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Addressing rebound effects in transport policy – Insights from exploring five case studies

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ABSTRACT

Although rebound effects are well-known as a phenomenon, the question of how to avoid and minimize rebound effects have largely been ignored in practical policy. In this study, five concrete cases of measures and policies in the transport sector illustrate primary effects, rebound effects and possible strategies to avoid or minimize rebound effects. The cases were explored and analyzed in a series of workshops involving in total 15 researchers and societal actors. In addition to the net impact of primary and rebound effects, factors such as the time horizon and the reversibility of the effect may also be important for the evaluation of measures and policies. To detect and avoid rebound effects – and to assess the effectiveness of a policy – a system perspective is needed rather than a narrow sector focus. When designing measures, broad system-wide strategies or specific measures addressing particularly emission-intensive activities tend to be most effective for avoiding rebound.

1. Introduction

In 2019 transport accounted for 23% of global energy related CO2 emissions (IEA, 2020). To reach climate targets in line with, *e.g.* the Paris agreement, these emissions must be substantially reduced. More energy-efficient cars, policy instruments for reduced road traffic and technologies facilitating digital communication are examples of measures that have the potential to lower GHG emissions related to mobility. However, such measures may also induce rebound effects - a type of secondary effects of policies or measures that generally reduce the primary and positive effects of these (Herring and Sorrell, 2009).

The magnitude of rebound effects has been widely studied and may vary from insignificant to more than 100% of the primary effect (Ackerman and Stanton, 2013; Chitnis et al., 2014). Significant rebound effects are common also in the area of transportation . Although the importance of rebound effects is well established in research, they are mostly ignored in practical policy making and societal planning (Sorrel 2007; Levett 2009; Font Vivanco et al., 2015; Font Vivanco et al., 2016a; Brockway et al., 2017). Taking rebound effects into account in transport policy and planning is important to ensure that desired targets – for example, reduced GHG emissions – are actually achieved. There is thus a need to study rebound effects in relation to policy and to probe into the possibilities to direct policy and strategies to avoid or minimize rebound effects in concrete policy situations.

In this paper, we therefore explore the question: What strategies and policy instruments can be used in policy practice to avoid and minimize rebound effects within the Swedish transport sector? This is done by exploring five different case studies with regard to the occurrence of rebound effects and factors that influence their significance. The case studies were selected and designed to reflect, and make it possible to demonstrate and discuss a wide array of different strategies to reduce GHG emissions from the transport sector in Sweden. These involved both current strategies, such as policy instruments for promoting electric cars and the Swedish aviation tax, as well as possible future strategies that have been proposed but never implemented, such as a cap on emissions from private travel. The cases were iteratively analyzed in a series of workshops involving researchers and societal actors. As a first step, the analysis of the cases involved identifying potentially important rebound effects in each different case. This relates to the drivers of, and possible magnitude of, rebound effects as well as other aspects that may be of importance, such as the temporality and reversibility of different effects.

Strategies are in the study primarily seen from a planner's perspective – to gain knowledge about what kind of policy instruments that may substantially reduce GHG emissions, considering both direct effects and rebound effects.

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In Section 2 we describe the principles behind the occurrence of rebound effects and present definitions of different categories of rebound effects that will be used later. Section 2 also presents previous research quantifying different types of rebound effects as well as research about strategies to avoid or minimize rebound effects in policy planning. In Section 3 we provide a description of our methodology. Section 4 presents our results, in Section 5 we discuss our results and finally Section 6 summarizes our conclusions.

2. Rebound effects

2.1. Definitions and mechanisms

Common to all rebound effects is that individuals or society as a whole increase any of their activities, and thereby the related emissions, in response to something that should primarily lead to reduced activity and emissions. The net effect of a policy or measure may then be a lower emission reduction than anticipated (partial rebound), or even that emissions increase (backfire). The classic example was given by Jevons already in the 19th century (Jevons, 1866) when he showed that making a product more fuel efficient may technically decrease the need for fuel, but in reality it generally increases the demand, since the cheaper product appeals to more people and more areas of use. Subsidizing green technology and making rationalizations and effectivizations to products and services may thus stimulate increased consumption either of this service or product, or of other services and goods due to cost savings (van den Bergh, 2011). Time savings can have similar consequences as cost savings (Jalas, 2009). In addition to mechanisms based on economy or time use, rebound effects have also been described from a psychological perspective (Peters and Dütschke, 2016). Rebound effects can occur as a result of efficiency measures as well as constraints (voluntary or imposed) that at first seem to prevent the use of some resource (Alcott 2008; Buhl and Acosta, 2016). At the societal level, increasing efficiency tends to stimulate an overall increase in production and consumption of goods and services (Birol and Keppler, 2000; Ayres and Warr, 2009).

There are several definitions and classifications of rebound effects in the literature (see e.g. Börjesson Rivera et al., 2014; Santarius, 2016; Freeman, 2018). In this study we will use the following classification:

Direct rebound effects occur when the activity, emission or usage that was supposed to be reduced by some measure does not decrease as much as the measure should technically entail, or even increases. An example is when technological innovation makes cars more fuel-efficient, but overall fuel consumption increases as people drive more, buy more cars, bigger cars, or cars with more features than before.

Indirect rebound effects occur when the activity, emission or usage that was supposed to be reduced by some measure actually decreases, but the same actor increases its consumption of another good or service so that other impacts (activity, emissions, usage) increase. This often happens when the consumption and environmental effects move from that which was addressed by the measure (and which was reduced) to something else as a result of cost savings (income effect). An example is when car owners are incentivized to instead join a carpool. Such stimulation may indeed lead to less driving, but costs saved by these individuals may be spent on, e.g., air travel or increased consumption of goods.

A third category, albeit vaguely defined in literature, is called economy-wide rebound effects. These may either comprise the sum of direct and indirect rebound effects at the societal level, or may also include completely different effects that arise when different actors interact. We define *interactive rebound effects* as cases where actors other than those directly influenced by a specific measure are affected in a way that stimulates increased resource consumption and negative environmental impacts. They could e.g. occur if reduced demand for energy in one sector results in lower energy prices, which stimulates demand in another sector; or if GHG reduction policies reduce traffic congestion, which in turn reduces disincentives to drive and partially increases car traffic. This type of rebound effect is less immediate and may happen in several steps.

Common to all rebound effects according to our definitions is that they operate in the opposite direction to the impact category that the primary effect refers to. That is, if the primary effect is reduced energy use or reduced GHG emissions, then a rebound effect means increased energy use or increased GHG emissions, that partly or completely counteracts the primary effect. If effects occur in a category other than the primary effect, for example increased use of chemicals or increased congestion, we call it a *side effect*.

2.2. Quantification of rebound effects

While the particular cases we discuss in this paper have not previously been examined with regards to rebound effects, in this section we provide examples of studies quantifying different types of rebound effects in other or similar contexts, in order to facilitate an understanding of the importance of rebound effects and to put our case studies in perspective.

Rebound effects can be investigated, for example, through econometric studies using demand models or general equilibrium models (Ackerman and Stanton, 2013; Murray, 2013; Chitnis et al., 2014). The following examples are given to illustrate magnitudes of rebound effects in real situations in general and in the transport sector in particular.

In one study, indirect rebound effects as a result of voluntary reduction of car use were reported to be about 20% (Murray, 2013). This means that 80% of the GHG reduction remained after accounting for the rebound effects. Another study found rebound effects of reduced fuel consumption in vehicles to be 25–65% (Chitnis et al., 2014). Font Vivanco et al. (2015) found in a scenario modeling study that out of seven innovations studied, only three gave a positive environmental net effect at the system level. The direct and indirect rebound effects in other cases were so large that the overall environmental effect was negative. The three innovations that gave positive results were direct-injection engines, park-and-ride facilities and catalytic converters. Car sharing, bicycle sharing, high-speed trains and diesel engines instead gave an increased environmental impact. The main variables to explain the magnitude of rebound effects are the change in income due to the innovation and the difference in environmental pressure per monetary unit for the studied activity and alternative consumption (Font Vivanco et al., 2015). Hennessy and Tol (2011) studied a tax reform in Ireland that led to a shift from petrol to diesel cars. This was estimated to give rebound effects of 37–61% as a result of lower fuel costs that led to longer driving distances. In a broader literature study, van den Bergh (2017) finds that the majority of studies on interactive[1] rebound effects suggest "[…] overall rebound is above 50% and possibly much higher." (p. 804). A recent review however points to rebound of around 10% in a context of fuel economy standards in the United States (Gillingham 2020). In relation to our specific cases of policies in a Swedish context (see section 3, Table 3), no estimates are available in literature.

Font Vivanco et al. (2016a) investigated how rebound effects have been treated in policy making in the EU and found that rebound effects are mentioned as early as the 1990s in official documents. In 1996, for example, the risk of rebound effects in the form of increased material consumption as a result of developments in information and communication technology was mentioned in a communication from the European Commission (CEC, 1996). Thereafter, however, rebound effects have been ignored for a long period to return to the agenda only a decade later. The authors argue that the complexity of the issue, and the scientific disagreement over definitions and levels of rebound effects, are some of the reasons why they have been ignored in legislation and practical policy work.

[1] van den Bergh (2017) uses the term economy-wide rebound effect, which we classify as "interactive rebound effect".

The literature on policy strategies for mitigating rebound effects is limited. Font Vivanco et al. (2016a) maintain that knowledge of possible policy pathways to mitigate or reduce rebound effects is still deficient, but refer to the following three general pathways: (1) increases in environmental efficiency across consumption sectors, (2) shifts to greener consumption patterns and (3) down-sizing consumption.

Several studies conclude that combinations of instruments that steer toward the same goal are necessary to manage rebound effects (Vieira et al., 2007; Christensen et al., 2007; Maxwell et al., 2011; Stelling 2014; Klumpp 2016; Font Vivanco et al., 2016b; Shove 2017). The fact that the design of policy instruments must be carefully adapted to the situation in order to avoid, for example, unwanted distributional effects is also emphasized. Maxwell et al. (2011) list the following evidence-based measures to address rebound effects in the design of both instruments and measures: (1) recognizing and accounting for rebound effects in the design and evaluation of policy, (2) use of an integrated mixture of instruments encompassing fiscal, behavioral and technology instruments, (3) sustainable lifestyles and behavior change among consumers, and (4) awareness raising and education for leveraging behavior change in business. In relation to our case studies presented below, we found the frameworks for problem formulation and policy principles presented by Jensen et al. (2019) and Levett (2009) particularly useful. Below, we give an overview of these frameworks.

2.3. Problem formulation and policy principles

Jensen et al. (2019) reviewed 1067 initiatives for sustainable residential energy use implemented in Europe. Based on previous research a typology was developed and the initiatives were categorized according to the underlying problem formulation behind the initiatives and their proposed solutions. How problems are formulated is crucial, as each problem formulation comes with its own assumptions and solutions, and sets the framework for the type of change that is possible. In our analysis, we will categorize our case studies according to Table 1.

Levett (2009) specifically addresses how rebound effects and other feedback effects can be managed and avoided in policy making. Since rebound effects result from complex system interaction, he suggests that it is necessary to focus efforts on managing exactly how systems work and start controlling system interactions and feedback loops. Levett therefore outlines a number of ‘systems literate’ policy principles designed to achieve effective governance and to achieve environmental and climate goals (Table 2). We will examine whether or not these principles are applicable to our case studies.

Table 1
Typology and examples of underlying problem formulations in sustainable energy consumption initiatives. Adapted from Jensen et al. (2019).

Category	Description	Typical measures
Changes in technology	This problem framing assumes that changing levels in energy use is a matter of technological change	Optimizing technology; information of technical performance of products; legal requirements; economic incentives for technology change
Changes in individual behavior	This problem framing assumes that changing levels of energy use is a matter of changing individuals’ behavior in terms their (personal) energy use, and their attitudes and choices related to energy efficiency	Information campaigns; education; coaching; financial incentives for behavior change
Changes in everyday-life situations	This problem framing assumes that changing levels of energy use is a matter of changing material components, images/norms and competences related to specific areas of daily life.	Co-creative methods; living-labs/neighborhood experiments. Information is often a part of the measure, but always in combination with other measures
Changes in complex interactions	This problem framing assumes that changing levels of energy use is a matter of changing complex interactions between several areas of household related activities, professions and sectors. This includes assuming that ‘social organization’ is the key target for change, and that water, heat and energy consumption happens because of certain ways of organizing daily life across domains, sectors and practices.	Bundled measures (e.g. legal, economic, co-creative methods, pilot- and policy experiments, information campaigns etc.) targeting the functioning of markets as well as the incentives and social norms of individuals, households, professions and societal sectors that set the frames for the type of energy use in focus.

3. Methodology

The methodology used is built around the co-created and explorative analysis of a number of case studies, designed to be examples of very different policy strategies (described in more detail below). We used this methodology as a way of analyzing rebound effects as an outcome of different kinds of policy interventions, and ways of minimizing them by policy design. As further described below, we have mainly analyzed rebound effects and policy choices qualitatively, supported by insights and theoretical frameworks on environmental policy design, and by empirical literature on rebound effects and policy. The cases were analyzed iteratively by the author group and a larger group of experts in a series of workshops (Fig. 1). In the results and discussion sections, we develop reasoning and argumentation about how we arrived at our assessments and conclusions.

The choice of methodology and study design draws upon insights from the literature of reflective governance for sustainable development that stresses the need for heterogenous perspectives; co-produced knowledge including tacit and practical insights from societal actors; and the importance of acknowledging and accepting complexity and uncertainty in both problem analysis and practical action for sustainability (Voss et al., 2006). The study design is also built on insights from future studies and backcasting methodology (Höjer et al., 2011) as well as the sheer necessity of constructing cases to study, when no real empirical cases exist of all relevant policy strategies to minimize GHG emissions in the transport sector.

Based on definitions and theories from literature about rebound effects and policy strategies to avoid them presented in the previous section, five case studies were designed and developed in order to represent a variety of important aspects related to our research question. Each case study was based on measures and strategies to reduce GHG emissions from transport (in Sweden) and they were intended to differ in scope and complexity and make it possible to practically explore and discuss different strategies to handle rebound effects in the transport sector in a manner that is close to reality and policy practice (Table 3). We intended our cases to illustrate common policy strategies as economic incentives of wanted behavior/technology, economic disincentives for unwanted behaviors (broad and small system scope), norm and behavior change by combined technology and policy changes, and regulation. But since we wanted to stay close to reality we tried to select suitable policy cases currently in use: as the policy case for promoting electric cars and the Swedish aviation tax. However, to include the possibility to also explore and analyze the potential of the policy strategies that have been proposed, but not ever implemented, the cases of Major green tax-switching and A cap on emissions from private travel were formulated.

The cases were analyzed with respect to different aspects in a series of three workshops involving between 8 and 12 persons in addition to the authors. The workshops were conducted between November 2019 and May 2020. Each workshop lasted around 3 h and the final workshop was held online due to the ongoing COVID-19 pandemic. Following general principles of purposeful sampling (e.g. Palinkas et al., 2015) the

Table 2
'Systems literate' policy principle, following Levett (2009).

1. Avoid encouraging unwanted feedbacks.
For example, refrain from providing additional parking or road capacity to avoid congestion, as this only leads to more traffic, and in the long run more congestion.
2. Forestall or neutralize unwanted feedbacks at source.
For example, raise the cost of energy at the same rate that efficiency is being improved, so that the system effect from increased efficiency does not increase consumption of electricity. It is pointed out that there may be practical or redistributive policy challenges in this strategy, but the broader point remains valid for counteracting rebound.
3. Use taxes (and other economic instruments) to tilt the playing field in favor of desirable feedbacks and against undesirable ones.
An example is to consider cost structures, and that it may be preferable to shift the costs off owning cars to driving miles, since driving accounts for most of the environmental damage. This may be done, for example, by replacing car taxes by higher fuel taxes, road-user charges or car insurance charged per mile rather than per year. In this way, the incentives are structured so that the desired outcome (less emissions from car traffic) becomes easier and more attractive for people when they make decisions about car ownership/driving.
4. Design commercial and regulatory structures and institutions to align commercial benefit with desired environmental outcomes, and to eliminate perverse feedbacks.
One example is to steer the market towards leasing rather than selling products and thereby replacing the traditional perverse incentive for manufacturers to build in obsolescence with a benign one to maximize product life and minimize resource costs.
5. In designing interventions, start from the desired behavior changes. This requires attention to 'trigger points'.
This principle is about the importance of understanding how people make their decisions, and what will make them adopt more sustainable options. For example, if the fear of getting stranded at work in the event of an unexpectedly late working day – past the time when the buses stop running – is one of the reasons why people avoid commuting collectively to a workplace, a measure may be to offer a guaranteed taxi ride home at such times or to expand the bus schedule.
6. Recognize where virtuous circles are working, avoid unintentionally disrupting them, and give support to keep them functional.
If a city has a vibrant center with urban living, good walking and cycling access and public transport, one should understand that such places can prevent the vicious circles of increasing congestion and degeneration from getting established.

invited participants were selected to represent different areas of expertise or experience of transport planning and environmental policy to provide both theoretical and practical insight to the research question at hand. New participants were invited to each workshop in order to broaden the representation to relevant areas of expertise. In addition to the participants involved we sought representation from the business community, but unfortunately this was not achieved. This has certainly affected the discussions and results, but as we assess it, not in a crucial way. In all, the participants included researchers in sociology, environment, mobility, digitalization, gender, economy and psychology; several representatives from transport authorities and from a municipality; and from a political NGO. Three persons participated in all workshops and in total 15 participants were involved (Table 4).

The cases were described to the participants according to the information in Table 3, and in each workshop a few specific issues were addressed in relation to the cases. We applied an inductive approach trying to be attentive to insights and opportunities emerging in the room and building each step in the process upon the previous (e.g. Eisenhardt et al., 2016). The result of each workshop thus provided input to the next. Before the third workshop two new cases were created that contained aspects that we found particularly relevant that were not represented in the previous case studies (*Major green tax-switching* and *Increased share of electric cars*).

In the first workshop the participants were asked to identify any possible rebound effects that could occur in each of the three presented cases. In addition, the list of possible rebound effects was complemented with rebound effects identified beforehand by the project group and the participants were asked to select the quantitatively most significant rebound effect in each case study according to their views and understanding. The focus of the second workshop was to identify and classify possible measures to counteract rebound effects in the three case studies. The participants were also asked to come up with examples of possible

Table 3
Schematic description of case studies. Cases marked with (*) were only used in the third workshop.

Name of case study	Description
Major green tax-switching *	For the benefit of the environment a major tax-switching takes place to change patterns of production and consumption. Material production, air and car travel are heavily taxed, financial support for airports and new road investments are reduced. By contrast, service sectors, and in particular personal services including health care and education, receive tax reliefs. This shift in taxation also stimulates the public welfare sector by making it less expensive. The economy-wide approach is designed to largely avoid rebound effects.
Increased working from home	Changing norms regarding working from home and virtual meetings are stimulated with incentives from both authorities and employers to facilitate reduced work-related travel. Regulations and digital equipment are combined with private benefits to also reduce private travel (e.g. extra vacation for those who choose to spend their holidays close to their homes).
Increased share of electric cars *	Technical development in combination with policy instruments results in a shift in the composition of the car fleet in favor of electric cars. The most important instruments for enforcing this change are the EU's carbon dioxide standard for new cars (95 g CO_2/km 2021) and the Swedish bonus-malus system. The latter means that the government subsidizes part of the higher purchasing price of e.g. electric cars (up to SEK 70 000) meanwhile there is an increase in taxation of fossil driven vehicles. We assume that the total number of cars in use is unchanged by these policies.
Aviation tax	This case is based on the aviation tax implemented in Sweden in 2018 on flights that start from a Swedish airport and increase with the flight distance. The tax per passenger is SEK 61 within Sweden and Europe; travel outside Europe less than 6000 km is taxed at SEK 255 per passenger; travel over 6000 km is taxed at SEK 408. However, the tax does not apply to transit passengers departing from Sweden within 24 h.
A cap on emissions from private travel	A system for personal emission trading for private travel is introduced in addition to existing regulation and taxation in the transport sector. The emission trading is linked to a cap on the total emissions of CO_2 equivalents from private travel that is based on ambitious emission targets and will be reduced over time. Personal allowances are distributed among the population (including private international travel). In principle, emission rights are distributed equally between all individuals, but persons living in areas with low accessibility to public transport get a slightly higher share and children get a slightly lower share than adults. Emission rights may be used up by their holders or traded between individuals. Electronic allowances are needed for e.g. fueling cars or buying travel tickets, and a market for trading allowances is established by a national authority.

measures and strategies to counteract rebound effects in general in relation to transport planning, not specifically addressing the case studies. Examples were classified according to the categories suggested by Jensen et al. (2019, see previous section). In order to better represent all four categories, the project group generated two additional cases addressed to be used the final workshop. In the third workshop the participants were asked to discuss possible consequences for different population groups of the strategies proposed in the case studies.

The results from the workshops were compiled and processed, and the outcome was critically evaluated and analyzed by the author group. In addition, the results were complemented in cases where the analysis was incomplete, since each case study was not addressed in all workshops. The series of workshops was an integral part of the analytical process, but the results presented in the next section are not primarily based on the workshop material, but our identification of possible rebound effects and strategies to avoid rebound effects in the

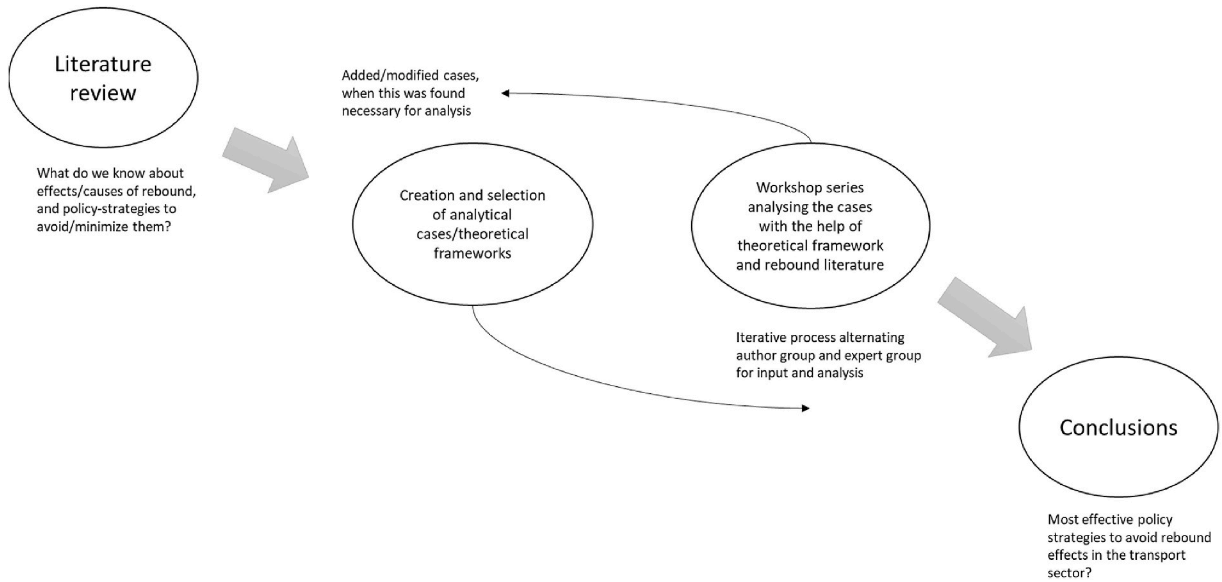

Fig. 1. A simplified sketch of the methodology.

Table 4
Description of workshop participants.

Participant	WS1: Identification of rebound effects	WS2: Identification and classification of counteracting measures	WS3: Identification and discussion of consequences of strategies
Researcher 1 (sociology)	x	x	x
Researcher 2 (mobility)	x	x	x
Researcher 3 (environment)	x	x	x
Researcher 4 (economy)	x	x	
Researcher 5 (psychology)	x		
Researcher 6 (digitalization)		x	x
Researcher 7 (mobility)		x	x
Researcher 8 (gender)			x
Authority 1 (transport)	x	x	
Authority 2 (municipality)	x		x
Authority 3 (transport)		x	x
Authority 4 (transport)			x
Authority 5 (transport)			x
NGO 1 (political)	x		
NGO 2 (political)		x	x

investigated case studies, using input from the workshops in combination with our own analysis.

The chosen design of the five cases, as well as the study's explorative and iterative design has of course impact on the results, and the interpretation of them. The results cannot be readily generalized but by purposeful selection of cases they are meant to provide insights that may be applicable in a wider context.

4. Results

4.1. Primary effects and rebound effects

We assessed the magnitude of the primary effect on GHG emissions from the defined measures in each case study as major, moderate or limited *in relation to the total emissions from the transport sector*. Potential rebound effects were identified for each case and the magnitude of these rebound effect were considered *in relation to the primary effect*. The assessments should be considered semi-quantitative as they are expert judgments supported by the input from the workshops and available literature sources, see further below.

Primary effects and identified rebound effects are summarized below and in Table 5. For reasons of completeness, we have included several rebound effects associated with infrastructure or manufacturing of equipment which could have been reported as part of the primary effects (see further Section 5.1 below). For the same reason, we have also included activities triggered by the measures such as registering travels as work-related instead of private and avoiding the aviation tax by traveling to a neighboring country by car, although these activities could be seen as a form of leakage due to imperfect policy design rather than rebound effects.

4.1.1. Major green tax-switching

In *Major green tax-switching* the measure consists of a changed tax structure, and the primary effect is that people will exchange their consumption of certain goods and services for others. This means that part of the increasing consumption should not be counted as a rebound effect but as part of the primary effect. The only identified rebound effect was that some low-income groups may be better off economically, and since lower income households tend to spend a larger share of their income on consumption compared with higher income households

Table 5
Primary effects and identified rebound effects per case study.

Major green tax-switching
Primary effect

- Major reduction of GHG emissions due to substantial tax-switching

Rebound effects

- Increased salaries and improved working conditions in service sectors stimulates private consumption from large societal groups (interactive) – limited effect

Increased working from home
Primary effect

Moderate reduction of GHG emissions under the assumption that a significant proportion of the population substantially increase their working from home
Rebound effects

- Longer work-related travel distances by car (but usually not every day) due to people settling farther from their working locations (direct) – moderate effect
- Reduced demand for office spaces (e.g. meeting rooms) decreases energy consumption (negative indirect) – moderate effect
- On the other hand, residential patterns and infrastructure may change due to the increased working from home so that people live more sparsely, bigger and more car-dependent, which leads to increased emissions from both everyday travel and housing (interactive) – moderate effect (limited in the short term)
- Increased demand for digital communication technology increases material and energy demand (indirect) – limited effect
- Reduced work-travel frees time and resources for private travel (direct) – moderate effect
- More people working full-time facilitated by working from home stimulates private consumption (indirect) – limited effect
- Increased working from home may create a feedback by facilitating new connections, meetings, networks and projects that may generate more travels, which is an unwanted feedback (interactive) – limited effect
- Reduced work-travel expenditures facilitate other private consumption (indirect) – limited effect

Increased share of electric cars
Primary effect

Moderate reduction of GHG emissions with the current policy instruments
Rebound effects

- Increased GHG emissions associated with manufacturing of electric cars and other infrastructure (direct) – moderate effect
- Increased travel due to reduced cost per kilometer and moral licensing (direct) – limited effect
- Decreased private (other) consumption due to more expensive car purchase (reversed indirect) – limited effect

Aviation tax
Primary effect

Limited reduction of GHG emissions with the current level of taxation
Rebound effects

- Increased air travel in other countries due to freed capacity (interactive) – limited effect
- Increased private consumption substituting air travel (indirect) – limited effect
- Moral licensing for air travel when paying a tax (direct) – limited effect
- Car travel to neighboring countries to avoid aviation tax (direct) – limited effect

A cap on emissions from private travel
Primary effect

Major reduction of GHG emissions following from ambitious emission targets
Rebound effects

- More trips registered as work-related travel and/or combined with vacation thus increasing work-related travel (direct) – limited effect
- Increased private consumption substituting private travel (indirect) – limited effect
- Increased private consumption from persons selling allowances (interactive) – limited effect

(Murray, 2013) this may generate a rebound effect.

4.1.2. Increased working from home

The primary effect in this case is that people reduce their daily commuting and thereby their GHG emissions. Several potential rebound effects were identified, and the net reduction of GHG emissions may consequently be limited (cf. Kim, 2017). Potential rebound effects include people settling farther from their working locations, which means longer travel distances; possibly moving to larger houses requiring more energy; and possibly having less access to public transportation. Additionally, time and money saved on commuting may be used for consumption or increased holiday traveling. On the other hand, the demand for office spaces may be reduced. The measures applied to counteract travel, like benefits for reduced holiday traveling, are also considered relatively weak. Emissions related to producing and using digital equipment are small compared to emissions related to mobility (Ong et al., 2012; Arnfalk et al., 2020).

4.1.3. Increased share of electric cars

Provided that a significant share of the vehicle fleet is replaced by electric cars we consider the primary effect to be a moderate reduction of GHG emissions from the transport sector. Since the variable kilometer costs are lower for electric cars compared to fossil-driven cars a rebound effect may be increased travel. However, as a large share of the energy mix in Sweden is fossil-free, this only causes minor GHG emissions. Additional eroding of road surfaces and an increasing need for maintenance of roads and vehicles may nevertheless be a consequence if travel distances increase. Emissions associated with manufacturing of the new vehicles may be counted as part of the primary effect or as a rebound effect. GHG emissions in manufacturing are about 60–100% higher for electric cars than for cars with combustion engines (Del Pero et al., 2018; Transport analysis, 2020a). Electric cars are more expensive to buy than traditional cars, which reduces the consumption space. The lower costs of usage counteract this over time, but parity in total cost of ownership will typically not be achieved until after 10–20 years. However, due to rapid technological development for electrovoltaics, cost parity can be expected earlier (Hagman 2020; Forbes 2020) hence freeing up consumption space earlier.

4.1.4. Aviation tax

Since the *Aviation tax* was introduced in Sweden in 2018 the increasing trend of aviation has been interrupted, both for domestic and international flights and both for private and work-related travels. However, this may be due to several reasons in addition to the relatively small aviation tax, including an economic slowdown and "flight shame" caused by environmental concerns. IEA, 2020 the COVID-19 pandemic hit the aviation sector in particular and as yet, it is difficult to assess the real effect of introducing the aviation tax (Transport analysis, 2019; 2020a). However, based on the actual outcome we assess the primary effect here to be limited. Reduced demand for aviation in Sweden may create rebound effects. Reductions in flights to and from Sweden could contribute to increased airport and airway capacity in other countries, which may in turn lower costs. If people refrain from flying due to the aviation tax, other consumption will take place with a share of the money saved, but this consumption is likely to have much less GHG intensity per monetary unit, i.e. will be less environmentally damaging than the canceled flight (see further Discussion). Finally, the aviation tax may lead some travelers to avoid the tax by traveling by car to neighboring countries and taking the flight from there. All rebound effects are considered to be limited in relation to the primary effect.

4.1.5. A cap on emissions from private travel

The primary effect of this instrument is dependent on the politically set level of the emission cap. Assuming ambitious emission targets the primary effect of a cap on emissions from private travel will be major. The policy is considered to be efficient by covering all types of private travel, but also due to the fact that almost every alternative kind of consumption that may induce indirect rebound effects is less GHG intensive. However, work-related travels may increase either due to timesaving when private travel decreases, or because they may be more attractive if combined with private leisure (Lichy and McLeay, 2017).

4.2. Strategies

Next, we will relate the occurrence of rebound effects to the strategies applied to reduce GHG emissions. In Table 6 we identify the problem framings according to Jensen et al. (2019) that appear to be behind the strategies characterizing the cases. As can be seen the main strategy is often associated with one or several complementary strategies (in brackets). Naturally, all strategies may induce certain systemic changes but here we identify the problem framings rather than their consequences.

Altogether the five cases represent a range of problem framings. Both *Increased share of electric cars* and *Aviation tax* seem to address individual behavior (B), in the first case by stimulating a change in technology (A) and in the other by taxing an unwanted behavior.

In *Major green tax-switching* the strategy is holistic and hence primarily following problem framing of complex interactions (D) even though the specific measures (adjusting taxes) also target individual behavior (B) and everyday-life situations (C), and changes in technology (A) may possibly follow although more as a consequence than as a strategy or problem framing. *Increased working from home* clearly addresses changes in everyday-life situations (C), while the outcome may be strongly supported by recent changes in technology (A) and reminiscent of the life of many households during the COVID-19 pandemic where changes in individual behavior (B) was an important trigger.

A cap on emissions from private travel primarily addresses individual behavior (B) through economic incentives supported by changes in everyday situations (C) that may result from absolute limitations of certain types of mobility. Since the strategy is limited to the area of private mobility it does not directly address more complex interactions. With complementary measures addressing norms and reasons behind traveling and ways of traveling, and with various measures facilitating reduced private travel and emissions by changing modes of transport, it could be transformed into C and D.

In Table 7 we identify instances where the six principles of systems-literate policy suggested by Levett (2009) are followed or violated in our case studies. We find that most cases follow one or several principles although principle number 5 is followed more or less by definition (see further in the Discussion below). We also find that the first principle is violated in two cases (at least). In our analysis we assume that a deep decarbonization is desirable, which means that measures that may lead to lock-in effects should be avoided. Scenario analyses have shown that emissions from both road traffic and aviation need to be reduced by up to 70% before 2030 to be in line with the Paris Agreement. This cannot only be achieved with technological development but also requires reduced road and air transport (Persson et al., 2019; Swedish Transport Administration, 2020; Sharmina et al., 2020).

4.3. Side effects and social effects

The case studies are based on different strategies to avoid GHG emissions and, by definition, rebound effects also operate on GHG emissions. However, effects on other environmental and social parameters are likely that may also affect the evaluation of strategies. *A major green tax-switching* can, for example, have positive effects on human health through an increased focus on welfare services and better working conditions in the welfare sector, but may on the other hand have a negative effect on groups and individuals who are currently dependent on traveling. *Increased working from home* could result in greater flexibility to work regardless of place of residence and thus benefit rural communities, but at the same time entail risks regarding physical as well as psychosocial working environment. An *Increased share of electric cars* has positive health effects as both noise and air pollution are reduced, but can at the same time exclude certain groups for economic and other reasons. In the same way, the restrictions on travel opportunities that come with *Aviation tax* and *A cap on emissions from private travel* may be problematic for some people. In Table 8 identified side effects and social effects are summarized.

Table 6
Problem framing according to categorization suggested by Jensen et al. (2019) in the different case studies.

Name of case study	Problem framing
Major green tax-switching	D (with B and C)
Increased working from home	C (with A and B)
Increased share of electric cars	A (with B)
Aviation tax	B
A cap on emissions from private travel	B (with C)

Table 7
Cases where systems-literate policy principles suggested by Levett (2009) are followed or contradicted.

Principle	Case
1. Avoid encouraging unwanted feedbacks.	*Major green tax-switching* and *A cap on emissions from private travel* are designed to avoid unwanted feedbacks by simultaneously addressing several sources of emissions. *Increased share of electric cars* may violate this principle by supporting current car-based society built on car-ownership. This may make it harder to reduce car travel in the extent and pace needed. *Increased working from home* may create a feedback by facilitating new connections, meetings, networks and projects that may generate more travels, which is an unwanted feedback.
2. Forestall or neutralize unwanted feedbacks at source.	*Increased share of electric cars* may achieve this for one of the negative feedbacks through the bonus-malus system, where the subsidy for electric cars is offset by a tax on fossil driven cars thus avoiding an indirect rebound effect.
3. Use taxes (and other economic instruments) to tilt the playing field in favor of desirable feedbacks and against undesirable ones.	*Major green tax-switching* and *Increased share of electric cars* are designed in accordance with this principle.
4. Design commercial and regulatory structures and institutions to align commercial benefit with desired environmental outcomes, and to eliminate perverse feedbacks.	The EU standard for CO_2 emissions from cars included in *Increased share of electric cars* is in line with this principle.
5. In designing interventions, start from the behavior changes desired. This requires attention to 'trigger points'.	All cases may follow this principle depending on the definition of "behavior changes desired" (see Discussion).
6. Recognize where virtuous circles are working, avoid unintentionally disrupting them, and give support to keep them functional.	*Major green tax-switching* and *Increased working from home* are in line with this principle in that people's desires (to some extent; e.g. working from home and more spending on welfare services) are supported by the strategies.

5. Discussion

5.1. Estimating the magnitude of rebound effects

According to our estimate, the two cases with the largest primary effect on GHG emissions were *Major green tax-switching* and *Cap on emissions from private travel*. The smallest primary effect was estimated for *Aviation tax*, due to the relatively low present tax level. Moderate rebound effects were estimated for most cases but not for *Major green tax-switching* or *Cap on emissions from private travel*. Several instances of moderate rebound effects were estimated for the case *Increased working from home*. Quantifying rebound effects as moderate would indicate that

Table 8
Side effects and social effects in case studies.

Beneficial effects	Detrimental effects
Major green tax-switching	*Major green tax-switching*
• Expanded welfare sector improving working conditions for large groups, especially for women • Expanded welfare sector improving public health by facilitating increased preventive focus and more even access • Enhanced social justice and trust • Less consumerist lifestyle appreciated by some people	• Heavy taxation of travels may harm areas with low accessibility of public transport • Negative consequences for remote social networks with more expensive air travel • Reduced material consumption may harm low income groups • Negative effects on employment in some sectors
Increased working from home	*Increased working from home*
• More prosperous rural communities and local services • Better opportunities for successful co-working regardless of geographic placement • Easier to combine work and parenthood with less commuting • Reduced spreading of diseases	• Detrimental effects on health and working environment • Environmental and social impacts of ICT equipment production • Lost jobs in transport sector • Difficulties to socialize at work
Increased share of electric cars	*Increased share of electric cars*
• Decreased noise and air pollution in urban environments	• More expensive cars may harm low income groups • Risk for lower prioritization of public transport, e.g. in rural areas • Charging infrastructure not available everywhere • Environmental and social impacts of battery production
Aviation tax	*Aviation tax*
• Decreased noise and air pollution	• Weekly aviation-commuters need to change jobs • More expensive aviation hurt low income groups • May hurt companies and destinations in remote areas
A cap on emissions from private travel	*A cap on emissions from private travel*
• A more equal distribution of travel possibilities	• Large administrative costs • May create an informal fuel market • The differentiated allocation of allowances may not adequately capture people's differentiated needs • People register in rural areas to get more allowances

a substantial part of the primary GHG reductions remain, but when several rebound effects are added together, as for *Increased working from home*, the net reduction of GHG emissions will be smaller – it might in fact be cancelled out or the net effect may be an increase in GHG emissions (backfire). While this could be a general concern, we do not have estimates of how large the sum of rebound effects is in this particular case. Two or more limited rebound effects were estimated to occur in all cases except *Major green tax-switching.*

Identified rebound effects included direct, indirect and interactive effects. The reasons for the occurrence of rebound effects vary and include economic effects (such as redistribution of income and expenditures), time use effects (time savings induce new activities) and psychological effects (such as moral licensing).

There is some room for interpretation regarding what should be counted as rebound effects. In our evaluation, we included GHG emissions associated with building new infrastructure, e.g. for electric cars or digital communication, but it is not clear whether they should be counted as rebound effects. Although the policies stimulating working from home or using electric cars do induce GHG emissions from new infrastructures, they could be a part of the primary effect of shifting from one mode of working/traveling to another mode. In theory, the net primary effect of shifting from e.g. fossil cars to electric cars, or from office work to working from home, should be calculated based on the life cycle emissions before and after the shift. However, there may exist thresholds that are passed due to specific policies. Consider, for example, a major railway construction that is induced by a limited transition from air to train travel due to an aviation tax. "Accounting" the emissions from this new infrastructure as a result of the aviation tax would not be a reasonable approach, since there are likely also many other factors in play when deciding on this infrastructure development. However, perhaps a share of these emissions could be assumed to be a secondary effect of the aviation tax.

Addressing activities like aviation and car travel will naturally induce limited indirect rebound effects due to their high GHG intensity. In order to estimate the magnitude of rebound effects associated with changed consumption patterns, the GHG intensity of the primarily reduced activity may be compared with the average GHG intensity of alternative consumption of goods and services. For Swedish residents the average is around 16 g CO_2-eq. per SEK, if estimated by dividing total consumption-based emissions (82 million tonnes) for Swedish residents by Gross National Income (5147 billion SEK IEA, 2020) (Swedish Environmental Protection Agency, 2020). For air travel and fossil cars, the emission intensity is higher, for international holiday packages by air around 200 g CO_2-eq. per SEK (Carlsson Kanyama et al., 2019), which means that the primary effect of reducing these activities is likely to significantly exceed any indirect rebound effects. Using GHG intensities, we may also roughly calculate the effects of reduced consumption elsewhere by increased expenditure for the purchase of, for example, electric cars. If the additional cost for buying an electric car (compared to a similar ICE car) is SEK 125 000, the reduced consumption of other goods and services would result in a reduction of CO_2 emissions by around 2 tonnes, if an average mix of goods and services is assumed. This may be compared with the additional emissions for manufacturing an electric car compared to an ICE which are in the order of 8 tonnes. Another example is the planned construction of a high-speed railway between the three major cities in Sweden, which has a projected cost of 230 billion SEK. The GHG emissions generated by the construction of this railway is estimated at 6.4 million tonnes (Swedish Transport Administration, 2017). Given that this investment would displace an equal sum of average consumption, the effect would be a reduction of GHG emissions by around 4 million tonnes. That is, this "reversed" rebound effect would cancel out more than half of the initial emissions.

5.2. The causes of rebound effects

Rebound effects may occur for several different reasons. They may be a result of political decisions about measures, regulations and other policy instruments, but could also be incurred by factors such as physical planning, price changes and innovation. Understanding why rebound effects occur in relation to these developments can help when planning how to avoid or minimize rebound. In the scientific literature, rebound effects occurring when certain activities are stimulated by price reductions and other economic factors, or due to time savings or psychological aspects are described. In this study we focus on policies and measures generating as well as limiting rebound effects in the transport sector.

A possible rebound effect from a subsidy is that consumers end up with more money in their pockets which can stimulate increased consumption. In our case *Increased share of electric cars*, however, the subsidy for electric cars is offset by an equal amount of taxation for fossil driven cars, and hence there is no increase in consumption possibilities at the system level. Conversely, a tax means that consumers end up with less money in their pockets, all other things being equal. In our case with *A major green tax-switching* this primarily lowers taxes on services with low GHG emissions, but there is also a distributional effect in favor of low-income households that tend to rebound more (Murray, 2013).

Changing behavior to avoid taxes – for example by reducing air travel, which is the purpose of an aviation tax – also provides alternative consumption possibilities and hence possible rebound effects. However, as long as the tax is placed on an activity with high GHG intensity it will likely be effective in reducing emissions. The reason why the aviation tax in our case has a limited primary effect is due to the low tax rate. Notably, a tax also provides revenue to the government that will be spent in some way. While subsidies increase the risk of rebound effects, they may involve other benefits such as stimulating technological development and promoting public acceptance of a change.

5.3. Assessing the importance of rebound effects

The importance of rebound effects may be assessed by different criteria. The relative size of the rebound effect as discussed above is a natural criterion but the time horizon and the reversibility of the effect may also be important. For example, the urban sprawl induced by increased working from home may be difficult to reverse. Such a change is likely to induce a negative feedback-loop which will increase travel demand and make it hard to exchange privately owned cars to other means of travel. Even if the net effect of decreasing mobility will be reduced GHG emissions, the change in residential patterns will induce new needs and habits that may become permanent at the systemic level. An increased share of electric cars apparently reduces GHG emissions from car travel but at the same time reinforces the car-centric transportation system. Lock-in effects may be due to sunk costs (the life span of a passenger car in Sweden is on average approximately 17 years, Transport Analysis 2020b), new infrastructures and habits both at the individual and institutional levels.

Time may be a critical factor for the climate effect of emissions. Delaying emissions will reduce the warming potential in the time perspective that global warming must be addressed. Heavy investments that induce CO_2 emissions in the short term but reduces CO_2 emissions in the long term may be wise to some extent but should be weighed against the time perspective. This could be another factor to consider for example when assessing the effect of increasing the share of electric cars if this also indicates investments in new cars and infrastructure.

5.4. Strategies to avoid rebound effects

Awareness of rebound effects is essential in societal planning and decision making. As indicated by the case studies, rebound effects are abundant but not necessarily a major problem as long as the net effect of a strategy is large enough, and as long as negative systemic effects do not offset the positive effect in the longer run. Indeed, there are also reversed rebound effects as when the purchase of electric cars limits the possibilities of other consumption.

Of course, a policymaker usually does not have the authority to select any possible measure but has a limited field of influence. A planner will often be busy building strategies for reducing emissions in a specific sector. But even in this endeavor, there may be room for maneuver to select measures that avoid rebound effects or irreversible consequences. Sectoral responsibility increases the risk of leakage so that indirect rebound effects occur outside the specific sector that may have been avoided had a more holistic approach been taken.

However, this does not necessarily imply that holistic measures are always preferable when it comes to avoiding rebound effects. Based on our case studies, large-scale or holistic strategies addressing many sources of emissions such as *Major green tax-switching* and *A cap on emissions from private travel* seem to provide the largest primary emission reductions and limited rebound effects, but the study also shows that more narrow approaches can sometimes be efficient and does not necessarily result in high impact rebound effects. In sectors with large GHG emissions such as the aviation sector, a narrow focus measure as the *Aviation tax* may be equally effective. A higher level of taxation than in our case for aviation might have produced a larger reduction of GHG emissions than some of the other strategies. The study also points to the difference between problem formulation according to Jensen et al. (2019) and measures: A holistic starting point may lead to specific and narrow measures that are efficient, while a narrow perspective increases the risk of unintended effects. In any case, a systemic understanding will improve the chances of building efficient strategies even within specific sectors. The multitude of identified rebound effects associated with *Increased working from home*, may for example be explained by the absence of a holistic problem framing, i.e. no part of the strategy addresses the more complex interactions between traveling and other aspects of living, but focuses on everyday-life situations (category C in Jensen et al.). On the other hand, *A cap on emissions from private travel* may indeed be formulated with a holistic starting point but leading to a change in individual behavior.

Different policy instruments lead to different types of measures, behaviors and choices of consumption, and will have different pros and cons regarding e.g. cost efficiency, distributional effects and public acceptance. Rebound effects is thus one of several aspects to consider in the selection of policy. Avoiding rebound effects may be achieved at different levels; beforehand at the planning level or by correcting strategies that are already underway; at a higher political level or at a detailed sectoral level. The success of any strategy should be seen with regard to the problem formulation.

5.5. Problem formulation and policy principles

Framing the problem in terms of changes in technology or changes in individual behavior limits the scope of action and, according to Jensen et al. (2019), addressing interactions between technology, behavior, culture and everyday life is more likely to promote a more radical sustainable transition. As we have seen, however, this is not fully apparent in our case studies where the most efficient strategies were not corresponding to any particular category suggested by Jensen et al. (2019). Even so, the problem framing determines the scope of analysis, and a wider scope facilitates identification of a wider array of potential rebound effects and unintended consequences.

In our analysis, we find that all cases apply one or several of the systems-literate policy principles suggested by Levett (2009), but also in some cases violate them. However, we do not see any clear correlation between the use of the principles and the occurrence of rebound effects, and how this relates to the net reduction of GHG emissions. With regard to the principle “In designing interventions, start from the behavior changes desired”, the question can also be asked what constitutes a desired behavior. The case with electric cars illustrates this issue. *An increased share of electric cars* is reasonably desirable, all other things being equal, but if this also means a strengthened car norm, it is not obvious that the instrument in our case study stimulates a desired behavior.

Levett’s policy principles may function as a toolbox to identify possible strategies to avoid or reduce rebound effects. In our case studies some principles that could have been applied would be to design the bonus for electric cars to promote car pools or mobility as a service (“Use taxes and other economic instruments to tilt the playing field in favor of desirable feedbacks and against undesirable ones”) or to introduce policies to counteract increased private travel in the case of working from home (”Forestall or neutralize unwanted feedbacks at source”). These principles may also help identify other systemic effects than pure rebound effects, including long-term and structural shifts in modes of travel.

The problem formulation and the application of systems-literate principles also need to be evaluated in relation to the transformation they are meant to support. Is the goal a deep decarbonization to the extent and pace needed to achieve the goal of less than 1.5 degrees of global warming, or is the goal just to improve the current situation? Measures aiming at the latter may contribute to strengthening prevailing structures in the long term. On the contrary, it is likely that a deep decarbonization will require adjustment at many levels and that the problem formulation cannot be reduced to technological changes (category A in the classification by Jensen et al., 2019). A systems perspective on sustainable mobility probably leads to a number of general conclusions, e.g. that car transport and aviation must be significantly reduced, and that urban planning, buildings and other infrastructure must support other modes of transportation. Embracing such a transition probably requires other strategies, instruments and principles than what is needed to gradually reduce emissions in the short term.

5.6. Rebound effects versus acceptance

As indicated by our analysis, to successfully avoid rebound effects either requires specific measures aimed at very emission intensive activities or working with broader system solutions. Intuitively it may seem more difficult to gain public acceptance for radical measures than for incremental ones, and technical solutions are probably less controversial than systemic change. Carbon pricing policies has been suggested as one potential tool to reduce rebound effects (e.g. Jenkins et al., 2011) that may meet a stronger resistance from citizens than subsidies. On the other hand, subsidies are more likely to induce rebound effects as they can stimulate the purchasing power of consumers.

However, policies leading to some rebound effects may be justified if they gain public acceptance (Drews & van den Bergh, 2015). At the same time, a more holistic approach also involves a possibility to negotiate and gain acceptance by combining sticks and carrots for different societal groups. Introducing a combination of measures that form an intelligible whole and clearly demonstrating how emissions are reduced may gain larger support than a limited set of individual measures (Brand et al., 2019).

Gaining acceptance for more system-wide and far-reaching measures may sometimes be difficult within the framework of the dominating forms of organization and governance, the latter often focusing on evidence-based policies and measurable goals (Voss et al., 2006; Levett, 2009). There is no incentive for decision-makers with narrow sectoral focus to consider the consequences of policies outside their scope of responsibility. In order to change this, it is probably necessary to have a wider problem formulation in connection with goal setting and to create incentives to also take into account potential rebound effects and system effects of proposed measures.

6. Conclusions

Guided by five illustrative cases of measures and policies in the transport sector where primary effects, rebound effects and possible strategies to avoid or minimize rebound effects were investigated, the main conclusions to be drawn in relation to the research question are the following.

- Different types of rebound effects seem likely and sometimes significant in connection with policies and measures to reduce GHG emissions in the transport sector.
- Detecting and avoiding rebound effects requires a system perspective. If effects and measures are investigated with too narrow system boundaries, risks of rebound effects in other sectors (indirect and interactive) are made invisible and opportunities to prevent them are missed.
- When designing measures, broad system-wide strategies or specific measures addressing particularly emission-intensive activities tend to be most effective.
- The choice of measures should account for when in time emission reductions occur, since rapid reductions of GHG emission are needed.
- However, measures that lock in structures that are difficult to change and in the long run prevent the achievement of sufficiently far-reaching changes should be avoided.
- When system-wide measures and combinations of policy instruments that together steer towards the same goal are necessary to minimize rebound effects, this creates challenges for authorities, decision-makers and experts who often only have influence over a certain sector.

These conclusions were the result of an analytical process where input from scientific literature and a series of workshops involving relevant experts and actors was used to support the reasoning and argumentation presented and discussed in the previous sections. The results of the study are qualitative and may be used to support transport policy, while more quantitative analysis will be needed to study precise implications of different policy choices.

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Author statement

All authors contributed equally to the design and analysis of the presented study. The first author wrote most of the text.

Data availability

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