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Development report 02/10

The energy-saving road

Improving socio-economic conditions by reducing rolling resistance. A socio-economic report

Date: May 2010
Authors: Connie Nielsen, NIRAS,
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Status: External report

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The energy-saving road

Improving socio-economic conditions by reducing rolling resistance. A socio-economic report

Date:	May 2010
Authors:	Connie Nielsen, NIRAS, and Trine de Fine Skibsted, NIRAS
Working group:	Ole-Jan Nielsen, NCC Roads, Jørn Bank Andersen, NCC Roads, Bjarne Schmidt, the Danish Road Directorate, and Henrik Thomasen, NIRAS
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PREFACE

NCC Roads A/S determined during the course of an earlier project that a reduction in rolling resistance has great potential for reducing fuel consumption. The present project should be seen as a continuation thereof. The aim is to examine whether it will be possible to achieve any socio-economic gains by using the energy-saving road pavement material rather than that which has been used in the past when planned replacements are made. This, therefore, is a socio-economic analysis of the advantages and disadvantages of a new type of road pavement material designed to reduce rolling resistance without any consequences for friction and, in turn, traffic safety.

The project is the work of Connie Nielsen and Trine de Fine Skibsted from NIRAS A/S. It has been regularly discussed by a focus group comprising Jørn Bank Andersen and Ole-Jan Nielsen (both from NCC Roads A/S), Henrik Thomasen (NIRAS) and Bjarne Schmidt (Danish Road Directorate/Danish Road Institute). Camilla K. Damgaard from NIRAS has verified the quality of the socio-economic analyses. NCC Roads A/S financed the study.

1. SUMMARY

The aim of this analysis is to examine the socio-economic advantages of an energy-saving road pavement material versus a traditional road pavement material. The energy-saving road pavement reduces rolling resistance, which in turn means that any vehicles which travel along the road can save fuel. Replacing the road pavement on all State roads over a period of 15 years will lead to total socio-economic savings of DKK 1.9 billion. These savings will come about as follows:

- The annual fuel consumption will be reduced by 48 million litres, equivalent to a value of at least DKK 250 million.

- The emission of greenhouse gases will be reduced by 45,000 tonnes of CO_2 equivalent annually, which corresponds to DKK 30.5 million.

- NO_x and SO_2 emissions will be reduced. This corresponds to DKK 28 million.

The socio-economic calculation is based on a technical study that has analysed the three relevant measurable parameters for a road pavement, namely the texture (MPD), roughness (IRI) and rigidity (deflection). On the basis of the technical study, it has been assumed in the socio-economic analysis that texture and roughness are what affect the rolling resistance since the impact of rigidity has proved to be marginal.

Chapter 3 examines the correlation between the MPD and IRI on the one hand, and the rolling resistance on the other. It also looks at the relationship between changes in rolling resistance and how these affect changes in vehicle fuel consumption.

Chapter 4 looks at the overall potential fuel savings on the Danish State road network if we assume that all roads have MPD and IRI values that are at least as good as the same values for the energy-saving asphalt. On average, it would be possible to save approximately 3.3% of the fuel used today when vehicles use the State road network by replacing the current road pavement with energy-saving road pavement materials. Measured in terms of fuel, this saving amounts to 47.4 million litres by scaling down the MPD to 0.6, and 6.5 million litres of fuel by scaling down the IRI to 0.9. The maximum values for both MPD and IRI on the entire State road network would require the replacement of 99.8% of the wearing surface on the old roads measured in kilometres.

Since the greatest contribution to potential savings by far comes from the road texture (MPD), Section 4.4 looks only at those stretches of road where it is possible to improve the texture. Splitting the chosen stretches of road into motorways and main roads reveals a potential annual saving of approximately 28 million litres of fuel for motorways, or just under 2.7%, and some 26 million litres on the main roads, or just under 4.6%. The reason for the potentially greater saving in terms of percentage for main roads is that there are relatively more of the measured IRI and MPD values at the higher end of the distribution for the main roads compared with the motorways.

The calculations showing potential fuel savings based on the existing State road network will appear too positive in a socio-economic analysis, since replacing the road pavement with a traditional road pavement material would equally contribute towards a reduction in fuel consumption. We have therefore chosen, in the socio-economic analysis, to compare the switch to energy-saving asphalt with using a traditional type of asphalt.

Chapter 5 sets out the investments required to switch to energy-saving asphalt on the one hand, and to using a traditional type of asphalt on the other. Similarly, the chapter shows the basis of calculation for the savings that may be achieved by moving from a traditional type of asphalt to the energy-saving asphalt.

Chapter 6 sets out the actual socio-economic analysis on the basis of the establishment costs and savings outlined in Chapter 5. The socio-economic analysis shows the gains, expenses and costs involved in replacing a traditional road pavement with an energy-saving road pavement material. In addition to a reduction in fuel consumption, the use of the energy-saving road pavement material also entails a reduction in the emission of greenhouse gases, SO_2 and NO_x. Both the fuel saving and the reduction in environmental impacts are included as gains in the analysis. The following table lists the gains to be achieved if the entire State road network were to be paved with the energy-saving road pavement material. As may be seen, the greatest benefit to be achieved by establishing an energy-saving road pavement stems from the reduction in fuel consumption.

Table 1.1: Potential savings in fuel consumption and environmental impacts on existing State road network

	Amount	Value, DKK millions
Fuel saving	47.6 million litres	250–410[1]
Greenhouse gases, total	44,882 tonnes CO_2 equivalent	30.5
SO_2	306 kg	0.01
NO_x	76,297 kg	28
Gains, total per year		**308.51–468.51**

1: The value depends on the year in question. In the table, the low value applies to 2010 while the high value applies to 2024.

In addition to the establishment costs, the distortion loss resulting from reduced tax proceeds leads to costs in the analysis.

If we assume that all roads in the State road network are paved with the energy-saving road pavement material over a 15-year period, it would result in an economic gain of DKK 187 million per year as shown in Table 1.2. The overall gain over the entire 15-year period is DKK 1.9 billion. The analysis includes a number of sensitivity analyses, and we may conclude on this background that the above-mentioned results are relatively solid.

Table 1.2: Results, DKK million per year

	Scenario 1: Motorways	Scenario 2: Main roads	Scenario 3: All State roads
Annual establishment costs for energy-saving road pavement	130.3	244.8	375.1
Annual establishment costs for traditional road pavement	142.3	223.0	365.4
Additional annual establishment costs for energy-saving road pavement versus traditional road pavement	*-12.0*	*21.8*	*9.8*
Annual value of gains	107.1	89.4	196.5
Annual socio-economic gain	**119.1**	**67.6**	**186.7**

The Danish Road Directorate has set aside an expected average of DKK 330 million per year over the next 10 years for new road pavements. This figure corresponds to the value of the annual savings in fuel and environmental impacts if the entire State road network were to be paved with energy-saving road pavement material, cf. Table 1.1. This level of funding actually means that it would be possible to repave more than 1/15 of the roads in the State road network every year, as presumed in this report. This would mean that the potential gains may be realised earlier, and that the overall socio-economic gain may therefore effectively be greater than DKK 1.9 billion.

2. INTRODUCTION

Road surfaces affect rolling resistance and thereby fuel consumption and CO_2 emissions. NCC Roads A/S has therefore initiated a development project in collaboration with the Danish Road Institute, the Danish Road Directorate and Dynatest Danmark A/S in order to identify potential opportunities for reducing energy consumption in road transport by using special types of road pavement materials. This collaborative effort resulted in the first technical report on energy-saving roads (Schmidt et al., 2009).

NCC Roads now aims to examine whether it would be possible to achieve any socio-economic gains by using the energy-saving road pavement material rather than that which has been used in the past when planned replacements are made. This, therefore, is a socio-economic analysis of the advantages and disadvantages of a new type of road pavement designed to reduce rolling resistance without any consequences for friction and, in turn, traffic safety. The project is being carried out in collaboration with the Danish Road Directorate/Danish Road Institute and NIRAS.

The present report is well in line with the Finance Act agreement for 2010, which provides opportunities for accelerating investments in road pavement and construction work on the Danish State road network as a result of the plan to boost maintenance work during the period 2010–2013. According to the agreement, the aim is also to ensure the most favourable 10-year maintenance strategy in order to minimise life-cycle costs for road pavement and structures.

The Danish Road Directorate has announced that some DKK 150 million were spent on asphalt every year prior to 2009. A sum of DKK 350 million was set aside for capital improvements in 2009, a figure that has since been increased to DKK 650 million every year for the period 2010–2011 (Jacobsen 2010).

The analyses in this report show how investments in energy-saving road pavement materials can achieve gains. The potential saving in energy achievable by using an energy-saving road pavement material would also mean a reduction in greenhouse gases, SO_2 and NO_x. The potential CO_2 reductions are over and above the reductions typically quoted.

3. TECHNICAL PRECONDITIONS FOR ECONOMIC ANALYSIS

Several factors affect rolling resistance as highlighted in the first technical report on energy-saving roads (Schmidt et al., 2010). In the present socio-economic analysis, we will be focusing on the correlation between road pavement and rolling resistance. The aim is to identify the amount of fuel that may be saved by using a new energy-saving road pavement material which is designed to reduce rolling resistance. For this purpose, we require technical data to illustrate the correlation between road pavement and rolling resistance on the one hand, and between rolling resistance and energy consumption on the other.

3.1 Correlation between road pavement type and rolling resistance

There are three factors in particular which may affect rolling resistance. These are the road's texture (Mean Profile Depth), roughness (International Roughness Index) and rigidity (deflection). Since the most important factors as regards rolling resistance are the road's texture (MPD) and roughness (IRI), the socio-economic analysis will focus on these values.

Energy Conservation in Road Pavement Design (ECRPD) has published figures for changes in rolling resistance for speeds of 54 km/h and 90 km/h (Hammarström et al., 2009). The published changes in rolling resistance as a result of changes in MPD and IRI values respectively, are as follows:

Correlation between IRI and rolling resistance
The change in rolling resistance expressed as a percentage for an increase in roughness of 1 metre per kilometre is 1.8% at a speed of 54 km/h and 6% at a speed of 90 km/h.

Correlation between MPD and rolling resistance
The change in rolling resistance expressed as a percentage for an increase in macro texture of 1 mm is 17% at a speed of 54 km/h and 30% at a speed of 90 km/h.

The correlations between IRI and rolling resistance on the one hand, and between MPD and rolling resistance on the other, are assumed to be linear. We have deemed these hypotheses reasonable for the interval of measured IRI and MPD values available for the existing Danish State road network.

According to a memo from the Danish Road Directorate (2008b), the average speed on the trunk roads in 2005 was measured at 83 km/h in Jutland and at 80 km/h elsewhere in the country. The memo also states that the average speed on the motorways has been measured at 115 km/h where the speed limit is 110 km/h, and at 120 km/h on motorways where the speed limit is 130 km/h. Since the average speeds are not far off 90 km/h, we have chosen to employ the correlation between IRI and MPD on the one hand and rolling resistance on the other for this speed.

3.2 Correlation between rolling resistance and fuel consumption

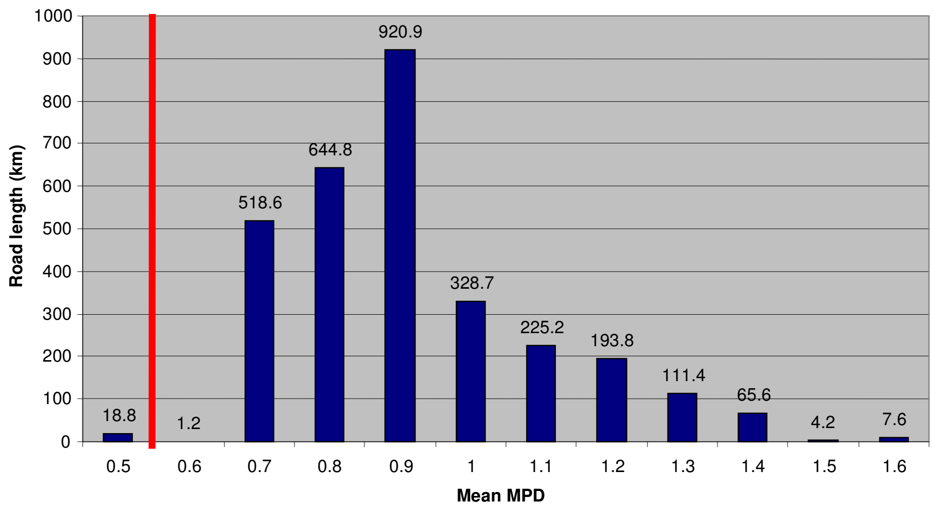
There are also various hypotheses regarding the correlation between rolling resistance and fuel consumption. According to a German study, an increase in rolling resistance of 10% leads to an increase in fuel consumption of 4%, or to an increase of 3% according to a study from Gdansk in Poland. On the basis of the prudence principle, we have chosen to employ the latter hypothesis, namely that fuel consumption increases by 3% when rolling resistance increases by 10%.

4. THE CONDITION OF THE STATE ROAD NETWORK

We have chosen to use the existing values for MPD and IRI on the Danish State road network as a basis for assessing the potential savings in fuel consumption. The traffic on the State road network constitutes 45% of the total traffic in Denmark (Danish Road Directorate, 2008). The total length of the State road network as of 1 January 2008 has been measured at 3,817 km, or 5% of the entire road network in Denmark. The Danish Road Directorate regularly collects a series of data concerning the Danish State road network, and these figures have been employed in the present study.

4.1 Measured values for texture and roughness on the Danish State road network

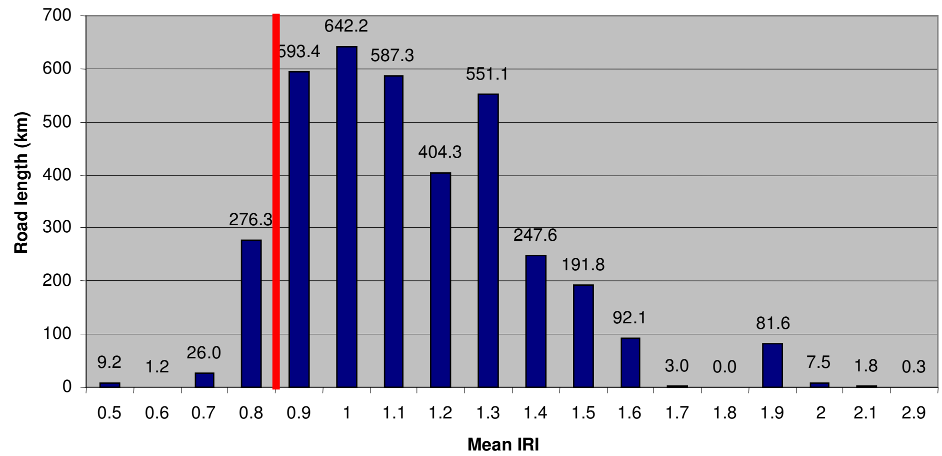
The measured values for texture (MPD) and roughness (IRI) on the Danish State road network both show a widespread distribution as illustrated in Figures 4.1 and 4.2, respectively.



Note: The column labelled 0.5 includes values which are greater than 0.5 and smaller than or equal to 0.6, so the interval for the measured values is (0.5;0.6].

Source: Danish Road Institute

Figure 4.1: Measured values for MPD (Mean Profile Depth) on the Danish State road network



Note:	The column labelled 0.8 includes values which are greater than 0.8 and smaller than or equal to 0.9, so the interval for the measured values is (0.8;0.9].
Source:	Danish Road Institute
Figure 4.2:	**Measured values for IRI (International Roughness Index) on the Danish State road network**

We can improve the current values for MPD and IRI on the Danish State road network so that the maximum values are MPD = 0.6 and IRI = 0.9. These values represent a reasonable level for energy-saving asphalt. This corresponds to scaling down all MPD values that exceed 0.6 in Figure 4.1 to being equal to maximum 0.6. As far as the current measured values for the State road network are concerned, this condition has been met for those values represented in the column to the left of the red line in Figure 4.1, since this covers the interval (0.5;0.6] and therefore includes a value of 0.6. Similarly, we can scale down all IRI values which exceed 0.9 to being equal to 0.9 in Figure 4.2. Once all values for MPD and IRI have been set to a maximum of 0.6 and 0.9 respectively (i.e. all the values to the right of the vertical red lines in Figures 4.1 and 4.2 are scaled down to these values), we can examine the amount of fuel that could be saved on the Danish State road network.

The values of 0.6 and 0.9 for MPD and IRI respectively were selected on the basis of an estimate of what may be achieved by renovating a stretch of road. If the MPD value becomes too low, there is a risk that the road may no longer meet the friction requirements stipulated by Danish road regulations. An MPD value of 0.3 is one of the critical parameters that will cause the Danish Road Institute to earmark a stretch of road for friction measurements. By selecting an MPD value of 0.6, it is felt that the risk of subsequent friction problems will be minimal. A higher IRI value would mean cars would ‘bounce’ considerably, which also has a negative impact on vehicles. The IRI value is therefore already included in a user cost expression that forms part of the planned road pavement replacement strategy for the Danish State road network. An IRI value of 0.9 is felt to be a reasonable roughness which may be achieved by means of careful levelling and alignment when renovating existing roads. In summary, there is a limit as to how low the MPD value may be and how high the desired IRI value may be in relation to the necessary replacement of the road pavement for maintenance reasons. Likewise, there is a limit as to how much the IRI value can be reduced depending on the costs involved in renovating the road.

4.2 Calculating the fuel saving per vehicle

On the basis of the improved MPD and IRI values, an example may be used to illustrate the principle behind the calculation to determine the fuel saving that may be achieved when a single vehicle travels along a stretch of road.

Let us assume that a vehicle travels at 90 km/h, which results in a 30% change in rolling resistance for an increase in the macro texture value (MPD) of 1 mm. Let us further assume that the MPD value is 1.0, so that a reduction in the MPD value to 0.6 contributes towards the saving in fuel as follows:

- The percentage-wise change in rolling resistance = (1-0.6) * 0.30 = 0.12

- The percentage-wise change in fuel consumption = 0.03*(0.12/0.10) = 0.036

The contribution made by the improvement in MPD value thus comprises 3.6% of the vehicle's total fuel consumption.

Let us assume that a vehicle travels at 90 km/h, which results in a 6% change in rolling resistance for an increase in roughness (IRI value) of one metre per kilometre. Let us further assume that the measured IRI value for the stretch of road whereupon the vehicle is travelling is 1.00. An improvement in the road's IRI value to 0.9 would, given the above assumptions, allow us to calculate the vehicle's fuel consumption as follows:

- The percentage-wise change in rolling resistance = (1.00-0.9) * 0.06 = 0.006

- The percentage-wise change in fuel consumption = 0.03*(0.006/0.10) = 0.0018

The contribution made by the improvement in the IRI value thus comprises 0.2% of the vehicle's total fuel consumption.

The total fuel saving achieved by changing both the MPD and IRI values, as shown in the two calculations above, is thus 3.8%.

4.3 Potential fuel savings on existing Danish State road network

The above example involving a single vehicle may be generalised to include all vehicles travelling on the Danish State road network. An overall assessment of the total potential fuel saving across the entire Danish State road network shows that it would be possible to save 3.3% of the fuel consumed today.

The saving of 3.3% is calculated by assuming that the values for texture and roughness are improved for all stretches of the Danish State road network so that they are max. 0.6 for MPD and 0.9 for IRI. In fact, these requirements would involve changes to all stretches of the Danish State road network except a single stretch of road measuring 9.2 km, for which the values of MPD and IRI are already below the above-mentioned values. The 3.3% saving therefore presupposes that 99.8% of the existing kilometres on the Danish State road network be replaced.

The 3.3% saving is based on the current fuel consumption being just short of 1,620 million litres given the measured values for annual average daily traffic (AADT), the number of kilometres that make up the Danish State road network and an assumption that a vehicle is capable of doing 11.83 km to the litre. By scaling down all MPD values in Figure 4.1 to a maximum value of 0.6, it would be possible to save approx. 47.4 million litres of fuel. Similarly, it would be possible to save 6.5 million litres of fuel by scaling down the IRI values to a maximum of 0.9 as shown in Figure 4.2.

4.4 Selected stretches of the Danish State road network in relation to texture

Since the greatest potential fuel saving lies in improving the texture of the road pavement (MPD), this section is based on the criterion that the MPD value must be equal to max. 0.6. This limit value alone would mean replacing large parts of the Danish State road network, and the roads to be replaced would also see their IRI value improved, thus bringing further gains. Figure 4.3 provides an overview of the share of the Danish State road network that would require replacing when the criterion is roads where MPD > 0.6.

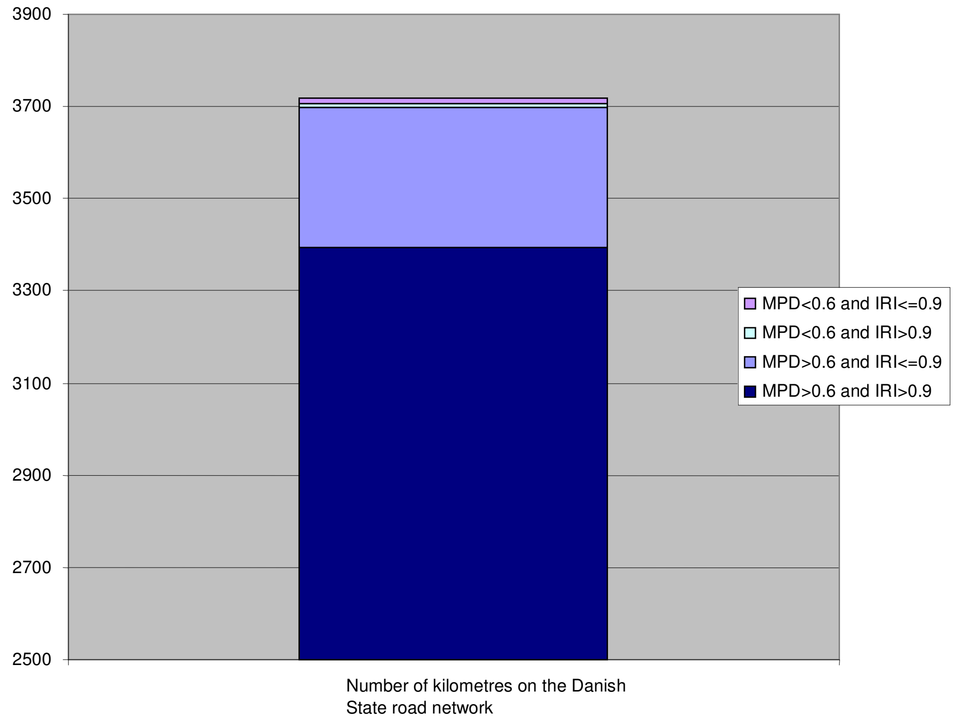


Figure 4.3: The Danish State road network divided according to criteria for the road pavement's texture (MPD) and roughness (IRI)

There are only three stretches of road where the measured MPD value is lower than the maximum value of 0.6. These stretches measure just under 19 km in total as shown in Figure 4.3.

Since the stretches of road which, if replaced, would contribute towards fuel savings as a result of improvements in *both* MPD and IRI represent the greatest potential, we have chosen to divide these still further. We have therefore taken all those stretches of the Danish State road network where the texture may be improved (i.e. MPD > 0.6), and divided these as shown in Table 4.1 according to whether or not the roughness value can *also* be improved (i.e. IRI <= 0.9 or IRI > 0.9).

Table 4.1: Annual saving in fuel consumption on the Danish State road network divided according to motorways and main roads and the values for texture (MPD) and roughness (IRI)

	Motorways		Main roads	
	Saving	Distance in km	Saving	Distance in km
MPD > 0.6 and IRI > 0.9	22.4 million litres (2.7%)	829	26.0 million litres (4.6%)	2566
MPD > 0.6 and IRI ≤ 0.9	5.3 million litres (2.4%)	254	0.2 million litres (2.3%)	50

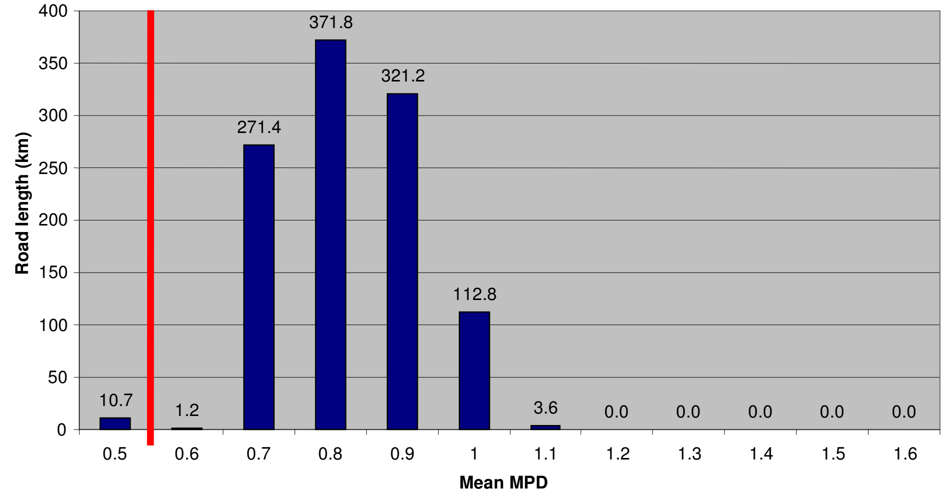
Note: There are only three stretches of the Danish State road network with MPD values of less than 0.6. The MPD values for these stretches are all greater than or equal to 0.5. The three stretches add up to 18.8 km in total.

As shown in Table 4.1, it would be possible to optimise both the MPD and IRI values for most stretches of the Danish State road network. This applies to 829 km of motorway and 2,566 km of main road. In these cases, a total saving of 22 million litres of fuel could be made on the motorways, along with 26 million litres on the main roads, which corresponds, respectively, to 2.7% and 4.6% of the total fuel consumption calculated for the stretches of road in question.

The values in Table 4.1 indicate that the total saving in fuel consumption on the existing Danish State road network of 3.3% mentioned in Section 4.3 may be split, so that the greatest potential for saving fuel is represented by the main roads followed by the motorways. The reason that the saving is greater in percentage terms for the main roads seems to be that there are relatively more of the measured values for MPD and IRI at the higher end of the distribution as illustrated by Figure 4.1 and Figure 4.2 in the subsequent Section 4.5.

4.5 Measured values for texture and roughness on the Danish State road network divided according to motorways and main roads

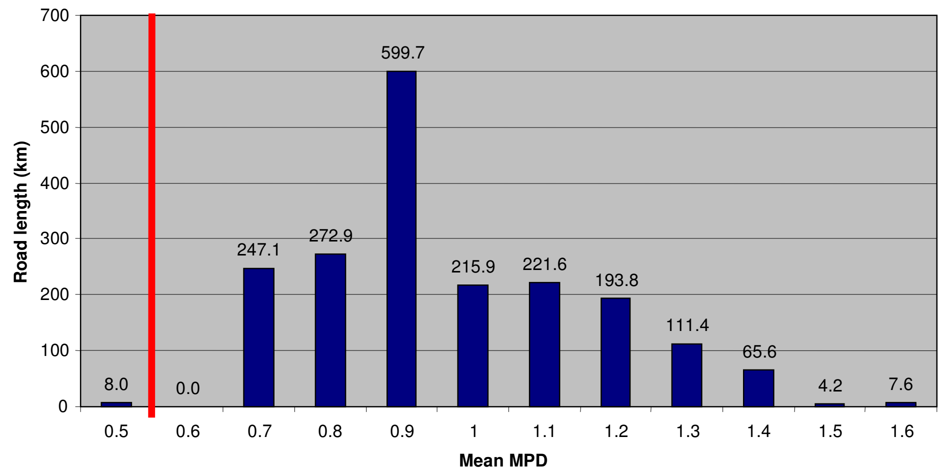
Splitting the MPD and IRI values from the total Danish State road network into values for motorways and main roads respectively shows that there are relatively more of the measured values for the main roads at the higher end of the distribution. Figure 4.4 and Figure 4.5 illustrate the distribution of measured MPD values for the Danish State road network divided into main roads and motorways. Similarly, Figure 4.6 and Figure 4.7 show the measured IRI values for motorways and main roads, respectively.



Source: Danish Road Institute

Note: The column labelled 0.5 includes values which are greater than 0.5 and smaller than or equal to 0.6, so the interval for the measured values is (0.5;0.6].

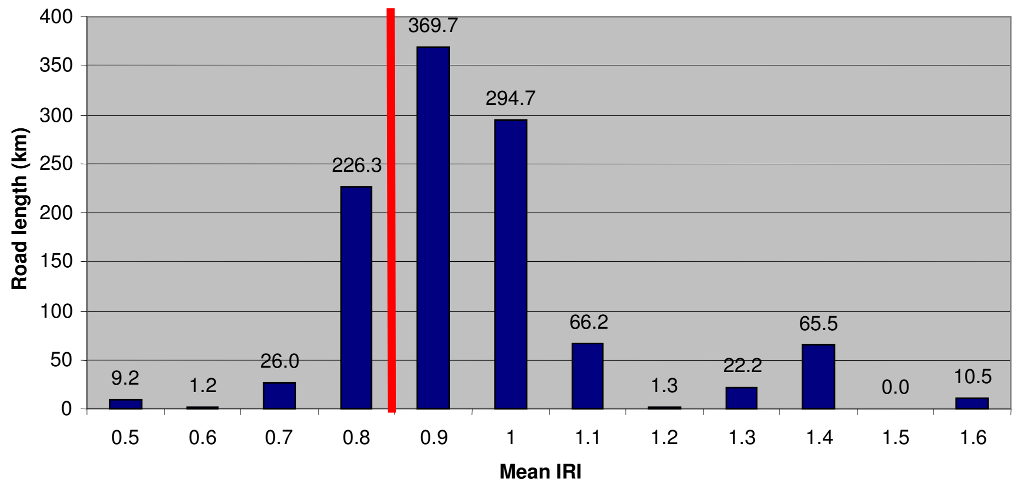
Figure 4.4: Measured values for MPD (Mean Profile Depth) on motorways



Source: Danish Road Institute

Note: The column labelled 0.5 includes values which are greater than 0.5 and smaller than or equal to 0.6, so the interval for the measured values is (0.5;0.6].

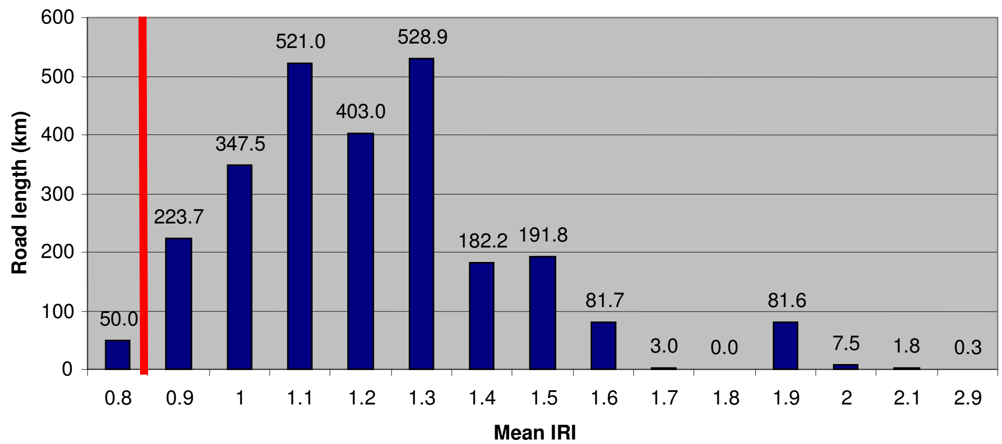
Figure 4.5: Measured values for MPD (Mean Profile Depth) on main roads



Note: The column labelled 0.8 includes values which are greater than 0.8 and smaller than or equal to 0.9, so the interval for the measured values is (0.8;0.9].

Source: Danish Road Institute

Figure 4.6: Measured values for IRI (International Roughness Index) on motorways



Note: The column labelled 0.8 includes values which are greater than 0.8 and smaller than or equal to 0.9, so the interval for the measured values is (0.8;0.9].

Source: Danish Road Institute

Figure 4.7: Measured values for IRI (International Roughness Index) on main roads

5. INVESTMENTS AND SCENARIOS

Considerable establishment costs are usually involved the year a stretch of road is repaved. The new pavement, however, may bring about such advantages that it pays for itself over the course of its lifetime, thus representing a worthwhile investment over time.

The actual establishment costs and the resultant advantages may be subject to selected points of reference. As the roads would also be improved by the use of a traditional road pavement material, we have chosen to compare the energy-saving asphalt with a traditional type of asphalt. Replacing the road surface with a traditional road pavement material is a point of reference when examining the benefits of replacing the surface with an energy-saving material.

5.1 Investments

We need to look at the effect of the energy-saving asphalt in relation to the type of pavement material that would otherwise be used on the roads. Maintenance work on the Danish State road network currently lags behind, and it appears unrealistic to expect the existing pavement to last for another 15 years, which is the lifetime of the new energy-saving asphalt. We therefore need to hold all factors associated with the energy-saving asphalt (establishment costs, fuel savings, etc.) up against a new surface layer of traditional asphalt, which, it is assumed, would be used if the energy-saving asphalt were not to be employed.

For this reason, we need to examine the establishment costs associated with both the energy-saving asphalt and a traditional asphalt type. The establishment costs for 1 km of asphalt are shown in the table below. In determining the establishment costs, it has been assumed that the load-carrying capacity of the existing stretch of road is adequate. No reinforcement layer costs have thus been included in any of the suggested solutions.

Table 5.1: Establishment costs, 2010-DKK (NCC 2010)

		Lifetime, years	Million DKK/km	Annuity DKK/km[3]
Energy-saving	Motorway, 4 lanes[1]	15	1.10	106,362
	Motorway, 6 lanes[2]	15	1.59	152,895
	Main road	15	0.86	83,240
Traditional	Motorway, 4 lanes	16	1.23	113,677
	Motorway, 6 lanes	16	1.77	163,410
	Main road	15	0.80	77,459

[1]: A 4-lane motorway with two lanes in each direction.
[2]: A 6-lane motorway with three lanes of 11.5 m in width in each direction.
[3]: A real interest rate of 5% has been employed.

In the case of motorways, the establishment costs for traditional asphalt are higher than those for energy-saving asphalt due to the thickness of the wearing surface. The expected lifetime of the energy-saving road pavement, however, has been conservatively estimated at a year less than the expected lifetime of the traditional road pavement. If we look at lifetime versus establishment costs, however, the establishment costs for the energy-saving road pavement are still lower than those associated with a traditional road pavement as may be seen in the last column of Table 5.2.

The same does not, however, apply to the main roads. Here, the traditional road pavement is less costly than the energy-saving material, partly because the traditional road pavement employs a more inexpensive wearing surface, and partly because the consequential costs associated with creating a smooth road are greater per kilometre due to the smaller width of the main roads, i.e. there are fewer square metres across which the costs may be spread.

Table 5.2 shows the total establishment costs associated with repaving the entire Danish State road network.

Table 5.2: Total establishment costs, 2010-DKK, factor prices

		Km road	Total establishment costs, DKK million
Energy-saving	Motorway	1,093	1,207
	Main road	2,624	2,267
Traditional	Motorway	1,093	1,347
	Main road	2,624	2,111

Note: All motorways are assumed to be four-laned.

5.2 Savings

In Chapter 4, the potential fuel savings were assessed on the basis of the existing road network. It would be a mistake, however, to employ this savings potential in the socio-economic analysis. The reason, among others, is that the socio-economic analysis presupposes that the road pavement will be replaced on a successive basis over the estimated lifetime of 15 years. The current condition of the roads, however, means that it is unrealistic to believe that the existing roads will last for this long. The socio-economic analysis is therefore carried out as a partial analysis, where the advantages of a new energy-saving road pavement are assessed in relation to the roads being repaved using a traditional road pavement material.

Table 5.3: Assumptions about IRI and MPD for energy-saving road pavement and traditional road pavement in the socio-economic analysis

	Energy-saving road pavement		Traditional road pavement	
	IRI	MPD	IRI	MPD
Motorways (MW)	0.9	0.6	1.0	0.86
Main roads (MR)	0.9	0.6	1.0	1.00

The energy-saving road pavement has an IRI value of 0.9 and an MPD value of 0.6 as described in Chapter 4. By comparison, it has been assumed that the traditional road pavement has an IRI value of 1.0 along with an MPD value of 1.0 for main roads and 0.86 for motorways. The MPD value of 0.86 on the motorways was chosen because it corresponds to the current average MPD value for motorways. In Section 6.2.1 the potential for saving fuel has been calculated for the energy-saving road pavement compared with a traditional road pavement using the method described in Section 4.2.

5.3 Scenarios

The analysis assesses the socio-economic costs using three different scenarios. The analysis is further supplemented by a number of sensitivity analyses.

Specifically, we examine the following scenarios:

1. Successive replacement of all motorway surfaces over a 15-year period.

2. Successive replacement of all main road surfaces over a 15-year period.

3. Successive replacement of all road surfaces across the entire Danish State road network over a 15-year period.

The results of the analysis are further enriched by means of sensitivity analyses that examine the discount factor, the fuel cost and the value of externalities.

6. SOCIO-ECONOMIC ANALYSIS

In the following, the total costs of paving the roads with an energy-saving asphalt material will be examined in relation to the gains that may be achieved. We will do so from a social perspective, i.e. the economics will be examined from the point of view of all Danish citizens as opposed to a single driver, whose interest lies in saving fuel.

A socio-economic approach differs from a personal finance approach in several ways. Firstly, taxes and duties are not included as they are simply seen as the transfer of funds between two parties. Secondly, various effects whose value is not immediately obvious in the market are included. The reason is that certain things, although they may not have a price, may still be of value to individual citizens. Thirdly, prices are calculated as market prices in order to reflect the willingness of consumers to pay. Specifically, this adjustment is calculated by means of the net tax factor (NTF)[1] and the tax distortion loss.

6.1 Preconditions

The socio-economic analysis has been carried out in accordance with the existing guidelines already published by the Danish Ministry of Finance (Danish Ministry of Finance, 1999). The conditions which are expected to be recommended in the new guidelines soon to be published by the Ministry have, however, been employed. This means, among other things:

- Net tax factor (NTF) of 1.35
- Tax distortion factor of 0.2
- Real discount rate of 5%

Using the Ministry of Finance guidelines as a basis provides a uniform frame of reference when the results are assessed in the context of other analyses.

The expected increase in energy prices is a determining factor when it comes to calculating the value of the fuel saving. Similarly, we need to calculate the value of environmental effects, i.e. greenhouse gases, SO_2 and NO_x. Prices are

[1] The NTF expresses the average tax level. By adjusting a factor price (price without taxes/duties and VAT) by the NTF we obtain a market price that reflects the willingness of consumers to pay. The tax distortion loss is further explained in Section 6.2.2.

determined on the basis of the conditions stipulated by the Danish Energy Agency (Danish Energy Agency, 2009).

6.2 Socio-economic gains and costs

The table below sums up the gains and costs of the initiative. The analysis will, as mentioned in the previous chapter, be carried out as a partial analysis in which we examine the difference between traditional asphalt and energy-saving asphalt.

Table 6.1: Gains and costs

Gains	Costs
Reduced fuel consumption	Establishment costs
Fewer emissions of greenhouse gases, N_2O, SO_2 and NO_x	Loss of taxes/duties
Less noise	

6.2.1 *Pricing and extent of gains*

The energy-saving asphalt leads to a reduction in fuel consumption. It is only the actual price of the fuel which is included since, as mentioned earlier, duties and taxes are seen purely as a transaction involving two parties.

Input for the analysis comprises the total fuel saving for every stretch of road. The total fuel saving is estimated on the basis of the annual average daily traffic (AADT) on the Danish State road network. The AADT is an average figure, and lorries are converted to car equivalents. The fuel saving is split into petrol and diesel based on consumption figures for 2009, with 61% of all engine fuel being diesel and the remainder petrol.

Table 6.2 sums up the total fuel saving. As may be seen, it would be possible to save a total of 47.6 million litres of fuel if the energy-saving pavement material were to be used to pave the entire Danish State road network. This calculation is based on the entire Danish State road network being repaved during the time period in question, with the MPD value being 0.6 and the IRI value 0.9. The fuel saving is calculated in relation to the alternative scenario wherein roads are repaved using a traditional asphalt material. It has been assumed that the new traditional asphalt surface has an IRI value of 1.0 for both motorways and main roads, and an MPD value of 1.0 for main roads. The MPD value for motorways has been set at the current average of 0.86. The values cannot, therefore, be directly compared with the fuel savings in Table 4.1 since the savings here were calculated in relation to actual IRI and MPD values.

Table 6.2: Total fuel saving for energy-saving surface in relation to new traditional asphalt surface

	Km road	Total fuel saving, million litres	Of which petrol, million litres	Of which diesel, million litres
Motorways	1,093	25.9	10.1	15.8
Main roads	2,624	21.7	8.4	13.2
Total	*3,717*	*47.6*	*18.5*	*29.1*

Note: Traditional asphalt has an IRI value of 1.0. The MPD value for the new traditional asphalt surface on main roads is 1.0, and for motorways it is the current MPD average value, cf. Section 5.2.

Since the analysis is not confined to the consequences of establishing an energy-saving road pavement over a single year, we need to take into account the fact that fuel prices will not remain constant. The Danish Energy Agency regularly publishes lists of anticipated future energy prices. The figure below shows the anticipated development in the price of petrol and diesel up until 2030. The prices are given in 2010 prices and exclude taxes and duties.

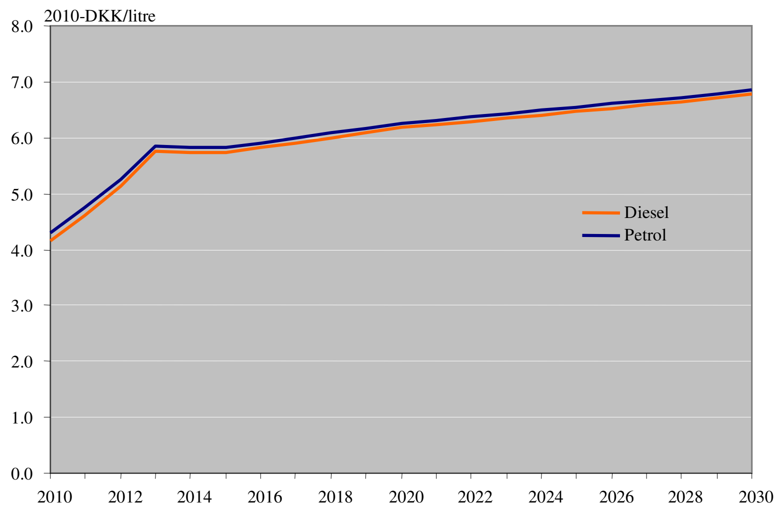


Figure 6.1: Developments in the price of petrol and diesel
Source: Danish Energy Agency (2009)

A reduction in fuel consumption also results in a reduction in the emission of particles and greenhouse gases. These emissions have a negative impact on health and the environment, and a reduction is therefore a bonus for society.

Table 6.3: Reduction in emissions

	Scenario 1: Motorways	Scenario 2: Main roads	Scenario 3: All state roads
Fuel saving, million litres	25.9	21.7	47.6
CO_2, tonnes	24,273	20,331	44,604
Methane (CH_4), kg	1,197	1,114	2,311
Laughing gas (N_2O), kg	266	474	740
Greenhouse gases total, tonnes CO_2-equivalent	24,380	20,501	44,882
SO_2, kg	166	139	306
NOx, kg	46,218	30,079	76,297

We can put a price on the value of the reduction in pollution based on official key figures as replicated in Table 6.4. The emission of CO_2, for instance, is independent of fuel type. The same, however, does not apply to methane.

Table 6.4: Emission coefficients

Fuel	Category	Road type	CO_2	CH_4	N_2O	SO_2	NO_x
			kg/GJ	g/GJ	g/GJ	g/GJ	g/GJ
Petrol	Cars	Main road	73	4.0	1.7	0.5	108
Petrol	Cars	Motorway	73	3.6	0.8	0.5	139
Diesel	Cars	Main road	74	1.9	2.2	0.5	298
Diesel	Cars	Motorway	74	0.9	2.0	0.5	320

Source: Danish Energy Agency (2009)

A price is put on the reduction in emissions using key figures from the Danish Energy Agency as show in Table 6.5.

Table 6.5: Price of externalities

	2010-DKK/kg
NO_x outside town	53.26
NO_x in town	53.26
SO_2 outside town	84.15
SO_2 in town	128.90
CO_2 (2010)	0.11
CO_2 (2011)	0.14
CO_2 (2012)	0.19
CO_2 (2013 onwards)	0.24

Note: N_2O and CH_4 are converted to CO_2-equivalents.
Source: Danish Energy Agency (2009)

On the basis of the above, we can put a price on the value of externalities from fuel. The value, for instance, of the externalities from 1 litre of petrol is DKK 0.46 in 2010 as seen in Table 6.6. This value is significantly lower than the duty on a litre of petrol, which currently stands at DKK 4.25 per litre. One reason for the fact that the duty – which in reality is meant to reflect the value of the externalities associated with the consumption of 1 litre of fuel – is markedly higher than the value of the externalities is that there are other externalities which cannot be priced in addition to the emission of particles. Examples include noise and congestion.

Table 6.6: Examples of calculations to find the value of externalities

Fuel	Emission kg/litre	Value DKK/litre
CO_2	73 kg/GJ x 0.033 GJ/litre = 2.409 kg/litre	
CH_4	4 g/GJ x 0.033 GJ/litre /1000 = 0.000132 kg/litre	
N_2O	1.7 g/GJ x 0.033 GJ/litre / 1000= 0.0000561 kg/litre	
Greenhouse gases, total	2.429 kg/litre	2.429 kg/litre x 0.11 DKK/kg = 0.27 DKK/litre
SO_2	0.5g/GJ x 0.033 GJ/litre /1000= 0.0000165 kg/litre	84.15 DKK/litre x 0.0000165 kg/litre = 0.001 DKK/litre
NO_x	108 g/GJ x 0.033 GJ/litre /1000= 0.0036 kg/litre	53.26 DKK/litre x 0.0036 kg/litre = 0.19 DKK/litre
Total		***0.46 DKK/litre***

An increase in traffic means an increase in the total fuel consumption. This means that the potential fuel saving resulting from the energy-saving road pavement is also greater. The Danish Infrastructure Commission (2008) has estimated that the traffic on the Danish State road network will increase by approximately 70% up to 2030. This corresponds to an annual increase in traffic of 2.2%.

Conversely, there will be a tendency to overestimate the expected fuel saving since more and more energy-efficient cars point towards a reduction in fuel consumption. The government is working to increase the energy-efficiency of cars through the EU. Today, new vehicles are significantly more energy-efficient than was the case just a few years ago, as may be seen in Figure 6.2. New vehicles, for instance, will travel 5.5% further on a litre of fuel today than just a year ago. This, together with the current demand for lighter vehicles that use less energy, means that the overall energy-efficiency of the fleet is improving all the time.

For the purpose of this analysis, we have assumed that the potentially greater fuel saving resulting from the anticipated increase in traffic makes up for the anticipated improvements resulting from more energy-efficient vehicles. The analysis presupposes that the current AADT level applies, and that vehicles are as energy-efficient as they are today.

Figure 6.2: Energy efficiency of new cars
Source: Statistics Denmark (2009)
Note: In Figure 6.2 the Danish term '*Km/liter'* is 'Km/litre*'* in English, '*Husholdningerne'* is 'Households*'* and '*Erhvervene*' means the 'Businesses*'*.

The energy-saving road pavement will be a modified type of the thin noise-reducing wearing surface, so it may be assumed that the noise-reducing effect will be considerable. It has been documented that noise has a negative influence on house prices and on the health of the Danish population. The energy-saving road pavement gives rise to less noise, and therefore benefits house owners as a result of an increase in the value of their homes. The data basis in the present analysis, however, is too shaky for us to include such gains in the calculations. The negative health effects have been documented, among others, by the Danish Ministry of the Environment in 2006. The Ministry found that up to 2,200 people living in Denmark were affected by heart disease every year as a result of traffic noise, and that up to 500 of those affected died as a result (Ohm et al. 2003).

6.2.2 *Pricing and extent of costs*

The actual establishment costs for the new road pavement are shown in Table 5.1. In addition to the establishment costs, we also have to take into account the tax distortion loss, which arises because the State incurs costs when it finances new measures by collecting taxes and/or duties. The staff responsible for collecting taxes and duties, for instance, must be paid. Similarly, the tax distortion loss must be taken into account in connection with the loss of tax revenues. Since fuel is subject to taxation, a reduction in fuel consumption will lead to a reduction in tax revenues for the State.

There is no indication that the costs of maintenance, winter preparedness, traffic accidents, etc. will be affected by the new type of asphalt as compared with paving the roads using a traditional material.

It has been assumed that consumers will not change their consumption habits as a result of a reduction in their fuel budget, so no additional effects have been taken into account.

6.3 Results

The two tables below show the annual investments for motorways and main roads respectively. All costs are fixed 2010 prices and have thus been adjusted for inflation. Since the expected lifetimes of the two types of road pavement materials differ, it has been presupposed that 1/15 of the road pavement will be replaced every year in the case of the energy-saving material, and 1/16 every year in the case of the traditional material.

If the motorway surfaces were to be replaced with the new energy-saving road pavement material, then the establishment costs may be divided by 1/15 a year. This would mean an investment of DKK 130 million a year. Altogether, replacing all motorway surfaces with the energy-saving road pavement would cost DKK 1,954 million. Since DKK 130 million in 15 years' time will not correspond to DKK 130 million in today's figures, future amounts will be discounted. The sum of future amounts (present value) indicates the amount to be set aside today for establishment costs over the period in question. This figure may be converted to an annual amount (annuity) which indicates the share of the total investment to be paid every year.

Fuel savings increase gradually as the share of the road network that is repaved using the energy-saving pavement material increases. Furthermore, the price of fuel and CO_2 do not remain constant. We must therefore convert the resultant gains into an annual value (annuity) in order to be able to compare them with the annual establishment costs. As may be seen in the table below, the annual value of gains (adjusted for tax losses) from the motorways increases from DKK 11.1 million in 2011 to DKK 240 million in 2025. Total gains for the entire period amount to DKK 1,112 million. Converting this figure into an annual gain gives a value of DKK 107 million.

Table 6.7: Establishment costs and annual costs for motorways, million 2010-DKK

Energy-saving road pavement	SUM	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Share to be replaced	1	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	
Establishment costs	1,954.4	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	
Present value, establishment costs	1,352.4	124.1	118.2	112.6	107.2	102.1	97.2	92.6	88.2	84.0	80.0	76.2	72.6	69.1	65.8	62.7	
Annuity		130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	130.3	
Traditional road pavement	**SUM**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Share to be replaced	1	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16
Establishment costs	2,181.0	136.3	136.3	136.3	136.3	136.3	136.3	136.3	136.3	136.3	136.3	136.3	136.3	136.3	136.3	136.3	136.3
Present value, establishment costs	1,477.3	129.8	123.6	117.8	112.1	106.8	101.7	96.9	92.3	87.9	83.7	79.7	75.9	72.3	68.8	65.6	62.4
Annuity		142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	142.3	
Other costs and gains	**SUM**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Tax loss	201.5	1.7	3.4	5.0	6.7	8.4	10.1	11.8	13.4	15.1	16.8	18.5	20.1	21.8	23.5	25.2	
Fuel saved	1,728.4	10.9	24.2	40.4	53.8	67.2	81.8	96.9	112.4	128.3	144.7	160.5	176.8	193.3	210.1	227.3	
Greenhouse gases	174.9	0.9	2.3	4.4	5.9	7.3	8.8	10.3	11.7	13.2	14.7	16.2	17.6	19.1	20.6	22.0	
NO_x	124.2	1.0	2.1	3.1	4.1	5.2	6.2	7.2	8.3	9.3	10.4	11.4	12.4	13.5	14.5	15.5	
SO_2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	
Total gains	1,826.5	11.1	25.1	42.9	57.2	71.4	86.8	102.7	119.0	135.7	152.9	169.6	186.7	204.0	221.7	239.7	
Present value of gains	1,111.6	10.6	22.8	37.1	47.0	55.9	64.8	73.0	80.5	87.5	93.9	99.2	104.0	108.2	112.0	115.3	
Annuity		107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	

The corresponding results for main roads may be seen in Table 6.8. The total cost of the energy-saving road pavement is DKK 3,673 million, which corresponds to an annual value of DKK 245. The corresponding value for the traditional road pavement is DKK 223 million. The corresponding gains achievable by using the energy-saving road pavement material compared with the traditional material amount to DKK 89 million per year as shown in the table below.

Table 6.8: Establishment costs and annual costs for main roads, million 2010-DKK

Energy-saving road pavement	SUM	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Share to be replaced	1	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	1/15	
Establishment costs	3,672.6	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	
Present value, establishment costs	2,541.4	233.2	222.1	211.5	201.4	191.8	182.7	174.0	165.7	157.8	150.3	143.2	136.3	129.8	123.7	117.8	
Annuity		244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	244.8	
Traditional road pavement	**SUM**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Share to be replaced	1	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16
Establishment costs	3,417.6	213.6	213.6	213.6	213.6	213.6	213.6	213.6	213.6	213.6	213.6	213.6	213.6	213.6	213.6	213.6	213.6
Present value, establishment costs	2.314.9	203.4	193.7	184.5	175.7	167.4	159.4	151.8	144.6	137.7	131.1	124.9	118.9	113.3	107.9	102.7	97.9
Annuity		223.0	223.0	223.0	223.0	223.0	223.0	223.0	223.0	223.0	223.0	223.0	223.0	223.0	223.0	223.0	
Other costs and gains	**SUM**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Tax loss	168.8	1.4	2.8	4.2	5.6	7.0	8.4	9.8	11.3	12.7	14.1	15.5	16.9	18.3	19.7	21.1	
Fuel saved	1,447.7	9.1	20.2	33.9	45.1	56.3	68.5	81.2	94.1	107.4	121.2	134.5	148.1	161.9	176.0	190.3	
Greenhouse gasses	146.8	0.7	1.9	3.7	4.9	6.2	7.4	8.6	9.9	11.1	12.3	13.6	14.8	16.0	17.3	18.5	
NO_x	99.1	0.8	1.7	2.5	3.3	4.1	5.0	5.8	6.6	7.4	8.3	9.1	9.9	10.7	11.6	12.4	
SO_2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total gains	1,525.2	9.3	21.0	35.8	47.7	59.6	72.5	85.8	99.4	113.3	127.7	141.7	155.9	170.4	185.1	200.2	
Present value of gains	928.2	8.8	19.0	30.9	39.3	46.7	54.1	60.9	67.2	73.0	78.4	82.8	86.8	90.4	93.5	96.3	
Annuity		89.4	89.4	89.4	89.4	89.4	89.4	89.4	89.4	89.4	89.4	89.4	89.4	89.4	89.4	89.4	

Since the existing road pavement has a limited lifetime, it will be necessary to pave the roads using a traditional road pavement material unless the energy-saving road pavement material is used. This means that the actual establishment costs for the energy-saving road pavement comprise only the difference between the establishment costs for the energy-saving material versus the traditional material. Since the lifetimes of the two types of road pavement materials differ, we need to compare the annual investments on the basis of their respective annuities. In Table 6.7, the lifetime of the energy-saving pavement material has been set to 15 years so that the annual establishment costs correspond to the value of the annuity. The lifetime of the traditional road pavement material, on the other hand, has been set to 16 years. Here, the annual establishment costs are lower than the annuity, which runs for 15 years during the forecast period.

In order to provide an overview, Table 6.9 sums up the total costs and savings from Table 6.7 and Table 6.8 for the forecast period of 15 years. Table 6.9 shows that if the establishment costs alone are used as the basis for the calculation, it would be possible to achieve an annual gain of DKK 12 million by replacing the surface of the motorways with an energy-saving road pavement material.

Conversely, using the material on the main roads would involve an annual cost of DKK 22 million. If we look at the establishment costs for all roads in the Danish State road network, then the use of the energy-saving road pavement material would involve an annual cost of DKK 10 million. The energy-saving road pavement, however, brings about large gains regardless of road type. These gains will, in all cases, exceed any additional establishment costs associated with the energy-saving material compared with the traditional material. Paving all the roads in the Danish State road network with the energy-saving road pavement material would result in a socio-economic gain of DKK 187 million per year. By far the greatest share of this gain comes from a reduction in fuel consumption.

Table 6.9: Costs and savings calculated as annuities, million DKK per year

	Scenario 1: Motorways	Scenario 2: Main roads	Scenario 3: All State roads
Annual establishment costs for energy-saving road pavement	130.3	244.8	375.1
Annual establishment costs for traditional road pavement	142.3	223.0	365.4
Additional annual establishment costs for energy-saving road pavement versus traditional road pavement	*-12.0*	*21.8*	*9.8*
Annual value of gains	107.1	89.4	196.5
Annual socio-economic gain	**119.1**	**67.6**	**186.7**

For reasons of method, the above calculation has been carried out such that the gains achieved by the measure are given as an annual value. The reason is that the traditional and energy-saving asphalts have different lifetimes. If we disregard this factor, we can calculate the total socio-economic gains for the entire period. Over the 15-year period, the present value of the total gains for both motorways and main roads would amount to DKK 2 billion. Establishing the energy-saving road pavement as opposed to the traditional road pavement requires an additional outlay of DKK 100 million, measured as the difference in present value for the two different establishment costs. In total, the socio-economic gain which may be achieved by this measure is therefore DKK 1.9 billion.

6.3.1 *Sensitivity analyses*

It has been assumed, in the analyses, that the price of fuel will rise over time in accordance with the projections published by the Danish Energy Agency. The gains to be made from the fuel saving are significant, and sensitivity analyses have therefore been carried out to show how the result would be affected if the price of fuel did not rise over time. The price of fuel, in other words, is assumed to be DKK 4.3 per litre for petrol and DKK 4.2 per litre for diesel for the entire period.

A discount rate of 5% has been applied in the analysis. The higher the discount rate, the less future amounts are weighted. A discount rate of 5% is the rate currently recommended for use in socio-economic analyses[2]. A sensitivity analysis has been carried out using a discount rate of 3% and 7% respectively in order to see how the choice of discount rate affects the overall results.

In the analysis, the value of the reduced emissions was set using key figures from the Danish Energy Agency. As mentioned previously, using this approach means that the values calculated for emissions are markedly lower than the current tax level. At present, the tax on petrol and diesel comprises a tax on CO_2 and a tax on energy. The applicable tax rates are shown in the table below. The analysis therefore also examines how the results would be affected if the current tax level were to be used as an estimate when valuing externalities.

Table 6.10: Tax on energy and CO_2 (2010 level)

	Energy tax (øre/litre)	CO_2 tax (øre/litre)	Total tax (øre/litre)
Petrol	388.1	37.3	425.4
Diesel	277.4	41.3	318.7

Source: The Danish Ministry of Taxation (2010) and the Danish Tax Panel (2009)

The results of the above-mentioned sensitivity analyses are shown in the two tables below. As may be seen, the annual socio-economic gains remain positive whatever parameter is adjusted. A lower discount rate means that future effects are weighted more heavily, with the result that the annual value increases. The reverse is true when the discount rate increases. A constant fuel price has the greatest effect on the results, which are more than halved. The reason is that the gain to be made from the fuel saving decreases if the fuel price is kept constant over time. The value of externalities increases significantly if set to be equal to current tax levels, and this therefore has a positive effect on the results.

Table 6.11: Annual value (million DKK) for motorways when central parameters are adjusted

	Motorways	Difference in relation to reference
Reference	119.1	-
Constant fuel price	57.8	-61.3
Discount rate 3%	126.0	6.8
Discount rate 7%	112.7	-6.4
Value of externalities corresponds to tax	161.0	41.9

[2] The guidelines published by the Danish Ministry of Finance in 1999 recommend the use of a discount rate of 6%. These guidelines, however, are currently being revised and a rate of 5% is expected to be recommended in future.

Table 6.12: Annual value (million DKK) for main roads when central parameters are adjusted

	Main roads	Difference in relation to reference
Reference	67.6	-
Constant fuel price	47.4	-20.2
Discount rate 3%	74.1	6.5
Discount rate 7%	61.5	-6.1
Value of externalities corresponds to tax	103.0	35.4

In addition to the sensitivity analyses above, we have looked at the effect of a change in establishment costs for the energy-saving road pavement on the annual socio-economic gain. The results are shown in the figure below. It has been assumed that the expenditure associated with the traditional road pavement remains constant. In the case of the main roads, the cost of the energy-saving road pavement may be increased by just below 30% before resulting in a negative socio-economic gain. The increase required for motorways is considerably larger, namely 120%.

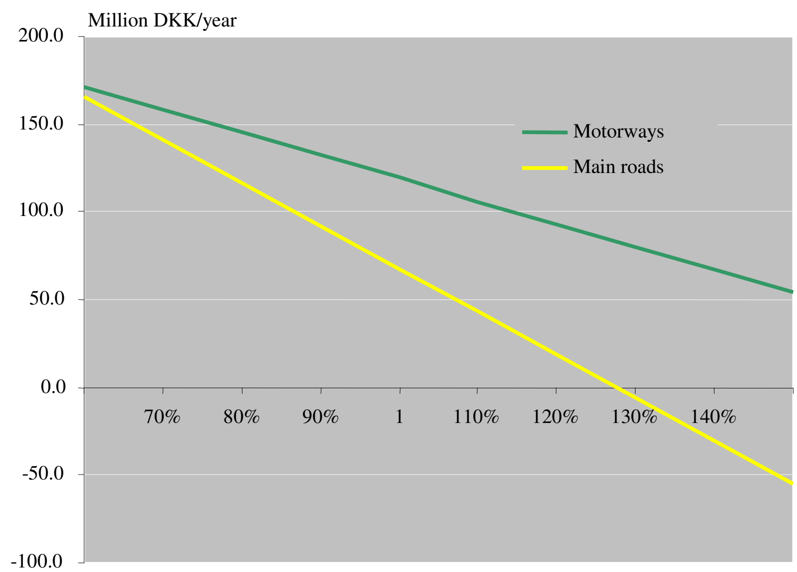


Figure 6.3: Significance of a change in establishment costs for annual gain

6.3.2 *The Danish Road Directorate's plan for the operation and maintenance of the road network*

When the Traffic Agreement was reached in December 2009, the parties involved (the Liberal Party, the Conservative People's Party, the Social Democrats, the Danish People's Party, the Socialist People's Party and the Liberal Alliance) agreed that maintenance work on the Danish State road network should be planned so as to ensure that it will be as inexpensive and financially rewarding for society as possible in the long term (Danish Ministry of Transport 2009). Table 6.13 shows the total expected funding levels for the operation and maintenance of the Danish State road network, and the funding available for the paving of roads.

Only the funding for 2010 to 2013 has been fully approved in the Traffic Agreement, however. On average, an expected DKK 330 million has been set aside per year for the next 10 years. The expected annual funding level therefore corresponds to the value of the fuel savings and environmental effects if the entire existing State road network were to be repaved using the energy-saving material rather than the traditional road pavement material (see Table 1.1).

Table 6.13: Annual funding levels for operation and maintenance, million 2010-DKK

	Historical	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total annual funding	964	1,626	1,813	1,358	1,317	1,220	1,257	1,161	1,040	992	1,006
Of which, road pavement	163	664	664	317	298	201	237	236	235	227	221

Source: Jacobsen (2010)

The scale of the funding means that it would be possible to establish more than 1/15 of the energy-saving road pavement a year. This would mean that the potential gains may be realised earlier, and that the overall economic gain may be greater than DKK 1.9 billion (see Section 6.3).

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