Switzerland: railway or aviation nation?

Emission saving potential from replacing air by train travel between Switzerland and Europe and the possibilities for the Swiss government to foster this mode shift.

Renè Inderbitzin

Master Thesis Series in Environmental Studies and Sustainability Science, No 2019:045

A thesis submitted in partial fulfillment of the requirements of Lund University International Master's Programme in Environmental Studies and Sustainability Science (30hp/credits)

LUCSUS

Lund University Centre for Sustainability Studies

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Submitted October 2, 2019

Supervisor: David O'Byrne, LUCSUS, Lund University

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Abstract

Even though flying is the most unsustainable mode of transport due to its high contribution to global climate change (global warming), it is widely used and is predicted to increase considerably in the future. This goes against the global goal to reduce greenhouse gas (GHG) emission in order to reach the two-degree target set in the Paris Agreement. I am addressing this problem by looking into the emission-saving potential (ESP) from a mode shift from air travel to train travel on connections between Switzerland and Europe. In a second step, I use the multi-level perspective (MLP) framework to analyze how this mode-shift can be achieved and how the Swiss government can foster it. I use flight data to calculate the emission saving potential and academic and grey literature to do the MLP-analysis. I found that the ESP of such a mode shift is high. Annually 7.8 million tonnes CO2e could be saved when replacing all air travel from Switzerland to Europe where train travel is available. If all air travel where train connections exist that are faster than 16 hours would be replaced, 4.8 tonnes CO2e could be saved per year. The current climate movement is likely to open a window of opportunity for such a mode-shift to happen. The Swiss elections coming up in October of 2019 are most likely going to bring a significant rise in seats for the green parties. This makes the changes needed to support a mode-shift more likely. These are the introduction of the VAT on international flight tickets and the flight ticket tax, the expansion of the night train network and support for innovations to improve online booking for international train travel.

Keywords: mode-shift, sustainable transport, air travel, train travel, multi-level perspective, Switzerland

Word count (thesis): 14’000

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List of Abbreviations

Institutions

amcham	The Swiss-American Chamber of Commerce
ARE	Bundesamt für Raumentwicklung
BAFU	Bundesamt für Umwelt
BAV	Bundesamt für Verkehr
BAZL	Bundesamt für Zivilluftfahrt
BCG	The Boston Consulting Group
BFS	Bundesamt für Statistik
EFD	Eidgenössisches Finanzdepartement
FSO	Federal Statistical Office
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
UBA	Umweltbundesamt Deutschland
UN	United Nations
UNEP	United Nations Environment Programme
UREK-S	Sekretariat der Kommissionen für Umwelt, Raumplanung und Energie

Non institutions

AE	Emissions resulting from air travel
MLP	Multi Level Perspective Framework
RF	Radiative forcing
VAT	Value Added Tax
TE	Emissions resulting from train travel

1 Introduction

Global warming is the biggest challenge humanity faces today. Each of the last three decades has been the warmest ever recorded. It is scientifically proven that global warming is caused by carbon dioxide (CO2) and other greenhouse gases (GHG) which are released by human activities (IPCC, 2013). The global community has agreed to keep the global average temperature rise well below two degrees compared to the pre-industrial average (UN, 2015). If this target is not achieved, we will leave the safe operating space of the planet and risk disastrous climate effects (Steffen et al., 2018). The countries who ratified the Paris Agreement are installing national climate targets to contribute their share to achieve the two-degree goal (Rogelj et al., 2016).

International air travel is not part of these targets even though it is a large and fast-growing emitter of GHG emissions (Gössling, 2018). While other sectors are making efforts to reduce their emissions, aviation emissions (AE) are steadily rising and predicted to continue to do so in the future (Bows-Larkin, Mander, Traut, Anderson, & Wood, 2016). The high level of emissions, these predictions and the fact that emissions from air travel are only emitted by very few people (only two-three percent of people take international air travel annually (Gössling & Upham, 2009)), makes air travel one of the biggest threats in achieving the two-degree target. In sustainability science, transportation is one of the big topics and is seen as a sector that has to be transformed as a whole to achieve a sustainable society (Geels, 2018). The complexity of the sector itself and the entanglement with all of the other sectors make the transition to a more sustainable transportation system a typical "wicked problem" (Geels, 2018).

In my thesis, I am looking into transportation and air travel from a specific geographical angle. I chose to study air travel and its possible substitution through train travel from a Swiss perspective. This is on one side based on my origin from this state and on the other hand on the fact that Swiss people fly the second most after Norwegians in the world. 77% of these flights are taken to European destinations (BFS and ARE, 2017), even though a good alternative mode of transport: train travel, exists. I am curious to find out if train travel could replace this air travel from Switzerland to European destinations. Looking into the existing literature showed, that there is no study done looking into the competition or mode-shift between air and rail travel from Switzerland to European destinations. Von Arx, Thao, Wegelin, Maarfield, and Frölicher (2018) looked into the influence of different business models on rail travel in Europe from a Swiss perspective. That study gives good insight into the train travel mode and very few comparisons with air travel. It doesn't look into mode-shift at all. There are studies regarding mode-shift from air travel to train travel which are not concerning Switzerland but are still of importance for my research. Dobruszkes (2011) researches the competition between air travel and high-speed rail (HSR) on five connections in Europe. His analysis based on travel-time and ticket price comparing the passenger development over time showed that the development of HSR didn't prevent growth in air traffic. His next study together with Dehon and Givoni (2014) analysed if the provision of air service is influenced by the availability of HSR on 161 routes in the EU. They found that there is less air-service on HSR routes faster than 2.5 hours, and there is no effect on the longer routes. Contrasting these two studies which only found little influence of HSR availability on air travel, a large-scale study modelling mode-shift from air to HSR showed that there will be a big effect in saving GHG emissions (Nelldal & Andersson, 2012). The results are based on the projected development of the HSR network in Europe, and the modal share based on journey time which is known from current connections. This study's results show that by 2050, 20-30 % of GHG emissions in Europe could be saved. Another study showing positive results regarding emissions saving was done by Baumeister (2019). He analysed 17 connections in Finland where train travel and air travel compete and found that a mode-shift could significantly reduce the country's climate-impact. Additionally, his results showed that train travel times can keep up with air travel-times up to 400 kilometres in travel distance. None of these studies looked closely into the socio-economic factors that influence a mode-shift in transportation. Geels (2018) does this thoroughly in the case of the UK by applying his multi-level perspective (MLP) on socio-economic transitions towards sustainability.

These studies indicate that 1) there is nothing known about the emission saving potential (ESP) regarding international air travel and train travel from Switzerland and 2) there is no study looking into the socio-economic factors of such a mode-shift from a Swiss perspective. This opens up a research gap for me to conduct my study. I am aiming to fill this gap by answering the following research questions:

RQ 1: In Switzerland, what is the potential of train travel to reduce GHG emissions in comparison to air travel, to the rest of Europe?

RQ 2: How can this mode-shift from air to rail on routes between Switzerland and the rest of Europe be achieved, and how can the Swiss government foster this mode-shift?

2 Background

2.1 Environmental impact of air and train travel

2.1.1 Environmental impact of air travel

Flying from Zurich to London in one hour and 45 minutes (flying time only) is without any doubt an impressive technical achievement. On the other hand, it is no surprise that lifting up an aluminium construction with up to 868 passengers and a total weight of up to 590 tones ('Airbus A380-800F Wide-Bodied Freighter', 2019) requires an immense amount of energy. Considering the fact that planes have to carry their energy supply along, it makes sense that airplanes are driven by the most energy-dense propellants: fossil fuel-based jet fuels. Even though these fuels are relatively light compared to the energy they deliver, they make up for 47% (277 tones) of the starting weight in an Airbus A380 (Buescher, 2001). Burning such an immense amount of fossil fuels makes air travel an extremely CO2-intense mode of traveling. The CO2-emissions and the consequential contribution to global warming are not the only environmental impact of airplanes, as we shall see in the following paragraph.

Gössling (2018) lists seven environmental issues with a total of 22 areas of concern as environmental impacts of air travel. The seven issues are: aircraft noise, local air quality, airport infrastructure construction, water and soil pollution, waste generation, aircraft accidents/incidents and global warming. The last one: air travel's contribution to global warming, is considered being the industry's biggest impact on the environment (O'Connell, 2018).

In 1999 the Intergovernmental Panel on Climate Change (IPCC), published a special report on air travel and global warming (IPCC, 1999) to emphasize the importance of this sector in relation to global warming. The air travel industry's contribution to global warming is important for several reasons. The political and economic reasons are discussed in the next chapter (2.2 The historical perspective). As explained previously, airplanes consume, by their nature, high amounts of fossil fuels. This results in high numbers of GHG emissions and additional negative effects in the sensitive layers of the atmosphere (O'Connell, 2018).

Kollmuss and Crimmins (2009) summarize the climate-impact of air travel in four categories: direct GHG emissions, indirect impacts of GHGs, emissions of aerosols, formation of contrails and cirrus clouds. There is scientific agreement that air travel's impact on global warming is higher than just the effects of the direct CO2 that the airplanes emit. Emissions in sensitive layers of the atmosphere, primarily the upper troposphere and lower stratosphere, have an additional negative effect on global warming due to reactions between atmospheric gases and the emissions (Jungbluth & Meili, 2019). To calculate the total effect of air travel on global warming, the concept of Radiative Forcing (RF) is used (Lee et al., 2009). RF describes the ability of a gas to alter our planet's energy balance. The earth receives energy from the sun, some of this energy is being reflected directedly back into space, and some is absorbed by the planet, turned into heat and reflected back into space in the form of infrared radiation. Gases and particles in the atmosphere can both prevent the sun's radiation from entering the atmosphere and prevent infrared radiation from being emitted into space. They therefore change the planet's energy balance. RF measures this change in the earth's energy balance caused by emissions in Watts per square meter (W/m2). RF is a good measure for the total impact of AE at one specific moment but does not express the impact they have in the future. Different gases and secondary effects from AE like cirrus clouds have widely varying lifetimes in the atmosphere. Therefore, it is clear that a measure like RF, which only expresses a momentary value, is not adequate to express the overall impact of air travel on global warming. Furthermore, newer research found that not only the altitude of the airplane, but also its location on the globe and the season have a remarkable influence on its RF (Lee et al., 2009).

As made clear in the previous section, calculation of air travel's contribution to global warming is complex and depends to a big extent on varying factors for each specific case. Nonetheless, in some cases, especially in Life Cycle Assessment (LCA) calculations, a simpler approach is needed. In these cases, the use of a multiplication factor is common to account for the RF of AE not related to CO2. The IPCC suggested to use the factor 2.7 in its report on air travel and global warming (IPCC, 1999). According to Kollmuss and Crimmins (2009) 2.7 is the most widely used factor in AE calculation. A newly published overview-study on the climate change potential of air travel (Jungbluth & Meili, 2019) suggest using the factor of two for overall calculations and the factor of 5.2 for emissions in the higher atmosphere. The average multiplication factor I used in this thesis is 1.43. The calculation of this factor is explained in Chapter 4.1.3.

2.1.2 Environmental impact of train travel

Song et al. (2014) group the environmental impact of train travel into four categories: impacts on the atmospheric environment, the ecological environment, the water environment and the voice environment. Each category contains effects from the railway construction and operation. In my thesis, I focus on the impact of train travel on global warming since this is the biggest impact of air travel, and my goal is to compare train travel to air travel.

To move a train from A to B, energy is needed. Compared to lift a plane up in the air, the amount of energy used to move a train is quite low. Trains roll along on railways and additionally don't have to carry their energy supply along since they are mostly powered by electricity (in Europe). The energy needed is determined by the weight of the train, the speed which influences the air resistance, the friction on the rails and the difference in altitude that has to be covered (UIC, 2016). The energy consumption rises with the speed of the train due to rising aerodynamic drag. According to the International Union of Railways (2016) at speeds over 200 Km/h, aerodynamic drag dominates the trains resistance to motion. That is why for high-speed trains the aerodynamic construction is of great importance.

The emissions resulting from train travel (TE) depend, as explained in the previous chapter, on the type of train and its energy consumption but also on the energy source used to power the train. In Europe, 60 % of all train travel kilometres are electrified, with 80% of the transport running on these lines (European Commission, 2017). Non-electrified railways use diesel locomotives as power units. The electrified railways source their energy from different sources depending on the country. In Europe, the railway fuel mix, including the diesel locomotives, consists of 61% fossil sources, 18% nuclear sources and 21% renewable sources (European Commission, 2017).

2.2 The historical perspective

2.2.1 History of train travel globally and in Europe

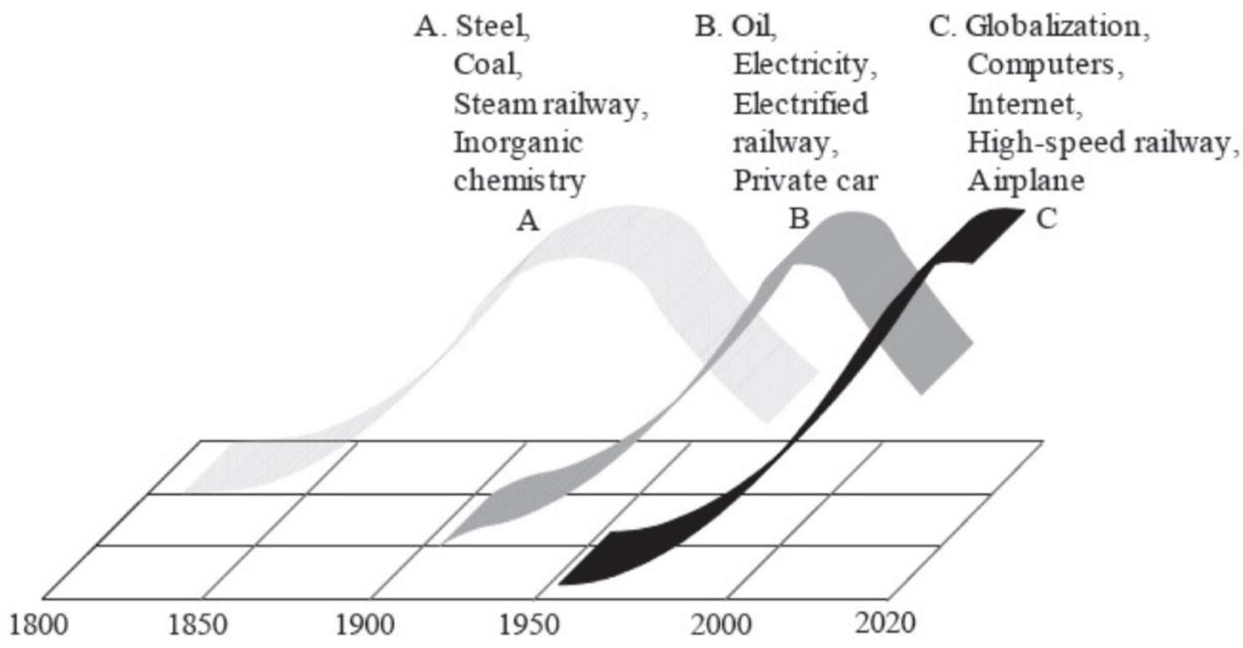

Figure 1: The three phases of the development of train travel (Profillidis, 2014).

The beginning of train travel as we know it today is closely connected to the Industrial Revolution. The invention of the steam engine and the exploitation of coal and steel were the technical and material base for the establishment of train travel (Profillidis, 2014). The first train travel lines were established around 1830 in several European countries. Profillidis (2014) divides the development of train travel into 3 phases which are all closely linked to a larger economic cycle on a global level (See Figure 1). In the previously described first phase, the railways were owned by private companies. These companies were a part of the flourishing economy after the 1850s and played with their ability to transport passengers and goods, an important role in the industrial revolution. Due to lower returns than predicted and high investments, these companies soon got into financial problems. The companies were rescued by the state and by 1935 many countries started to nationalize their railways because they played an important role for their economic development (Profillidis, 2014).

The electrification of the railways in the beginning of the 20th century marks the third phase of train travel development (see Figure 1). Electrical engines and especially the ability for automatic train control and signalling enlarged the carrying capacity of train travels from the 1950s onwards (Profillidis, 2014). At the same time, the competition from cars and airplanes was growing. In many countries, the national train travel companies were not seen as sufficiently competitive anymore. The countries reacted with privatization or semi-privatization of their train travel or opening up the rail network for competitors (Profillidis, 2006).

2.2.2 History of aviation globally

Air travel has a much shorter history than train travel. In 1903, the Wright brothers were the first to construct a flying and manoeuvrable airplane (Gössling & Upham, 2009). Just 6 years later, Louis Bleriot's crossing of the English Channel was a huge sensation and widely covered by the media (Grant, 2017). In the First World War, aircraft was used for the first time on a daily basis and was further developed under the pressure of competition. In WWII, planes were a crucial component of warfare. For military and for civil causes, the speed of aircrafts was crucial. During and after the war, jet aircrafts, which made significantly faster air travel possible, were invented. These faster planes, combined with more comfort and bigger cabin sizes, accelerated commercial air travel in the 1950s. Many transatlantic air routes were established, and by 1957, more people were crossing the Atlantic by plane than by boat (Grant, 2017). Since the 1950 up to today annual passenger kilometres travelled by airplanes have been continuously rising (see Figure 2).

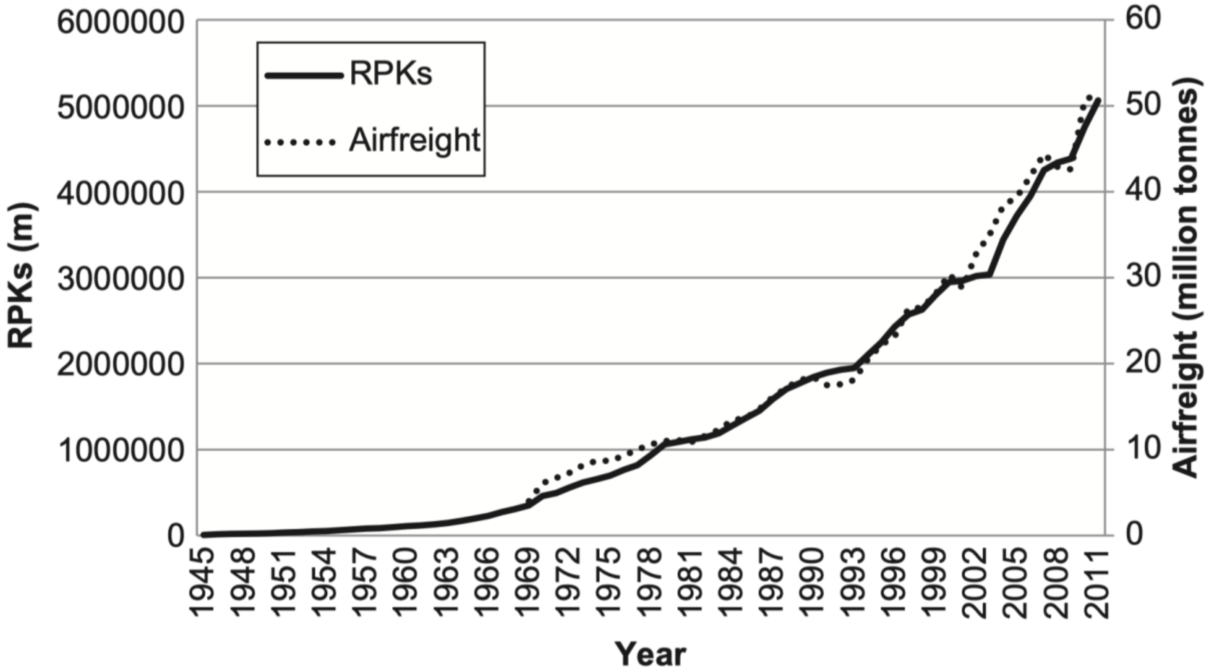

Figure 2: The kilometres travelled by passengers per year (RPKS) between 1945 and 2011(Budd, Griggs, & Howarth, 2013).

3 Theoretical Approach

3.1 The multi-level perspective framework (MLP)

In the first part of the results, I will indicate how much GHG emissions could be saved by replacing air travel from and to Swiss airports with train travel. This is a more-or-less straightforward calculation. Looking at the problem in reality and the possibility to solve it is a much more complex matter. This complexity is typical for current sustainability problems (Jerneck et al., 2011), so-called "wicked problems".

This complexity and multidimensionality is, according to Geels (2010), typical for a modern sustainability problems. Geels (2010) states that environmental problems in the 1970s, like acid rain and water pollution, were simpler and could be fixed more easily, with technological interventions alone. The complex environmental problems of today cannot be fixed so easily. Whole sectors like transportation, agriculture or energy have to be transformed in order to achieve a transition towards a more sustainable world. Geels (2010) calls these transitions socio-technical transitions because technological fixes alone cannot address their complexity. Changes "in markets, user practices, policy and cultural meanings"(Geels, 2010, p. 495) are needed. According to Geels (2010), transitions towards sustainability are very difficult to achieve and have three special characteristics which set them apart from many other transitions. First, they are goal oriented, meaning a specific, more-sustainable state of a system wants to be achieved. The historical transitions that Geels (2010) analysed to develop his framework were mostly emergent, meaning companies were taking the opportunities that new technological inventions opened up. Second, sustainability transitions have no obvious benefits for users or companies. The improvement that is done regarding sustainability is for a collective good. This means that the economic conditions have to be changed, like introducing new taxes, subsidies or regulatory frameworks. Third, the important domains for sustainability transitions like transportation, energy and agri-food are dominated by big established companies which are going to stick to business as usual and make it difficult for innovation to break through.

To understand these socio-technical transitions better, Geels (2010) reviewed theories about social change from seven different ontologies (rational choice, evolution theory, structuralism, interpretivism, functionalism, conflict and power struggle and relationism). Based on that review, he developed the MLP on sustainability transitions (O'Brien, 2018). This framework can be used to analyse complex socio-technical transitions towards sustainability.

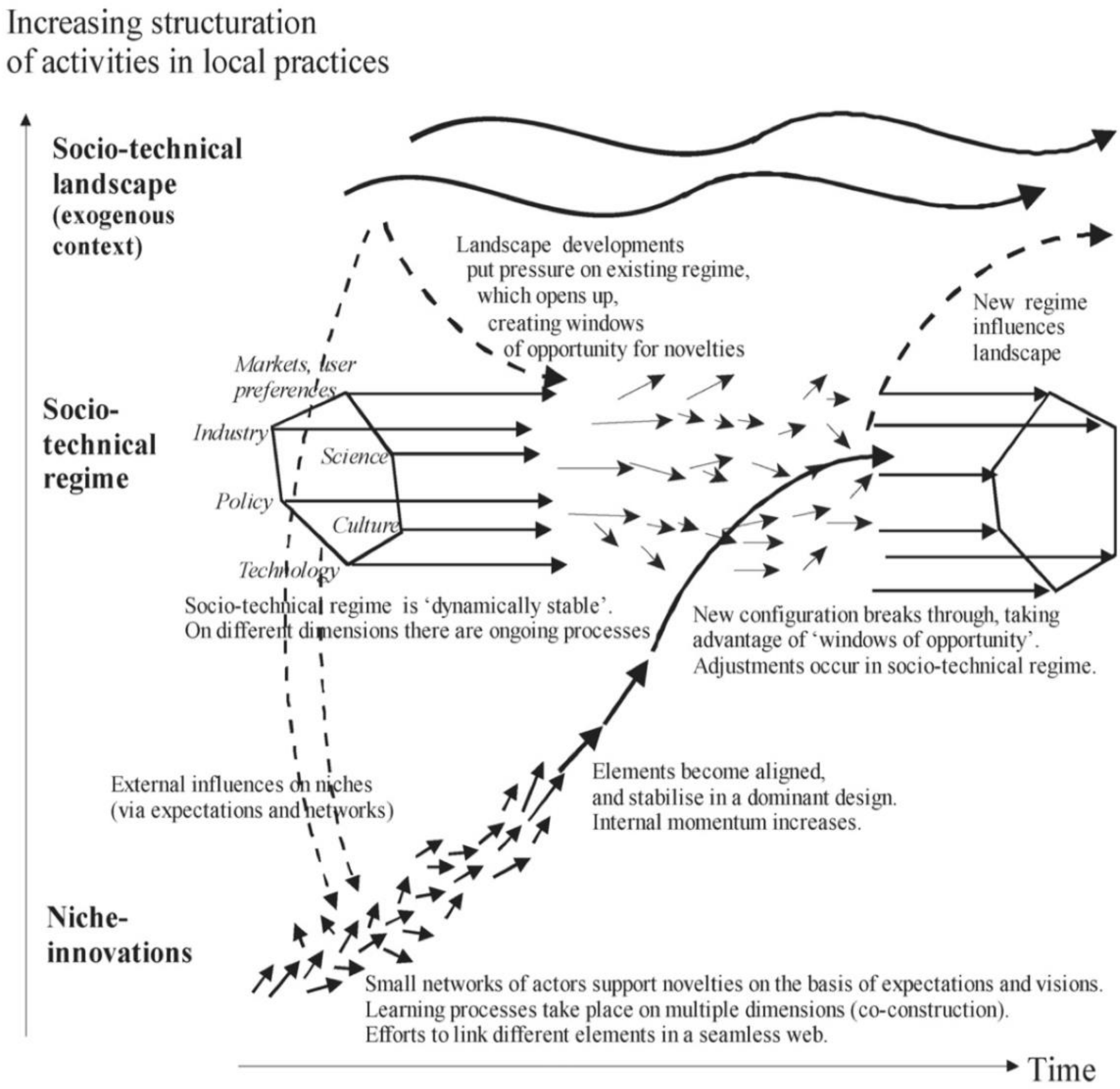

Figure 3: Socio-economic transitions towards sustainability happen through interactions on the niche, regime and landscape level (Geels & Schot, 2007).

Geels and Schot (2007) structure socio-economic transitions towards sustainability in three levels: the socio-technical landscape, the socio-technical regime and the niche-innovations (Figure 3). The regime level consists of systems that have established themselves over a long period of time and are therefore in a dynamically stable state. Changes such as innovations can occur in these regimes, but only at a slow pace and in a stable manner. The socio-technical regime is a system that consists of sub-systems that are in exchange and stabilize each other. These subsystems are related to socio-culture, policy, science, technology, production networks and industry structures, and user practices and markets (see Figure 4). If such an established regime is not sustainable and actors want to change it into a more sustainable one, this stability means it is difficult to alter the system, resulting in a lock-in. The established cultures, policies and especially markets, which are typically dominated by incumbent firms, want to keep the current regime in place.

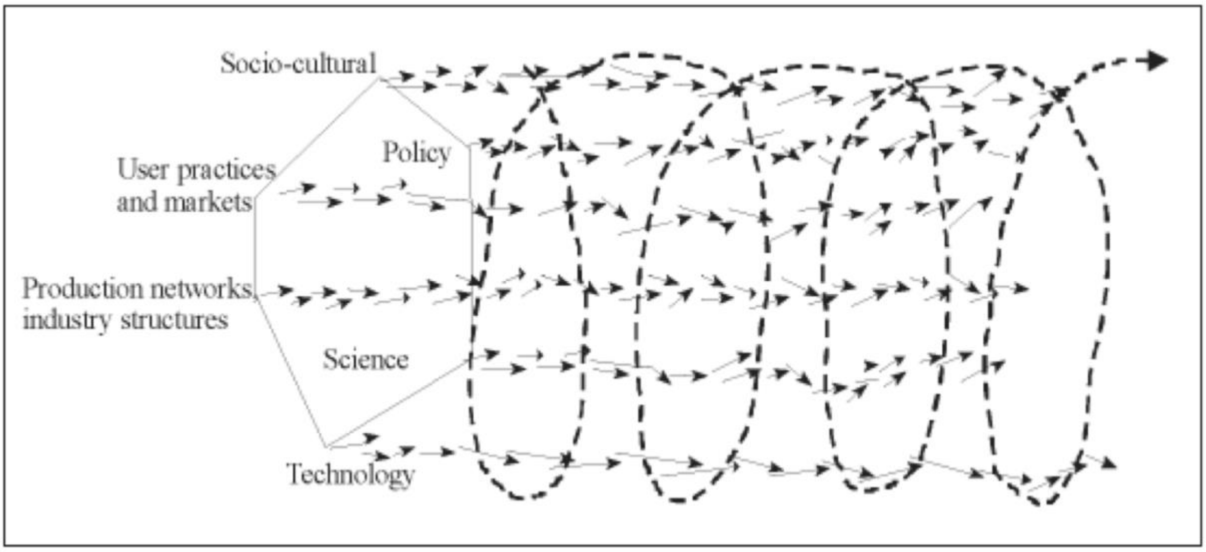

Figure 4: A regime is a stable system which can develop in a incremental way through interaction between its sub-systems (Geels & Schot, 2010).

Even though Geels (2016) states that incumbent firms can be part of bigger socio-economical change, , in most cases this change comes from smaller, more innovative players on the niche level.

In the MLP framework , the disruptive change of socio-technical regimes comes from niche-innovations (niche-level) (Geels, 2011). Niches are protected spaces where innovation can happen outside of market pressure. These niches can be research and development laboratories in companies, projects that are financed by subsidies or small market-niches where there are specific customers who are willing to pay more for products or services that align with their missions. Due to the absence of market-pressure innovations are more likely to occur in these niches. These niche-innovations can be off technological nature, new services or new business models. Niche-innovations can develop certain strength within the niche level through learning processes, developing networks and attracting investors. However, in order to challenge the existing regime, simultaneous processes in the niche regime and landscape level are necessary. Additional to a niche getting stronger, a weakening off the existing regime has to happen from within and on the landscape level, processes have to open up a window of opportunity (Geels, 2011).

Geels defines (2011). the socio-technical landscape (landscape level) is the external context in which regime and niche level are embedded but cannot influence. It includes slow-changing trends such as demographic development, societal values or geopolitical dynamics. Additionally, it also contains external shock events such as wars, economic crises or political riots. Landscape events such as global warming can put pressure on the existing regimes and destabilize them. According to the MLP theory, a transition is never just caused by one driver. Only an alignment of dynamics in the landscape regime and niche level and in-between them makes big social-economic transitions possible. A typical transition according to the MLP framework happens in the following way: an event in the landscape level puts pressure on the existing regime and opens a window of opportunity, if at the same time the regime is destabilized from dynamics within and innovation has developed strong enough in the niche level, then this innovation can disrupt the existing regime and replace it (Geels, 2011).

According to Geels etal. (2017) this transition-process typically happen in four phases. The first phase is characterized by many small and experimental unstable innovations. Most of them fail and the networks of the innovators are still small and unstable. In the second phase, innovations create their own market-niche and attract first small investments. Rules and regulations around the innovations start to develop. The third phase is characterized by a wide breakthrough of the innovation. The niche-market has grown to a size where it starts to compete with the existing regime. In this phase, the niche-innovation and the existing regime compete with each other on many levels. The logic of the MLP such as pressures from the landscape level destabilizing the existing regime and competition for subsidies and social acceptance now play an important role. The fourth phase describes the replacement of the actual regime by their former niche-innovation. In this phase, the whole social and economic system adjusts to the new regime on a political, economic and cultural level (Geels, 2011).

3.2 The MLP in transportation theory

The transition I'm looking into in my thesis is the transition from air travel to train travel in Europe. In transportation-theory, the different ways to travel, like air travel and train travel, are called modes. A transition from one to the other mode is called a mode-shift (Rodrigue, 2017). At this point, I want to mention that a mode-shift is not the only way to make transportation more sustainable. The avoid-shift-improve approach (IEA, 2019; UN, 2016) summarizes the possibilities to make transportation more sustainable. Meaning, first the need for travel can be avoided or reduced, second the mode of transportation can be shifted to a more environmentally friendly one (mode-shift) and third, the energy efficiency of each mode can be improved.

According to transportation-theory (Rodrigue, 2017), a mode-shift happens when one mode of transport has a comparative advantage over the other. Such an advantage can be faster travel-time, cheaper ticket prices, the mode is more reliable, has higher capacity or is more flexible (Rodrigue, 2017). However, if we look at mode-shifts in transportation from a transition-theory perspective, we know that transitions don't come about so easily and are not driven by single factors. This raises the question if the MLP can be applied to explained mode-shifts in transportation? According to Geels

(2012, 2018) the MLP can be used to explain transitions in transportation. To do so, it has to be adapted and extended in some places. The biggest difference in transportation compared to other transition-processes it that there are several more-or-less stable transportation-regimes in place simultaneously (Geels, 2012). In most cases the automobile regime is the dominant one and the train, cycling, bus, and tram are the sub-altered ones (Geels, 2012). However, since these smaller regimes are also established and stable, it doesn't make sense to treat them as niches as the traditional MLP would suggest. Niches in the extended framework are therefore not getting stronger and becoming new dominant regimes. Developments on the niche level are still happening and can replace components of the regimes and can be adopted into them, they can create new linkages between regimes or influence mobility demand (Geels, 2018). Similarly, to looking into several parallel regimes and multiple niche-innovations influencing regimes in the extended MLP, Geels looks into multiple landscape dynamics and how they influence the different regimes, possibly in different ways! In my thesis I am going to use this Extended MLP framework as explained by Geels (2018).

4 Methodology

In order to answer my first research question, I chose a quantitative approach. The goal of this is to find out the magnitude of the emission saving potential. This means that exact numbers are not always important in these calculations. If reliable estimations can be made with saving time over exact calculations or collection of huge datasets, then the former solution was chosen. I will explain how the data was collected and how the calculations and estimations were conducted.

4.1 Calculations research question 1

In order to answer RQ1, I needed the data for all air travel to and from Switzerland. I chose the year 2018 because that was the most up-to-date data that is fully available. The Swiss Federal Statistical Office (Bundesamt für Statistik) supplies this data in an Excel file (BFS, 2019), together with all its data about air travel (German: Luftverkehr). In this Excel File (*su-b-11-LFS-2018-K0.xlsx),* I used the sheet *C2* containing the details about all air travel from Swiss airports in 2018, taken by local passengers. The authors of the data defined local passengers as people starting their journey from Swiss airports in contrast to transit and transfer passengers (BFS, 2019). The sheet contains the number of passengers who travelled from the seven Swiss international airports to their final destinations. The stop-over destinations are not described in this data.

As a first step, I reduced the worldwide dataset to Europe by using the already existing regional classification in the dataset. Later on, while working with the data, I found that the definition of Europe in the Dataset included the Asian part of Turkey and Russia and the islands in the European Outermost Regions (OMR). I removed this data and reduced the dataset to political Europe without the OMRs.

4.1.1 Train time calculations

In the next step, I calculated the travel-times for train travel and air travel. In order to compare the two modes of transport, I calculated the travel-times from city center to city center. To be able to do so, I deducted the city names from the airport names in my data. To calculate the train travel-times, I used the Google Distance Matrix API. To use this API, I had to open a Google developer account and obtain an API key. After importing my data to Google Sheets, I used the Google Distance Matrix API to automatically obtain the public transport travel-times between the city pairs. The API request was done with the following API request string (1):

(1)

```
=ImportJSON("https://maps.googleapis.com/maps/api/distancematrix/json?&origins="& I3 & "&destinations=" & J3 & "&mode=transit&departure_time=1568185200&key= AIzaSyDvLxQfLESoHOFeLkxvHzdXZIn8QKjWfkc", "/rows/elements/duration/text")
```

The string contains the following values:

ImportJSON: this is a script that enables Google Sheets to communicate with the API

There is no native Google Sheets ImportJSON function. I used this open source scrips from Github and ran it in the Google Script editor in Google Sheets. (Jasper, 2012/2019)

Origins (connected to cell I3): the departure city

As the origin, I used the city names, and Google then chooses the city center automatically.

Destinations (connected to cell J3): the destination city

As the destination, I used the city names, and Google then chooses the city center automatically.

Mode (Mode of transport): transit means public transport

Google automatically chooses the fastest public transport combination, including private carriers like Flixbus and Lime. The time response from the API includes the changing times and is therefore the journey time.

Departure_time: 1568185200 is the Unix timestamp in seconds for Wednesday, September 11, 2019 9:00:00 AM in the time zone GMT GMT+02:00 DST.

Key: This is my API-key (which is de-activated now)

The API-key gives me access to this service.

"/rows/elements/duration/text": Choosing the value from the API response

Each API request gets an answer response with several values. This last part of the string chooses the result which is shown in my Google Sheets cell. In this case of the public transport travel-time it is the duration of the journey as a text value, for example 1h 14 min.

To compare travel-times, I wanted to be sure that I did not accidently get a bad connection if I were to only request the travel duration leaving around 09:00. I decided to look for the fastest time for each connection. The Google distance matrix API doesn't have such a function. That's why I did travel-time requests for 8 different daytimes (03:00, 06:00, 09:00, 12:00, 15:00, 18:00, 21:00, 24:00). I always used a Wednesday to be sure not to get into the weekend timetables. Afterwards, I used Excel to find the fastest of the eight times for each connection. To ensure the quality of my data, I looked over all of the data and looked up travel-times online in Google Maps and Deutsche Bahn if they seemed wrong or were missing.

4.1.2 Flight time calculations

The overall air travel journey-time from the departure city center to the arrival city center comprises of five sections. (1) The train ride or drive from the departure city center to the airport, (2) the transit, waiting and check-in time at the airport, (3) the flight time, (4) the transit, waiting and check out time at the airport and (5) the train ride or drive to the city center at the destination. I used Google Maps to calculate the train times to each of the seven Swiss airports from the respective city center (See Table 1). The train times from the arrival airports to the city center of the destinations were calculated using the Google API as explained in the previous paragraph. I also calculated the driving times to and from the airports to the city center for the cases where the travellers want to take the taxi or drive their own or a rental car. When calculating driving times using the Google Distance Matrix API, it is important to mention that Google takes that traffic into account. I calculated the driving times for a Wednesday afternoon at 4 o'clock. For the travel-times from the airports to the city center, I used the train time as a standard. If the driving time only took 60% of the train time or less, I used that driving time instead. For the transit time at the departure airport, meaning the duration from when the passengers arrive at the airport by public transport or car to when their flight leaves, I use the official recommendations from the seven Swiss airports (see Table 1) and cross checked them with scientific literature. In the literature search I focused on the three large airports because they make up 99% (BFS, 2019) of Swiss air travel. Basel and Geneva recommend arriving at the airport two hours before departure. Adding a transfer time from the train station or carpark it would add up to roughly two hours and 15 minutes. The Zurich airport has an online travel planer which I used to calculate the times from arriving at the airport by train to the departure time for the seven most-common air travel connections in my Data (Berlin, London, Vienna, Amsterdam, Hamburg, Düsseldorf, and Barcelona). The average transfer time was one hour and 49 minutes.

All of the authors cited in the following paragraph state that multiple factors determine how much before the departure passengers should arrive at the airport. In Schultz and Frickes' (2011) model to calculate waiting times at check-in, it can be seen that most of passengers arrive at check-in 1,5 to two hours before their flight departs. Park and Ahn (Park & Ahn, 2003) show that a typical arrival distribution at the airport means that 50% of passengers arrived 120 min before departure and around 80% did so 90 min before departure. Another study looking at when passengers arrive at the security check, which is after the check-in, showed that most of the passengers arrived there 60 to 90 min before departure (Postorino, Mantecchini, Malandri, & Paganelli, 2019). A study looking into how much before their departure passengers arrive at three different airports found that in Bratislava, travellers arrived 121 min before departure, in Brno-Turany airport: 110 minutes and in Hamburg airport: 90

minutes. These results confirm that the recommendations by the three Swiss airports seem to translate well into practice. Based on the scientific literature and the recommendations by the three big Swiss airports, I decided to use two hours as a transfer time for these airports.

For the transit times at the destination airports, I looked into scientific literature. There seems to be no common value that is being used for this time. The closest study to mine was conducted by Baumeister et al. (2019). They looked into to what extent domestic air travel could be replaced by train travel in Finland. In their methods section, they described that they used 40 minutes as a transfer time at the arrival airports. Taking into consideration that they only studied domestic air travel, I decided to add 20 minutes to their transfer time resulting in a transfer time at the arrival airport of 60 minutes. This time describes the duration from when the flight is scheduled to land until the travellers are on the train to the city center.

Table 1: Travel-times from city centers to the seven Swiss departure airports and the respective transfer times to the flights.

Departure airport	Center to airport	Transfer time*	Source and explanation
Basel Mulhouse	16 min	2 hours	To the airport: 16 minutes by train. Transfer time: 2 hours before departure is recommended as latest time at the airport terminal.
Bern Belp	37 min	1h 15min	To the airport: 37 minutes by train and bus, 24 minutes by car (64%). Transfer time: The latest check-in time is 45 minutes before the plane leaves (Bern Airport, 2009). The bus stop is directly in front of the airport. I added 30 minutes to walk from the bus station to the airport and the check-in and as a buffer.
Genève Cointrin	7 min	2 hours	To the airport: 7 minutes by train, 10 to 20 minutes by car. Transfer time: The airport recommends being at the check-in 2 hours before departure and 3 hours before departure on winter weekends (Genève Aéroport, 2019).
Lugano Agno	23 min	50 min	To the airport: 23 minutes by train, 16 to 20 minutes by car.

			Transfer time: The latest check-in time is 20 minutes before the plane leaves (Lugano Airport, 2019). I added 30 minutes to walk from the train station (walk 13 min.) to the airport and the check-in and as a buffer.
Sion	11 min	01h 05min	To the airport: 11 minutes by bus, 7-8 minutes by car. Transfer time: The latest check-in time is 45 minutes before the plane leaves (Sion Airport, 2019). I added 40 minutes to walk to the check-in from the bus stop and as a buffer.
St. Gallen Altenrhein	33 min	01h 15min	To the airport: train 33 minutes, car 18-22 minutes (60.6 %). Transfer time: The latest check-in time is 45 minutes before the plane leaves (Peoples, 2019). I added 30 minutes to walk from the bus station to the airport and the check-in and as a buffer. The bus station and parking are right next to the airport.
Zürich Kloten	9 min	2 hours	To the airport: 9 minutes by train, 12-20 min by car. Transfer time: Calculated with the airports Travel planer (Zurich Airport, 2019) is 01 hours and 49 minutes.

* Time from arriving at the airport by public transport or car to the departure time of the plane.

For the actual flight time, I was planning to do an API request as I did with the train travel-times. This was not possible, because the Google flight API has recently been closed down and I couldn't find another easy-to-use, non-commercial API. Due to that, I obtained the flight times by hand for all the 900 airport pairs. I used Google Maps in flight mode to find the travelling times between the airports. If Google Maps didn't find a direct flight, I used Google flights and double checked with Skyscanner, the most comprehensive flight search engine.

4.1.3 Emissions calculations

To calculate flight emissions, I was planning to use the emission API from GoClimateNeutral. I got a free API key from this company to use in my master thesis. Unfortunately, this is API was not as easy to use and integrate with my data in Google Sheets as the Google API. I decided to do the emissions calculations by using a third-party emissions calculator. A web search revealed that Ecopassenger is the best tool for me to use. It is ideal to calculate the train travel in Europe, because it integrates all the different electricity mixes of the European countries. Furthermore, is it capable of calculating AE with stopovers and has a very elaborate AE calculation model (explained later). The tool is developed together with a scientific partner, the Institute for Energy and Environmental Research (ifeu) Heidelberg in Germany (Ecopassenger, 2019).

Aviation emissions calculation methods in Ecopassenger

Ecopassenger uses the TREMOD methodology, which was developed at the ifeu in Heidelberg to calculate the AE (Ecopassenger, 2019). Airplanes use different amounts of fuel in the different flight phases, like the climb, cruise or decent and at different flight heights. These flight phases are differently distributed depending on the flight length. The AE are furthermore affected by the airplane types. Both flight phases and airplane type used depend on the distance of the flight. Therefore, the energy consumption and the AE are related to the flight distance class Table 2. Ecopassenger uses the average fleet mix starting from German airports for each distance class. They state that this values are very similar to other airports in Europe (Ecopassenger, 2019)

Table 2: Energy consumption and emissions from flights by distance class (Ecopassenger, 2019).

Distance class	Energy consumption (g kerosene/seat-km)	NOx (g/kg*)	NMHC (g/kg*)	PM (g/kg*)
125 km	120.5	12.6	0.95	0.24
250 km	75.7	14.2	0.72	0.27
375 km	60.1	13.8	0.72	0.26
500 km	42.7	16.6	0.52	0.29
625 km	38.4	15.1	0.58	0.29
750 km	36.0	14.7	0.59	0.30
1000 km	33.2	14.2	0.51	0.30
>1000 km	19.0	14.4	0.45	0.31

*Emissions in gram per kg kerosene
Source: EMEP-EEA-Guidebook 2013, ifeu-assumptions

As explained in the theory section (chapter 2.1.1), CO2 is not the only AE influencing global warming. Nitrogen oxides, ozone, water, soot, and sulphur emitted by airplanes are also influencing the radiative forcing of the planet and can therefore contribute to global warming (Jungbluth & Meili, 2019). The effects caused by these emissions are mainly applicable to altitudes over nine km, which is the typical cruise height of airplanes. This cruise height is typically reached on flights longer than 400 to 500 km (Ecopassenger, 2019). Ecopassenger multiplies the CO2 emissions by a factor of three for the phase of the plane in cruise height to account for these additional effects. This results in different factors applied by Ecopassenger for different flight heights ranging from 1.27 for flights up to 500 kilometers to 2.5 for flights longer than 1000 kilometers (Table 1) (Ecopassenger, 2019). This so-called Radiative Forcing Index (RFI) factor seems highly realistic when compared to the newest literature, which was summarized by Jungblut and Meili (2019). They recommend using an RFI factor of around two, which is based on the current literature.

Table 3: Average RFI factor used by Ecopassenger (2019) by distance class.

Distance class (km)	Average RFI factor
500 km	1.27
625 km	1.47
750 km	1.6
1000 km	1.87
>1000 km	2.5

Source: ATMOSFAIR 2008, IPCC 1999, ifeu-assumptions

The last factor influencing AE per passenger is to what extent the airplane is filled up, the load factor. Ecopassenger uses the average European numbers for their calculations. The factors they use are: 71% for the distance classes from 125 to 175 km, 75% for the distance classes 500 and 625 kilometers and 80% for the distance classes over 750 kilometers.

Train emissions calculation methods in Ecopassenger

The TE in Ecopassengers are calculated based on the International Union of Railways (UIC) CO2 and Energy Database (Ecopassenger, 2019). Ecopassenger is not allowed to publish its detailed content. For seven countries (Belgium, Switzerland, Czech Republic, Germany, Spain, Finland and Russian Federation), they use different emissions per passenger kilometer for the three different rail services: high-speed, intercity and regional/urban. For 13 countries (Austria, Bulgaria, Denmark, France, Croatia, Hungary, Ireland, Italy, Lithuania, Netherlands, Romania, Sweden, Slovenia), these values are not available; therefore, averages over all services are used. The average values for the whole of Europe are public: 88.2 watthours per passenger kilometer for electric trains and 25.2 grams diesel per passenger kilometers for combustion trains. If the average load factors for the connections are available, they are used, otherwise the average load factor of 35% is used (Ecopassenger, 2019).

Application of Ecopassenger

The dataset I used with all of the air travel from Swiss airports by local passengers to European airports contains 790 rows. Therefore, I was not able to calculate all of them by using the Ecopassenger online tool. I decided to calculate the AE and TE for the 20 routes with the most passengers in 2018 on direct flight routes and on the 20 most-used flight routes with stopovers involved. From these samples, I calculated the correlation to the driving distances and the air travel-time and train travel-time of each corresponding-route. I used the driving distances because I could request them automatically from my Google distance matrix API and because nearly all driving distances were available for my connections because Google Maps uses ferry connections and counts these kilometers as well in the driving distance. The only connection where Google could not calculate the driving distances were Zurich and Geneva to Longyearbyen and Geneva and Lugano to Reykjavik. I calculated these driving distances by measuring the linear distance and multiplying it by 1.417, the United States national detour index (Boscoe, Henry, & Zdeb, 2012), which would be most similar to Europe.

Train travel-time squared correlations

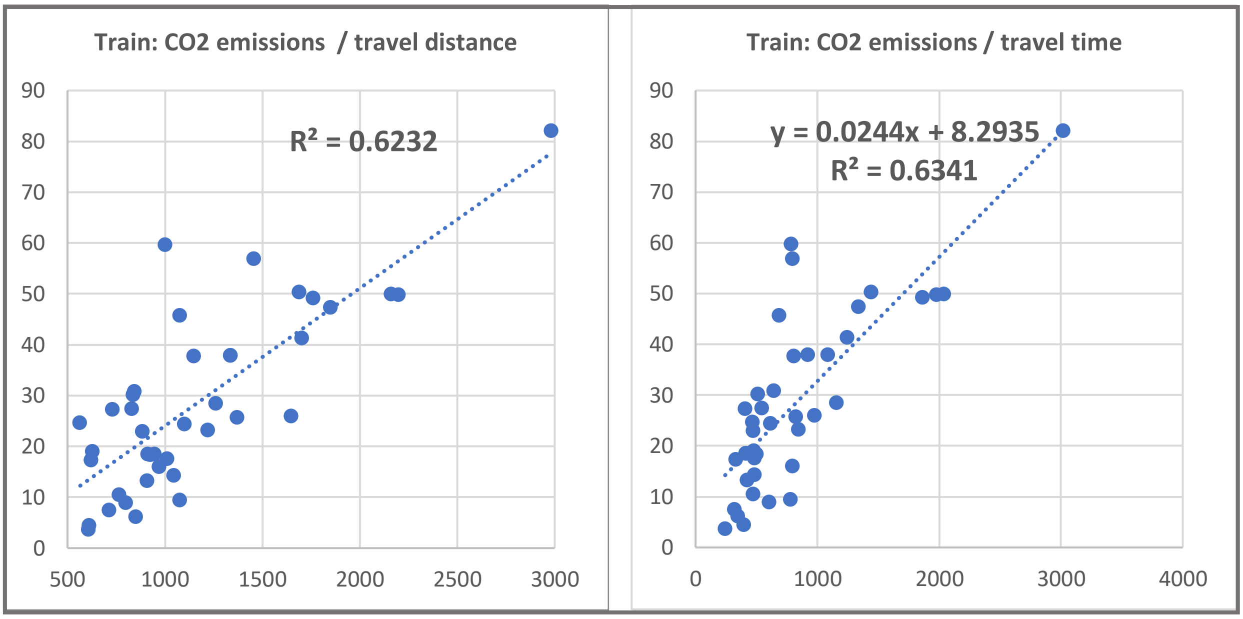

Figure 5: Regression and squared correlation between the CO2 emissions from train travel and travel distance left and train travel time on the right (own creation).

The squared correlation between the 40 connections calculated with the Ecopassenger tool was slightly better by using the train travel-time (R2=0.6341) than the driving distance (R2=0.6232) (Figure 5).

Therefore, I used the train travel-time to calculate the emissions from train travel by applying the following equation:

*CO_2 emissions from train travel [kg CO_2] = train travel time [min.] * 0.0244 + 8.2935.*

Flight without change squared correlation

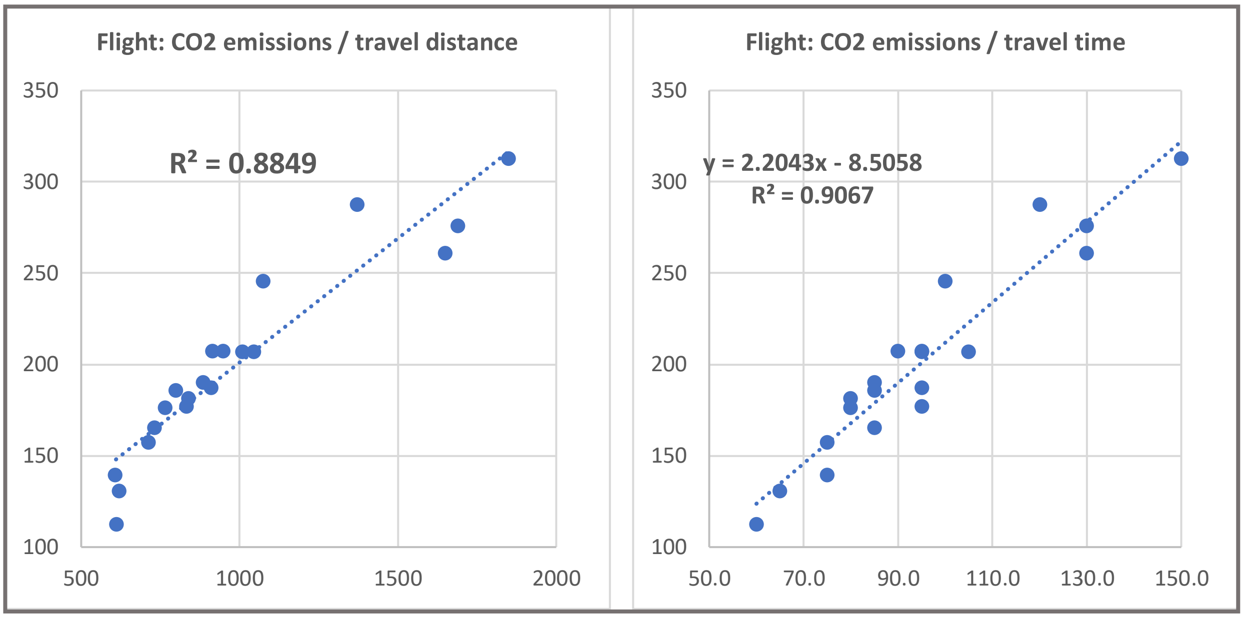

Figure 6: Regression and squared correlation between the CO_2 emissions from flight travel and travel distance left and flight travel time on the right (own creation).

For the flights without change, the squared correlation between the 20 connections I calculated with the Ecopassenger tool was slightly better by using the flight time (R^2=0.9067) than the driving distance (R^2=0.8849) (Figure 6). Therefore, I used the flight time to calculate the AE with no stopover by applying the following equation:

*CO_2 equivalent emissions from air travel [kg CO_2 eq.] = flight time [min.] * 2.2043 - 8.5058.*

Flight with change squared correlation

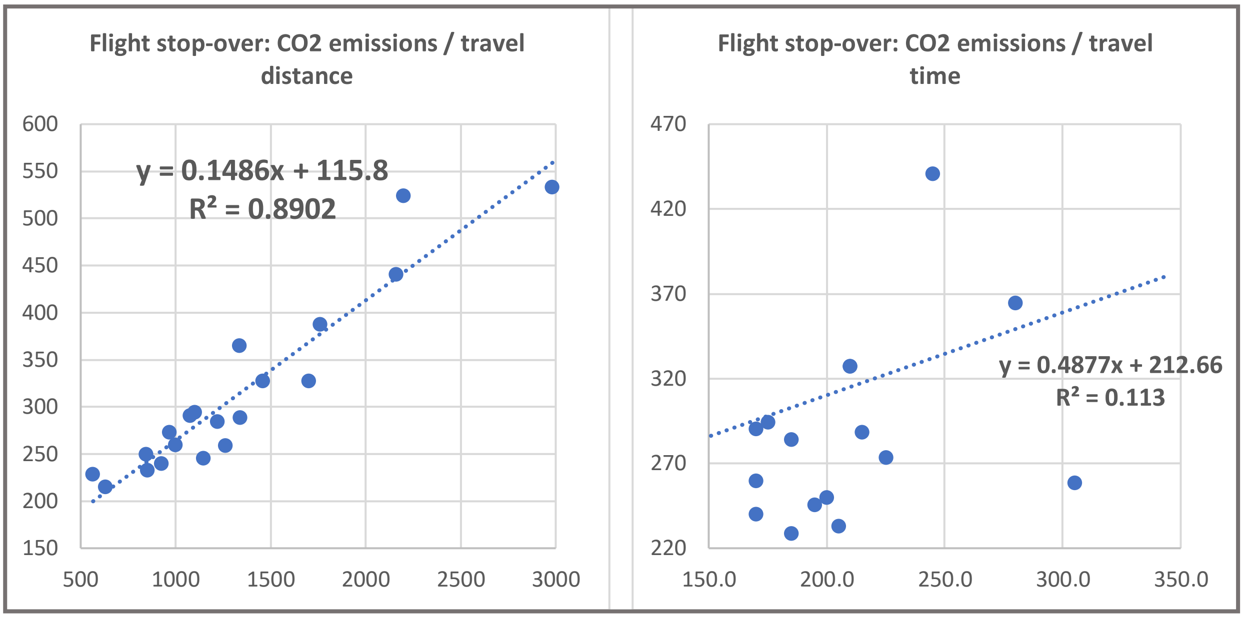

Figure 7: Regression and squared correlation between the CO2 emissions from flights with stop-overs and travel distance left and flight with stop-overs and travel time on the right (own creation).

For the air travel with stop-overs, the squared correlation between the 20 connections I calculated with the Ecopassenger tool was significantly better by using the driving distance (R2=0.8902) than the air travel-time (R2=0.3989) (Figure 7). Therefore, I used the driving distance to calculate the AE with stopovers by applying the following equation:

*CO2 equivalent emissions from air travel [kg CO2 eq.] = driving distance [km] * 0.1486 + 115.8.*

I multiplied all emissions by the factor of two to take into account that these local travellers starting their journey in Switzerland are most-likely coming back with the same mode of transport. This is in-line with the overall goal of this thesis, to find the emission saving potential from a mode-shift, which would affect both directions of the connections where such a shift could be introduced.

4.2 Methods research question 2

My spatial focus is to analyze the transportation system in Europe, even though I am asking my questions from a Swiss perspective. The fact that I am looking into the possibilities to replace air travel makes it clear that a European analysis is needed. Switzerland has very little air travel, due to its small size. Nevertheless, I am keeping an additional Swiss focus during the analysis to take into account the Swiss politics, market and culture. The methods to analyze a possible mod-shift are based on the MLP theory as explained in the preceding chapter, specifically on the works of Geels (2011, 2018).
Concretely I first analysed the landscape dynamics that are influencing the current and transportation-

regimes and that could influence them in the future. Then I analysed the dynamics between the aviation and railway regime. Afterwards I analysed the air travel and train travel regime. After the regime level, I looked into the niche level and mapped out the relevant niche developments for a possible future modal shift. The dynamics between the regimes and the potential for the Swiss government to influence them is analysed last and shown in the discussion section.

To find the data for this analysis I looked into grey literature like governmental, EU and NGO reports and academic literature.

4.3 Limitations

The fallowing limitations are important to keep in mind when reading this thesis:

- For the calculation of the flight journey time I used the same transfer times for all the destination airports. The results could be made more accurate by using different times for different sized airports and depending on the country.

5 Results

5.1 Research question 1: calculations

All the following tables and figures are my own creations based on my calculations, this will not be re-stated in each figure and table caption.

5.1.1 Connections and flights

In 2018, 22 million passengers took air travel on 790 connections from the seven Swiss international Airports to European destinations. The three big airports transported by-far the most passengers to the rest of Europe: Zurich 10 million, Geneva 7.8 million, and Basel 3.9 million. The three small International Swiss airports passenger numbers were comparably small: Bern 67’000, Lugano 28’000, Sion 3’000 (see Table 4). The 790 connections transported passengers from the seven Swiss airports to 220 cities. The most passengers travelled to London (2.7 million), followed by Berlin (974’000), Amsterdam (838’000), Barcelona (835’000) and Paris (783’000) (see Table 4). The countries where most people flew to in Europe were Great Britain with 3.5 million passengers followed by Germany with three million and Spain with 2.9 million (see Table 4).

Table 4: Number of passengers [millions] in 2018 by departure airport, destination country and destination cities.

Leaving from	Passengers	To country	Passengers	To city	Passengers
Zürich Kloten	10.1	Great Britain	3.6	London	2.66
Genève Cointrin	7.8	Germany	3	Berlin	0.97
Basel Mulhouse	3.9	Spain	2.9	Amsterdam	0.84
Bern Belp	0.067	France	1.9	Barcelona	0.83
Lugano Agno	0.027	Italy	1.6	Paris	0.78
Sion	0.003	Portugal	1.3	Porto	0.64

5.1.2 Travel-times

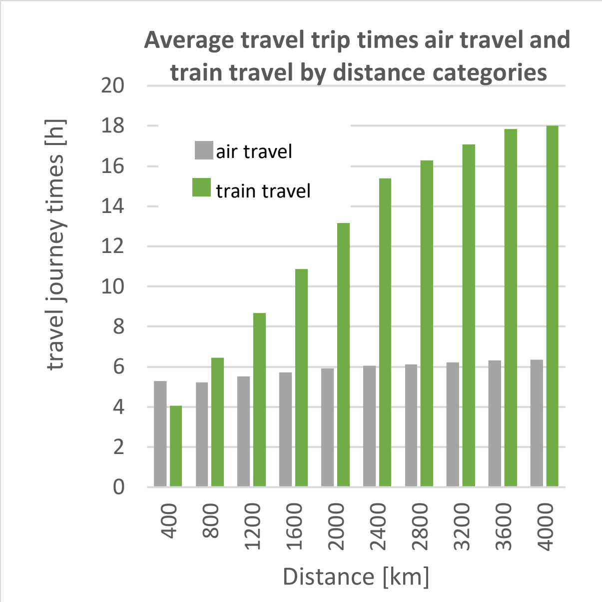

Figure 8: Travel journey times from city center to city center take between 5 and 6.5 hours for journeys between 400 and 4000 kilometers. train travel-times are faster than air travel-times up to 400 km, around the same up to 800 km and are getting considerably higher with increasing travel distance.

Table 5: The 10 destinations with the most passengers and the according journey times by air travel, train travel and the difference between the two. Sorted by journey time difference.

	nr. Pass.	flight	train	diff
Paris	783'619	5:13	3:55	- 1:18
London	2'657'747	5:23	7:57	2:34
Berlin	973'839	5:13	8:50	3:36
Amsterdam	838'219	4:36	8:21	3:44
Hamburg	546'718	4:43	8:39	3:55
Wien	639'440	4:34	9:08	4:33
Barcelona	834'861	4:54	12:43	7:49
Madrid	634'536	5:49	16:02	10:13
Lisboa	568'124	5:57	24:00	18:03
Porto	644'197	6:17	26:12	19:54

Table 6: Average air travel and train travel-times from all journeys, and the split times for the flight journey.

	Average overall	City-to-airport	Transfer	Flight	Transfer	Airport-to-city
Flight	6:21	0:13	1:47	2:57	1:00	0:23
Train	18:05					

The analysis of the travel-times showed that on average, the whole journey from city center to city center is 2.8 times faster by air travel than by train travel. The average flight journey time per distance category was between 5 and 5.5 hours (see Figure 8). The flight journey is calculated by adding up 5-time splits: The city-to-airport time, the transfer part at the departure airport, the flight time, the transfer time at the destination airport and the airport-to-city time. The averages for these sub-times can be found in Table 6. The average train travel-times per distance category show that train travel is faster than air travel in the category up to 400 kilometers. In the category between 400 and 800 kilometers, train travel and air travel take around the same time and above 800 kilometers, train travel is slower than air travel (see Figure 8). Looking into the ten most-visited cities, nine out of 10 times, the air travel is faster with differences between 2.5 hours (London) and 20 hours (Porto). From Swiss cities to Paris, the train travel-time is in average 1 hour and 18 minutes faster (Table 5).

5.1.3 Emissions and emission saving potential

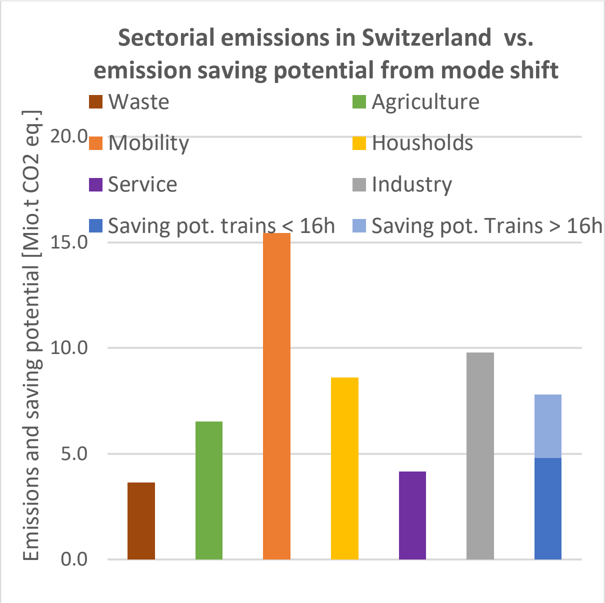

Figure 10: If all air travel and their returns taken from Swiss airports to European destinations in one year by local passengers would be replaced by train travel, 7.8 Mio. tones CO2 equivalents could be saved. This corresponds to the amount of CO2 equivalents emitted by Swiss households annually. The emission saving potential (emission saving potential) from train travel which are less than 16 hours (4.8 mio. t. CO2 eq.) is around the same amount the service industry emits annually.

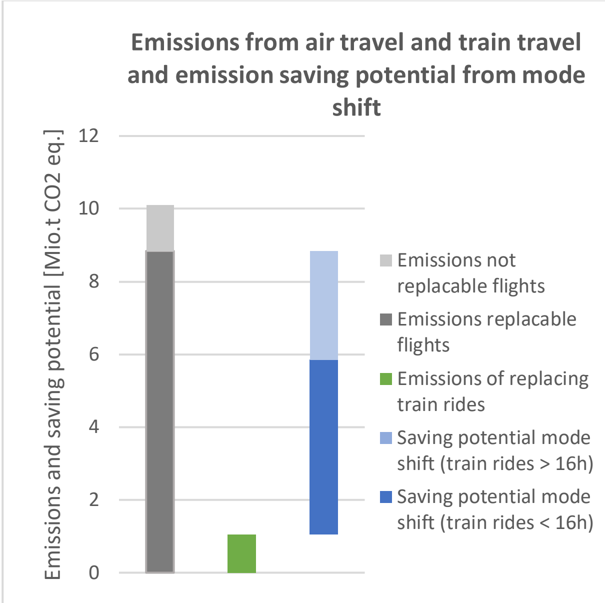

Figure 9: All the air travel taken from Swiss airports to European destinations by local passengers and their returns add up to 10.1 Mio. CO2 equivalents annually. For most of this air travel, responsible for emissions of 8.8 Mio. CO2 eq., train travel is available, which would emit 1.0 Mio. CO2 eq. for the same trips. If all the air travel where train travel taking less than 16 hours is available, were replaced, 4.8 Mio. CO2 eq. could be saved. 3.0 Mio. CO2 eq. could be saved if all the train travel taking more than 16 hours would replace the according air travel.

All of the emissions from the air travel taken from Swiss airports to Europe by local passengers and their returns added up to 10.1 million tones CO2 eq in 2018 (see Figure 9). This is slightly more than the industry sector in Switzerland emits annually (9.8 Mio. tones) (see Figure 10). The analysis of train travel connections showed that most of this air travel is responsible for 8.8 Mio tones CO2 eq., could be replaced by train travel. My calculations showed, that this train travel emit on average 8.8 times less CO2 eq for the same connections, a total of 1.0 Mio tones (see Figure 9). The difference between the emissions of the replaceable air travel and the train travel for the same connections is the emission saving potential. If all air travel were replaced by train travel where there are connections, a total of 7.8 Mio tones CO2 eq. could be saved. This is more than the whole agricultural sector in Switzerland emits annually (6.5 Mio. tones CO2 eq.) and slightly less than all the Swiss households emit annually (8.6 Mio. tones CO2 eq) (see Figure 9). The emission saving potential for train travel taking less than 16 hours is 4.8 Mio. tones CO2 eq. and the potential for train travel taking more than 16 hours, is 3.0 Mio. tones CO2 eq.

A closer analysis of the emission saving potential reveals that most emissions could be saved in the train travel-time categories of four-eight hours and eight-12 hours (see Figure 12). The emission saving potential in these two categories adds up to 3.8 million tonnes CO2e. Looking into the emission saving potential regarding destination cities reveals that 15 cities are responsible for 50% of the emission saving potential (Figure 11). Looking at the train travel under 16 hours, where a mode-shift seems more likely, replacing the air travel to seven cities by train travel would add up to 50% of the emission saving potential (Figure 11). London alone, the top destination for Swiss travels in Europe, has an emission saving potential of 1 million CO2e. Regarding countries, 70 % of the total emission saving potential could be reached by replacing air travel to 11 countries (see Figure 13). Looking into train travel faster than 16 hours, all air travel to four countries would have to be replaced to reach 70% of the emission saving potential.

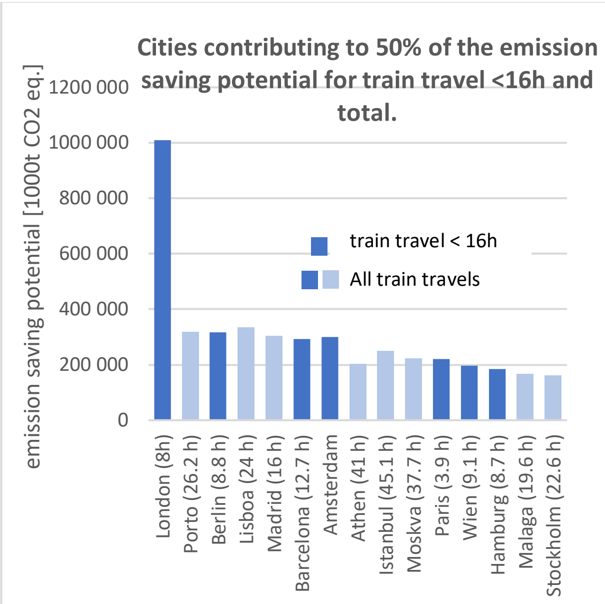

Figure 11: If all the air travel from Switzerland to these 15 cities would be replaced by train travel, 50% of the emission saving potential could be achieved. If the air travel to the 7 dark blue cities were replaced, 50% of the emission saving potential for train travel under 16 hours could be achieved.

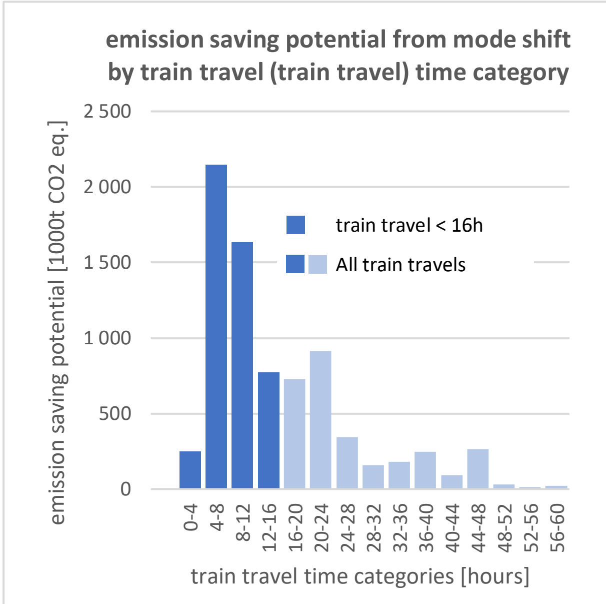

Figure 12: If all the possible air travel from Switzerland to Europe and their returns would be replaced by train travel, most emissions could be saved from train travel between 4 and 8 hours and train travel between 8 and 12 hours. The travel-time between 12 and 16, 16 and 29 and 20 to 24 hours have a medium emission saving potential. I consider the train travel up to 16 hours (dark blue) as a realistic emission saving potential, because this is the maximum night train duration.

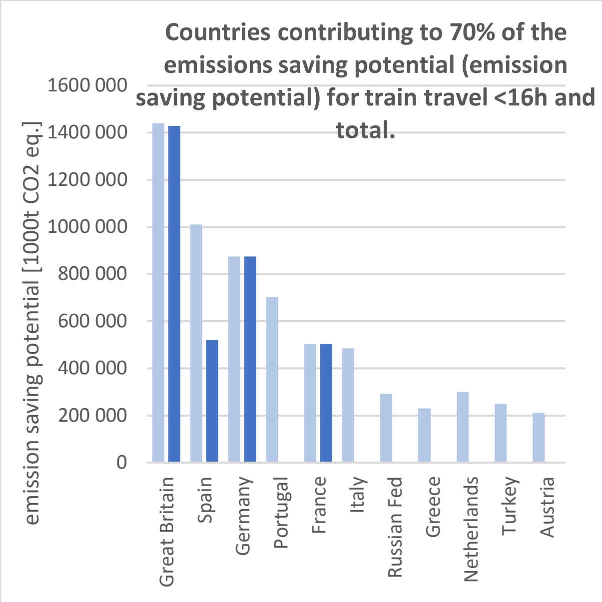

Figure 13: If all the air travel from Switzerland to these 11 countries would be replaced by train travel, 70% of the emission saving potential could be achieved. If the air travel to the 4 dark blue countries were replaced, 70% of the emission saving potential for train travel under 16 hours could be achieved.

5.2 Research question 2: modal shift

5.2.1 Landscape developments and how they influence air and train regime

Geels (2018) names five landscape developments that were influencing the UK transportation-regime: neoliberal ideology, global warming, Information and communications technology (ICT) and information society, financial crises, austerity and Brexit and the oil price. From these developments, global warming seems to have the biggest chance to open a window of opportunity for a mode-shift from air travel to train travel within Switzerland. The climate movement, which is on the rise at the moment, seems to have already influenced Swiss politics to take action. The small chamber approved a stricter new CO2 act including flight ticket taxation, which would not have been possible before this movement started (Schmid, 2019). An additional development that could open up windows of opportunities for a mode-shift is the predicted gains of the pro-environmental parties in the coming elections this October. The last official polls showed that the green party and the green liberal party are predicted to gain 5.7 percentage while the only Swiss party not supporting climate policies, the SVP, is losing 2.6 percent (SRF 4 News, 2019).

5.2.2 Between regimes

When applying the MLP framework to transportation, the modes of transport represent different regimes that exist next to each other (Geels, 2018). In addition to analysing these regimes the interaction between them has to be analysed. Geels (2018) names three different ways the regimes can interact: competition, symbiosis and integration. In my case, the modal shift from air travel to train travel, the competition is the most important to look into, because such a shift means that train travel has to outcompete air travel.

A crucial factor for the competition between air travel and train travel is the mode-choice behaviour of the passengers. Several studies looked into which factor determines if passengers choose air travel or train travel as a mode of transport on routes where they compete with each other. Pagliara et al. (2012) analysed mode-choice between train travel and air travel on the route between Madrid and Barcelona. They found that travel-time, service frequency, ticket price, reliability, comfort and the possibility to work or do other activities during the trip the main aspects influencing mode-choice. Teoh and Khoo (2012) show in a study that for Malaysian business travelers, their mode-choice depends on travel-time, travel cost, safety and comfort. In a study in China, Li et al. (2016) explain that departure time, ticket prices and travel-time are the most important factors influencing mode-choice. They also found that adjusting ticket prices is an effective measure to influence a mode-shift. The finding abut travel time can be confirmed with real-world data from the connection between Berlin and Munich. One year after the introduction of the high-speed train on that connection the passenger numbers doubled compared to the previous year. The modal share of train travel increased from 23 to 46 Percent making it the leading mode on that connection (Deutsche Bahn, 2018)(see Figure 14).

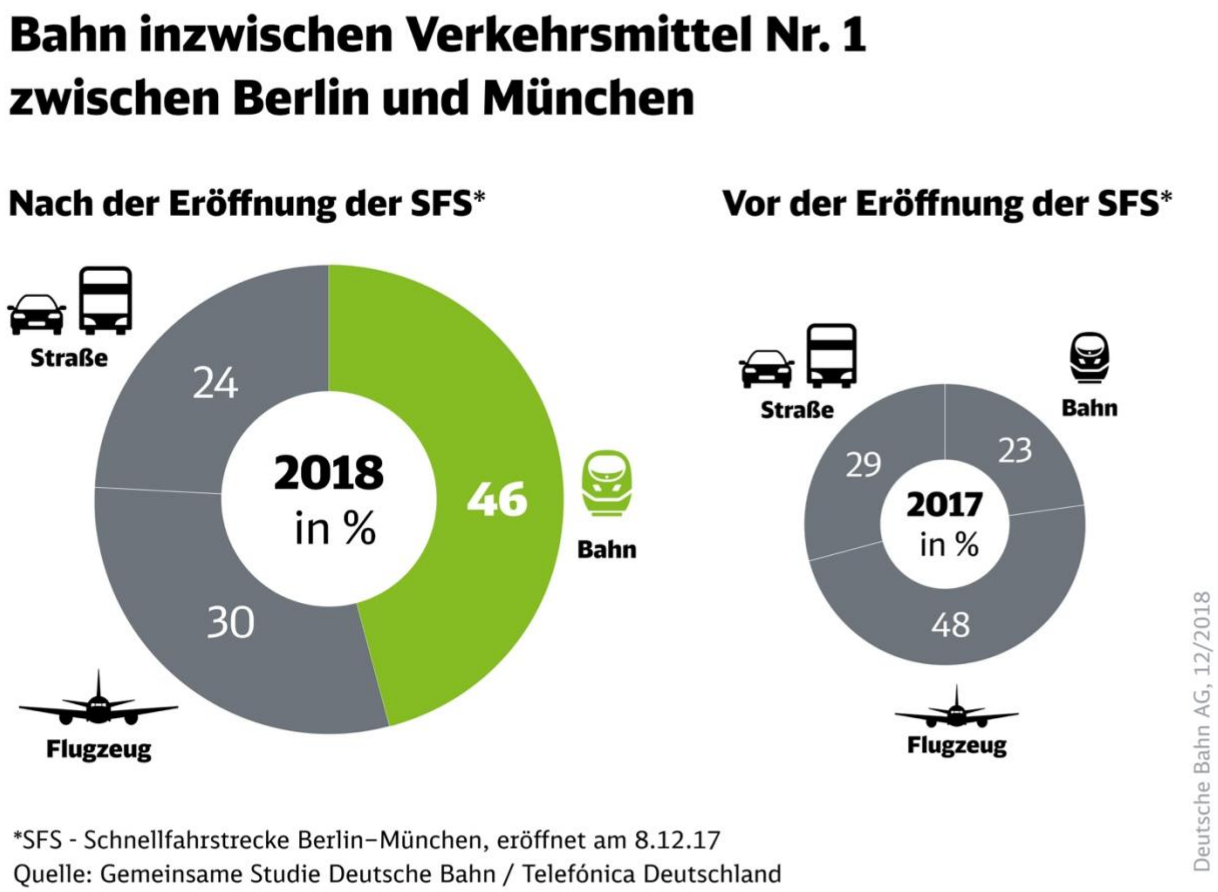

Figure 14: In 2017 before the opening of the highspeed train travel connection between Berlin and Munich, the rail had a modal share of 23%. This share increased to 46% in 2018, making train travel the most used mean of transport on that route. Source: (Deutsche Bahn, 2018).

In the Swiss mobility micro-census (BFS and ARE, 2017), the authors found that for people who chose public transport for multi-day trips (2/3 to destinations abroad) the main reasons to do so were: 1) it was the most convenient solution 46%, 2) there was no other option, 3) for the comfort, 4) fastest travel-time, 5) the costs. For passengers who chose air travel, the following were the main reasons: 1) fast travel-time, 2) most convenient solution, 3) no other possibility, 4) the costs.

5.2.3 Dynamics within the railway regime

Techno economic developments and consumers

The last chapter showed that travel-time is a crucial factor in passengers' mode-choice and therefore also for a mode-shift towards more train travel from Switzerland to Europe. The speed of train travel has gradually evolved up to travel speed between 250 and 320 kilometres per hour for current high-speed trains. To use these trains, the routes have to be built for high-speed as well or existing routes have to be adapted. Europe started to build its HSR network in the 1970s after the petrol crisis. By now, 9000km of high-speed line are in-use and 1700km are being built (European Court of Auditors, 2018). The EU sees a high-speed network for trains as an important measure to reach its goals for sustainable transportation and its cohesion policy objectives. The EU has spent €23.7 billion on co-founding this network since the year 2000. Its goal by 2030 is to triple the high-speed line kilometres (European Court of Auditors, 2018).

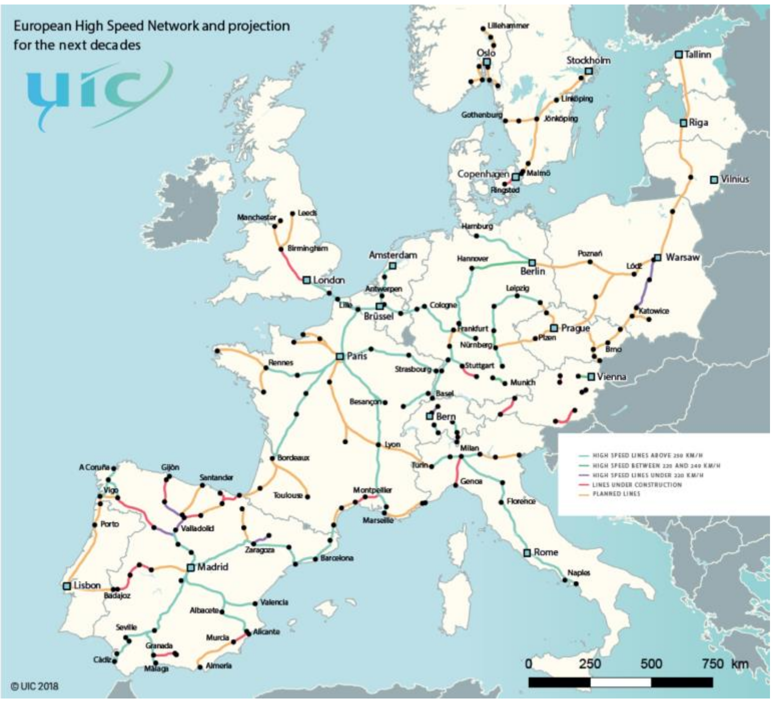

Figure 16: Existing and planned high-speed rail (HSR) lines in Europe. Source: (European Court of Auditors, 2018).

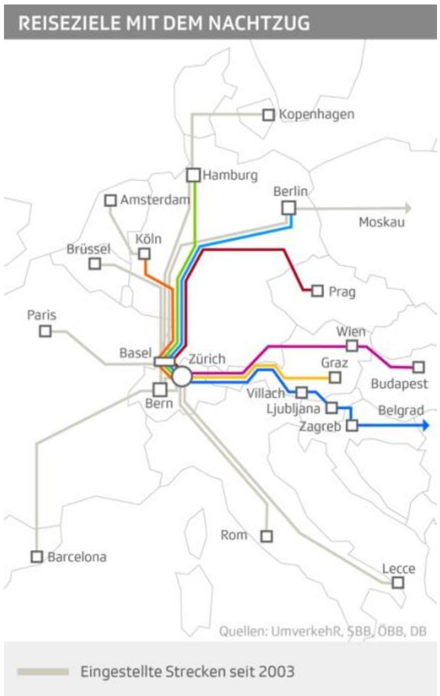

Figure 15: Night trains to and from Switzerland before 2003 (grey) and in 2018. Source: (Von Burg, 2018)

In Switzerland, there is no true high-speed network. The high-speed standard is between 160 and 200 km per hour (SBB Swiss Federal Railways, n.d.). Due to Switzerland's small size, terrain and closely meshed rail network, higher speeds are not economical. Switzerland focuses instead on connecting its centers to the European HSR network (BAV, 2019).

Another way to "save" travel-time is the use of night trains. In my opinion It can be argued that a night on the train, if sleep quality is good, is no lost time at all. Europe used to have an extensive night train network to which Switzerland was well-connected. In 2003 the Swiss railway company stopped running night trains and therefore the destinations reachable by night train decreased drastically (See Figure 15) (Von Burg, 2018). Today, all of the night train connections to and from Switzerland are run by the Austrian railway company (ÖBB). Von Arx et al. state in their 2018 study, that these connections are doing well in terms of survival rates. Sparked by the climate movement, demand for night trains is rising again in Europe. The ÖBB and the SBB are planning to expand the night trains from Switzerland to several, yet unnamed, destinations (SRF news, 2019).

Industry / firms

Among the 500 largest Swiss companies measured by annual turn-over, there are eight companies from the train travel sector: Schweizerische Bundesbahnen with a turnover of 9645 million Swiss francs (CHF), Stadler Rail AG with 2001 million CHF, SBB Cargo AG with 988 million CHF, Transports publics genevois (TPG) with 435 million CHF, Rhätische Bahn RhB AG with 372 million CHF, Basler Verkehrs-Betriebe with 251 million CHF, BLS Cargo AG with 235 million CHF, Jungfraubahn Holding AG with 213 million CHF and BLS AG with 118 million CHF (Bisnode, n.d.).

Policy

The European train travel sector is dominated by national train travel companies. An assessment of the HSR lines in Europe showed, that all countries focus mainly on their domestic market when developing their infrastructure and products. This is seen as the biggest hindrance of further development and improvement of the HSR in Europe (European Court of Auditors, 2018).

The taxation of train travel companies and train travellers is different in all European countries. The existing taxes are the following: fuel taxes for diesel trains, electricity taxes, rail infrastructure access charge, charges on specific parts of the rail infrastructure and fees for the European Emissions Trading Scheme (European Commission, 2017). From the consumer-side, all countries charge VAT travel on domestic train travel and some countries also on international train travel. When starting a trip from Germany for example, Von Arx et al. (2018) calculated that on international train travel, the VAT travel and the taxes on electricity are responsible for 25 percent on international prices.

The Swiss train travel company pays taxes for the electricity and the infrastructure, the passenger pays VAT on ticket prices for domestic and international train travel (von Arx et al., 2018).

5.2.4 Dynamics within aviation regime

Techno economic developments and consumers

Details about the global development of air travel can be found in the chapters 2.2.2. In short it can be said, that global air travel's annual growth accelerated in the 1960s and has been growing ever since. Predictions forecast a continuous growth by 3.7% annually, from 3.8 billion passengers in 2016 to 7.2 billion in 2035 (IATA, 2016). This past and future growth in air travel reflects in the increase of emissions released by aviation (see Figure 17). Bows-Larkin et al. (2016) show, that emissions from aviation have been steadily rising in the time between 1992 and 2013 and will continue to do so when looking into the future scenarios for aviation published by the ICAO (see Figure 17). This rise of emissions goes in no way together with the scenarios describing the cuts in emissions necessary to reach the 2-degree target agreed on in the Paris agreement (Bows-Larkin et al., 2016).

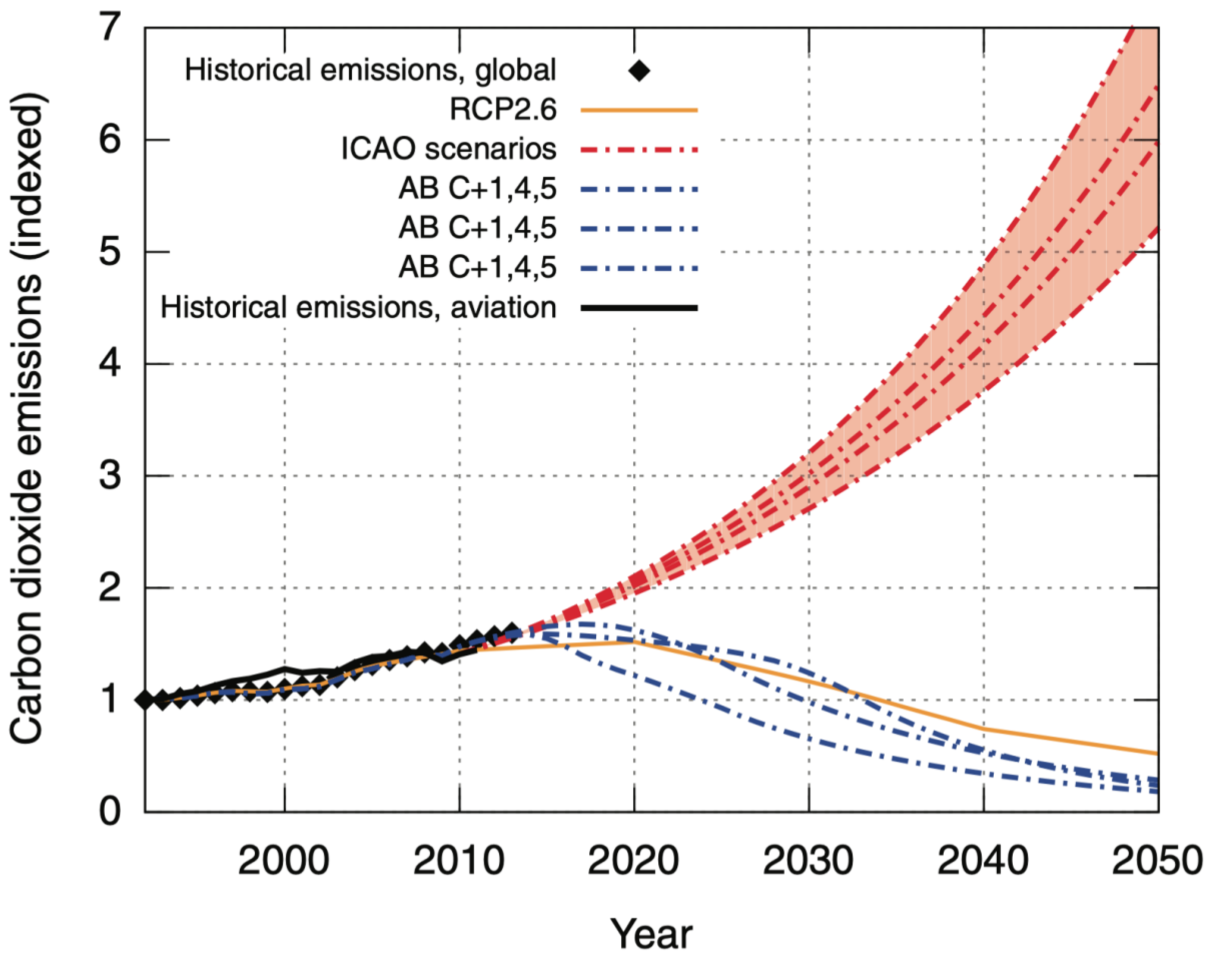

Figure 17: Carbon dioxide emissions from aviation have been rising since the 1990ies (black line) and are predicted to rise into the future (red lines). The blue and orange lines show scenarios with the necessary emission reductions to reach the 2-degree target. All the trajectories are indexed to 1992=1 (Bows-Larkin et al., 2016).

Industry

Among the 500 largest Swiss companies measured by annual turn-over, there are five companies from the air travel sector: Swiss International Airlines, with a turnover of 4954 Swiss Francs (CHF), the Zurich airport with 1037 million CHF, the Pilatus Flugzeugwerke with 986 million CHF, the Edelweiss Air with 537 million CHF and Skyguide SA with 482 million CHF (Bisnode, n.d.). Both of the airlines are owned by the German company Lufthansa, the Swiss government sold all of its shares (20% of total at that time) in 2005(EFD, 2005). Different from other countries, the Swiss state does not own shares in Swiss airports (amcham & BCG, 2018).

Policy

Global

The impacts of air travel as described in chapter 2.1.1 has been known for decades. According to Lee et al. (2009), it was described scientifically already in the 1960s. The growing scientific concerns resulted in a special report from the IPCC about air travel’s impact on global warming (IPCC, 1999). But unlike all other sectors, AE are not monitored by the United Nations Framework Convention on Climate Change (UNFCCC) but by the International Civil Aviation Organisation (ICAO) (Gössling, 2018).The emissions from air travel are not included in the Paris Agreement and are therefore also not part of the national emission reduction targets (Gössling & Upham, 2009). Air travel is regulated by its own organization, International Civil Aviation Organization (ICAO).

The reduction of AE is crucial for the global community to reach the global 2 degree target (Bows-Larkin et al., 2016). So far, no regulation has been in place to reduce AE on a global level (Gössling, 2018). Quite contrary, air travel has been indirectly subsidised by the ban on kerosene taxation. This was agreed on in the Chicago Convention in 1944 in the attempt to achieve world peace (Gössling & Upham, 2009). Since then, this prohibition made it into numerous air service agreements and is therefore seen as nearly impossible to remove in the future (Gössling & Upham, 2009). The ICAO is planning to launche a global Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Its goal is to stabilize AE on the 2020 level. Airlines can purchase carbon credits or offset carbon in other sectors to stay within their carbon budgets (Scheelhaase, Maertens, Grimme, & Jung, 2018). In addition to the uncertainty of the effectiveness of carbon offsetting in general, Scheelhaase et al. (2018) state that the impact of CORSIA will only be marginal. The United Nations Environment Program (UNEP) (2017) sates that CORSIA would in the best case contribute 0.3Gt CO_2e compared to the 16-19 Gt CO_2e needed keep the global temperature below 1.5 degrees compared to preindustrial levels by 2030.

Swiss

Air travel discussions in Switzerland, specifically in Zurich, where the biggest airport is, have recently been primarily about noise emissions (amcham & BCG, 2018). Many of Swiss airports are close to cities and to the country’s border. These two circumstances, in combination with the Swiss direct democracy and its tools for codetermination, creates lots of potential for complaints against airports. In Zurich, groups from the German and Swiss side of the border managed to achieve a limitation of air travel after 22:00 (amcham & BCG, 2018). In the last two years, discussion started to center more around AE and global warming related to Swiss air travel.

In addition to the lack of a tax on kerosene, Switzerland has, like many countries, no VAT travel tax on flight tickets (BAFU, 2018). Unlike all of its neighbouring countries, it also has no CO2 tax on air travel (BAFU, 2018).
The German Environmental agency calculated the environmental costs for releasing CO2 into the atmosphere. One tonne of CO2 causes environmental damage with a value of €360. Applying these costs to air travel from Geneva to London (one-way) would mean €36 per passenger would have to be added to the ticket price to pay for these damages (UBA, 2019). In Switzerland, such flight ticket tax to pay for the released CO2 is planned to be part of the new CO2 Act (UREK-S, 2019). The UREK-S has handed in a proposition to the small chamber of the Federal Assembly of Switzerland for a flight ticket tax. According to UREK-S (2019), the flight ticket tax of air travel originating from Switzerland will be between 30 and 120 CHF. 51% of the revenue from this tax will be redistributed back to the people to compensate for income differences when paying the ticket tax. The other 49% will be used for climate action in Switzerland (UREK-S, 2019). For the new CO2 Act to be implemented, it has to find a majority in the big and small chamber of the Federal Assembly. Additionally, it is likely a referendum will be handed in, meaning the people will have to vote on the matter (UREK-S, 2019). Another option is implementing the flight ticket tax as a steering tax (Lenkungsabgabe) which is technically no tax and therefore wouldn't involve a change in constitution. There has been no study done to estimate the effect of such a flight ticket tax in Switzerland. There is however a study looking into the effects of a possible application of the EU EHS, the European emission trading scheme in Switzerland (infras for BAZL, 2009). Using this study and applying it to the flight ticket tax suggests that a steering effect in the single-digit percentage range can be accepted. The opinion research institute GFS-Zurich (2018) found that a majority of Swiss people would support a flight ticket tax of around 50.- CHF.

5.2.5 Niche-innovations

ICT and booking platforms

Geels (2018) states that Information and Communication Technologies (ICT) is a landscape development that could influence the transportation and travel sector in the future. In my analysis I look into international booking platforms as a niche (regarding railway booking) which is influenced by this landscape development and has potential to contribute to a mode shift. In air travel, booking platforms are well established and are functioning well for finding and booking the cheapest flights (von Arx et al., 2018). In international rail travel comparing prices is difficult. They are displayed on the national railway companies webpages and usually don't appear on booking sites (von Arx et al., 2018). This has not only the effect, that booking international train rides is inconvenient, but also that costumers perceive the rail prices as higher as air prices, even if that might not be the case (von Arx et al., 2018).

6 Discussion

6.1 Emission saving potential

In the first part of my discussion I am answering my first research question. **RQ 1:** In Switzerland, what is the potential of train travel to reduce GHG emissions in comparison to air travel, to the rest of Europe?

The emission saving potential from train travel when replacing air travel is high. On the routes I researched, train travel emitted 8.8 times less CO2e compared to air travel. If all air travel, where train travel connections exist, would be replaced by train travel, 7.8 Million tonnes of CO2e could be reduced annually. This is nearly as much as all of the households in Switzerland emit in a year. Even though this is the theoretical potential, I argue it makes more sense for the Swiss government to focus on the train travel connections that take less than 16 hours. According to an EU-study, is the use of night trains up to 16 hours in the EU possible and common practice (Steer Davies Gleave supported by TRASPOL - Politecnico di Milano, 2017). If all of the air travel where train travel connections with up to 16 hours journey of time could be replaced by train travel, 4.8 Million CO2e would be saved annually. In the next chapter, I look into how this mode-shift for train travel under 16 hours could come about and what the Swiss government can do to foster it.

6.2 Mode shift and the governments influence

These following sections are aiming at answering my second research question: **RQ 2:** How can this mode-shift from air to rail on routes between Switzerland and the rest of Europe be achieved, and how can the Swiss government foster this mode-shift?

6.2.1 Mode-choice

I decided to organize the ways the mode-shift can be achieved and fostered by the Swiss Government, around the factors influencing mode-choice, because the people choosing between the modes of transport can be seen as the base for a mode-shift. Table 7 shows these factors that were named by Scientific literature (Li et al., 2016; Pagliara et al., 2012; Teoh & Khoo, 2012) and by the Swiss mobility census (BFS and ARE, 2017). I marked the ones to which I found sufficient literature yellow and used them to structure the fallowing part of my discussion.

Table 7: The factors influencing mode choice in transportation from scientific literature (Li et al., 2016; Pagliara et al., 2012; Teoh & Khoo, 2012) and the Swiss mobility census (BFS and ARE, 2017).

Factors named in scientific literature	Nr. papers mentioning it
Travel-time	3
Ticket price	3
Service frequency + departure time	2
Comfort	2
Reliability	1
Safety	1

Factors named by the Swiss mobility census	Public transport	Airplane
Travel-time	12.0	57.1
Travel costs	9.8	10.0
No other option	18.5	13.8
Comfort / enjoyment	13.5	1.7
Most convenient solution	46.8	25.7

6.2.2 Travel-time

As the Swiss mobility census and the academic literature showed, travel-time is one of the most important factors influencing mode-choice. My calculations showed that train travel is mostly slower than air travel on the connection between Swiss airports and European cities. Most of the train travel was found in the travel-time category four to eight hours. According to EU reports (European Court of Auditors, 2018), the HSR in Europe is far from being well-connected, because the states develop their systems with the local market in mind. One possibility for train travel-times that can compete better with the air travel-times is the improvement of the HSR system in Europe. According to the mentioned report, this is unlikely in the near future. Furthermore, the Swiss government's influence on this topic is very limited.

The second and third-most train connections are found in the travel-time categories eight to 12 and 12 to 16 hours. These are travel-times which are typically covered by night trains (Steer Davies Gleave supported by TRASPOL - Politecnico di Milano, 2017). A closer look into the most-visited cities shows that five of the seven most-visited cities used to be reachable by night trains (Barcelona, Amsterdam), or are still reachable by night trains (Berlin, Wien, Hamburg) now. This shows that night trains are needed and according to Von Arx et al. (2018), the existing connections are functioning well. However, they are at the moment not strong enough to compete with air travel. One factor I identified that could shift more people to train travel on this connection are the landscape movements related to global warming. Several social movements in Switzerland have requested more night trains (source) and the Swiss train travel company (SBB) announced the release of more night train connections by 2022 in cooperation with the Austrian train travel company. This is leverage for the Swiss State, who owns the SBB. Additionally, to support night train connections, the Swiss government could also support the Swiss company Stadler Rail in the production of night trains.

For Paris, which is among the seven most-visited cities, train travel is 1hour and 18 minutes faster than the plane travel when looking at the over-all journey time. Yet 800 000 people fly from Switzerland to Paris annually. This indicates that travel-time is not the only factor important for mode-choice, the second important factor, price, is discussed in the following chapter.

6.2.3 Price

Due to the scope of this thesis, I couldn't do a ticket price analysis for all my connections. In the policy analysis, however, costs and regulations influencing ticket prices turned out to be most important. The rise of air travel is closely connected to regulations affecting ticket prices. In the 1940s during WWII, the international community decided to subsidize international air travel with the idea to bring people closer together to ensure world peace (Gössling & Upham, 2009). The regulation to achieve that was the kerosene taxation ban. Ironically, now this ban turns out to contribute to the biggest threat that humanity is facing, global warming. Experts say that this ban is difficult to get rid of in the close future (Gössling & Upham, 2009). In comparison to the air travel industry, the train travel industry pays taxes on the electricity it consumes and has to pay into the European Emissions trading scheme for the CO2 it produces. Additionally, international train passengers have to pay VAT travel on their tickets, where international flight tickets include no VAT travel. The train travel sector is, in terms of taxation, clearly disadvantaged compared to air travel (von Arx et al., 2018).

On that matter the Swiss government has several possibilities to influence this situation and support a mode-shift towards more sustainable transportation. The two most-realistic solutions are the introduction of VAT travel on flight tickets and a new flight ticket tax which makes air passengers pay for the CO2 they release into the atmosphere (Schmid, 2019). Both projects have good chances to succeed due to the pro-environmental movement on the landscape level (GFS-Zürich & Stefan Keller, 2018). The biggest gains in the elections in October 2019 are predicted for the green parties (GP, GLP) and the biggest losses for the party which is against environmental reforms (SVP) (SRF 4 News, 2019). Recently, a nation-wide survey showed that the new CO2 act in which the flight ticket tax will be incorporated is widely supported by the citizens (GFS-Zürich & Stefan Keller, 2018).

6.2.4 Comfort

The Swiss mobility census and the scientific literature showed that the comfort while traveling is also an important factor for mode-choice (BFS and ARE, 2017). This is a factor where train travel is already ahead of air travel from my won experience. Especially for business travellers, the option to work on the train seems like a big advantage. The ÖBB, the biggest operator of night trains in Europe, will invest €220 million to adapt the night trains to modern standards in order to improve comfort on train journeys (Bauer, 2019).

6.2.5 Most convenient solution

In the Swiss mobility census (BFS and ARE, 2017), the factor «most convenient solution» was the most important for train travel and the second most important for air travel. The report doesn't describe what is specifically meant by that choice. One obvious advantage regarding convenience is the central location of most railway stations in cities compared to airports, which are typically located outside of the city. My calculations regarding overall journey times showed, that on average, air travel passengers spend 2:57hr on the flight, while spending 3:23hr with waiting and transfer. Another factor that can be placed in the category of convenience is the booking process. Flight prices can be compared easily and be booked from travel platforms. There is no such platforms which include all the prices from the European Railway companies, which makes price comparison and booking more difficult (von Arx et al., 2018). Here I see a potential for the Swiss government to create a protected market niche and support research and development for such systems and platforms accordingly.

6.2.6 General

In this section I address findings that did not fit into the previous categories. My analysis of the air travel and train travel industries in Switzerland showed that there are more large Swiss companies in the train travel sector than in the air travel sector. This could be an important argument for the Swiss government to support the train travel sector. In terms of international partnership, it is important to keep in mind, that 70% of the emission saving potential comes from air travel for only 4 countries (Great Britain, Spain, Germany, France).

6.2.7 Possible barriers

The argument that airports are important for the Swiss economy is still strong (amcham & BCG, 2018). I am not sure how well this argument is supported. Maybe this hub function could be taken over by the train travel infrastructure. An investigation into this topic could strengthen the economic position of Swiss policies for sustainable transport.

6.3 Compared to other findings

As stated in the introduction, there are no studies looking into a mode-shift from air travel to train travel from a Swiss perspective. One result in the Finnish study is comparable is the travel-time calculations. Baumeister (2019) found very similar results to mine. He states that a mode-shift would significantly reduce Finland's climate impact. I could definitely say the same about my results with savings of 7.8 or 4.8 million tonnes CO2e. Furthermore, our results regarding the travel distance threshold up to where train travel can compete with air travel are similar, around 400 kilometres. Several studies (Dobruszkes, 2011; Dobruszkes et al., 2014; Nelldal & Andersson, 2012) which I cited in the introduction analysed whether the availability of HSR and travel-time in general can influence a mode-shift. Dobruszkes et al. (2014) and Dobruszkes (2011) found none or only a corelation for HSR travel-time under 2.5 hours. Nelldal & Andersson (2012) see a big emission saving potential from such a mode-shift to train travel. With my data, I cannot make a qualified statement on this matter because I did not compare passenger numbers between the two modes. Looking at the air travel passenger numbers, where Paris is ranked fifth, with 780’000 passengers per year, even though train travel is more than one hour faster, I can say that travel-time is certainly not the only factor.

6.4 Reflections and further research

Looking back on this study, there are several aspects that I couldn’t look into which opens up opportunities for future research:

- During my research work, I started to realize that many of these changes towards more-sustainable transportation were and are brought about at the moment by social movements. Research into their role in this mode-shift seems important.
- Research into the importance of airports for the Swiss economy and the possibility for the railway to take-over this role could bring better arguments for the Swiss government to support a mode-shift.
- While I was looking up flight and travel –times, I was using different travel platforms. I found that booking tickets for air travel is by-far more straight-forward for international travels than booking train travel. Researching this process and how the Swiss government could influence it could be important for a mode-shift to happen.
- My data-analysis was only based on the air travel passenger numbers. Looking into the train travel passenger numbers on the same routes and the according ticket prices would add value to the data.
- A closer look into the competition of cheap airlines and railway and their employees working-conditions wages could add a new dimension to the topic.

6.5 Contribution to Sustainability Science

My research is taking part in transportation, a typical study area for sustainability science (Geels, 2018). Transportation is a complex system which is entangled with many other fields like city planning, special planning, or the economy. This complexity makes it difficult to tackle problems bring about changes in such a field (Jerneck et al., 2011). The way I am addressing this research by looking into the problem of emissions and how it could be improved is typical for sustainability science. Sustainability science is problem-driven (Clark & Dickson, 2003) and solution-orientated (Fang, Zhou, Tu, Ma, & Wu, 2018). The orientation on reducing emissions and making transportation more-sustainable is a typical normative goal of sustainability science research (Spangenberg, 2011). My research contributes to sustainability science by bringing more insights about the possibilities to make the Swiss travel system more sustainable. Furthermore, it contributes methodically by demonstrating a case how the MLP framework can be combined with quantitative research and applied to transportation.

7 Conclusion

My study showed that the emission saving potential from a mode-shift from air travel to train travel on routes from Switzerland to Europe is high. A full replacement of all routes that offer train travel possibilities under 16 hours would save 4.8 million tonnes CO2 equivalent. If all air travel would be replaced where there are train travel routes, 7.8 million tonnes of CO2 could be saved.

Switzerland has a very limited influence on the travel-times, an important factor for mode-choice, for train travel to European destinations, because this train travel is mostly taking place in foreign territories. The government has to influence creating favorable conditions for the re-introduction of night trains and support this process financially because night trains are more cost-intensive to establish and operate. These investments are likely to pay out in terms of emissions saved, because the connections with train travel between 8 and 16 hours have a very high emission saving potential.

On the air travel side, lies the most leverage for the Swiss government to intervene. The biggest cost-saver for air travel, the kerosene tax ban, is not removable in the close future (Gössling & Upham, 2009). There are two other options to bring improved cost pricing to the air travel sector that the Swiss government should use: the introduction of the VAT on international air travel tickets and the flight ticket tax. Both undertakings can profit from the window of opportunity which is opening up at the moment from the climate protests on the streets and from the coming elections which are most-likely going to bring a shift to the left and towards more green members in the Swiss Federal Assembly.

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