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Analysis of energy saving potentials in energy generation: Final results

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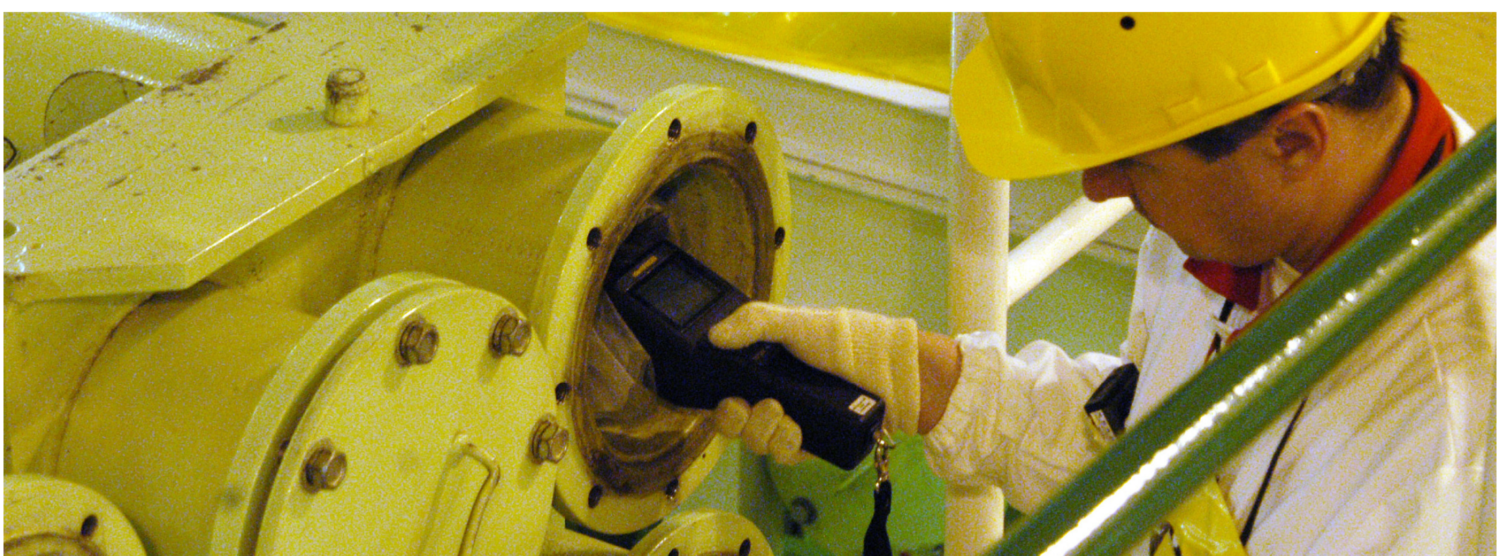

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1. INTRODUCTION

Technical developments continue to increase the energy efficiency of power generation technology, which offers potential primary energy savings. This document provides an estimate of the primary energy savings that can be achieved by applying best available technologies (“BAT”) in the power generation sector.

2. METHODOLOGY AND ASSUMPTIONS

2.1. Power plant fleet baseline

For this analysis, the baseline of the current EU-27 power plant fleet has been taken from the Platt’s PowerVision database[1], which contains details such as age and fuel, of every individual power plant in Europe. The database is current as of the 3rd quarter of 2010. Table 1 provides an overview of the EU-27 capacity by fuel. For the purpose of this analysis, the focus is on technologies fuelled by natural gas, hard coal, heavy oil and soft coal / lignite. These technologies represent 54.6% of all generation capacity in the EU-27. The other large categories of power plants are nuclear, hydro and wind, but these are not relevant for our analysis of primary energy savings.

Table 1: Distribution of operating power generation capacity by primary fuel in EU-27. Source: Platt’s Powervision (Q3 2010).

Primary fuel*	Share in power generation capacity
Natural gas	**22.0%**
Nuclear	16.7%
Hard coal	**15.3%**
Hydro	15.1%
Heavy oil	**9.0%**
Soft coal / lignite	**8.3%**
Wind	8.1%
Other thermal	5.1%
Other	0.4%
Total within scope	**54.6%**

* Capacity within the scope of the analysis is shown in bold.

In this document, natural gas will be referred to as “Gas”, heavy oil will be referred to as “Oil”, and hard coal and soft coal / lignite will be lumped together under the term “Coal”.

2.2. BAT efficiencies

The efficiency of the best available technology (“BAT”) for each of the fuels is taken from the JRC’s Technology Map 2009[2]. The reference efficiencies for Coal and Gas are shown in the following table.

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[1] Platts, 2011. PowerVision database, version 2010 Q3. Platts (The McGraw-Hill Companies), New York.
[2] European Commission, 2009. 2009 Technology Map of the European Strategic Energy Technology Plan (SET-Plan). JRC Scientific and Technical Reports. EUR 24117 EN.

Table 2: Reference efficiencies of the BAT power plant per fuel, for 2007 and 2030. Source: Technology Map 2009.

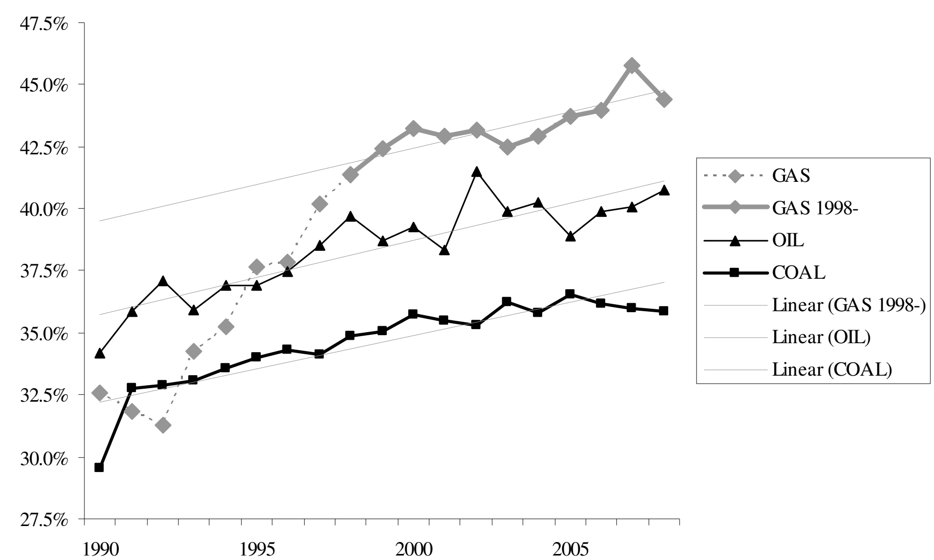
Fuel	BAT	Efficiency 2007	Efficiency 2030
Coal	Puliverised Coal Combustion (PCC)	47%	54%
Gas	Combined Cycle Gas Turbine (CCGT)	58%	65%

Estimation of the BAT efficiency for Oil is based on separate assumptions, as will be explained below.

2.3. Vintage efficiencies

Efficiencies of individual existing power plants are different from the BAT efficiency. Actual efficiency values of individual power plants are generally confidential. However, a realistic estimate can be made, based on the year in which the power plant was built, i.e. the "vintage". Older power plants typically have lower efficiency. This is evident when looking at the efficiency of the entire European electricity system per fuel, as shown in the following figure. The efficiencies in the figure have been calculated using Eurostat data on gross electricity production and primary energy input per fuel.

Figure 1: EU-27 electricity system efficiencies per fuel 1990-2008. Source: Eurostat.

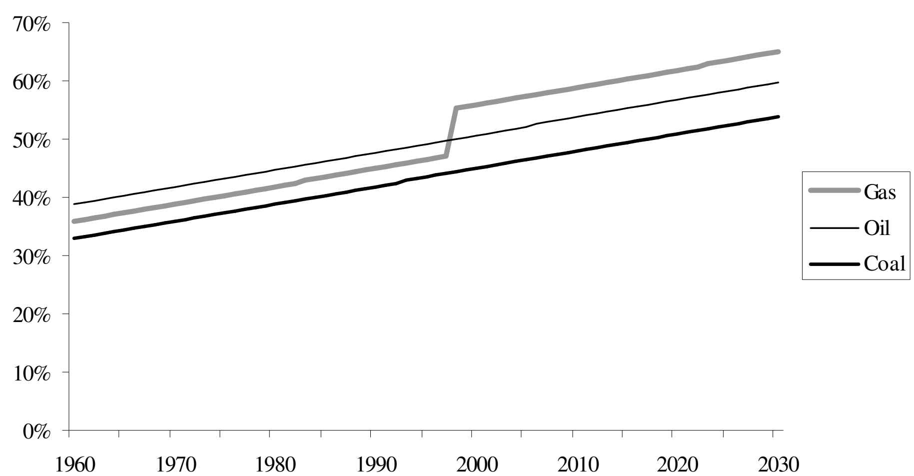


For Coal and Oil, the efficiency has been steadily increasing throughout the entire period. For Gas, the efficiency has first increased more rapidly – related to the widespread deployment of CCGT, followed by an increase at the same pace as Coal and Oil as of 1998. The figure also contains the linear least-squares best-fit lines for the efficiencies of Coal (1990-2008), Oil (1990-2008) and Gas (1998-2008). It is very remarkable that the lines are nearly perfectly parallel, corresponding to an annual increase in efficiency of 0.30 percentage points.

The efficiencies in Figure 1 are *system* efficiencies, i.e. they refer to the entire electricity system at a given point in time. This is different from the *vintage* efficiency, which refers to the best available technology at the given point in time. However, due to the very consistent trend of increasing efficiency in the figure, it is reasonable to assume that vintage efficiencies follow the same trend. This means that a power plant built 10 years ago would have an efficiency that is 10x0.30%=3.0% lower than a power plant built today. Applying this rule to the BAT efficiencies listed in Table 2 makes it possible to construct a full time series of vintage efficiencies of Coal and Gas, both for the past and for the future. Note also that the increase in efficiency between 2007 and 2030 as projected in Table 2 is fully consistent with an annual increase of 0.30 percentage points, which further supports our assumption. In order to account for the significantly lower efficiencies of Gas before 1998, we assume that Gas vintage efficiencies of plants built before 1998 are an additional 8% lower than what they would be if only the annual trend of 0.30% is applied.

The ratio between BAT efficiency in 2007 (from Table 2) and system efficiency in 2007 (from Figure 1, corrected for stochastic fluctuations) is 1.3 both for Coal and for Gas. It is therefore reasonable to assume that the same holds for Oil, which allows for the completion of the time series of vintage efficiencies. The full time series 1960-2030 are shown in the following figure.

Figure 2: Assumed vintage efficiencies for power plants built from 1960 to 2030, for different fuels.



The Eurostat data on which Figure 1 is based, is only for electricity, not for heat. Due to data availability issues it is difficult to make a reliable comparable graph for combined generation of heat and power (CHP). Therefore, in this analysis, CHP is not considered separately. Rather, the primary energy savings resulting from the deployment of best available technologies in electricity-only generation are computed, and then extrapolated to the entire electricity system, including CHP. Since the penetration of CHP is relatively limited, as shown in the Progress Report (deliverable 1.2 in the context of this Administrative Arrangement), this does not significantly affect the results.

2.4. System efficiency

The assumed vintage efficiencies from Figure 2 are applied to all current power plants depending on their age. The resulting system efficiency of the total fleet of coal-fired power plants in 2010 would be 37.5%, which is identical to what would be obtained if the Coal efficiencies in Figure 1 are extrapolated to 2010. For Oil and Gas however, there are differences between the actual system efficiency (as seen in Figure 1) and the system efficiency obtained when applying the vintage efficiencies of Figure 2 to the current fleet. There could be several reasons for this. Most notably, Gas and Oil plants are often operated only during peak-load, which leads to significant ramp-up and ramp-down time, as a result of which the power plant is only operating at maximum efficiency during part of the time. To account for this, a downward correction of 3 and 7 percentage points efficiency is applied to Oil and Gas, plants respectively, when they are integrated in the system.

2.5. Load factors

Primary energy savings depend not only on the efficiency of the various power plants in the fleet, but also on the load factors of the plants. Using Eurostat data on electricity production and the power plant capacity data from PowerVision, the following average load factors are obtained:

Table 3: Average load factors of power plants in EU-27 by fuel. Source: Platt's Powervision (Q3 2010), Eurostat.

Fuel	Load factor %
Coal	66
Gas	67
Oil	16

In this document it is assumed that the same load factors hold in the future.

2.6. Lifetime

The potential total primary energy savings that can be achieved through the replacement of older inefficient power plants with BAT power plants, depend on the timing of the replacement. In one of the scenarios analysed in the next section, it is assumed that power plants are replaced when the end of their projected lifetime is reached. The 2009 Technology Map mentions a technical lifetime of 25 and 40 years for Gas and Coal, respectively. Experience shows that the lifetime of power plants is often extended in practice at a cost far below the investment cost of a new power plant. This is further supported by the fact that the European electricity system contains many operating Gas and Coal power plants of more than 25 and 40 years old, respectively. In this analysis, it is assumed that the lifetime of power plants, after their initial technical lifetime, is extended by 10 years. Lifetime of Oil plants is assumed to be the same as Coal plants. The assumed lifetimes are summarised in the following table.

Table 4: Assumed lifetimes of power plants by fuel.

Fuel	Lifetime Years
Coal	50
Gas	35
Oil	50

2.7. CO_2 emissions

Specific CO_2 emissions per fuel are taken from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[3]:

[3] IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume Energy, Chapter 2: Stationary Combustion.

Table 5: CO_2 emissions per fuel.

Fuel	CO_2 emissions from combustion t / TJ
Coal*	98.3
Gas	56.1
Oil	74.1

* The value for anthracite is used.

3. SCENARIOS

Four scenarios are studied in the remainder of this document.

3.1. Scenario 1: Baseline

The Baseline scenario assumes that the current power plant fleet is maintained in its current condition until 2030. This is obviously not a realistic scenario, since power plants are ageing and many power plants will need to be replaced in the next 20 years. The scenario therefore serves only as a theoretical baseline against which the other scenarios can be compared.

3.2. Scenario 2: Overnight replacement

This scenario assumes that the 2010 power plant fleet is replaced overnight with the best available technologies in 2010. Coal capacity is replaced with BAT Coal capacity, Gas capacity with BAT Gas capacity, and Oil capacity with BAT Oil capacity. Again, this is obviously not a realistic scenario, but it provides a benchmark for the primary energy savings that can be achieved.

3.3. Scenario 3: Gradual replacement

In this scenario, capacity is gradually replaced as and when its lifetime, according to Table 4, is reached. As in Scenario 2 – "Overnight replacement" – capacity is replaced on a like-for-like basis, i.e. Coal capacity is replaced by Coal capacity and so on. The efficiency of the new plant depends on the vintage efficiency applicable to the year in which the replacement is carried out. The vintage efficiencies are taken from Figure 2. Consequently, power plants that are replaced later in time, will be replaced by more efficient power plants than power plants that are replaced earlier in time.

3.4. Scenario 4: PRIMES Reference scenario

This scenario is taken from the *EU Energy Trends to 2030 – Update 2009*[4]. In a model such as PRIMES, the replacement of power plants is determined from a broader economic perspective, rather than the heuristic rules of the previous scenarios. Power plants are replaced when it is optimal for the power plant owners to do so, subject to emissions reductions and other constraints. The fuel of the new power plant is not necessarily the same as the old one,

[4] Capros P, Mantzos L, Tasios N, De Vita A, Kouvaritakis N, 2010. EU energy trends to 2030 - Update 2009. Publications Office of the European Union, Luxembourg.

and the total capacity of fossil-fuel power plants may increase or decrease. For example, a large increase in renewables (e.g. solar, wind) may lead to lower thermal capacity. Hence, even without efficiency improvements, there would be some primary energy savings. Care must therefore be taken when comparing the PRIMES results with the other scenarios.

3.5. Scenario 4: PRIMES Efficiency scenario

This scenario is taken from simulations performed for DG ENER by the PRIMES team. The same comments apply as for the PRIMES Reference scenario

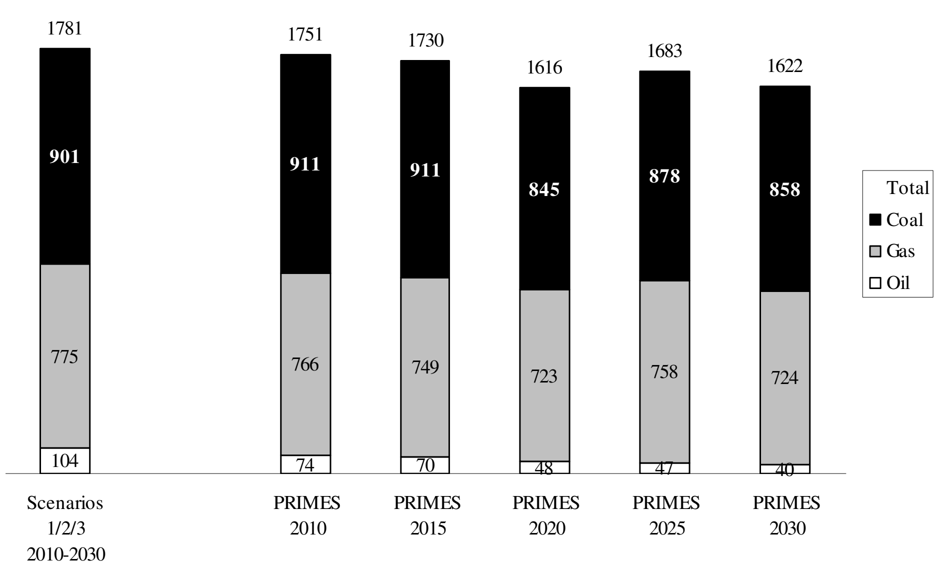
4. RESULTS

4.1. Capacity and electricity production

By construction, the total power generation capacity in Coal, Gas and Oil is constant over time in scenarios 1 ("Baseline"), 2 ("Overnight") and 3 ("Gradual"). The total capacity is 364 GW, of which 156 GW Coal, 132 GW Gas, and 76 GW Oil. Since load factors are assumed constant, power generation is also constant, at 1781 TWh per year, i.e. a total of 35611 TWh over the entire period 2011-2030.

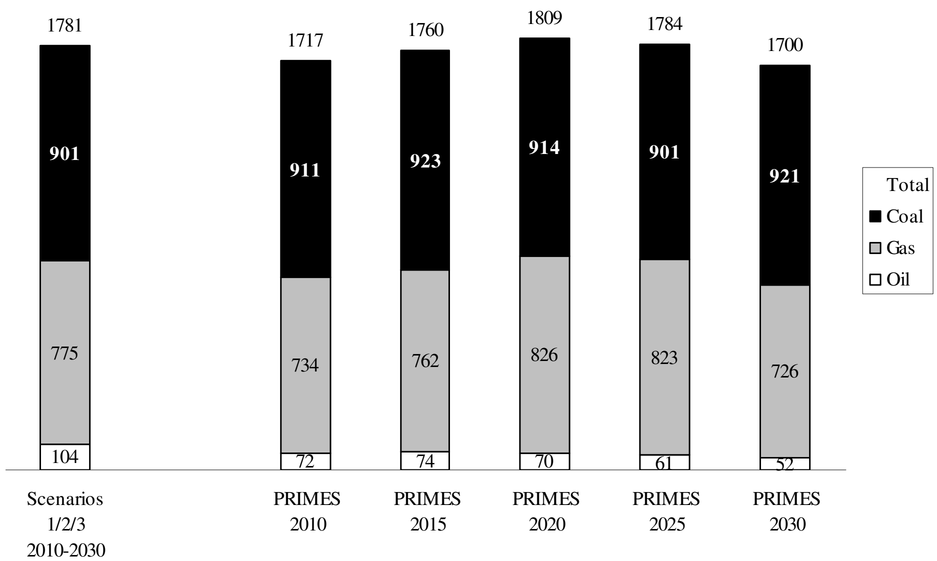
By contrast, as mentioned before, power generation capacity and load factors, and hence electricity production, are not constant over time in scenarios 4 and 5 ("PRIMES Ref" and "PRIMES Eff", respectively). The following two figures compare the constant electricity production mix of scenarios 1/2/3 with the mix projected by the two PRIMES scenarios, respectively. In the PRIMES Reference scenario, electricity generation from fossil fuels exhibits a declining trend, decreasing at 0.4% per year on average. The decline is most pronounced for Oil, which declines at 3.0% per year on average. In this PRIMES Reference scenario, the share of fossil fuels in power generation declines from 53% in 2010 to 40% in 2030. The decline in fossil-fuel power generation in PRIMES needs to be taken into account when comparing with the results of scenarios 1/2/3 in the next section.

Figure 3: Electricity generation from Coal, Gas and Oil in 2010-2030 for the 3 non-PRIMES scenarios, as compared with the PRIMES Reference scenario [TWh / y].



In the PRIMES Efficiency scenario, electricity generation from fossil fuels exhibits a increasing trend up to 2020 and a declining trend afterwards. On balance there is an average decline of 0.1% per year. The decline is most pronounced for Oil, which declines at 1.6% per year on average. There is actually an *increase* in power generation from coal. Overall, the share of fossil fuels in power generation declines from 52% in 2010 to 41% in 2030.Again, the decline in fossil-fuel power generation in PRIMES needs to be taken into account when comparing with the results of scenarios 1/2/3 in the next section.

Figure 4: Electricity generation from Coal, Gas and Oil in 2010-2030 for the 3 non-PRIMES scenarios, as compared with the PRIMES Efficiency scenario [TWh / y].



The next table compares electricity generation from fossil fuels in the two PRIMES scenarios to the value in 2010, expressed in percentage decline.

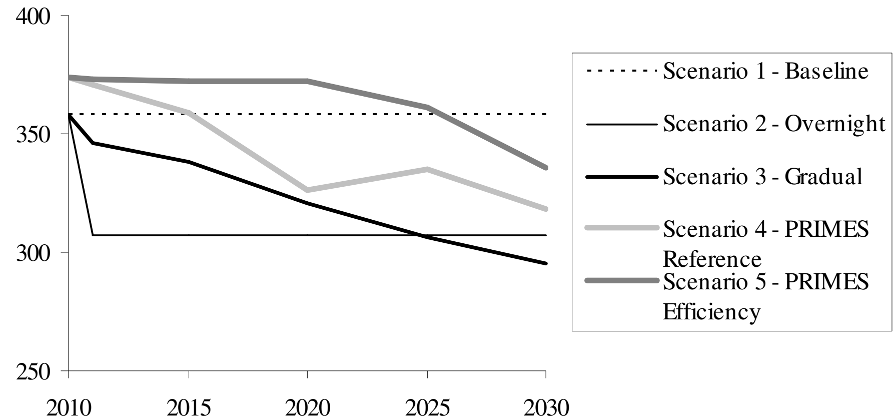
Table 6: Reduction of electricity generation in 2015-2030 in the two PRIMES scenarios, compared to 2010 [Percent]

Scenario	2015	2020	2025	2030
PRIMES Reference	-1.2%	-7.7%	-3.9%	-7.4%
PRIMES Efficiency	2.5%	5.4%	3.9%	-1.0%

4.2. Primary energy savings

The following figure shows the evolution of primary energy consumption by Coal, Gas and Oil power plants in each of the five scenarios. For the Baseline scenario, this value remains constant by construction. For the Overnight scenario, the consumption shows a sharp drop initially, due to the sudden introduction of more efficient power plants, after which it remains constant. The Gradual scenario exhibits a gradual decline, which in 2014 goes below the Overnight scenario, because the Gradual scenario replaces power plants later, when more efficient technologies are available. The PRIMES Reference scenario starts from a slightly higher point (due to differences in calibration parameters) but has overall the same downward trend as the Gradual scenario. The PRIMES Efficiency scenario has a flat profile up to 2020 (presumable because fuel savings take place outside the power generation sector due to energy efficiency measures), after which it follows the same downward trend as the Gradual scenario.

Figure 5: Primary energy consumption of Coal, Gas and Oil in each of the 5 scenarios [Mtoe / y].



The following table provides an overview of the primary energy savings, defined as the difference between the actual primary energy consumption of each scenario, and the primary energy consumption that would have occurred if the initial 2010 value had been maintained throughout the period. It is interesting to observe that the Gradual scenario has the largest savings when considering the difference in annual savings between 2010 and 2030, while the Overnight scenario has the largest total savings over the period. Although the Gradual scenario implements more efficient technologies, the Overnight scenario has higher savings because it starts implementation earlier. The savings of the two PRIMES scenarios consist of two components. The first component represents the savings obtained from deploying more efficient fossil fuel technologies. This number corresponds to the savings obtained in scenarios 1-3. The second component – marked with * - represents the additional savings obtained in the PRIMES scenarios due to the reduction of electricity generation from fossil fuels in these scenario (i.e. the shift away from fossil fuels), as described in the previous section. For the PRIMES Reference scenario, the total savings are slightly below the Gradual scenario, which could already be observed visually in Figure 5. However, only half of this is due to the deployment of more efficient technologies, the other half being due to the reduction in electricity generation from fossil fuels. For the PRIMES Efficiency scenario, the annual savings in 2030 are much lower. Although the savings stemming from efficiency gains are higher than in the PRIMES Reference scenario (34 versus 28 Mtoe/y), the total savings are lower due to a lower reduction of electricity generation from fossil fuels. In fact, , the second component is negative when considering the total over the entire period 2011-2030, because in the PRIMES Efficiency scenario there is initially an increase in electricity generation from fossil fuels.

Table 7: Primary energy savings of the 5 scenarios.

Scenario	**Difference in annual primary energy consumption 2010-2030**		**Total primary energy savings over the period 2011-2030**
	Mtoe / y	% of 2010 consumption	Mtoe
1 – Baseline	0	0%	0
2 – Overnight	51	14%	1024
3 – Gradual	63	18%	756
4 – PRIMES Reference	28+28*=56	7%+7%*=15%	338+308*=646
5 – PRIMES Efficiency	34+4*=38	9%+1%*=10%	377–210*=167

* Savings marked with * are obtained through reduction of electricity generation from fossil fuel capacity, rather than through shifting towards more efficient technologies

As mentioned before, the results of the Gradual scenario are obtained by considering the age and vintage efficiency of every individual power plant in the EU-27, and replacing each power plant with the BAT as and when its lifetime expires. The results can therefore easily be broken down to Member State level, as shown in the following table. In absolute terms, the largest primary energy savings potential is in those Member States with large Coal fleets, most notably the United Kingdom, Germany and Poland. The annual primary energy savings potential in relative terms – shown as a percentage in the table – is largest in Latvia, Estonia and Slovenia. Note again that this analysis is based on the simplifying assumptions described in Section 2, and that further detailed investigation would be required to confirm the potential, hence the information provided here should be treated with care.

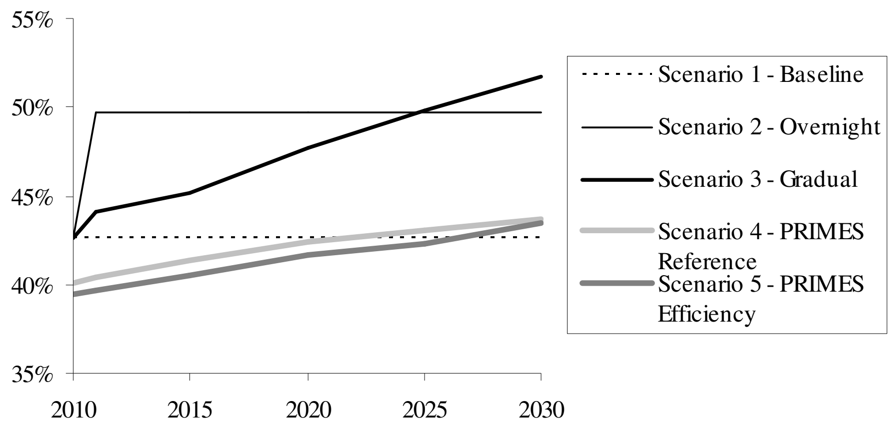
Table 3: Primary energy savings in Scenario 3 (Gradual), broken down to Member State level.

Member State	Difference in annual primary energy consumption 2010-2030		Total primary energy savings over the period 2011-2030
	Mtoe / y	% of 2010 consumption	Mtoe
Austria	0.7	19%	13
Belgium	1.4	20%	17
Bulgaria	1.3	18%	10
Cyprus	0.0	5%	0
Czech Republic	2.9	26%	35
Denmark	0.5	26%	5
Estonia	0.1	30%	1
Finland	0.8	19%	6
France	4.2	20%	55
Germany	7.9	21%	98
Greece	1.0	11%	9
Hungary	1.4	27%	27
Ireland	0.5	9%	6
Italy	6.0	11%	79
Latvia	0.1	31%	3
Lithuania	0.2	28%	3
Luxembourg	0.0	1%	0
Malta	0.0	6%	0
Netherlands	3.4	21%	57
Poland	7.1	20%	76
Portugal	0.1	3%	1
Romania	2.1	22%	18
Slovakia	0.6	27%	10
Slovenia	0.4	30%	4
Spain	3.8	9%	42
Sweden	0.3	19%	3
United Kingdom	16.2	20%	178
Total	**63.0**	**18%**	**756**

4.3. Efficiency

As pointed out above, comparisons of primary energy savings between PRIMES and the other three scenarios are biased because electricity production is not the same. In the previous sections, this was addressed by breaking down the primary energy savings from PRIMES into two components. Another way to study this issue is in Figure 6, where total system efficiencies (all fuels combined) are shown, i.e. the ratio between electricity produced and primary energy consumed. The efficiency in the PRIMES scenarios increases a bit less rapidly than in the Gradual scenario, which is consistent with the previous section, in which it was shown that the PRIMES scenarios have less savings from efficiency gains. This may be due to lower assumed BAT efficiency improvements over time, slower replacement rates of power plants, or other differences in power plant fleet modelling calibration parameters. The efficiency gains in the two scenarios are very similar to each other. The fact that the PRIMES Efficiency scenario shows higher absolute savings from efficiency gains (i.e. the first component in Table 7) compared to the PRIMES Reference scenario, is therefore almost entirely due to its higher share of fossil fuels in the generation mix.

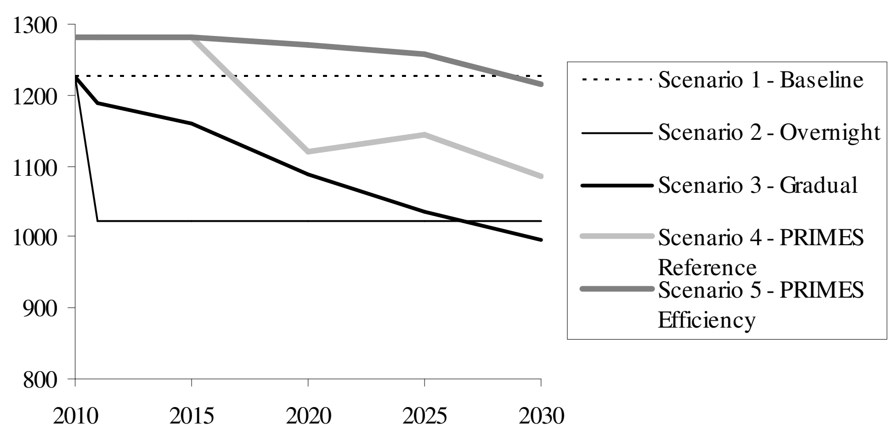
Figure 6: System efficiency of power plants with Coal, Gas and Oil combined, in each of the 4 scenarios [%].



4.4. CO_2 emissions

The primary energy savings mentioned above, lead to a reduction in CO_2 emissions. The following figure and table provide an overview of the reductions. The results are analogous to the results on primary energy savings.

Figure 7: CO_2 emissions* of Coal, Gas and Oil in each of the 4 scenarios [Mt_{CO2} / y].



* Since CO_2 emissions in the PRIMES results are not broken down by fuel, the CO_2 emissions of the PRIMES scenarios have been estimated using the coefficients from Table 5.

Table 8: CO_2 emissions reductions of the 4 scenarios.

Scenario	Difference in annual CO_2 emissions 2010-2030		Total CO_2 emissions reduction over the period 2011-2030
	Mt_{CO2} / y	% of 2010 emissions	Mt_{CO2}
1 – Baseline	0	0%	0
2 – Overnight	203	17%	4069
3 – Gradual	230	19%	2704
4 – PRIMES Reference	196	15%	2225
5 – PRIMES Efficiency	66	5%	321

5. CONCLUSIONS

The introduction of best available technologies in the current fleet of fossil-fuel power generation could generate primary energy savings of 14-18% by 2030, compared to primary energy consumption in 2010.

A gradual replacement of power plants at the end of their lifetime, by the best available technology could lead to around 750 Mtoe of total primary energy savings over the period 2011-2030. Total CO_2 emissions over the period would be reduced by 2.7 Gt. The largest potential is in Member States with large coal-fired power plant fleets.

These potentials are slightly higher than the PRIMES Reference scenario. In addition, around half of the potential in the PRIMES Reference scenario is due to a shift away from fossil fuels, rather than efficiency improvements. The potential is also much higher than the PRIMES Efficiency scenario. In the latter scenario, the shift away from fossil fuels is much less pronounced than in the PRIMES Reference scenario.

The results are strongly dependent on the assumptions made, hence care should be taken when interpreting them.

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