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Influence of Changes in CO_2 and Investment Costs on the Benefit-Cost-Ratio of Transport Infrastructure Projects

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Abstract

The German Bundesverkehrswegeplan (BVWP) is the national transport infrastructure assessment. It is done approximately every 15 years. One central part of it is a benefit-cost analysis (BCA) for each project. The last Bundesverkehrswegeplan (BVWP) is from 2016, and its methodology and cost factors bases on the year 2012. Since this time, there is a significant change in the cost factors for e.g., carbon dioxide (CO_2)-prices, driven by the goal of climate neutrality by 2045/2050 in the European Union (EU). In this study, we recalculate the benefit-cost analysis (BCA) of the national transport infrastructure assessment using a more current CO_2-price, as well as updated investments costs for the projects, and analyze the effects on the project's assessment. Additionally, we include further cases to illustrate even more advanced (higher) pricing / cost schemes.

We found that the selected price of the CO_2 emissions as well as the development of the investment costs have a significant influence on the project's assessment. When changing only one of the two investigated effects (CO_2-price OR investment costs) will cause 11% to 28% of the projects to fall under the threshold of benefit-cost ratio (BCR) equals 1. Not realizing these projects would save 6% to 34% of the overall investment costs and 8% to 33% of the additional annual CO_2 emissions. When considering both effects, the changes will be even more significant, with 25% – 46% of the projects falling to BCR < 1. Discarding them safes between 20% and 51% of the investment costs and reduces the annual CO_2 impact of the plan by 20% to 53%.

Keywords: infrastructure; CO_2; benefit-cost analysis; BVWP

1. Introduction

Motivation. At the *Conference of the Parties to the United Nations Framework Convention on Climate Change* in Paris 2015, the participating countries agreed to limit global warming to below 2°C above pre-industrial level (United Nations, 2015). In 2019, the European Commission agreed on the *European Green Deal*, achieving zero net Greenhouse Gas (GHG) by 2050. This is translated to the target to reduce the emissions from transport by 90% by 2050

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(European Commision, 2019). Germany has, as many other countries, its *Climate Action Plan 2050*, aiming to reduce GHG-emissions from the transport sector by 40% by 2030 compared to 1990 (BMUB, 2016).

Research objective. Every approximately 15 years, Germany undertakes a national transport infrastructure assessment, called Bundesverkehrswegeplan (BVWP). The last such assessment is from 2016; it is named Bundesverkehrswegeplan 2030 (BVWP 2030) after its target year. It covers roads, railroads, and waterways, and includes extensions of existing infrastructure as well as new infrastructures (BMVI, 2016). As part of the preparation of the BVWP 2030, the projects were assessed using a defined methodology (PTV et al., 2016). The results are published in a web-based project information system (Projektinformationssystem (PRINS); see BMDV, 2024b). For each project, the following information is provided:

- General information about the project, such a project type, length, informational maps, etc.
- Physical impact of the project, such as changes in Vehicle Kilometers (*vkm*s) or emissions.
- Intermediate and final results of a benefit-cost analysis (BCA).
- other non-monetized criteria, such as additional environmental impacts or – if relevant – changes regarding the spatial and/or urban planning

The resulting benefit-cost ratio (BCR) is used as input for the political decision; it is, however, not the only criterion. Still, projects with a BCR< 1 face much larger difficulties of realization. According to this project information, almost all street projects lead to an increase in carbon dioxide (CO_2) emissions. So it is questionable if all of them should be realized.

2. Methodology

We extracted all relevant data for all motorway projects from the web-based project information system (PRINS; see BMDV, 2024b): In total, 221 projects with approx. 7,560 lane-km are planned to be added to the system; this compares to a current size of the system of about 61,000 lane-km (BMDV, 2024a). According to BMDV (2024b), these projects are expected to add, to the already existing 237,300 million *vkm* (in 2022 BMDV, 2024c) on motorways, an amount of approx. 1,139 million additional *vkm* (cars: 1,055 mio; trucks: 84 mio) , albeit that number is contested as being too low (see discussion, Section 6). The investment costs for all these projects will sum up to €26,607 millions.

Based on the extracted values, we recalculate the BCR for changes of the CO_2-price, and the investment costs, as described more in the following. We are interested in the influence on the project plan: how sensitive do the project evaluations react to these changes? How many projects will fall to BCR< 1? What amount of CO_2-emissions can be saved by not realizing those projects? What investment costs can be saved when discarding them?

CO2-price. The assessment method for the BVWP 2030 from 2012 uses a CO_2-price of € 145 (PTV et al., 2016). Following more current data, like Umweltbundesamt (2020), the value for the year 2020 should be € 700, which is an increase by about a factor of four within less than a decade. In this study, we are updating the BCA calculation, using the new CO_2-price, and then analyze the effects on the project assessment. One might argue that approaching net-zero emission, the price might even be significantly higher. To illustrate such a development, we also investigate what happens with a price of € 2000.

In a BCA, all the prices must be consistent with each other. For this, we financially convert the € 700 from 2020 to 2012. For this, we use the consumer prices in Germany, which were 8.3% lower in 2012 compared to 2020 (Destatis, 2024). Taking this into account, € 700 in 2020 is equivalent to € $700 \cdot 0.917 \approx$ € 642 (cost state 2012), which we will use in our calculation.

Our analysis includes emissions from the usage of the infrastructure (vehicles energy consumption) as well as from building and maintaining the infrastructure itself.

Investment costs. Investment costs have risen significantly since 2012. Due to the direct influence of investment costs on the BCR, this is particularly "critical" for projects that were already only just economically viable according to previous planning.

Based on the simple formula for the BCR

$$BCR = \frac{B}{C} \quad \text{, with } B\text{: Benefits and } C\text{: Costs}$$

it is clear that, e.g., doubling the costs ($2 \cdot C$) leads to a revised BCR^* that is half as high:

$$BCR^* = \frac{B}{2 \cdot C} = \frac{1}{2}\frac{B}{C} = \frac{1}{2}BCR$$

This means that all projects with an original BCR < 2 lose their profitability just because the investment costs are doubled. In our study, we will consider the following three cases:

1. Updated project-specific investment costs by BMDV (2023)
2. An increase in investment costs by 50% for all projects (*invcosts150*).
3. An increase in investment costs by 100% for all projects (*invcosts200*).

3. Calculation 1: Updated CO2-price

As described in Section 2, we evaluate the influence of an price of €700 and €2000 per ton of CO_2.
Recalculating the BCR based on the changed CO_2-prices leads to the following results.

- A price increase to *€700* leads to
    1. A notable decrease in the BCR of nearly all projects (see Figure 1 (top)).
    2. 25 of the 221 motorway projects (-11.3 %) are no longer profitable (BCR below 1).
    3. Not implementing these projects would save 132,970 tons of CO_2 per year (-8.3%) and €1,514 millions in total investment costs (-5.7%).
- A significantly more increased of price of *€2000* leads to
    1. A drastically stronger decrease in the BCR of nearly all projects (see Figure 1 (bottom)).
    2. 62 of the 221 motorway projects (-28.1 %) are no longer profitable (BCR below 1).
    3. Not implementing these projects would save 522,241 tons of CO_2 per year (-32.7%) and €6,841 millions in investment costs (-25.7%).

4. Calculation 2: changed investment costs

As described in Section 2, we evaluate the influence of different investment costs for the projects: n project-specific updated price list, an increase for all project by +50%, and one by +100%. Very obviously, the BCR will fall when the investment costs increases. Table 1 summarizes the main results compared to the original data. The result for the **project-specific list** and the **increase by 50%** are comparable, with over 30 projects falling to BCR < 1. Also, the investment costs saved (approx. €4,000 millions) and the annual saving on CO_2 emissions (approx. 200,000 tons/year) are roughly the same .In case that the investment costs for all projects are **doubled**, the impact is much higher: 58 projects with a financial volume of €8,959 millions and 423,375 tons of CO_2 emissions per year fall to BCR < 1. This is roughly twice the impact on these key figures.

Case	# of projects		Investment costs saved (Mio. EUR)		CO2-emissions saved (t/a)	
	change abs.	change rel.	change abs.	change rel.	change abs.	change rel.
invcostTud	-31	-14.0%	-3,827	-14.4%	-189,028	-11.8%
invcost150	-35	-15.8%	-4,486	-16.9%	-211,453	-13.2%
invcost200	-58	-26.2%	-8,959	-33.7%	-423,375	-26.5%

Table 1: Results with **changed investment costs** of the projects (updated list, +50%, and +100%): number of projects, sum of investment costs and CO_2-emissions of all projects which lost their profitability by falling to BCR < 1. The relative share is compared to all projects included in this analysis.

Figure 2 shows the changes of the BCR of all projects compared to the original value. For the project-specific changes (Figure 2 TOP), we see that most projects will receive a lower BCR, while some projects even get an increased BCR. We also see that some project's BCR is also reduced by the same factor.

Figure 2 (Bottom) shows the reduction of the BCR by the same factor for all projects. Both factors are shown: +50% (blue) and +100% (red).

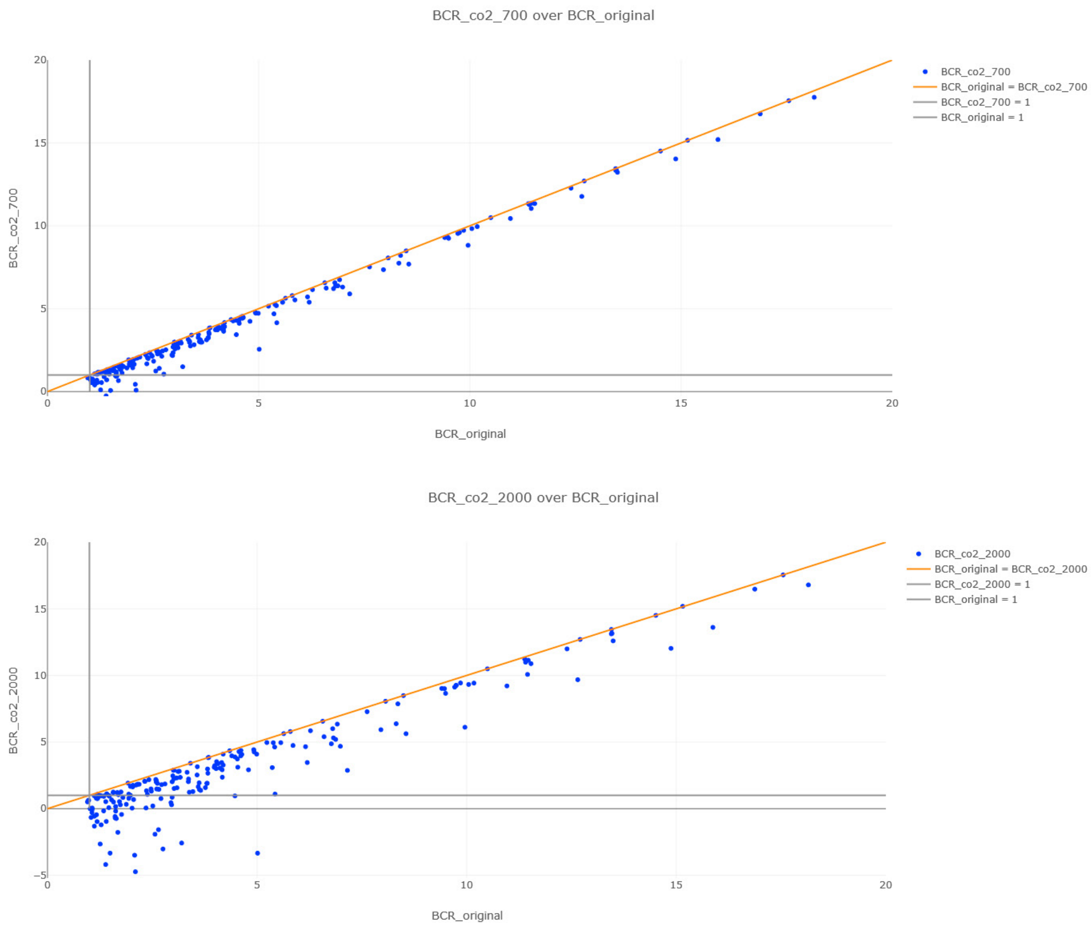

Fig. 1: The BCR calculated based on the **increased** CO_2 **price** over the original BCR (€145). The orange line shows the equality of both values, while the gray lines are the critical value of BCR equals 1; TOP: The increased CO_2 price of *€700*: Most projects remain above this critical value – and most of those ending up below one are already in a low-priority category. BOTTOM: The increased CO_2 price of *€2000*: The effect becomes quite noticeable, and a larger number of projects slides below the critical value.

5. Calculation 3: Combining updated CO2-price and increased investment costs

As shown in Sections 3 and 4, both changes influence the BCR already on their own. But in reality, there is a high probability that the CO_2-price and the investment costs will change both in parallel. Therefore, we are providing a sensitivity study with all possible combinations. This adds six cases. The results of the six additional cases are shown in Table 2. The changes of the BCR for the three additional cases with a CO_2-price of €700 is visualized in Figure 3, while Figure 4 shows it for the three additional cases with a CO_2-price of €2000.

The combination of both effects leads, as expected, to a significant increase in projects falling to BCR < 1. For a CO_2-price of **€700** per ton, the number of these projects increases from 25 (original investment costs) up to 72 (doubled investment costs). For a CO_2-price of **€2,000** per ton, it increases from 62 (original investment costs) up to 101 (doubled investment costs).

When looking at the changed investment costs, we can observe an increase of such projects from 31 (original CO_2-price) to 84 (€2000 per ton). Again, the cases with the project-specific updated price list and the case with 50% higher investment costs for all projects are very similar in terms of number of projects, saved investment costs and saved CO_2 emissions on the plan level. With doubling the investment costs, the effect of an additional increase in the

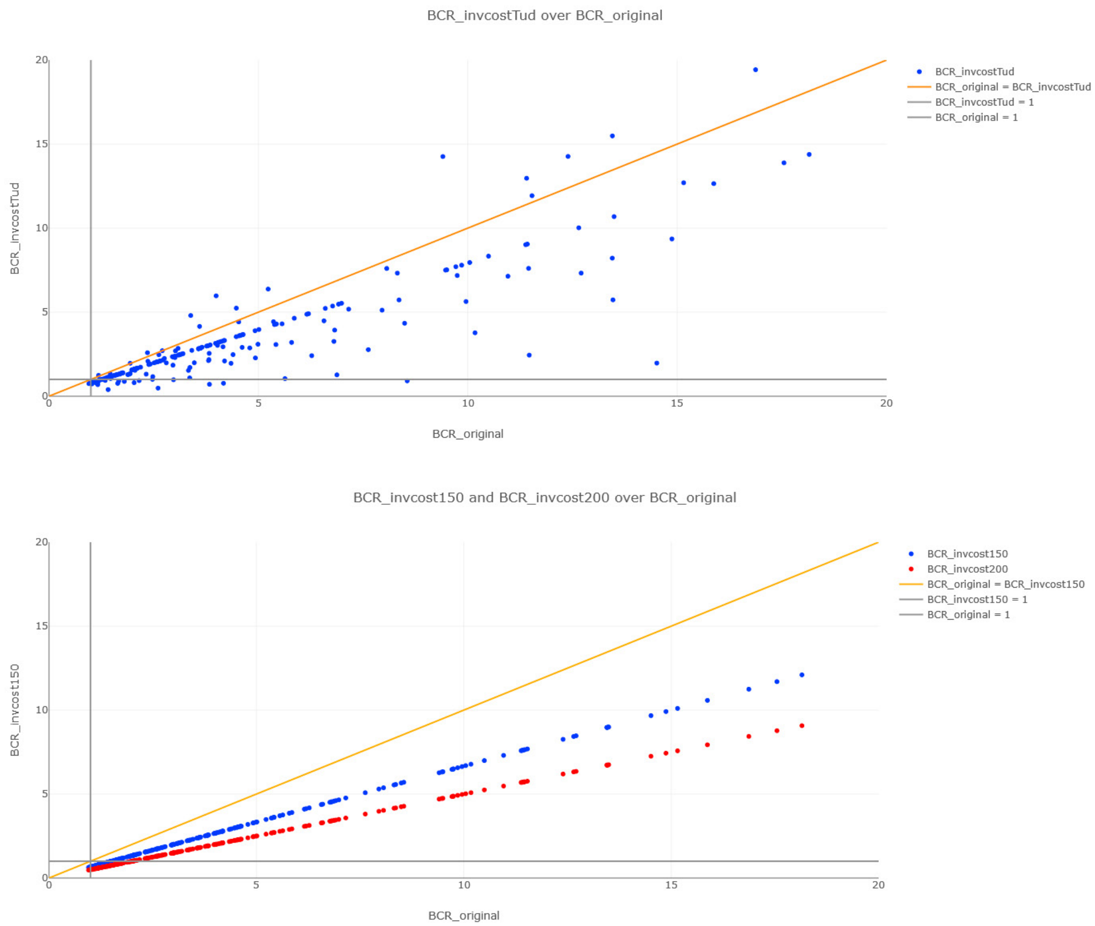

Fig. 2: The BCR calculated based on the increased investment costs over the original BCR. The orange line shows the equality of both values, while the gray lines are the critical value of BCR equals 1; TOP: The project-specific changed investment costs based on the data of BMDV (2023) : Most projects remain above this critical value – and most of those ending up below one are already in a low-priority category. BOTTOM: increased investment costs for ALL projects: +50% (BLUE) and +100% (RED). The BCR of all projects is significantly reduced. Thus, a noticeable number of projects end up with a value below 1 and another significant number of projects drop to the region of one. A higher increase in investment costs results in a lower BCR.

Case	# of projects		Investment costs saved (Mio. EUR)		CO2-emissions saved (t/a)	
	change abs.	change rel.	change abs.	change rel.	change abs.	change rel.
co2_700_invcostTud	-56	-25.3%	-5,200	-19.5%	-313,634	-19.6%
co2_700_invcost150	-56	-25.3%	-5,932	-22.3%	-355,996	-22.3%
co2_700_invcost200	-72	-32.6%	-10,570	-39.7%	-582,947	-36.5%
co2_2000_invcostTud	-84	-38.0%	-11,346	-42.6%	-696,130	-43.5%
co2_2000_invcost150	-83	-37.6%	-11,642	-43.8%	-725,442	-45.4%
co2_2000_invcost200	-101	-45.7%	-13,570	-51.0%	-843,685	-52.8%

Table 2: Results of the combination of both CO_2 prices (€700 and €2000), with changed investment costs of the projects (updated list, +50%, and +100%.): number of projects, sum of investment costs and CO_2-emissions of all projects which lost their profitability by falling to BCR < 1. The relative share is compared to all projects included in this analysis.

CO_2 price increases the number of projects with BCR < 1 from 62 (original CO_2 price) to 101 (€2000 per ton). That is almost half of all projects.

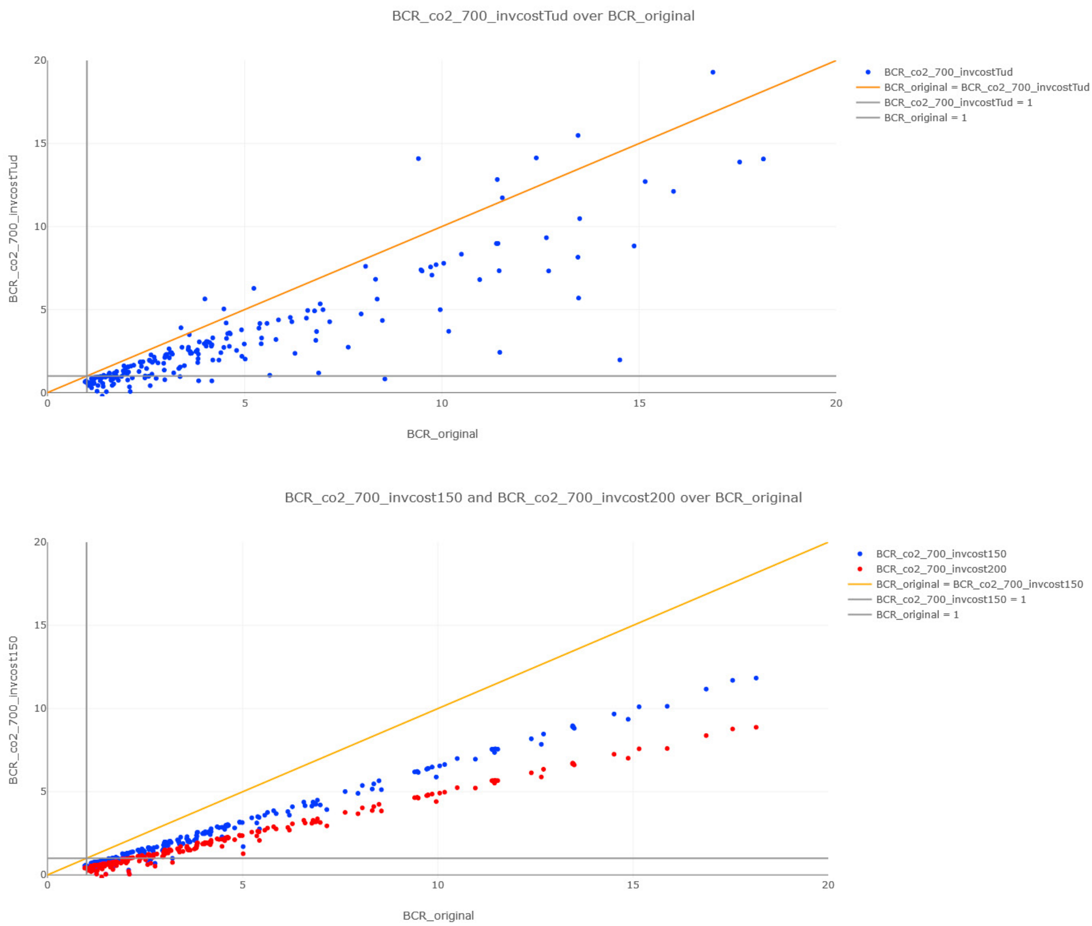

Fig. 3: The BCR calculated based on an increased CO_2 price of €700 AND the increased investment costs over the original BCR. The orange line shows the equality of both values, while the gray lines are the critical value of BCR equals 1; TOP: Project-specific changed investment costs based on the data of BMDV (2023) BOTTOM: increased investment costs for ALL projects: +50% (BLUE) and +100% (RED).

6. Discussion

Some more general points to mention are:

1. The original data set already contains 3 projects where the costs exceed the benefits. However, their rounded BCR value was 1.0, so that this was obviously not noticed. These three projects are responsible for 19,632 million tons of CO_2 per year and costs of €419 millions.
2. Heyl (2023) notices that the additional *vkm*s travelled in the BVWP 2030 are underestimated for the construction of more infrastructure. At present, we would basically follow this argument. However, our current assessment is that the underestimation is less severe than assumed by Heyl (2023). Nonetheless, more traffic also leads directly to more CO_2 emissions, which – especially in combination with a higher CO_2 price – leads to a further decline in project benefits.
3. Currently not considered is that in the future more and more non-fossil vehicles will drive around, leading to less exhaust emissions. However, even with non-fossil vehicles, some *non-exhaust* emissions remain (Grigoratos and Martini, 2014; INFRAS, 2019).
4. Even if the environmental aspects take up more space in the discussion, it should not be forgotten that in the vast majority of cases their (negative) benefits only account for a small to medium proportion of the benefit components – especially compared to the positive benefits from time savings.

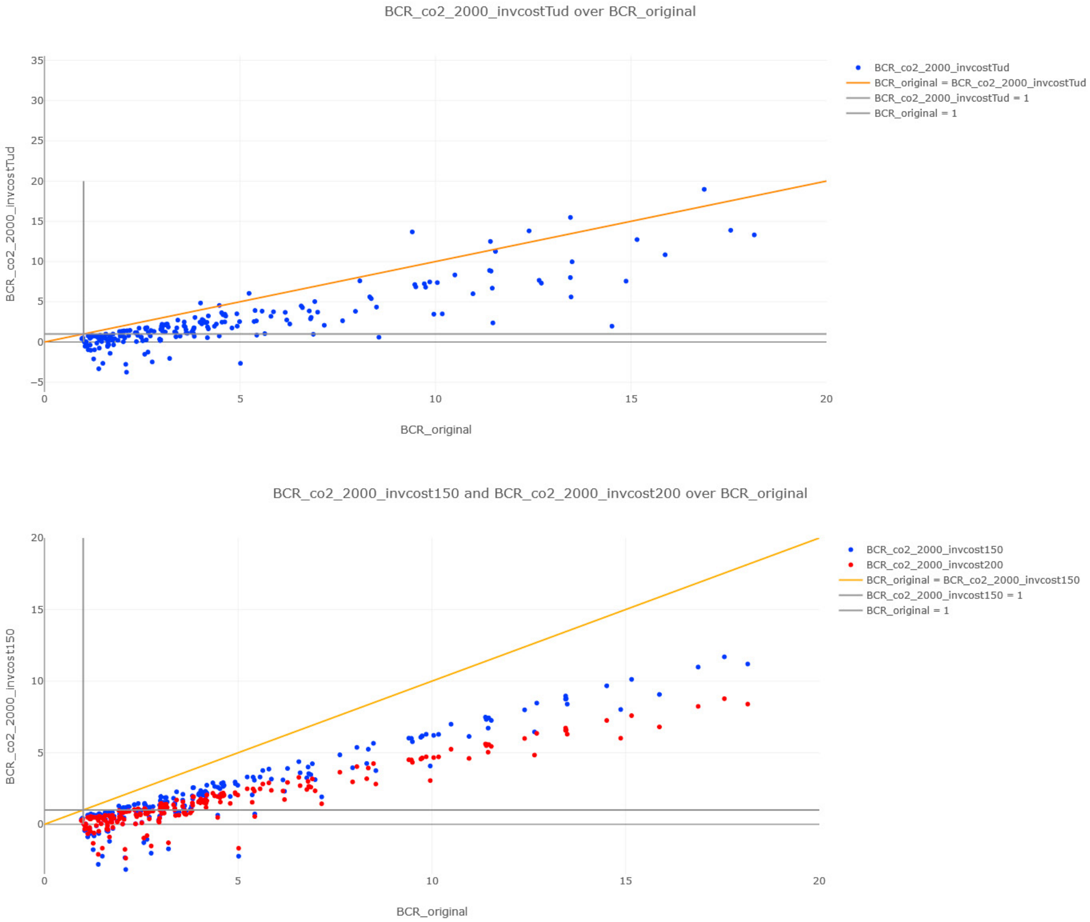

Fig. 4: The BCR calculated based on an increased CO_2 price of €2000 AND the increased investment costs over the original BCR. The orange line shows the equality of both values, while the gray lines are the critical value of BCR equals 1; TOP: Project-specific changed investment costs based on the data of BMDV (2023) BOTTOM: increased investment costs for ALL projects: +50% (BLUE) and +100% (RED).

5. BVWP 2030 is computed with a discount rate of 1.7%. This means that costs and benefits in future years are "discounted down" compared to costs and benefits in the base year. One option to obtain a discount rate for economic assessment is to use the social time preference rate (STPR), which is the sum of the pure time preference rate (PTPR) and a term that balances marginal utility gains from spending at different prosperity levels (Beckers et al., 2009). The 700 Eu/t are computed with an STPR of 1% (Umweltbundesamt, 2020), which is inconsistent with BVWP 2030's 1.7%. To bring them in line one could argue that for long-term damages, such as those by carbon emissions, the PTPR should be set to a lower value than for short-term costs and benefits.

7. Conclusion and Outlook

In this study we present the influence of an increased price on CO_2 emissions, as well as an increase in the investment costs, on the BCR of Germany's national transport infrastructure assessment (Bundesverkehrswegeplan (BVWP)). We focus on the motorway projects. The BCR is important for the decision if a project gets realized or not.

We find that changing only one of the two investigated effects will cause 11% to 28% of the projects to fall under the threshold of BCR equals 1. Not realizing these projects would save 6% to 34% of the overall investment costs and 8% to 33% of the annual CO_2 emissions. When considering both effects, the changes will be even more significant, with 25% – 46% of the projects falling to BCR $<$ 1. Discarding them saves between 20 and 51% of the investment costs and reduces the annual CO_2 impact of the plan by 20% to 53%. Another more general result is that the relative changes in saved CO_2 emissions are in most investigated cases similar to the relative changes of the saved investment costs.

We conclude that the selected price of the CO_2 emissions as well as the development of the investment costs have a significant influence on the project's assessment. Besides, e.g., taking a deeper view on the structure of affected projects, there are other aspects, as discussed in Section 6, to look at in further research activities.

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