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Greenhouse gas emissions from the transport sector: Mitigation options for Kenya

Methodology and Results

Short report
Zurich, 22 November 2018

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Editorial Information

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Content

Glossary

BEV	Battery-electric vehicle
BRT	Bus Rapid Transit
CO_2e	CO_2 equivalents
LCV	Light commercial vehicle
HGV	Heavy goods vehicle
GHG	Greenhouse gas
Gtkm	Gross tonne-km (Tonne kilometre of freight including empty wagon weight; for railways: train without locomotive)
MC	Motorcycle
NCCAP	National Climate Change Action Plan (Kenya)
PC	Passenger car
PHEV	Plug-in hybrid electric vehicle
TTW	tank-to-wheel (emissions from combustion or use of fuel in vehicle)
WTT	well-to-tank (upstream emissions, e.g. from production and transportation of fuels)
WTW	well-to-wheel (total emissions, sum of TTW and WTT)

1. Introduction

The Kenyan government launched a revision process of its National Climate Change Action Plan (NCCAP, Government of Kenya 2013) in November 2017. The first NCCAP identified a number of priority mitigation actions for the transport sector (e.g. Bus Rapid Transit (BRT) and Light Rail Transit system implementation in Nairobi, passenger vehicle stock efficiency, improving heavy-duty vehicle (HDV) stock efficiency, bioethanol, biodiesel and shift of freight from road to rail). These actions were reviewed as part of the development of the second NCCAP (2018-2022). With the TraCS project (Advancing Transport Climate Strategies), the Ministry of Transport, Infrastructure, Housing and Urban Development (MoTIHUD) in Kenya and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH are developing a sectoral climate change strategy and a related accounting framework. The mitigation actions are one element of this strategy.

This project aims at recalculating the mitigation potential of four transport mitigation actions for Kenya (shift from road to rail, passenger vehicles efficiency, heavy goods vehicles efficiency, and electrification) all of which are included in the new priority actions of the second NCCAP. Bus rapid transit (BRT), which is assumed to have a significant mitigation potential as well, is reviewed separately from the other actions due to its different system boundaries.
The report at hand includes information about the methodology used for the calculations and about important underlying assumptions. Furthermore, it shortly discusses the results of the calculations. The detailed results are included in two separate Excel files, which use two different grid emission factor for electricity consumption:

- The first Excel calculation file includes the grid emission factor "Basic" *("GIZ_Kenya_MitPot_Calc_gridEFbasic.xlsx")*,
- The second Excel calculation file includes the grid emission factor "Alternative" *("GIZ_Kenya_MitPot_Calc_gridEFalternative.xlsx")*.

Both Excel files contain all the data used, the calculations with the equations, as well as figures and tables with results. A further, separate output is a PowerPoint file containing the resulting figures and tables *(GIZ_Kenya_MitPot_Results.pptx")*.

2. Methodology

2.1. General information valid for all four scenarios

2.1.1. System boundaries and scope

Four scenarios were evaluated for Kenya's transport sector: (1) Shift from road to rail transport; (2) Passenger vehicles efficiency; (3) Heavy goods vehicles efficiency and (4) Electrification. The following system boundaries are valid for all scenarios:

- Temporal: The base year for the analyses is 2015. Starting from the base year, the mitigation potentials are projected up to 2050 (in 5-year intervals).
- Geographical: The analyses reflect a national perspective. Accordingly, emissions are accounted for only if they occur within the national borders of Kenya. This particularly excludes upstream (well-to-tank, WTT) emissions of fossil fuels, i.e. the emissions from the production and transportation of fuels, since these largely occur outside Kenya. For electricity, on the other hand the upstream emissions of power generation are included in the scenario emissions, since the electricity is largely produced in Kenya itself. Thus, the results use the same assessment boundary as the national GHG inventory reporting (based on IPCC). This national perspective does therefore not reflect the full mitigation potential from a global perspective (reductions of WTT emissions from fossil fuels are not included). For this reason, the results on a global level (i.e. including WTT emissions from all fuels) are also provided in the Excel calculation file and in chapter 3 in order to show the difference between the national and the global perspective.
- Transport sector: The mitigation actions mainly aim at road transport (passenger cars, light commercial vehicles (LCV), buses and coaches, heavy goods vehicles (HGV) and motorcycles (MC)). However, the mitigation action on shift from road to rail also includes rail transport. An overview of the modes and vehicle segmentation considered in the analyses is shown in Chapter 2.1.2.
- Greenhouse gases (GHGs): The results of the analyses reflect total GHG emissions in CO_2 equivalents (CO_2e).

2.1.2. Modes and vehicle segmentation

Table 1 shows the vehicle segmentation for road transport used in the analyses. Matatus, Kenyan mini buses, are categorised as light commercial vehicles (LCV N1-III).

Table 1: Road transport (vehicle segmentation)[1]

Vehicle category	Segments	Further information	Baseline / Scenario
Passenger cars (PC)	PC petrol < 1.4L	Size classes based on engine capacity in litres. Hybrid-electric vehicles (HEV; non-off-vehicle charging) are included here.	Both
	PC petrol 1.4 – 2L		Both
	PC petrol ≥ 2L		Both
	PC diesel < 1.4L		Both
	PC diesel 1.4 – 2L		Both
	PC diesel ≥ 2L		Both
	PC BEV	Battery electric vehicle	Scenario only
	PC PHEV (petrol)	Plug-in hybrid electric vehicle	Scenario only
Light commercial vehicles (LCV)[2]	LCV petrol M+N1-I	Empty weight < 1305 kg	Both
	LCV petrol N1-II	Empty weight 1305 - 1760 kg	Both
	LCV petrol N1-III	Empty weight > 1760 kg	Both
	LCV diesel M+N1-I	Empty weight < 1305 kg	Both
	LCV diesel N1-II	Empty weight 1305 - 1760 kg	Both
	LCV diesel N1-III	Empty weight > 1760 kg	Both
	LCV BEV N1-II	Battery electric vehicle	Scenario only
Buses	Coach Std ≤ 18t (diesel)	Standard (med. size) bus/coach	Both
Heavy goods vehicles (HGV)	Rigid Truck < 7.5t (diesel)		Both
	Rigid Truck 7.5 – 12t (diesel)		Both
	Rigid Truck 12 – 14t (diesel)		Both
	Rigid Truck 14 – 20t (diesel)		Both
	Rigid Truck 20 – 26t (diesel)		Both
	TT/AT 20 – 28t (diesel)	Truck and trailer (TT) or articulated truck (AT)	Both
	TT/AT 28 – 34t (diesel)		Both
	TT/AT 34 – 40t (diesel)		Both
Motorcycles (MC)	MC 4S ≤ 150cc (petrol)	4-stroke engine	Both
	MC 4S 151 - 250cc (petrol)		Both
	MC 4S 151 - 250cc (petrol)		Both
	eScooter		Scenario only

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For the shift from road to rail, trains between Mombasa (port to international waterways), Nairobi (capital city) and Malaba (border to Uganda) were considered (see Table 2).

[1] Annex A2 shows how the NTSA body types are reflected by this segmentation.
[2] Class M: LCV for passenger transport with less than 6 seats and less than 2.5 tonnes empty weight
Class N1: LCV for passenger transport with more than 6 seats and more than 2.5 t empty weight or LCV for freight transport in three weight classes I-III (as listed under further information)

Table 2: Rail transport (trains used)

Route	Trains	Further information	Baseline / Scenario
Mombasa (port) to Nairobi to Malaba (border to Uganda)	Electric passenger train	900 t gross weight, 2’622 kW locomotive (analogous to Chinese electric trains)	Scenario only
	Diesel passenger train	900 t gross weight, 3’610 kW locomotive	Scenario only
	Electric freight train	4’000 t gross weight, 2’622 kW locomotive (analogous to Chinese electric trains)	Scenario only
	Diesel freight train	4’000 t gross weight, 3’680 kW locomotive	Scenario only

Table INFRAS.

2.1.3. Emission factors

Tank-to-wheel emission factors

The basis for estimating tank-to-wheel (TTW) emission factors for road transport in Kenya is the Handbook of Emission Factors for Road Transport (HBEFA Version 3.3, see INFRAS 2017a). The CO_2 emission factors for Kenya in the year 2015 were estimated in a separate pilot study (INFRAS 2018). In brief, a country-specific fleet composition and distribution of traffic situations for Kenya were derived and applied to the HBEFA energy/fuel consumption and GHG emission factors (see INFRAS 2018 for technical and methodological details).

The CO_2 emission factors from HBEFA are transformed into CO_2 equivalent (CO_2e) emission factors by using the ratio between CO_2 and CO_2e from to the EN 16258 standard (EU methodology for calculation and declaration of energy consumption and GHG emissions of transport services, see CEN 2012). These ratios (CO_2e per CO_2) amount to 102.45% for petrol and 101.64% for diesel. Accordingly, the results of the analyses reflect total GHG emissions in CO_2 equivalents.

The following assumptions were made for the development of the emission factors up to 2050 in the baseline:

- Regarding fuel efficiency development: The yearly reduction in fuel consumption of newly registered conventional (non-electric vehicles) is as follows (range of values indicate that the reduction is not linear over time):
  - Light duty vehicles (PC and LCV): 1.2% reduction/a, based on optimization potentials of ICE engines and hybridization[3] (SCCER Mobility 2017)
  - HGV: 0.4 to 1.2% reduction/a of FC (based on ifeu and TUG 2015)

[3] Example: fuel consumption in l/100 km of an average PC in Kenya in the year 2050 corresponds to that of a 2018 Toyota Prius.

  - Buses and motorcycles: no reduction (since no information is available and it is assumed that there will not be legislation for buses and motorcycles similar as is already in force or planned for PC, LCV and HGV e.g. in the European Union)
- The inputs regarding the fleet composition, and therefore the penetration of the efficiency of new vehicles in the entire vehicle fleet, are described in chapter 2.1.2.

The resulting average TTW emission factors for the baseline fleet in Kenya are show in Table 3.

Table 3: Tank-to-wheel (TTW) implied emission factors for road vehicle categories in the baseline

in gCO_2e/km	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
PC	189.6	170.0	151.1	137.9	128.4	120.5	113.5	107.1
LCV	220.2	213.1	205.5	195.3	184.4	173.9	164.0	154.6
Bus	860.1	864.8	866.2	866.6	866.7	866.7	866.7	866.7
HGV	772.3	742.5	708.0	671.7	637.0	608.1	589.0	574.7
MC	70.1	69.1	66.1	64.2	63.3	62.9	62.7	62.6

Table INFRAS. Source: INFRAS (2017a), INFRAS (2017b)

Well-to-tank emission factors

Well-to-tank (WTT) emission factors of fossil fuels are calculated according to the EN 16258 standard (CEN 2012) by using the ratio given between TTW and WTT emission factors by fuel type. The WTT emission factors amount to 19% of the TTW emission factors in the case of petrol and for 21% in the case of diesel.

Grid emission factors are used for **WTT emissions of electric vehicles** (i.e., BEV, PHEV, eScooters and electric powered trains). Two different versions of grid emission factors as shown in Table 4 were used in order to show how different assumptions regarding power sector development influence the mitigation potentials. For further information about the grid emission factors see Annex A1.

Table 4: Grid emission factors used for electric powered vehicles

in gCO_2e/MJ	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
"Basic": Grid EF from Kenya's Second National Communication (Government of Kenya 2015)	33.4	96.1	104.6	103.2	90.3	89.3	88.6	87.9
"Alternative": Grid EF from Least Cost Power Development Plan (LCPDP) Vision scenario[4] (ERC 2018)	22.0	5.3	9.3	38.2	39.6	41.4	41.4	41.4

Table INFRAS. Source: Government of Kenya (2015) and ERC (2018)

2.1.4. Activity data

The following paragraphs describe the activity data (mainly vehicle-stock related information) relevant for the calculations in all four scenarios. The differentiation of the input data corresponds to the vehicle segmentation described in Chapter 2.1.2.

- Numbers of new registrations per year and vehicle category (see Table 6) were estimated by the University of Nairobi (Ogot et al. 2018);
- Survival probabilities and age distributions of new registrations are based on Ogot et al. (2018). The age distributions of new registrations show that for PC and LCV, most newly registered vehicles are 8 or 9 years old, which corresponds well to the maximum import age of 8 years. For the other vehicle categories, most vehicles are newer at first registration in Kenya (less than 5 years old).
- The shares of the vehicle segments in new registrations within a given vehicle category are assumed equal to the shares in stock 2015/2016 (i.e. based on the petrol station survey carried out by Ogot et al. 2018, respectively with the modifications carried out in INFRAS 2018);
- The individual mileage per vehicle is assumed to remain constant from 2015 up to 2050 (there is no data or information available that suggests otherwise).

From the above inputs, the HBEFA fleet model calculated the fleet composition regarding number of vehicles and mileage shares, as well as total mileage of road transport.

Table 5: Projection of new registrations per year and vehicle category in Kenya

Baseline, number of vehicles	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
passenger cars	68'489	93'622	124'981	161'131	202'073	247'806	298'331	353'648
light commercial vehicles	23'878	18'016	23'471	29'836	37'113	45'300	54'397	64'406
buses	2'342	2'833	3'804	4'950	6'271	7'768	9'441	11'289
heavy goods vehicles	13'785	15'495	21'427	29'886	36'339	45'318	55'313	66'324
motorcycles	134'645	137'244	150'978	164'711	178'444	192'178	205'911	219'645

Table INFRAS. Source: Government of Kenya (2013), Ogot et al. (2018), estimated by University of Nairobi.

[4] Note that the update of the Least Cost Power Development Plan only includes data up to 2037. The grid EF was therefore kept constant between 2037 and 2050.

Additionally, population projections were used to derive the development of transport volumes in rail transport (Table 6).

Table 6: Projection of population development in Kenya

In 1000 inhabitants	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Kenya national population	46'050	53'115	60'180	67'245	74'310	81'375	88'440	95'505

Data between 2015 and 2050 interpolated.

Table INFRAS. Source: United Nations (2015).

2.2. Shift from road to rail

The “shift from road to rail” scenario considers passenger cars, heavy goods vehicles and buses as well as diesel and electric trains on the route between Mombasa, Nairobi and Malaba (since relevant train lines only exist on this route).

Emission factors

The emission factors for road transport in the shift from road to rail scenario are identical as for the baseline. For rail transport, energy consumption of diesel and electric trains is based on EcoTransIT (2018), i.e. 10 Wh/Gtkm for electric and 27 Wh/Gtkm for diesel trains (both assumed to weigh 4000 t; see Table 7). The conversion factor from energy consumption to CO_2e emissions for diesel trains is based on Transphorm (2012); it takes the constant value of 720.6 g CO_2e/kWh.
For electric powered trains, the WTT (i.e. grid) emission factors were used as shown in Table 4.

Activity data

One main assumption in this scenario is that there is no rail transport in the baseline[5]. The transport volumes between Mombasa – Nairobi and between Nairobi – Malaba for the year 2015 were extracted from the Transport Volumes Shapefile (KRB 2015) and projected according to population growth. It was assumed that the shift of passenger transport from road to rail will start from 2020 on (10% of passengers shifted) and reach 20% shift in passenger km from road to rail in 2050 (in between, the shift was linearly interpolated). The modal split in the shift from passenger cars and buses was estimated to be constant and equal to the modal shift in the baseline in the year 2015 (11% of passenger km with passenger cars, 89% with bus). For

[5] The old meter-gauge railway is ignored since it is not relevant in terms of transport volumes. The new Standard-gauge railway (SGR), although already in operation between Nairobi and Mombasa, is counted as a mitigation action.

freight transport, the capacity of rail freight is expected to reach 10’500 kt (22% of total capacity) in 2020 and 22’000 kt (35% of total capacity) in 2025, remaining constant after that until 2050 (in 2050: rail capacity amounts 16% of total capacity) (Kenya Railways 2018). It is assumed that 50% of the rail system will be electrified by 2050, starting from 0% in 2020 (linearly interpolated, assumption by the authors).
A shift from airplanes to road or rail transport was not included in the analysis, which is therefore conservative.

Table 7: Important parameters for the shift from road to rail scenario (assumed constant for 2015-2050)

Parameter	Value	Source
Capacity of PC	5 persons per vehicle	Assumption by the authors
Occupancy of PC	2 persons per vehicle	Assumption by the authors
Capacity of buses	44 persons per vehicle	Research by GIZ Kenya
Occupancy rate of buses	60%	Assumption from the authors
Capacity of trucks	26 tonnes (for 40-t-trucks)	INFRAS 2017a
Average load of trucks	50%	EcoTransIt 2018
Capacity of passenger trains	1200 passengers	Kenya Railways 2018
Gross weight diesel passenger trains	900 tonnes	Research by GIZ Kenya
Gross weight electric passenger trains	900 tonnes	Assumption by the authors
Power diesel passenger trains	17.7 Wh/Gtkm	EcoTransIt 2018
Power electric passenger trains	47.8 Wh/Gtkm	EcoTransIt 2018
Occupancy of trains	703 passengers	Atkins 2018
Capacity of freight trains	2600 tonnes	Kenya Railways 2018
Average load of freight trains	54%	Kenya Railways 2018
Gross weight diesel freight trains	4000 tonnes	Kenya Railways 2018
Gross weight electric freight trains	4000 tonnes	Assumption by the authors
Power diesel freight trains	27 Wh/Gtkm	EcoTransIt 2018
Power electric freight trains	10 Wh/Gtkm	EcoTransIt 2018

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2.3. Passenger vehicles efficiency

The “passenger vehicles efficiency” scenario includes the road passenger vehicle fleets in the whole country.

Emission factors

The only change assumed in this scenario with respect to the baseline is that the maximum import age is lowered to 5 years (from 8 years as in the baseline). The age distributions of new registration were adapted accordingly, lowering their emission factors of new registrations.

Activity data

The activity data for the passenger vehicles efficiency scenario is mostly unchanged in comparison to the baseline. The only change in the scenario is that the maximum age of new registration vehicles is max. 5 years (100% of the new registrations) in comparison to the baseline, where the maximum import age is 8 years (see also Chapter 2.1.4).

The younger import age results in a longer duration of a vehicle being in use in Kenya until it is scrapped. For instance, if a vehicle was imported to Kenya at the age of 8 years and it was scrapped at the age of 30 years, it would be in use in Kenya for 22 years. In the scenario, the vehicle would be imported at the age of 5 years. The scrappage is assumed similar, i.e. at 30 years of age, and accordingly the vehicle is in use for 25 years in Kenya.

If the other parameters (number of new registrations, annual mileage) were kept constant, the longer duration of a vehicle being in use in the scenario would lead to a higher total mileage of passenger vehicles in the scenario. This is not intended - the total mileage must be identical in baseline and scenario. Therefore, the individual annual mileage of the vehicles was lowered in the scenario in order to keep total mileage the same in the scenario and the baseline. Alternatively, the number of new registration per year could have been reduced (which may be the more likely effect, for instance due to higher average vehicle prices because they are imported at younger age). However, it does not matter for the calculated emissions which parameter is lowered. Reducing individual annual mileage was the more convenient approach, which is why this approach was chosen for adjusting the total mileage in the scenario.

2.4. Heavy goods vehicles efficiency

The “HGV efficiency” scenario includes HGV fleets in the whole country.

Emission factors

In the HGV efficiency scenario, the emission factors were changed compared to the baseline. Four effects were considered:

- Traffic density, congestion: it was assumed that the density of HGV traffic on rural roads and motorways is reduced due to infrastructure expansion. This was implemented by adapting the traffic situation distribution in HBEFA for these road categories in such a manner that all levels of service (LOS) except for free flow are changed to the next "lower" (i.e. less dense) level of service, i.e.:

  - "free flow" remains "free flow"
  - "heavy" becomes "free flow"
  - "saturated" becomes "heavy"
  - "stop + go" becomes "saturated"

  This change in traffic situation distributions leads to a reduction in the TTW emission factor by 2.5% up to nearly 10% (depending on the year).
- Superstructures and tyres: in addition to the annual reduction of fuel consumption of new vehicles already assumed for the baseline emission factors (see Table 3), an additional efficiency gain was assumed due to improved superstructures (e.g. aerodynamics of superstructures), tyres (e.g. air pressure), and further effects.
  These effects lead to 3.5 to 4% reduction of the emission factor.
- Road pavement: it was assumed that road roughness is reduced through better pavement conditions. Data on the International Roughness Index (IRI) was used from the Road Sector Investment Programme & Strategy (Government of Kenya 2010) for the years 2015 to 2024 (IRI 2015: 4.2, IRI 2024: 3.4). After that, it was assumed by the authors that IRI can be improved again in 2030 and will be constant from then on (IRI 2030-2050: 3.0). The effect of the IRI on the emission f actor was estimated according to Memarian et al. (2014).
  Through improved road pavements, the emission factor is reduced by 1.5 to 2.3%.
- Eco-Drive: it was assumed that eco-drive education for HGV drivers could reduce 10% of the fuel consumption (based on BFE 2007 and Hornung et al. 2001)[6]. It was further assumed that from the year 2020 on, the drivers of around 10'000 heavy goods vehicles could be reached through the education yearly and that the effect of the eco-drive education has an effect for 5 years.
  This effect was estimated to lead to a 1% to 3.5% reduction of the emission factor.

Resulting from these efficiency assumptions, the following HGV TTW implied emission factors result for the HGV efficiency scenario:

[6] Studies find varying impacts of eco-drive: while BFE 2007 and Hornung et al. 2001 find impacts between 10-17%, Jeffreys et al. (2018) only find an impact of about 5%. The mean value of 10% was chosen for this analysis.

Table 8: Tank-to-wheel (TTW) implied emission factors for the HGV efficiency scenario

in gCO_2e/km	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
HGV	708.7	674.6	629.4	597.8	568.8	539.1	509.8	481.6

Table INFRAS. Source: INFRAS (2017a), with data from Government of Kenya (2010), Memarian et al. (2014), BFE (2007), Hornung et al. (2001)

Activity data

For heavy goods vehicles efficiency, the activity data in the scenario is mostly unchanged compared to the baseline. Lowering the maximum import age does not have any effect since most HGV are imported at ages <5 years in the baseline already.

2.5. Electrification

For the "electrification" scenario, the entire fleet of road vehicle categories is included.

Emission factors

The emission factors for conventional road transport vehicles are identical as for the baseline. For electric vehicles, two different grid emission factors were used (see Table 4).

Activity data

The shares of battery electric vehicles (PC BEV and LCV BEV) and plug-in hybrid vehicles (PC PHEV) in new registrations are taken from a Swiss study (INFRAS 2017b) since no other data was available. However, an 8-year delay in the introduction of electric vehicles is assumed, since 8 years is the age of most imported vehicles in Kenya. This results in:

- PC: First electric vehicles in 2024[7], about 5.6% shares of BEV/PHEV (each) in new registrations by 2030, about 23.6% shares (each) in new registrations by 2050.
- LCV: First electric vehicles in 2024, about 2.3% share of BEV in new registrations by 2030, about 20% share in new registrations by 2050 (no PHEVs)
- The fuel efficiency development for the internal combustion engine of PHEVs is assumed similar as in Switzerland and taken from INFRAS (2017b). This was assumed because there is no other information available.

Furthermore, the following assumptions were made for the other electric vehicle categories:

- MC: Assumption of a very quick electrification of about half the fleet (using tax incentives as in the original introduction of bodabodas): Within 2015-2021, the share of e-Scooters in new registrations rises from 0% to 50%, then remains at the 50% level up to 2050.
- No CNG or fuel cell vehicles are assumed.

[7] The authors are aware that a very small number of electric vehicles have already been registered in Kenya as of today, but their share in new registrations is assumed to remain insignificant until it grows to above 5% in 2024.

3. Overview of results

This section contains a short overview of the most important results (e.g. emission factors, mitigation potentials). More details can be found in the Excel and PowerPoint result files.

Emissions for the baseline and the scenarios are calculated by multiplying emission factors with activity data. The mitigation potential is calculated by subtracting the baseline emissions from the scenario emissions. The following table shows the mitigation potential results for the four scenarios. More detailed results are included in the Excel file; further figures can be found in the PowerPoint file.

Note that the different scenarios cannot be cumulated. The potentials of the different scenarios can be overlapping, because the measures (partially) target the same fleet. For instance, Kenya implements measures for both, a shift from road to rail passenger transport and a more efficient passenger vehicle fleet. According to our analysis for the mitigation action "passenger vehicle efficiency", we assume that the whole fleet gets more efficient. The mitigation potential is the difference between the baseline and the scenario. However, if a specific share of the fleet is shifted to rail transport, there is no mitigation potential for this specific segment. The potential of the passenger vehicle efficiency can therefore not be fully exploited. Accordingly, if the potential of shift from road to rail and of passenger vehicle efficiency were cumulated, the total potential would be overestimated.

Table 9: Mitigation potential results for the four scenarios with the national perspective (grid EF «Basic»)

Scenario (national perspective)		**unit**	2015	2020	2025	**2030**	2035	2040	2045	**2050**	**Total (2015-2050)**	**% of total BL**
Shift road rail (grid EF "Basic")	Pot.	kt CO_2e	-	-8	-33	-45	-64	-87	-122	-163	-2'197	-0.3%
	BL	kt CO_2e	1'245	1'658	2'026	2'351	2'643	2'919	3'207	3'498	85'875	
Shift road rail (grid EF "Alternative")	Pot.	kt CO_2e	-	-8	-42	-58	-79	-107	-147	-194	-2'686	-0.4%
	BL	kt CO_2e	1'245	1'658	2'026	2'351	2'643	2'919	3'207	3'498	85'875	
Passenger vehicle efficiency	Pot.	kt CO_2e	-	-117	-154	-159	-171	-188	-210	-235	-5'589	-0.8%
	BL	kt CO_2e	4'080	5'694	6'874	8'225	9'773	11'476	13'295	15'197	324'884	
HGV efficiency	Pot.	kt CO_2e	-233	-417	-691	-914	-1'117	-1'436	-2'054	-2'952	-41'106	-6.2%
	BL	kt CO_2e	2'821	4'561	6'228	8'310	10'433	12'658	15'271	18'214	339'891	
Electrification (grid EF "Basic")	Pot.	kt CO_2e	-	-6	-218	-437	-508	-286	162	785	-4'501	-0.7%
	BL	kt CO_2e	6'901	10'255	13'102	16'535	20'206	24'134	28'566	33'411	664'775	
Electrification (grid EF "Alternative")	Pot.	kt CO_2e	-	-6	-253	-583	-840	-1'002	-1'098	-1'130	-21'731	-3.3%
	BL	kt CO_2e	6'901	10'255	13'102	16'535	20'206	24'134	28'566	33'411	664'775	
Total Kenya Road Transportation	BL	kt CO_2e	6'901	10'255	13'102	16'535	20'206	24'134	28'566	33'411	664'775	

Legend: Pot. = mitigation potential; BL = baseline. Negative values indicate an emission reduction compared to the baseline, positive values an emission increase. Note that the baseline emissions are different for the four scenarios (different system boundaries for each scenario). Note that the shift from road to rail scenario also includes rail emissions, which are not included in the Total Kenya Road Transport baseline (last row in table).

Table INFRAS.

Table 10 shows the same results as Table 9, but for the global instead of the national perspective. These results from the global perspective include all upstream emissions in the mitigation potentials, including those occurring outside of Kenya. Accordingly, the potentials are higher for the two scenarios "shift from road to rail" (due to an electrified rail system) and "electrification" (due to electric vehicles).

Table 10: Mitigation potential results for the four scenarios with the global perspective

Scenario (global perspective)		**unit**	2015	2020	2025	**2030**	2035	2040	2045	**2050**	**Total (2015-2050)**	**% of total BL**
Shift road rail (grid EF "Basic")	Pot.	kt CO_2e	-	-9	-42	-58	-83	-113	-157	-210	-2'838	-0.4%
	BL	kt CO_2e	1'509	2'010	2'456	2'850	3'204	3'540	3'890	4'242	104'125	
Shift road rail (grid EF "Alternative")	Pot.	kt CO_2e	-	-9	-51	-71	-98	-133	-182	-241	-3'327	-0.5%
	BL	kt CO_2e	1'509	2'010	2'456	2'850	3'204	3'540	3'890	4'242	104'125	
Passenger vehicle efficiency	Pot.	kt CO_2e	-	-140	-184	-190	-204	-225	-250	-280	-6'664	-1.0%
	BL	kt CO_2e	4'881	6'811	8'224	9'842	11'697	13'738	15'919	18'199	388'861	
HGV efficiency	Pot.	kt CO_2e	-346	-608	-975	-1'290	-1'585	-2'018	-2'817	-3'958	-57'227	-8.6%
	BL	kt CO_2e	3'423	5'534	7'557	10'084	12'660	15'359	18'530	22'102	412'432	
Electrification (grid EF "Basic")	Pot.	kt CO_2e	-7	-267	-564	-717	-596	-261	238	-	-10'850	-1.6%
	BL	kt CO_2e	8'304	12'346	15'781	19'926	24'357	29'097	34'449	40'301	801'293	
Electrification (grid EF "Alternative")	Pot.	kt CO_2e	-7	-302	-710	-1'049	-1'311	-1'521	-1'676	-	-32'867	-4.9%
	BL	kt CO_2e	8'304	12'346	15'781	19'926	24'357	29'097	34'449	40'301	801'293	
Total Kenya Road Transportation	BL	kt CO_2e	8'304	12'346	15'781	19'926	24'357	29'097	34'449	40'301	801'293	

Legend: Pot. = mitigation potential; BL = baseline. Negative values indicate an emission reduction compared to the baseline, positive values an emission increase. Note that the baseline emissions are different for the four scenarios (different system boundaries for each scenario). Note that the shift from road to rail scenario also includes rail emissions, which are not included in the Total Kenya Road Transport baseline (last row in table).

Table INFRAS.

4. Discussion

Emissions from road transport are expected to increase strongly by 2050.
The total vehicle-km of road transport in Kenya increase exponentially between 2015 and 2050. The main reason for this increase is the increase of new registrations, which is developing in parallel with the projected population growth, along with mileage being assumed constant. This leads to a strong increase in emissions of road transport by 2050, and consequently, to rising annual mitigation potentials up to 2050.

Kenya benefits from the improvements in fuel efficiency in the countries of origin of the imported vehicles, even in the baseline scenario.
The increase in emissions is less pronounced than the increase in mileage due to improved fuel efficiency in the countries of origin of the vehicles imported to Kenya. A large share of the emission savings potential is already realized through this efficiency improvement, and these savings are included in the baseline. This means that the additional mitigation potential to be realized in Kenya itself rests in measures that lower efficiency beyond this inherent improvement. Improved road conditions, for instance, reduce emissions of heavy goods vehicles by about 2% (see chp. 2.4). The more efficient new registered vehicles arrive in Kenya, however, the lower the absolute mitigation potential through this measure (improving road conditions).

The highest potential lies in the efficiency of freight transport.
The relevance of freight transport in Kenya is very high (in the baseline scenario, HGV account for 41% of total road transport GHG emissions in 2015, for 50% in 2030 and for 55% in 2050). Already today, emissions from freight transport account for a large share of Kenya's road transport emissions. Therefore, measures not linked to the efficiency of the engine (like optimization of superstructures or tyres, reduced road roughness, eco-driving, etc.) can still have a major impact. In contrast, the efficiency improvements in passenger transport are limited due to the improvements already realised in the countries of origin (which are included in the baseline), and due to relatively minor changes assumed in the scenarios "passenger vehicles efficiency" and "electrification". Higher mitigation rates could be achieved in the passenger vehicle sector with more stringent policies on fuel economy standards or incentives for electric vehicles.

From the national perspective (which only includes upstream emissions of fuels that are produced in Kenya), the potential of electric powered vehicles is relatively small.

For both mitigation activities, the shift from road to (partially electric) rail as well as the electrification, the potential depends on the assumed grid emission factor for upstream emissions of electricity production. With the grid emission factor "Basic", which is equivalent to the grid emission factor used in Kenya's Second National Communication, the mitigation action even leads to higher emissions from the year 2045 onwards due to an assumed high carbon intensity of the national grid. This is different when using the grid emission factor "Alternative", which assumes much higher renewable shares in the electricity mix[8]; it reflects the latest Least Cost Power Development Plan (LCPDP). With the "Alternative" grid emission factor, the mitigation potential becomes significant. Second, the upstream emissions from electricity are included in the national perspective, whilst the upstream emissions from imported fossil fuels are not. The reduction of upstream fossil fuel emissions is not accounted for, while the increase of upstream electricity emissions is. Therefore, the potential of electrification is higher from the global than from the national perspective. Third, the assumed carbon intensity of the national grid in the "Basic" scenario is rather high and assumed to remain that high. A stronger impact of electrification can only be achieved in an integrative approach with a parallel de-carbonisation of the power sector.

From a global perspective, the reduction of upstream emissions of fossil fuels adds potential to electrification (in comparison to the national perspective)

The potential of the electrification mitigation option is about 2.5-times higher when assessing it with the global perspective (i.e. with all upstream emissions) compared to the national perspective (i.e. only upstream emissions of electricity). The reason for this that from the national perspective, the reduction of upstream emissions for producing and transporting fossil fuels are outside the system boundaries and therefore not included. However, although the potential is clearly higher from the global perspective than from the national perspective, it is still rather small when compared to total road transport emissions in Kenya. Mitigation actions would need to be considerably strengthened and the de-carbonisation of the national grid would be a requirement to achieve significant emissions reductions through electrification, as – to an extent – assumed in the grid emission factor "Alternative". Accordingly, with this grid emission factor, the potential becomes more relevant and is the second-largest potential of the four mitigation actions assessed. One may assume that over the considered timeframe, many of the

[8] Note that the grid emission factor «Alternative» drops in the year 2020 due to a complete and prompt phase-out of oil which is mainly compensated by electricity imports. See Annex A1 for more details.

main countries that export vehicles to Kenya may undergo a shift from fossil to electric vehicles. In addition, in line with the implementation of the Paris Agreement, it may be assumed that the Kenyan national grid will be de-carbonized so that electrification brings a higher mitigation impact than based on the assumptions included in the "Basic" scenario.

The mitigation potential of a mode shift from road to rail seems small.

The mitigation potential of a shift from road to rail is limited due to several reasons:

- High emission factor per pkm of diesel rail. A shift from bus to diesel train actually increases emissions (bus: 32-33 g/pkm TTW vs. diesel train: 44 g/pkm TTW, mainly due to occupancy rates).
- Only one intercity train line in the whole country is assumed, naturally limiting the mitigation potential of a shift to rail.
- Little information was available at the time of writing on the planned capacity of the Standard Gauge Rail (SGR). Its potential in terms of capacity may become higher than assumed here.

The mitigation potential of a shift from road to rail largely depends on electrification. More specifically, it depends on a) when the rail system is electrified and b) what the carbon intensity of the electricity grid will be like (see discussion on electrification). Accordingly, the potential is higher when the grid emission factor "Alternative" is included in the analysis.

Uncertainties in the calculations of the mitigation potentials are rather high.

A lot of activity data was not readily available. Therefore, the authors were required to make assumptions on sensible parameters for the calculations or use data with high uncertainty, for instance:

- Mode shift in the shift from road to rail scenario (in particular for the route between Nairobi and Malaba, where no rail transport is in place yet);
- Little information about the origin of HGV and about which efficiency improvements are achieved in Kenya and which in the countries of origin.

Results in this report should therefore be interpreted with caution and readers are invited to consult the corresponding Excel file to further understand the assumptions taken.

5. Conclusion and Outlook

Kenya's road transport sector is expected to grow rapidly until 2050, both in terms of number of vehicles and in terms of emissions. Significant mitigation potentials exist in efficiency improvements in the freight sector and in electrification of passenger transport if, and only if, the electricity grid is decarbonised (the share of renewable energies increases). (The mitigation potential of bus rapid transit was not assessed in this study). To increase the mitigation potential, more stringent policies and incentives for efficient/electric vehicles are required. The ongoing discussions on Kenya's climate change strategy in the transport sector could therefore consider some of the following questions:

- Given the high grid emission factors: What potentials to de-carbonise the power sector are there?
- Regarding electrification of the vehicle fleet, what is the chance for the Kenyan vehicle market to become more independent of vehicle imports from industrial countries? In the results presented, we assume the same development as conservatively expected in Japan or Europe, with an 8-year delay. However, the Kenyan fleet could potentially be electrified much faster if incentive policies are put in place.
- Regarding efficiency improvements apart from electrification: Only one, not very drastic, measure is currently envisaged, i.e. reduction of the maximum import age from eight to five years. One could also discuss a complete ban on used imported cars, which other countries (e.g. Latin-American or North African countries) have implemented already or feebates incentivising more efficient vehicles.
- Shift from road to rail: Could it be feasible to envisage more ambitious goals in terms of mode shift – e.g. increased passenger capacity than currently expected (see Table 11 for illustration) or more train lines than just along one corridor?

Table 11: Passenger kilometres in the shift from road to rail scenario (for SGR)

In Mio. pkm	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Road	8'629	8'982	9'993	10'961	11'886	12'768	13'607	14'403
Rail	0	971	1'284	1'640	2'038	2'480	2'965	3'493

Table INFRAS.

- What could be done on behalf of policy makers to exploit the mitigation potential in the freight transport sector?

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Annex

A1. Grid emission factors

The electricity mix used for the **grid emission factor "Basic"** from Kenya's Second National Communication (Government of Kenya 2015) is not publicly available. However, in the executive summary (p. 4) states that *"Hydropower, which constitutes over half of the total effective grid connected electricity, is highly vulnerable to variations in hydrology and climate. Poor rains result in hydroelectricity shortfalls, leading to more costly and GHG-intensive electricity generation through diesel. Geothermal accounts for 12.2 per cent of the electricity mix and the remaining 29.7 per cent is predominantly petroleum-based thermal generation. Kenya's National Energy Policy 2014, which has been formulated within the framework of Vision 2030, encourages diversification of electricity sources, including addition of geothermal (1,646MW), natural gas (1,050MW), wind (630MW) and coal (1,920MW). This new plan, despite potentially increasing GHG emissions from coal, aims to improve energy security and reduce the recent trend of oil thermal comprising the largest portion of new capacity."*

The electricity mix used for the **grid emission factor "Alternative"** from the LCPDP Vision scenario (ERC 2018) is shown in Table 12. The LCPDP Vision scenario assumes that by 2037, geothermal electricity generation will account for the largest share of production. In addition, the scenario assumes that there is a complete and prompt phase out of oil in the year 2020. The electricity gap occurring from that would be covered by imports, which would not lead to emissions in the national perspective (because WTT emissions occurring abroad are not included in the national perspective and TTW emissions of electricity are assumed to be zero).

Table 12: Electricity mix for the grid emission factor "Alternative" (LCPDP Vision)

Technology	unit	2015	2020	2025	2030	2035	2037
Onshore Wind	Gwh	0.8%	12.3%	12.9%	10.9%	11.9%	10.3%
Offshore Wind	Gwh	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*
Solar PV	Gwh	0.0%	2.9%	4.9%	3.9%	2.8%	2.5%
Biopower	Gwh	*0.0%*	1.5%	3.2%	2.8%	2.3%	2.1%
Hydro	Gwh	39.6%	24.1%	16.9%	16.1%	11.5%	10.2%
Geothermal	Gwh	52.3%	42.3%	50.1%	43.4%	50.9%	47.3%
Natural Gas	Gwh	*0.0%*	*0.0%*	*0.0%*	2.5%	2.3%	3.0%
Coal	Gwh	*0.0%*	*0.0%*	1.3%	12.7%	13.0%	13.6%
Oil	Gwh	7.3%	0.0%	*0.0%*	0.0%	*0.0%*	*0.0%*
Nuclear	Gwh	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	6.3%
Solar Minigrid	Gwh	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*
Wind Minigrid	Gwh	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*
Diesel Minigrid	Gwh	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*
Generic backup	Gwh	*0.0%*	*0.0%*	*0.0%*	*0.0%*	0.0%	0.1%
Import	Gwh	*0.0%*	16.9%	10.7%	7.8%	5.4%	4.7%
Total	Gwh	9'453	15'633	24'580	34'805	50'555	57'985

Table INFRAS. Source: ERC (2018)

A2. NTSA body type classification and HBEFA segmentation

Table 13: Assignment of NTSA body types to HBEFA vehicle types

Body type ID	NTSA Body type	HBEFA vehicle category	HBEFA segment[9] assignment
1	S.WAGON	Passenger car (PC)	based on engine capacity [l]
2	LORRY/TRUCK	Heavy goods vehicle (HGV)	based on max. weight [t]
3	PICKUP	Light commercial vehicle (LCV)	based on empty weight [t]
4	CRAWLER	N/A (non-road mobile machinery)	
5	ROLLER/GRADER/CRANE/COMBINE HARVESTER		
6	Combine harvester		
7	PRIME MOVER		
8	BACKHOE LOADER		
9	SPECIAL PURPOSE		
10	TRAILER	Not directly assigned, since trailers only circulate combined with a tractor. Considered via HBEFA "transformation pattern", which specifies the percentage of tractor vehicles moving with trailer, by size class.	
11	M.BUS/MATATU	Light commercial vehicle (LCV)	based on empty weight [t]
12	MOTOR CYCLE	Motorcycle (MC)	
13	FORK LIFT	N/A (non-road mobile machinery)	
14	BUS/COACH	Coach	assumed standard size class (<=18 t max. weight)
15	COUPE	Passenger car (PC)	based on engine capacity [l]
16	TIPPER	Heavy goods vehicle (HGV)	based on max. weight [t]
17	THREE WHEELER	Neglected, since low population and no corresponding HBEFA vehicle type available	
18	WHEEL/TRACTOR	Heavy goods vehicle (HGV)	based on max. weight [t]
19	DOUBLE CAB	Light commercial vehicle (LCV)	based on empty weight [t]
20	VAN	Light commercial vehicle (LCV)	based on empty weight [t]
21	SALOON	Passenger car (PC)	based on engine capacity [l]
22	WHEEL LOADER	N/A (non-road mobile machinery)	
23	Others		

Table INFRAS. Source: University of Nairobi, own analysis