Incorporating greenhouse gas emissions in Benefit-Cost Analysis in the transport sector in Norway

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ABSTRACT

Norway has used Benefit-Cost Analysis (BCA) for a number of decades to assess the economic merit of its transportation projects. BCA is constantly being revised and updated to accommodate more impacts that can be taken into account when choosing among alignment alternatives within a project or when prioritising among projects. Greenhouse gas (GHG) emissions from the transport sector have recently attracted attention due to their serious detrimental impact on the environment.

The Norwegian Public Roads Administration has developed a methodology that incorporates the impact of GHG emissions during the construction phase and from relevant maintenance work throughout the lifetime of a project. These indirect emissions, together with the direct emissions from traffic, can be incorporated in the BCAs that are performed. The methodology has been operationalised and is integrated in the standard software package used for performing BCA.

1. INTRODUCTION

Norway has used Benefit-Cost Analysis (BCA) to assess the economic merit of its transportation projects for several decades. BCA is constantly being revised and updated to accommodate more impacts that can be taken into account when choosing among alignment alternatives within a project or when prioritising among projects. This paper presents the methodology for BCA and the methodology developed for assessing GHG emissions from the transport sector in Norway. This methodology, which is based on Life Cycle Assessment (LCA), aggregates emissions from the extraction of raw materials, preparation of materials, construction and usage. The underlying principle for calculation is that greenhouse gas emissions are equal to input factors multiplied by emission factors. The methodology is primarily designed for calculating GHG emissions from ordinary roads in open terrain, steel and concrete bridges, ferries and tunnels – all of these elements that may be part of an ordinary transport project.

2. BACKGROUND

2.1 Benefit-Cost Analysis

As mentioned in the Introduction, Norway has used Benefit-Cost Analysis (BCA) for several decades to assess the economic merit of its transportation projects. This Benefit-Cost Analysis is a part of a more comprehensive assessment procedure that takes into account both monetised impacts and non-monetised impacts, making it possible to compare alternatives within a project in a systematic manner. Figure 1 below shows the elements included in the assessment procedure.

Participants	Theme	Category
Transport users	Benefit for transport users	Monetised BCA
Operators	Operator benefit	
The government	Budget effects	
Third parties	Traffic accidents	
	Noise and air pollution	
	Residual value	
	Cost of government funds	
	Landscape	Non-monetised
	Community life and outdoor life	
	Natural environment	
	Cultural heritage	
	Natural resources	

Figure 1: Impacts that should be considered at the preliminary planning stage

The monetised impacts are included in an ordinary BCA. The most important assumptions for conducting a BCA are:

Social discount rate	4.5%
Cost of government funds	20%
Average lifetime of construction	40 years
Assessment period	25 years

The main results from the BCA are “Net present value” (NPV) and “Net benefit cost ratio” (BCR), where BCR is NPV divided by the “Government costs”.
The main features of the framework for the BCA are the accounting framework and what is called the Inclusive Method. This means that VAT and other taxes are taken into account. The parties involved or affected by a policy are divided into four participants or sectors – Transport users, operators, the Government and Third parties – with a suitable subdivision by mode and purpose of trip, type of operator, government agencies etc. Costs and benefits for each sector or subsector are computed separately and entered into the sector accounting cost.

In Norway BCA is carried out regularly for the planning stages Early Project Appraisal and Municipal Master Plan. The results are used firstly to decide on which alternative to choose within a project and secondly to prioritise among projects within a limited budget framework.

2.2 Life Cycle Assessment

Life Cycle Assessment is a methodological framework for estimating and assessing the environmental consequences attributable to the life cycle of a product or a service. The framework is described in ISO-14041 *Environmental management - Life cycle assessment - Principles and framework* (ISO 2006), as shown in Figure 2. The four steps of an LCA are presented briefly in the following.

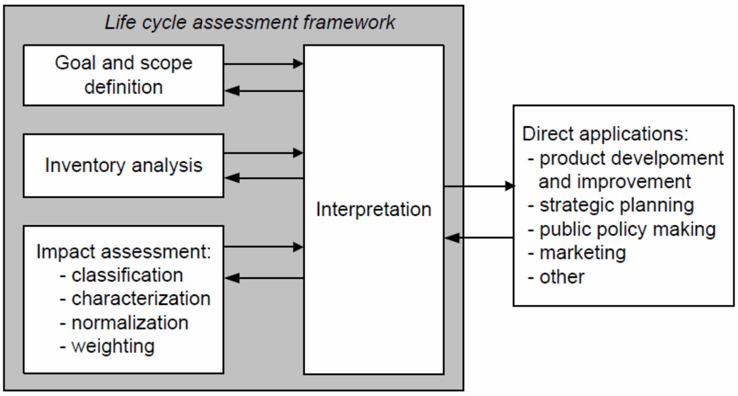

Figure 2: LCA framework according to ISO 14041

2.2.1 Goal and scope definition

Examples of goals of an LCA may be revelation of the life cycle process that contributes the most to environmental impacts related to the product(s), possibilities for improvement in the products' life cycle, environmental consequences of changing certain processes in the life cycle in various ways, or comparison of environmental performance for different product design alternatives. The formulated goal sets the premises for methodological choices in the study.

Defining the scope of the study means making a number of choices and assumptions: which options to model, which impact categories to include, which method for impact assessment to employ, system boundaries etc. Data quality requirements related to the goal of the study must also be considered.

To facilitate systematic data collection and comparison between LCA studies, a *functional unit* of the system studied must be defined. The functional unit reflects the function or service the product is fulfilling; for instance, when comparing various transport modes for commuting, the functional unit should represent transportation of a distinct number of persons over a specified distance and period of time. A relevant functional unit here could be: *Transportation of one person 30 km per day for one year, at a given location*. Principles for allocation must also be considered. For instance, if data for an entire production site is obtained, the inputs and outputs have to be allocated to obtain data for the single process of interest, and how this is to be done must be clarified (Baumann 2004).

2.2.2 Inventory analysis

A process flow chart displaying the different steps in the life cycle of the product in question is constructed, including the production of its most important components. For each process unit (production site, building, truck etc.) in the life cycle of the product and the production of its most important components, inputs and outputs are mapped, and the related environmental stressors (CO_2, PM_{10}, Hg, NH_3 etc.) are accounted. These inventory data must be handled consistently, in order to be able to aggregate them further in the analysis.
Obtained data often need to be recalculated, e.g. to be valid for a single functional unit of the product (Baumann 2004). Inputs may be raw materials, materials, components, chemicals and energy. Outputs may be products, residual products, energy, waste and emissions to water, soil and air. Inventory data can be obtained from various sources, such as companies, suppliers and producers, environmental reports, company and/or

public statistics, earlier LCA studies, LCA experts, public or computer program specific databases etc. (Rydh, Lindahl et al. 2002).
The system boundaries of the study determine what processes and stressors are included. The resulting flow chart and list of emissions throughout the life cycle comprise the system's Life Cycle Inventory (LCI).

2.2.3 Impact assessment in LCA

Impact assessment is a method for converting the inventory data into more graspable environmentally relevant information, reflecting the potential impacts the emissions and resource uses have on the environment.

The first step in impact assessment is *classification* of the emissions into environmental impact categories (e.g. global warming, acidification, eutrophication etc.).

The next step, *characterisation*, is a quantitative step where environmental impact per category is calculated using characterisation indicators. These indicators are based on the physicochemical mechanisms of how different substances contribute to the different impact categories. For instance, CO_2 is the equivalent for the impact category global warming, i.e. impact on global warming is expressed in CO_2-equivalents. Methane is a greenhouse gas which contributes to global warming 23 times as much as CO_2, and is hence multiplied by a factor of 23 and added to the category of CO_2-equivalents. Characterisation methods in LCA are based on scientific methods drawn from environmental chemistry, toxicology, ecology etc. for describing environmental impacts. The effects of deposition in geographical areas with different sensitivities to pollutants are disregarded, meaning that impacts calculated represent the maximum impact; in other words, that *potential* impacts are calculated (Baumann 2004).

The next two steps, *normalisation* and *weighting*, are optional steps. Normalisation relates the characterisation results to an actual (or predicted) magnitude for each impact category. This magnitude may be total impact for a whole country or region or on a per person level. For instance, impacts to the acidification category can be compared to total acidification emissions in the country where the product under study is used. The aim of normalisation is to gain a better understanding of the relative magnitude of the environmental impacts caused by the system under study (Baumann 2004).

The last step, *weighting*, is a qualitative or quantitative procedure where the importance of the environmental impact categories is weighted relative to the others. This is done in order to get a single indicator for the overall environmental performance of the product. Weighting may be based on political targets, critical emission limits or willingness to pay (Rydh, Lindahl et al. 2002). Weighting is not always performed in LCA studies, as it implies subjective valuation of environmental issues in relation to each other. Accordingly, it is a topic of subjective judgment and controversy.

2.2.4 Interpretation

Interpretation is the process of assessing results in order to draw conclusions.
As shown in Figure 2, the performance of an LCA is an iterative process, and work on one part of the LCA will often result in adjustments in other parts.

3. THE SOFTWARE PACKAGE FOR ANALYSING ROAD SCHEMES

Benefit-Cost Analysis has recently been integrated more closely with the transport models. Two main types of transport models are used, depending on the complexity of the traffic situation on this strategic level:

1. Transport Model with Fixed trip matrix
2. Transport Model with Variable trip matrix

This can be illustrated as below

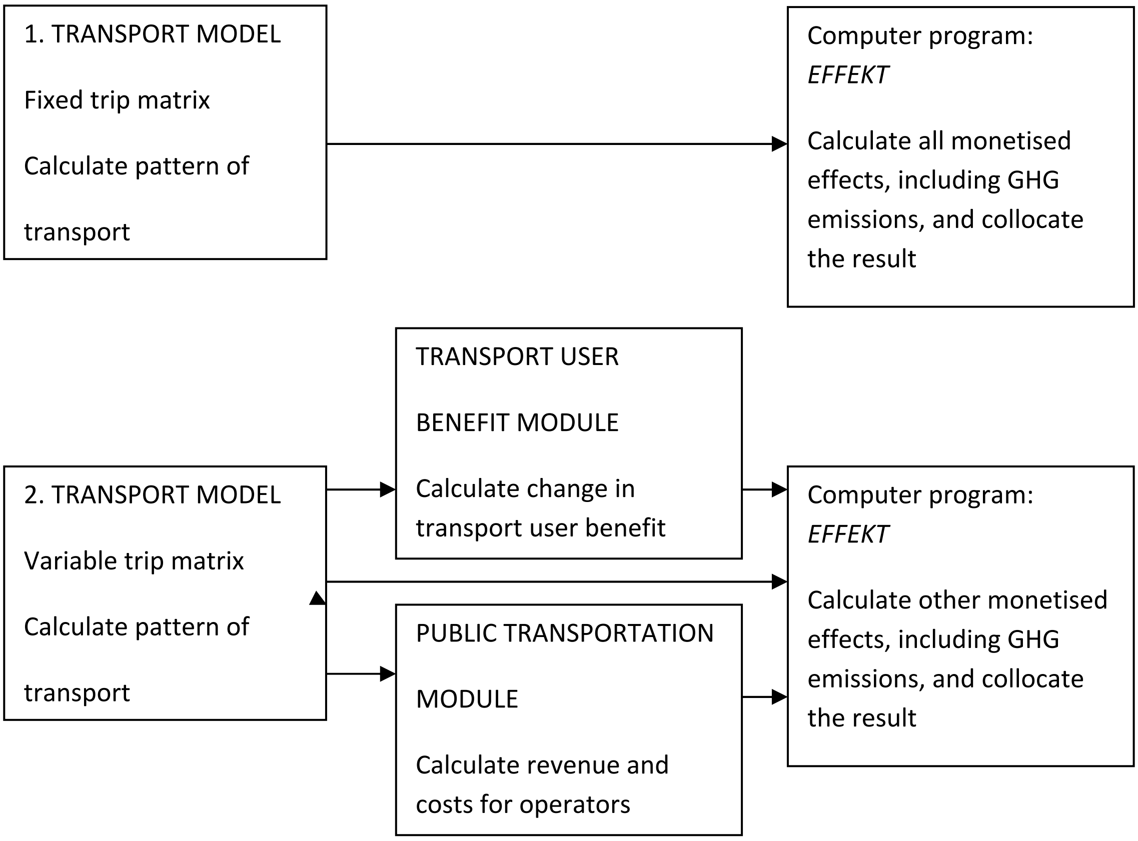

Figure 3: Transport Models with fixed and variable trip matrix and integration with the BCA.

When using a variable trip matrix, the Transport model, the Transport user benefit module and the Public transportation module are all integrated in the CUBE shell.

The trip matrix is calculated for car drivers, car passengers, public transport cyclists and pedestrians and for five different travel purposes. To date heavy vehicles are always handled as a fixed matrix.

In both cases the impact of GHG emissions is calculated using the computer program *EFFEKT*.

4. THE ADAPTION OF LCA IN BCA METHODOLOGY

Lifecycle climate gas emissions are included in the BCA related to the construction and the use phase of road projects. Based on literature and a case study, the most important materials and processes for road construction and operation have been identified for each of the four road elements included: open road, tunnel, bridge and ferry. The various materials needed for construction and operation of these four elements are shown in Figure 4 below.

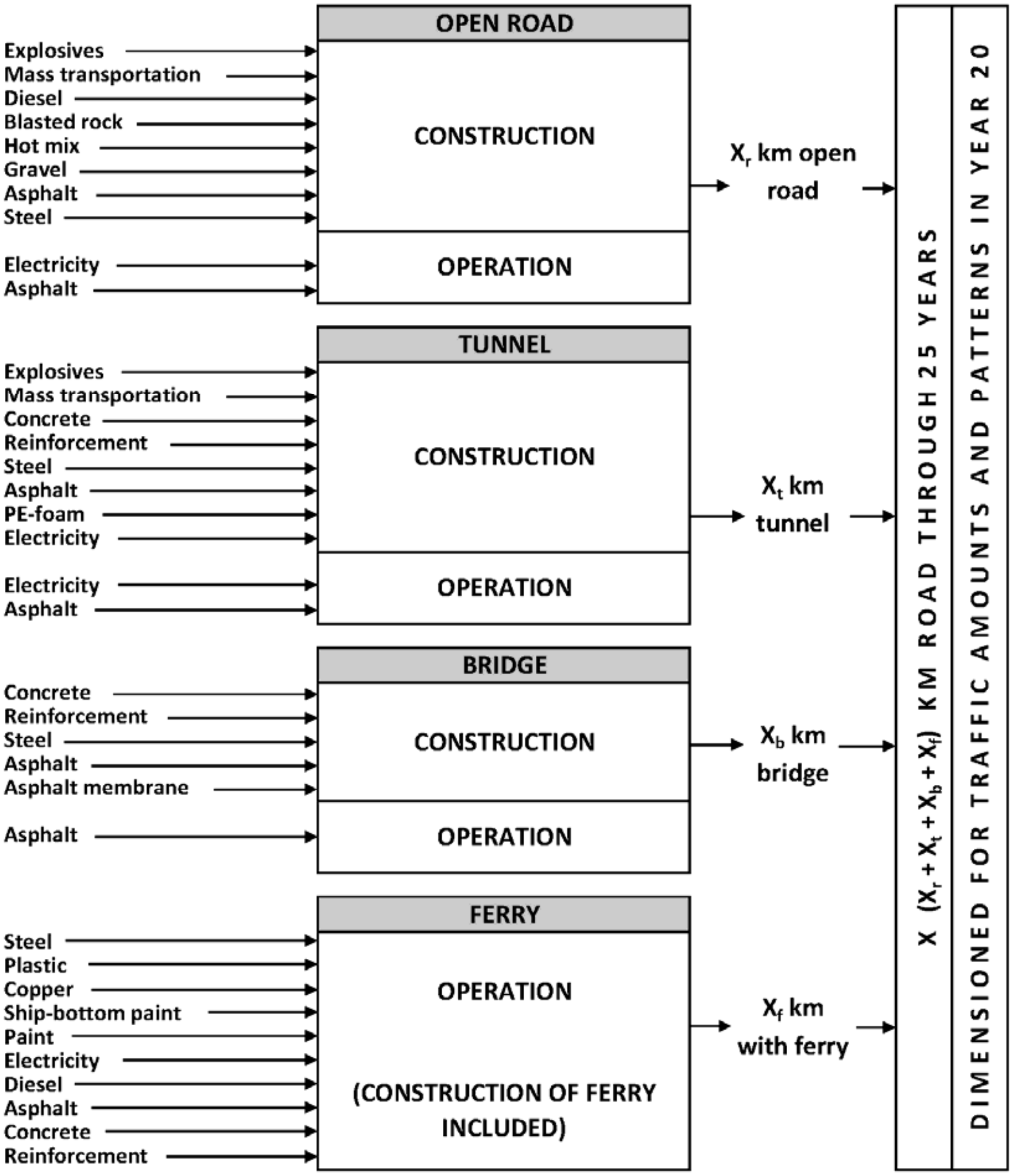

Figure 4: Various materials in construction and operation

For each of the materials, total emissions of CO_2, CH_4 and N_2O and accumulated energy demand from cradle-to-gate are gathered and expressed in CO_2-equivalents and Mega Joule (MJ) for each of the materials respectively. Cradle-to-gate represents the value chain of the materials from raw material extraction via processing to finished material at the plant. The emission data is gathered using the Swiss LCI database ecoinvent (Ecoinvent 2008) adjusted for use with case specific data. As there is no current consensus regarding electricity mix for LCA's in Norway, two choices are made available for the user of the software; Norwegian and Nordic electricity mix, based on electricity production in year 2004. Choice of electricity mix affects direct electricity use both in the construction and use phase and in the production of the materials.

As the analysis period in *EFFEKT* is 25 years, operation of the road elements for 25 years is included in the results. The various road elements have different technical lifetimes, but economic lifetime is applied in the analysis, defined as 40 years for all elements. The end-of-life of the road elements is not included. The main reason for this is that the tunnels and open roads are seldom demolished after end-of-life; they tend to be left in the terrain, either for alternate use or closed (tunnels). Earlier studies on bridges in particular have shown that the end-of-life phase does not account for much of the total GHG emissions throughout the whole lifetime. There is currently a lack of knowledge on how ferries are treated at end-of-life.

The cradle-to-gate GHG emissions per unit of material are multiplied by the amounts of material used, which is calculated within *EFFEKT* to obtain total GHG emissions and total accumulated energy use. The coefficients for GHG emissions and accumulated energy demand for each of the materials included are given in table 1.

		Norwegian electricity mix	Nordic electricity mix
Material	Unit	CO_2-eq [kg]	CO_2-eq [kg]
Asphalt	tonne	28.87	30.39
Gravel	tonne	2.16	3.76
Hot mix	tonne	26.77	28.47
Blasted rock	tonne	1.80	1.80
Asphalt membrane	kg	0.20	0.21
Steel	tonne	1 550.74	1 607.02
Concrete	m^3	235.30	236.07
Reinforcement	tonne	754.79	836.63
PE-foam	kg	2.34	2.47
Explosives	kg	2.38	2.38
Aluminum	tonne	6 994.66	7 008.51
Paint	tonne	2 833.38	2 840.94
Copper	tonne	1 499.77	1 933.15
Plastic	tonne	2 001.25	2 091.00
Glass	tonne	549.17	549.17
Mass transport	Tkm	0.13	0.13
Diesel	L	3.17	3.17
Electricity	kWh	0.02	0.20
Gasoline	L	2.72	2.72
MGO	L	3.21	3.21
LNG	l MGO energy eq	3.16	3.16

Table 1: Cradle-to-gate GHG emissions

Norwegian electricity mix		Non-renewable		Renewable			
Material	Unit	Fossil	Nuclear	Hydro	Biomass	Wind, sun, geo	TOTAL
		MJ	MJ	MJ	MJ	MJ	MJ
Asphalt	tonne	2 973	97	50.02	2.66	0.99	3 124
Gravel	tonne	31.16	1.35	35.01	0.68	0.12	68.32
Hot mix	tonne	2 717	94.36	49.72	2.54	0.93	2 865
Blasted rock	tonne	21.92	1.49	0.85	0.44	0.01	24.71
Asphalt membrane	kg	6.52	0.14	0.15	0.07	0.00	6.88
Steel	tonne	21 592	2 032	1 861	185.35	40.32	25 710
Concrete	m^3	188.27	44.08	27.30	1.18	0.28	261.10
Reinforcement	tonne	11 545	759	1 903	97.69	18.40	14 324
PE-foam	kg	74.51	7.62	3.96	0.44	0.01	86.54
Explosives	kg	22.69	2.78	2.36	0.89	0.02	28.75
Aluminum	tonne	89 676	22 472	23 121	626.00	73.22	135 968
Paint	tonne	71 177	6 266	981.50	4 119	108.76	82 653
Copper	tonne	17 776	22 398	14 778	18 243	177.07	73 372
Plastic	tonne	73 190	4 912	2 549	905.04	6.83	81 563
Glass	tonne	11 730	848.36	156.48	0.0327	14.52	12 749
Mass transport	tkm	1.79	0.02	0.00	0.00	0.00	1.82
Diesel	l	47.45	0.27	0.10	0.03	0.01	47.85
Electricity	kWh	0.16	0.03	4.27	0.07	0.01	4.53
Gasoline	l	41.98	0.69	0.03	0.01	0.09	42.79
MGO	l	47.45	0.27	0.10	0.03	0.01	47.85
LNG	l MGO energy eq	43.02	0.08	0.06	0.00	0.00	43.15

Table 2: Accumulated energy Megajoule (MJ), Norwegian electricity mix

5. EXAMPLES OF CALCULATIONS OF ROAD SCHEMES

5.1 Description of an example

To show how GHG emissions and energy usage vary for different solutions and how this can influence the benefit of a project, a fictitious example is shown below in figure 5. The site is a fjord named “Vestfjorden” which is 15 kilometres long. The existing road (alternative 0) goes through point A to the ferry crossing and on to point B. Four new alternatives are considered; all of them have A as their starting point and end up in point B.

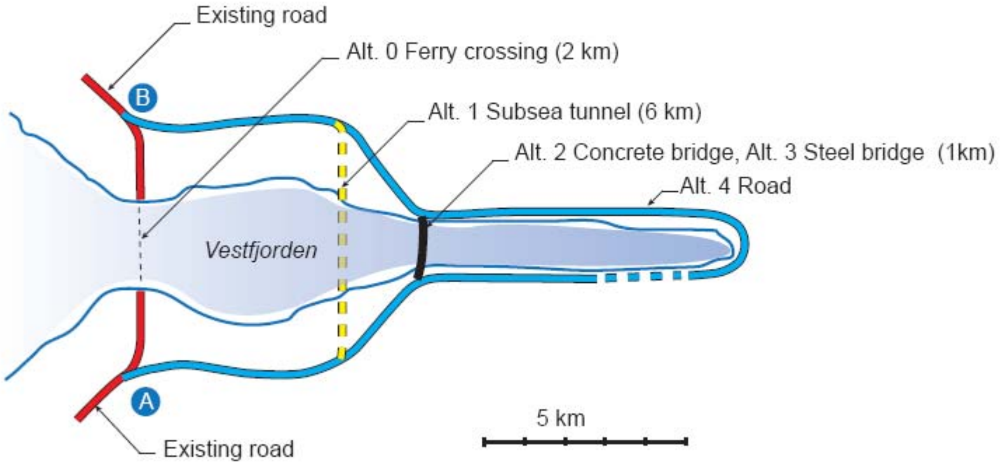

Figure 5: Replacing existing ferry crossing of "Vestfjorden" with different alternatives

There are different elements in the different alternatives, as shown below in table 3. The figure also shows the length of the alternatives and the investment costs.

Alternative	Type of construction	Total length Km	Investment Costs MNOK[1]
0	Ferry 2 km + road 4 km	6.0	0
1	Subsea tunnel 6 km + road 10 km	16.0	1080
2	Concrete bridge 1 km + road 16.5 km	17.5	1175
3	Steel bridge 1 km + road 16.5 km	17.5	1315
4	Tunnel 2 km + road 31.5 km	33.5	1165

[1] 1 US$ equals 6 NOK

Table 3: Elements, length and investment costs for the alternatives

The terrain and the road have the following characteristics:
- The share of rock is 0.6
- Average height of cutting and filling is 1.5 metres
- Road width is 8.5 metres
- The share of guard rail is 0.46

The need for earth work, blasting and transport is calculated from the characteristics of the terrain and the new road.
The average annual traffic for the ferry connection before the opening of the fixed link is 1500, and it is stipulated to increase to approximately 1630 caused by induced traffic due to easier travelling in alternatives 1 to 4.

5.2 Results from the BCA

As shown in figure 6 below, all four alternatives give substantial benefit to the transport users due to much easier travelling compared to the ferry crossing in alternative 0. The benefit is calculated for an analysis period of 25 years and discounted to net present value. Alternative 1, the subsea tunnel, has the most direct route and gives slightly more benefit to the transport users compared to alternatives 2 and 3 (bridges). Alternative 4, which is a road around the fjord, gives much less benefit to the transport users as the distance is considerably longer compared to the other alternatives.

In this case, the operators (which are the ferry company and public transport suppliers) have to be subsidised, so the operators as a whole have no benefit in the socioeconomic analysis.

The “Government costs” mainly cover the investment costs and the present value of maintenance costs. As we see from the figure, Alternative 3 has the highest government costs due to the highest investment costs.

The participant “Third parties” covers accidents costs that increase for all four alternatives, the cost of Government funds and the residual value, as the period of analysis (25 years) is shorter than the lifetime for the project (40 years). The cost of air pollution is also covered by “Third parties”; in this case the value is positive as the reference alternative (alternative 0) using a ferry has a greater amount of air pollution.

The costs of GHG emissions are included in the BCA as follows: The emissions from the construction phase are for the year of construction multiplied by the unit price for these emissions and handled as an ordinary cost in the BCA. The emissions from the maintenance phase and the transport phase, which cover the analysis period of 25 years, are dealt with in a similar manner.

Figure 6 shows that alternatives 1, 2 and 3 all have a positive Net Present Value, which means that they are worthwhile from an economic perspective. The fourth alternative, however, has a negative Net Present Value, which means that this alternative is not worthwhile.

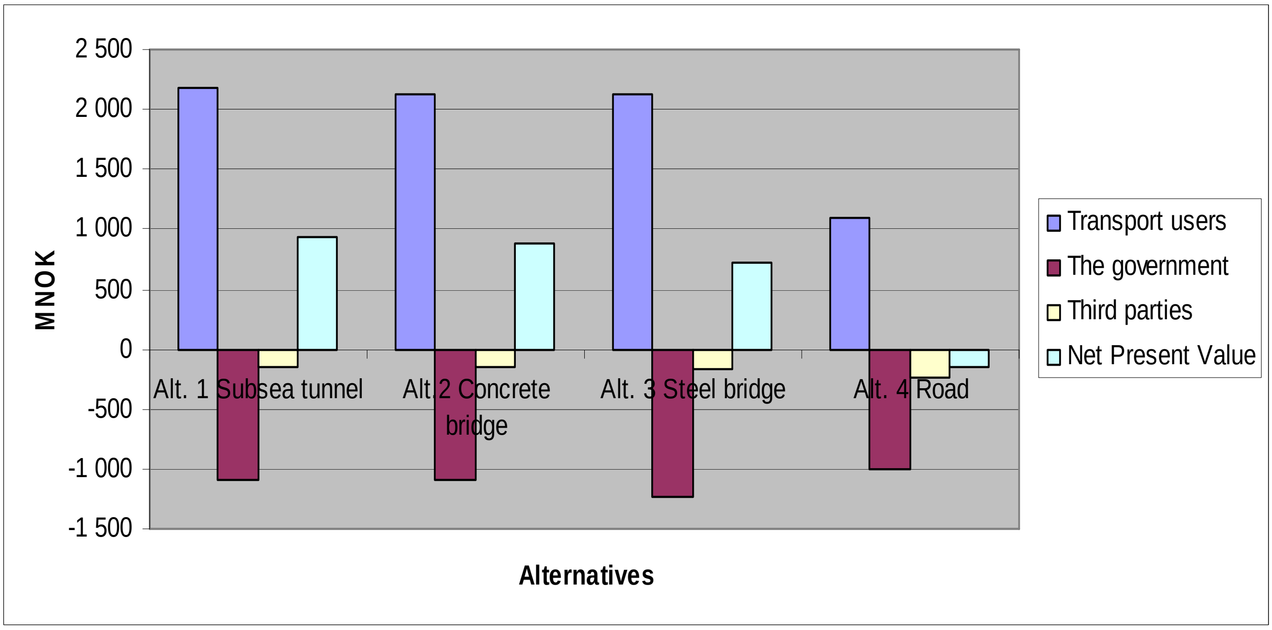

Figure 6: Benefit of different alternatives for participants

5.3 GHG emissions from different phases and alternatives

Figure 7 shows the GHG emissions in tonnes CO_2-equivalents from the following three phases: 1. the construction phase, 2. the maintenance phase, and 3. the transport phase. The figure also covers the emissions from the reference alternative 0 (ferry). For each alternative and each phase the emissions are summed up in tonnes and without any discounting. Due to the analysis period of 25 years and lifetime of construction 40 years, the GHG emissions from the construction phase included in figure 7, 8 and 9 is 25/40 of total emissions from this phase.

As can be seen from the figure, the emissions from the maintenance phase are rather low for all four alternatives compared to the construction phase and transport phase. The main contribution in the maintenance phase is asphalt; for the subsea tunnel pumping, ventilation and lighting are additional sources. The high amount of GHG emissions from alternative 0 in the maintenance phase is caused by the marine gas oil from the ferry over a period of 25 years. In addition the construction of the ferries are included in the maintenance phase.

Although the volume of traffic is rather low, somewhat above 1600 average annual traffic at the opening of the project and increasing by 0.4% yearly throughout the analysis period, the GHG emissions from the transport phase dominate.

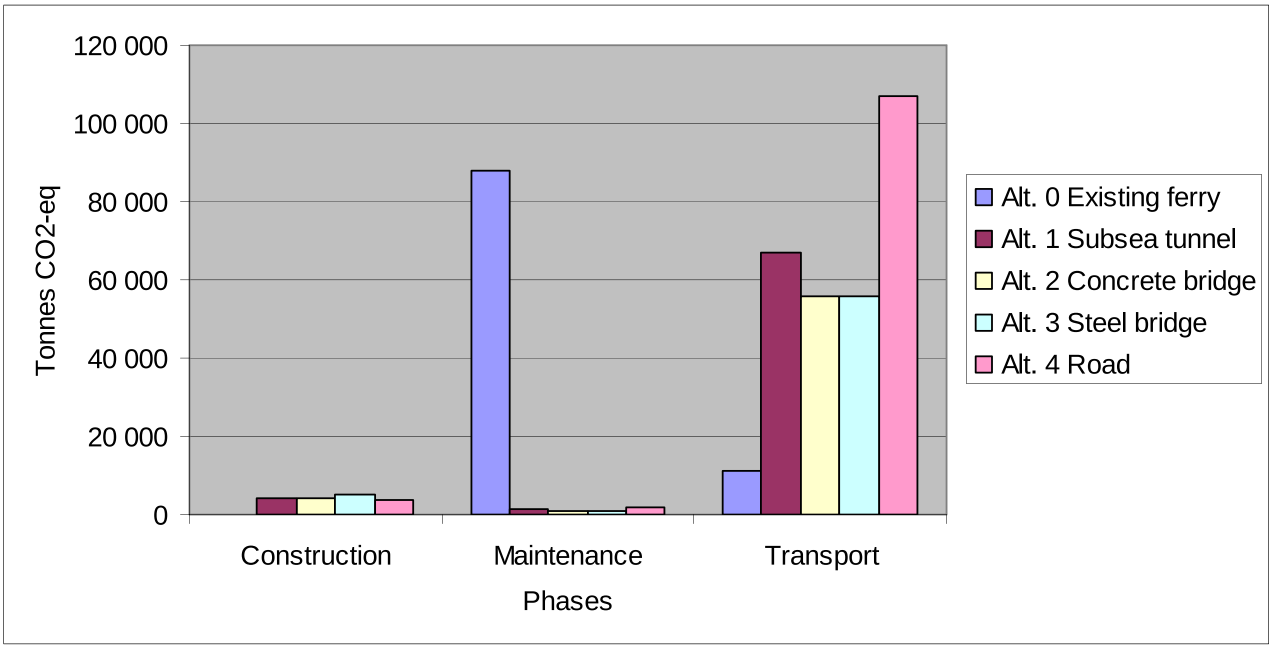

Figure 7: GHG emissions from different phases and different alternatives

Figure 8 below shows the total GHG emissions from all three phases for each alternative. For alternatives 1 to 3, which are the subsea tunnel, concrete bridge and steel bridge, the GHG emissions from the construction phase are similar, with the emissions from a steel bridge slightly greater compared to a subsea tunnel or a concrete bridge. Alternative 4, a road around the fjord, has the lowest GHG emissions during the construction phase even though this alternative includes a 2-km tunnel and has a considerably longer road to construct. During the transport phase the subsea tunnel has greater GHG emissions compared to alternatives 2 and 3, which both have the same geometry for the traffic. The traffic has a shorter trip through the subsea tunnel compared to the bridges in alternatives 2 and 3, but most of the tunnel has a gradient of 6% so fuel consumption is higher compared to alternatives 2 and 3 even though these two are longer. Taking all GHG emissions into consideration, alternative 4 (a road around the fjord) has the highest GHG emissions.

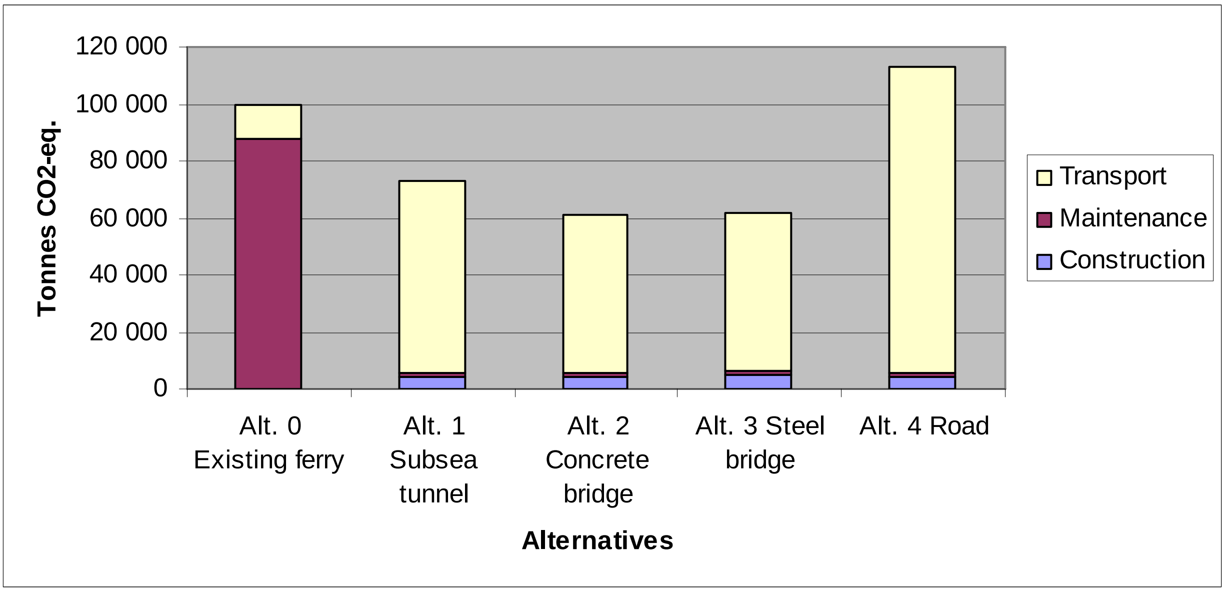

Figure 8: Total GHG emissions from the 3 phases: Construction, Maintenance and Transport

5.4 Energy use during the construction phase

As shown in section 4, all materials and activities that require energy use are divided into the two groups “Renewable” and “Non-renewable” energy. Figure 9 below shows the energy use in megajoule for alternatives 1 to 4 during the construction phase. Although a Norwegian electricity mix is assumed, with a high renewable share in production due to the availability of hydropower, the share of renewable energy usage in the construction phase is rather low for all alternatives. This is because a lot of the materials are produced abroad with limited use of renewable energy. The highest energy usage is for alternative 3 (Steel bridge), due to the high energy usage for producing steel, and for alternative 4 (Road around the fjord), due to high amounts of construction materials such as asphalt, hot mix and steel for guard rail for the road. Energy usage for machinery has a lower share of the total energy usage.

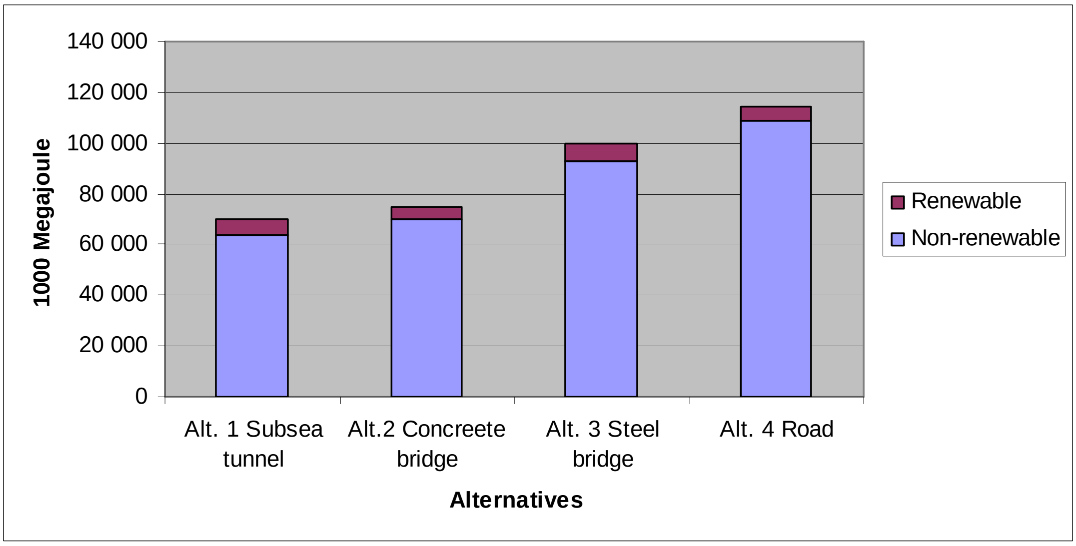

Figure 9: Energy usage for the construction phase divided into renewable and non-renewable energy.

6. THE IMPACT ON BCA TAKING GREENHOUSE GAS EMISSIONS INTO CONSIDERATION

Standard prices are used for calculating the impact of GHG emissions. The current values, on which the benefit-cost analyses are based, are shown in figure 13.

Year	NOK per tonne CO_2
2015	210
2020	320
2030	800

Table 4: Standard prices for CO_2 emissions

In this case we have presented, it is assumed that the construction phase ends in 2014 and the road opens in 2015. Accordingly, NOK 210 per tonne CO_2 is used for the construction phase. As we can see from the figure below, GHG emissions have a minor impact on the Net Present Value of this project. For a project completed later, when the price of CO_2 has risen to NOK 800 per tonne CO_2, for instance, the impact on the net present value during the construction phase will still be almost negligible.

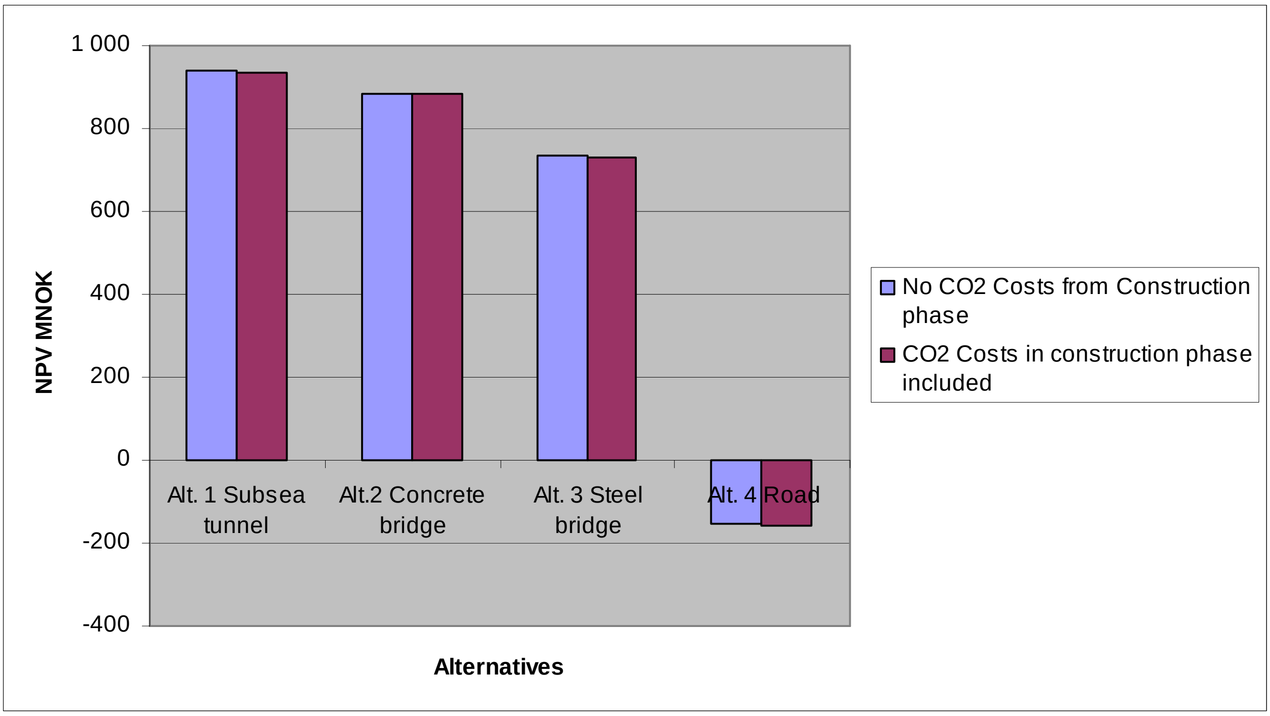

Figure 10: The influence of CO_2 costs from the construction phase on Net Present Value

For the maintenance phase the difference in GHG emissions between the alternative for construction and the reference alternative (alternative 0) is relevant for the BCA. In our case we see that for alternatives 1 to 4 the amount of GHG emissions for these alternatives during this phase is quite small. In this project, where the reference alternative was a ferry with a vast amount of emissions, there will be a substantial reduction in GHG emissions for all alternatives during the maintenance phase.

For the transport phase of this project, construction alternatives 1 – 4 have considerably more GHG emissions compared to the reference alternative (ferry). This means a negative contribution to the Net Present Value of the project. However, the costs from the emissions during the period of analysis have to be discounted, so the resulting impact on the Net Present Value of the project is not great.

In summary we can say that taking the GHG emissions into consideration for this specific project does not seriously change the result of the BCA, and we can assume that in this case it would not alter the priority of what alternative to choose for construction.

7. CONCLUDING REMARKS AND SUGGESTIONS FOR FURTHER WORK

The inclusion of lifecycle GHG emissions in BCA for road projects offers a comparison of the environmental performance of various road project designs. The methodology needs to be further tested and refined. For some of the materials, the amounts consumed are quite roughly estimated. In addition some of the emission coefficients should be further improved by applying more case specific data. This is especially important for the materials contributing the most to the total emissions. Another possible improvement would be to include more environmental impact categories.

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