ESTIMATED IMPACT OF CO_2 AND NO_X EMISSION REDUCTION TARGETS ON CAR OWNERSHIP AND CAR USE IN THE NETHERLANDS

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ABSTRACT
Densely populated areas are major sources of air, soil and water pollution. Agriculture, manufacturing, consumer households and road traffic all have their share. This is particularly true for the country featured in this paper: the Netherlands. Continuous pollution of the air and soil manifests itself as acification, decalcification and eutrofication. Biodiversity becomes lower and lower in nature areas. Biological farms are also under threat. In case of mobility, local air pollution may have a huge health impact. Effective policy is called for, after high courts blocked construction projects, because of foreseen building- and transport-related NO_x emissions. EU law makers are after Dutch governments, because these favoured economics and politics over environmental and liveability concerns. But, people in the Netherlands are strongly divided. The latest provincial elections were dominated by environmental concerns, next to many socio-economic issues. NO_x and CO_2 emissions by passenger cars are in focus. Technical means and increasing fuel economy norms strongly reduced NO_x emissions to a still too high level. A larger number of cars neutralized a technological reduction of CO_2 emissions. The question is: What would be the impact of a drastic mandatory reduction in CO_2, NO_x, and PM_{10} emissions on car ownership and use in the Netherlands? The authors used literature, scenario analysis and simulation modelling to answer this question. Electric mobility could remove these emissions. Its full impact will only be achieved if the grid-mix, which is still dominated by fossil fuels, becomes green(er), which is a gradual, long-term, process. EVs compete with other consumers of electricity, as many other activities, such as heating, are also electrifying. With the current grid-mix, it is inevitable that the number of km per vehicle per year is reduced to reach the scenario targets (−25% resp. −50% CO_2 emissions by cars). This calls for an individual mobility budget per car user.
Keywords: climate change, CO_2 emissions, fuel efficiency, electric vehicles, behaviour, policymaking.

1 INTRODUCTION

1.1 Main topic: Climate change mitigation

The long-term average temperature global temperature is on the rise. Without mitigation of CO_2 emissions by human activities, it will reach a critical level (+2.5%) by the year 2100, beyond which climate change will be unstoppable. As a result, earth will become an unbearable place to live according to most climate researchers [1]. Mitigation of the average rise in temperature has to be pursued, preferably 'to limit the temperature increase to 1.5°C above pre-industrial levels' [2]. Adaptation to already measurable and visible effects, such as rising sea levels and more unpredictable weather is inevitable.

Several global climate summits took place to establish a legal basis for positive climate action, develop (national) action plans and monitor their progress. The first global agreement is known as The Paris Agreement. It became effective on 4 November 2016.

Climate change mitigation policy is the latest and probably most complex branch of environmental policy. Experience with environmental policy tells us that its impact is on average fairly modest. While there are environmentally aware and financially well-off

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'environmental pioneers', an overwhelming majority systematically underestimates the impact of its behaviour on the environment [3], [4].

The amount of free environmental information available rules out a lack of awareness for environmental problems. A well-informed individual should be able to behave in a climate saving manner. But, information is not enough. Psychology is instrumental for change. How does a person perceive the necessity to change his or her behaviour? An individual has an almost negligible impact on the climate, which stimulates denial of responsibility; the classic Tragedy of the Commons [5]. Such behaviour is stimulated if peers or other influencers behave in the same manner.

There are also objective, material, circumstances. An individual may for instance not have an alternative or the alternative may be more or too expensive than the existing one; a (potential) case of locked-in [6]. The alternative may also have restricted applications.

Technology is progressing however, delivering a smaller environmental (carbon) footprint. This can either enhance the effect of behavioural change or make it less urgent, allowing for a slower change in behaviour. Zero emission technology has arrived and it is gradually being implemented. Yet, it should be implemented on a large scale, in order to overcome two problems. First, there is the (higher) cost of the new technologies. A lower cost of climate saving technologies may also break the spinal cord of specific economic sectors, such as the fossil fuel sector, still a relevant economic and political force in many countries. Second, there is another problem, namely a growing consumption and production of goods and services worldwide due to a growing world population.

1.2 Scope: Car mobility and emissions

The paper is about climate change and mobility, in particular with mobility by private car and ways to cut the CO_2 and NO_x emissions of combustion of fossil fuels by such cars. About 25% of all CO_2 emissions are caused by traffic in the European Union a; 71.7% by road (60.6% of which by cars) [7]. Not only this high share in overall emissions makes it an important area to study, but even more the fact that mobility is the only sector where emissions have grown over time; by 33.5% between 1990 and 2019 [7].

Similar figures hold for the country of study, The Netherlands, one of the richest countries on a per capita basis in the world. Its population density is high and still growing due to immigration, which goes along with a high and growing car density and, as a consequence, a huge amount of CO_2/GHG emissions by cars (Fig. 1).

The number of cars in this country has grown to 8.9 million by January 2023 [8]. The growth in car numbers is partially compensated by the higher fuel efficiency of new cars. Unfortunately, a large majority of Dutch consumers buy cars second hand, which means that fuel efficiency improvements are measurable only in the longer term. The number of battery electric vehicles (BEV) is now over 380,000. There are also nearly 200,000 plugin hybrid EV (PHEV) on the road [9], but these were not considered due to the uncertainty about the actual, variable, fuel mix. As the gross purchase price of an EV is much higher than the purchase price of a petrol or diesel car, tax deductions are regarded as necessary to lower the CAPEX gap and stimulate sales. EV users in the Netherlands are exempted from road tax and purchase tax (BPM) until 2024 [10]. The net purchase price is still high, which explains why electric cars are mainly sold to business users.

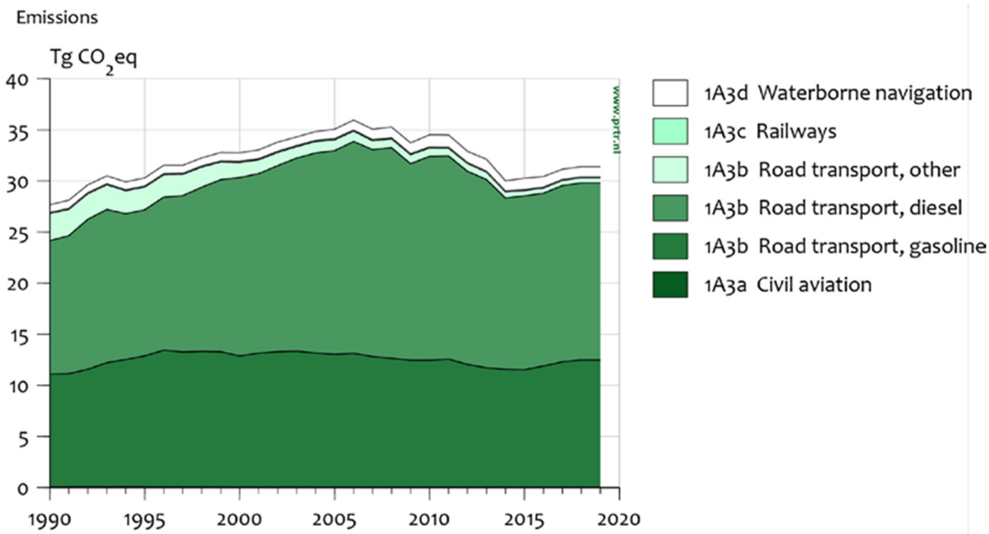

Figure 1: GHG emissions from transport in the Netherlands [11].

1.3 Climate change mitigation policy

The idea to write this paper came after the Climate Plan 2021–2030 [12] was published by the Dutch National Government. This plan aims to invest €28 billion in 120 different instruments to incentivise its citizens and business to emit less CO_2. Although the overall goals for 2030 and 2050 were defined as −50% and −100% respectively, different targets and pathways were set for specific activities. For traffic, a reduction in CO_2 emissions of 1.3–3.6 Mt CO_2 should be realised by 2030, which corresponds to a 4–10% reduction of the 1990 emission levels. In 2018, 35.6 Mt CO_2 was emitted by all traffic. To support these aims, a set of policy instruments was introduced, part of which already existing. To be mentioned are

- Promotion of electric cars and e-bikes;
- Focus on a selected number of large companies who should reduce CO_2 emissions by work and business trips by 50% by reducing car use.

  Amidst the COVID-19 pandemic, home-to-work trips were significantly reduced, but today road traffic (and congestion) volumes are higher than before the pandemic, because many public transport users switched to cars and continued to do so after the restrictions were lifted. Many companies continue to offer online facilities, removing the need for daily commuting and other business trips, yet many also require their staff to work at the office. Economic growth and a growing population are other factors behind the recovery of road traffic volumes, which already started in the later part of the pandemic [13].

1.4 NO_x crisis

National activities generate 65% of NO_x emissions [14]. Such emissions have several impacts. There is a health impact of poorer air quality, in particular in combination with its companion, PM_{10}. Under certain atmospheric conditions, smog might occur, which is very unhealthy. Next victim is nature. Emissions eventually drop upon the soil and in the water, a process also known as eutrophying deposition.

These emissions are another topic featuring high on the environmental agenda of Dutch policymakers, the polluters and their victims in the Netherlands. They cause environmental degradation and reduce biodiversity. This impact is even stronger, because the Netherlands has a very limited amount of nature area. Then pollution can take alarming proportions. Conventional agriculture is of main concern here, followed by industrial activities and traffic.

Nature is degrading so fast that it has drawn attention from the European Commission, who has demanded rapid action. Do nothing was already impossible after several courts stopped many building projects, both planned and in situ. Societal awareness is rising, giving rise to protests from nature lovers and polluters (in particular farmers). Farming emits massive amounts of ammonia and was responsible for 46% (in 2018) of all NO_x emissions. Industry and transport are the next main source of NO_x emissions [15].

1.5 Trends in road traffic emissions

Although the emissions by traffic are considerable, there is a decoupling between transport growth and emissions visible (Fig. 2).

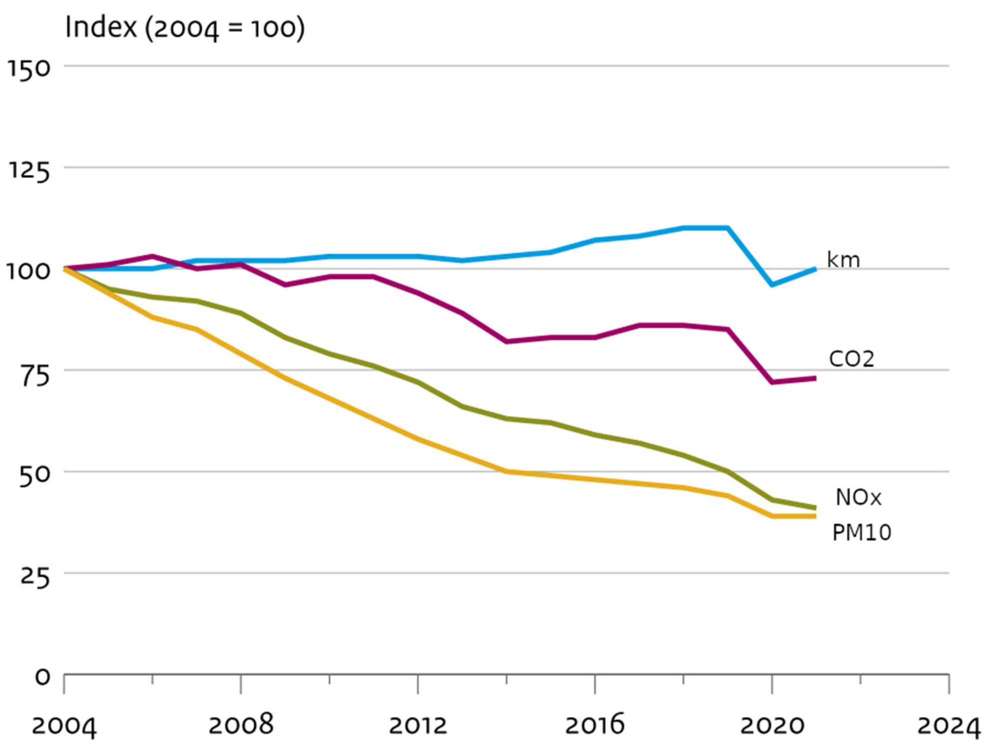

Figure 2: Road transport volume and emissions 2004–2021 [16].

Three causes were found: Introduction of catalysers and soot filters (in diesel vehicles) and changing purchase behaviour in favour of compact, more fuel efficient, cars. The impact of the pandemic is also noticeable [16].

For CO_2 emissions, the gradual stabilisation around 75% is far away from the zero-emission target, as the country has just 27 years to reach that goal. Emissions of NO_x have dropped even more. However, the current emissions of this substance are still higher than the critical absorption levels. The environmental 'sink' is not limitless. Calcium depletion is an increasing problem in nature areas, which affects flora and fauna. It has become a systemic, devastating, problem [15].

1.6 Research gap

Existing Dutch studies are mainly carried out by established Dutch government funded institutes like Plan Bureau voor de Leefomgeving (PBL). Centraal Plan Bureau (CPB) and TNO. They are frequently limited by the scope set by their commissioner. As independent authors, we are not restricted by such constraints.

2 METHODOLOGY

2.1 Research aim and questions

The Dutch national target for CO_2 emission reduction by 2030 is −49%. A target of −4% to 10% for mobility is weak. But, it follows a well-known strategy in politics to undermine policies if their impact is socially controversial. It is very detrimental and counterproductive for climate change abatement. There is no time to wait for cheaper or better technologies. It would also mean that the remainder would have to be realised in the next 20 years, which is rather unlikely.

This leads to the main research question: What would be the impact of a drastic mandatory reduction in CO_2, NO_x and PM_{10} emissions on car ownership and use in the Netherlands?

The main research question will be addressed by answering the following subquestions:

1. Would it be possible to reduce the CO_2, NO_x and PM_{10} emissions of private cars by 25% resp. 50% from reference levels?
2. What role could policymaking play in achieving these targets?

2.2 Research approach

The research for this paper was intended to:

- Study literature. Relevant policy documents, papers and data were retrieved;
- Modify an existing scenario simulation model for the paper;
- Collect additional data if needed and filter it. Fill gaps in data by assumptions;
- Run the model with the developed scenarios to estimate fuel consumption and emissions;
- Evaluate the simulation results quantitatively;
- Write policy recommendations based on this evaluation.

2.3 Conditions and assumptions

Several assumptions were made because of practical concerns. The focus is on passenger transport by car in the Netherlands. A macro perspective was taken, whereby the total number of car kms was used to estimate emissions. Externalities considered are the contribution to climate change (by CO_2 emissions) and local air pollution (NO_x only), as far as the available public data allow. The time horizon is the year 2030.

2.4 The model

A MS® Excel® model, validated in previous studies, was calibrated to estimate the energy consumption and emissions of the Dutch car fleet. Fuel consumption is an average based on the estimated km driven per year. Emissions are based on this estimated fuel consumption and emission factors for each fuel. The model contains

- A data entry and calibration module allowing changes in user data, e.g. transport means, fuels and trip (section) length;
- Matrices with energy consumption, emission factors (ef), tank-to-wheel (ttw) emissions;
- A choice box to estimate emissions of different source mixes to produce electricity;
- A solver module with policy scenarios as constraints to the linear programming.

3 SCENARIO ANALYSIS

3.1 Introduction

Backcasting scenarios were developed and tested in the model to assess the feasibility of specific CO_2 emission reduction targets for the target year 2030. Reference year is 2021.

According to CBS [17], the overall CO_2 emission of mobility was ±29.8 Mt in 2021. Passenger cars emitted ±14.9 Mt CO_2 ;10.4 Mt by petrol cars and 2.9 Mt by diesel cars.

In order to simplify the already complex estimations and make 2021 and 2030 comparable, it was assumed that the number of km driven by private car (104.5 million km) does not change between 2021 and 2030. This could be the outcome of a complex set of developments. On the one hand, the number of people living in the Netherlands is on the rise due to immigration. This would lead to more car mobility. But, policymakers are also experimenting with alternative policies to promote alternatives (mobility hubs, subsidy for e-bikes etc.) and reduce the attractiveness of cars (increase of parking prices, reduction of parking places, 30 km zones, shared spaces) or even impossible (car free (inner)cities). Such measures are either investigated or being introduced in the Netherlands. Another limiting factor is the ongoing urbanization process, which goes along with a lower car ownership and use, compared to rural areas.

3.2 Scenario 1: 25% reduction of CO_2 emissions

In this scenario, several variants were considered. In Variant a1, it was assumed that fuel economy of non-EV will not improve after 2021. In variant A2 the grid-mix will become 10% greener compared to the current level. The latter follows from a planned increase of solar and wind installations in the Netherlands.

In 2021 an EV covered on average around 15,000 km per year in the Netherlands [17]. The 380,000 BEV drove around 5.7 billion km on the Dutch roads. Since the large majority of EV is used for business trips and diesel cars are the most prolific among business users, it is assumed that they replace diesel cars. Table 1 contains the results of this variant.

Another variant (variant B1) takes variant A2 and adds 10% more fuel efficiency. In variant V2 the number of BEV doubles to 760,000. Both variants can be found in Table 2.

A 10% higher fuel efficiency of combustion engine cars results in a CO_2 emission reduction (about 10.3%). In line with scenario a1, BEV do not make a difference in reducing the level of overall emissions in case of a 10% greener grid mix.

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Table 1: Impact of a 10% greener grid mix. *(Source: Own estimations.)*

Scenario variant	**CO_2 (in Mt)**	**NO_x (in Mt)**	**PM_{10} (in Mt)**
A1: 2021 380,000 BEV	13.6 (11.2 + 2.4 + 0.024)[a]	0.016 (0.01 + 0.006 + 0)[a]	0.0099 (0.0075 + 0.0024 + 0)[a]
A2: 2030 380,000 BEV	13.6 (11.2 + 2.4 + 0.022)[a]	0.016 (0.01 + 0.006 + 0)[a]	0.0099 (0.0075 + 0.0024 + 0)[a]

[a]Petrol, diesel, EV.

Table 2: Impact of a 10% greener grid mix +10% fuel efficiency improvement. *(Source: Own estimations.)*

Scenario variant	**CO_2 (in Mt)**	**NO_x (in Mt)**	**PM_{10} (in Mt)**
B1: 2030 380,000 BEV	12.2 (10 + 2.2 + 0.022)[a]	0.015	0.0088
B2: 2030 Petrol + diesel + 760,000 BEV	12.1 (11.2 + 2.4 + 0.022)[a]	0.014 (0.01 + 0.006 + 0)[a]	0.0087 (0.0075 + 0.0024 + 0)[a]

[a]Petrol, diesel, EV.

The number of BEV doubles in variant B2 to 760,000 cars to replace 380,000 diesel cars. Fuel efficiency and grid mix both improve by 10%. Again, the impact on all emissions is very limited. Due to the different technical characteristics, it is expected that an EV drives slightly less than the diesel variant it replaced. This results in a marginal reduction in km (104.5 billion versus 103.9 billion yearly).

Variant B3 (Table 3) takes another perspective. It assumes that petrol cars are still available, but all diesel cars have disappeared due to stricter environmental regulation.

Table 3: Impact of 10% fuel efficiency improvement + 10% greener grid mix. *(Source: Own estimations.)*

Scenario variant	**CO_2 (in Mt)**	**NO_x (in Mt)**	**PM_{10} (in Mt)**
B3: 2030 petrol + 380,000 BEV	12 (−12.4%)	0.0064 (−60%)	0.0075 (−24%)
B4: 2030 8.9 million BEV	4.4 (−68%)	0.0012	0.00001

A full replacement of diesel km (variant B3) by BEV km has a significant impact on emissions.

What would happen if the number of cars in 2030 is the same as in 2021, but all cars are electric? Variant B4 shows that a BEV only scenario will reduce CO_2 emissions by 68% compared to a mix of petrol and diesel cars. A 10% greener grid would additionally reduce overall CO_2 emission to 3.9 Mt. A number of BEV will be charged by solar panels and wind energy. With higher car numbers charged in that way, a further reduction in overall emissions is feasible. It must be kept in mind that these are tank-to-wheel estimates. The upstream CO_2 emissions of (B)EV production are higher than those of petrol or diesel car production [18]. Still, over the whole lifecycle, (B)EV are thought to have lower CO_2/(GHG) emissions [19]. However, there are other concerns. Li-on batteries are built from lithium. Its mining is disastrous, as massive amounts of water are withdrawn from nature and farm land. The water is wasted and polluted. It takes 1.8 M litres of water to mine just 1 t of lithium [20].

If the (mandatory) CO_2 emission target cannot be reached with these scenarios, the question is, what is additionally necessary?

With current combustion technology, a petrol engine is cleaner than a diesel equivalent. At the same time, EV are cleaner, but we are in a transition phase. A situation with 100% EV is not feasible in the next decade(s) due to

- the higher purchase price of EV;
- limited capacity to produce EV car battery packs;
- lack of a high-density charging network (in Europe).

In variant B5 (Table 4) a total of 104.5 billion km is split between 76% by petrol cars and 24% EV.

Table 4: Impact of 10% fuel efficiency improvement + 10% greener grid mix. *(Source: Own estimations.)*

Scenario variant	**CO_2 (in Mt)**	**NO_x (in Mt)**	**PM_{10} (in Mt)**
B5: 2030 76% petrol km + remainder km by BEV	10.2 (−25%)	0.0051 (−68%)	0.0057 (−57%)

In order to fully understand the limited impact of increased EV use on emissions, the following is interesting.

The grid mix in Europe has changed considerably over time [21] due to an increased use of PV, wind and thermal energy over time. National electricity grids are also becoming more integrated, which allows exchange of electricity between European countries. But, the grid-mix is still far from green in most EU countries.

With the small number of EV on Dutch roads, a 10% greener grid mix has no significant impact on (estimated) emissions (Table 5).

Table 5: Impact of a much greener grid mix. *(Source: Own estimations.)*

Grid mix emission factors (average)	**CO_2(g/kWh)**	**NO_x (g/kWh)**	**PM_{10}(g/kWh)**
2008 [22]	605	0,5	0,01
2021	344	0,092	0,0009

These emission factors are almost identical to variant a1. The overall CO_2 emission due to EV use reduces from 0.0239 to 0.0215 Mt.

3.3 Scenario 2: 50% reduction of CO_2 emissions

A 25% reduction in CO_2 emissions might not be enough to save the planet. In case the government wants to achieve a 50% CO_2 reduction, then an expansion of scenario B5 is needed by increasing the number of EV to replace petrol cars. CO_2 emissions drop to 6.8 Mt if less than one third of the petrol cars are left on the streets and the rest of the kilometres is covered by EV. NO_x and PM_{10} emissions are reduced by around 50% compared to variant B5 (Table 6). A 50% reduction in CO_2 emissions will take considerable time, however.

Table 6: Impact of less km by petrol fuelled cars. *(Source: Own estimations.)*

Scenario variant	CO_2 (in Mt)	NO_x (in Mt)	PM_{10} (in Mt)
B6: 2030 76% petrol km + remainder km by BEV	6.8	0.0028	0.0023

Two other variants could be envisioned. They assume that those with a driving license will receive an individual mobility budget. This implies that each of them is allowed to drive 25% (variant C1) resp. 50% less km (variant C2) per year. Again, the impact on emissions is estimated (Table 7). CO_2 emissions are comparable to scenario B5, but local emissions are higher. This indicates that with old school technology (petrol and diesel engines) a 25% CO_2 reduction can be achieved via a rigid mobility budget, just like scenario B5, but EV technology is a must to reduce the local emissions.

Table 7: Impact of less km (mobility budget). *(Source: Own estimations.)*

Scenario variant	CO_2 (in Mt)	NO_x (in Mt)	PM_{10} (in Mt)
C1: 2030 −25% petrol + diesel km	10.3	0.0124	0.0074
C2: 2030 −50% petrol + diesel km	6.8	0.0083	0.0050

A 50% reduction in km driven will reduce CO_2 emissions to the level of variant B6, but, again, the local air quality stays behind the levels achievable by variant B6.

The discussion of variants has shown that a varying reduction of emissions is feasible depending on the way individuals, car manufacturers and car owners/users make decisions regarding car ownership and use. A partial reduction of emissions is feasible, but it might be very difficult to achieve the specified emission targets. This addresses sub question 1.

3.4 Decision- and policymaking

It is possible to reduce the CO_2 and NO_x emissions of private cars in a more substantial way. Several options have been studied by means of scenario variants:

- By having more fuel-efficient cars on the road. This assumes willingness to produce and buy these cars. The first is dependent on (higher) fuel economy and emissions standards. The impact of such cars is mitigated by the low number of new cars bought compared to the large number of second-hand cars sold each year, however [23];
- By having more BEV on the road. This again assumes a willingness to buy BEV. They are more expensive and there are technical limitations (driving range – density of charging network, park and charge options), which are gradually being addressed. Who will the new buyers be, exiting diesel and/or petrol drivers or people who did not own a car so far (former public transport users for instance). Will this shift occur voluntary or mandatory? Are subsidies needed?
- A more impactful solution could be to introduce an individual mobility budget per driving license owner. This would directly reduce the number of km driven on the road per year. It could be combined with a shift from petrol and/or diesel to BEV in order to achieve a higher impact on emissions.

Subquestion 2 also has now been addressed.

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4 DISCUSSION

A significant reduction of emissions is feasible with existing car technology. More BEV on the road requires user readiness, sufficient supply of BEV and a charging network. The pace of electrification is moderate in the Netherlands. Next to the current tax deductions for electric car purchase, an additional stimulus may come from a mobility budget (scenario variants C1, C2). It may seem a drastic proposal, but it is fairly democratic, because it affects every individual car user/owner, unlike a higher price for mobility, for instance, by road pricing, which is mainly felt by those with a low income. A mobility budget will certainly lead to heated discussions in society, as the proliferation of car ownership in society and the freedom to use them is regarded as a civil right. Yet, as climate change is speeding up, what is the value of such freedom?

Expanding the charging network is a necessary condition for wider application of (B)EV. However, the electricity grid is at its limits. The grid-mix is also mainly based on fossil fuels, at least at a yearly average basis. Greening the grid is then another precondition for reaching the national emission reduction targets.

In the paper a few simplifications were made. One was the assumption that car sales, whose number has been steadily growing over time, would stabilize after 2021. Where would such a trend breach come from? This depends on several developments. One is the growth in population and disposable income due to immigration. More people with more income translates to more cars and more km driven. On the other hand, there is the ongoing urbanization. It is known that car ownership and use is less in urban areas than in non-urbanized areas due to the higher density of facilities and amenities on short distance (stimulating walking or cycling). Public transport is usually of a higher quality in urban areas. Mobility apps support a modal shift as well.

Another factor limiting car mobility and thereby emissions, is the growing number of restrictions on car use in urban areas, starting with the classical reduction of parking lots and differentiated parking tariffs to measures such as car free areas or shared spaces, 80 km and 30 km speed limits and environmental zones. To increase ownership and use of BEV, a higher spatial density of charging points is instrumental. The lower operational expenses (OPEX) of a BEV [24] are another factor in favour of electric mobility.

5 CONCLUSIONS AND RECOMMENDATIONS

Electric mobility, BEV in particular, is very useful to reduce emissions of CO_2, NO_x and PM_{10}. Its full impact will only be achieved if the grid-mix, which is still dominated by fossil fuels, becomes green(er), which is a gradual, long-term, process. EVs compete with other consumers of electricity, as many other activities, such as heating, are also electrifying. With the current grid-mix, it is inevitable that the number of km per vehicle per year is reduced to reach the scenario targets (−25% resp. −50% CO_2 emissions by cars). This calls for an individual mobility budget per car user.

Whether electrical mobility is the best solution from an environmental perspective is one of the topics for further research. Lithium mining and disposal of batteries is a serious matter. Then there are the huge investments in high capacity electricity networks. These networks are already under tremendous stress. Should EV charging get priority over other activities? Will EV be used as load stabilizing hardware? Other research could be done into practical issues such as competition for parking lots, as EV charging in public spaces creates growing tensions with non-EV users.

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