Less commuting and climate protection:

An estimation exercise for the Frankfurt/Rhein-Main region

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Abstracts in English and German

In Germany, millions of people commute from their homes to work every day. The car is the most important means of transportation. This has essentially a major impact on greenhouse gas emissions and is thus fuelling climate change. The study at hand views the efficiency potentials of reduced commuting and the respective contribution of greenhouse gas emissions at district level and at the level of functional space. Frankfurt/Rhein-Main is an exemplary case study region. The empirical foundation consists of data on local out-commuting at district level and out-commuting at the level of functionally classified space. Those data are combined with various parameters specifying shares of engine types, the respective average emission per kilometer, single driver trips versus ride sharing and rebound effects. At district level, the relative maximum saving effect, provided a maximum feasible 20 percent reduction in commuting, remains moderate with results lower than 0.5 percent. Nevertheless, commuting, especially in economic core zones, will remain one of the regulating screws of climate change.

In Deutschland pendeln täglich Millionen von Menschen von zu Hause zur Arbeit. Das Auto ist das wichtigste Transportmittel. Dies hat einen bedeutenden Einfluss auf die Treibhausgasemissionen und treibt somit den Klimawandel an. In der vorliegenden Studie werden die Effizienzpotenziale eines reduzierten Pendlerverkehrs und der jeweilige Beitrag der Treibhausgasemissionen auf Landkreisebene und auf Ebene der Funktionsräume untersucht. Die empirische Grundlage besteht aus Daten zum lokalen Pendeln auf Landkreisebene und auf der Ebene des funktional klassifizierten Raums. Frankfurt/Rhein-Main ist eine exemplarische Fallstudie. Diese Daten werden mit verschiedenen Parametern kombiniert, die Anteile der Motortypen, die jeweilige durchschnittliche Emission pro Kilometer, Fahrten einzelner Fahrer im Vergleich zu Mitfahrgelegenheiten und Rebound-Effekten angeben. Auf Landkreisebene bleibt der relative maximale Einsparungseffekt bei einer maximal realisierbaren Reduzierung des Pendlerverkehrs um 20 Prozent mit Ergebnissen von weniger als 0,5 Prozent moderat. Dennoch wird das Pendeln, insbesondere in wirtschaftlichen Kernzonen, eine der Stellschrauben des Klimawandels bleiben.

1. Introduction

1.1 The leading research question

Smart commuting concepts – having already been discussed for decades - seem to be a feasible alternative to reduce GHG-emissions. The discussions around these concepts gravitate towards transportation alternatives that sensitize people to avoid using single-occupancy vehicles. Also, biking, car-sharing and public transportation seem to be practical alternatives towards gridlock. Apart from these views, there is an even more powerful concept, which has been supported by several studies: Telecommuting (or Teleworking, Homeworking). Telecommuting appeared to have a clear impact on the working life and on GHG emissions respectively. Based on this, homeworking has been increasingly introduced by several companies in many sectors as a prospective and promising way of working. Further to that, many states have begun to incorporate homeworking into their legislation as a political instrument for alleviate the climate change. In 2010, the United States has introduced homeworking into the constitution (the "Telework Enhancement Act" was signed by President Barack Obama on Dec 09, 2010) The Act obliges governmental institutions to establish teleworking policies and seeks to expand the number of federal agencies eligible to teleworking. [1]

Through the fast development and spread of connectivity and other IT-based technologies, (e.g. laptops combined with docking stations, cloud-based file sharing, instant messenger and videoconferencing capabilities, as well as smartphones and tablets) tremendous changes have occurred in the labour market and the world of work. It became possible that more jobs than ever before can also be performed from long distances (e.g. from home) and not necessarily from the working place. It appeared to be conceivable, that telecommuting may significantly reduce employee commuting costs, GHG emissions, commuting time, and expenditures on office heating and energy consumption and rental costs. Even sickness leave could be reduced (less traffic accidents, less exposure to job and traffic stressors etc.).

Worldwide, the reality is still a very different one. In Germany for example, roughly 11 million people[2], commute from their homes to work every day by car and many feel well with that despite being caught up in the traffic jam every morning and evening[3]. The car is the most important means of transportation. Approximately 68 percent of commuters use their vehicles to get to work. The share of working population regularly travelling to work by public transport is thus a minor one. For the majority of the employed persons (70 percent), the time spent on the daily commute to work was less than 30 minutes. Between 30 and 60 minutes was needed by 22 percent of commuters. 5 percent needed one hour or more to get to work[4]. Recent estimations indicate that the GHG (carbon dioxide, methane and nitrous oxide) in Germany are the main source for around 98.3 percent of climate-impacting

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[1] U.S. Office of Personnel Management: Telework Legislation, Telework Enhancement Act, 2010. *https://www.telework.gov/guidance-legislation/telework-legislation/telework-enhancement-act/*

[2] Die ZEIT Online, 20. November 2018.

[3] Aral-Studie (2018) Mehr als jeder zweite Pendler schätzt den Berufsverkehr als Moment der Ruhe (https://www.aral.de/content/dam/aral/business-sites/de/global/retail/presse/pressemeldungen/2018/2018-12-18-pm-aral-kaffeestudie-pendler.pdf)

[4] DESTATIS – Statistisches Bundesamt 2020: Pendeln in Deutschland.

emissions[5]. Roughly 20 percent of emissions are caused by the transport sector, which amounts to over 150 million tonnes of CO_2 per year. More than half of these emissions are generated from the exhaust pipes of the 41 million vehicles alone[6]. Based on the information provided by the Federal Environmental office (UBA), the GHG emissions per vehicle and kilometers are approximately 147 grams, i.e. cars produce the second highest emissions of all transportation means within the passenger traffic (see Figure 1).[7]

The detrimental effect of traffic congestion and GHG emissions on the environment and people's health has been subject to research on for a long time. Especially in densely populated economic core zones such negative agglomeration externalities pose a major risk for the national economy and people's welfare.

In this study the leading research question of how much GHG emissions can be potentially saved by a maximum feasible reduction of commuter traffic in a core economic zone of an advanced EU country is addressed. The study views the Frankfurt/Rhein-Main region as an example.

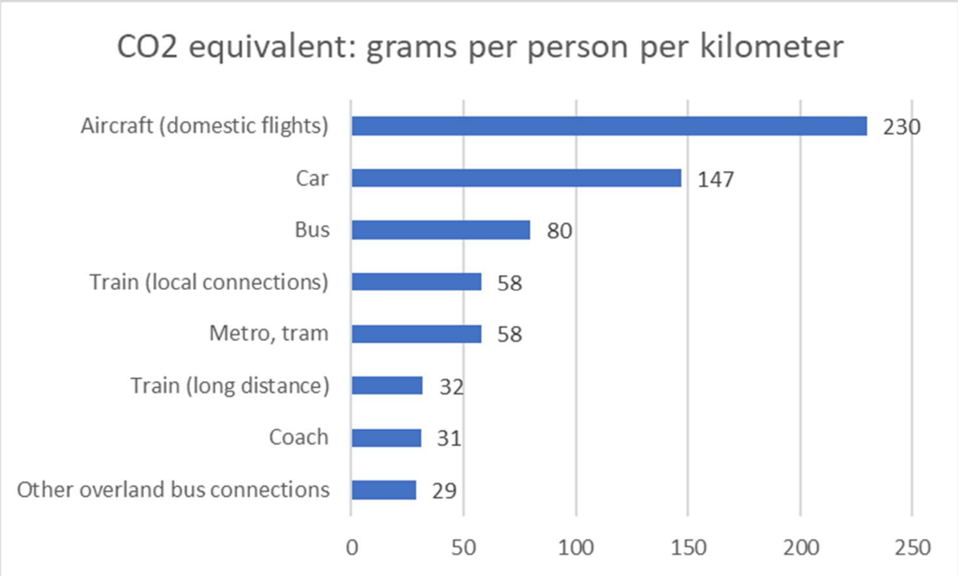
The paper is structured into introductory chapters describing the relationship of GHG emissions and commuting at the level of the Bundesland Hessen and the Frankfurt/Rhein-Main region, a methodological introduction into the database, the parameters and the calculation approach, empirical results at district and functional area level and a further outlook dealing with a more holistic argumentation for reduced commuting.

[5] Greenhouse gas (GHG) emissions are produced by mobile sources as fossil fuels are burned. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are emitted directly through the combustion of fossil fuels in different types of mobile equipment.

[6] For comparison Global carbon dioxide emissions have been rising steadily since 1960 and will reach their highest level to date of around 36.6 billion tonnes of carbon dioxide in 2018. By 2050, annual CO_2 emissions are forecast to increase by up to 43.1 billion tonnes. Statista: Weltweiter CO_2-Ausstoß in den Jahren 1960 bis 2018: https://de.statista.com/statistik/daten/studie/37187/umfrage/der-weltweite-co2-ausstoss-seit-1751/

[7] Umwelt Bundesamt: Emissionsdaten 2018, https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten#handbuch-fur-emissionsfaktoren-hbefa

Figure 1 Comparison of average GHG gas emissions by transport mode in Germany (2018)



Source: Umwelt-Bundesamt (UBA): Emissionsdaten 2018

1.2 Commuting and GHG emissions in the State of Hesse

The commuting and GHG situation in the state of Hesse follows the pattern of the national level : Around 1,235 million of the 3,063 million working people living in Hesse have their place of work at their place of residence. At the same time, more than 1,829 million Hessian employees (59.7 percent) commute to their place of work in Hesse and the neighbouring federal states.[8]

As compared to the rest of Germany, a similarly high share of GHG emissions can be monitored in Hessen. Around 40.8 million tons CO_2 equivalents were emitted. The GHG carbon dioxide accounted for 37.1 million tons CO_2.

In 2017, the CO_2 emissions of the transport sector in Hesse amounted to 14.6 million tons. An increase in emissions was monitored here until the end of the nineties. The highest level of traffic emissions has been reached in 1999 with 16.0 million tons CO_2. In the following ten years, they have decreased significantly by an average of 310,000 tons CO_2 per year and amounted to 13.0 million tons CO_2 in 2009. Since then, however, they have risen continuously. Since 2016, transport emissions have been back above the level of the base year 1990[9].

1.3 Commuting in the Frankfurt-Rhine-Main-Region

The commuting and GHG situation in the Frankfurt-Rhine-Main-Region follow likewise the same trend as the national average. However, due to Hesse's differentiated economic structure, higher growth and its high population density, the frequency of commuting is considered to be above the average compared with other regions in Germany.

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[8] Hessisches Statistisches Landesamt - Staat und Wirtschaft in Hessen: Pendeln und Mobilität in Hessen, 2018, p. 3

[9] Hessisches Ministerium für Umwelt, Klimaschutz, Landwirtschaft und Verbraucherschutz: Treibhausgasbilanz für das Land Hessen Bilanzjahr 2017, p. 19.

The table 3 below, which comprises specific NUTS3 Regions (Frankfurt, Groß-Gerau, Hochtaunuskreis, Main-Kinzig-Kreis, Main-Taunus-Kreis, Offenbach Land, Offenbach Stadt, Wetteraukreis) indicates, that the out-commuting gross (i.e. the total number of commuters using various transportations ranges to about 530,000. Out of those, the out-commuting net or those commuters who use their private (or company-owned) vehicles, range to about 350,000. The proportion of commuters travel by car operated by a combustion engine is at 83.9 percent as indicated by Destatis. The share of those using vehicles operated by electric engines is only 2.1 percent. Whereas 67.7 percent of commuters use private (or company-owned) vehicles to travel to the working place, 86 percent use the vehicle as a single passenger.[10]

2. Methodology for calculating GHG emissions and possible saving effects through less commuting

Recent data on local out-commuting at district level[11] combined with empirically validated parameters on shares of combustion versus electric engines, single rides versus ride sharing allow the estimation of the total emissions caused by these commuting activities in the specified NUTS3-Regions. With the online tool "CO_2-Rechner für Auto, Flugzeug und Co." GHG emissions for different transport modes, engine types and number of car passengers can be calculated. The assumed relationship between different levels of capacity use is however linear, i.e. for one person 1, for two persons 0.5, for three persons 0.33 and so forth. The approach is thus essentially a simplified one as non-linearities are obvious (at least imaginable) when modelling GHG emission saving effects (e.g. increased fuel consumption due to increasing car weight with growing numbers of car passengers). Further to that, global (or German) parameters used in this study may disregard regional peculiarities of travel patterns (e.g. a possible deviating local distribution of engine and car types due to different regional wealth levels or preferences); further to that non-linearities are also imaginable when modelling saving effects of less commuting. By keeping other GHG emissions (e.g. carriage of freight, heating) constant, minor or major error may be induced into the calculation even though a global correction parameter for rebound effects (taken from the respective literature) is explicitly considered in this study. Therefore, it is to be noted that this study must not claim sufficient reliability in terms of confirmed evidence but only a rough indication of a possible scope of achievement when reducing commuter traffic in a metropolitan region.

Table 1 Parameters used in this study

Variable	Estimate (Germany; global)	Source
Commuters using private cars (%)	67.7	Destatis
Out of those: single drivers (%)	86.0	Aral
Out of those: combustion engines (%)	83.9	ifaa – Institut für

[10] Destatis: 2016 data; Aral-Studie (2018) Mehr als jeder zweite Pendler schätzt den Berufsverkehr als Moment der Ruhe (https://www.aral.de/content/dam/aral/business-sites/de/global/retail/presse/pressemeldungen/2018/2018-12-18-pm-aral-kaffeestudie-pendler.pdf)
[11] For data on the Frankfurt metropolitan area: IHK Darmstadt - Initiative PERFORM Zukunftsregion FrankfurtRheinMain (2018) Stau- und Pendlerstudie, pp. 7 ff

		angewandte Arbeitswissenschaft[12]
Out of those: electric engines (%)	2.1	ifaa – Institut für angewandte Arbeitswissenschaft
Ride sharing: two passengers (%)	12.0	Aral
Ride sharing: ≥ three passengers (%)	2.0	Aral
Share of electric cars (%)	2.1	ENBW
Mean daily commuting distance (km)	34.0	ifaa – Institut für angewandte Arbeitswissenschaft
GHG emission (combustion engine) per kilometre (kilogrammes)[13]	0.19	https://www.quarks.de/umwelt/klimawandel/co2-rechner-fuer-auto-flugzeug-und-co/
GHG emission (electric car) per kilometer (kilogrammes)	0.1	https://www.quarks.de/umwelt/klimawandel/co2-rechner-fuer-auto-flugzeug-und-co/
Global estimate of rebound effects with 20 percent reduction of commuting (%)	27.4	Reitan FA 2014 The Rebound Effect: A Simulation Model of Telecommuting. MSc. Thesis. Trondheim: Norwegian University of Science and Technology, Department of Telematics, pp. 75 f. and 79-80

As stated above, whereas 83.9 percent of commuting vehicles with single driver are operated by combustion engines, the proportion of car pools (two persons) is at 12 percent and commuting vehicles run by electric engines is only 2.1 percent.

To determine the annual total of CO_2 emissions caused by the 83.9 percent of commuters using combustion (Diesel or petrol) engines, a calculation approach based on the following assumptions was applied [14]:

Assumption 1:

Total annual distance travelled by all commuters =

$$\sum_{k=1}^{n} daily\ distance\ between\ home\ and\ work\ (km)\ \cdot\ 5\ \cdot\ number\ of\ commuting\ weeks\ per\ year$$

If we assume, that commuters *k* travel 34 kilometers/day during 44 working weeks (five days), we will then obtain the following total annual distance travelled by one commuter

34 kilometers/day x 5 x 44 weeks = 7.480 kilometers

This distance can be travelled by public transport, alone in one private car, by ride sharing and with vehicles powered by different types of engines. Reducing this individual and total mileage is supposed to have an alleviation effect on climate change.

[12] Sascha Stowasser et al. (2019) Gutachten zur mobilen Arbeit, Düsseldorf: IFAA-Institut für angewandte Arbeitswissenschaft

[13] There are various sources with different numbers: while the online calculator works with 0.19 kilogrammes per kilometer, the respective number of the UBA is 0.147 (see earlier)

[14] https://www.quarks.de/umwelt/klimawandel/co2-rechner-fuer-auto-flugzeug-und-co.
Further: World Resources Institute & World Business Council for Sustainable Development (2013), Technical Guidance for Calculating Scope 3 Emissions, Category 7, p. 89
The United States Environmental Protection Agency (2008): Optional Emissions from Commuting, Business Travel and Product Transport, 05/2008

The variation of GHG emission by keeping the average commuting distance constant can be displayed by the following assumption.

Assumption 2:

Total kilogrammes CO_2 caused by commuting =

$$\sum_{v=1}^{n} total\ distance\ travelled\ by\ vehicle\ v \cdot vehicle\ specific\ emission\ factor \cdot working\ time\ per\ year$$

For one vehicle: 0.19 kilogrammes CO_2 x 34 km **x 5** *x 44 weeks =*

6.4 kilogrammes x 34 kilometers x 5 x 44 weeks=1,408 kilogrammes

83.5 percent of commuters travel alone with an emission of those 1,408 kilogrammes on average per year. However, the remaining 16.5 percent of commuters travel by ride sharing (two, three or more persons per car) or electric cars. Out of those, 12 percent are car pools with two persons:

3.2 kilogrammes CO_2 x 5 x 44 weeks = 704 kilogrammes

and 2 percent those with three persons:

2.1 kilogrammes CO_2 x 5 x 44 weeks = 462 kilogrammes

A simplified approach is used for the minor portion of commuters (2.1 percent) using electric cars:

34 kilometers/day x 5 x 44 Weeks= 7,480 kilometers (*total distance travelled by vehicle per year)*

4.2 kilogrammes CO_2 x 5 x 44 weeks = 924 kilogrammes

Under consideration of assumptions 1 and 2 we can now roughly estimate the potential saving effect of less commuting. Less commuting can be partly using home office, local office sharing or other such smart solutions. In this paper we just take an abstract percentage value of present total commuting mileage in the Frankfurt/Rhein-Main region.

3. Potential saving effects

3.1 Telecommuting and GHG- emissions saving in Frankfurt-Rhine-Main region

Under the calculation methodology described above, it appears to be evident, that commuting impacts the environment and the GHG emissions.

Regarding telecommuting in the Frankfurt-Rhine-Main region, we have estimated that a 20 percent reduction in commuter traffic could generate tangible GHG saving effects (see Tables 3 and 4). Assuming that the CO_2 equivalent emitted from commuting for the entire region is 453,157 tons CO_2, then a 20 percent share of work devoted to telecommuting (gross saving effects II) results in a GHG saving of 90,632 tons. Taking a more moderate10 percent telecommuting into consideration, the saving effect would be half, i.e. 45,316 tons assuming a simple linear relationship (Gross saving effect I).

These calculated savings can only be efficiently generated if homeworking is systematically examined, accordingly encouraged, promoted and ultimately introduced. Moreover, the generation of savings depend on the proper and rational planning and utilization of the home office, data security and the quality of local broadband connection to a large extent. The energy savings and the environmental benefits (reduction of traffic congestion, accidents and air pollution) from homeworking could be realized if homeworking is implemented in the right way. A significant rebound effect[15] of homeworking is higher home energy consumption, incurring increased carbon emissions and monetary expenditures. While additional electricity consumption, primarily from IT equipment, is likely to be low, much depends on behaviour around heating, particularly from increased home heating in the winter season and additional non-commuting car trips (see below). For example, it is a lot more efficient to heat a home office used by several employees, rather than to heat several home offices each is used by a single person. Therefore, it is essential to examine each specific situation of the home office to properly account for the potential optimal energy and GHG-saving impacts. "…Homeworking is still therefore, a potential "win-win", just not automatically so. Yet even if a homeworker is cutting out a long commute, or is scrooge-like with heating, this is still not the ideal carbon-saving solution. The efficiencies of scale gained by office environments but lost through long commutes, says Swift, are best realised in co-working environments such as libraries and communal hubs close to people's homes…."[16]

3.2 Impact of telecommuting on GHG emissions

As discussed above, a relevant contribution of homeworking to GHG savings is strongly dependent on the rebound effects. Several sources assume that energy consumption in the home office constitutes one of the major obstacles to decrease GHG emissions. The effectiveness of the home office in terms of its environmental benefits (i.e. CO_2 saving potential) could be measured by analysing seven rebound effects [17]

i. Home Office: Heating and cooling of the home office
ii. Devices: Personal electronic devices
iii. Home: Induced use of lighting, appliance and electronics

[15] - Direct rebound effect: an increase in efficiency leads to a reduction in the price of an energy service, which is therefore in greater demand. This has an impact on energy consumption (substitution effect).
- Indirect rebound effect: Making energy services cheaper increases the income of a household, which it can spend on other goods and services. This can also have an impact on energy consumption (income effect).
- Other effects: The increase in energy efficiency can trigger further long-term effects in the economy as a whole. For example, increasing energy efficiency can stimulate the development of new products and services or change consumer preferences. This also influences the energy consumption of an economy (dynamic effects). Mathias Binswanger (2015) Nachhaltigkeit als Chance für Unternehmen und Gesellschaft?, Windisch: Fachhochschule Nordwestschweiz

[16] The Guardian: Carbon benefits of homeworking under the spotlight, 29.05.2014. https://www.theguardian.com/sustainable-business/homeworking-carbon-increases-emissions

[17] Fredrik Aadne Reitan (2014) The Rebound Effect:
A Simulation Model of Telecommuting. MSc. Thesis. Trondheim: Norwegian University of Science and Technology, Department of Telematics, p. 80

iv. Office: Flexible office and office related energy consumption
v. Relocation: Telecommuters moving further away from work
vi. Car availability: Car available for the household
vii. Congestion: Reduction in travel time due to less commuters

The examination of the individual rebound effects and their interrelations would provide an overall assessment of whether homeworking is an environmentally friendly or environmentally harmful solution. Since energy consumption is considered to be one of the crucial factors of homeworking, some sources propose to introduce homeworking within seasons with less intensive energy consumption, particularly in the winter months. The consideration of such variations is however hampered by the insufficient availability of data.

In light of the views stated above, when considering a properly rationalized 20 percent share of telecommuting[18], the rebound effect is estimated by international sources between 25 and 35 percent. Rebound effects do not only arise with E-working but also other so-called "smart solutions". Hilty and Bieser (2017, p. 31) estimate the following rebound effects for different purposes for Switzerland:[19]

Table 2 Example of rebound effects estimated for different "smart solutions" in Switzerland

Use Case	Effect	Description
Smart Logistics	18%	Cost: Cost reduction in freight logistics increase the demand for freight
Traffic Control & Optimization	20%	Cost: Reduction in cost of transportation increases transportation for other purposes
Smart Buildings	4%	Cost: Reduction in energy consumption for buildings increases consumption for other purposes
Smart Energy	4%	Cost: Reduction in energy consumption increases consumption for other purposes
E-Learning	23%	Time and cost: Reduction in transportation for learning increases transportation for other purposes.
E-Commerce	37%	Time and cost: Reduction in transportation for purchases increases transport for other purposes
E-Work	31%	Time and cost: Reduction in transportation for work increases transportation for other purposes.
E-Banking	17%	Time and cost: Reduction in transportation for banking increases transportation for other purposes
Connected Private Transportation	20%	Cost: Reduction in cost of transportation increases transportation for other purposes
E-Health	37%	Time and cost: Reduction in transportation for health service increases transportation for other purposes.

[18] This can be potentially assumed at least as regards broadband performance: Broadband coverage in the Frankfurt/Rhein-Main region is favourable and quite homogenously distributed across space as illustrated by the Breitband-Atlas (https://www.bmvi.de/DE/Themen/Digitales/Breitbandausbau/Breitbandatlas-Karte/start.html).

[19] Lorenz M. Hilty and Jan C.T. Bieser (2017):
Opportunities and Risks of Digitalization for Climate Protection in Switzerland, Department of Informatics University of Zurich, Zurich, Switzerland

Reitan (2014) provides the global estimate for telecommuting of 27,4 percent, based on a simulation study for the Los Angeles region; For the purpose of simplicity we have also used that parameter in this study on Frankfurt/Rhein-Main[20]. Provided the 20 percent commuter reduction can potentially materialise, provided social partners (employers and trade unions) and policy will establish an adequate legal framework for that, the rebound effect for the entire NUTS3 Region Frankfurt/Rhein-Main would be thus 24,833 tons (rebound effect II; cf. table 3). This effect is to be subtracted from the gross saving effect of 90,632 tons. The remaining net effect for the entire region thus remains at around 65,800 tons. This is however just an absolute number and does not contain information whether this constitutes a potential major regulating screw for adjustment in combating climate change. This will become transparent when comparing commuter caused GHG emissions with total emissions at a respective spatial level.

3.3 Relative saving effect at district level (NUTS 3)

Taking in account the data and parameters of the various data sources and studies it is possible to estimate the spatial variation of CO_2 saving effects as compared to total GHG emissions. For this purpose, the maximum share of saving effects from the total GHG emissions at district level is calculated (based on a 20 percent reduction of commuting). The total CO_2 equivalent emitted in this region was specified as to 24 million tons CO_2 tons in 2016[21]. This only comprises emissions from energy outputs. Even though energy is in fact the major emitter of GHG (84 percent in 2018 for Germany), there are other sources of GHG emissions, such as industry, agriculture and waste not covered by the calculation below.[22]

As shown in table 3, the overall relative effect is significantly below 0.5 percent with a variation between 0.14 percent for the city of Frankfurt and 0.44 percent for the city of Offenbach. The mean for the region is 0.27 percent, the unweighted mean for all districts is around 0.33 percent and the standard deviation at 0.1.

Table 3 GHG reduction effect at district level

NUTS 3	Out-commuting gross	Out-commuting net	CO_2 equivalent	Gross saving effects I	Gross saving effects II
Frankfurt	96,074	63,486	82,178,175	8,217,817	16,435,635
Groß-Gerau	64,883	42,875	55,498,538	5,549,854	11,099,708
Hochtaunuskreis	47,408	31,327	40,551,064	4,055,106	8,110,213
Main-Kinzig-Kreis	74,012	48,907	63,307,149	6,330,715	12,661,430
Main-Taunus-Kreis	62,765	41,475	53,686,878	5,368,688	10,737,376
Offenbach Land	83,368	55,090	71,309,928	7,130,993	14,261,986

[20] Fredrik Aadne Reitan (2014) ibid.; Binswanger, M. (2001): Technological progress and sustainable development: what about the Rebound Effect? Ecological Economics 36: 119-132; Sorrell, S. (2007): The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency. London: UK Energy Research Centre, Imperial College

[21] Total calculated from: Regionalverband Frankfurt/Rhein-Main: Kommunale Energiesteckbriefe 2016, Frankfurt, 2018

[22] Cf.: Umweltbundesamt: https://www.umweltbundesamt.de/themen/klima-energie/treibhausgas-emissionen

Offenbach Stadt	36,393	24,048	31,129,237	3,112,924	6,225,847
Wetteraukreis	64,888	42,878	55,502,814	5,550,281	11,100,563
Total	529,791	350,086	453,163,783	45,316,378	90,632,757

Table contd.

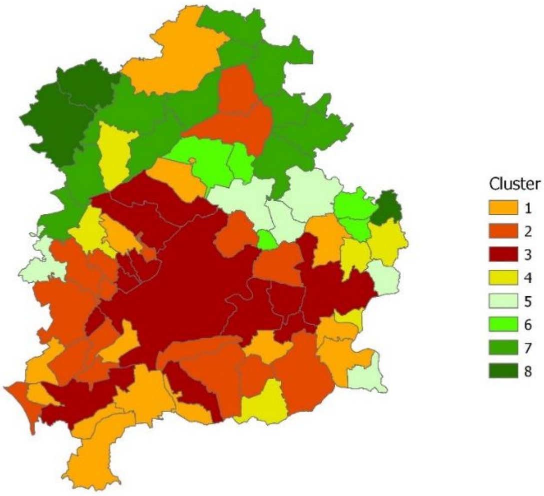
NUTS 3	Rebound effects I	Rebound effects II	Net effects I	Net effects II	Total emission	**Saving share max. (%)**
Frankfurt	2,251,682	4,503,364	5,966,135	11,932,271	8,278,061,000	**0.14**
Groß-Gerau	1,520,660	3,041,320	4,029,194	8,058,388	1,876,779,000	**0.43**
Hochtaunuskreis	1,111,099	2,222,198	2,944,007	5,888,014	2,215,323,000	**0.27**
Main-Kinzig-Kreis	1,734,616	3,469,232	4,596,099	9,192,198	3,453,534,000	**0.27**
Main-Taunus-Kreis	1,471,020	2,942,041	3,897,667	7,795,335	2,080,566,000	**0.37**
Offenbach Land	1,953,892	3,907,784	5,177,101	10,354,202	3,200,578,000	**0.32**
Offenbach Stadt	852,941	1,705,882	2,259,983	4,519,965	1,034,978,000	**0.44**
Wetteraukreis	1,520,777	3,041,554	4,029,504	8,059,009	1,923,548,000	**0.42**
Total	12,416,688	24,833,375	32,899,691	65,799,381	24,063,367,000	***0.33***

3.4 The effect at the level of functional space

It is also possible to estimate the GHG saving effect of a 20 percent reduction in commuting for urban, peri-urban and rural space classes. For that purpose, we can draw on the statistical classification by Budde (2018) who extracted one urban, one rural and three peri-urban classes of functional space by using kernel density estimation on the distribution of population density (based on small-scale grid data on population density)[23]. This classification was further refined by cluster analysis in order to examine differences in commuting patterns among and within such functional regions. The analysis resulted in eight clusters as presented in the following map:

[23] Budde, Rüdiger (2018): Socio-economic analysis of the urban-rural continuum of the Frankfurt / Rhine-Main region: An in-depth exploration at small spatial scale, Bad Soden (ROBUST deliverable 2.3)

Figure 2 Segmentation of functional sub-regions based on kernel density and subsequent cluster analysis



Source of data: Microm, IAB (see: Budde 2018)

Clusters 1, 2 and 3 are urban, peri-urban and rural regions and have a lively commuter exchange among themselves. Cluster 3 clearly represents the central urban region. The municipalities in cluster groups 4, 5 and 6 show a similar commuting pattern but those are less densely populated, so that they rather represent smaller and medium-sized peri-urban structures. The municipalities in cluster groups 7 and 8 represent primarily rural areas. It can be seen that these areas maintain a lively commuter exchange among themselves. A reason might be longer distance, poor accessibility and less capacities of public transport.

For all eight classes the commuter linkages and streams were estimated. Table 2 shows out-commuting among the municipalities (thus within the region of the Regionalverband Frankfurt/Rhein-Main). The data on out-commuters at district level show the totals, i.e. including out-commuting streams beyond the boundaries of the Regionalverband. This has resulted in different totals (428,000 versus 529,000 commuters).

Further to that, Table 4 shows the net saving effects based on the analogous methodology. Since there are no data on total GHG emissions for the eight functional classes, we can only display the absolute numbers. In absolute terms, the largest saving potentials can be identified in the central urban region (cluster 3), followed by peri-urban areas belonging to cluster 2. This also comprises sub-regions isolated from the central urban region (e.g. Friedberg and Bad Nauheim). With potential saving effects of more than 7,000 tons Cluster 1 comprises a spatially more dispersed distribution. The potential absolute saving effect in the municipalities represented by the other clusters is substantially lower.

Table 4 GHG reduction effect at the level of functionally classified space[24]

Rural-urban*	Out-commuting	Out-commuting net	CO_2 equivalent	Gross saving effects II	Rebound effects II	Net effects II
1	61,335	40,530	52,463,709	10,500,848	2,877,232	7,623,615
2	117,873	77,890	100,824,239	20,180,426	5,529,437	14,650,989
3	168,164	111,123	143,841,315	28,790,488	7,888,594	20,901,894
4	22,500	14,868	19,245,674	3,852,108	1,055,478	2,796,631
5	23,079	15,251	19,740,930	3,951,236	1,082,639	2,868,597
6	8,905	5,884	7,617,010	1,524,579	417,735	1,106,844
7	22,350	14,769	19,117,370	3,826,428	1,048,441	2,777,987
8	3,763	2,487	3,218,732	644,244	176,523	467,721
Totals	427,969	282,802	366,068,980	73,270,356	20,076,078	53,194,279

* Rural urban functional continuum (eight clusters)

Source of data: Microm GmbH, IAB (see. Budde 2018)

4. Conclusion

The relative effect of a 20 percent reduction of commuting appears rather moderate. The reason for that is that vehicle fuel makes up only about 15-25 percent of all CO_2 emissions (Frankfurt 17 percent, Offenbach 25 percent, Main-Kinzig 19 percent). Other bigger emission sources are coal, mineral oil, and gas, notably for heating and production. As regards the mix of car fuel it is to be stressed that slightly more than half of vehicle fuel is represented by Diesel. Here it is to be noted that a major share of Diesel consumption is attributed to commercial transport (trucks, buses, trains, inland water transport) and not just private cars. Further to that, commuting is only part of possible car use. Hence, on the one hand, the reverse conclusion, at a first glimpse, would be that commuting does not appear to be a powerful regulating screw of climate change. On the other hand, the absolute effect of around 65,800 tons per year for a region with slightly less than 2.5 million inhabitants on just 2,500 square kilometres is quite substantial. Due to the fact that the region is densely populated, being a central part of a leading metropolitan German region, the overall relative effect (for the country) is much larger than that of a sparsely populated region of similar spatial size. With other words: just in agglomeration regions such as Frankfurt/Rhein-Main it would be worth considering less commuting for a better environment.

5. Further outlook

The threat of climate change is not the only argument of expounding undamped increase of commuting, especially in densely populated boom regions such as Frankfurt/Rhein-Main.

Rapidly increasing potentials of rationalisation and the use of artificial intelligence will anyway lead to a major structural change in industry and services with a major reduction of the

[24] 20 percent reduction in commuting; Net effects II

contribution of the production factor labour. Erik Brynjolfsson and Andrew McAfee (2010) have shown how information technologies are affecting jobs, skills, wages, and the economy. The enormous fear of unemployment is seen as a cultural phenomenon but in fact it is much less a terrible scourge as perceived by a majority of people. In fact, it can be understood as the opposite. The most important finding is that: … "The economics of digital information, in short, are the economics not of scarcity but of abundance. This is a fundamental shift, and a fundamentally beneficial one ..."[25]. It is therefore little choice between the strong forces of such major structural change in work life and weak forces aimed at withstanding such structural change, or with the words of Jeremy Rifkin: "The end of work"[26]. This secular trend will inevitably lead to less commuting – not understood as an indication of rampant unemployment with broad impoverishment but rather one of increasing social wealth.

A second strand of argumentation is related to how jobs in different sectors benefit individuals on the one hand and the civil society on the other. Without going into detail, the work of David Graeber contemplating on the divide between necessary jobs and the big number of so-called "bullshit jobs" reveals a lot about issues of efficiency and squandering valuable resources in modern economies[27]. Graeber refers to the famous economist John Maynard Keynes who already in 1930 predicted a fifteen-hours working week by the end of the 20th century in Britain and in the US. Technologically this would have been feasible. However, new technology has not only been applied to rationalise but rather used to create new jobs, not necessarily the sort of jobs that benefits the civil society but in many cases rather just to perpetuate work as an end in itself.

Both above mentioned threads of economic-philosophical argumentation are still rather abstract, and they hardly represent operational categories for local policies for the time being. However, they make clear that the direly needed protection of the world climate is more than just the search for smart solutions, such as telecommuting in gridlock-stuck boom regions.

[25] Erik Brynjolfsson and Andrew McAfee (2010) Race against the machine, Lexongton (Mass.): Digital Frontier Press

[26] Jeremy Rifkin (1995) The end of work: The decline of the global labour force and the dawn of the post-market era, New York: J. P. Putnam's Sons

[27] David Graeber (2018) Bullshit jobs: A theory, New York: Simon & Schuster