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ENERGY SAVING FOR TRAFFIC ON MINOR RURAL ROADS: OPPORTUNITIES WITHIN RE-DEVELOPMENT PROJECTS

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Abstract

Environmental problems have drawn increased attention to the role of fossil energy. In this light, an investigation took place into more efficient consumption of fossil energy for traffic on minor rural roads by changing flows and improving road conditions. The savings in two re-development projects are shown to be modest.

INTRODUCTION

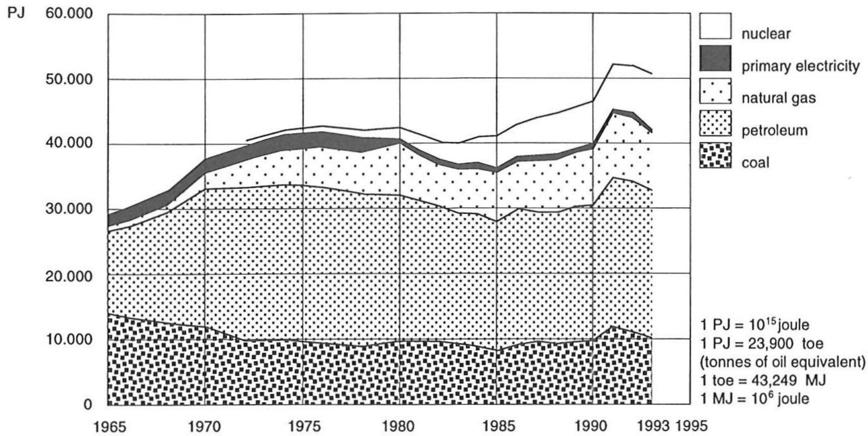
Environmental problems such as smog, acid rain and the greenhouse effect have drawn increased attention to the role of fossil energy. Transport is a major contributor to the consumption of fossil energy. Nearly all vehicles drive on petroleum-based fuels. Therefore energy saving in traffic and transportation is an important item, especially since the early 1970s. Much attention is given to improving energy efficiency (see for example CEC, 1989). For example, improving of traffic flow by measures on the road network and a modal shift from cars to bicycles or public transport are measures that may contribute to this goal, by a decrease of energy consumption per passenger-kilometre. Generally these studies focus on urban areas (see for example OECD, 1978, 1988 and 1990). This paper deals with rural areas. In rural areas, land use and land exploitation as well as energy consumption depend on such factors as soil properties, water management systems and physical layout. These factors, and in this way the energy consumption, can be influenced by rural land re-development projects. Therefore, Jaarsma (1992) investigates the relationship between re-development of the countryside and energy-efficiency and consumption for various land uses (farming, outdoor recreation, rural roads, landscape-ecological developments). Jaarsma and Van Lier (1993) summarize the background and the applied method of this research. Jaarsma and Van Lier (1994) give a global overview of the results.

This paper aims to describe energetic aspects of rural traffic and transportation, the influencing factors and the opportunities for enlarging energy-efficiency, especially within the scope of rural land re-development projects. First, the next section explains in more detail the relationship between transport and fossil energy. The following section illustrates the specific circumstances in rural areas. Then the next section deals with the theory on fuel consumption. The results for two case studies in the Netherlands are presented. In the final section the conclusions will be mentioned.

TRANSPORTATION AND FOSSIL ENERGY

Between 1965 and 1975 energy consumption in the twelve member states of the European Communities (EC) increased gradually from nearly 30,000 PJ to 43,000 PJ. During the next five years the consumption stabilized. The early 1980s are characterized by a small decrease. Since 1983 energy consumption increases every year. In the early 1990s it stabilizes at a level of about 52,000 PJ. For the period 1965-1993 this means an average growth of 2.1 per cent per annum. This is in a close agreement with the remarkably consistent long-term growth rate demonstrated by Odell (1988). Figure 1 gives details, including the energy consumption by source. Since the early 1980s the quantity of petroleum consumed is constant.

Strati (1993) investigated the share of transport in energy consumption at the European level in 1970 and 1988. In 1988 this share varies from 23 per cent in the Netherlands to 31.5 per cent in France. In 1970 the share was only 17 to 20% (Table 1). This increase is attended by a slightly increased share of the 'other sectors' and a considerable decrease of that attributable to industry. The Eurostat data in the table lead to the conclusion that the share of the transport sector is stabilizing after 1990.



Source: Eurostat

Figure 1 **Energy consumption (in PJ) per source in the European Communities, 1965-1993**

Table 1 **Development of the share of transport in total energy consumption in various European countries and in the EC (Source: Eurostat)**

Country	1970*)	1975	1980	1985	1988*)	1990	1992
Germany	17%	20%	22%	24%	26%	29%	28%
France	18%	23%	25%	28%	32%	33%	32%
Italy	20%	22%	26%	30%	31%	31%	33%
The Netherlands	18%	18%	20%	21%	23%	24%	25%
United Kingdom	18%	22%	25%	28%	31%	33%	32%
EC 12**)		21%	24%	27%		32%	32%

Notes:
*) Data from Strati (1993)
**) In 1975 and 1980 EC 10 (without Portugal and Spain)

The transport sector is nearly completely dependent on only one source of fossil energy: petroleum and its derivates. The share of the transport sector in the consumption of petroleum in 1992 can be estimated on about 70 per cent. This one-sided dependency was sharply demonstrated during the so-called oil crises at the end of 1973 (with a shortage of petroleum and rising prices after the Jom Kippoer War) and in the early 1980s (due to a new, sharp increase of the price of petroleum). This encouraged measures to decrease the dependency on petroleum and to improve energy efficiency in a wide field, including traffic and transportation. Because of technological developments, fuel consumption of cars decreased during the last decade (in the Netherlands from 9.2 to 8.3 litres of petrol per 100 km between 1980 and 1990). However, this decreasing trend is strongly slowed down by another trend: growing weights of cars. Nor in the field of alternative fuels, nor in the field of alternative modes (such as electric cars) or a modal shift (short trips from cars to bicycle or walking, for example) a great progress is made. So the dependency of traffic and transportation on petroleum remains.

Beside the availability and the prices of fossil energy, the environmental effects during winning and transport and the emission of acid gasses and greenhouse gasses as a by-product of combustion have drawn increased attention. Sustainability, as defined in the Brundtland report (WCED, 1987), has been generally adapted as a goal for future developments in our society. To obtain sustainable development, a reduction of fossil energy consumption is necessary, in urban as well as in rural areas.

RE-DEVELOPMENT OF RURAL AREAS AND ROAD PLANNING

Rural areas in the Netherlands developed from an exclusive economic function for agriculture to a more divers use. From the society there is an increasing interest to emphasize the use of rural areas for other activities, such as nature development and outdoor recreation. Cultural-history and the value of the landscape are increasingly important. These developments ask for adaptations of landscape structures and land layout. To realise this, so-called land re-development projects are executed. This governmental instrument developed from the improvement of farm conditions to a integral improvement of rural areas. Modern rural re-development projects aim at the improvement of land and water conditions, accessibility, and conditions for outdoor recreation and for nature development. Non-agricultural land uses play an important role in rural re-development projects today. View from the angle of sustainability, plans are needed to use fossil energy more efficiently for various land uses.

According to their function the road network in rural areas can be categorized into the next three groups:

1) motorways (primary roads for fast transport on long distances);
2) rural highways (secondary roads, connecting regions);
3) minor rural roads (for local access).

In the Netherlands the length of the network of motorways is about 2,500 km. Rural highways include a 7,000 km and the minor rural roads about 48,500 km paved and 13,000 km unpaved roads. (Another 47,000 km of roads are situated in built-up areas). So 83 per cent of the paved roads outside built-up areas are minor rural roads. Road improvement in land re-development projects focuses on these roads.

Minor rural roads do not form a unity at all. There is a large diversity in technical layout as well as in traffic characteristics. The road characteristics of minor rural roads are modest: mostly one lane roads with restricted pavement width. In the Netherlands the distribution of pavement widths for minor rural roads is as follows: 11 per cent less than 3 m; 57 per cent between 3 and 4 m; 20 per cent between 4 and 5 m and only 12 per cent more than 5 m.

Minor rural roads have various functions. Jaarsma (1991) presents a detailed functional classification. A global classification, based on the roads role in the rural access, distinguishes three types, namely access roads to (1) parcels or a few farms only; (2) a larger number of farms and/or other land uses in the countryside; and (3) villages. The first type has an access function only. Type 2 mainly has an access function and only a slight traffic function. Roads of type 3 are connecting villages to one another and with the major road network. They are also collecting traffic from roads of type 1 and 2. Roads of type 3 mainly have a traffic function and only a slight access function. The different functions also hold different volumes, as showed in Figure 2. Depending on the density of the local road network and on the presence of major rural roads, volumes on minor rural roads may rise to more than 5,000 motor-vehicles per day.

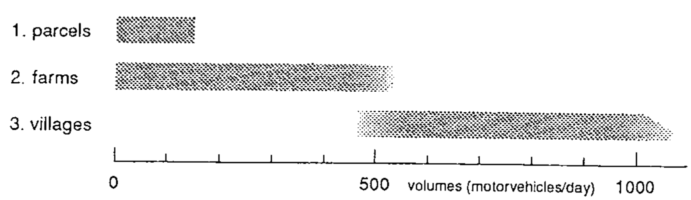


Figure 2 Minor rural roads: average annual daily volumes per type (Jaarsma, 1994)

Traffic on minor rural roads has a mixed composition by mode. Heavy and light vehicles, slow and fast vehicles, cars and bicycles occur together. The composition slightly depends on the type of road (Figure 3). As far as numbers go passenger cars are very dominant. Remarkable is the small portion of agricultural vehicles, even on agricultural access roads. Probably the portion of bicycles is typical for the Dutch situation. Besides vehicles also pedestrians use minor rural roads, for activities such as walking and jogging. By this mixed use large differences in speeds appear. Speeds vary from less than 5 km.h^{-1} for pedestrians and about 15 km.h^{-1} for cyclists, through 15 to 30 km.h^{-1} for agricultural vehicles. For cars, speeds vary from 60 up to 100 km.h^{-1} or even more. (The common legal limit is 80 km.h^{-1}.) These traffic characteristics, combined with the road characteristics of minor rural roads, form an unfavoured starting-point for traffic safety.

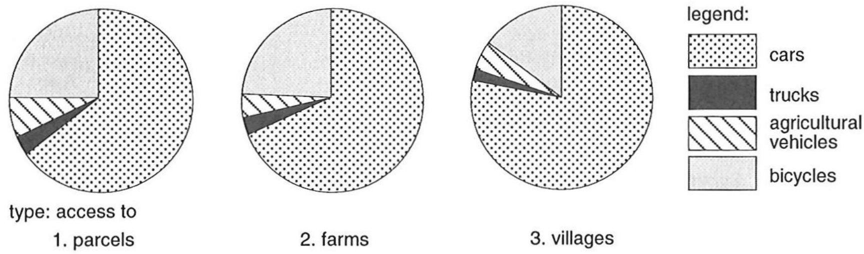


Figure 3 Minor rural roads: modal split per type (Jaarsma, 1994)

Within a land re-development project the road network may be adapted to developments in the countryside. Another important goal may be the reduction of unsafety (Jaarsma, 1994). To get a safe and efficient traffic management, first a functional classification is made, in a so-called Road Structure Plan. This classification is based on an inventory of the present situation (considering function, traffic volumes and speeds, traffic accidents, acceptable road capacity, geometric features and so on), transportation plans, possible changes in land use and traffic volumes. For roads classified as bottlenecks in the present rural road network a technical elaboration is needed, based on the technical condition of the roads (Jaarsma, 1991).

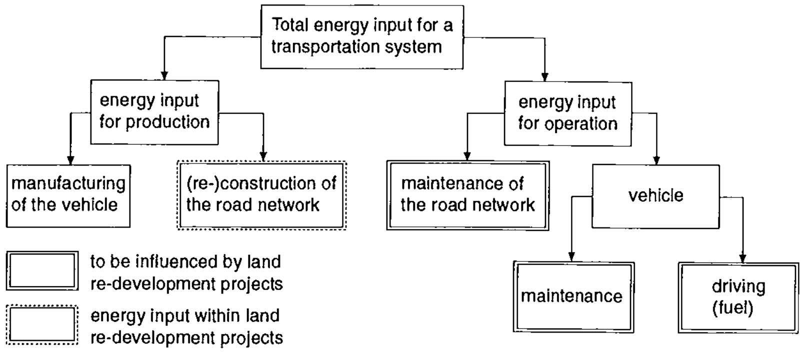
The Road Structure Plan is worked out into an improvement scheme for the network of minor rural roads in the re-development project. Road improvements may include technical reconstruction with or without widening of pavement, construction of cycle paths or (by exception) new roads. In modern projects, also closing of roads, to get a better regional traffic distribution, is a common measure.

THEORETICAL

Introduction

Fuel consumption by cars is only one, although important, component of the total energy consumption of a transportation system. Figure 4 presents a total overview. The energy consumption is divided into two parts. A distinction is made between production energy (for the construction of the system) and consumption energy (for using the system). Both production and consumption energy are divided into two parts again, representing the vehicles and the infrastructure. Finally, the consumption energy for the vehicles is divided into maintenance and fuel.

A weak point of such schemes is that many components (for example the production energy of a car) cannot be calculated exactly. As a rule of thumb the production energy of a car is often presumed to be of the same order of magnitude as the fuel consumption during the car's life time. Energy consumption for road construction is generally considered to be small in relation to the fuel used by the cars on the road (see for example Hiersche and Tenzinger, 1985). However, for minor rural roads the construction energy has a larger share (Jaarsma and Baltjes, 1992). Both the maintenance components are also small. It is concluded that the fuel consumption of the cars is the most important component to take into further consideration.



Jaarsma and Van Lier, 1992

Figure 4 Schematic representation of the energy input for a transportation system

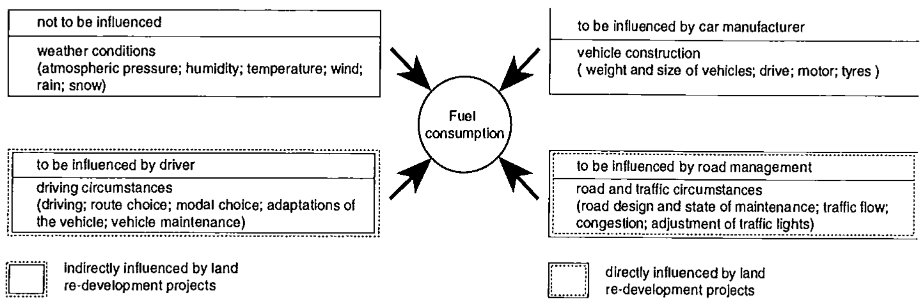


Figure 5 Factors influencing fuel consumption of a car (Förster, 1980)

Figure 5 schematizes the influencing factors upon fuel consumption of a car. In rural re-development projects adaptations of the road network may be realized. This will influence the technical condition of the roads, and through this the traffic speeds and traffic flows (the right-below part of the figure). Indirectly these changes may influence the driving behaviour (left-below in the figure). To quantify the resulting changes in fuel consumption we need to find relationships between road design, driving conditions, road quality and fuel consumption.

Fuel consumption of a car depends on resistances for rolling, gradient and air. The air resistance is proportionally to the squared speed. Therefore traffic speed is an important factor in explaining fuel consumption. This will be elaborated in the next section. The first two resistance terms are proportionally to the mass of the vehicle, which is not changing due to the land re-development project. By improvement of the road surface the rolling resistance may decrease. This will be discussed later.

Fuel consumption in relation to traffic flow

Already in the 1960s investigations were carried out to find the effects on fuel consumption of various highway design features, traffic speed and traffic conditions. "For the cars fuel consumption is lowest when conditions cause an average speed of about 55 $km.h^{-1}$ and is particularly high in low speed traffic, being double the minimum at 16 $km.h^{-1}$" (Everall, 1968). Hooker (1988) finds considerable differences between individual cars: the optimal speed for 15 "late-model automobiles" varies from 28 to 76 $km.h^{-1}$. Figure 6 shows speed-consumption relationships presented by Wentink (1992) and Kurzak (1984), based on observations in the Netherlands and Germany respectively.

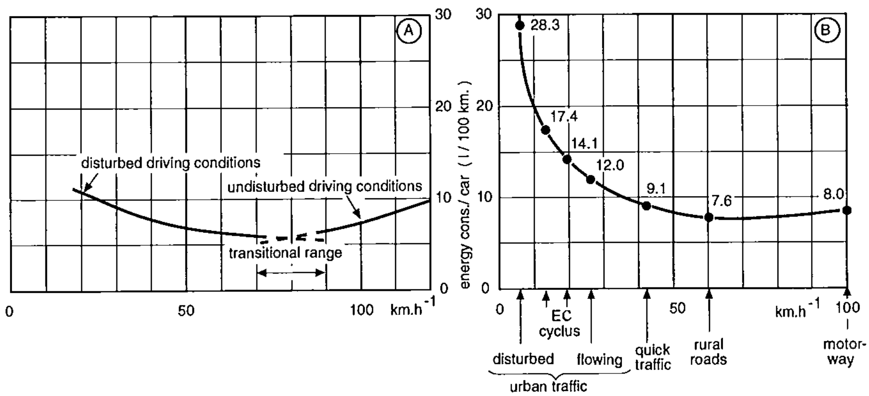


Figure 6 **Fuel consumption (litres per 100 km) of cars as a function of speed in (A) the Netherlands (left) and (B) Germany (Jaarsma and Baltjes, 1992)**

Both relationships show a lower fuel consumption with increasing average speeds, till a speed level of about 65 $km.h^{-1}$. For average speeds above 80 $km.h^{-1}$ fuel consumption increases with increasing speeds. Remarkable is the flatter curve for Germany. Traffic speeds between 60 to 80 $km.h^{-1}$ are very common on minor rural roads, with an 80 $km.h^{-1}$ limit. It can be concluded that these speeds are close to the optimum speed for fuel consumption.

The left-hand part of the curves in Figure 6 can be described approximately by the formula:

$$B_l = k_1 + \frac{k_2}{v} \qquad (1)$$

whereas the right-hand part is described by:

$$B_l = p_1 + \frac{p_2}{v} + p_3 \cdot v^2 \qquad (2)$$

where:

B_l = fuel consumption per covered distance [$l.km^{-1}$]

v = average speed [$km.h^{-1}$]

k_1, p_1 = model parameter for fixed fuel consumption per covered distance [$l.km^{-1}$]

k_2, p_2 = model parameter for fuel consumption per unit of time [$l.h^{-1}$]

p_3 = model parameter [$l.h^2.km^{-3}$].

Tanja and Rijkeboer (1986) applied these formulae for calculating the fuel consumption of cars on a national scale in the Netherlands. The parameter values *k* and *p* depend on the type of fuel (Table 2). For an average speed near about 80 $km.h^{-1}$ both formulae calculate the same fuel consumption.

Table 2 **Parameter values for k and p (x100) in formulae (1) and (2) for cars by fuel type, 1985**

Fuel type	k_1	k_2	p_1	p_2	p_3
Petrol	4.16	89.60	1.65	89.60	3.92×10^{-4}
Diesel oil	4.34	64.88	1.80	64.88	3.68×10^{-4}
Natural petrol gas	5.69	130.64	2.31	130.64	5.04×10^{-4}

Source: Tanja and Rijkeboer, 1986

Formula (1) is based on disturbed traffic flows, with a stop-and-go character. Formula (2) is based on constant speeds. Tanja and Rijkeboer (1986) consider this formula applicable for motorways only. Traffic on minor rural roads does not have the stop-and-go character of congested urban roads. But generally, due to road and traffic conditions, a constant speed is not realizable. The relative small pavement width, short road links between frequent exits and crossings and (sharp) bends will force the driver to accelerate and decelerate frequently. The high volumes on many minor rural roads (Figure 2) with two directional traffic and a mixed character of traffic by mode (Figure 3) will reinforce the irregularity of traffic flow. Therefore only formula (1) is applicable to calculate fuel consumption of cars for this type of traffic flows. Therefore, fuel consumption on minor rural roads will decrease slightly with increasing speeds. This result is in close agreement with a study on economic design of so-called low-traffic roads (OECD, 1986). That study summarises the impact of various geometric design standards on the factors normally considered in technical and economical analyses. For fuel consumption a reduction is suggested for larger widths of carriageway, a larger shoulder or a hard shoulder, a larger horizontal or vertical radius of curvature and less bends.

After calculating fuel consumption (B_l) as a function of average speed (v) for each link in the network of minor rural roads with formula (1), next, fuel consumption (in litres per kilometre) has to be expressed into units of primary energy (MJ per vehicle kilometre). This conversion is made with:

$$C_n = \sum_k (B_{lk} \cdot E_k \cdot P \cdot F_k) \qquad (3)$$

where:

C_n = energy input per vehicle kilometre on road link n, primary energy [$MJ.km^{-1}$]

$B_{l,k}$ = fuel consumption per covered distance for cars with fuel k, calculated with formula (1) [$l.km^{-1}$]

E_k = energy value of fuel k [$MJ.l^{-1}$] (see Table 3)

P = conversion factor to primary energy (P = 1.065; CBS (1991))

F_k = fraction of cars with fuel k

k = type of fuel: 1 (petrol), 2 (diesel oil) or 3 (natural petrol gas).

The values for F_k, presented in Table 3, are specific for a country's car population.

Table 3 Energy value and fraction of cars by fuel type (CBS, 1991)

Type of fuel	Petrol	Diesel oil	Natural petrol gas
Energy value [$MJ.l^{-1}$]	32.912	35.868	23.954
Fraction of cars	0.647	0.181	0.172

The output of formula (3) is a function of the average speed v, because of the relationship between B_l and average speed described in formula (1). Energy consumption in the network of minor rural roads is calculated by an addition of the energy consumptions of the links in the network:

$$Y_c = 365 \cdot \sum_n C_n \cdot L_n \cdot Q_n \qquad (4)$$

where:

Y_C = total yearly energy consumption on the complete network [MJ]

n = road link within the network, $n = 1,....,N$

L_n = length of link n [km]

Q_n = volume on link n (AADT) [$vehicles.day^{-1}$].

Fuel consumption and road quality

The roughness of the road surface and the longitudinal and transverse flatness of the road also act upon fuel consumption of cars. Hiersche and Tenzinger (1985) describe an extensive literature study in this field.

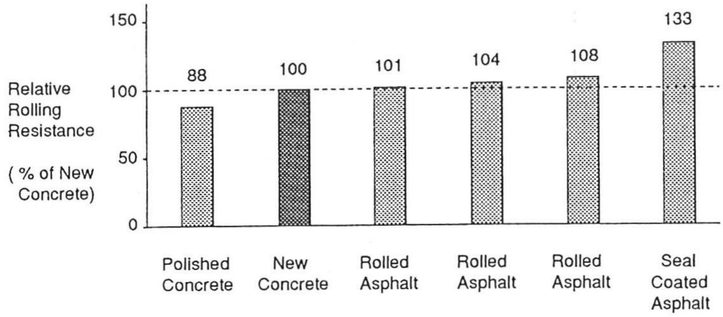


Figure 7 Tyre rolling resistance versus pavement surface structure (De Raad, 1977)

Direct relationships between roughness and energy consumption are reported to be scarce. More common is the relationship between rolling resistance and several pavement types (Figure 7). There is no unambiguousness upon the influence of a lower rolling resistance on fuel consumption. Results vary from a 2 per cent decrease of consumption for a 10 per cent decrease of the rolling resistance to only 1 per cent for a 20 to 30 per cent decrease. Based on these findings in the literature Jaarsma and Baltjes (1992) estimate a 1 per cent decrease of fuel consumption on minor rural roads, if a rough road surface is replaced by smooth rolled asphalt.

Table 4 Extra fuel consumption in comparison to a smooth flat, non-deformable roadway (PSI = 4,5)

Description	Very good	Good	Moderate	Bad
PSI	4.1	3.75	3.0	1.5
Extra fuel consumption	1.9%	2.6%	5.0%	9.2%

Source: based on Schmuck, 1984

The relationship between flatness and fuel consumption can be quantified by the so-called Pavement Serviceability Index, PSI. The PSI depends mainly on the longitudinal flatness. The lower the value of the PSI, the unflatter the road and the higher the fuel consumption. Schmuck (1984) gives an overview of the extra consumption compared with a smooth flat, non-deformable roadway (Table 4). The worst part of a road link decides the value for the PSI.

By measuring the PSI value per road link in the present situation and by approximating the future PSI values, fuel reduction can be calculated using the data from Table 4.

Changes in gradient also influence fuel consumption of cars. In the (flat) circumstances in the Netherlands gradients are not important. Moreover, normally the gradients of the minor rural roads hardly will be changed by road reconstructions.

Energy input for road (re)construction

The equipment set in and the materials applied for construction, reconstruction and maintenance of roads also require input of energy. The amount of energy is strongly dependent on the construction type and the dimensions of the road. After a reconstruction of a road the energy input for maintenance in the next decades will decrease. Jaarsma and Baltjes made several calculations for a land re-development project. In this project the energy input for (re)constructed road varies from 2000 to 7000 $MJ.m^{-1}$. Without a road reconstruction, extra road maintenance would be needed. This would require an input of on average two thirds of the input for reconstruction.

A network of rural roads is necessary for the accessibility of the countryside. It is not (re)constructed to save energy, but to give an improved access. Moreover, only in theory the energy inputs for driving (fuel) and for road (re)construction (mainly asphalt) are exchangeable. Therefore this paper will not consider the energy input for (re)construction and maintenance of roads further.

Conclusions

From the foregoing it can be concluded that the fuel consumption of cars is an important component of the energy consumption of a transportation system in rural areas. Measures on the network of minor rural roads may influence fuel consumption of cars in two ways:

a) changing flows (volumes, speeds) in the network

b) improved road conditions (roughness and flatness).

For a calculation of energy consumption, first for all road links in the region speeds and PSI are determined, for both the present and the planned network. Next, daily traffic volumes per road link are calculated, for example with a traffic model for rural areas. Finally, the energy consumption on the project scale is calculated with formula (4). Per link of the road network a correction is made for the value of the PSI, conform Table 4. Finally, a 1 per cent reduction of fuel consumption is given to links with smooth rolled asphalt.

CASE STUDIES

For two re-development projects (Melderslo and Roden-Norg) the impacts of a road improvement scheme on energy consumption are calculated, conforming to the previous section. Because of the improvement scheme more cars will travel on roads with a larger pavement width. Therefore traffic flows will be more smoothly and traffic speeds will slightly increase. The distances to be travelled also may slightly increase. Because of the increased speeds (within the range of 60 to 80 $km.h^{-1}$) energy consumption will slightly decrease. The same is true for road links with an improved technical condition.

The re-development project Melderslo (70 km^2) is in the northem part of the southem Province of Limburg in the Netherlands (Figure 8A). It is a small scale sandy area, situated west of the river Meuse (Maas). Seven secondary roads connect the project area with other regions. Within the project area the secondary roads form the veins of the network, where the minor rural roads are the capillaries. There is a high density of minor rural roads: 2.0, 0.7 and 2.3 $km.km^{-2}$ for paved, semi-paved and unpaved roads respectively. The scatter of farm parcels in the area is an important reason for the high density of roads. Notwithstanding this high density, 5 kilometres of new roads have to be constructed, to get a satisfactory access to all parcels. For 8 kilometres a reconstruction is planned.

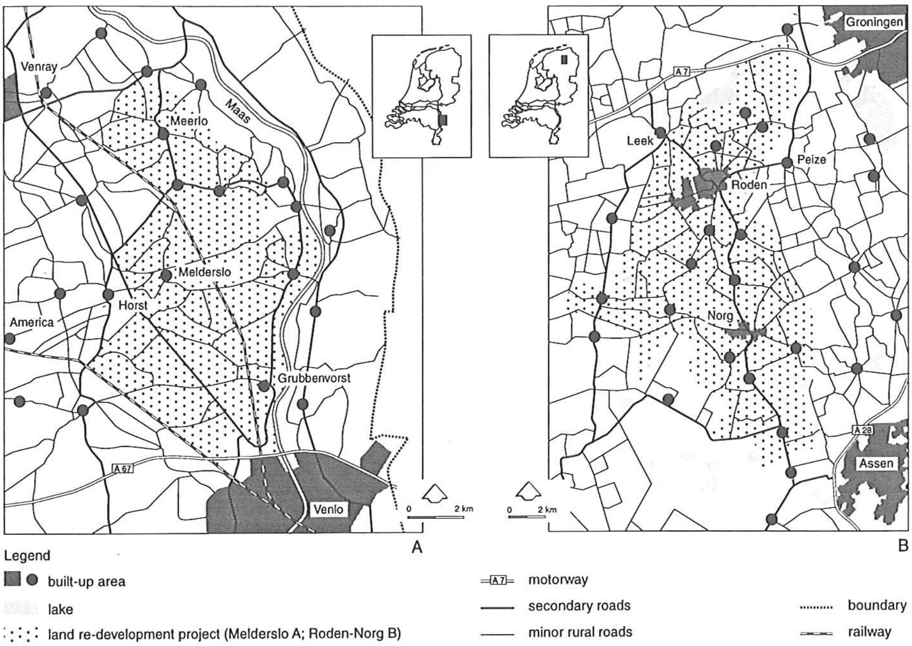


Figure 8 The rural re-development projects (A) Melderslo and (B) Roden-Norg

The re-development project Roden-Norg (130 km^2) is in the northern part of the northern Province of Drenthe in the Netherlands (Figure 8B). The area is acknowledged to have high natural values and it is attractive for recreation. About 80 per cent of the area is used as agricultural land. The project area is connected with other regions by secondary roads (Leek—Roden—Peize; Roden—Norg—Assen; Norg—Haulerwijk; see Figure 9). The density of paved and unpaved minor rural roads in the project area is about 1.2 and 1.7 $km.km^{-2}$ respectively. For about 36 kilometres a reconstruction is planned and for about 5 kilometres minor rural roads the pavement width will be widened. Further about 10 kilometres of bicycle paths will be constructed in the project area.

The yearly results for both projects are summarized in Table 5 (Jaarsma and Baltjes, 1992) and in Table 6, for Melderslo and Roden-Norg respectively.

Table 5 Yearly vehicle kilometres and energy consumption in the Melderslo project, before and after the improvement of the network of minor rural roads

	Vehicle-kilometres	**Energy consumption [$MJ.year^{-1}$]**			***x 10^6***
	[$km.year^{-1}$] *x 10^6*	(1)	(2)	(3)	Total
Present situation	57.4	115.2	3.0	-	118.2
Planned situation	57.4	115.0	2.9	0.053	117.9
Saving	0.0	0.2	0.1	0.053	0.3

Notes:

1) energy consumption based on traffic speed, volumes and length of links (formula 4)
2) extra consumption in comparison to a smooth flat roadway (Table 3)
3) reduction on energy consumption by smooth rolled asphalt

The total yearly reduction of energy in the Melderslo project is 300,000 MJ. The largest amount, 58 per cent, comes from changing flows in the network. Another 24 per cent is the result of a better flatness, where a decreased roughness forces 18 per cent of the total savings. Absolutely the savings are very modest: 300.000 MJ is the order of magnitude of the *daily* energy consumption of traffic in the project area. Looking at these figures it should be realized, that the Road Improvement Scheme for the project area is based on mainly agricultural considerations. Probably alternatives may be developed with a larger amount of energy savings.

Table 6 Yearly vehicle kilometres and energy consumption in the Roden-Norg project, before and after the improvement of the network of minor rural roads

	Vehicle-kilometres	Energy consumption [MJ.year^{-1}]			x 10^6
	[km.year^{-1}] x 10^6	(1)	(2)	(3)	Total
Present situation	128.7	254.9	7.5	-	262.4
Planned situation	129.0	254.6	7.0	0.1	261.5
Saving	-0.3	0.3	0.5	0.1	0.9

Notes:
1) energy consumption based on traffic speed, volumes and length of links (formula 4)
2) extra consumption in comparison to a smooth flat roadway (Table 3)
3) reduction on energy consumption by smooth rolled asphalt

After the road improvements in the Roden-Norg project the number of vehicle kilometres will slightly increase. Despite this increase, there is a reduction of energy consumption: in total 900,000 MJ yearly. The largest amount, 56 per cent, is the result of a better flatness. Another 33 per cent comes from changing flows in the network, where decreased roughness forces 11 per cent of the total savings. These small savings (0.34% of total energy input for traffic) are realised, despite a small increase of the total kilometrage (with about 0.23%). The yearly saving for this project is just more than the average daily consumption in the project area.

CONCLUSIONS AND FINAL REMARKS

The conclusions are divided into three parts. Successively the conclusions regarding the relevance, the method and the results are presented.

The conclusions regarding the relevance of energy savings for traffic and transportation are:

- environmental problems force a strengthened approach to the consumption of fossil energy;
- to obtain a sustainable development, a reduction of fossil energy consumption is necessary, in urban as well as in rural areas;
- transport has a considerable share in total energy consumption and it highly depends on only one source of fossil energy (petrol);
- within the transport sector the road sector has a share of 80 to 90 per cent of the energy consumption, with a dominating role for cars;
- in rural areas the dependency of cars is greater than in urban areas.

Therefore energy saving in traffic and transportation is an important item, also in rural areas. In this paper the opportunities for enlarging energy-efficiency and/or saving of energy are considered within the scope of rural land re-development projects.

The conclusions regarding the method to quantify changes in energy consumption for rural traffic are:

- the fuel consumption of cars is the most important factor to describe the energy input for traffic and transportation on a rural road network;
- measures on the network of minor rural roads may influence volumes and speeds of traffic flows as well as roughness and flatness of the road surface;
- the fuel consumption as a function of volume and speed can be calculated with the formula (4) and the included formulae (1) and (3);

- the fuel consumption per road link is corrected for flatness by means of the value of the Pavement Serviceability Index, PSI (Table 4), and for roughness by means of a 1 per cent reduction for links with smooth rolled asphalt.

The conclusions regarding the results for the re-development projects Melderslo and Roden-Norg are:

- road improvements in a rural re-development project lead to a modest saving on energy consumption of cars; the *yearly* saving is in the order of magnitude of the *daily* consumption in the project area;
- in the Melderslo project 58 per cent of the total savings comes from changing flows in the network; in Roden-Norg this is only 33 per cent;
- a better flatness results in 56 per cent of the total savings in Roden-Norg; in Melderslo this is only 24 per cent;
- in both projects the role of a decreased roughness is rather modest (11 per cent in Roden-Norg and 18 per cent in Melderslo);
- it should be realized that for both project areas these savings are a "by-product" of a "traditional" Road Improvement Scheme, offering optimal rural access and not considering energetic impacts;
- in the future the method developed is applicable to compare the energetic impacts of alternative plans for road improvement in rural re-development projects.

To complete this paper, some final remarks are made. Successively the relevance for other modes, the relationship between energy consumption and emissions and the role of future land re-development projects will be discussed.

The calculation of fuel consumption is restricted to cars. It can be presumed that savings for trucks proportionally will be higher. Because of the larger mass of trucks these vehicles will be more sensitive for improvement of both traffic and road conditions. The results for the land re-development projects form a lower limit for the savings realizable in practice.

As stated already in the introduction, nowadays environmental problems instead of shortage of oil draw the attention to the role of fossil energy. Generally, emissions will decrease with decreasing fuel consumption and with better traffic flow conditions. For a more accurate calculation a microscopic traffic flow simulation is advised. Benz (1985) presents a model to predict energy consumption and exhaust emissions of individual vehicles by such a simulation. However, such a simulation is not directly applicable on a regional network.

In the future land re-development projects must help to create sustainable uses of land in the countryside. One specific effect is a reduction of the consumption of fossil energy and/or an improvement of the energy efficiency. This paper shows that for rural roads and transportation the rural re-development can give a modest, but absolutely not negligible contribution to this goal. When a good accessibility of a rural area is considered as a basic condition, even a modest reduction of energy consumption is to be considered as a positive effect of a re-development project.

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