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Ministry of Transport and Energy

Estimation of Revenues and Costs of different Scenarios of a HGV Charging System in Denmark

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Table of Contents

Version History

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Definitions and Abbreviations

ANPR	Automatic number plate reading
ASECAP	Association Européenne des Concessionnaires d'Autoroutes et d'Ouvrages à peage
BOT	Build, operate, transfer
CEN	Comité Europeen de Normalisation
CESARE	Common EFC System for ASECAP Road Tolling European System
CITS	Central IT System
Clearing	Settlement – Payment from issuer to operator for services provided by the operator used by issuer's customers
CN	Cellular Network (e.g. GSM)
DSRC	Dedicated Short range Communication
EETS	European Electronic Tolling Service
EFC	Electronic Fee Collection
GNSS	Geographical Navigation Satellite System (e.g. GPS, Galileo)
HGV	Heavy Goods Vehicle
LOBU	"Light" On Board Unit
LPN	License plate number
LSVA	Swiss heavy vehicle fee "Leistungsabhängige Schwerverkehrsabgabe"
NORITS	NORdic Interoperable Tolling System
OBE	On Board Equipment
OBU	On Board Unit
Operator	The of the tolling system
RSE	Road Side Equipment
RUC	Road User Charging
S&B	Sund & Baelt AS
TEN	Trans European Network
TOBU	OBU for time based area charging
TSP	Transport Service Provider
User	The person and/or the entity having an agreement with an operator for using the RUC liable road network/area
VAS	Value Added Services
VAT	Value Added Tax

Executive Summary

The Danish Ministry for Transport and Energy is investigating the possibilities of replacing the Eurovignette with a distance based Heavy Goods Vehicle (HGV) charging scheme. Rapp Trans has been assigned for estimating the financial effects on the costs and income of different EFC schemes corresponding to alternative charging scenarios. The work has been followed by an advisory group with representatives from the Ministry of Taxation, the Road Directorate and tolling experts from Sund&Bælt.

The study has been conducted in 3 steps. In Step 1, four HGV charging scenarios have been determined and described based on the Client's task description. In Step 2, the financial estimate regarding the revenues and the infrastructural and operational costs of the scenarios was calculated in relation to the traffic data and the defined tolling sections generated by the Danish Road Directorate. In Step 3, the scenarios have been evaluated and checked against benchmark figures from existing HGV charging schemes.

4 Scenarios have been determined using two alternative technologies:

Scenario Group 1: Network charging

1A: Satellite positioning technology

1B: Tag and beacon technology

Scenario Group 2: Area charging

2A: Distance charging based on Tachograph impulses

2B: Charging based on driving time using motion sensors

Scenario Group 1: Charging of a Defined Road Network

HGV Charging on motorways and expressways can be done distance related or time based (i.e. day pass, monthly or yearly permit). This study only focuses on distance related network charging. It is possible to execute distance charging by several available technologies.

The road network should include :

- Roads with significant presence of HGV traffic
- Roads which offer alternatives to present itineraries if the present itineraries were subject to charge
- Roads with important foreign HGV traffic
- Roads which connect the parts of the country
- Roads which are a functional part of the international road network (European road naming scheme, Trans-European Road Network)
- Roads which complete the network to a whole connected entity.

The Road Directorate, RD, is responsible for 985 km of motorways and Sund & Bælt for the 7 km long Øresundsmotorway i.e. in total 992 km motorways. For the relevant road network approx. 2,500 km of non-motorways are included, adding to a total of 3,500 km. The Greatbelt and Øresund links are not a part of the relevant road network, since these links are already subject to fee collection.

The inclusion of other roads than motorways into the network charging scenarios raises delicate issues which do not have proven solutions to this day, and which imply important reservations on their feasibility:

- Dividing a non-motorway network into chargeable segments
- Positioning of physical gantries on non-motorway network segments
- Identification of the chargeable network by the user
- Avoiding detour traffic.

Scenario 1A: Network Charging Using the GNSS/Cellular Network Technology

One approved technology for network tolling is GNSS/CN. It uses two technologies adapted from other applications; namely, GNSS (Global Navigation Satellite System), whose satellites enable suitably equipped vehicles to calculate their location accurately; and a two-way communication link (e.g. GSM/GPRS) based upon cellular telephone network. According to the position, the system recognises if the vehicle is driving on a toll road. In contrast to DSRC based systems GNSS/CN systems need practically no roadside infrastructure. Due to the several limitation by using GNSS only (no GNSS signal by shadowing effects, temporary system turn-off, etc.) the OBU is connected to or equipped by other sensors for localisation and distance measurement (tachograph, wheel sensors, gyrocompass, etc.).

Two main designs of the overall system are technically possible. The one approach uses a high-end GNSS/CN OBU (so called "fat client") which means all the intelligence for a single fee calculation is inside the OBU. This OBU transmits complete fee transaction data to a central system where they are cumulated and further processed for billing.This technology is operated by Toll Collect in the German LKW-Maut System. The other approach is a low-end GNSS/CN OBU (so called "thin client"). This OBU collects only position data (GNSS position and time plus potential other sensors) and sends this to a central IT system. Based on the position data received from the OBU the central system calculates the dedicated fee. The map matching process and the tariff management run in the central system. The investment and operating costs are much lower. This technology has been proposed by bidders in the UK Lorry Road User Charging project. Scenario 1A is based on the thin client architecture.

Scenario 1B: Network Charging Using the DSRC Technology

The payment transaction takes place between an electronic On Board Units (OBU), which is fixed at the windscreen of the car, and the toll road operator's electronic road side equipment while the vehicle is in motion. The relevant information between the OBU and the roadside equipment is exchanged, using a standardised 5.8 GHz microwave communication. The DSRC technology implies that each section of a tolled road network is equipped by a beacon installed on a gantry. The OBU itself has a size of a credit card (but thicker) and has its own power supply (internal battery) with a lifetime of usually 5 years. The cost savings of simple OBU come along with more extensive resources regarding installation of roadside equipment (gantries with DSRC beacons).

Scenario Group 2: Area Charging

This type of scheme applies to trips made within the borders of Denmark on all roads. Users of HGV who wish to use their vehicles within Denmark would need to have an On Board Equipment which measures distance or duration of vehicles usage. A key advantage for area charging is that there is no evasion of traffic to uncharged parallel roads. Main requirement of area charging is the existence of well defined borders with a limited number of border crossings. The charge in an area pricing scheme is assessed by the EFC operator based on the self-declaration of the vehicle holder. The OBU stores defined events in a log file which is sent by the vehicle holder after the end of the declaration period to the central service via chip card or via internet.

For area charging, all roads on national territory are included:

Motorways (Road Directorate)	985	km
Øresundsmotorway (Sund & Bælt)	7	km
Dual carriageways	352	km
Other roads	70'872	km
Total road network	72'216	km

The Great Belt and the Øresund links (app. 40 km.) are excluded because HGV charging already applies on these links.

Scenario 2A: Distance Based Area Charging

The approach of distance based area charging is implemented by means of a permanently built in OBU with a connection to the vehicle’s tachograph. Additional sensors (GPS, gyroscope, motion sensors) supervise the correctness of the measurement of the OBU. This technology is applied by the Swiss distance related HGV charging scheme (LSVA). Foreign occasional users are provided with a light OBU (LOBU) without a connection to the tachograph. The driver has to enter the km reading of the tachograph manually into the LOBU each time he enters or exit Denmark. For reasons of practicability no modulation of tariff regarding the type of road and regarding the time of day is included in the scenario.

Scenario 2B: Time Based Area Charging

Different to the distance based area charging the time based area charge is based on the time period during which the road network in Denmark is used. A low-cost TOBU (Time based area charging OBU) is used containing a conventional 5.8 GHz DSRC tolling tag, a clock, vibration sensors capable of determining whether the engine is switched on or off, and accelerometers capable of determining whether vehicle is moving or stationary. The TOBU logs the time when the vehicle is moving inside Denmark. A chip card or a USB stick is used for downloading the log file and the user declares his charging parameters by sending in the chip card or via the Internet. With appropriate roadside infrastructure at the area boundary the charging data can also be automatic transmitted to the Central System when a vehicle is entering and leaving Denmark. The key advantage of the time based approach of this scenario is that the TOBU is autonomous and can be self-mounted in the same way as the DSRC tags of Scenario 1b. Therefore, there is no need for an manual declaration scheme for non-equipped users as in scenario 2A.

Vehicles

The Danish vehicle stock is known through the car register. The following figures are from 2005.

Lorries above 6 t gross weight	30'710
Semitrailer trucks	13'021

Out of the 30,710 lorries above 6 tons, 28,640 are assumed to be above 12 tons. This ratio is transposed from the statistics on traffic performance per vehicle weight class. With these assumptions, the total Danish vehicle stock above 12 tons is 41,660.

The relevant figure is the number of different foreign vehicles who use the Danish network within a given period of time. These vehicles are cost-relevant since they need to be equipped with an OBU when they come into contact with the EFC system for the first time. No statistics are available on this subject. Based on estimates from Sund & Bælt and the Danish Ministry of Transport and analogies from HGV charging schemes in Austria and Switzerland the estimate is 100,000 different foreign vehicles per year, with a renewal rate of 30 % per year.

Traffic performance

Depending on the scenario, the revenue-relevant figures are:

- Total distance travelled (vehicle-kilometres),
- Total driving time (vehicle-hours).

The Danish Ministry of Transport has provided an estimate of the total distance travelled by HGV above 12 tons on the network on state roads and former county roads. Using extrapolations, and a conversion from total distance to total driving time based on assumptions of average speed, the resulting estimate is indicative of the order of magnitude.

Traffic performance per year [million veh-km or million veh-min]	1A	1B	2A	2B
Vehicle-km on chargeable roads	1'660	1'660	2'406	
Vehicle-minutes on chargeable roads				3'020

Revenues

The revenue to be raised by the HGV charging scheme is intended to account for a determined share of the external cost of road transport in Denmark in accordance with the approach of the Amendment of the Eurovignette directive 1999/62/EC, which aims at a fair allocation of road transport costs to transport operators. [1]

The estimated infrastructure cost allocated to HGV traffic are taken from a report from COWI.[2] It must be noted that the figures from the COWI report are being used without having been produced for that purpose. Therefore, the toll levels calculated in the present study are subject to some uncertainty and must be studied further in a next step.

The maximum potential revenue of the HGV charging scheme is assumed to be equal to the infrastructure cost allocated to HGV which according to COWI is 2'733 million DKK per year for HGV>6t. If the cost allocation is limited to HGV >12 t it is 2'460 million DKK per year. By further restricting the cost allocation, for each scenario, to the road network concerned and by adding the costs of the charging system itself[3], the total costs that can be allocated for each scenario are determined. For network charging, the tariff is determined by dividing the potential revenue by the annual kilometres driven on the network. For area charging, the tariff is limited to the tariff corresponding to the Eurovignette approach on the trunk network. The effective revenue of the scheme is computed by taking the adjustments for traffic evasion and for non-payment of due charges into account, and by adding the revenue of enforced charges and penalties. These adjustments are scenario-dependent.

Revenue Summary

in million DKK/year	**Scenario 1A**	**Scenario 1B**	**Scenario 2A**	**Scenario 2B**
infrastructure cost HGV>12 t assigned to chargeable network	984	984	2'460	2'460
costs of HGV charging system	486	534	399	328
total assignable costs	1'470	1'517	2'858	2'787
average tariff in DKK/veh-km	0.89	0.91	0.89	
average tariff in DKK/veh-hour				41.31
Revenue before adjustments based on average tariff	1'470	1'517	2'126	2'074
Adjustments for charge evasion and penalties	-60	-61	21	21
Effective Charging Revenue	**1'410**	**1'456**	**2'148**	**2'094**

[1] Directive 2006/…/EC amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures, PE-CONS 3682/05 (6 March 2006)

[2] COWI, "Total external costs of road and rail transport in Denmark", 3rd Report, July 2004

[3] conformant to Annex II of the Directive 2006/…/EC amending Directive 1999/62/EC

Costs

The cost estimations are based on the following general assumptions:

- 41,660 Danish vehicles above 12 t maximum permissible weight per year
- 100,000 foreign vehicles above 12 t maximum permissible weight per year
- on average: Every 12th toll section is an enforcement section

Scenario-specific assumptions:

Scenario 1A and 1B:

- 1,571 toll sections
- 430 points of sales
- 20% OBU leakage per year for DSRC-OBU and GPS-OBU

Scenario 2A:

- 18 system entry points (border crossing stations)
- 90 points of sales
- 6% OBU replacement per year of fixed mounted OBU
- 30% OBU leakage per year of LOBU

Scenario 2B:

- 18 system entry points (border crossing stations)
- 90 points of sales
- 20% OBU leakage per year for time based OBU

For all scenarios, it is assumed that all vehicles registered in Denmark and all foreign HGV travelling in Denmark must be equipped with an OBU. Potential cost savings from interoperability are not included in the estimates.

It is assumed that the EFC system is procured under a BOT arrangement. The capital investment includes the whole costs of the tender (12 months) and the implementation (18 months) phase as well as the costs for external consulting within the first 6 months after start of operation.

The investment and implementation costs include:

- Charging services
  - on board equipment (OBU, LOBU)
  - roadside equipment (gantries and beacons)
  - integration of existing toll stations

- Enforcement services
  - fixed roadside enforcement stations
  - portable enforcement stations
  - mobile enforcement units
  - beacon and enforcement IT
- Central services
  - points of sales, including POS software
  - central IT system
  - central back office
  - test equipment
  - training equipment
  - pre sale activities
  - marketing and information incl. call center
  - project management

The operating costs include:

- human resources costs Management Authority
- human resources costs Service Provider
- new on board equipment (OBE leackage and system growth)
- maintenance costs (on board equipment, road side equipment, enforcment equipment, POS)
- IT maintenance and support, programme licences
- maintenance of test and training equipment

The costs per year include the operating costs plus the amortisation of the investments. The amortisation costs are based on the estimated lifetime of the components. No interests or other financing costs are included.

Cost Summary

Capital investments and implementation costs

in million DKK	Scenario 1A	Scenario 1B	Scenario 2A	Scenario 2B
charging services	350	1'941	242	85
enforcement services	291	288	60	127
central services	435	459	420	406
Total investment costs	**1'076**	**2'688**	**723**	**618**

Costs per year

in million DKK/year	Scenario 1A	Scenario 1B	Scenario 2A	Scenario 2B
charging services	136	197	64	26
enforcement services	182	181	138	154
central services	167	155	196	147
Total costs per year	**486**	**534**	**399**	**328**

Sensitivity analysis

Several sensitivity analyses have been conducted. They show the following:

- Gantry density: the cost estimates are based on the assumption that the average segment length on the non-motorway network is 4.4. km similar to the motorway network. If the number of segments is doubled, the total annual cost of Scenario 1A remain approximately the same whereas they increase in Scenario 1B by 24%.

- If the density of enforcement stations is increased from 1 enforcement gantry out of 12 gantries to 1 enforcement gantry out of 7 gantries the total annual costs increase for Scenario 1A by 6% and for Scenario 1B by 4%.

- The OBU leakage (= percent of new OBUs that must be issued to occasional users) is assumed to be significantly less with the HGV charging schemes in Austria and Switzerland due to a more stable clientele of foreign trucks passing through Denmark. If the leakage ratios were the same than in Austria and Switzerland, Scenario 1A would become significantly more expensive (75% increase of OBU cost, 8% increase of total annual cost). The other scenarios much less sensible to OBU leakage.

Benchmarks

	Scenario 1A	**Scenario 1B**	**Scenario 2A**	**Scenario 2B**
Vehicle kilometers per year (mio km)	1'660	1'660	2'406	2'406
Total costs per year in mio. DKK	486	534	399	328
Effective charging revenue per year in mio DKK	1'410	1'456	2'148	2'094
Effective charging revenue per vehicle kilometer in DKK	0.85	0.88	0.89	0.87
Total costs per vehicle kilometer in DKK	**0.29**	**0.32**	**0.17**	**0.14**
Net revenue per vehicle kilometer in DKK	**0.56**	**0.56**	**0.73**	**0.73**

All scenarios show that an important part of the revenues are consumed by the operating costs. The area charging scenarios show significantly lower charging system costs and higher revenues than the network scenarios.

In addition to comparing the scenarios against each other, the cost and revenue estimates of the scenarios 1A, 1B, and 2A have been benchmarked against figures from the functionally corresponding HGV charging schemes in Europe.

Benchmark costs:

Scenario	**EFC Costs per vehicle kilometre**		
	Denmark DKK	**Foreign scheme** DKK	Country
1A	0.29	0.20	Germany
1B	0.32	0.22	Austria
2A	0.17	0.23	Switzerland

The reasons for the comparatively higher costs of the network schemes in Denmark are:

- compared to Germany: scale effects with the Danish scheme being much smaller. The high OBU costs penalise the comparatively small territory of Denmark because much less kilometers are registered per OBU than in Germany.

- compared to Austria: inclusion of the non-motorway segments. If the Danish scheme was reduced to motorways only, the DSRC gantry infrastructure costs would be significantly lower.

Compared to the LSVA scheme in Switzerland the Danish scheme compares favourably due to the fact that Denmark has only very few system entry points (18 in Denmark versus 120 in Switzerland).

Benchmark revenues:

Scenario	**Net revenue per vehicle kilometre**		
	Denmark DKK	Foreign scheme DKK	Country
1A	0.56	0.74	Germany
1B	0.56	1.86	Austria
2A	0.73	3.05	Switzerland

The network scenarios compare unfavourably with the motorway HGV charging schemes in Austria and Germany. The reasons are the relatively low tariffs of the Danish system (based on low infrastructure costs that can be attributed) and the comparatively smaller HGV traffic volume than the motorways-only networks in Germany and Austria. The benchmark with the Swiss LSVA shows that the Swiss have a much higher tariff yielding a significantly higher net revenue despite the higher cost of their system.

The benchmarks are a result of the assumptions on which the Danish study is based. These assumptions need to be reviewed in further studies. The present estimates give correct orders of magnitude.

Risks

Introducing a nationwide EFC system for HGV charging carries high risks. In Germany, the introduction of the scheme was delayed by 15 months, and in the UK the implementation of the Lorry Road User Charging scheme has been halted. On the other hand, the schemes in Switzerland and Austria went life on time and are running smoothly.

The major risks are:

- political risk of implementing a system without the necessary acceptance from the hauliers and the public
- making the system too complex with functional requirements that are too demanding. Such requirements could be:
  - differentiating road types other than all motorways
  - differentiating time of day or traffic conditions
  - differentiating vehicle categories that cannot be easily detected by automatic road side equipment (e.g. exempting HGV or special tariffs on the ground of trip purpose)
  - complex repayment or rebate schemes
  - mixing added value services with a tax-like charging system
- relying too much on technology to meet complex functional requirements and thereby neglecting usability aspects (e.g. unpractical fall-back options in case of equipment failure)
- relying too much on the industry to come up with answers instead of clear functional specifications and a firm leadership from governement.
- insufficient experience of industry operating a tax-like system
- legal challenges of the system if the scheme is inequitable for some user groups
- lack of interoperability with the future EETS (whatever the EETS specifications may be)
- unwanted traffic reactions such as detour traffic or HGV parking problems at POS.

Conclusions and recommendations

The results of the present study must be interpreted with caution. The costs are based on those of EFC systems that were procured some time ago reflecting the particular competitive prices of the particular situation. The revenues rest on assumptions regarding the infrastructure costs that could be allocated to HGV>12t on different networks based on figures of a study which has not been produced for this particular purpose. Nevertheless, the results certainly indicate a probable order of magnitude and they allow to show the trends between the different scenarios.

Key figures of the scenarios:

	Scenario 1A in million DKK	**Scenario 1B** in million DKK	**Scenario 2A** in million DKK	**Scenario 2B** in million DKK
Effective Charging Revenue	1'410	1'456	2'148	2'094
Costs per year	486	534	399	328
Net Revenue per year	924	922	1'749	1'767
Costs in % of effective charging revenue	34%	37%	19%	16%

Under the present assumptions none of the scenarios show a satisfying cost effectiveness. The reasons are

- the low tariff resulting from the comparatively low infrastructure costs upon which the potential charging revenues are based, and
- for the network charging scenarios the extent of the network resulting from the inclusion of a large part of the trunk roads. Including non-motorways is particularly penalising for the DSRC technology.
- the assumption, that all HGV travelling in Denmark must be equipped with a Danish OBU and there are no cost savings from interoperability.

The situation regarding the European Electronic Tolling System (EETS) is yet too unclear for allowing to estimate the cost effects in the present study. We recommend to review the estimates as soon as the EETS specifications have been settled by the relevant European bodies. The cost reduction from interoperability is likely to be the highest with scenario 1A.

Notwithstanding possible interoperability benefits in Scenario 1A, the area charging scenarios are likely to remain significantly more cost-effective than the network scenarios as long as non-motorways are included. The geography and network topology of Denmark favour area charging over network charging more than in any other European country.

It is difficult to answer the question if the cost difference of 18% between driving time related area charging and distance related area charging is big enough to engage in a discussion for this entirely novel approach to road user charging with the EU. We assume that the debate on the subject of driving time related charging will rather be taken up for light vehicles than for HGV.

1 Introduction

The Danish Ministry for Transport and Energy is investigating the possibilities of replacing the Eurovignette with a distance based HGV charging scheme. Rapp Trans has been assigned for estimating the financial effects on the costs and income of different EFC schemes corresponding to alternative charging scenarios. The work has been followed by an advisory group with representatives from the Ministry of Taxation, the Road Directorate and tolling experts from Sund&Bælt.

The assignment is described in the "Task description concerning the preparation of a financial estimate for the implementation and operation of an electronic system for the collection of road tolls for HGVs (Heavy Goods Vehicles) in Denmark". The project has been started 23 January 2006 and the target date was end of April 2006 when the draft final report was delivered.

To have a realistic estimation of costs Rapp Trans has used confidential data from other schemes originating from operators and industries. Therefore, the detailed calculations cannot be published but are part of the confidential annex. The summary figures of the cost and revenue estimations are part of this report and can be published.

2 Approach and Methodology

The study has been conducted in 3 steps.

Step 1: Scenario description

Based on the "Task description concerning the preparation of a financial estimate for the implement-tation and operation of an electronic system for the collection of road tolls for HGVs (Heavy Goods Vehicles) in Denmark"[4] four scenarios have been determined and described. The characteristics of the scenarios were further developed and discussed in detail in the first Workshop with the Working Group of the Danish Ministry of Transport and Energy.

Step 2: Estimation of costs and revenues of the Scenarios

In relation to the traffic data and the defined tolling sections generated by the Danish Road Directorate, the financial estimate regarding the revenues and the infrastructural and operational costs of the scenarios was calculated. The costs are structured into the following groups:

- Charging Services
- Enforcement Services
- Central Services

Step 3: Evaluation of the Scenarios

The financial evaluation of the scenarios is based on benchmarks. The key benchmark figure used is the total EFC system costs per vehicle kilometres travelled on the charged network by chargeable vehicles.
The evaluation includes a risks and issues list for each of the four scenarios.

[4] Sund & Bælt, Note dated 21 December 2005

3 High Level Description of the Scenarios

4 Scenarios have been determined using two alternative technologies each:

Scenario Group 1: Network charging

1A: Satellite positioning technology

1B: Tag and beacon technology

Scenario Group 2: Area charging

2A: Distance charging based on Tachograph impulses

2B: Charging based on driving time using motion sensors

The table below shows the detailed charactersitics of the 4 scenarios.

Scenario	1A	1B	2A	2B	*Alternative characteristics not included in the scenarios*
Charging policy					
Charging principle	Network charging		Area charging		
Road network charged	Motorway network and main road network (3,500 km)		Entire road network incl. private roads and yards (approx. 72,000 km)		*Motorway network only*
Legal status of charge	Tax				*Fee*
VAT	No VAT				*VAT*
Vehicles subject to charge	HGV>12t				*HGV>3.5 t*
Tariff base	Distance based			Driving time based	
Tariff level	Eurovignette proposal				*Full inclusion of the external costs*
Compensation strategy	Not to be considered				
Tariff modulation – type of road	None / separate cost estimate for road type differentiation		None		
Tariff modulation – vehicle class	Registered weight or number of axles		Registered maximum permissible weight of road train		
Tariff modulation - trailers	Non				
Tariff modulation – emission class	EURO norm				
Tariff modulation – time of day	None / separate estimate for time of day differentiation		None		

Scenario	1A	1B	2A	2B	*Alternative characteristics not included in the scenarios*
Exemptions	Exempted vehicle categories				*Exempted trip purposes or exempted individual journeys*
Interoperability strategy	EETS compliant			Only one-way interoperability	
Technology					
System for occasional users	The On Board Equipment (OBE) is mandatory				
Technology for capturing usage	Virtual gantries & toll section identification GNSS	Physical gantries DSRC	Tachograph impulses supervised by GNSS	Movement sensors	
Technology for transmitting charging data to central system	GSM/GPRS	DSRC	Smartcard (domestic users) / DSRC (foreign users)		
Traffic flow at charge points	Free-flow multi-lane				*Toll plazas with single lanes*
Open or closed system	Open system		--- (does not apply to area charging)		*Closed system*
Classification method	Classification parameters stored in OBU and transmitted to RSE				*Classification parameters measured by road-side sensing equipment*
Accounting	Central				
Payment mode	Guaranteed payment/Post-payment				*Pre-payment*
Payment method	Electronic payment				*Manual payment and automatic payment*
Payment means	Cash/ Credit cards / Petrol cards / central account				
Registration method (first time users)	Manned POS at borders, manned and unmanned POS and fax in inland		Manned POS at borders (occasional user) and registration data provided automatically by the vehicle registration database		

Scenario	1A	1B	2A	2B	*Alternative characteristics not included in the scenarios*
Registration data stored in central system	Vehicle account, contract number, vehicle data (e.g. LPN, emission class et.) and account of guaranteed payment				
Distribution of OBU	Manned POS at entry points of charging network, manned POS and postal expedition in inland			Manned POS at borders (occasional user) and certified fitters	*Certified fitters*
Mounting of OBU	Self mounting			Self mounting (occasional user) and certified fitters	*Certified fitters*
Enforcement					
Responsibility for declaration	Joint several liability of driver and vehicle holder/owner				*Holder/owner only*
Legal determination of vehicle data	Declaration				*observation*
Data used for proof	Photographic picture of license plate plus overview				*In addition: picture for identifying driver*
Enforcement means	Fixed and portable enforcement gantries and extensive mobile patrols		Fixed enforcement gantries and strong OBU and enforcement at charging area boundary, few mobile patrols		
Progressivity of sanctions	Distinction between administrative fee for retarded payment and fine				
Access to charge evaders	Mobile patrol and mail		Mail and enforcement at charging area boundary		*Barriers*
Verification of registration data supplied by user	At time of registration				*At enforcement checks*
Enforcement strategy	Risk profiling				*Based on cost/benefit of enforcement activities*
Organisational and institutional characteristics					
Management authority	Unit of national government				
EFC system provider/operator	Private company or public authority				
Enforcement operator	Public agency or privat EFC operator				
Scope of EFC system provider contract	Build and operate EFC system				*Supply of EFC system components*

Scenario	1A	1B	2A	2B	*Alternative characteristics not included in the scenarios*
Remuneration of EFC system provider	Fixed				*Depending of charging revenues or depending of chargeable traffic volume*
Responsibility for charging income lost by evasion	National government				
Ownership of OBU	EFC operator				*User or management authority*
Charge for OBU	Deposit (according to draft Eurovignette directive) not covering full OBU cost				*No deposit or deposit covering full OBU cost*

3.1 General Assumptions pertaining to all Scenarios

In this chapter the main general assumptions regarding to the table of scenarios are characterised.

3.1.1 Legal status of the charge is a tax.

The Danish tax freeze makes it difficult to conclude whether a road charge should be implemented as a tax or as a fee. It requires a political decision to choose the legal status of the charge. However, this report assumes that the legal status will be a tax in all of the scenarios, since it is necessary to make the same assumption identical in all scenarios in order to be able to perform comparative studies across the scenarios.

A tax is a charge where only a governmental authority has the fiscal sovereignty to collect it. A tax is normally a charge that does not give a right to a certain service. Taxes are simply instruments for financing the governmental budget.

In contrast a fee is normally a charge directly related to the usage of a service. A fee can be collected by a public authority or a private entity on behalf on it.

For taxes usually strict national regulations apply. In most countries, only public authorities can operate the collection system. Toll charges with a tax status often also rely on a user declaration of the road usage and the technical equipment is only considered a tool to help the declaration. With fees, the freedom in system design is higher since the environment is less regulated.

If a road usage charge is legally considered a tax, it is not subject to Value Added Tax (VAT). If a charge is considered a fee, VAT normally applies. The VAT is an issue of handling and processing the payments, but not an issue for the RUC scheme in itself. It is also an issue for procedural and contractual interoperability.

An other advantage of a tax is the governmental source of power to execute the enforcement. Enforcement of a tax is much more effective then the enforcement of a fee. A private company has in most cases no access to the official vehicle registration database and no possibility to hinder the road user to continue his trip.

However, in the Danish tax system taxes can also be subject to VAT. Furthermore, not only the public authorities can operate the collection system and third parties are in these cases well equipped with the power to execute the enforcement of collection. Often the system is established in this way, because third parties are regarded as better executers than the authorities, since they possess more information to screen the customers with respect to payment credibility. To keep things as simple as possible it is assumed in this report that the road charge is a tax not subject to VAT.

The contractual interoperability between EFC systems where the charge is a fee are commonly simpler to handle than if the charge is a tax. The issues of a taxes that are being collected by (foreign) third parties must be explored.

3.1.2 Vehicles subject to charge are HGV above 12 tonnes.

Denmark is currently participating in the Eurovignette scheme. All Heavy Goode Vehicles (HGV) heavier than 12 tons have to be registered at the Eurovignette database for paying their fee. Since Germany contracted out of the agreement of the Eurovignette scheme in 2004, the discussions about the possible end of Eurovignette scheme started. The introduction of a Road User Charge for vehicles above 12 t could be understood as succession of the Eurovignette using current technologies. Therefore it could get a higher acceptance in the haulier trade than a 3.5 t limit.

3.1.3 Tariff is modulated regarding the emission class.

A tariff related to the emission class has a significant impact on the status of the vehicles fleet of a country (e.g. in the Swiss LSVA scheme the modulation of tariff regarding the emission class had a significant impact on the renovation of the hauliers' fleets). The emission class is part of the master data and can not be manipulated at the OBU by the user. The tariff could be differentiated depending to the EURO norm emission classes (EURO 1 to 5).

3.1.4 Basically, the EFC system should able to differentiate in a further step regarding to the area/network or time of day

In scenarios (1A, 1B, 2B) it is possible to modulate the tariff regarding the zone of an area or the road network and the time of day. In case of an area charging additional DSRC roadside equipment and several adaptations at the central IT system are necessary.

In case of a distance based area charging (scenario 2A) the time related tariff is only in combination with a defined road network (e.g. motorways) or zones (e.g. inner part of a citiy) possible since there is the need for passing a DSRC gantry which triggers a logfile entry.

3.1.5 The charge depends on the number of axles in scenario 1A and B and on the registered maximum permissible weight in scenario 2A and B

The simplest way of taking the vehicle weight in to account of charging is to use the maximum permissible weight of the road train. The charge would be the same for full and empty HGV and for tractor vehicles pulling a trailer or not, thereby incentivising a maximum utilisation of the loading capacity and a most efficient use of road capacity of road goods transport. However, this approach is considered being unfair by the road haulage industry. Compromises are the use of the number of axles for classification ore the use of the registered maximum permissible weight of the pulling unit with separate declaration of the trailer weight.

3.1.6 The scheme has to be compliant with NORITS (NORdic interoperable Tolling System)

NORITS is a service offered to all users of toll collection systems in the Scandinavian countries. The service makes it possible for any user to pay his road user charge in all Scandinavian schemes with the OBE he has received from his local toll operator. Therefore it was necessary to create a standardised transaction (technical interoperability), common procedures (procedural interoperability) and a common contractual framework (contractual interoperability). Every new scheme within Scandinavia has to be compliant with this NORITS framework.

3.1.7 The scheme has to be EETS compliant.

The Directive 2004/52/EC on the interoperability of electronic road toll systems in the community defines the technologies of electronic toll systems brought into service after the 1st January 2007. They shall, for carrying out electronic toll transactions, use one or more of the following technologies:

- satellite positioning;
- mobile communications using the GSM GPRS standard;
- 5,8 GHz microwave technology.

Interoperability shall be achieved by On Board Units which work in all systems and not by harmonising the national systems. The specifications for the European Electronic Tolling System EETS are not yet determined. Nevertheless, the assumption is that the Danish HGV Charging Operator will accept customers who want to pay the charge by using an EETS OBE linked to an EETS contract. This is literally meant in all four scenarios possible. But since the European discussions and the directive about EETS emanate a distance based RUC it is not possible to act on the assumption that a time based area charge is EETS compliant. However a one directional interoperability will be possible.

3.1.8 The On Board Equipment (OBE) is mandatory.

The handling of occasional users strongly determines the overall design of a charging system solution. If a technical solution for tolling requires the usage of special On Board Equipment (OBE) then it can be assumed that frequent users will equip themselves with such a device to take part at the scheme. But according to the UN Convention on Road Traffic and to the EU non discrimination logic (e.g. Treaty of Nice), frequent and occasional users must be admitted to the charged road network in the same non-discriminatory fashion. Especially occasional users will not be prepared to equip themselves with permanent equipment.

If the technical solution is based on a complex OBE with high effort for integration in the vehicle, e.g. installation time of several hours and only in certified workshops, then a second solution must be offered to cover the needs of occasional users. This second technical solution must ensure that the unequipped or occasional users can have access to the system in an easy way and with minimal effort, e.g. with a ticket based solution or with an OBE that can be obtained and mounted by the driver in a matter of minutes.

In charging, equal treatment especially means that all user groups pay the same when using the same roads under the same conditions. System design must therefore ensure that users with permanently fitted equipment pay the same as non-equipped or temporarily equipped users. It is questionable whether users with permanently fitted equipment can be offered better tariffs or whether occasional users can be treated with a simplified charge.

From this it follows that even the most sophisticated technical charging solution is limited in its charging flexibility (flexible tariffs, flexible extensibility of charging area, etc.) to the capabilities of the technical solution for the occasional users. Only what can be done for the occasional or unequipped users can also be done for the frequent or equipped users.

For charging systems, the requirement "no barrier to free trade" especially means that foreign users, which are often occasional or unequipped ones, must have easy access to the charged road network. It is not allowed that the charging solution takes a lot of time or requires high deposits to be paid in advance.

One solution to the problem of occasional and foreign users is to construct the road user charge as a national tax which foreign users do not have to pay. The Netherlands had been planning such a system for all vehicles for several years. The system was planned as a distance dependent charge on all roads and required the installation of an on-board unit in all vehicles. The intention was to replace the taxes on vehicle use (annual vehicle tax, petrol taxes, etc.) with a distance dependent tax that has demand management aspects (differentiation of the fee according to time of day and according to type of road). Since the fee was constructed as a national tax, subsidiarity applies and the Netherlands had maximum freedom in system design, e.g. there would have been no obstacles to introduce a mandatory on-board unit in every vehicle as a kind of "tax meter".

Since the OBE which is used to measure the distance in a distance based area charging scheme like the Swiss LSVA needs an electrical connection to the tachograph (installation of the OBE needs more then an hour). This requirement makes it necessary to develop an alternative solution for occasional users. Therefore the Swiss LSVA uses ticketing machines where the user enters his mileage and gets a ticket. At the end of his trip in Switzerland the user declares his new mileage at the moment of exit on this ticket and gives it to the custom officer. A more comfortable solution for this functionality could be a self mountable, autonomous DSRC Low use OBU (LOBU) with a display and a keypad to enter the mileage. At the border crossing the user has to enter the mileage of his vehicle and the vehicle configuration into the LOBU. Passing the border the data will be transmitted to a central IT system via DSRC.

One main cost driver regarding OBE is the so-called OBE leakage: loss of OBE mainly through foreign users who enter Denmark rarely or just one single time, and through the high number of new registered vehicles. The experiences of the Austrian and the Swiss scheme show that 140,000 new OBE per year are distributed in Austria on top of the 400,000 OBE at the start of operation. 90,000 new vehicles per year are registered at the Swiss border.

3.1.9 It has to be a free-flow multi-lane tolling system.

There should be no barriers for the traffic resulting out of the charging procedures. After registration of the vehicle and haulier or payment data and if necessary after installation of the OBE in the vehicle the user has not to stop trip anymore because of the tolling system. Independent of the number of lanes and traffic conditions charging has to be possible.

3.1.10 The central account is the master and comes with the only confirmed balance.

In an area charging system, the self declaration principle is the only effective way to obtain the charging data of vehicles that never or seldom leave the area. Self declaration does not allow informing the user about the used charge since the assessment for HGV charge is based on the users declaration by the back office of the charging system operator. Therefore a prepayment solution comprising an on board account is not applicable. The user may be offered the possibility to check the log file entries informing him about the used distance and the declared weight. Based on this information he can estimate the charge, but the system cannot give him any assurance for the amount before the declaration has been accepted.

Neither a thin client GPS/CN scenario which is not as costly as a fat client GPS/CN scenario has the possibility to provide a on board account. Since in this case the map matching and the calculation of the tariff is done in the central IT system, the actual balance of the charge is not online available. Within a certain time it is possible to transmit the balance from the central IT system to the thin client OBE.

Only a DSRC OBE could easily provide an on board account, since the receipt including the tariff of the toll section is part of the DSRC transaction and is stored in the OBE.

3.1.11 An anonymous use of the system is not possible.

Every vehicle using the charged network or area has to be registered. Therefore at least a vehicle account has to be opened, a contract number has to be generated, the license plate number and other vehicle data (like emission class etc.) have to be stored and a payment mean has to be authorized.

3.1.12 The driver and the vehicle holder share the liability regarding the HGV charge.

Primarily liable for the HGV charge is the vehicle holder. He is responsible for the payment of the charge. The driver can be enforced by the mobile enforcement officers in case of not executing his obligation to co-operate.

3.1.13 At the time of registration declared vehicle data are verified.

To register the vehicle for the road user charge (RUC) the user has to show his vehicle registration certificate. Based on the vehicle registration certificate the employee of the point of sales (POS) has the possibility to verify the declared vehicle data. During the introduction of the charging system (some moth before and after the start of operation) there should be the possibility to register vehicles by fax or letter. The vehicle holder has to attach photocopies of the vehicle registration certificates to the declared vehicle data as a proof. The fact that there are no unassured vehicle data in the system data base takes a huge burden off from the enforcement system.

3.1.14 The enforcement strategy will be based on a assessment of fraud.

Enforcement is one of the main cost drivers of a charging system. The frequency of fraud depends from the density of enforcement (the more enforcement the less fraud). But after a certain point the impact of enforcement on fraud decrease and the operating costs increase strongly. Therefore it is necessary to assess the risk and frequency of fraud. Based on this fraud assessment there will be an estimation of the best density of enforcement/operating costs ratio for each Scenario. The following parameters have influence on the density of enforcement:

- the number of toll sections
- the number of operating fix and portable enforcementstations
- the geographical and stratigic location of fix and portable enforcementstations (at all areas of a road network and at points with the most traffic)
- the frequency of mobile enforcement especially regarding foreign users

The following parameters have influence on the operating costs of enforcement mainly on the need of manual post processing:

- the number of operating fix and portable enforcementstations
- the quality of the automatic number plate recognition
  - not readable LPN
  - wrong read LPN
- the quality of vehicle classification
  - wrong classification regarding the liability
  - wrong classification regarding the vehicle class (incl. trailer)

3.1.15 The OBE is in the ownership of the EFC operator.

Especially the more sophisticating on board units should not be out of control of the EFC operator for reasons of security. The ownership of the OBE allows the EFC operator an easier handling regarding the operation and the maintenance of the OBE. Since the RUC should be a tax the acceptance of the charging system is necessary for the political decision finding process. Additional costs for the road user regarding the OBE will not be accepted, especially if the costs are high like in the case of a distance based area pricing scheme.

3.2 Scenario Group 1: Charging of a Defined Road Network

HGV Charging on motorways and expressways can be done distance related or time based (i.e. day pass, monthly or yearly permit). This study only focuses on distance related network charging. It is possible to execute distance charging by several available technologies (DSRC, ANPR, GNSS/Cellular Network,). In some schemes like the one in Austria, the motorway and expressway toll is combined with a corridor pricing for tunnels and bridges, which are part of the motorway network. In many European countries (e.g. France, Spain, Italy, Portugal, Slovenia, Austria, , Germany, Hungary) HGV are charged on motorways. In all of these countries, the toll is well accepted by hauliers.

One of the main problems of motorway and expressway charging is the evasion of traffic to uncharged parallel roads particularly by occasional (foreign) users. To solve this problem, there are intentions to expand the tolling liability on certain parallel (not tolled) roads, especially in Germany.

Enforcement
The level of enforcement in a network charging scheme depends on the number of enforcement points (permanent installations or mobile units) relative to the length of the network. The Austrian HV charging scheme comprises 120 permanently installed enforcement stations, 20 portable enforcement stations and 40 mobile enforcement units which are 7 days 24 hours active on a 2,000 km road network with 800 toll sections. The German HGV charging scheme covers 12,000 km of road network with 5,500 toll sections. The German enforcement system is based on 300 permanent enforcement

stations and 280 mobile enforcement units. Only a limited number of enforcement stations and mobile enforcement units are in operation at any time to decrease the operating costs of enforcement since every picture of a potential enforcement case has to be checked manually.

Figure 1: Mobile enforcement executed by the BAG (Germany) and ASFINAG (Austria)

Registration and distribution of OBU

Before using the charged road network the user has to register his vehicle at a manned or unmanned point of sales (POS) or via fax (see chapter 3.1.13) or on the internet. After registration he gets his OBU which is personalized via CN in case of a GNSS/CN scheme and via DSRC at the POS in case off a DSRC scheme. The OBU is mounted in both cases by the user/driver himself.

3.2.1 Scenario 1A: Network Charging Using the GNSS/Cellular Network Technology

One approved technology for network tolling is GNSS/CN. It uses two technologies adapted from other applications; namely, GNSS (Global Navigation Satellite System), whose satellites enable suitably equipped vehicles to calculate their location accurately; and a two-way communication link (e.g. GSM/GPRS) based upon cellular telephone network. According to the position, the system recognises if the vehicle is driving on a toll road. In contrast to DSRC based systems GNSS/CN systems need only a few, if any, roadside infrastructure (gantries). Due to the several limitation by using GNSS only (no GNSS signal by shadowing effects, temporary system turn-off, etc.) the OBU is connected to or equipped by other sensors for localisation and distance measurement (tachograph, wheel sensors, gyrocompass, etc.).

Two main designs of the overall system are technically possible. The one approach uses a high-end GNSS/CN OBU (so called "fat client") which means all the intelligence for a single fee calculation is inside the OBU. This OBU transmits complete fee transaction data to a central system where they are cumulated and further processed for billing. The OBU recognizes by itself whether it is on a toll section or not and if yes what tariff applies and when. This implies that an application with map matching algorithm and tariff handling must run on the OBU. If the properties of the charged network change, e.g. new tolled sections or tariff, the OBU software must be updated over the CN interface. This kind of system architecture was implemented by the German toll operator Toll Collect. The fat client architecture is highly sophisticated and has to be mounted by certified garages because of the necessary connection to the antennas and other sensing equipment and power supply. Therefore, the capital investment and the operating costs of fat client architecture are relatively high. Since the map matching and the calculation of tariff is executed by the OBU, the liability of the road network and the actual charge can be displayed online to the driver. This technology is applied for the German LKW Maut system by Toll Collect.

The other approach is a low-end GNSS/CN OBU (so called "thin client"). This OBU collects only position data (GNSS position and time plus potential other sensors) and sends this to a central IT system. Based on the position data received from the OBU the central system calculates the dedicated fee. The map matching process and the tariff management run in the central system. The needed OBU software updates are limited, because the fee calculation process is done by the central system. In current discussions about architecture of GNSS/CN EFC systems, the thin client architecture is favoured by the industry. The complexity of the OBU is less than in a fat client architecture and can be handled easier. In spite of higher communication rates via CN (since the localisation is not done in the OBU) the investment and operating costs are much lower. Regarding the main current European interoperability projects the EETS OBU could be a thin client. This technology has been proposed for the UK Lorry Road User Charging project. Scenario 1A is based on the thin client architecture.

At the time when the tender of the German "LKW Maut" was prepared, telematics platforms integrated into the vehicles to provide different value added services (VAS) beside EFC were in the expert's minds. The concept was to create an OBU which is able to run different applications using a single hardware platform. This telematics platform should include technical components processing the localisation of the vehicle and communication equipment to transfer data to the different service providers. The German OBU should be such a telematics platform running different applications and providing VAS. After the start of operation of the German LKW Maut was postponed, the priority changed. First priority became the start of operation of the German HGV charge. Currently Toll Collect is not allowed providing VAS. The German OBU is a very complex multi application device which runs only one application to collect RUC. The hype of VAS provided in the vehicle has cooled off. There is no reason anymore to invest a lot of money into a device which is able to provide several services in the vehicle which are not demanded by the market.

The thin client architecture does not provide the same potential to implement Value Added Services (VAS). On the other hand, there are less implementation risks and lower cost than with a fat. The German fat client concept was originally designed to act as a general telematics platform in the vehicle. Only when the problems of delivery of the systems became obvious a new policy was adopted to only implement the charging function and to abstain from offering VAS.

The power consumption of a GNSS/CN OBU is much higher than with a DSRC OBU. This comes from the current drain of the GNSS module itself and from the higher computing power. The power supply of such an OBU usually can not be provided internally (by battery) for a sufficient time, therefore it is necessary to have connection to the power supply of the vehicle (permanent power supply connection - fat client; power supply to recharge the battery – thin client).

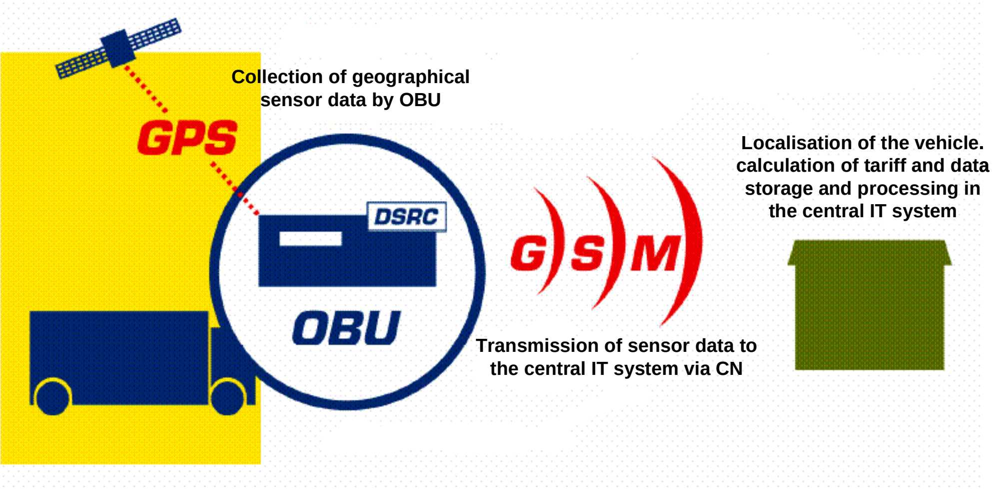


Figure 2: Key-functionality of a GNSS/CN charging system (thin client architecture)

Virtual gantries and toll section identification via GNSS and map matching
Currently there are two different ways to charge a toll section in a GNSS/CN charging systems. First there is the German Toll Collect approach which allows the identification of a certain point (small area) at a road network and with it a particular toll section. Passing this particular point the vehicle is charged for the corresponding toll section. The other approach identifies a toll section by recognition of pattern based on different geoposition data. The localisation is done via map matching. In the thin client architecture the geographical data are collected by the OBU and transmitted to a central IT system which is processes the map matching and calculates the tariff. Regarding the capital investment it is to consider that both approaches are patented. It is to emanate that potential supplier of such a technology will be able to come with a corresponding license.

Communication between OBU and central IT system via cellular network
The communication between the OBU and the central IT system like the transmission of geographical data will be proceeded by a public cellular network (CN) for instance a GSM/GPRS network. To minimize the communication costs a flat fee for a certain time (e.g. day) has to be negotiated with the supplier of the CN.

Figure 3: GNSS/CN OBU: possible solution of a thin client and a German enforcement station using IR beacons

3.2.2 Network Charging Using the DSRC Technology

Instead of using cash or payment cards, the payment transaction takes place between an electronic On Board Units (OBU), which is fixed at the windscreen of the car, and the toll road operator's electronic road side equipment while the vehicle is in motion. During a split of a second, the relevant information between the OBU and the roadside equipment is exchanged, using a standardised 5.8 GHz microwave communication. In Europe commonly two standardized types of 5.8 GHz DSRC links are used. One is the DSRC link according to the approved CEN standard, which is the most common, and the other one is the DSRC link according to the Italian UNI standard.

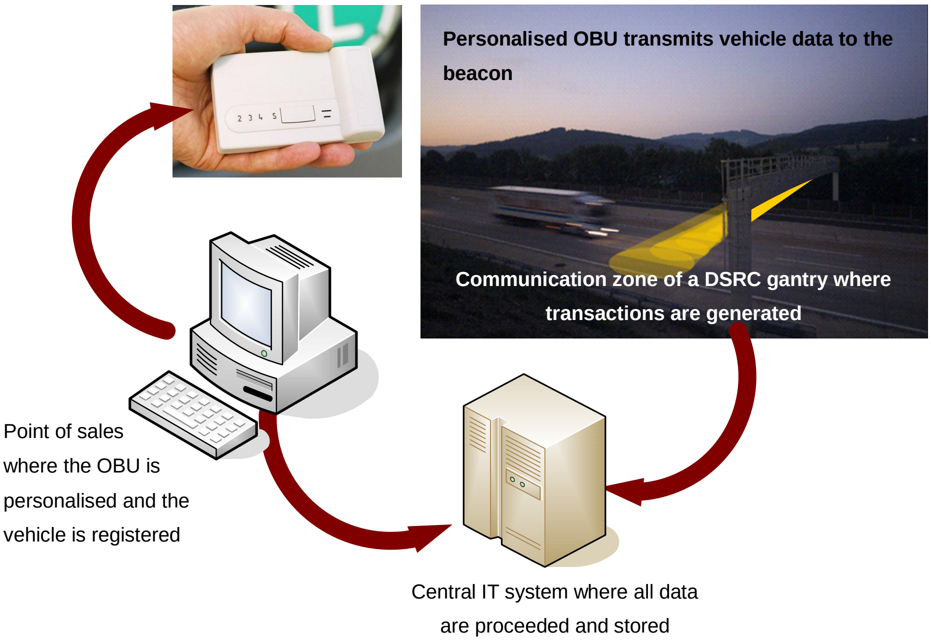


Figure 4: Key-functionality of a DSRC charging system

In a DSRC system the data exchange necessary for tolling happens between the OBU installed in the vehicle and a beacon installed roadside usually on a gantry. If the vehicle is passing underneath such a gantry the relevant data for tolling (e.g. vehicle data, contract data, etc.) are provided by the OBU to the beacon. Having received this information the beacon calculates the fee based on its additional information like time and section tariff. The OBU gets a receipt from the beacon including this information. The data from all the beacons installed on the network are collected in a central system for further processing (billing etc.). From the central system the beacons are provided with data which are subject to change, like tariffs, lists etc. This happens normally by using leased lines. The DSRC technology implies that each section of a tolled road network is equipped by a beacon installed on a gantry. The OBU itself has a size of a credit card (but thicker) and has its own power supply (internal battery) with a lifetime of usually 5 years. The cost savings of simple OBU come along with more extensive resources regarding installation of roadside equipment (gantries and beacons). It is assumed that the DSRC system would be conformant to NORITS interoperability (technical, operational and contractual interoperability).

Figure 5: DSRC gantries and OBU in Austria (left: DSRC only, right: DSRC and enforcement).

3.3 Scenario Group 2: Area Charging

This type of scheme applies to trips made within a defined area – in our case the area within the borders of Denmark. Users of HGV who wish to use their vehicles within Denmark would need to have an On Board Equipment which measures distance or duration of vehicles usage. A key advantage for this type of pricing mechanism is that there is no evasion of traffic to uncharged parallel roads. The experience with the Swiss HGV Fee (LSVA) shows that this kind of area charging allows having a significant impact on traffic. Main requirement of area charging is the existence of well defined borders with a limited number of border crossings. Regarding the geographical position of Denmark, there are perfect conditions for such a system.

Self-declaration principle

Different to road network charging schemes like the Austrian and the German one which proceed the charging of a vehicle automatically without intervention by the user beside the declaration of the vehicle class at the OBU, the charge in an area pricing scheme is assessed by the EFC operator based on the self-declaration of the vehicles holder. Therefore the vehicle holder is responsible for the declaration of the charge. The OBU stores defined events (e.g. start of trip, declaration of trailer, crossing of border etc.) in a log file. This log file is sent by the vehicle holder after the end of the declaration period (one month) to the central service via chip card or via internet. In the case of OBU errors or the break down of the OBU the user has the obligation to enter his mileage/time and his weight/vehicle class regarding the different events into a formula until the OBU is repaired by a certified garage. Regarding the operating costs the experience of the Swiss LSVA shows that approximately 80% of the RUC assessment is done automatically by the central IT system and 20% of the RUC assessment has to be proceeded manual.

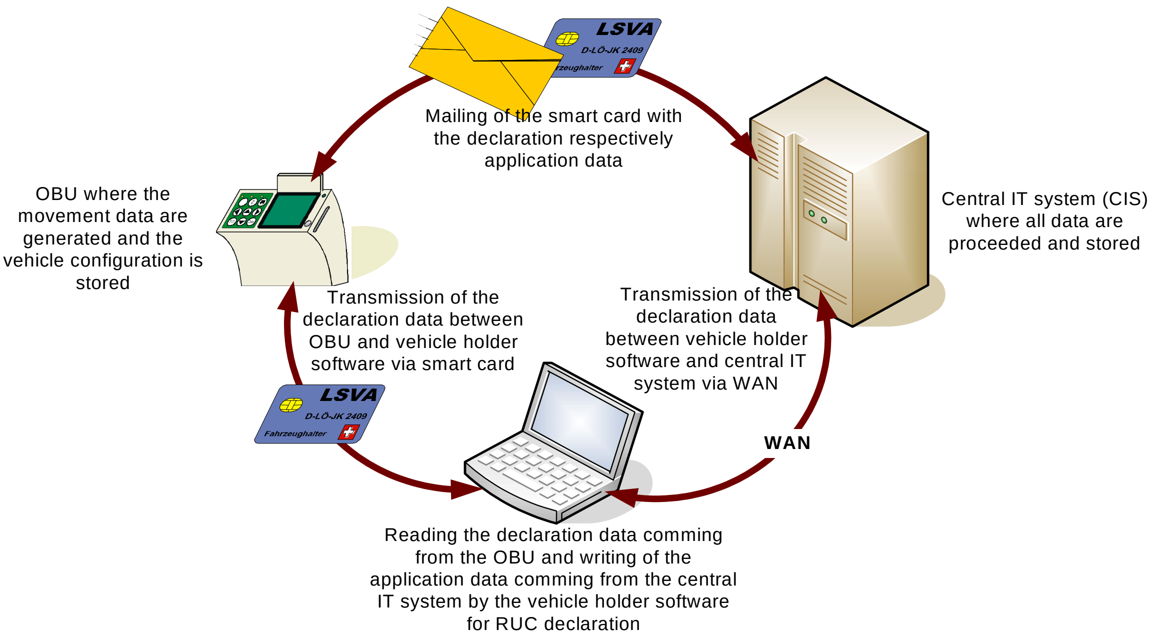


Figure 6: Key-functionality of an area charging scheme

3.3.1 Scenario 2A: Distance Based Area Charging

This approach is based on the principle of fee payment for using the road network in a defined area according to the driven distance. That means the every type of road in this area is subject to a fee. With the possibility to have different tariffs for different vehicles on different roads, as was planned in the UK for the Lorry Road User Charging Programme (LRUC), or with one tariff for a dedicated vehicle on all roads, like the Heavy Goods Vehicle Fee (LSVA) in Switzerland. The first approach has the advantage for better traffic management by varying the tariff for the road categories. But this has a huge impact on the technical complexity for implementing such a system. The second approach aims more on the general reduction of driven mileage in a defined area by a dedicated vehicle group and the change of the modal split – e.g. transferring goods from road to rail like with the LSVA in Switzerland. This approach is technically easier to implement as the first one. But nevertheless the technical solution is just a derivation from the overall political and financial objective of the scheme. In Scenario 2A there will be no modulation of tariff regarding the type of road and regarding the time of day.

The approach of distance based area charging especially for HGV postulates, if seriously handled, a connection to the vehicle's tachograph as the only certified source for distance measurement. Additional sensors can supervise the correctness of the operation of the OBU. The access to the priced area must be clearly recognized by the OBU, most suitable by redundant way.

Registration, installation and initiation of the OBU

If a vehicle is registered at the Danish vehicle registration the database automatically provides the data set to the central IT system of the EFC operator. The user receives a confirmation for the installation and initiation of the OBU at a certified garage. Foreign users which would like to use the Danish road network should have the possibility to apply for the installation of an OBU.

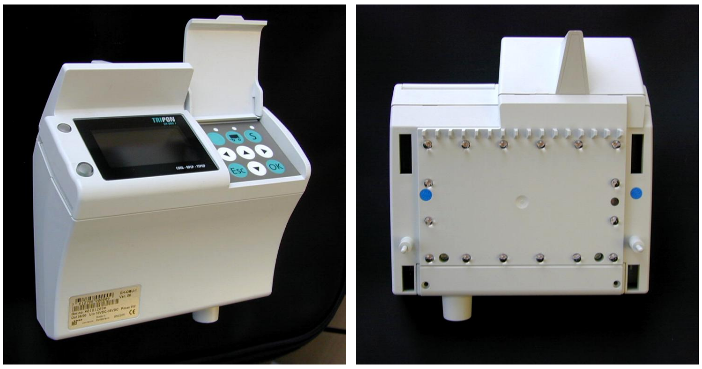


Figure 7: OBU of the Swiss HGV Fee (LSVA)

Registration and OBE of occasional users

Vehicles which are registered in another country have to be registered regarding the RUC at the entry point to the charging area the first time they enter into Denmark. After registration at a manned POS they get a personalized LOBU which stores the mileage and weight at the area entry point, the mileage and new weight at the moment of change of the vehicle configuration and the mileage and weight at the area exit. All those data are entered by the user/driver at the keyboard of this LOBU. Passing the area boundary the LOBU transmits all those data via DSRC to the central IT system. The TAG is mounted at the windscreen by the user himself.

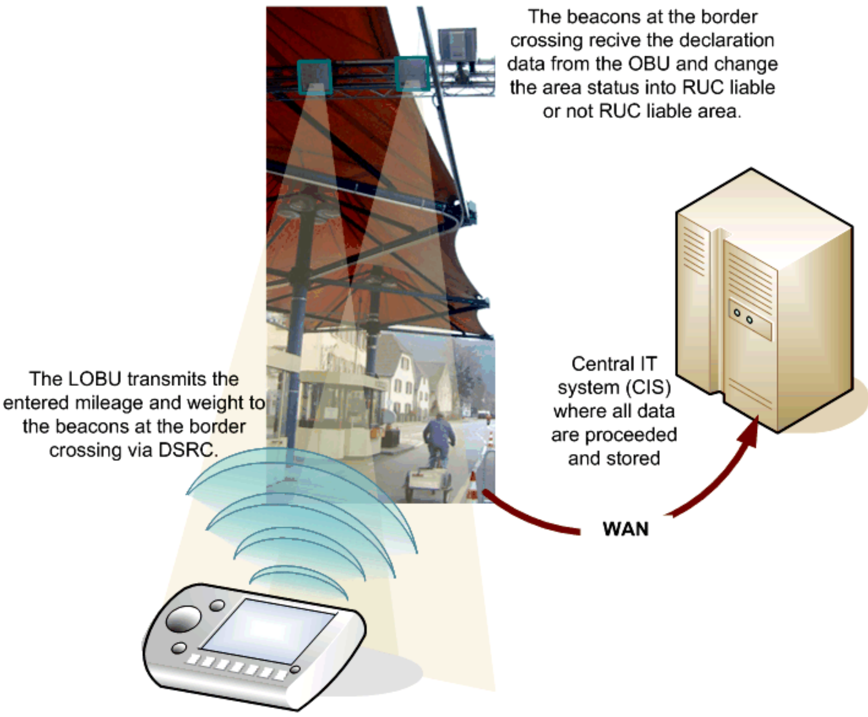


Figure 8: Key-functionality of distance based area charging for occasional users using a LOBU

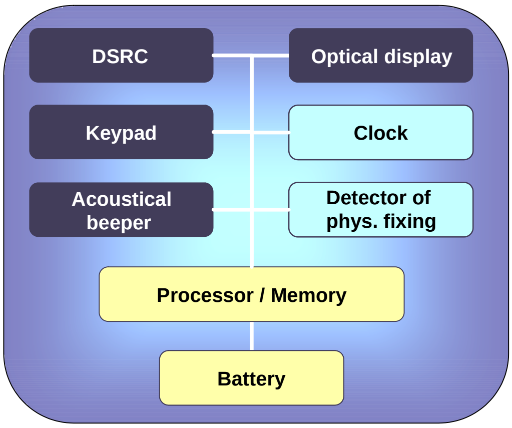


Figure 9: Architecture of the LOBU (light OBU)

Enforcement

The self declaration principle requires that the OBU must store the driven distance of the vehicle and the declaration of a trailer (number of axles of the road train or additional weight). It must be ensured that the OBU is in the assigned vehicle and in operation independent of the vehicle infrastructure. The permanent enforcement stations are focusing primarily on the foreign vehicles equipped with a LOBU and on the detection of trailers. For vehicles fitted with a permanent OBU, the OBU accomplishes the monitoring tasks autonomously and permanent enforcement stations are less critical. Since in the scenario 2A the vehicle classification is done regarding the registered maximum permissible weight of the road train, it is possible to mix the permanent and portable enforcement. For LOBU users the driven distance is based on tachograph readings and it is entered manually by the driver. The entry and exit mileage is spot-checked at the border on the one hand, on the other hand the driven distance can be verified to with a distance matrix (entry/exit/passages at enforcement sites). In Switzerland there are 18 automatic enforcement stations, 1 mobile non-stop enforcement unit and about 80 border crossings for HGV. The permanent enforcement and particularly the portable enforcement of a time based area charging are focussing on two tasks: (1) the detection of not equipped vehicles and (2) the monitoring of correct trailer declaration.

Figure 10: LSVA enforcement station and tachograph camera to check the mileage of vehicles without OBU

3.3.2 Scenario 2B: Time Based Area Charging

By definition the movement of vehicles is a function of distance and time. This means that in theory distance and/or time could be used as the basis of usage based road pricing. Different to the distance based area charging the time based area charge is charged according to the time period the road network in a certain area is used. Similar to the cordon pricing like in Stockholm there is a clearly defined boundary round the RUC liable area. The area will be identical to the territory of Denmark but small adjustments of the boundary for practical purposes may be considered in co-operation with neighbouring states.[5] Instead of charging the entering into this area (cordon pricing) the time of movement inside of the boundary is charged.

A low-cost TOBU is used containing a conventional 5.8 GHz DSRC tolling tag, a clock, vibration sensors capable of determining whether the engine is switched on or off, and accelerometers capable of determining whether vehicle is moving or stationary. The TOBU logs the time when the vehicle is moving inside Denmark. A chip card or a USB stick is used for downloading the log file and the user declares his charging parameters by sending in the chip card or via the Internet. With appropriate roadside infrastructure at the area boundary the charging data can also be automatic transmitted to the Central System when a vehicle is entering and leaving Denmark. The key advantage of the time based approach of this scenario is that the TOBU is autonomous and can be self-mounted in the same way as the DSRC tags of Scenario 1b. Therefore, there is no need for an manual declaration scheme for non-equipped users as in scenario 2A. The EFC system is much less complex than with distance based charging and the capital investment and the operating costs are low due to the absence of localisation technology on board or at the roadside excepting the installations at the boundary.

Since there is currently no scheme using this technology regarding the requirements of a time based area charging, the proposed solution is not validated. Two problems could arise during the development phase:

- accuracy of the determination whether the engine is switched on or off by the vibration sensor
- the power supply by batteries

Both points would change the concept in its fundamental advantages (e.g. the distribution concept with a self mountable TOBU would not be possible with the need of connection with the vehicles power supply).

[5] For the Swiss LSVA such adjustments have been agreed with France, Germany and Liechtenstein.

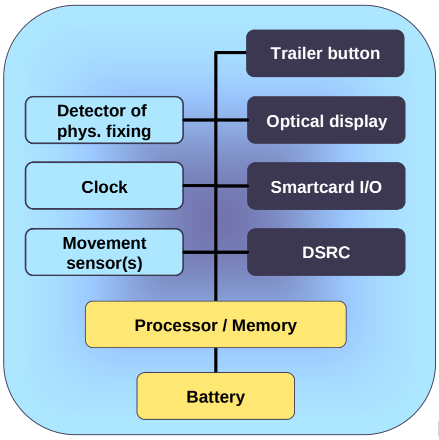


Figure 11: Architecture of the TOBU for time based area charging

Potential Effects

If a user is intent on minimising the level of charges incurred in the context of a time-based charging scheme, then in principle they will need to take the quickest route and adopt the fastest driving style for the road conditions encountered on the way. This could encourage driving at excessive speeds, unsafe overtaking manoeuvres, and so on. More helpfully it could also result in drivers diverting or changing time of travel to avoid delays and congestion. But in practice how likely is it that the particularly undesirable behaviours will occur? It is a well-established principle that different users / trip purpose combinations lead to very different values of travel time. If the difference in cost of travel time between different user / trip purpose combinations are genuine, then such an economic incentive towards unacceptable driving behaviour already exists for some relative to others (most likely at a greater cost per hour than would be considered for road pricing purposes). If this differential economic incentive is material in terms of influencing driving style, then user type / trip purpose combinations ought already to be being highlighted by the road safety community as major influences on accident risk or accident severity. Yet this is not the case, suggesting that the primary motivations for such undesirable driving behaviour today are not primarily about the cost of the journey. Overall this suggests that charging on the basis of time need not necessarily result in any more undesirable user behavioural responses than that associated with distance-based charging. This aspect of time-based charging would certainly benefit from further research to establish more precisely the degree of any likely behavioural effects in practice. The effects must not be over-rated because the existing cost associated to HGV travel time (driver's wage, use cost of lorry, time-based cost of goods transported) will always remain much higher than the supplementary cost of the charge.

There could be a positive effect on pollution. However, there studies analysing vehicle emission data based on time are not available. All research on vehicle emission data is distance based.[6]

Enforcement

Different to the distance based area charging the TOBU of the time based area charging comprise only a few secondary supervising sensors. Therefore there is the need of a higher enforcement density, but not as high as for a net charging scheme. The following 4 types of fraud are thinkable in a time based area charging scheme:

- no TOBU on board

[6] Travelling 100 km on interurban roads does not pollute the same as travelling 10 times 10 km on urban roads. Emission correlate better to driving time.

- not correct mounted TOBU (in case of self mountable TOBU)
- wrong TOBU in the vehicle

To face these fraud types in a time based area charging scheme the enforcement should provide the following enforcement equipment regarding the necessary enforcement density:

- a moderate number of permanent enforcement stations strategically located at the main transit roads and in the agglomeration of big cities
- portable enforcement stations variably located in remote geographical parts of the RUC liable area
- a relatively large number of mobile enforcement units which are nearly 7/24 in operation

4 Volumetrics

Besides the system characteristics described in the preceding chapter, the cost and revenue estimations depend on the quantitative system dimensions.

In this chapter, we quote selected figures on Danish HGV traffic, which we use in the following cost and revenue estimations. The figures come from the Ministry of Transport and Energy, unless stated otherwise.

4.1 Road Network

4.1.1 Network charging

The road network for network charging corresponds to a previous proposal from the Road Directorate, and has been used as an input to the present study. It has the merit of providing a basis for cost and revenue estimation, and a starting point for discussing the impacts of different scale factors on the four scenarios.

We must underline the preliminary character of these network definitions. Several issues must be studied in more detail. We present the most important of them in chapter 5.

In a memorandum of Vejdirektoratet dated 3rd May 2004, a first proposal of a main road network appropriate for HGV charging is laid down.

It is considered that the network should include :

- Roads with significant present HGV traffic
- Roads which offer alternatives to present itineraries if the present itineraries were subject to charge
- Roads with important foreign HGV traffic
- Roads which connect the parts of the country
- Roads which are a functional part of the international road network (European road naming scheme, Trans-European Road Network)
- Roads which complete the network to a whole connected entity.

The Road Directorate, RD, is responsible for 985 km of motorways and Sund & Bælt for the 7 km long Øresundsmotorway i.e. in total 992 km motorways. For the relevant road network approx. 2,500 km of non-motorways are included, adding to a total of 3,500 km. The Greatbelt and Øresund links are not a part of the relevant road network, since these links are already subject to fee collection.

Figure 12: Map of the relevant road network

4.1.2 Area charging

For area charging, all roads on national territory are included:

Motorways (Road Directorate)	985	km	)	
Øresundsmotorway (Sund & Bælt)	7	km	)	motorways (total length) 992 km
Dual carriageways	352	km		
Other roads	70 872	km		
Total road network	72 216	km		

The Great Belt and the Øresund links (app. 40 km.) are excluded because HGV charging already applies on these links.

The limits of a Danish area charging consist of all terrestrial border crossing points with relevance for heavy vehicles, and all seaports where heavy vehicles are shipped for international trips. These are the entry and exit points to and from the charging network. If there are international piggy-back railway terminals for heavy vehicles, they are limits of area charging as well.

Our assumptions are:

Terrestrial border crossings[7]	DK – D	7
	DK – S	1
Seaports with ferry connections DK – abroad[8]		12

Beyond these basic assumptions, a detailed study of an area charging scheme must:

- Establish the official list of regular entry and points,
- Define the rules that apply to exceptional entry and exit points.

For practical reasons, a discrepancy between charging area and national territory may be introduced at that stage. For instance, closed seaport facilities might be excluded from the charging area, since it is preferable to install a charging gantry at the entrance of the seaport premise rather than to equip several docks.

The Swiss HGV charging area differs in many details from the national territory. In each case, bilateral agreements with the neighbouring countries have been concluded. For instance,

- a German enclave is included in the charging area,
- the territory of Liechtenstein is included in the charging area,
- the charging area border points around Geneva and Basel are shifted inwards or outwards with respect to the geographical border for practical convenience (maximum 1,5 km).

4.1.3 Summary of network lengths

Road network	**1A**	**1B**	**2A**	**2B**
Total length [km]	3,500	3,500	70,872	70,872
Number of regular entry/exit points			20	20

[7] Source http://www.trafikken.dk/hent/A0-Plot_DK_Tungvogn_2005.pdf.

[8] Source http://www.trafikken.dk/wimpdoc.asp?page=document&objno=74714. Rødby, Gedser, Rønne, Køge, København, Helsingør, Grenaa, Frederikshavn, Hirtshals, Hanstholm, Esbjerg, Romø.

For comparison, the German LKW-Maut covers 12,000 km of motorways, comprising 5,200 toll sections.

The Austrian Go-Maut covers 2,100 km of motorways and double carriageways, 140 km of which are subject to a higher tariff. The number of toll sections is 800.

The Czech Republic plans a first stage of HGV charging on 1,500 km of motorways. In a second stage, it is planned to add 5,000 km of major trunk roads and 1st class highways.

The Swiss HGV charging area comprises 70,000 km of roads, 1,800 km of which are motorways. There are 82 regular border crossing points.

4.2 Vehicle stock

4.2.1 Danish vehicles

The Danish vehicle stock is known through the car register.

Lorries above 6 t gross weight	30,710
Articulated vehicles	13,021

Out of the 30,710 lorries above 6 tons, we assume that 28,640 are above 12 tons. This ratio is transposed from the statistics on traffic performance per vehicle weight class. We assume that all articulated vehicles are above 12 tons. With these assumptions, the total Danish vehicle stock above 12 tons is 41,660.

4.2.2 Foreign vehicles

The relevant figure is the number of different foreign vehicles who use the Danish network within a given period of time. These vehicles are cost-relevant since they need to be equipped with the mandatory OBU when they come into contact with the EFC system for the first time.

No regular statistics are available on this subject. The data must be estimated from indirect sources.

Sund & Bælt has estimated the number of different foreign HGV passing on Storebælt within a year. A high level of uncertainty rises from the source data as well as from the method of estimation. The best estimate amounts to 30,000 – 35,000 different foreign trucks a year. This estimate is for Storebælt only, situated on a East-West route which is not a main transit axis.

Estimates provided by the Danish Ministry of Transport[9], based on data from a survey of transit traffic[10], amount to 141,985 transit trips undertaken by foreign vehicles, and 690,000 import-export trips undertaken by foreign vehicles. However, no estimate on the number of different vehicles can be drawn from these data. The sum (832,000 trips undertaken by foreign vehicles) sets an upper limit.

[9] We acknowledge helpful input from Mr. Ole Kveiborg from the Danish Transport Research Institute (DTF).

[10] NUTRADA

In foreign HGV charging schemes, the only stable figure is the yearly number of new registrations. For comparison, 90,000 new foreign vehicles are registered in the Swiss LSVA per year. 140,000 new OBU are issued by the Austrian HGV charging scheme per year, this figure is however an upper limit to the number of new foreign vehicles since it comprises the renewal of OBU for Austrian lorries.

On the basis of these elements, our best guess is 100,000 different foreign vehicles per year, with a renewal rate of 30 % per year. This is an uncertain estimate. Therefore we have conducted a sensitivity test (impact of this assumption on system costs), see further below.

We assume that the vehicle stock is the same for area charging and network charging. This means that all HGV circulating on Danish roads come into contact with the chargeable network of scenarios 1A and 1B.

Vehicle stock	**1A**	**1B**	**2A**	**2B**
Danish vehicles	41,660	41,660	41,660	41,660
Different foreign vehicles per year	100,000	100,000	100,000	100,000

4.3 Traffic performance

Depending on the scenario, the revenue-relevant figures are:

- Total distance travelled (vehicle-kilometres),
- Total driving time (vehicle-hours).

4.3.1 Traffic counts

Traffic counts are systematically conducted on state and county roads. The counts use a length classification of the vehicle. The statistics assume that length above 5,80 meters corresponds to weight above 3,5 tons. An exact identification of the share of HGV above 12 tons is not possible.

In principle, an estimate of the total distance travelled on a given network would be obtained by multiplying traffic count by link length, for each link. An estimate of the total driving time would be obtained by multiplying the traffic count by the average link travel time, for each link. Unfortunately, such aggregates are not available at present.

4.3.2 Odometer data

The odometer count is systematically collected from each Danish vehicle, each time it undergoes a technical verification. The data are statistically aggregated. Their limit is that foreign vehicles are not included, and that network categories cannot be distinguished.

4.3.3 Estimation of traffic performance

The Danish Ministry of Transport[11] has provided an estimate of the total distance travelled by HGV above 12 tons on the network on state roads and former county roads described further above.

The estimate is based on HGV odometer readings, and seaport and border crossing entry/exit statistics collected by Denmarks Statistics, and on own assumptions related to the allocation of traffic to network categories, and to average distances travelled by foreign vehicles.

It contains traffic with all vehicles above 6 tons total permissible weight; except the purely national traffic, where the vehicles above 12 tons total weight could be isolated. Since most international traffic is undertaken with vehicles above 12 tons, DTF considers that the error contained in the figures is very small.

The figures refer to year 2003. The annual growth factor is 2%.

[1,000 veh-km]	**DK-DK**	**DK-Abroad**	**Abroad-DK**	**Import-export traffic total**	**Transit**	**Total**
	3,500 km network					
Danish veh.	1,443	55	54	109	0	1,552
Foreign veh.	0	38	38	76	32	108
Total	**1,443**	**93**	**92**	**185**	**32**	**1,660**
	Total network (70,000 km)					
Danish veh.	2,104	80	79	159	0	2,263
Foreign veh.	0	56	55	111	32	143
Total	**2,104**	**136**	**134**	**270**	**32**	**2,406**

Table 1: Estimate of vehicle-kilometres of HGV >12 t on 3,500-km network (scenarios 1A and 1B) and on the total network (scenarios 2A and 2B).

No available data allow the direct estimation of total driving time by HGV>12t on the Danish roads. We use a simple conversion from total distance to total driving time, based on two assumptions of average speed: 65 km/h for the main road network (motorways and future state roads) where HGV can be assumed to travel at "overland" speed, 30 km/h for the other roads where HGV are either travelling, or accessing facilities and destinations on small roads, or even manoeuvring.

The resulting estimate is indicative of the order of magnitude. We will not use it in cost and revenue calculation, but simply to derive the order of magnitude of the time-based tariff.

[11] We acknowledge helpful input from Mr. Ole Kveiborg from the Danish Transport Research Institute (DTF).

Road category	Vehicle-km per year [in millions]	Average speed [in km/h]	Vehicle-minutes per year [in millions]
3,500 km of motorways and main roads	1,660	65	1,530
All other roads	746	30	1,490
Total road network (70,000 km)	2,406		3,020

Table 2: Estimate of vehicle-time of HGV >12t on Danish roads.

4.3.4 Summary of traffic performance

Traffic performance per year [million veh-km or million veh-min]	1A	1B	2A	2B
Vehicle-km on chargeable roads	1,660	1,660	2,406	
Vehicle-minutes on chargeable roads				3,020

5 Issues Related to the Definition of the Road Network

In this chapter, we take up the most important issues related to the definition of the Road Network, as indicated in section 4.1.1 above.

5.1 Case of existing charging schemes

- German and Austrian distance-based HGV charging applies to **all motorways**, while all other roads are exempt. The same is true for the light-vehicle "vignettes" of Austria, Hungary, Czech Republic, and Switzerland. The latter are not distance based, but lump sum fees for a determined duration.

- Swiss distance-based HGV charging applies to **all roads** on the national territory. Urban congestion charging schemes apply to all roads within a city cordon. Again, the latter are not distance based, but lump sum taxes for a determined duration.

- Conventional motorway tolling in Southern Europe (France, Italy, Spain etc) applies to **portions of the motorway network**, delimited by toll plazas. Motorway sections in urban areas are often exempt.

  Thanks to the exemption of urban areas, space-consuming and flow-hindering toll plazas are avoided where flows are biggest and space is rarest. Many small transactions, corresponding to short motorway sections and to a bad ratio between transaction cost and charging product, are avoided. Credible alternative routes, which are a legal requirement where the charge has the status of a fee, must not be offered in urban areas where indeed the priority is to canalise HGV traffic on motorways.

- Certain "vignette" schemes apply to **motorways and selected main roads**: the Belgian Eurovignette for HGV, and the light-vehicle vignettes of Austria and Czech Republic are in this case.

Hence, we have only two variants, at present, for strictly distance based schemes: motorways only, or all roads.

Germany and the Czech Republic are planning the extension of their HGV charging schemes from motorways to selected main roads. In neither case, detailed plans are known at present. Germany has not announced the date of introduction. The Czech Republic plans to put into service its new HGV charging scheme in 2007 on motorways, and in 2008 on main roads.

5.2 Segmenting a non-motorway network

A motorway network is made of identifiable sections. Their number is limited, and each of them has a significant length (~ 1 to 15 km). The charging principle consists in summing up the each section's elementary charge over all sections that make up the user's itinerary.

The extension of a network charge on non-motorways implies decomposing the non-motorway network into elementary sections, since the charging principle remains the same.

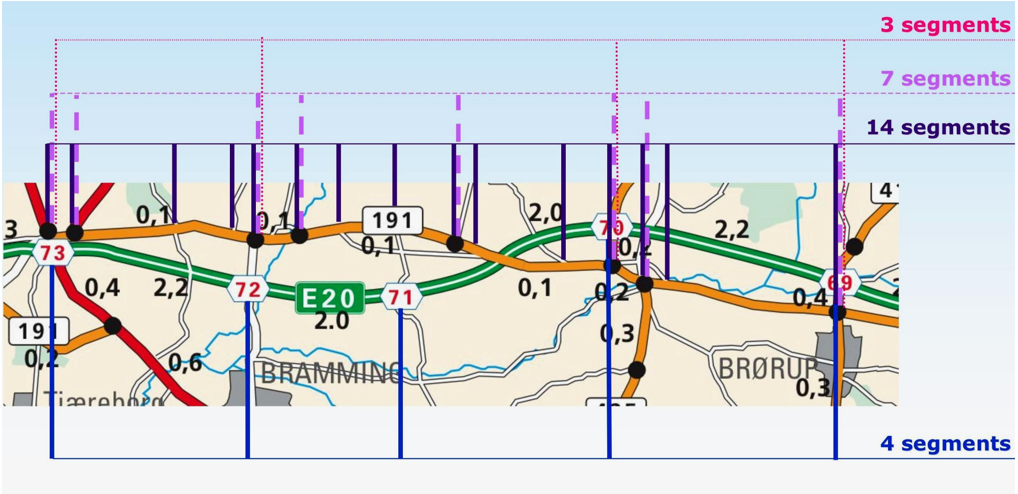


Figure 13 : Illustration of the problem of segmenting a non-motorway road. Since there are minor intersections and private accesses all along the road, none of the sketched segmentations reaches the characteristic of the motorway segmentation : namely, that the detection of the vehicle at one point is sufficient to conclude that it has travelled over the whole section length.

For each section, two terms must be defined :

- a section length (which might be a virtual length different from the real length)
- a measurement criterion which allows to determine that a vehicle has travelled through the section and may be charged.

The common measurement criterion in DSRC and GPS systems is that a HGV is detected when passing under the physical or virtual gantry placed on each elementary section. The gantry point stands for the whole section.

While this measurement is fully acceptable on motorways, it is insufficient to guarantee the equity of charging off motorways.


Figure 14 : Minor intersections on Road 150. Their unavoidable presence is the source of potential issues of charging equity.

Where minor intersections and private accesses are present all along the section, the detection of the vehicle at one point is not sufficient to conclude that it has travelled over the whole length of the section. Partial trips on the section, or even U-turns and repeated back-and-forth movements within the same section are possible. If such movements are not identified and charged, then there is a risk that the charging system will be challenged by certain trades on the grounds of non-equitable treatment.

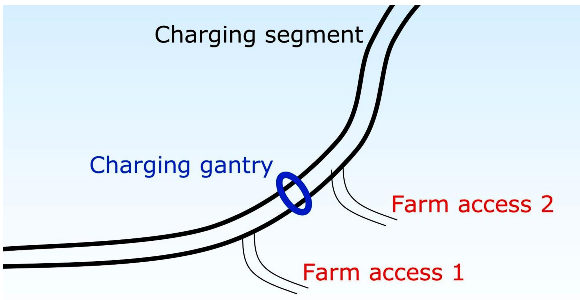


Figure 15 : Illustration of an issue of charging equity. Even if Farm 1 and Farm 2 are at practically the same distance from a given destination, one is systematically charged for the road segment partially used, while the other is systematically exempt.

5.3 Equipping a non-motorway network

The equipment of each elementary section with a gantry is more difficult off motorways than on motorways.

The farther the chargeable road network goes down in the hierarchy of roads, the lesser will be the traffic covered by a single gantry, and the lesser will be the revenue generated by a single gantry. The "Return on Investment" of a single gantry decreases.

5.3.1 Case of physical gantries

The number of physical gantries will have a direct impact on the system cost.

The unit cost of a gantry is drawn downwards off motorways by the fact that less traffic lanes are present. It is pushed upwards by the fact that specific local requirements are present:

- built environment and availability of space,
- electrical and communication infrastructure,
- landscape and architectural requirements,
- interference with property and use rights.

To illustrate the dependency between the length of a toll section respectively number of gantries and the system costs we calculated the operating costs of the system regarding an average toll section length of 4.4 km for the whole liable network and the operating costs of the system regarding an average toll section length of 4.4 km for motorways and an average toll section length of 2.2 km for the 2,500 km of the secondary road network.

5.3.2 Case of virtual gantries

Satellite coverage and backscattering in built-up areas require major attention.

On motorways, passage under a virtual gantry is detected when the positioning signal falls on a gantry location ; the required precision of the positioning is reduced, since the vehicle is necessarily driving on the same section for 30 seconds or more. Situations where two highways are parallel and closely adjacent can be excluded.

Off motorways, such favourable conditions cannot be taken for granted. The metrological tolerance may have to be reduced in order to achieve the required security of transaction.

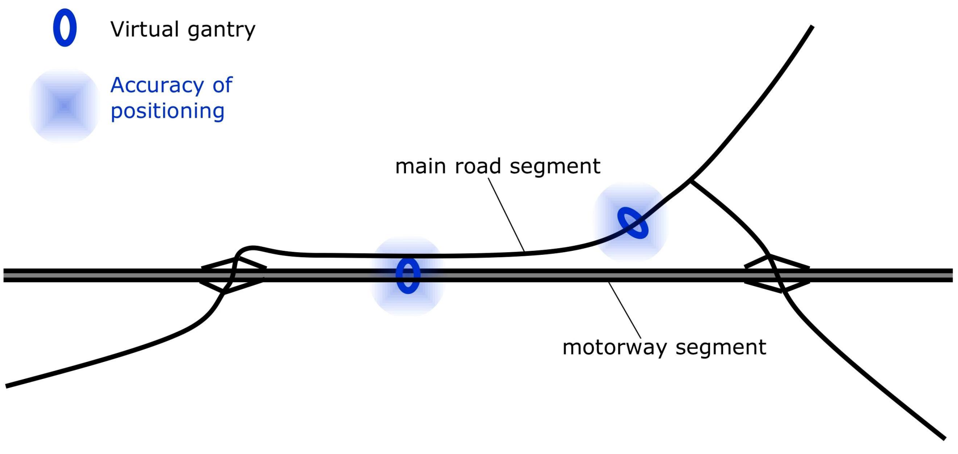


Figure 16 : A situation where accurate positioning is needed : parallel adjacent toll sections. The metrological tolerance may have to be reduced in order to achieve the required security of transaction.

Identical movements at two distinct moments must induce the same tax. For example, an irregular GPS signal at the gantry point may not induce that vehicle A, who would pass at a moment with strong GPS signal, is detected and debited while vehicle B, who would pass at a moment with weak GPS signal, is not detected. If vehicle A would leave the chargeable road and enter a private domain just 20 meters before the gantry point, and would do so every day, it would either have to be debited each time, or never.

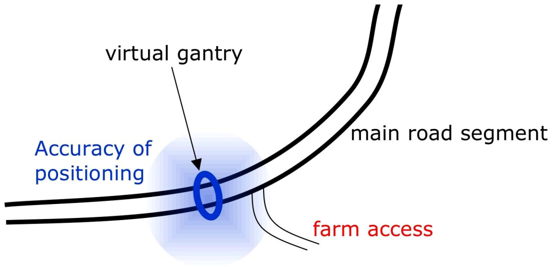


Figure 17 : Another situation where accurate positioning is needed in order to achieve the required security of transaction. The trip to or from the farm must either give rise to a transaction at each time, or never.

5.4 Identifying the chargeable network

The road user must understand where he is subject to charging and where he is not.

Since paying the charge is an obligation of road traffic legislation to the same virtue as, say, observing speed and weight limits, one could argue that it should be represented by road traffic signs wherever it applies. In other words, specific road traffic sings would have to be installed at every point where a user can enter or exit the obligation to pay.

In practice, HGV charging schemes cope easily with this requirement, since the entry and exit points of the obligation to pay coincide with national borders (for area charging) or with motorway junctions (for network charging). In both cases, corresponding traffic signals at the roadside already exist. The obligation to pay does not have to be communicated specifically.

However, if the charging network is a new artificial entity, heterogeneous with respect to existing road categories and unfamiliar to road users, this issue requires further attention. It might give rise to specific operational tasks and to specific costs.

Similar considerations could be developed for representations on road maps.

Figure 18 : Fictitious road traffic signs for marking where the user enters and exits the obligation to pay. Existing charging schemes feature no such signs, since small adaptations to motorway signage (for network charging) or to border crossing signage (for area charging) are sufficient to communicate the obligation to pay.

Naming and numbering of the road charging segments is a further aspect. On motorways, the section limits are officially named or numbered junctions, and the names or numbers are known to road users.

Off motorways, no equivalent existing naming scheme is available. The physical reality of the section limits will be very heterogeneous. The section limits could be major crossings in town centres or outside, with traffic lights or without, of large or small dimensions ; it could also be exterior limits of towns or industrial areas, etc. A specific naming scheme may have to be introduced and managed.

5.5 Detour traffic

Generation of detour traffic is the major drawback of a charging scheme limited to motorways. Detour traffic is undesirable under every aspect, given that motorways minimize all negative impacts of HGV traffic on the environment (traffic hindrance, infrastructure damage, noise, air pollution, accidents).

The risk of detour traffic is particularly high where main roads have been raised to high standards in the past (2x2 lanes, few level crossings).

Detour traffic must be tolerated to a certain extent, if the road user charge is a fee rather than a tax. A fee must correspond to a service and be in proportion to the service; there must be alternatives to using the service. In case of a tax, no detour traffic has to be tolerated.

Recently introduced HGV charging schemes give rise to several observations:

- After the introduction of the German LKW-Maut, traffic from motorways to main roads ("Bundesstrassen") have been observed. For instance, the international south-north traffic in the upper Rhine valley has shifted partly from the German A5 motorway to the toll-free French motorway A35. At the Swiss border at Basel, border crossings to Germany have diminished by 10%, those to France have increased by 10%. In the Strasbourg area, north-south HGV traffic has increased by 20%.
- Two types of measures are at present discussed in Germany: (1) the extension of the charging scheme to parallel roads, (2) ban of HGV transit traffic on critical sections of main roads. However, the problem is never definitively solved by such measures, but shifted downwards in road hierarchy and in spatial scale.
- In Austria, the detour problem has also been observed, although on a less critical scale than in Germany due to the structure of the Austrian motorway network, i.e. more significant difference of travel speed between motorways and main roads.
- In Switzerland, there is no difference between charged and uncharged network links. After the introduction of area charging, shorter routes in terms of distance have become more attractive as compared to shorter routes in terms of time. However, only exceptional situations have produced a measurable effect.

Estimating the detour traffic requires a traffic assignment model which takes the price elasticity of HGV route choice into account. No such model has been used in the present study. In chapter 6.4, assumptions on a very high level are introduced.

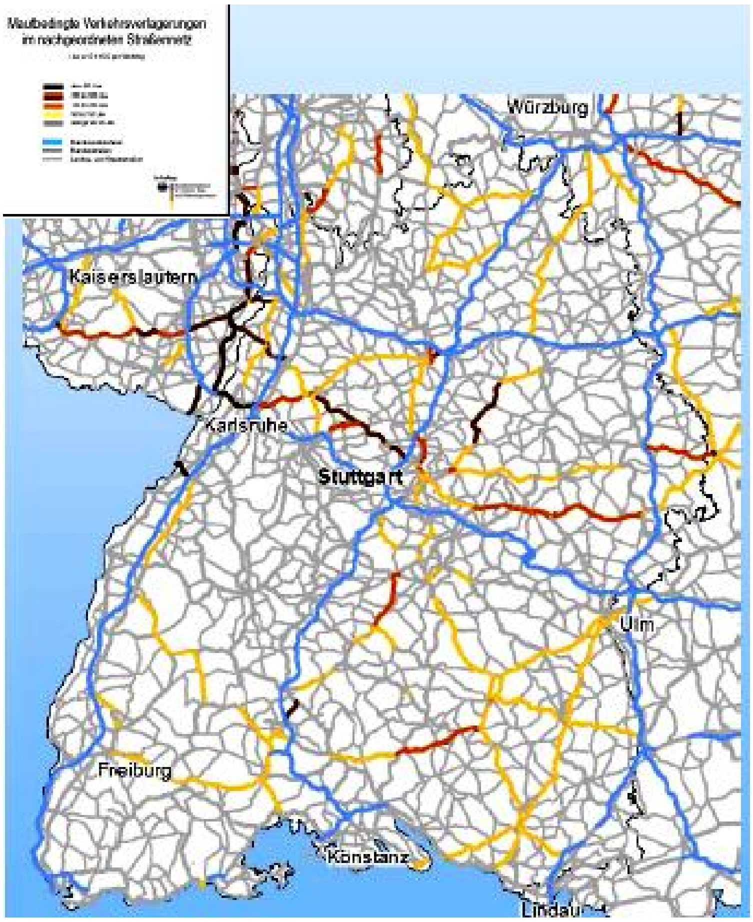


Figure 19: Detour Traffic in SW-Germany after implementation of LKW-Maut (dark segments show HGV increase)

5.6 Further issues

The work of enforcement agents is eased when the charging network is of simple definition.

If HGV charging applies to motorways only, then there will be vehicles, agricultural in particular, which will never be concerned. If main roads are included, these cases will be less frequent. For example, in the actual Walloon Eurovignette scheme, where some main roads are subject to charging, all vehicles registered in the Walloon region are subject to the tax *ex officio*.

5.7 Summary

As stated in paragraph 4.1.1, the present study uses a preliminary orientation for the network definition, provided by the Road Directorate. The inclusion of other roads than motorways into the network charging scenarios raises delicate issues which do not have proven solutions to this day, and which imply important reservations on their feasibility.

Regardless of these reservations, we leave this subject for further detailed studies. For our present purpose, we will continue to work with the assumptions presented in chapter 4.

6 Revenues

6.1 Approach to Revenue Estimation

6.1.1 Philosophy

The revenue to be raised by the HGV charging scheme is intended to account for a determined share of the external cost of road transport in Denmark.

This philosophy is in accordance with the approach of the Eurovignette directive 1999/62/EC and its amendments, which aims at a fair allocation of road transport costs to transport operators.[12]

Important debate has accompanied the Eurovignette directive and its modification agreed at the end of 2005. Matters of debate were the way of computing the infrastructure costs, and the issue of including or not, and how to include, external costs not related to infrastructure.

Within the context of this European issue, Denmark is establishing its methodology for computing the costs of road transport, and elaborating its relevant cost figures.

It is out of the scope of the present study to discuss these matters. In accordance with the Danish Ministry of Transport, we refer to chapter 7 (Infrastructure) of a recent report on external costs of transport in Denmark, issued for the Ministry by COWI[13].

For the present study, we take the infrastructure cost allocated to HGV traffic, as estimated by the COWI report, as the maximal potential revenue for the HGV charging scheme. It is for the Danish Ministry of Transport in accordance with the Ministry of Finance to identify additional infrastructure cost elements that could be included in the tariff calculation according to the Eurovignette Directive 1999/62/EC.

6.1.2 Method

We assimilate the estimated infrastructure cost allocated to HGV traffic by the COWI report (see figures below) to the **maximal revenue** of the HGV charging scheme.

By restricting the maximal potential revenue, for each scenario, to the vehicles concerned and to the road network concerned, we determine a **potential target revenue** for each scenario.

For each scenario, from the target revenue, we estimate an average tariff by means of an estimate of the charging basis. These figures are not used further in the subsequent estimations, but they give additional substance to the scenarios, and a further indication on their plausibility.

In accordance with the Danish Ministry of Transport, we set the target revenue for the area charging scenarios to less than the potential maximum. This adaptation represents a working hypothesis which holds the place of the future political decision on the level of the charge. Also, we assume that the distance based HGV charging scheme is the only fiscal charge lying on the transport operators on the

[12] Directive 2006/…/EC amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures, PE-CONS 3682/05 (6 March 2006)

[13] External Costs of Transport : 3rd Report – Total external costs of road and rail transport in Denmark. Danish Ministry of Transport, July 2004.

grounds of external costs of road infrastructure, for otherwise the target revenue should be reduced further in order to avoid that the transport operators be charged twice for the same purpose. Through these steps, we determine the supposed **target revenue** for each scenario.

At this point, we proceed to corrections of this figure, in order to arrive to the **effective revenue** of the scheme. These corrections account for traffic evasion, for non-payment of due charges, and for revenue of enforced charges and penalties. The corrections are scenario-dependent.

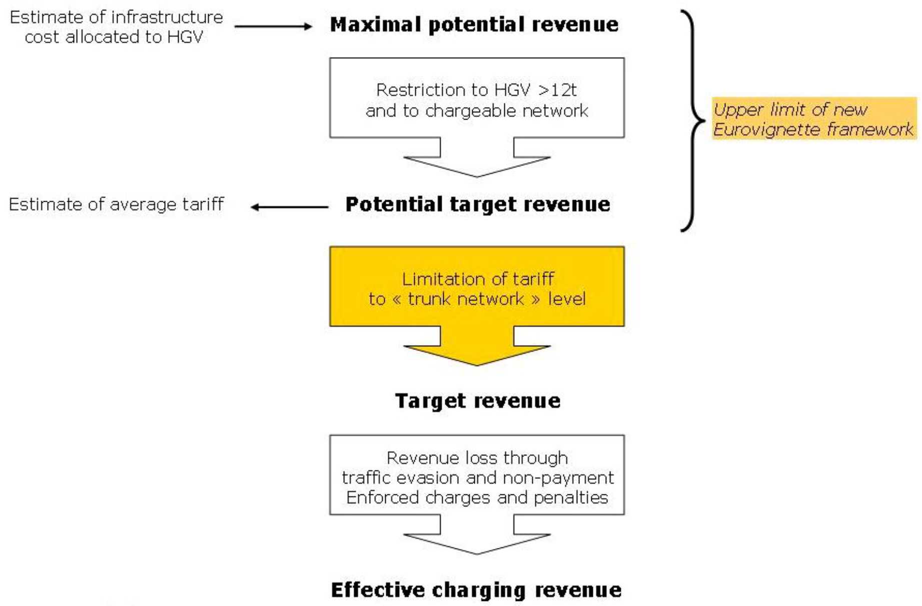


Figure 20: Method of revenue estimation

6.1.3 Road infrastructure cost allocated to HGV traffic by the COWI report

The report takes into account external costs in five areas: air quality, climate change, noise, accidents, and road infrastructure.

On road infrastructure, the report states costs in five categories of expenditure :

- Administration
- Winter maintenance
- Other maintenance
- Surface renewal
- New construction.

For each category, it states the costs incurred on three administrative levels :

- national
- regional
- local.

For allocating these costs to vehicle categories, a matrix of cost allocation factors is applied. The factors depend on :

- Category of expenditure (listed above),
- Administrative level (listed above),
- Four performance types :
  - Fixed costs
  - Vehicle-kilometre related costs
  - Vehicle-length-kilometre related costs
  - Standard-axle weight factor kilometre costs,
- The vehicle categories are :
  - Cars
  - Vans (< 6 tons)
  - HGV (> 6 tons)
  - Busses.

For the vehicle category **HGV**, the main findings are :

- Total infrastructure cost allocated to HGV traffic (> 6 tons) is **2'733 million DKK** per year.
- This represents **15 %** of the total infrastructure cost.
- The average infrastructure cost for a HGV vehicle-kilometre is **1.79 DKK**.

All costs are given for year 2000.

6.2 Cost allocation for tariff calculation

6.2.1 Restriction to HGV > 12 tons

As the starting point for determining the target revenue, we take the total infrastructure cost allocated to HGV traffic according to the COWI report (2'733 million DKK per year). This figure refers to all HGV above 6 tons. It has to be restricted to the proportion corresponding to HGV above 12 tons.

A an approximation, we estimate the proportion to be equal to the proportion of vehicle-kilometres. According to data from Vejdirektoratet for 2002 :

HGV > 6 t : 1'840 million vehicle-km/year

HGV > 12 t : 1'660 million vehicle-km/year **= 90 %**.

This restriction applies to all scenarios in the same way.

Restriction to HGV > 12t	**1A**	**1B**	**2A**	**2B**
% of HGV infrastructure costs allocated to HGV > 12t	90%	90%	90%	90%

6.2.2 Restriction to chargeable network (scenarios 1A and 1B)

The cost estimation quoted above refers to the complete Danish road network. For scenarios 1A and 1B (network charging), it has to be restricted to the chargeable network (trunk network of 3'500 km).

A separate cost estimation for this network is not available.

Since the 3'500-km trunk network is entirely included in the 11'626 km of roads administered on national and county level (at present), it could be argued that an upper limit could be extracted from the decomposition of infrastructure costs according to the administrative levels, which is available in the COWI report. National and county levels represent 49,2% of the costs. This upper limit should be further reduced to the share which effectively corresponds to the 3'500 km of trunk network, the length ratio being 3.3 (3'500km out of 11'626 km).

However, this procedure neglects that HGV traffic is concentrated on the trunk network, where it contributes strongly to surface renewal and road capital costs, which in turn are strong components of infrastructure costs on the national and regional levels. A proper estimate would require, firstly, to isolate the total costs incurred on the trunk network, and secondly, to proceed to a separate application of a cost allocation model between vehicle categories (as the one presented in the COWI report).

Lacking a better figure, we estimate that the trunk network accounts for 40% of the infrastructure costs allocated to HGV traffic.

Restriction to chargeable network	**1A**	**1B**	**2A**	**2B**
% of HGV infrastructure costs allocated to chargeable network	40%	40%	100%	100%

6.2.3 Exclusion of other charges levied on the ground of external costs

Any revenue generated by any other taxes and duties than distance based HGV charging, to which the transport operators would be subject on the grounds of external costs of road infrastructure **in parallel to the distance based charging scheme**, should be subtracted from the target revenue. Otherwise, the transport operators would be charged twice for the same purpose.

For example, this might be the case of fuel excise duties. It would be the case of the current Eurovignette if this scheme would not be abolished by the new distance based scheme.

6.2.4 Inclusion of costs of charging system

According to the Eurovignette Directive, the following costs can be included in the basis for the charging revenue:

- the costs of estabilishing and implementing the charging system
- the costs of operating, administering and enforcing the chaging system

6.2.5 Tariff calculation

[million DKK/year]	1A	1B	2A	2B
Infrastructure cost allocated to HGV > 6 t	2'733	2'733	2'733	2'733
Restriction to HGV > 12 t	2'460	2'460	2'460	2'460
Restriction to chargeable network	984	984	2'460	2'460
Costs of the charging system	486	534	399	328
Total allocated costs = Potential target revenue	1'470	1'517	2'858	2'787
Charging basis (see paragraph 4.3)	1'660 million veh-km	1'660 million veh-km	2,406 million veh-km	3'020 million veh-minutes
Potential tariff	0,89 DKK/ veh-km	0,91 DKK/ veh-km	1,19 DKK/ veh-km	0,92 DKK/ veh-minute

The tariff for network charging is low in comparison to other HGV charging schemes in Europe. The trunk network is appropriate for HGV traffic and produces a high share of the national HGV traffic performance. Hence it is an economic infrastructure. Charged "at cost" to the road users, it results in a low tariff.

The tariff for area charging is higher because less "productive" roads are included. The km-tariff is relatively high, comparable to the future German tariff if the planned increase takes place. It remains lower than the Austrian tariff, Austria having justified exceptionally high infrastructure costs and having chosen to raise as high a revenue as possible from the HGV charge.

The time-based tariff does not have any direct equivalent. Comparisons could be drawn from the one-day tariff of the Eurovignette directive: 8 EUR = 60 DKK in 1999/62/CE and 11 EUR = 82 DKK in the amendment voted by the European Parliament end of 2005. With regard to the average tariff derived here, this is roughly equivalent to 75 and 100 minutes respectively.

6.3 Limitation of tariff to trunk network level

In accordance with the Danish Ministry of Transport, we limit in the present study the tariff for area charging to the tariff corresponding to the Eurovignette approach on the trunk network. In this way, we ensure for all four scenarios that the Eurovignette framework, which applies to the TEN roads, is respected on the TEN roads. In principle, Denmark could use any other non-discriminative methodology for determining the tariff on the remaining network.

[million DKK/year]	1A	1B	2A	2B
Potential target revenue (from 6.2.5)	1'470	1'517	2'858	2'787
Charging basis (from 4.3.4)	1,660 million veh-km	1,660 million veh-km	2,406 million veh-km	3,020 million veh-minutes
Potential tariff (from 6.2.5)	0,89 DKK/ veh-km	0,91 DKK/ veh-km	1,19 DKK/ veh-km	0,92 DKK/ veh-minute
Average tariff			0,89 DKK/ veh-km	0,69 DKK/ veh-minute
Limited target revenue	**1'470**	**1'517**	**2'126**	**2'074**

6.4 Effective charging revenue

We estimate an effective charging revenue by applying three types of adjustments to the target revenue.

6.4.1 Traffic evasion

Traffic shifts are dependent on the relative generalised travel cost of alternative routes, as perceived by the driver (or in certain cases by the dispatcher).

Generalised travel costs are composed of:

- Travel time
- Distance-related HGV costs (fuel and other operating costs)
- Tolls (amount of toll and effort related to registeration and payment)
- Costs related to unreliable service (unpredictable congestion, etc.).

In the absence of a traffic assignment model able to reproduce the route choices including these cost elements, we estimate only a global percentage of traffic shift from the chargeable network to the non-chargeable network for scenarios 1A and 1B. Assuming that the increase of the HGV travel cost induced by the charge is 10%, we estimate the shift is in the order of 5%, corresponding to a price elasticity of 0.5.

For area charging, there is an increase of travel costs for all the alternative routes. At the present level of the study, the effect is negligible.

Traffic evasion	1A	1B	2A	2B
% of traffic lost through traffic evasion (detour traffic)	5%	5%	0%	0%

6.4.2 Unpaid charges

Non-payment includes real fraud as well as irregular situations of any kind, where users justify themselves through practical problems, misunderstandings, special circumstances and any kind of reasons. The limit between these categories is blurred, and non-payers cannot generally be suspected to act in bad faith. Surcharge taxes and administrative penalty schemes are a means of handling users who are in this ambiguity, comparable to common practice in public transport. Penal action should be reserved to qualified fraud (repeated, intentional, manipulation of equipment).

The level of non-payment depends on:

- The level of the charge (kilometre price higher for area charging than for network charging)
- The level of surcharge taxes and penalties for non-payment (same for all scenarios)
- The risk of fraud being detected (higher for area charging)
- The success rate of enforcement (same for all scenarios)
- The ease of paying regularly (same for all scenarios)
- The acceptance of the scheme (same for all scenarios)
- The share of occasional users (same for all scenarios).

At the present level of the study, we assume that the global factor is the same for all scenarios.

Unpaid charges	**1A**	**1B**	**2A**	**2B**
Danish vehicles Foreign vehicles	2% 5%	2% 5%	2% 5%	2% 5%
% of due charges which are not paid (all vehicles)	3%	3%	3%	3%

6.4.3 Enforced charges and penalties

The collection of penalty payments or surcharge taxes gives rise to a revenue complement. This does not include, in our revenue estimation, the costs of collecting these payments. The collection costs are taken into account, along with all other enforcement costs, in the cost estimation (see chapter 7).

The direct balance between revenue of penalty payments and enforcement costs is generally negative, because detecting the offence and processing the penalty is costly. Enforcement must primarily aim at getting non-payers to become future regular payers; since an additional regular payer generally generates a better cost-revenue ratio than an additional penalty payer. Also, public acceptance of a fee collection scheme suffers if the users perceive the penalty payments as a means of maximizing revenue, be that perception justified or not.

In other words, EFC operator and enforcement authority must strive not to collect more penalties, but to minimize the level of non-payers.

We estimate the monetary product of enforced charges and penalties as the combined result of the level of detection of non-paid charges, of the facility with which the enforcement body can get hold of the non-payers and execute the sanction ("success rate" of enforcement), and of the amount of the penalty.

Experience shows that the success rate of enforcement is close to 100% for regular users, while there are numerous causes of incomplete pursuit of occasional users, in particular foreign users.

We assume that a penalty charge is applied, equivalent to 200% markup of the regular charge which has not been paid.

Enforced charges and penalties	**1A**	**1B**	**2A**	**2B**
% of unpaid charges (see 6.4.2)				
- Danish vehicles	2%	2%	2%	2%
- Foreign vehicles	5%	5%	5%	5%
All vehicles	3%	3%	3%	3%
% of successfully enforced charges				
- Danish vehicles (success rate 100%)	2%	2%	2%	2%
- Foreign vehicles (success rate 50%)	2,5%	2,5%	2,5%	2,5%
All vehicles	2%	2%	2%	2%
Average height of penalty	200%	200%	200%	200%
(Ratio between enforced charge plus penalty / regular charge)				

6.5 Revenues

in thousand DKK per year	Scenario 1A	Scenario 1B	Scenario 2A	Scenario 2B
External data (COWI 3rd Report)				
Infrastructure cost allocated to HGV>6t	2'733'000			
Scenario characteristics				
% of infrastructure cost allocated to HGV>12t	90%	90%	90%	90%
% of infrastructure cost allocated to chargeable network	40%	40%	100%	100%
Charging basis in million veh-km	1'660	1'660	2'402	
Charging basis in million veh-hours				50.2
Assumptions for revenue estimation				
% of traffic lost through evasion	5%	5%	0%	0%
% of unpaid charges	3%	3%	3%	3%
% of successfully enforced charges	2%	2%	2%	2%
penalty markup	200%	200%	200%	200%
Calculation				
Potential revenue HGV>6t	2'733'000	2'733'000	2'733'000	2'733'000
infrastructure cost assigned to HGV > 12t	2'459'700	2'459'700	2'459'700	2'459'700
infrastructure cost HGV>12 t assigned to chargeable network	983'880	983'880	2'459'700	2'459'700
costs of HGV charging system	485'678	533'603	398'516	327'563
total assignable costs	1'469'558	1'517'483	2'858'216	2'787'263
potential tariff in DKK/veh-km	*0.89*	*0.91*	*1.19*	
potential tariff in DKK/veh-hour				*55.52*
average tariff in DKK/veh-km	***0.89***	***0.91***	***0.89***	
average tariff in DKK/veh-hour				***41.31***
Revenue before adjustments based on average tariff	1'469'558	1'517'483	2'126'433	2'073'646
Loss through traffic evasion	73'478	75'874	0	0
adjusted revenue 1	1'396'080	1'441'609	2'126'433	2'073'646
Loss through unpaid charges	41'882	43'248	63'793	62'209
adjusted revenue 2	1'354'198	1'398'361	2'062'640	2'011'436
Revenue of enforced charges and penalties	55'843	57'664	85'057	82'946
Effective Charging Revenue in million DKK per year	**1'410**	**1'456**	**2'148**	**2'094**

7 Costs

7.1.1 Assumptions

The cost estimations are based on the following general assumptions:

- 41,660 Danish vehicles above 12 t maximum permissible weight per year
- 100,000 foreign vehicles above 12 t maximum permissible weight per year
- on average: Every 12th toll section is an enforcement section

Scenario-specific assumptions:

Scenario 1A and 1B:

- 1,571 toll sections
- 430 points of sales
- 20% OBU leakage per year for DSRC-OBU and GPS-OBU

Scenario 2A:

- 18 system entry points (border crossing stations)
- 90 points of sales
- 6% OBU replacement per year of fixed mounted OBU
- 30% OBU leakage per year of LOBU

Scenario 2B:

- 18 system entry points (border crossing stations)
- 90 points of sales
- 20% OBU leakage per year for time based OBU

For all scenarios, it is assumed that all vehicles registered in Denmark and all foreign HGV travelling in Denmark must be equipped with an OBU. Potential cost savings from interoperability are not included in the estimates.

It is assumed that the EFC system is procured under a BOT arrangement. The capital investment includes the whole costs of the tender (12 months) and the implementation (18 months) phase as well as the costs for external consulting within the first 6 months after start of operation.

The investment and implementation costs include:

- Charging services
  - on board equipment (OBU, LOBU)
  - roadside equipment (gantries and beacons)

- integration of existing toll stations

- Enforcement services
  - fixed roadside enforcement stations
  - portable enforcement stations
  - mobile enforcement units
  - beacon and enforcement IT

- Central services
  - points of sales, including POS software
  - central IT system
  - central back office
  - test equipment
  - training equipment
  - pre sale activities
  - marketing and information incl. call center
  - project management

The operating costs include:

- human resources costs Management Authority
- human resources costs Service Provider
- new on board equipment (OBE leackage and system growth)
- maintenance costs (on board equipment, road side equipment, enforcment equipment, POS)
- IT maintenance and support, programme licences
- maintenance of test and training equipment

The costs per year include the operating costs plus the amortisation of the investments. The amortisation costs are based on the estimated lifetime of the components. No interests or other financing costs are included.

7.2 Capital Investment (Tender and Implementation Phase)

The capital investment includes the whole costs of the tender (12 months) and the implementation (18 months) phase as well as the costs for external consulting within the first 6 moth after start of operation.

The following table shows the total capital investment regarding the different scenarios:

	Scenario 1A in thousand DKK	Scenario 1B in thousand DKK	Scenario 2A in thousand DKK	Scenario 2B in thousand DKK
Total capital investment in million DKK	**1.077**	**2.698**	**723**	**618**
in million EUR	144	360	96	82
in % (Scenario 2B = 100%)	174	436	117	100

7.2.1 Charging Services

	Scenario 1A in thousand DKK	Scenario 1B in thousand DKK	Scenario 2A in thousand DKK	Scenario 2B in thousand DKK
Charging Services				
Total on board equipment	265.613	26.561	194.348	37.186
Total roadside equipment	85.297	1.924.049	43.815	43.815
Total existing toll stations	0	0	4.038	4.038
Total charging services	**350.910**	**1.950.610**	**242.201**	**85.039**

7.2.2 Enforcement Services

	Scenario 1A in thousand DKK	Scenario 1B in thousand DKK	Scenario 2A in thousand DKK	Scenario 2B in thousand DKK
Enforcement Services				
Total roadside equipment	232.033	229.670	0	68.431
Total mobile Enforcement units	32.175	32.175	33.975	32.175
Total beacon & enforcement IT	27.197	27.197	26.438	26.891
Total enforcement services	**291.405**	**289.043**	**60.413**	**127.497**

7.2.3 Central Services

	Scenario 1A in thousand DKK	Scenario 1B in thousand DKK	Scenario 2A in thousand DKK	Scenario 2B in thousand DKK
Central Services				
Total point of sales	50.513	84.263	33.698	24.135
Total central IT system	149.985	142.425	153.735	153.735
Total Test equipment	24.660	22.973	28.538	24.173
Total training equipment	11.138	10.969	11.651	10.958
Total pre sale	1.013	1.122	1.013	1.169
Total marketing & information	27.750	27.750	27.750	27.750
Total project management	169.662	169.232	163.856	163.856
Total central services	**434.720**	**458.732**	**420.239**	**405.775**

7.3 Operating Costs (Operational Phase)

The operating costs include the depreciation of the different system components.

	Scenario 1A in thousand DKK	Scenario 1B in thousand DKK	Scenario 2A in thousand DKK	Scenario 2B in thousand DKK
Total operating costs in million DKK per year	**486**	**535**	**399**	**328**
in million EUR per year	65	71	53	44
in % (Scenario 2B = 100%)	148	163	122	100

The system costs for hauliers additional to the RUC are only in scenario 2A remarkable. In this scenario there are costs to calculate for mounting and installation which takes nearly 2 hours and in average 1 time per year OBU maintenance. That means the service fees for the certified fitter and the missing material gain for the 2 hours per vehicle life cycle and 1 hour maintenance per year.

7.3.1 Charging Services

	Scenario 1A in thousand DKK	Scenario 1B in thousand DKK	Scenario 2A in thousand DKK	Scenario 2B in thousand DKK
Charging Services				
Total OBU costs	126.166	12.617	55.603	17.663
Total roadside equipment	7.716	182.854	4.807	4.807
Total HR costs	2.625	2.625	3.900	3.900
Total charging services	**136.507**	**198.095**	**64.310**	**26.370**

7.3.2 Enforcement Services

	Scenario 1A in thousand DKK	Scenario 1B in thousand DKK	Scenario 2A in thousand DKK	Scenario 2B in thousand DKK
Enforcement Services				
Total permanent enforcement	31.304	31.304	0	7.467
Total portable enforcement	4.455	3.983	0	3.960
Total mobile Enforcement units	8.989	8.989	9.439	8.989
Total beacon & enforcement IT	5.508	5.508	5.288	5.417
Total HR costs	131.700	131.700	123.000	128.700
Total enforcement services	**181.956**	**181.484**	**137.726**	**154.532**

7.3.3 Central Services

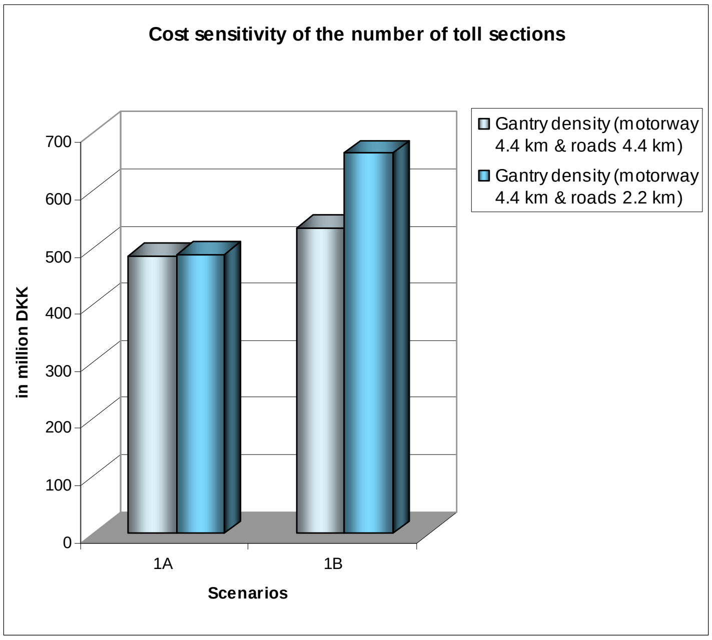
	Scenario 1A in thousand DKK	Scenario 1B in thousand DKK	Scenario 2A in thousand DKK	Scenario 2B in thousand DKK
Central Services				
Total point of sales	10.665	19.028	7.624	5.255
Total central IT system	29.535	28.485	30.285	30.285
Total Test equipment	2.292	1.828	2.901	2.073
Total training equipment	1.964	1.918	2.399	1.571
Total general costs	73.012	53.888	99.647	53.888
Total HR costs	49.875	49.875	53.625	53.625
Total central services	**167.343**	**155.021**	**196.480**	**146.696**

7.4 Cost Sensitivities

7.4.1 Cost sensitivity of number of tolling segments

In order to show the cost impact of the density of charging sections the number of segments on the non-motorway roads were doubled.

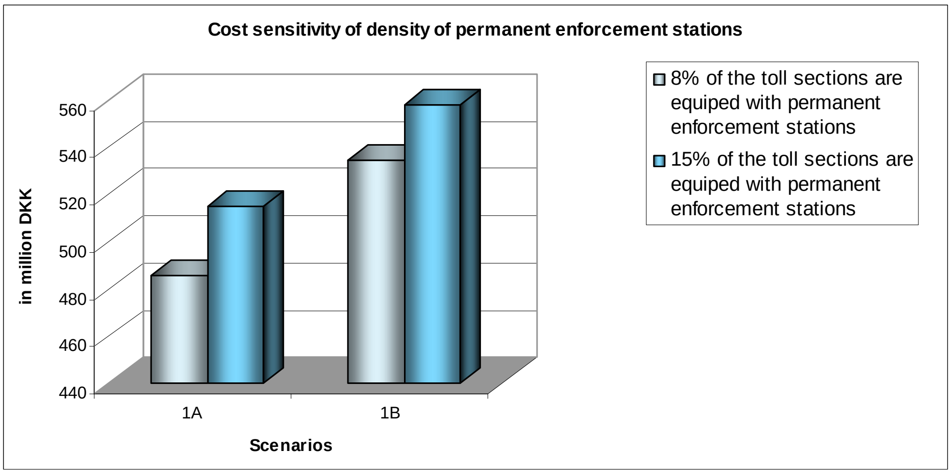
in million DKK per year	1A	1B
Gantry density (motorway 4.4 km & roads 4.4 km)	486	535
Gantry density (motorway 4.4 km & roads 2.2 km)	489	666



The cost estimates are based on the assumption that the average segment length on the non-motorway network is 4.5. km similar to the motorway network. If the number of segments on the non-motorway network is doubled, the total annual cost of Scenario 1A remain approximately the same whereas they increase in Scenario 1B by 24%.

7.4.2 Cost sensitivity of the number of permanent enforcement stations

in million DKK per year	1A	1B
8% of the toll sections are equiped with permanent enforcement stations	486	535
15% of the toll sections are equiped with permanent enforcement stations	515	558



If the density of enforcement stations is increased from 1 enforcement gantry out of 12 gantries to 1 enforcement gantry out of 7 gantries the total annual costs increase for Scenario 1A by 6% and for Scenario 1B by 4%.

7.4.3 Cost sensitivity of OBE leakage - Cost Effect of EETS

OBE leakage is the percentage of new OBU, LOBU or TOBU that must be issued every year to occasional users. The leakage percentages are scenario dependent and in scenario 2A are different for the built-in OBU for regular users and LOBU for occasional users. The percentages further depend on the expectations of interoperability between the Danish HGV charging scheme and the foreing schemes. The following figures and charts show three levels of interoperability:

- Low interoperability and high proportion of occasional international transit: high leakage percentages according to the experiences with the existing Austrian and Swiss schemes that offer a very limited interoperability (only unilateral interoperability from Switzerland to Austria, i.e. a Swiss OBU can be used fro the Austrian charge).

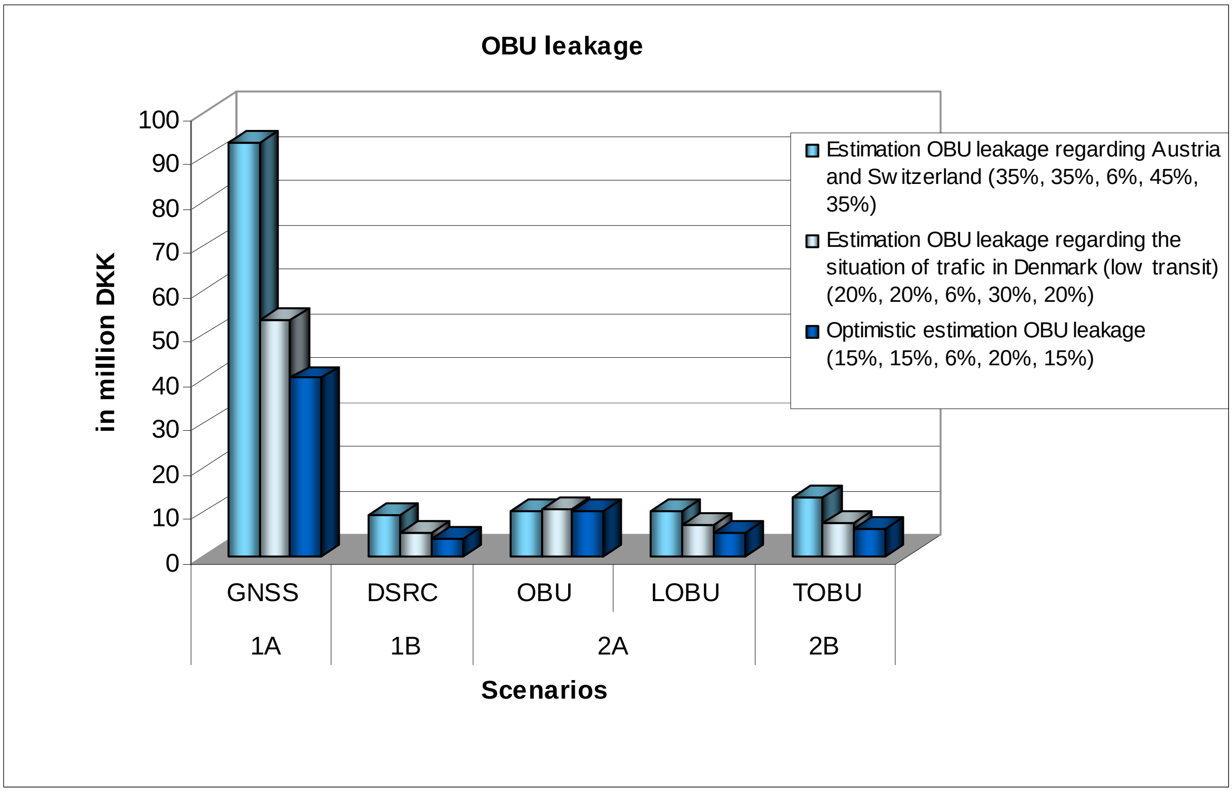
- Medium interoperability (NORITS) and smaller proportion of non-regular international transit: medium leakage percentages

- High interoperability (EETS implemented): low leakage percentages.

The cost estimates in Chapter 7 are based on the medium leakage percentages.

Sensitivity of OBU costs:

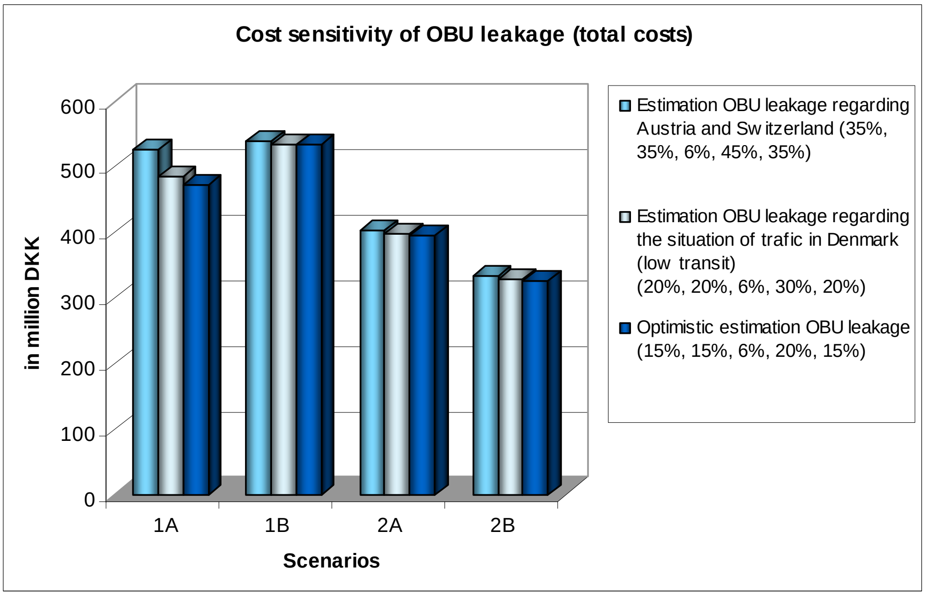
in million DKK per year	1A GNSS	1B DSRC	2A OBU	2A LOBU	2B TOBU
Estimation OBU leakage regarding Austria and Switzerland (35%, 35%, 6%, 45%, 35%)	**93**	**9**	**10**	**10**	**13**
Estimation OBU leakage regarding the situation of trafic in Denmark (low transit) (20%, 20%, 6%, 30%, 20%)	**53**	**5**	**10**	**7**	**7**
Optimistic estimation OBU leakage (15%, 15%, 6%, 20%, 15%)	**40**	**4**	**10**	**5**	**6**



For Scenario 2A, the leakage percentages are different for the permanent OBU, where only replacements of broken OBU or OBU for new vehicles must be considered, and LOBU, where all HGV that come for the first time to Denmark must be equipped.

Sensitivity of total annual costs:

in million DKK per year	1A	1B	2A	2B
Estimation OBU leakage regarding Austria and Switzerland (35%, 35%, 6%, 45%, 35%)	526	539	402	333
Estimation OBU leakage regarding the situation of trafic in Denmark (low transit) (20%, 20%, 6%, 30%, 20%)	486	535	399	328
Optimistic estimation OBU leakage (15%, 15%, 6%, 20%, 15%)	472	533	396	326



It can be observed that Scenario reacts most senitively on varying assumptions regarding interoperability and OBU leakage. If the leakage ratios were as high as they are in Austria and Switzerland, Scenario 1A would become significantly more expensive (75% increase of OBU cost, 8% increase of total annual cost). On the other hand, with EETS, the total annual costs of this scenario could be reduced by 3%. The other scenarios are much less sensible to OBU leakage.

8 Evaluation of the Scenarios

8.1 Key Figures at a Glance

	Scenario 1A in million DKK	**Scenario 1B** in million DKK	**Scenario 2A** in million DKK	**Scenario 2B** in million DKK
Effective Charging Revenue	1'410	1'456	2'148	2'094
Costs per year	486	534	399	328
Net Revenue per year	924	922	1'749	1'767
Costs in % of effective charging revenue	34%	37%	19%	16%

The above figures can be compared with the Eurovignette for Denmark:

- Revenue 395,7 million DKK/year
- Cost 10,4 million DKK/year

8.2 Benchmarks

8.2.1 Benchmark figures of the four scenarios

The benchmarks are a result of the assumptions on which the Danish study is based. Even if these assumptions need to be reviewed in further studies, our present estimates give correct orders of magnitude. The results are based on real cost figures transposed from other road charging schemes. Also, our cost and revenue model is sufficiently complete to identify and represent the main factors which determine the behaviour of costs and revenues.

	Scenario 1A	**Scenario 1B**	**Scenario 2A**	**Scenario 2B**
Vehicle kilometers per year (mio km)	1'660	1'660	2'406	2'406
Total costs per year in mio. DKK	486	534	399	328
Effective charging revenue per year in mio DKK	1'410	1'456	2'148	2'094
Effective charging revenue per vehicle kilometer in DKK	0.85	0.88	0.89	0.87
Total costs per vehicle kilometer in DKK	**0.29**	**0.32**	**0.17**	**0.14**
Net revenue per vehicle kilometer in DKK	**0.56**	**0.56**	**0.73**	**0.73**

8.2.2 Comparison with foreign HGV Charging schemes

In addition to comparing the scenarios against each other, the cost and revenue estimates of the scenarios 1A, 1B, and 2A have been benchmarked against figures from the functionally corresponding HGV charging schemes in Europe. It is not possible to split the benchmark figures into benchmarks for the charging services, enforcment services and central services because the cost data of the foreign schemes are not split in the same way as the cost estimates in this study.

Comparison with German scheme	**Scenario 1A**	**Germany**
Vehicle kilometers per year (mio km)	1'660	22'700
Total costs per year in mio. DKK	486	4'500
Effective charging revenue per year in mio DKK	1'410	21'375
Effective charging revenue per vehicle kilometer in DKK	0.85	0.94
Total costs per vehicle kilometer in DKK	0.29	0.20
Net revenue per vehicle kilometer in DKK	0.56	0.74
Costs in % of charging revenue	34%	21%

Comparison with Austrian scheme	**Scenario 1B**	**Austria**
Vehicle kilometers per year (mio km)	1'660	2'700
Total costs per year in mio. DKK	534	600
Effective charging revenue per year in mio DKK	1'456	5'625
Effective charging revenue per vehicle kilometer in DKK	0.88	2.08
Total costs per vehicle kilometer in DKK	0.32	0.22
Net revenue per vehicle kilometer in DKK	0.56	1.86
Costs in % of charging revenue	37%	11%

Comparison with Swiss scheme	**Scenario 2A**	**Switzerland**
Vehicle kilometers per year (mio km)	2'406	2'080
Total costs per year in mio. DKK	399	480
Effective charging revenue per year in mio DKK	2'148	6'830
Effective charging revenue per vehicle kilometer in DKK	0.89	3.28
Total costs per vehicle kilometer in DKK	0.17	0.23
Net revenue per vehicle kilometer in DKK	0.73	3.05
Costs in % of charging revenue	19%	7%

8.2.3 Benchmark costs

Scenario	EFC Costs per vehicle kilometre		
	Denmark DKK	**Foreign scheme** DKK	Country
1A	0.29	0.20	Germany
1B	0.32	0.22	Austria
2A	0.17	0.23	Switzerland

The reasons for the comparatively higher costs of the network schemes in Denmark are:

- compared to Germany: scale effects with the Danish scheme being much smaller. The high OBU costs penalise the comparatively small territory of Denmark because much less kilometers are registered per OBU than in Germany.
- compared to Austria: inclusion of the non-motorway segments. If the Danish scheme was reduced to motorways only, the DSRC gantry infrastructure costs would be significantly lower.

Compared to the LSVA scheme in Switzerland the Danish scheme compares favourably due to the fact that Denmark has only very few system entry points (18 in Denmark versus 120 in Switzerland).

8.2.4 Benchmark revenues

Scenario	Net revenue per vehicle kilometre		
	Denmark DKK	Foreign scheme DKK	Country
1A	0.56	0.74	Germany
1B	0.56	1.86	Austria
2A	0.73	3.05	Switzerland

The three Danish scenarios show a high percentage of revenue which is consumed by the operating costs. The area charging scenarios show significantly better relationships than the network scenarios. The network scenarios compare unfavourably with the motorway HGV charging schemes in Austria and Germany. The reasons are the relatively low tariffs of the Danish system (based on low infrastructure costs that can be attributed) and the comparatively smaller HGV traffic volume than the motorways-only networks in Germany and Austria. The benchmark with the Swiss LSVA shows that the Swiss have a much higher tariff yielding a significantly higher net revenue despite the higher cost of their system.

The benchmarks are a result of the assumptions on which the Danish study is based. These assumptions need to be reviewed in further studies. The present estimates give correct orders of magnitude.

8.3 Risks

Introducing a nationwide EFC system for HGV charging carries high risks. In Germany, the introduction of the scheme was delayed by 15 months, and in the UK the implementation of the Lorry Road User Charging scheme has been halted. On the other hand, the schemes in Switzerland and Austria went life on time and are running smoothly.

The major risks are:

- political risk of implementing a system without the necessary acceptance from the hauliers and the public
- making the system too complex with functional requirements that are too demanding. Such requirements could be:
  - differentiating road types other than all motorways
  - differentiating time of day or traffic conditions
  - differentiating vehicle categories that cannot be easily detected by automatic road side equipment (e.g. exempting HGV or special tariffs on the ground of trip purpose)
  - complex repayment or rebate schemes
  - mixing added value services with a tax-like charging system
- relying too much on technology to meet complex functional requirements and thereby neglecting usability aspects (e.g. unpractical fall-back options in case of equipment failure)
- relying too much on the industry to come up with answers instead of clear functional specifications and a firm leadership from governement.
- insufficient experience of industry operating a tax-like system
- legal challenges of the system if the scheme is inequitable for some user groups
- lack of interoperability with the future EETS (whatever the EETS specifications may be)
- unwanted traffic reactions such as detour traffic or HGV parking problems at POS.

8.4 Conclusions and recommendations

The results of the present study must be interpreted with caution. The costs are based on those of EFC systems that were procured some time ago reflecting the particular competitive prices of the particular situation. The revenues rest on assumptions regarding the infrastructure costs that could be allocated to HGV>12t on different networks based on figures of a study which has not been produced for this particular purpose. Nevertheless, the results certainly indicate a probable order of magnitude and they allow to show the trends between the different scenarios.

Under the present assumptions none of the scenarios show a favourable cost effectiveness. The reasons are

- the low tariff resulting from the comparatively low infrastructure costs upon which the potential charging revenues are based, and
- for the network charging scenarios the extent of the network resulting from the inclusion of a large part of the trunk roads. Including non-motorways is particularly penalising for the DSRC technology.
- the assumption, that all HGV travelling in Denmark must be equipped with a Danish OBU and there are no cost savings from interoperability.

The situation regarding the European Electronic Tolling System (EETS) is yet too unclear for allowing to estimate the cost effects in the present study. We recommend to review the estimates as soon as the EETS specifications have been settled by the relevant European bodies. The cost reduction from interoperability is likely to be the highest with scenario 1A.

Notwithstanding possible interoperability benefits in Scenario 1A, the area charging scenarios are likely to remain significantly more cost-effective than the network scenarios as long as non-motorways are included. The geography and network topology of Denmark favour area charging over network charging more than in any other European country.

It is difficult to answer the question if the cost difference of 18% between driving time related area charging and distance related area charging is big enough to engage in a discussion for this entierly novel approach to road user charging with the EU. We assume that the debate on the subject of driving time related charging will rather be taken up for light vehicles than for HGV.

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