_{nom,t}^{(H)}$</td><td>$1/\mu_{nom,t}^{(H)}$</td><td>$1/\mu_{ref}^{(H)}$</td></tr>
<tr><td rowspan="6">Non Fuels</td><td colspan="2">Hydraulic and Wind</td><td rowspan="4">$\alpha_{mtj}^{(P)}$</td><td rowspan="2">1</td><td rowspan="3">$1/\eta_{nom,t}^{(f)}$</td><td rowspan="4">$1/\eta_{BP}$</td><td rowspan="5">$1/\eta_{nom,t}^{(f+n)}$</td><td rowspan="6">$1/\eta_{nom,t}^{(f)}$</td><td rowspan="6">$1/\eta_{ref}^{(f)}$</td></tr>
<tr><td rowspan="2">Solar</td><td>To PV Plants</td></tr>
<tr><td>To CSP Plants</td><td>$1/\eta_{tj}^{(P)}$</td></tr>
<tr><td colspan="2">Geothermal</td><td colspan="2">$1/\eta_{tj}^{(P)}$</td></tr>
<tr><td colspan="2">Net Electricity Import</td><td>$\gamma_{mt}^{(I)}$</td><td colspan="2">1</td><td>0</td></tr>
<tr><td colspan="2">Nuclear</td><td>$\alpha_{mtj}^{(P)}$</td><td colspan="2">$1/\eta_{tj}^{(P)}$</td><td>$1/\eta_{BP}$</td><td>$1/\eta_{tj}^{(P)}$</td></tr>
</table>

Savings from CHP Plants

Three methods value electricity and heat from CHP plants as the heat required to deliver such heat and electricity without CHP plants: NL Agency (renewable energy only), NRV (both fossil and renewable energy) and TRV (both fossil and renewable energy).

We can define the primary energy valuation for CHP plants using flow j as:

$$PEV_{mtj}^{(CHP)} = W_{tj}^{(CHP)}\alpha_{mtj}^{(CHP)} + U_{tj}^{(CHP)}\beta_{mtj}^{(CHP)} \tag{13}$$

For simplicity, let us define the valuation efficiency for power only and for heat only as respectively η_{mt} and μ_{mt}. These take the value appropriate for each method (Table 4).

Valuation Efficiency	NL Agency	NRV	TRV
η_{mt}	$\eta_{nom,t}^{(f+n)}$	$\eta_{nom,t}^{(f)}$	$\eta_{ref}^{(f)}$
μ_{mt}	$\mu_{nom,t}^{(H)}$	$\mu_{nom,t}^{(H)}$	$\mu_{ref}^{(H)}$

Table 4 – Valuation Efficiencies for Calculating Savings

Then, for these methods, the primary energy valuation for CHP plants using a flow j is:

$$PEV_{mtj}^{(CHP)} = W_{tj}^{(CHP)}\frac{1}{\eta_{mt}} + U_{tj}^{(CHP)}\frac{1}{\mu_{mt}} \tag{14}$$

From equation (8), the heat input to CHP plants using flow j at year t can be written as:

$$Q_{tj}^{(CHP)} = W_{tj}^{(CHP)} \cdot \frac{1}{\eta_{tj}^{(CHP)}} \tag{15}$$

The savings from CHP, $S_{mtj}^{(CHP)}$, can be written as the difference between the valuation of the flow and the heat input:

$$S_{mtj}^{(CHP)} = PEV_{mtj}^{(CHP)} - Q_{tj}^{(CHP)} \tag{16}$$

$$S_{mtj}^{(CHP)} = W_{tj}^{(CHP)}\left(\frac{1}{\eta_{mt}} - \frac{1}{\eta_{tj}^{(CHP)}}\right) + U_{tj}^{(CHP)}\frac{1}{\mu_{mt}} \tag{17}$$

Savings from Fossil Fuel Power Plants

Two methods value electricity from fossil fuel power plants as the heat required to deliver such electricity: NRV and TRV.

We can define the primary energy valuation for fossil fuel power plants as:

$$PEV_{mtj}^{(P)} = W_{tj}^{(P)} \alpha_{mtj}^{(P)} \tag{18}$$

where the flow j is a fossil fuel flow. Taking the reference efficiencies as defined in Table 4, we can write the valuation of these two methods as:

$$PEV_{mtj}^{(P)} = W_{tj}^{(P)} \frac{1}{\eta_{mt}} \tag{19}$$

From equation (5), the heat input to fossil fuel power plants using flow j at year t can be written as:

$$Q_{tj}^{(P)} = W_{tj}^{(P)} \cdot \frac{1}{\eta_{tj}^{(P)}} \tag{20}$$

The savings from fossil fuel efficiency changes, $S_{mtj}^{(P)}$, can be written as the difference between the valuation of the flow and the heat input:

$$S_{mtj}^{(P)} = PEV_{mtj}^{(P)} - Q_{tj}^{(P)} \tag{21}$$

$$S_{mtj}^{(P)} = W_{tj}^{(P)} \left(\frac{1}{\eta_{mt}} - \frac{1}{\eta_{tj}^{(P)}} \right) \tag{22}$$

Annex 3 – Numerical Example

In this annex, we give a numerical example to illustrate the application of the different methods with the mathematical expressions given in Annex 2.

Data

The data for the numerical example (Table 1) is from Portuguese flows for year 2009 (see Annex 4). We consider for this example four flows:

- a fossil fuel (natural gas);
- a renewable fuel (wood and wood waste);
- a non-fuel non-thermal flow (hydraulic energy);
- a non-fuel thermal flow (geothermal energy);

Table 5 – Data for the Numerical Example

Primary Energy Flow		Symbol	Natural Gas	Wood and Wood Waste	Hydraulic Energy	Geothermal Energy
		j	1	2	3	4
Power Plants	Heat input (toe)	$Q_{tj}^{(P)}$	1,830,244	122,170	-	158,240[a]
	Efficiency	$\eta_{tj}^{(P)}$	55.98%[b]	24.57%[a]	-	10%[c]
	Electricity (toe)	$W_{tj}^{(P)}$	1,024,571[a]	30,014	775,204	15,824
CHP Plants	Heat input (toe)	$Q_{tj}^{(CHP)}$	816,793	167,968	-	-
	Electric efficiency	$\eta_{tj}^{(CHP)}$	33.64%[b]	12.60%[a]	-	-
	Electricity (toe)	$W_{tj}^{(CHP)}$	274,769[a]	21,156	-	-
	Useful heat efficiency	$\mu_{tj}^{(CHP)}$	51.34%[d]		-	-
	Useful heat (toe)	$U_{tj}^{(CHP)}$	419,342[a]	86,235[a]	-	-
Other	Heat (toe)	$Q_{tj}^{(H)}$	1,586,299	1,745,146	-	-

[a] Calculated.
[b] Estimated using IEA data.
[c] Estimated using IEA's suggestion for an approximate value (OECD/IEA, 2005, p. 138).
[d] Average useful heat efficiency for all CHP plants in 2009.

From equation (2), the primary energy valuation is given by:

$$\begin{aligned} PEV_{m,2009} = {} & W_{2009,1}^{(P)}\alpha_{m,2009,1}^{(P)} + W_{2009,1}^{(CHP)}\alpha_{m,2009,1}^{(CHP)} + U_{2009,1}^{(CHP)}\beta_{m,2009,1}^{(CHP)} + Q_{2009,1}^{(H)} \\ & + W_{2009,2}^{(P)}\alpha_{m,2009,2}^{(P)} + W_{2009,2}^{(CHP)}\alpha_{m,2009,2}^{(CHP)} + U_{2009,2}^{(CHP)}\beta_{m,2009,2}^{(CHP)} + Q_{2009,2}^{(H)} \\ & + W_{2009,3}^{(P)}\alpha_{m,2009,3}^{(P)} + W_{2009,4}^{(P)}\alpha_{m,2009,4}^{(P)} \end{aligned} \quad (23)$$

Given that our numerical example is for year 2009, for clarity we can omit the year subscript and thus write:

$$PEV_m = W_1^{(P)}\alpha_{m,1}^{(P)} + W_1^{(CHP)}\alpha_{m,1}^{(CHP)} + U_1^{(CHP)}\beta_{m,1}^{(CHP)} + Q_1^{(H)} + W_2^{(P)}\alpha_{m,2}^{(P)} + W_2^{(CHP)}\alpha_{m,2}^{(CHP)} + U_2^{(CHP)}\beta_{m,2}^{(CHP)} + Q_2^{(H)} + W_3^{(P)}\alpha_{m,3}^{(P)} + W_4^{(P)}\alpha_{m,4}^{(P)} \quad (24)$$

For the application of the methods, the nominal efficiency for fossil fuel power plants (and nuclear power plants, given the there is none in Portugal) calculated from DGEG data is:

$$\eta_{nom}^{(f)} = \eta_{nom}^{(f+n)} = 45.17\% \quad (25)$$

For NRV method, we use 1994 as a reference year:

$$\eta_{ref}^{(\mathrm{f})} = \eta_{nom,1994}^{(f)} = 38.94\% \quad (26)$$

For the efficiency of heat only delivery we take for any year t

$$\mu_{nom,t}^{(H)} = \mu_{ref}^{(H)} = 90\% \quad (27)$$

Recall from equation that for BP's method we take:

$$\eta_{BP} = 38\% \quad (28)$$

OECD/IEA and EUROSTAT's Method

With OECD/IEA and EUROSTAT's method, substituting the valuation factors (Table 3), the primary energy value is:

$$PEV_{IEA} = \frac{W_1^{(P)}}{\eta_1^{(P)}} + \frac{W_1^{(CHP)}}{\eta_1^{(CHP)}} + U_1^{(CHP)} \cdot 0 + Q_1^{(H)} + \frac{W_2^{(P)}}{\eta_2^{(P)}} + \frac{W_2^{(CHP)}}{\eta_2^{(CHP)}} + U_2^{(CHP)} \cdot 0 + Q_2^{(H)} + W_3^{(P)} \cdot 1 + \frac{W_4^{(P)}}{\eta_4^{(P)}} \quad (29)$$

$$PEV_{IEA} = Q_1^{(P)} + Q_1^{(CHP)} + Q_1^{(H)} + Q_2^{(P)} + Q_2^{(CHP)} + Q_2^{(H)} + W_3^{(P)} + Q_4^{(P)} \quad (30)$$

$$PEV_{IEA} = 1{,}830{,}244 + 816{,}793 + 1{,}586{,}299 + 122{,}170 + 167{,}968 + 1{,}745{,}146 + 775{,}204 + 158{,}240\ toe \quad (31)$$

$$PEV_{IEA} = 7{,}202 ktoe \quad (32)$$

USEIA's Method

With USEIA's, substituting the valuation factors (Table 3), the primary energy value is:

$$PEV_{IEA} = Q_1^{(P)} + Q_1^{(CHP)} + Q_1^{(H)} + Q_2^{(P)} + Q_2^{(CHP)} + Q_2^{(H)} + \frac{W_3^{(P)}}{\eta_{nom}^{(f)}} + Q_4^{(P)} \quad (33)$$

$$PEV_{USEIA} = 1{,}830{,}244 + 816{,}793 + 1{,}586{,}299 + 122{,}170 + 167{,}968 + 1{,}745{,}146 + \frac{775{,}204}{45.17\%} + 158{,}240\ toe \quad (34)$$

$$PEV_{USEIA} = 8{,}143 ktoe \quad (35)$$

BP's Method

With BP's method, substituting the valuation factors (Table 3), the primary energy value is:

$$PEV_{BP} = Q_1^{(P)} + Q_1^{(CHP)} + Q_1^{(H)} + \frac{W_2^{(P)}}{\eta_{BP}} + Q_2^{(CHP)} + Q_2^{(H)} + \frac{W_3^{(P)}}{\eta_{BP}} + \frac{W_4^{(P)}}{\eta_{BP}} \quad (36)$$

$$PEV_{BP} = 1{,}830{,}244 + 816{,}793 + 1{,}586{,}299 + \frac{30{,}014}{38\%} + 167{,}968 + 1{,}745{,}146 + \frac{775{,}204}{38\%} + \frac{15{,}824}{38\%}\ toe \quad (37)$$

$$PEV_{BP} = 8{,}307 ktoe \quad (38)$$

NL Agency's Method

With NL Agency's method, substituting the valuation factors (Table 3), the primary energy value is:

$$PEV_{NL\ AGENCY} = Q_1^{(P)} + Q_1^{(CHP)} + Q_1^{(H)} + \frac{W_2^{(P)}}{\eta_{nom}^{(f+n)}} + \frac{W_2^{(CHP)}}{\eta_{nom}^{(f+n)}} + \frac{U_2^{(CHP)}}{\mu_{nom}^{(H)}} + Q_2^{(H)} + \frac{W_3^{(P)}}{\eta_{nom}^{(f+n)}} + \frac{W_4^{(P)}}{\eta_{nom}^{(f+n)}} \quad (39)$$

$$PEV_{NL\ AGENCY} = 1{,}830{,}244 + 816{,}793 + 1{,}586{,}299 + \frac{30{,}014}{45.17\%} + \frac{21{,}156}{45.17\%} + \frac{86{,}235}{90\%} + 1{,}745{,}146 + \frac{775{,}204}{45.17\%} + \frac{15{,}824}{45.17\%}\ toe \quad (40)$$

$$PEV_{NL\ AGENCY} = 7939 ktoe \quad (41)$$

NRV Method

In the proposed NRV method, substituting the valuation factors (Table 3), the primary energy value is:

$$PEV_{NRV} = \frac{W_1^{(P)}}{\eta_{nom}^{(f)}} + \frac{W_1^{(CHP)}}{\eta_{nom}^{(f)}} + \frac{U_1^{(CHP)}}{\mu_{nom}^{(H)}} + Q_1^{(H)} + \frac{W_2^{(P)}}{\eta_{nom}^{(f)}} + \frac{W_2^{(CHP)}}{\eta_{nom}^{(f)}} + \frac{U_2^{(CHP)}}{\mu_{nom}^{(H)}} + Q_2^{(H)} + \frac{W_3^{(P)}}{\eta_{nom}^{(f)}} + \frac{W_4^{(P)}}{\eta_{nom}^{(f)}} \quad (42)$$

$$PEV_{NRV} = \frac{1{,}024{,}571}{45.17\%} + \frac{274{,}769}{45.17\%} + \frac{419{,}342}{90\%} + 1{,}586{,}299 + \frac{30{,}014}{45.17\%} + \frac{21{,}156}{45.17\%} + \frac{86{,}235}{90\%} + 1{,}745{,}146 + \frac{775{,}204}{45.17\%} + \frac{15{,}824}{45.17\%} toe \tag{43}$$

$$PEV_{NRV} = 8{,}634 ktoe \tag{44}$$

TRV Method

$$PEV_{TRV} = \frac{W_1^{(P)}}{\eta_{ref}^{(f)}} + \frac{W_1^{(CHP)}}{\eta_{ref}^{(f)}} + \frac{U_1^{(CHP)}}{\mu_{ref}^{(H)}} + Q_1^{(H)} + \frac{W_2^{(P)}}{\eta_{ref}^{(f)}} + \frac{W_2^{(CHP)}}{\eta_{ref}^{(f)}} + \frac{U_2^{(CHP)}}{\mu_{ref}^{(H)}} + Q_2^{(H)} + \frac{W_3^{(P)}}{\eta_{ref}^{(f)}} + \frac{W_4^{(P)}}{\eta_{ref}^{(f)}} \tag{45}$$

$$PEV_{TRV} = \frac{1{,}024{,}571}{38.94\%} + \frac{274{,}769}{38.94\%} + \frac{419{,}342}{90\%} + 1{,}586{,}299 + \frac{30{,}014}{38.94\%} + \frac{21{,}156}{38.94\%} + \frac{86{,}235}{90\%} + 1{,}745{,}146 + \frac{775{,}204}{38.94\%} + \frac{15{,}824}{38.94\%} toe \tag{46}$$

$$PEV_{TRV} = 9{,}393 ktoe \tag{47}$$

Savings from CHP Plants

The savings from CHP plants are obtained using equation (17).

Savings from CHP plants using natural gas can be calculated with NRV and TRV methods:

$$S_{NRV,1}^{(CHP)} = W_1^{(CHP)} \left(\frac{1}{\eta_{nom}^{(f)}} - \frac{1}{\eta_1^{(CHP)}} \right) + U_1^{(CHP)} \frac{1}{\mu_{nom}^{(H)}} = 274{,}769 \left(\frac{1}{45.17\%} - \frac{1}{33.64\%} \right) + \frac{419{,}342}{90\%} toe = 257 ktoe \tag{48}$$

$$S_{TRV,1}^{(CHP)} = W_1^{(CHP)} \left(\frac{1}{\eta_{ref}^{(f)}} - \frac{1}{\eta_1^{(CHP)}} \right) + U_1^{(CHP)} \frac{1}{\mu_{ref}^{(H)}} = 274{,}769 \left(\frac{1}{38.94\%} - \frac{1}{33.64\%} \right) + \frac{419{,}342}{90\%} toe = 355 ktoe \tag{49}$$

Savings from CHP plants using wood and wood waste can be calculated with NL Agency's, NRV and TRV methods:

$$S_{NL\,Agency,2}^{(CHP)} = S_{NRV,2}^{(CHP)} = W_2^{(CHP)}\left(\frac{1}{\eta_{nom}^{(f+n)}} - \frac{1}{\eta_2^{(CHP)}}\right) + \frac{U_2^{(CHP)}}{\mu_{nom}^{(H)}}$$

$$= W_2^{(CHP)}\left(\frac{1}{\eta_{nom}^{(f)}} - \frac{1}{\eta_2^{(CHP)}}\right) + \frac{U_2^{(CHP)}}{\mu_{nom}^{(H)}} \quad (50)$$

$$= 21{,}156\left(\frac{1}{45.17\%} - \frac{1}{12.60\%}\right) + \frac{86{,}235}{90\%} toe = -25ktoe$$

$$S_{TRV,2}^{(CHP)} = W_2^{(CHP)}\left(\frac{1}{\eta_{ref}^{(f)}} - \frac{1}{\eta_2^{(CHP)}}\right) + \frac{U_2^{(CHP)}}{\mu_{ref}^{(H)}} \quad (51)$$

$$= 21{,}156\left(\frac{1}{38.94\%} - \frac{1}{12.60\%}\right) + \frac{86{,}235}{90\%} toe = -18ktoe$$

Savings from Fossil Fuel Power Plants

Savings from efficiency increases in fossil fuel power plants can be obtained for NRV and TRV methods by using equation (22):

$$S_{NRV,1}^{(P)} = W_1^{(P)}\left(\frac{1}{\eta_{nom,t}^{(f)}} - \frac{1}{\eta_1^{(P)}}\right) = 1{,}024{,}571\left(\frac{1}{45.17\%} - \frac{1}{55.98\%}\right) toe = 438ktoe \quad (52)$$

$$S_{TRV,1}^{(P)} = W_1^{(P)}\left(\frac{1}{\eta_{ref}^{(f)}} - \frac{1}{\eta_1^{(P)}}\right) = 1{,}024{,}571\left(\frac{1}{38.94\%} - \frac{1}{55.98\%}\right) toe = 801ktoe \quad (53)$$

Annex 4 – Application to Portugal

NL Agency’s Method Adaptation

The adaptation of NL Agency’s method consisted in performing only the substitutions indicated in Table 1, which means that we did not perform substitutions indicated in NL Agency (2010).

One substitution we did not follow is the substitution of final energy flows, e.g. wood burning in households and in industry for delivering heat.[22] Given that wood stoves can be of low efficiency (compared to burning fossil fuels), NL Agency (2010, pp. 40-41) substitutes the heat obtained from wood with the heat that would be required if a fossil fuel was used.

This substitution gives insight into the fossil fuels saved by such use of biomass, but it relates to the final system and not to the energy system, which is one reason why we did not perform it. Image we would instead perform such a substitution and that the only thing changing in both the energy and the final systems was that the average efficiency of wood stoves was increasing. With the substitution, primary energy would remain constant, and yet there would be a change in the energy used by the final system. Because of our interest in trends in the final system, we refrain from performing this substitution.

The other reason why we did not perform this substitution of final energy flows is that none of the other methods under consideration performs it. By refraining from performing it, we may compare the methods without the interferences that such substitution would introduce.

Another substitution by NL Agency (2010) that we do not follow is the standardization of hydro and wind electricity to the last 15 years and 5 years average (respectively). Again, one reason why we refrain from performing such standardization is that it would make the methods less comparable, as the other methods do not perform it. The other reason is that by not performing the standardization we may observe and quantify the influence of the variability of hydraulic energy in the total renewable primary energy.

[22] Such substitution is also performed by by Segers (2008) and Harmsen *et al.* (2011).

Data Sources

The main data used were the Portuguese National Energy Balances from 1994 to 2009. These are publicly available through DGEG's webpage (www.dgge.pt).

For three non-fuel flows (wind, geothermal power and photovoltaic power), the National Energy Balances from 1994 to 2005 present aggregate values. DGEG provided disaggregated data, which we present in Table 6.

Table 6 – Electricity from Wind, Geothermal and Photovoltaic Power Plants (1994-2005)

Year	Wind Power (toe)	Geothermal Power (toe)	Photovoltaic Power (toe)
1994	1,290	3,010	0
1995	1,376	3,612	0
1996	1,806	4,214	0
1997	3,268	4,386	0
1998	7,654	4,988	0
1999	10,578	6,880	0
2000	14,448	6,880	0
2001	22,016	9,030	0
2002	31,132	8,256	172
2003	42,656	7,740	258
2004	70,176	7,224	258
2005	152,478	6,106	258

The data of the National Energy Balances (completed with the data from Table 6) provides several of the information required to apply the methods. This includes (using the symbols introduced in Annex 2, where t denotes the year and j denotes the primary energy flow):

- electricity flows, $W_{tj}^{(P)}$, from non-fuel power plants (hydraulic, wind, geothermal, and solar photovoltaic);
- electricity net import, $W_t^{(I)}$;
- for each fuel or heat flow (fossil, renewable or mixed): [23]
  - heat input to power plants, $Q_{tj}^{(P)}$;
  - heat input to CHP plants $Q_{tj}^{(CHP)}$
  - heat to other uses $Q_{tj}^{(H)}$
- for the total of fuels:
  - total useful heat obtained from all CHP plants, $\sum_j U_{tj}^{(CHP)}$

All electricity flows are considered gross electricity flows.

[23] Municipal Solid Waste (hereafter MSW) is the only fuel in the National Energy Balances which is a mix of renewable and fossil fuels. The renewable and fossil fuel fractions are addressed in Annex 5.

To apply the current and proposed methods, we need to establish electricity flows from power plants and CHP plants and the useful heat from CHP plants for each flow, $U_{tj}^{(CHP)}$, instead of the total for all flows, $\sum_j \ U_{tj}^{(CHP)}$. Bellow we present how such values were obtained.

Useful Heat from CHP Plants for each Flow

For each flow, from the National Energy Balances we already know the heat input to CHP plants, $Q_{tj}^{(CHP)}$. We need to determine the heat efficiency $\mu_{tj}^{(CHP)}$ for each flow, so that we can calculate the useful heat per flow $U_{tj}^{(CHP)}$:

$$U_{tj}^{(CHP)} = Q_{tj}^{(CHP)} \cdot \mu_{tj}^{(CHP)} \tag{54}$$

Given that no additional data were available, we considered the heat efficiency for each flow $\mu_{tj}^{(CHP)}$ to be the same as the average heat efficiency of all flows, i.e.:

$$\mu_{tj}^{(CHP)} = \frac{\sum_j \ U_{tj}^{(CHP)}}{\sum_\mathrm{j} \ Q_{tj}^{(CHP)}} \tag{55}$$

Electricity Flows from Power Plants and CHP Plants

For each flow, from the National Energy Balances we already know the heat input to power plants, $Q_{tj}^{(P)}$, and the heat input to CHP plants, $Q_{tj}^{(CHP)}$. We need to determine the electric efficiencies for power plants and CHP plants, $\eta_{tj}^{(P)}$ and $\eta_{tj}^{(CHP)}$ respectively. Then we can calculate the electricity flows from power plants and CHP plants, $W_{tj}^{(P)}$ and $W_{tj}^{(CHP)}$ respectively:

$$W_{tj}^{(P)} = Q_{tj}^{(P)} \cdot \eta_{tj}^{(P)} \tag{56}$$

$$W_{tj}^{(CHP)} = Q_{tj}^{(CHP)} \cdot \eta_{tj}^{(CHP)} \tag{57}$$

For the year 2009, DGEG provided electricity flows from power plants and from CHP plants for three fuels: MSW, wood and wood waste, and black liquor (Table 7).

Table 7 – Electricity from MSW, Wood and Wood Waste and Black Liquor (2009)

Fuel	Electricity from power plants (toe)	Electricity from CHP plants (toe)
MSW	49,794	not applicable
wood and wood waste	30,014	21,156
black liquor	not applicable	96,148

We used this additional data to determine the 2009 efficiencies for these three flows:

$$\eta_{tj}^{(P)} = \frac{W_{tj}^{(P)}}{Q_{tj}^{(P)}} \tag{58}$$

$$\eta_{tj}^{(CHP)} = \frac{W_{tj}^{(CHP)}}{Q_{tj}^{(CHP)}} \quad (59)$$

These calculated electric efficiency values for 2009 were used for other flows and years (Table 8).

Table 8 – Electric Efficiency

Electric efficiency calculated using DGEG Data for:		Calculated electric efficiency from DGEG used also for:	
Flow	**Year**	**Flow:**	**Years**
MSW	2009	MSW	2007 to 2008
wood and wood waste	2009	wood and wood waste other renewable fuels	1994 to 2008
black liquor	2009	black liquor	1994 to 2008

For the remaining other flows and years, we used electric efficiencies calculated using data from IEA. The data we had available covered 1994 to 2006, and thus for 2007 to 2009 we considered the efficiency values equal to those of 2006.

Efficiency for the Separate Delivery of Heat from Fossil Fuels

We considered the reference efficiency for the separate delivery of heat from fossil fuels to be 90% in all cases in all methods that use it. Therefore for any year t

$$\mu_{nom,t}^{(H)} = \mu_{ref}^{(H)} = 90\% \quad (60)$$

Implementation

Using the data sources described in this annex, the mathematical expressions given in Annex 2 were applied to the Portuguese case from 1994 to 2009.

Our implementation of the calculations required for this application was performed using:

- Linux operative system (openSUSE 11.4);
- MySQL database engine (5.5.15 MySQL Community Server);
- R (version 2.12.1);
- Perl (v5.12.3 and modules DBI and Statistics::R)

Thus all calculations were performed using freely distributed software.

Annex 5 – Data for Municipal Solid Waste

Analysis

Municipal Solid Waste (MSW) is the only fuel in the Portuguese Energy Balance which is a mixture of fossil and renewable fractions. DGEG adopts the IEA suggestion of assuming the fraction of renewable heat to be 50%.[24]

To investigate the validly of such an assumption, information on the composition of MSW for electricity generation in the Portuguese mainland and in the Madeira region was obtained, respectively from *Agência Portuguesa do Ambiente* and from *Valor Ambiente - Gestão e Administração de Resíduos da Madeira, S.A.*

For the Portuguese mainland, the average mass fraction of renewable fuels is estimated at least at 44% (including bio-waste and wood) for 2009 and 2010.

For the Madeira region, the fraction of renewable fuels (including paper, wood and bio-waste) can be estimated at least at:

- 48% for August 2007;
- 61% for November 2007;
- 66% for February 2008;
- 73% for May 2008;
- 59% for 2010.

This confirms that the mass fraction of renewable fuels in MSW is significant. However, to further investigate the validity of the 50% assumption for renewable heat from MSW, we would require a more detailed characterization of the mass fractions of waste and the knowledge of the calorific value of each mass fraction.

Given that such data was not available, the assumption of 50% fraction for renewable heat from MSW was also used in this work.

The information received is presented bellow (in Portuguese).

[24] Personal communication from Eng. Paulo Salteiro Rodrigues of DGEG, 2011.

Information received for the Portuguese mainland

De: Alexandra Rodrigues [mailto:alexandra.rodrigues@apambiente.pt]
Enviada: sexta-feira, 30 de Setembro de 2011 10:25
Para: nuno.cegonho@ist.utl.pt
Cc: Francisco Silva
Assunto: RE: Caracterização de RSU destinados a centrais de incineração
Importância: Alta

Exmo. Senhor

Em resposta ao e-mail remetido por V.Exa. relativo aos dados de caracterização de resíduos enviados para incineração, remete-se o quadro abaixo com a média dos valores reportados, em 2009 e 2010, pelas 2 centrais de incineração existentes no continente: Lisboa (VALORSUL) e Porto (Lipor).

A caracterização foi realizada de acordo com o definido na Portaria n.º 851/2009, de 7 de Agosto, tendo os resíduos sido caracterizados em termos do conteúdo de materiais e fluxos que constam da grelha de análise apresentada no quadro n.º 4 da referida portaria.

Resíduos recicláveis…. (%)	Bio-resíduos	43,24
	Papel/cartão (incluindo ECAL)	14,51
	Plástico	10,30
	Metais	1,7
	Vidro	4,74
	Madeira	0,92
	Resíduos de equipamentos eléctricos e electrónicos (REEE)	0,1
	Pilhas e acumuladores	0,05
Outros resíduos (%)		24,44

Com os melhores cumprimentos

Alexandra Rodrigues

Técnica Superior
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Para: nuno.cegonho@ist.utl.pt
Assunto: Caracterização dos resíduos urbanos destinados a incineração na ETRS da Meia Serra

Junto se anexa documento relativo ao assunto supra mencionado.

Com os melhores cumprimentos,

O Departamento de Gestão Documental e Expediente

IGSERV - Investimentos, Gestão e Serviços, S.A. | IGA - Investimentos e Gestão da Água, S.A. | VALOR AMBIENTE Gestão e Administração de Resíduos da Madeira, S.A. | IGH - Investimentos e Gestão Hidroagrícola, S.A. | ARM - Águas e Resíduos da Madeira, S.A.

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VALOR AMBIENTE
Gestão e Administração de Resíduos da Madeira, S.A.

E-MAIL

Valor Ambiente - Gestão e Administração de Resíduos da Madeira, S.A.
VA_S/2011/6272 03-10-2011

De:	Valor Ambiente, S.A.		
Para:	Nuno Cegonho		
A/C:		**E-mail:**	nuno.cegonho@ist.utl.pt
C/C:	---	**E-mail:**	---
Nº Telef.:	965 273 273	**Anexos:**	Sim
Refª:	DTE/463	**Processo:**	CI04
Assunto:	**Caracterização dos Resíduos Urbanos destinados a incineração na ETRS da Meia Serra**		

Na sequência da sua solicitação, de 19/09/2011, relativa ao assunto em epígrafe, junto se anexa os resultados da caracterização dos resíduos urbanos destinados à incineração na Instalação de Incineração de Resíduos Sólidos Urbanos (IIRSU) da Estação de Tratamento de Resíduos Sólidos Urbanos (ETRS) da Meia Serra, obtidos nas campanhas realizadas nos anos de 2007, 2008 e 2010.

Com os melhores cumprimentos,

O Presidente do Conselho de Administração

(José Alberto Faria e Pimenta de França)

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Tabela 1 – Resultados das campanhas de caracterização física dos RSU afluentes à ETRS da Meia Serra realizadas nos anos de 2007 e 2008.

Componentes		1.ª Campanha - 2007 (20/08 a 01/09)		2.ª Campanha - 2007 (12/11 a 24/11)		1.ª Campanha - 2008 (11/02 a 23/02)		2.ª Campanha - 2008 (05/05 a 17/05)	
		Média de cada sub-categoria (%)	Categorias principais (%)	Média de cada sub-categoria (%)	Categorias principais (%)	Média de cada sub-categoria (%)	Categorias principais (%)	Média de cada sub-categoria (%)	Categorias principais (%)
Papel/cartão	Alvo da SPV	7,85	13,35	5,40	10,70	13,8	21,5	11,8	21,60
	Não alvo da SPV	5,50		5,30		7,7		9,8	
Vidro	Alvo da SPV	8,97	8,99	2,50	2,50	2,1	2,2	2,3	2,30
	Não alvo da SPV	0,03		0,00		0,00		0,0	
Plástico	Alvo da SPV	9,39	10,98	20,50	20,60	17,6	17,7	13,4	13,50
	Não alvo da SPV	1,59		0,10		0,2		0,1	
Metais ferrosos	Alvo da SPV	0,71	0,89	0,90	1,30	0,7	1	0,6	0,78
	Não alvo da SPV	0,03		0,20		0,1		0,2	
Metais não ferrosos	Alvo da SPV	0,14		0,10		0,2		0,0	
	Não alvo da SPV	0,02		0,00		0,1		0,0	
Madeira	Alvo da SPV	0,10	0,31	0,30	0,50	0,3	0,6	0,1	0,20
	Não alvo da SPV	0,20		0,20		0,3		0,1	
ECAL		0,51	0,51	0,90	0,90	0,7	0,7	0,49	0,49
Materiais fermentáveis		34,62	34,62	50,00	50,00	43,5	43,5	51,34	51,34
Têxteis		6,94	6,94	3,10	3,10	3,8	3,8	1,11	1,11
Finos (dimensão < 20mm)		4,13	4,13	3,70	3,70	3,4	3,4	3,35	3,35
Outros		19,28	19,28	6,60	6,60	5,7	5,7	5,23	5,23
TOTAL		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

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Tabela 2 – Resultados da caracterização física dos resíduos indiferenciados obtidos 2010.

Categoria	Subcategoria	Peso médio na base húmida (kg)	Peso médio na base húmida por categoria (kg)	Percentagem por subcategoria (%)	Percentagem por categoria (%)
Bio-resíduos	Alimentares	116,92	137,08	33,05%	38,71%
	Jardim	15,83		4,45%	
	Outros putrescíveis	4,33		1,21%	
Papel/cartão	Embalagens de papel/cartão	20,83	68,33	5,87%	19,32%
	Jornais e revistas	16,67		4,73%	
	Outros resíduos de papel/cartão	30,83		8,72%	
Plástico	Filme plástico	27,83	51,46	7,84%	14,51%
	PET	4,33		1,22%	
	PEAD	2,67		0,75%	
	EPS	1,00		0,28%	
	Outras embalagens de plástico	12,67		3,58%	
	Outros resíduos plástico	2,96		0,83%	
Vidro	Embalagens de vidro	15,83	18,79	4,47%	5,30%
	Outros resíduos vidro	2,96		0,83%	
Compósitos	ECAL	5,17	10,03	1,46%	2,84%
	Outras embalagens compósitas	2,26		0,64%	
	Pequenos aparelhos	1,83		0,52%	
	Outros resíduos compósitos	0,78		0,22%	
Têxteis	Embalagens têxteis	1,13	10,96	0,32%	3,07%
	Outros resíduos têxteis	9,83		2,76%	
Têxteis sanitários		14,67	14,67	4,15%	4,15%
Metais	Embalagens ferrosas	5,00	8,05	1,41%	2,28%
	Embalagens não ferrosas	1,33		0,38%	
	Outros resíduos ferrosos	0,90		0,26%	
	Outros resíduos metálicos	0,82		0,23%	
Madeira	Embalagens de madeira	0,72	3,01	0,20%	0,85%
	Outros resíduos madeira	2,29		0,65%	
Resíduos perigosos	Produtos químicos	0,58	1,90	0,16%	0,54%
	Tubos fluorescentes e lâmpadas	0,12		0,03%	
	Pilhas e acumuladores	0,26		0,07%	
	Outros resíduos perigosos	0,93		0,26%	
Outros resíduos	Outros resíduos embalagem	1,17	10,42	0,32%	2,92%
	Outros resíduos não embalagem	9,25		2,60%	
Resíduos verdes (recolhidos separadamente)		0,00	0,00	0,00%	0,00%
Resíduos volumosos		0,08	0,08	0,02%	0,02%
Finos < 20mm		19,42	19,42	5,49%	5,49%

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