

On Assessing Climate Effects of Electrifying the Transport Sector

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Abstract

Shifting transportation to electrified modes, e.g., rail, is a politically attractive way of reducing greenhouse gas (GHG) emissions from the transportation sector. There is a vivid debate about the effects such a shift has on GHG emission and how these should be assessed and appraised. We argue that this debate largely originates from differences in how the debaters characterize the situation at hand, in particular how markets are organized and which policy instruments are in place. To shed light on this, we start by identifying the appropriate assessment approach in a hypothetical situation without any climate or energy policies and then gradually add realistic circumstances into the equation. Our main conclusion is that evaluating the climate impacts from a transportation shift is a highly complex task in the initial situation. The closer we move towards a climate-policy architecture of the current EU-type, the simpler the task becomes. Given a comprehensive global climate treaty, there is no need for any special treatment of the GHG effects since all relevant effects then would be internalized in producer and consumer prices.

Keywords: Climate, transport, cost-benefit analysis

JEL Codes: H54, Q51, R42

1. Introduction

Transportation relies heavily on fossil fuels. In most developed countries 90 per cent or more of the energy use in the transportation sector originates from fossil sources. Not surprisingly, the transport sector thus answers for a large share of these countries' greenhouse gas (GHG) emissions. Furthermore, the demand for transportation, in particular for air travels and freight transports on roads, is expected to continue to grow rapidly. Cost-effective fulfillment of stated climate policy objectives, notably the EU's objective of reducing its GHG emissions by 20 percent to the year 2020 and by 80 percent to the year 2050, is therefore likely to require substantial adjustments within the transport sector. The palette of policy measures is broad but politicians seem particularly interested in projects that curb the GHG emissions from transportation without restricting transportation *per se*. One suggested such project is to electrify (parts of) the transportation system by promoting electric vehicles on roads or facilitating shifts from road to (electrified) railways.

In this paper we discuss principles for identifying and appraising the impact on GHG emissions from electrifying transportation. We are primarily interested in the road-to-rail case, but the principles apply to other cases as well, both inside and outside the transportation sector. The underlying motive for the paper is an ongoing debate regarding how and to what extent investments in rail infrastructure influences GHG emissions and how to adequately consider these effects in cost-benefit analyses (CBAs) of such investments. Various approaches have been proposed. For instance, some argue that one should use the average GHG-emission factor (AEF) of electricity production, *i.e.* total emissions from the power sector divided by total production. Other argues that it is the marginal emission factor (MEF) that is of interest, *i.e.* emissions per electricity unit for the power plant lastly employed. It has also been argued that if the railway operator only purchases electricity based on renewable fuels, the investment would produce no GHG emissions. Still other advocates the use of so-called life-cycle analysis (LCA) of electricity production as well as of the transport investment. At the other end of the spectrum some note that if power producers are included in a cap-and-trade system, the incremental electricity demand

would only influence permit prices, not aggregate emissions.¹ Also when it comes to how to value the identified effects on GHG emissions the views diverge. Setting aside the very abstract level, there is no simple and universal answer to how to deal with the impact on GHG emissions of electrifying transportation. However, we believe that the opposing standpoints to a large extent originate from divergent views on what circumstances are present in any particular case, rather than from misunderstandings. As will be shown, the answers to any of the above-mentioned disputes are highly context dependent. Our objective is to provide a structured discussion that sheds light on the problem of where and when various approaches are valid.

Our discussion is mainly of principal nature. However, references are occasionally made to the Swedish case, which may be of particular interest since the power production there is essentially carbon free and since Sweden has a rather long experience of non-mandatory green electricity contracts as well as a mandatory system of so-called tradable green electricity certificates. To fix ideas, we consider a railway investment that would transfer a certain freight transport volume from road to rail. Such a project may have several significant effects, including a reduction (increment) in the congestion on roads (rails), changes in operational costs and transport time as well as energy use. Here, we focus on two sub-questions, namely the consequences of the incremental electricity demand that follows our investment project and how any changes in GHG emissions should be dealt with in an otherwise complete and adequate cost-benefit analysis of our railway project. Throughout the analysis we assume that market prices reflect the values of all resources but GHG emissions.

The analytical approach adopted below is to start (in Section 2) with a seemingly simple context where there is no climate or energy policies. We then sequentially add circumstances that make the analytical context more realistic. In Section 3 a mandatory system of green electricity certificates is introduced. Thereafter, in Section 4, we add climate policy instruments, *e.g.* tradable emission permits, carbon taxes and an international climate agreement. The context thereby becomes increasingly complex during the presentation. However, one of the main messages of the paper is

¹ Banverket/SIKA (2002a, b) include an early and interesting discussion where SIKA, a Swedish governmental agency responsible for gathering and analyzing transport sector statistics, and the Swedish National Rail Administration express completely opposing views on some of these questions. For instance, the latter argues for the use of *AEF* and that renewable fuel contracts play a central role.

that the adequate approach of identifying and appraising the relevant GHG effects of our investment at the same time becomes less complicated, not to say simple. Section 5 sums up and concludes.

2. No Climate Policies

We begin by discussing the short-term impact on GHG emissions of an increased electricity demand in a context where no climate or energy policies are present. By short term we mean the time period during which the electricity production capacity is fixed. Three questions are central for our discussion. First, should one use the *MEF* or *AEF* of electricity production to assess the effect a railway investment has on GHG emissions? Second, does the existence of any voluntary contractual arrangement specifying that the railway operator only purchases green electricity matter? Third, how should we value the quantified GHG effect?

Of particular importance to the first question is the merit order of power producing facilities on a competitive power market. Typically, production facilities are employed in a cost-increasing order. Power plants producing at a low short-run variable cost (*SRVC*) are used before plants with higher costs. High-cost plants are started only when needed to meet occasional demand spikes. This makes sense since any other procedure would imply waste of scarce resources. Given the uncertainty surrounding future demand for electricity (D) and future fuel prices and the long time it takes to create new production capacity, there usually exists a substantial reserve capacity on the market. This situation is schematically illustrated in Figure 1, where D_0 denotes the expected demand schedule in the absence of our railway project and the graph S illustrates the supply curve² (the merit order of existing production plants). Our railway project consumes A units of electricity and therefore shifts the demand curve to D_1 . More costly plants than plant x must then be employed and the electricity price increases from p_0 to p_1 . This fosters the electricity demand somewhat. After this demand adjustment, the produced and consumed amount of electricity has increased

² At the Nordic/Scandinavian power market Nordpool, producers submit their individual supply schedules (*i.e.* how much they are willing to produce at different price levels) while electricity retailers and large consumers submit their individual demand schedules. Given profit interested firms and a competitive environment this procedure yields a market supply curve close to a merit ordering based on *SRVC*, Cason and Plott (1996), Joskow et.al. (1998).

from q_1 to q_0 . As long as electricity demand is not totally inelastic the incremental power production will be smaller than the railway project's direct consumption of electricity. The GHG effect of the incremental production equals $\Delta GHG = a_x \Delta kWh_x + a_y \Delta kWh_y$, where a_i denotes plant i 's specific emission factor (*i.e.*, GHG emission per kWh production). This is the (true) *MEF*-approach,³ which is the appropriate approach to use as it thus captures the effects from the project at hand.

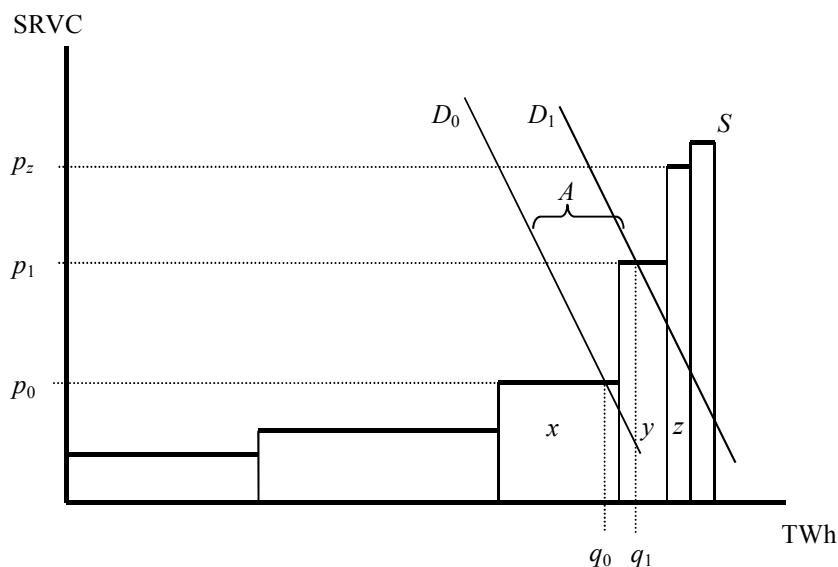


Figure 1. Illustration of the power market

Under the *AEF*-approach, the incremental production is multiplied with the average emission factor a (= total emissions from power production / total production). Then, the assessed GHG-effect becomes $a(\Delta kWh_x + \Delta kWh_y)$. If plant y were the only carbon emitting one, the *AEF*-approach would hold our railway investment accountable for less carbon emissions than actually created, *i.e.*, $a(\Delta kWh_x + \Delta kWh_y) < a_y \Delta kWh_y$. If, on the other hand all plants but x and y are emitting, the opposite would apply. The size of the error depends crucially on how heterogeneous power plants are in terms of their specific emission factors for carbon dioxide (CO₂). That the error may be substantial is shown by the following example.⁴

³ Hawkes (2010) discusses strengths and weaknesses with existing approaches of estimating the MEF in practice.

⁴ Also, see *e.g.* Bettle *et.al.* (2006) that examine the differences between the AEF and the MEF for the case of England and Wales.

Consider a railway investment that increases the yearly power production with 50 GWh. If this production were coal based (for which $a_i \sim 890$ gCO₂ per kWh)⁵ the yearly CO₂ emissions would increase with ~44 kton. If we instead would apply the AEF found in Swedish power production, ~20 gCO₂ per kWh⁶ the investment would seem to increase emissions by 1 kton. As an extreme illustration, assume that total annual power production amounts to 135 TWh (approximately true for Sweden). However, assume that, without the investment, no coal based power would be used. This would yield an AEF of ~0.3 gCO₂ per kWh. Applying this figure to the investment will hold it accountable for a yearly CO₂ increase of only ~15 ton.

We now turn to the second question, namely the effects of voluntary green electricity contracts (*i.e.*, contracts specifying that the electricity purchased should come from carbon free power plants). The selling idea of such contracts is to alter the merit order at the power market in a “climate friendly” direction. However, it is not evident that they actually accomplish this. A contract giving the owner of plant z a total unit remuneration of at least p_z would make him/her willing to produce electricity. Plant z would thereby exclude plant y from the market and plant x would be the price setting plant also after our railway project. In this case, our railway operator would pay more for electricity but on the other hand create no additional direct GHG emissions. Two things should be noted, though. First, since the market price is unchanged, there would be no fostering of the demand for electricity. Second, we have implicitly assumed that plant z would otherwise be idle. However, it is not likely that such a situation would arise. Instead, we would expect that our operator, when entering a green contract, excludes some other agent from entering a similar contract with plant z and thereby forcing this agent to buy conventional power. In this more likely situation, whether or not our operator engage in a green contract is irrelevant for our railway project’s effects on the GHG emissions from power production.

So far we have considered only direct GHG emissions of power production (essentially carbon emissions from fuel combustion).⁷ GHG emissions arise also when

⁵ See Hondo (2002).

⁶ Source; Svensk Energi

⁷ Also combustion of biomass releases carbon. Usually it is assumed that the direct emissions from bio-fuel combustion equal the amount of carbon assimilated by the bio mass during its growing phase, an assumption we here maintain.

fuels are extracted, processed and transported. This is so for both fossil fuels and biomass based fuels. To consider such indirect emissions (IE) a life cycle analysis (LCA) must be conducted of the incremental electricity production as well as the reduced fuel use for road transportation. Studies indicate that these indirect emissions may be substantial, see *e.g.* Searchinger *et al.* (2008), and Lapola *et al.* (2010). Our railway investment's net-effect on global emissions then becomes.

$$(1) \quad \Delta GHG = \sum a_i \Delta kWh_i + \sum \Delta IE_i + (\Delta GHG_{Road} + \Delta IE_{Road})$$

The first two terms of the right-hand side captures the effects associated with the incremental electricity production while the last two terms capture the change in emissions due to less road traffic.

Electricity is traded across borders, a trade expected to grow in Europe as new transmission cables materialize between countries and regulatory hinders are erased. To only consider domestic power production capacity when assessing equation (1) may therefore be misleading. For instance, Sweden is an integrated part of the North European electricity market for which the marginal power plants are coal fired, implying that the relevant *MEF* is close to 900 gCO₂ per kWh even though the Swedish *MEF* is much lower, as discussed in the example above.

In the longer run new power plants will be built. This generally takes considerable time, *e.g.*, due to technical complexity, juridical procedures and bureaucracy.⁸ Consequently, there is a non-negligible mid-term to consider. During this time, an (unexpected) shift in electricity demand will not influence the characteristics of the power generating capital, although some electricity may be produced in new plants. These plants have not been directly motivated by the demand shift, *i.e.*, they were planned but not constructed at the time of the demand shift. Thus, the principles relevant for the short term apply also in the mid-term, although the relevant *MEF* may be different since new plants are added to the power generating capital.

In the long run, our railway-project may influence the composition of the power production. It is then the characteristics of these new plants that will determine how

⁸ As an example of the latter; the average time from applying for building approval for a new wind mill to when construction begins is 48 months in Sweden, much because there are currently 27 different instances that have to approve the construction plans. Source; <http://www.goldwind.nu/vindkraft.php> (110620)

much GHG emissions our project causes. In the absence of energy and climate policies, new capacity is likely to be coal based. However, voluntary green contracts might render “green” power plants to be built in which case $a_x = 0$. Our railway operator would then pay more for electricity in order to avoid (direct) GHG emissions. It should also be noted that in the long run the LCA of power production also includes emissions from construction of the plants and land use changes, which may be substantial (see e.g., Hondo, 2002, and Wibe 2010).

We now turn to the third question, namely how to value GHG emissions accruing to our railway investment. In this simple context with no international climate treaty or other climate or energy policy instruments, higher GHG emissions from the power sector imply essentially the same increment in global emissions. The risk for climate change is a global public bad. A global and benevolent social planner would therefore attach a value v_G to an additional emission reduction that equals the sum of all individuals’ valuation of the risk thereby avoided. However, in the absence of an international/global treaty coordinating nations’ behavior, it is sub-optimal for any single country to unilaterally abate up to the point where the cost for further abatements equal v_G . Instead, a government (with the objective of maximizing its citizens’ welfare) would only consider the unilateral, domestic valuation of this additional risk (v_S) which by definition lies below v_G , and by circumstances substantially so (see e.g., IPCC, 1996). The reader should note that this is not a policy recommendation, just a conclusion consistent with the assumed context. It should also be noted that, irrespectively of which approach one takes, it is by no means a simple task to arrive at precise estimates of v_G or v_S . In both cases one has to assess the sum of many future generations valuation of the climate effects incurred.

To sum up: In this context with no climate or energy policies an amount $v_S \Delta GHG$, should be added to the cost side of an otherwise correct CBA of our railway investment. ΔGHG is given by (1) and based on a *MEF* calculated for the relevant electricity market, which in many cases may be larger than the domestic one. For the Swedish case the relevant market amounts to the North European one. In the short run, voluntary green electricity contracts are not likely to influence the emissions from incremental power production. In the long run they may. Then, the railway operator will pay a higher electricity price in order to lower the project’s climate cost. Whether this increases or reduces the cost-benefit ratio of the project depends on how large the markup on the green electricity is relative the value of emission reductions.

3. Tradable Green Electricity Certificates

We now add to the analytical context a mandatory system that mills in electricity based on renewable energy sources. The system we have in mind resembles the system of tradable green electricity certificates used in several EU-countries, including Sweden.⁹ Such a system gives producers of green electricity a certificate for each unit produced. This creates a supply of certificates. To create a demand, electricity consumers (or on their behalf electricity distributors) are obliged to hold a certain number of certificates per electricity unit consumed (sold). The producers of renewable energy may sell certificates to the electricity consumers, thus getting revenues over and above the market price on electricity. The policy variable is the number of certificates the consumers are obliged to hold per consumed unit, α . Figure 2 illustrates such a certificate system. For simplicity, we assume a totally inelastic electricity demand, located at q . Thus, the demand for certificates equals αq . We denote this q_G which thus equals the amount of green electricity produced. The remaining electricity demand is catered by conventional power production, q_C .

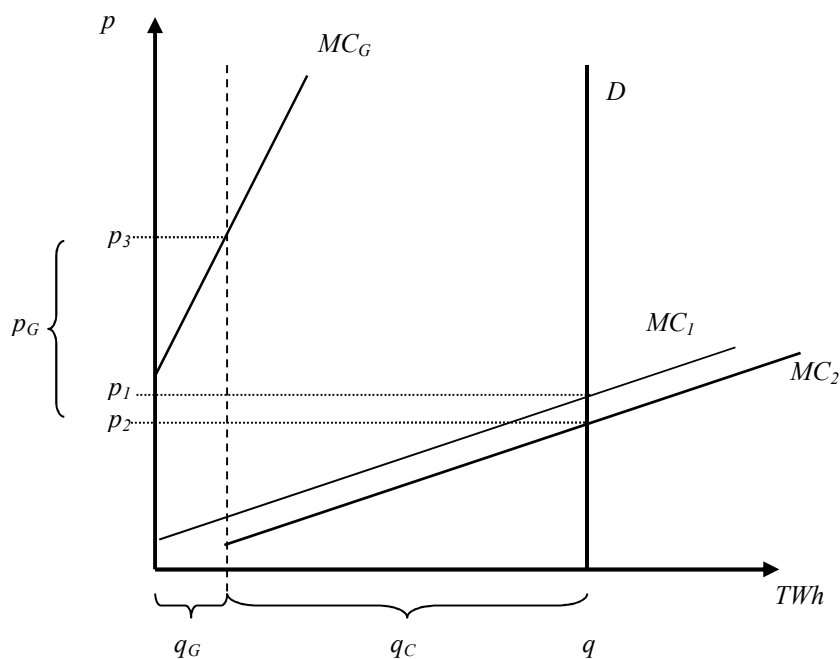


Figure 2. Green electricity certificates

⁹ Similar systems are in used in, *e.g.*, Norway, the UK, Poland, Romania, Italy and Belgium, (EU, 2008)

As Figure 2 is drawn there would be no green electricity without the system¹⁰ and the supply of electricity would be given by MC_1 . Consequently, the competitive electricity price would be p_1 . By milling in q_G units of green electricity the system shifts the supply curve of conventional electricity rightwards to MC_2 . The market price then becomes p_2 , and only q_C units of conventional electricity is produced. Thus, the system reduces the market price on electricity. This is so because it is the most costly conventional power plants that are substituted away in favor of green electricity. In order for q_G units to be produced the price on green electricity must at least be p_3 . Given a market price of p_2 this implies a competitive certificate price equal to $p_G (=p_3-p_2)$. The total expenditures on green electricity ($= p_3 q_G$) is distributed over consumers by a certain fee on electricity consumption, so the consumers end up paying $p_2 + p_G q_G / q$ per electricity unit.¹¹

The formula for our railway project's net-effect on global GHG emissions is still given by (1) and this effect is still to be valued by v_S . However, an increment in electricity consumption will now be met partly by green power plants and partly by conventional ones. So even if the price on the regional (*e.g.*, North-European) power market is set by coal fired plants, the relevant *MEF* contains domestic green power plants. The green certificate system thereby lowers the direct GHG emissions from power production associated with our project. To what extent the system influences the indirect emissions of power production is an open question. As compared to the non-policy case the CBA of our project is affected in two ways: (i) *via* the change in net-emissions and (ii) *via* higher electricity expenditures.

It should be noted that a mandatory system for electricity certificates makes voluntary green contracts insignificant. Such contracts, when leading to investments in green production capacity, will reduce the price on certificates and thereby lead to less investment in green power capacities elsewhere. For a discussion on this topic see *e.g.* Broberg and Brännlund (2010). So, in the presence of a mandatory green electricity

¹⁰ This is because MC_G intercepts the p -axis at a price above p_1 . Thus, the first unit of green electricity costs more to produce than it could be sold for.

¹¹ In principle this consumer price may lie below or above p_1 . However, in practice it is likely to be above. For more about green electricity certificates, see Carlén, Carling and Mandell (2005).

certificate system additional voluntary green power contracts only increases our project's electricity expenditures.¹²

4. Climate Policy Instruments

So far there has been some robustness in the formula constituting the “climate post” in an otherwise perfect CBA of our railway project. The reason behind this is that we so far only have considered second-best responses to the threat of rapid climate changes, *i.e.*, behavior and/or policy measures indirectly affecting parts of GHG emissions, such as voluntary green power contracts and a mandatory system for green electricity certificates. We now add climate-policy instruments to the analytical context. The instruments we consider steer *via* the price on GHG emissions and have the capability of attaining the policy targets cost-effectively.

First we introduce a cap-and-trade system for carbon emissions from electricity production and other energy intensive industries, *i.e.* a policy instrument akin to the European Emission Trading System (EU ETS). Thereafter we add an emission cap also for other GHG emissions. We then have a policy context closely resembling the current climate-policy architecture in EU. Finally, we discuss the effects of our railway project in the presence of a comprehensive global climate treaty of the Kyoto Protocol type.

4.1 Cap-and-trade system covering power production (EU ETS)

A cap-and-trade system sets a cap for the system's aggregate emissions and allocates tradable emission permits to the participating firms. Given compliant behavior, aggregate emissions will equal the cap level irrespectively of how permit trading distributes emissions/abatements amongst the firms. Competitive permit trade allocates abatement efforts in a cost-effective way, *i.e.*, so that the unit cost of further abatements equals the permit price, p_{ETS} .¹³ An immediate implication of this system is that our railway project no longer influences aggregate (direct) emissions from power producers and other firms under the cap. Increased power production now only leads

¹² It should be noted that if the mandatory system's definition of green electricity does not comprise all GHG production technologies, voluntary green electricity contracts may induce additional GHG emission reductions.

¹³ See *e.g.* Dales (1968) and Montgomery (1972).

to that someone else under the cap must abate further. The climate policy effect of our railroad investment now equals $p_{ETS}\sum a_i\Delta kWh_i + v_s[\sum\Delta IE_i + \Delta GHG_{Road} + \Delta IE_{Road}]$. The first term of this expression is included in the electricity price and will therefore appear as an increment of our project's expenditures on electricity. Thus, the climate policy post in an otherwise complete and adequate CBA of our railway project reduces to

$$(2) \quad v_s[\sum\Delta IE_i + (\Delta GHG_{Road} + \Delta IE_{Road})]$$

We no longer have to worry about *MEF* of power production and how to value emissions from electricity production. However, we still need to quantify and value the project's effects on emissions outside the cap-and-trade system.¹⁴ It should be noted that now neither voluntary green power contracts nor the mandatory system of electricity certificates has any effects on GHG emissions. In the present context they would only serve to increase our project's electricity expenditures.

4.2 EU Burden Sharing Agreements

It is often believed that only the emissions from the EU ETS are capped. This is not the case, however. The so-called burden sharing agreement between the EU-15 countries (EC, 1999) allots national quotas to the member states for their GHG emissions during 2008-12. The permit allocations to the EU ETS firms are drawn from these quotas. The remaining part of a member state's quota defines a national cap for the emissions from emitters outside the EU ETS. We subsequently refer to all these non-EU ETS emitters as the other sector (OS).¹⁵ A second agreement (EU, 2009) defines national caps for the member states OS for the period 2013-20. The caps for the OS and the caps for the EU ETS constitute a cap for EU's aggregate emissions for the period up to 2020.¹⁶ Both these agreements allow for inter-

¹⁴ It is possible that some of the emissions we have labeled indirect now materialize under the emission cap, in which case the term $\sum\Delta IE_i$ now is smaller. However, in practice this effect is likely to be small and is henceforth ignored.

¹⁵ Usually, this sector, which broadly comprises transportation, light industry, business and services, is called the non-trading sector. However, as will become obvious below, this is a somewhat misleading terms whereby we instead uses the term OS.

¹⁶ For the year 2020 the two caps sum to 80 per cent of the emission level in 1990. The aggregated cap level may be adjusted if member states and/or firms under the EU ETS trade emission quota units/permits with agents outside the EU, *i.e.*, engage in IET, JI and/or CDM. Given compliance behavior, the former two transactions only reallocate emissions. This stand in contrast to CDM

governmental trade with quota units for the OS. Given well-functioning such quota unit trade there will be an EU-wide price on GHG emissions from the member states' OS.

Most European countries use domestic fuel taxes to control their GHG emissions. Some countries, such as Sweden, have an explicit CO₂ tax. The Swedish carbon tax currently amounts to 1.08 SEK per kg CO₂, which is substantially above p_{ETS} (approx. .20 SEK per kg CO₂) and most estimates of v_G and also v_S (Tol, 2008; Brännlund, 2009). However, since the Swedish carbon tax has dual objectives – to finance public expenditures and to control emissions – we cannot interpret its level as the marginal abatement costs in the Swedish OS. This poses a practical problem for CBAs of our railway project that we return to below.

The shift from road to rail induced by our investment will now not influence the EU's aggregate (direct) GHG emissions. The reason is that the government will either adjust the tax level so that the emissions in the Swedish OS is kept at a constant level or keep the tax level constant whereby some quota units are freed. In the latter case, the government may sell additional quota units to other governments or save them for future use.¹⁷ In both cases revenues are created for Sweden. In the former case, abatement costs are avoided in the Swedish OS. In the latter case, revenues from geographical or inter-temporal emissions trading materialize. For the moment, assume that the revenue of these options are the same (*i.e.*, that the Swedish policy is cost-effective) and let t_{OS} denote this value. The climate policy relevant effect of our railway investment can then be stated as $p_{ETS}\sum a_i \Delta kWh_i + t_{OS}\Delta GHG_{Road} + v_S[\sum \Delta IE_i + \Delta IE_{Road}]$. Since the first two terms are internalized in market prices, the adequate explicit climate post in our CBA reduces to

$$(3) \quad v_S[\sum \Delta IE_i + \Delta IE_{Road}]$$

Now we only have to quantify and value the indirect emissions of our railway project. As indicated above these indirect emissions may be large, especially for bio-fuels. Nevertheless, they are often ignored. It may seem strange that this effect on global emissions should be valued by the domestic (here; Swedish) valuation of reduced risk

projects, which are likely to increase global emission (see *e.g.*, Bohm (1994) and Rosendahl and Strand, 2009).

¹⁷ Only if the government annuls quota units would a global emission reduction materialize. However, such a behavior is not in accordance with an efficiency oriented government.

for rapid and large climate changes. However, as explained above, this is the consistent approach for emissions that is not subject to any international climate treaty.

The market based climate policies we discuss here operate via market prices such that these will be calibrated to reflect the cost of GHG emissions (as it has been defined by political negotiations). These market prices will influence the decisions of individuals and firms and are thus very powerful tools for steering the entire economy in a more “climate friendly” direction. Thus, that the implementation of these climate policy instruments implies that less of our project’s effects related to GHG-emissions require explicit treatment in the CBA should not be interpreted as them being less important.

It should be noted that our railway project may have a climate policy dividend even when not reducing the aggregate demand for emissions. This happens if t_{OS} is sufficiently above p_{ETS} . Then, shifting transport activities from the OS to EU ETS (thereby substituting high-cost abatements with low-cost abatements) will contribute to a more cost-effective climate policy. As noted above, it is not straightforward to interpret the level of the Swedish carbon tax as the marginal abatement cost within the Swedish OS. To arrive at an adequate CBA of our project we need information about to what extent the tax level is motivated by fiscal considerations (*i.e.*, how large the tax would be in the case there would be no climate threat) and which part of it that is motivated by climate concerns.

4.3 A Global Climate Treaty of Kyoto Protocol type.

The world is striving for a global climate treaty. Although some steps have been taken in this direction, e.g., the negotiation of the Kyoto Protocol, the road to such a treaty is by no means straightforward. Nevertheless, let us here assume the existence of a global climate treaty of the Kyoto Protocol type and discuss what it would imply for the CBA of our railway investment.

Now also the indirect emissions of our project will materialize under an emission cap. The aggregate global emissions will thus be unaffected. Our project now only imply that someone else has to undertake further or less abatements, and therefore leads to that abatement costs are incurred or avoided elsewhere. These effects are reflected by the international quota unit price (p_W) under this climate treaty. The climate policy relevant effects of our projects can then be stated as $p_{ETS}\sum a_i \Delta kWh_i + t_{OS}\Delta GHG_{Road} + p_W(\sum \Delta IE_i + \Delta IE_{Road})$. Now also the last term is internalized in market prices and will

therefore appear in various places in a complete and adequate CBA of our railway project. For instance, the initial demand for road transports will be smaller under the current context than under the previous ones. There is therefore no need for a special treatment of GHG emissions in the CBA. Most notable, the planner does not have to assess the environmental cost of GHG emissions.

5. Concluding Remark

We have here discussed principles for assessments of the GHG effects of a railway project that shifts a certain amount of transports from road to rail. Our main message is that the adequate way of considering these effects in an otherwise complete CBA of the project crucially depends on the climate and energy policy context under which the project is undertaken.

In a context with no climate or energy policies at all, the relevant climate post of our railway investment equals the country's unilateral valuation of the projects net-effect on the global GHG emissions. This net-effect consists of the changes in direct and indirect GHG emissions of power production and the change in *dito* for road traffic. The direct emissions from power production should be assessed by the means of the marginal emission factor (*MEF*) of electricity production derived for the relevant regional electricity market, which often is larger than the domestic market. For the Swedish case this amounts to the North European market, at which the marginal power production is coal based.

Voluntary green electricity contracts between the railway operator and power producers may in the long run imply that the project is responsible for less GHG emissions than a traditional *MEF*-assessment would indicate. In the short run such contracts only serve to increase the project's expenditures on electricity. A system of tradable green electricity certificates (of the Swedish type) has three implications in this otherwise non-policy context: (i) the relevant *MEF* now consists of the weighted sum of the marginal plant on the North European power market and the marginal green power plant in Sweden and (ii) the extra cost of green electricity is now included in the consumer price on electricity and (iii) any voluntary purchases of green electricity (over and above the green certificate system) produce no additional green electricity nor emission reductions.

At the other end of the policy-context spectrum we have a comprehensive global climate treaty inducing a uniform price on GHG emissions. In this case, market prices reflect all relevant climate policy effects and there is no need for any specific and explicit treatment of these effects in the CBA of our railway investment. In fact, by doing so we would count the same effect twice. This is not to say that our project of electrifying transportation cannot produce climate policy dividends, only that such dividends automatically and correctly will be considered in the CBA of the project. Such a comprehensive global climate treaty has yet to materialize although some steps have been taken.

The member states of the EU have agreed upon a rather comprehensive regional climate policy treaty consisting of two cap and trade systems – the EU ETS and a system for intergovernmental emission quota trade. Thus for a foreseeable future most emissions within the EU are capped. A railway investment electrifying (part of) the transport sector will therefore give rise to mainly pecuniary effects which existing market prices reflect. Even though the effect on global GHG emissions will be minor, reallocating abatements between the road transport sector and the EU ETS may contribute to a cost-effective fulfillment of the EU's climate policy targets. This would be the case if it is more costly to abate in the former than in the latter sector. Since the relevant effects are internalized in the electricity and fuel prices any such dividends are automatically captured by a comprehensive CBA. An explicit treatment is only called for to the extent the project affects emissions outside EU's emission caps. Example of such emissions is some of the indirect emissions of power production and (bio and fossil) fuel consumptions. To adequately consider these effects a life-cycle-analysis are needed.

The circumstance that less and less of our project's climate policy relevant effects needs explicit consideration by the means of an separate climate post in the CBA should not be interpreted as the threat of rapid climate changes being less prioritized. On the contrary, it is a consequence of effective climate policies being implemented, policies that internalize the value/cost of GHG emissions (as it has been defined by the political system) in market prices. Billions of every-day decisions as well as larger investment decisions are now steered in a more "climate friendly" direction.

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