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Primary Energy Methodologies Applied to Portugal

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Primary Energy Valuation Methods: Review and Proposal for a Time Reference Valuation

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Abstract

We review current primary energy valuation methods assessing the valuation criteria implicit in the substitutions that they perform for certain primary energy flows. We then introduce the Time Reference Valuation (TRV) method. This method has a double purpose: to obtain the trend in energy use without the influence of changes in the electric system and to establish a baseline for assessing the changes occurring in the electric system. We apply the current methods and the proposed method to Portugal from 1994 to 2009 to illustrate the usefulness of the TRV method.

Keywords

Primary Energy, Renewable Energy, Power Plants, Combined Heat and Power

1 Introduction

Primary Energy, defined as energy extracted from natural resources (1) is used for a variety of studies of energy use, such as comparing vehicles (2), analyzing different buildings (3) or evaluating the influence of lifestyles (4).

Another option would be to use the final energy, which is defined as energy sold to a user. However, primary energy is required for delivering such final energy. The most notable case is burning fossil fuels to deliver electricity: one unit of electrical energy requires two to three units of heat from fossil fuels. Thus, instead of comparing final energy uses, one may instead compare the primary energy associated with the final energy uses, in order to account for the upstream differences.

There are other areas of study, where we account for the indirect flows (of primary energy) associated with the direct flow (of final energy), e.g. Life Cycle Assessment and Input-Output Analysis.

However, for such an accounting to be performed, we must be able to value the primary energy flows extracted from nature. Several methods are currently in use to perform such a valuation, notably by the International Energy Agency (IEA) of the Organisation for Economic Co-operation and Development (OECD) and EUROSTAT (1), the United States Energy Information Administration (USEIA) (5), BP (6) and NL Agency (7).

An important use of primary energy is expressing the value of the energy used by a country. In this case, when choosing to refer to data for instance by OECD/IEA and EUROSTAT, a choice is also implicitly made with regard to using OECD/IEA and EUROSTAT's method.

The reasoning for using primary energy instead of final energy appears to be clear, but the motives for using one particular method to value primary energy need clarification.

2 Literature Review

Lightfoot (8) commented the methods for calculating primary energy used by USEIA, IEA and by 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 but that the chosen scale must be used consistently.

Segers (9), affiliated with Statistics Netherlands, which applies NL Agency's methodology, compared the results of IEA's method and a method close to NL Agency's method with those of using the final energy method (for the EU 27 countries for the year 2005). The author concluded that the percentage of renewable energy calculated using the method close to NL Agency's does not have the methodological accuracy problems of IEA's method and of the final energy method, and requires only very limited concessions related to data accuracy and simplicity.

Harmsen *et al.* (10) approached the issue of primary energy valuation methods focusing on its interaction with Europe's energy savings target. The authors used IEA/OECD and EUROSTAT's method and observed how it leads to primary energy savings as power generation from wind, hydro and solar electricity increase.

3 Motivation

OECD/IEA and EUROSTAT's method appears to be the most well known method, being mentioned in the literature as *the* "primary energy method", e.g. Segers (9) and Harmsen *et al.* (10). Other methods are usually considered "substitution methods". However, all methods involve substitutions: actual physical flows (e.g. hydraulic energy flows) are substituted with other quantities (e.g. electrical energy).

A non-substitution method would be to actually use the energy flow extracted from nature (e.g. for wind power the mechanical energy flow from wind). Although expressed in energy units, such flows in general are not directly comparable: is a given amount of wind (mechanical) energy worth more or less than a given amount of heat obtainable from natural gas?

To answer this question, primary energy flows are substituted with other values, in order to express them in terms comparable to heat. Here we name the different procedures for such substitutions as primary energy valuation methods, to highlight the fact that the primary energy itself is not necessarily used.

Recognizing that we are dealing with valuation methods leads us to review the current methods in order to observe the valuation criteria which are implicit in the substitutions performed.

4 Review of Current Methods

In table 1 we summarized the current primary energy valuation methods of OECD/IEA and EUROSTAT (1), USEIA (5), BP (6) and NL Agency (7). These methods differ in three main valuation options.

As a first valuation option, non-thermal renewable energy (i.e. hydraulic energy, wind energy and solar photovoltaic energy) is valued by OECD/IEA and EUROSTAT as the electricity obtained. This is the same as the heating value of such electricity, given that electricity can be fully converted to heat. Thus, hydraulic energy is valued as the heat obtainable from the electricity it delivers, and such heat is compared to heat obtainable from burning natural gas. This can be an interesting option if electricity is to be used mainly for conversion to heat (11).

Alternatively, we may consider that electricity can be used to deliver work instead of heat and that this use can be significant. We can thus argue that primary energy from these non-thermal renewable flows can be given a different value, to express its usefulness to deliver work. This alternative valuation is performed by USEIA, BP and NL Agency. In this case, 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. For such valuation, the methods differ in the used efficiency of thermal power plants. USEIA uses the yearly average efficiency of fossil fuel power plants. BP uses an efficiency value of 38%, stated to be the efficiency of a modern thermal power plant. NL Agency uses the yearly average efficiency of both fossil fuel and nuclear power plants.

As a second valuation option, OECD/IEA and EUROSTAT's method gives always the same value to heat, whether it is obtained by burning a renewable fuel (e.g. biomass) or by burning fossil fuels. This valuation option considers that, regardless of the particular technology and regardless of the primary energy flow, heat can (at least potentially) be equally useful.

Alternatively, realizing that biomass for electricity delivery is usually used in local smaller power plants, less efficient than large fossil fuel power plants, we could argue that such biomass is less useful.

This alternative valuation is performed by BP by substituting renewable fuels by the heat that would be required to obtain the same electricity (but using thermal power plants).

USEIA proceeds as OECD/IEA and EUROSTAT for some of the renewable primary energy flows but as BP for other of the renewable primary energy flows. This approach is interesting if one wishes to consider that some primary energy flows and technologies can (at least potentially) be used as efficiently as fossil fuel heat, but that other primary energy flows or technologies do not have such a potential. For instance, in USEIA's method biomass primary 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).

Finally, a third valuation option regards primary energy to Combined Heat and Power (CHP) plants. OECD/IEA and EUROSTAT value such primary energy in the same way as primary energy to power (only) 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 (apparently) by BP.

NL Agency chooses an alternative valuation for primary energy from renewable fuels to CHP: they are valued as the heat required to separately deliver the same electricity and the same heat. This requires using a reference efficiency for heat only delivery. It is an interesting option if we wish to consider that not all plants can potentially be CHP plants. In this case, because using CHP plants to deliver electricity and heat can be more efficient than separately delivering electricity and heat, then the renewable primary energy delivered to CHP plants can be considered more useful. This approach allows us to take such a difference into account.

5 Time Reference Valuation

5.1 Purpose

Our purpose for introducing a primary energy valuation method is twofold.

First, we wish to observe throughout time the energy use trend but without the effects of the changes in the electric system.

Second, we are interested in assessing the impact that changes in the electric system have on the primary energy. For this, we need to establish a baseline against which to compare the changes. Such baseline can be used for example to determine how much primary energy is saved by efficiency increases in fossil fuel power plants.

For such a purpose, we introduce two main differences relative to current methods. To illustrate these two differences, we take a stepwise approach, and introduce an intermediate method, which we named Nominal Reference Valuation, with only one difference, and only then we introduce the Time Reference Valuation, with both differences.

5.2 Valuation Criteria

As a first valuation option, we consider that a significant amount of electricity is not used for heating, and thus choose to value non-thermal renewable electricity as the heat required to produce it using thermal power plants (thus following USEIA, BP and NL Agency, instead of OECD/IEA).

As a second valuation option, because of our interest in assessing actual changes in the electric system, we are less interested in using potential values as a reference. Instead, we choose to value all flows as according to a reference technology. We assume that the primary energy of fossil fuels is the main provider of heat and electricity and we thus consider this to be our reference. In this we follow BP and NL Agency instead of OECD/IEA or USEIA.

As a third valuation option, because of our interest in uncovering the effect of both renewable CHP and non-renewable CHP, we choose to value both the renewable and fossil fuels to CHP as the heat from fossil fuels that would be required to separately deliver the same electricity and heat. We therefore follow NL Agency for renewable CHP (instead of BP, USEIA or OECD/IEA) and introduce a different valuation option for fossil fuels to CHP. We start by using a yearly average efficiency of fossil fuel power plants as the efficiency for such substitutions.

Fossil fuels can be used in large centralized power plants (e.g. natural gas in a combined cycle power plant) but also in other smaller power plants (e.g. natural gas for co-combustion with waste). Thus, we choose to substitute also all fossil fuels to power plants with the heat required to deliver the same amount of electricity.

We use Nominal Reference Valuation (NRV) to refer to this valuation method which values *all* flows as the heat flows required to separately deliver electricity and heat, using the yearly average efficiency.

Finally, as a fourth valuation option, we observe that because average fossil fuel power plant efficiency varies with time, then if we use it for substitutions (as USEIA and NL Agency) we will be introducing changes in valuation due to changes in the electric system. Instead, we choose to use a fixed value, taken as the average efficiency of a reference year

Thus TRV method has two main differences relative to the other methods.

First, TRV (as NRV) differs from current methods in that also heat from fossil fuels (both to power plants and to combined heat and power plants) is to be substituted with the heat that would be required to separately deliver the same electricity (and heat if applicable)

Second, regarding the efficiency used for the substitutions, it differs from USEIA and NL Agency (as well as from TRV) because a constant efficiency is used instead of a variable efficiency. It also differs from BP (that also uses a constant efficiency) because the efficiency is not only constant but it is relative to a given year of reference.

In summary, the Time Reference Valuation expresses the value of all primary energy flows (i.e. fossil fuels, nuclear energy, renewable fuels and other renewables) as the value of the heat from fossil fuels required for the separate delivery of the same electricity and heat at a reference year.

6 Application to Portugal

6.1 Methods Applied

The current and proposed methods were applied to Portugal from 1994 to 2009.

Regarding NL Agency's method, an adaptation of the method was applied, which consisted in performing only the substitutions indicated in Table 1. Other substitutions performed in NL Agency's method (e.g. replacing electricity from hydro with the average production per installed MW in the last 15 years) were not performed in order to maintain the different methods comparable.

For TRV it is interesting to observe the differences that arise from using different reference years. We thus included two possibilities: using the first year of the data range as a reference (1994) or using the last year (2009).

6.2 Data Used

The main source of information used was the set of National Energy Balances and associated information of the Portuguese Directorate-General of Energy and Geology. This information was used for most flows and for determining the average fossil fuel power plant efficiency for each year.

For fuels (e.g. biomass or fuel oil), we used data from IEA to estimate the electricity delivered per fuel used in power plants and in CHP plants.

For CHP, as the reference efficiency for separate heat delivery with fossil fuels, we used 90% in all cases (for NL Agency's method adaptation, NRV and TRV).

6.3 Background

To provide appropriate context, we briefly outline the Portuguese energy sector.

There is no production of fossil fuels, and thus coal, crude oil and natural gas are imported. Crude oil can be processed at two refineries and refined products are both imported and exported. Natural gas was introduced in 1998. Until then power plants included mainly coal and fuel units, but since natural gas was introduced a number of combined cycle units were added. This contributed to increase the average fossil fuel power plant efficiency, given the greater efficiency of these power plants. Hydropower provides a significant share of gross electricity and wind power has greatly increased its contribution in the last few years. The Portuguese electric grid is interconnected with the Spanish grid, allowing for electricity import and export. There are no nuclear power plants.

7 Results

We give the total primary energy calculated with each method (Fig. 1) and the shares of renewable energy (Fig. 2), net electricity imports (Fig. 3), savings from CHP plants (Fig. 4) and savings from efficiency increases in fossil fuel power plants (Fig. 5).

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

8 Discussion

Total primary energy (Fig. 1) is lowest with IEA's method, a result of its valuation of non-fuel renewables as the heat that can be obtained from the electricity. BP gives higher values, by its valuation of renewables as the heat required to deliver them. However, given that it does not account for electricity trade, in recent years its values are lower than NL Agency's values. With regard to NRV and TRV methods, because they perform additional substitutions (e.g. fossil fuels to power plants and to CHP plants), they give higher values than NL Agency's method. NRV is close to TRV 1994 for years close to 1994 and close to TRV 2009 for years close to 2009, given that for such situations the average efficiency from TRV is close to the reference efficiency for TRV. TRV 1994 gives higher primary energy values than TRV 2009 because the reference efficiency is lower for 1994 than for 2009.

We can use TRV 1994 and TRV 2009 methods, which value primary energy with a fixed reference electric system, to realize that a decrease in primary energy occurs from 2005 to 2009. This trend is also visible in other methods, but with the TRV method, because we removed the trend associated with the electric system, we know that such decrease is not due to the changes in the electric system.

The share of renewable energy in primary energy (Fig. 2) is lower for IEA's method, which is explained by its particular valuation of non-thermal renewables, as discussed in the literature.

The share of net electricity imports receives less attention in the literature but its valuation varies significantly (Fig. 3). The value is null for BP's method. IEA's method gives significantly lower values than NL Agency's method (adaptation), NRV or TRV.

The share of savings from CHP in primary energy (Fig. 4) is not calculated for BP's and IEA's method (represented as null values). For NL Agency's method it includes only savings from renewable energies, but it is negative (expressing that heat to such CHP plants is actually less valuable than a same amount of heat to fossil fuel power plants with the year's efficiency).

For NRV, TRV 1994 and TRV 2009 the share of savings from CHP (Fig. 4) includes both renewable and fossil fuels and is positive. With the NRV method the variations of the share of CHP savings can be due to changes in the use of CHP and due to changes in the electric system. Thus, although with NRV we observe a decrease in CHP savings since 2006, it could be due to efficiency improvements of power plants. With TRV we also observe such a decline since 2006, and thus we realize that after removing the influence of the changes of the electric system we conclude that there is a decrease in CHP savings.

Savings due to the increase in the efficiency of fossil fuel power plants show an increasing trend using the proposed TRV method (Fig. 5). Using 1994 as a reference year, we realize that such savings are a greater proportion of primary energy than the savings due to the use of CHP plants.

9 Conclusion

By examining current methods used in energy statistics to calculate primary energy, we concluded that all such 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 thus named these methods as primary energy valuation methods, in order to clarify that the actual primary energy flow is not necessarily used.

We reviewed the current methods and concluded that the different valuation options are: whether to consider that the main use of electricity is heat; whether to consider that the value of heat is different for different flows or technologies; and whether to consider or not that all plants can potentially be CHP plants.

We have proposed a valuation method for primary energy which we named Time Reference Valuation that differs from the existing methods in two fundamental aspects: (i) all primary energy flows are valued as heat required to separately deliver the heat and the electricity; (ii) the efficiencies used in the valuation are those of a given reference year.

We applied the TRV method to Portugal and observed a primary energy decrease since 2005. Whilst other methods also show such a decreases, the TRV method allowed us to conclude that the decrease occurs even when the trend due to the changes in the electric system is removed. This illustrates one main application of the TRV method: to uncover primary energy use trends when the effect of changing the electric system is removed.

The Portuguese case study also permitted us to illustrate another application of the TRV method: to establish a baseline for comparing contributions to primary energy. We concluded that for recent years net electricity imports are a greater contribution to primary energy than savings from efficiency increases in fossil fuel power plants since 1994. We also observed than the contribution from savings by CHP plants has been declining since 2006.

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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Table 1 – Current Primary Energy Valuation Methods

Primary Energy Flow			Valuation of Primary Energy Flow[a]			
			IEA	USEIA	BP	NL Agency
Fuels	Fossil Fuels	To Power Plants	Fuel Heating Value[c]			
		To CHP[b] Plants				
	Renewable Fuels	To Power Plants			Heat to deliver the electricity at 38% efficiency	Heat to deliver the electricity and (if relevant) the heat, at the nominal efficiency[e]
		To CHP[b] Plants				
Non Fuels	Hydraulic and Wind		Electricity Heating Value[d]	Heat to deliver the electricity at the nominal efficiency[e]	Heat to deliver the electricity at 38% efficiency	
	Solar	To PV[b] Plants				
		To CSP[b] Plants	Heat from solar energy			
	Geothermal		Heat from geothermal reservoir			
	Net Electricity Import		Electricity Heating Value[d]		Zero[f]	
	Nuclear		Heat from nuclear energy		Heat to deliver the electricity at 38% efficiency	Heat from nuclear energy[g]

[a] Based on (1) and (12) for IEA, (5) for USEIA, (6) for BP and (7) for NL Agency.

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

[c] For renewable fuels to CHP plants, for BP 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 yearly average efficiency of thermal power plants. USEIA considers only fossil fuel power plants. NL Agency considers fossil fuel and nuclear power plants.

[f] Presumed, given that BP (6) mentions that cross-border electricity is not accounted for.

[g] Presumed, given that NL Agency (7) includes nuclear power plants in the nominal efficiency.

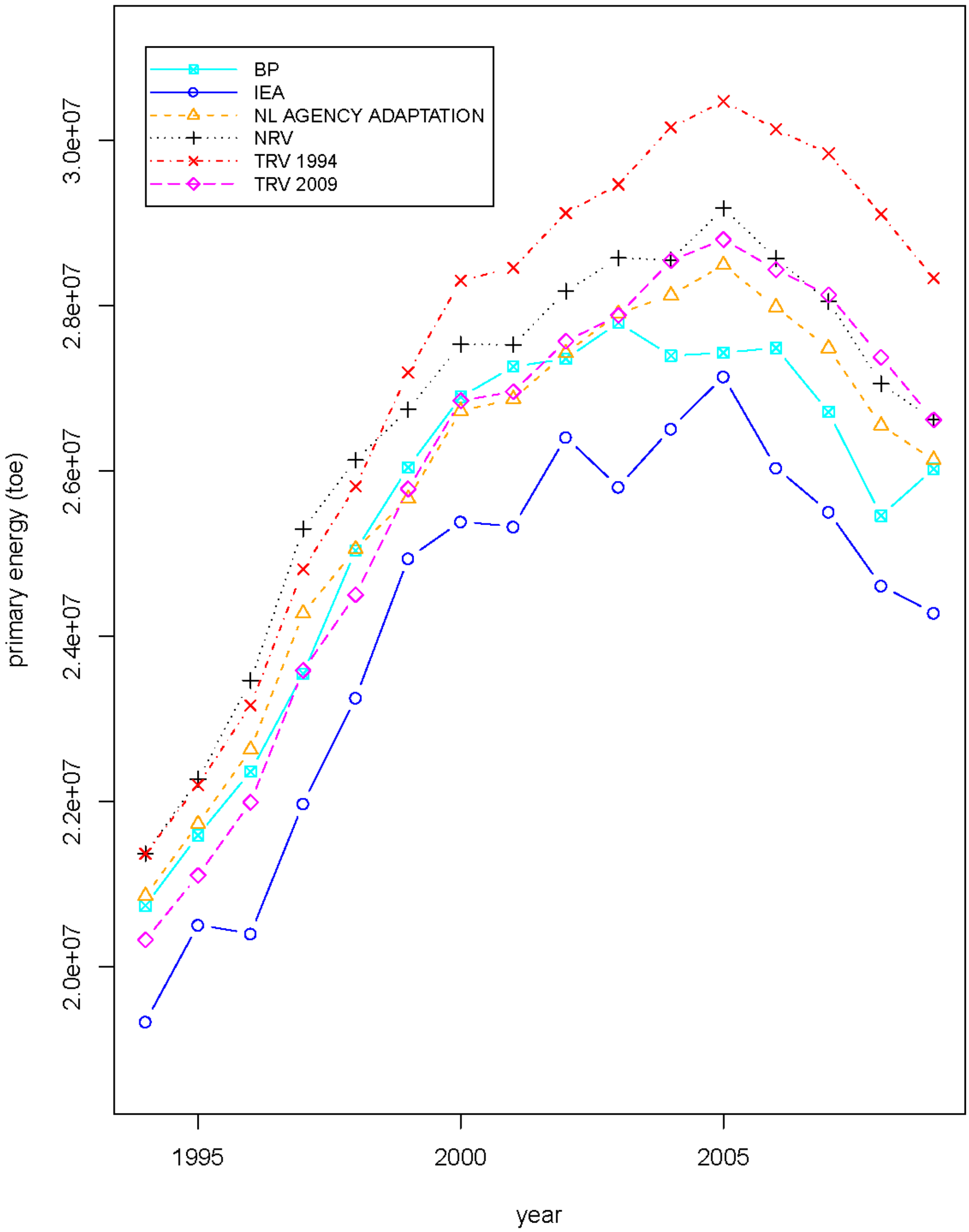

Fig. 1. Total Primary Energy

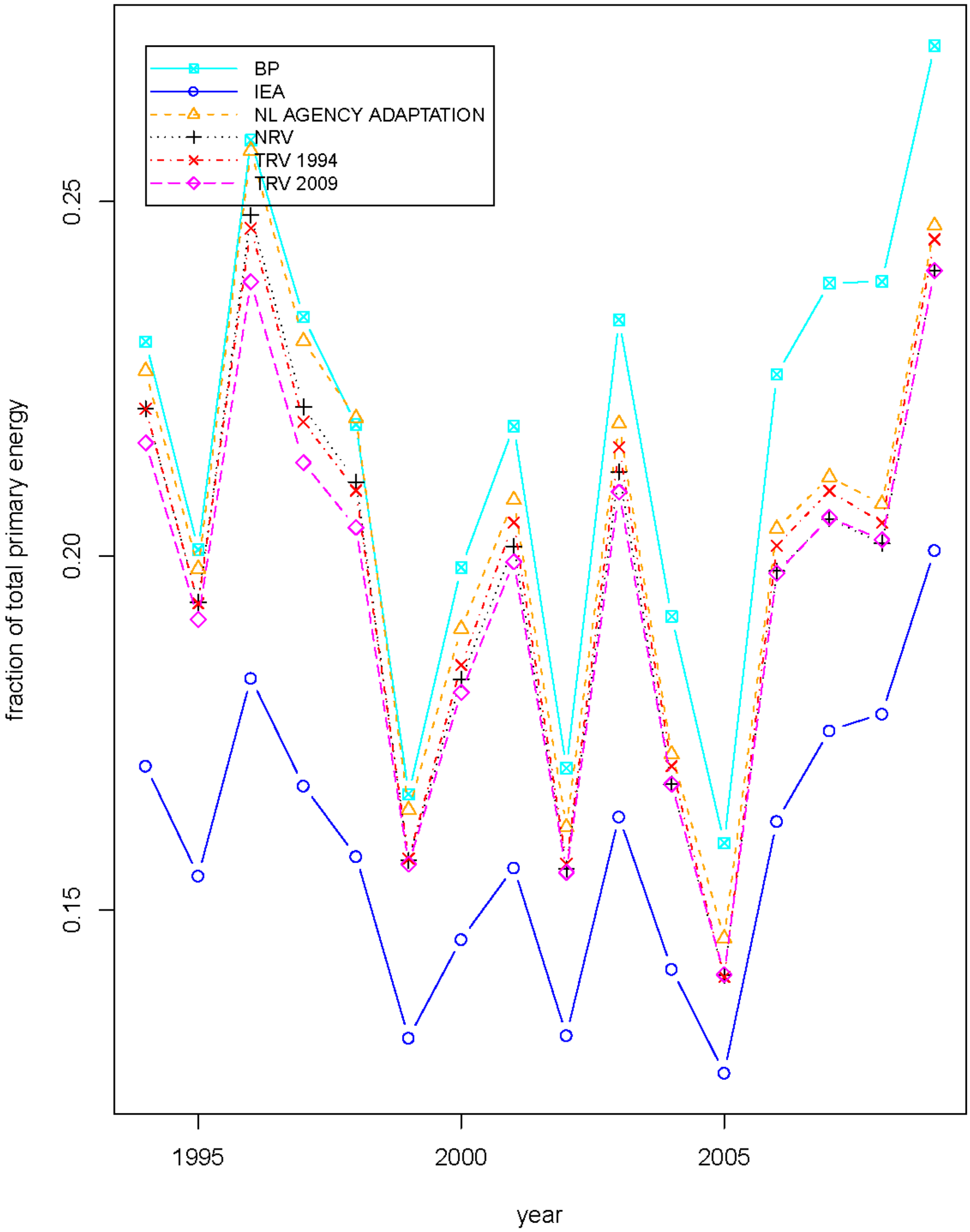

Fig. 2. Share of Renewable Energy

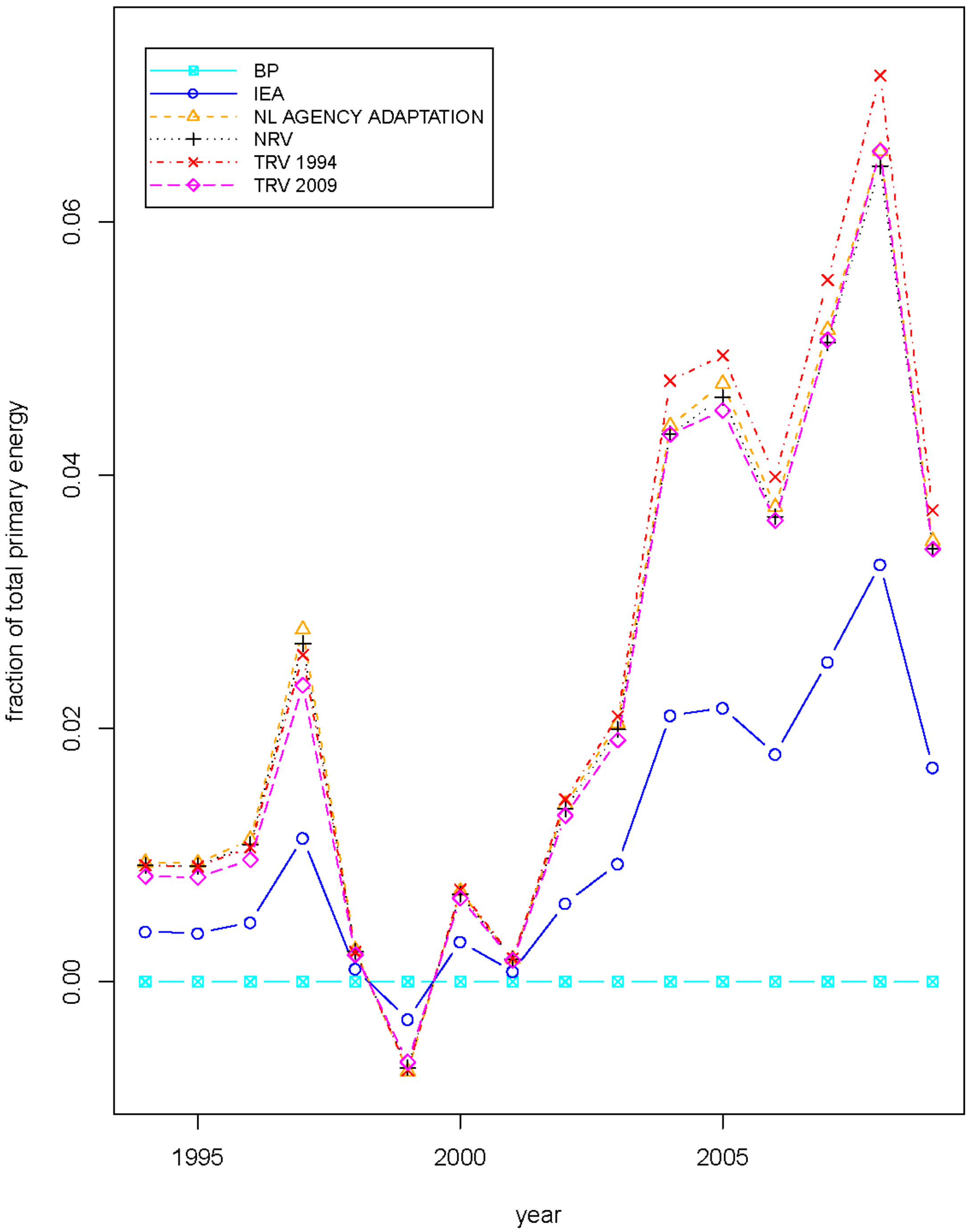

Fig. 3. Share of Net Electricity Imports

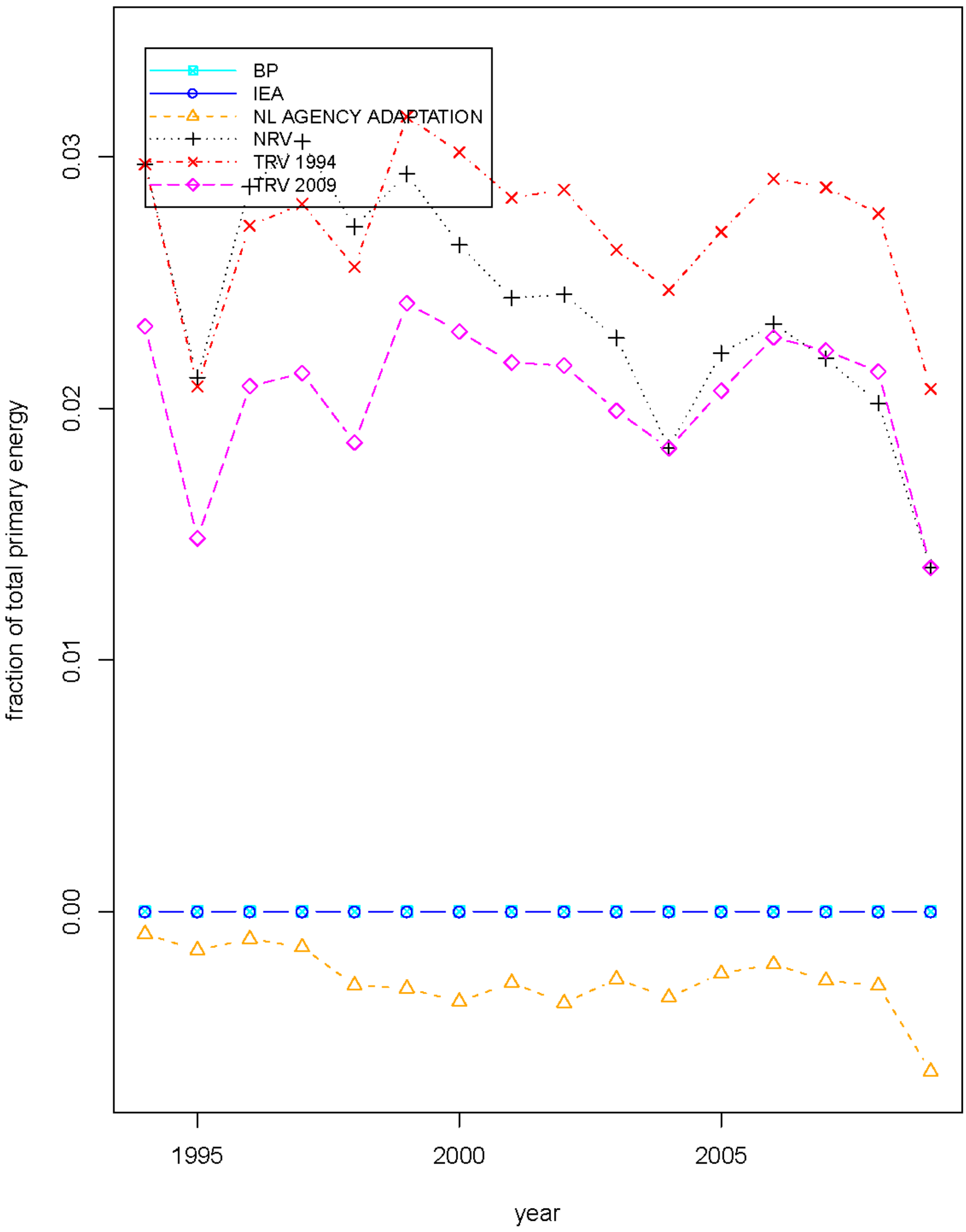

Fig. 4. Share of Savings from CHP Plants

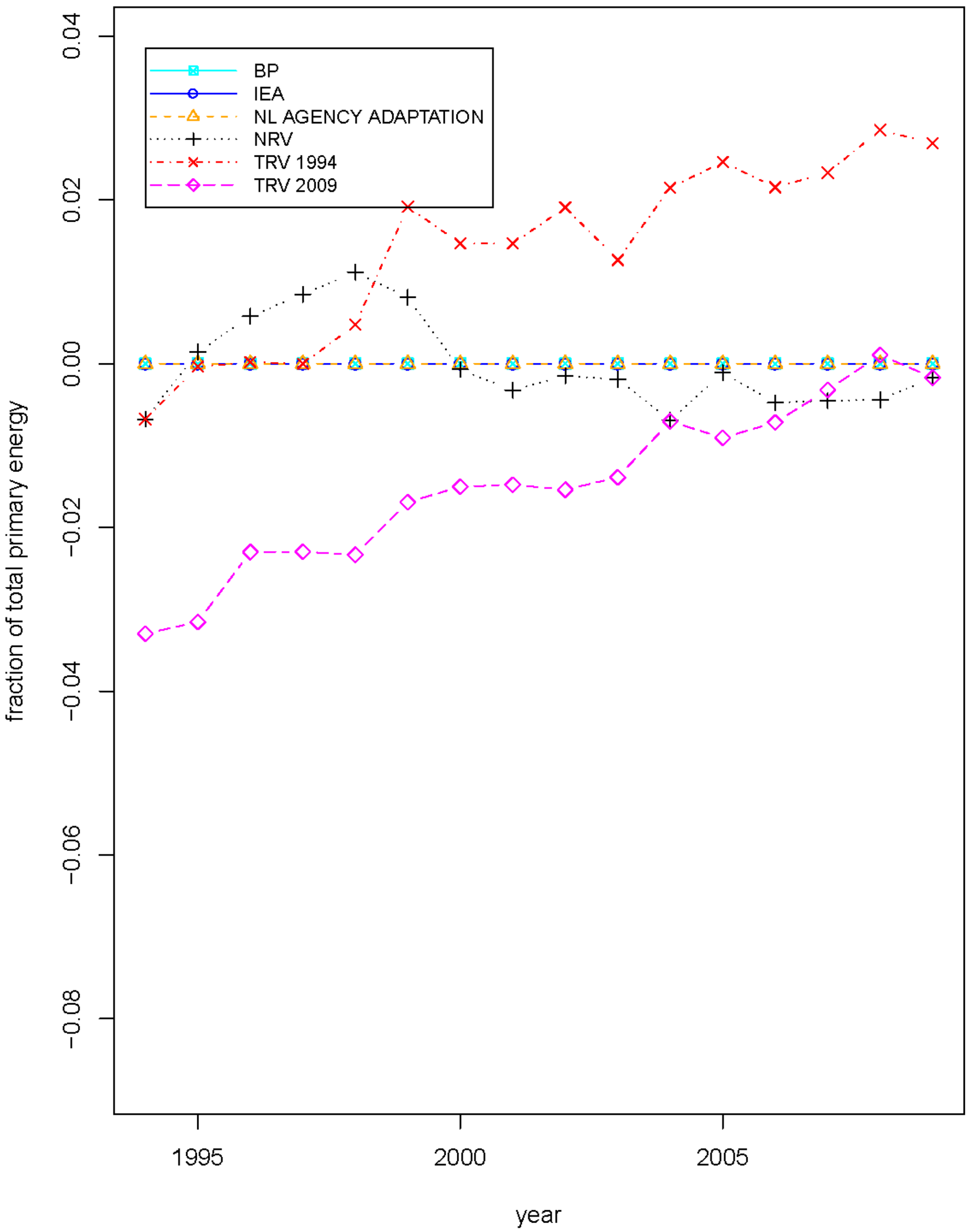

Fig. 5. Share of Savings from Efficiency Increases in Fossil Fuel Power Plants