Estimating externalities from GPS traces using MATSim

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Abstract

Providing people with information on the external costs of their mobility, including generated emissions, contribution to congestion, and noise pollution, has been shown to influence their travel behavior. However, directly measuring these externalities at the source is unfeasible. We have therefore developed a pipeline for estimating the generated externalities of recorded trips using the multi-agent simulation software MATSim. First, collected GPS traces are matched to the MATSim network and converted to MATSim events. These events are then processed to impute externalities for each individual. Emission values for various pollutants are calculated for each link using the HBEFA database, accounting for vehicle type, road category and traffic conditions. For congestion, we leverage MATSim modules developed by Kaddoura to compute average link delays for each hour of the day using the MATSim scenario of Switzerland, which are then assigned to links traveled by the participants. We adapt this pipeline to further account for the Swiss valuation of externalities. To validate our approach, the externalities generated for the Swiss MATSim scenario will be compared to ARE estimates and the swiss norm values. The application of the pipeline will be demonstrated for GPS traces collected from the SBB Green Class project.

Keywords

Keywords, in English, language

1 Introduction

It is increasingly recognized that both the environmental and social costs of travel need to be internalized to meet the demand on already strained transport networks by encouraging shifts in travel patterns. In this direction, there is a growing body of evidence that informal feedback on energy use can encourage more efficient behavior, both regarding home energy use (Faruqui *et al.,* 2010) and travel behavior (Taniguchi *et al.,* 2003, Fujii and Taniguchi, 2006). However, providing feedback on external costs in transport is particularly challenging, due to the heterogeneous nature of the users and privacy constraints.

The main externalities of transportation can be divided into two groups: those that affect other road users, namely congestion, and those that affect non-road users such as noise and emissions (Button, 2004). The impact of congestion is primarily the loss of time spent waiting in traffic, whereas emissions and noise have both environmental and health consequences. When people choose to drive on a road, they only have to pay for their private time and car usage costs. However, they do not have to pay the *marginal social cost* (MSC) of their trip, that is, the additional costs the driver imposes on other drivers by increasing demand on the route. From economic theory, internalizing this MSC in the form of a tax would reduce congestion and provide an overall social benefit (Arnott and Small, 1994, Pigou, 2013).

Microsimulation provides advantages from both the supply (network representation) and demand (individual agents) side when modeling road pricing. Arnott *et al.* (2001) notes that traditional macroscopic models focus on link congestion, while ignoring or simplifying other elements of congestion such as nodal congestion, parking and interactions with pedestrians and spillback. Microsimulated models allow for the representation of non-homogenous driver behaviour and preferences. In particular, the importance of value of time heterogenity among individuals in road pricing models has been recognized by numerous researchers (Small and Yan, 2001, Verhoef and Small, 2004). Modern traffic microsimulation frameworks such as MATSim (Balmer *et al.,* 2009) are able incorporate these various heterogeneities, making them useful for such modeling.

Kaddoura (2015) developed an agent-based marginal-cost pricing approach for congestion, emissions and noise externalities, and applied numerous models successfully to a large-scale scenario of Greater Berlin. When considering the internalization of congestion costs, a particular contribution of his work was to assign the external congestion costs to the causing agents. In particular, Kaddoura (2015) notes that it is simple to calculate the incurred congestion for each agent, but much more challenging to map it back to the causing agent. The approach calculates each agent's contribution to the delays on traveled links using a queue-based node-link model including spillback.

In real networks, such an approach requires knowing the location and VTTS of every driver connected to a particular incident of congestion. This is clearly unrealistic. Instead, this work presents an approach to impute externalities only using the GPS trace of the trip, a representation of the road network and aggregated congestion values generated from an agent-based MATSim simulation for Switzerland.

1.1 Swiss MATSim Scenario

The IVT 2015 Baseline Scenario (Bösch *et al.,* 2016) represents a typical working day in Switzerland for the year 2015. As a MATSim scenario, the population consists of individual agents, each with daily travel plans (preferences) and social-demographic characteristics. These agents represent the entire population of Switzerland on the network from Bösch and Ciari (2015). The 2015 scenario extends the work of Balmer *et al.* (2006) to add households and household incomes and model elements. The scenario is available in 1%, 10% and 100% samples with respectively increasing runtimes.

1.2 Analysis of road transport externalities in Switzerland

Numerous sources are available for the analysis of external costs in Switzerland, including standards, government reports and databases. These sources guide and inform the evaluation of new and existing infrastructure projects. A report on the external costs and benefits analysis of transport in Switzerland is available from the Federal Office of Spatial Development ARE (2016), built on the methodology developed in Ecoplan / Infras (2014). It presents the most recent external cost-benefit analysis for the Swiss transport system, primarily focusing on external environmental, health and accident-related costs. Specifically, external costs for 12 different cost categories are computed, differentiated according to three different perspectives: transport mode (road/rail/air/water, passenger/freight, vehicle type), transport type (particulary heavy vehicles) and transport user.

For the modeling of road transport pollutant emissions in Switzerland (and other European countries), emission factors are generally taken from the Handbook for Emission Factor Analysis (HBEFA) (Maibach *et al.,* 2008). The HBEFA database contains emission factors for a range of vehicle categories and traffic situations, differentiated by emission type, pollutant and year. The HBEFA is the standard for road pollutant analysis in Germany, Switzerland and Austria, and is supported by the European Commission.

FOEN (2010) use the HBEFA to provide a detailed analysis of past and predicted future pollutant emissions, covering road transport in Switzerland from 1990 to 2035. Emissions values are calculated for three emissions types: emissions when the engine is in hot operating condition, cold-start emissions and evaporation emissions. The calculation of these values require both traffic volume data as well as the emissions factors from the HBEFA for each emission type. The authors model the development of the vehicle fleet composition, vehicle specific mileage and emission standards trends, resulting in traffic volumes (mileage and start/stop processes) differentiated by vehicle category, emission standard and road category. These traffic volumes are then multiplied by the corresponding emissions factors to obtain the final emissions values.

Concerning congestion specifically, Keller and Wüthrich (2016) estimate the external traffic delay costs for the years 2009 to 2014. The objective of this study was to estimate vehicle hours of delay and identify the contribution from heavy vehicles. For 2013, this was achieved by combining and aligning INRIX traffic flow data and traffic demand data from the National Passenger Transport Model. The time lost per road section was calculated by subtracting the free-flow travel time from actual travel time, where traffic jams are considered to occur only when the actual speed is less than 65% of the free-flow speed. For the other years, online data from the Federal Roads Office (FEDRO) counting stations was used. A summary of their results is provided in Table 1. The values provide a useful estimate of delay costs in Switzerland; however, the use of an "at-least" approach will tend to underestimate the lost time and resulting associated delay costs (Keller and Wüthrich, 2016). This is particularly the case for non-motorways road segments, where long road lengths and flawed speed data play a significant role.

With respect to monetizing externalities, the Swiss Association of Road and Transportation Experts (VSS) has published a series of norms (SN 641 82* : Cost Benefit Analysis for Road Traffic) aimed at guiding the accessment of monetary effects and the cost benefit analysis of transport projects, policies and regulations. Norms SN 641 820 (Basic Standard), SN 641 822a (Travel Time Costs for Passenger Traffic) and SN 641 828 (External Costs) can be of particular interest in the context of external cost evaluation. For example, they provide standard values for time costs and willingness to pay per vehicle type and trip purposes as well as standard methods for evaluating the monetary impacts of air pollution and climate impacts.

Table 1: Updated estimates of vehicle hours of delay for 2009-2014 and comparison to previously reported values from ARE 2012 for Light (LMV) and Heavy Motorized Vehicles (HMV)

		Vehicle hours of delay (Mio/a)						
		Motorway		Non-motorway		All roads		
		LMV	HMV	LMV	HMV	LMV	HMV	Both
Updated	2009	11.41	0.53	11.23	0.22	22.64	0.75	23.39
	2010	15.19	0.79	11.23	0.22	26.42	1.00	27.42
	2011	15.68	0.81	11.23	0.22	26.90	1.03	27.93
	2012	16.45	0.85	11.23	0.22	27.68	1.07	28.75
	2013	15.67	0.82	11.23	0.22	26.90	1.04	27.93
	2014	16.62	0.87	11.23	0.22	27.85	1.09	28.94
Previous	2009	12.40	1.08	14.10	0.28	26.5	1.4	27.9

Source: Keller and Wüthrich (2016), p.141, Annexe A4

1.3 Green Class Data

In the Green Class 2016 pilot project, the SBB created a new mobility offering for subscribers which consisted of a General Abonnenment (GA) travelcard, an electric BMW i3, a park+ride subscription, and car and bike sharing subscriptions. The 139 participants were tracked for the duration of the project using the "SBB DailyTracks" app enabled with GPS. The collection process recorded their individual trips and mode of travel. The fields available for trips and GPS points are repsectively:

Trip leg records

- user id
- trip leg id
- start timestamp
- end timestamp
- mode of travel

GPS waypoints:

- longitude
- latitude
- timestamp
- accuracy (meters)
- user id

For the 139 participants, a total of 163,417 trips were recorded, with an average of 4.5 trip legs per person per day (see Table 2). For this research, the dataset was filtered to only include those trip legs performed either with a personal car or the provided electric vehicle. For this

Table 2: Green Class Trips and Waypoints

	Full Dataset		Within Switzerland		
	Full Dataset	(E)cars	(E)cars	Cars	E-cars
Users	139		139		
Trips	163,417	90,568	81,365	51,843	31,219
Trip Legs	301,270	100,865	90,040	57,426	32,614
GPS Points (millions)	152.81	30.28	19.93	10.91	9.01
GPS Points / Trip Leg	935.11	302.30	224.51	193.5	278.56
Trips/person/day	4.97	3.05	2.94	2.94	2.94

analysis, only trips starting and ending within Switzerland using either the electric car or personal automobile were selected.

2 Methodology

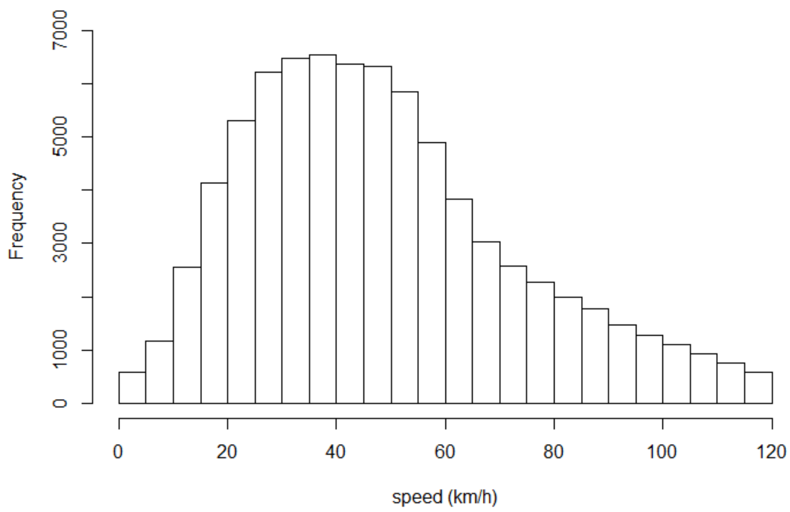
In this section, the methodology for imputing externalities on GPS data is presented. For the imputation, reference values for both emitted air pollutants and caused congestion are required. For emissions, the HEBFA database (version 3.2) is used (Rexeis *et al.,* 2013). For congestion, the output of a 10% sample from the 2015 MATSim scenario for Switzerland (see Section 1.1) is processed to determine average hourly values per link for both the delay caused and experienced by a vehicle present on that link. This is done using the approach of Kaddoura (2015), previously described in more detail in Section 1.

2.1 GPS processing pipeline

A multistage pipeline has been developed for imputing externalities on GPS traces using the MATSim framework. The pipeline consists of the following steps, further described in more detail below.

1. Clean GPS data
2. Map match to the MATSim network using Graphhopper
3. Calculate link entry and exit times
4. Convert to MATSim events

Figure 1: Histogram of average trip leg speed after filtering



5. Imputate of externalities on MATSim events

The pipeline can essentially be delineated into two parts: the first creates a series of MATSim events representing the map-matched path of the GPS traces, whereas the second processes those events using the previously mentioned reference values to impute the generated emissions and delays.

Data cleaning GPS data accuracy can vary considerably depending on the sensor used, the surrounding environment and even geographical location. The data collected as part of the Green Class project included not only longitude, latitude and time, but also an accuracy indicator, in meters. The filtering was performed only using the latter metric, with any point having an accuracy greater than 200 meters excluded from the dataset. This proved sufficient for effective map matching. Other possible filtering techniques include exluding points based on the speed between consecutive points. It is worth noting that Graphhopper also performs some additional filtering, removing points within a measurement error of the previous point, in order to speed up the map-matching computation. Inconsistencies in the provided GPS data meant that some trips had unusually high average speeds (due to ping-ponging) or very short trip durations. Therefore, trips with an average speed over 120 kmh^{-1} or a duration of less than one minute were removed. The invalid trips made up 9% of the dataset. The remaining trips show a nice average speed profile (Figure 1).

Map matching Using a MATSim adapted version of Graphhopper, the trip legs are matched to the MATSim road network. A Hidden Markov Model (Newson and Krumm, 2009) identifies canditate links for each GPS point, with a measurement sigma of 50m. An unlimited distance between consecutive points is allowed. The Graphhopper routing engine then identifies the best route from the set of candidate links. A minimum of two matched GPS points are required. The map matching module returns a list of links thier matched GPS points.

Link entry and exit time calculation To convert the GPS traces to MATSim events and calculate externalities, the travel time for each link is required. This is not calculated by Graphhopper, as the state of the art Hidden Markov Model approach used (Newson and Krumm, 2009) does not consider speed limits or feasible travel times when identifying candidate links for matching. In the absence of high-frequency GPS measurements or additional sensor information, there may be insufficient GPS measurements to match every intersection in a trivial manner. Hence, an algorithm that also handles links where few or no GPS measurements are available has been developed for determining this.

A trip leg contains a sequence of links L with the set of GPS points $P(l)$ matched to each link l. For convenience, let the first and last GPS point on each link in the set L be $p_{l,s}$ and $p_{l,e}$ respectively. The start and end links of a trip leg always have at least one GPS point associated with them, while other links may have none or more GPS points. Hence, trip legs are divided into sets of consecutive links L', beginning at l'_1, where $l'_{2..k}$ have no GPS points. The GPS recorded travel time over the links in L' is then proportionally allocated based on the freespeed travel time of each link L', where l_{k+1} is the next non-empty link.

Let the projection of GPS point $p_{l,i}$ onto link l be $p'_{l,i}$. A helper function $time\_between(a, b)$ returns the time needed to travel between projected points and the verticies of a link l, i.e. from $p'_{l,e}$ to the end of the link; or the start of the link to the first projected point on that link $p'_{l,s}$. $tt(l)$ gives the time needed to travel a link under free flow conditions, and $time_between(p_{l,e}, p_{l',s})$ gives the time difference between the last and first points on two links respectively.

In MATSim, the assumptions hold that an agent always starts and ends somewhere on a link. Hence, only the exit time for the first link and the entry time for the last link need to be calculated. Additionally, $entry\_time(l_j) = exit\_time(l_{j-1}), \forall j = 1..n$. As such, the algorithm can be separated into two cases:

- **First Link** For the first link l_1, $exit\_time(l_1) = time(p'_{l_1,e}) + time\_between(p'_{l_1,e}, l_1)$
- **Other Links**
  $entry\_time(l_j) = exit\_time(l_{j-1})$

if $P(l_j) = \emptyset$ **then** $exit\_time(l_j) = entry\_time(l_j) + \frac{length(l_j) \cdot time\_between(p'_{l_{j-1},e}, p'_{l_{j+k},s})}{distance(p'_{l_{j-1},e}, p'_{l_{j+k},s})}$
where l_k is the next successive link with $P(l_k) \neq \emptyset$
else $exit\_time(l_j) = entry\_time(l_j) + time\_between(l_j, p'_{l_j,e}) + \frac{time\_between(p'_{l_j,e}, l_j) \cdot time\_between(p'_{l_j,e}, p'_{l_{j+1},s})}{time\_between(p'_{l_j,e}, l_j) + time\_between(l_{j+1}, p'_{l_{j+1},s})}$

Conversion to MATSim events The sequence of links with entry and exit times are then converted to valid MATSim events and grouped by person and date.

Imputation of externalities on MATSim events To impute the externalities of each trip leg, the events are processed using a MATSim framework set up with two additional modules. The first, developed by Kaddoura *et al.* (2017) calculates the emitted pollutant amounts inccured on each link, based on the observed travel speed. Values and emissions factors are taken from the HBEFA database (version 3.2). Average speeds on each link are capped at the link freespeed. The road types for assigning emissions factors are taken from OSM. Each driver is assigned a medium sized vehicle with a 4-cylinder EURO-4 compliant petrol engine. It was not possible at this stage to represent the actual owned vehicles of the study participants.

For congestion, the caused delays per link are imputed from the average hourly values calculated from the MATSim scenario. The time lost per link is defined as the difference between the link travel time and travel time under free flow conditions. From here, it is straightforward to determine the total generated pollution and caused and experienced delay per trip leg.

3 Results

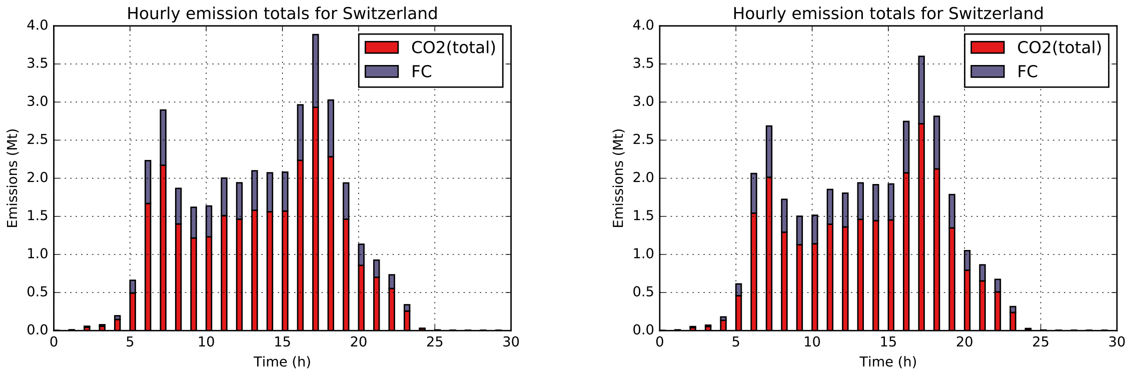
3.1 Validation

To validate the externality values estimated using MATSim, the produced outputs are analyzed both temporally and spatially to check for plausibility and then compared with estimates from previous Swiss external cost reports.

Figure 2: Hourly emissions values for Switzerland. Only total CO_2 and FC emissions are shown, as the values for the other pollutants are negligeable in comparison.

(a) 30% diesel vehicles

(b) 40% diesel vehicles



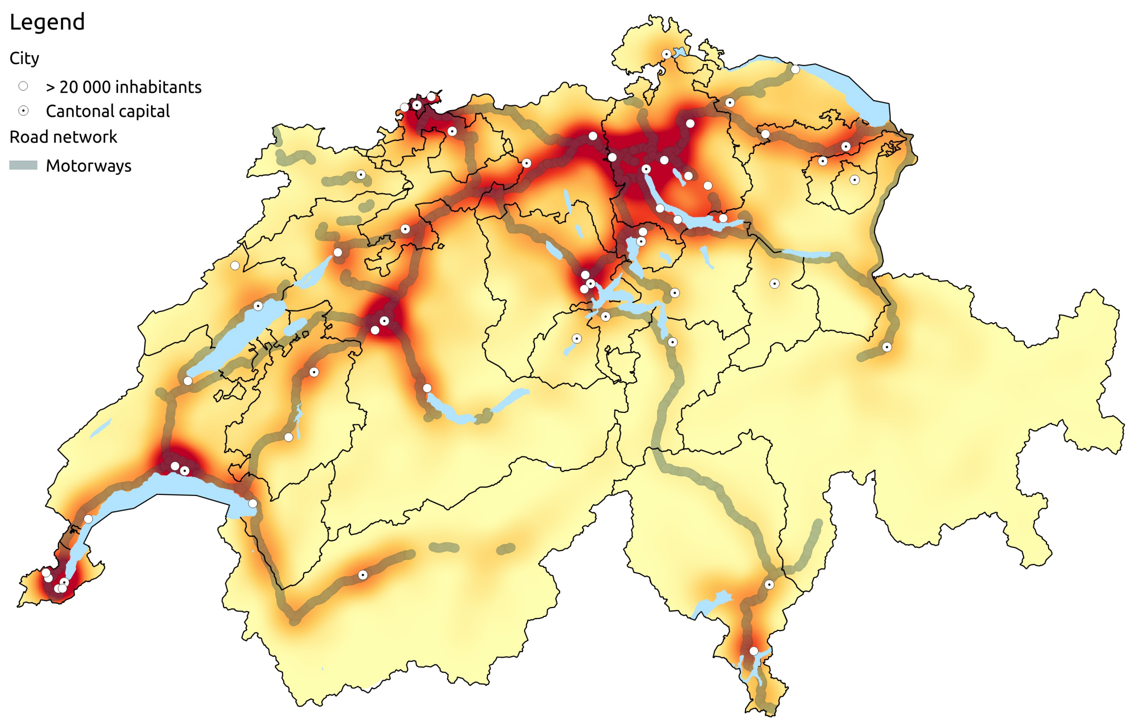
3.1.1 Emissions

Emissions values can be estimated with MATSim directly from the processed GPS traces and therefore do not explicitely require a calibrated MATSim scenario for Switzerland. Nevertheless, in order to validate our estimations, emission values are first calculated using a 10% MATSim scenario for Switzerland. To comply with new vehicle registration statistics according to Blessing and Burgener (2009), Blessing and Burgener (2013) and Bianchetti *et al.* (2016) as well as the vehicle ownership predictions from FOEN (2010), two scenarios where 30% and 40% of vehicles are randomly assigned a diesel engine were examined.

The emission values are estimated for each road link in the MATSim network for the following pollutants: CO, total CO_2, FC, HC, NMHC, NO_2, NO_x, PM and SO_2. The values are aggregated into hourly time bins. These emission estimates are then first analyzed temporally and spatially to assure the plausibility of the output.

When analyzing the temporal evolution of emissions over the course of a typical workday, we would expect it to correlate with typical commuter patterns, i.e. low emissions both in the early morning and late evening and higher emissions during the day, with spikes corresponding to rush-hour periods. Figure 2 shows the typical daily emission of each pollutant per hourly time bin estimated from the MATSim scenario, for both the 30% and 40% diesel engine ownership scenarios. Note that only total CO_2 and FC are shown, as the emissions values for the other pollutants are negligeable in comparison. As expected, two distinct peaks corresponding to morning and evening rush-hour can be observed, while the early morning and late-night values are near zero and the midday values lie somewhere in between.

Figure 4: Spatial distribution of total emissions in Switzerland with 40% diesel engines



The spatial analysis of emissions is expected to show higher emissions in and around larger cities and within highly populated cantons, where more people live and therefore more commutes are observed. Figure 4 shows the spatial distribution of the total daily emissions over all of Switzerland with 40% diesel engine ownership. The heatmap is generated by summing the total emissions with a 10 km radius around each point. Indeed, it can be seen that total emission values are higher in the main metropolitan areas (Zurich, Geneva, Basel, Bern, Lausanne, Lucerne, St-Gallen) than in rural areas within e.g. Graubünden, Valais, Schwyz or Appenzell. Higher emissions also tend to coincide with the presence of motorways.

The MATSim computed emissions values are then compared to those estimated by FOEN (2010) for 2015. Since MATSim simulates a single typical workday for 10% of the entire Swiss population, our values need to be scaled in order to be comparable. The emissions values are thus multiplied by 10 to account for the population sampling, then by 365 days and finally by an additional scale factor such that the total traveled distance matches the one reported by FOEN (2010) for 2015. Table 3 shows the total estimated emissions values for both MATSim scenarios and FOEN (2010) and Figure 5 plots the percent deviation of the MATSim estimates from the reported 2015 estimates. The total emission values for all pollutants except

Table 3: MATSim and FOEN estimated emission value comparison

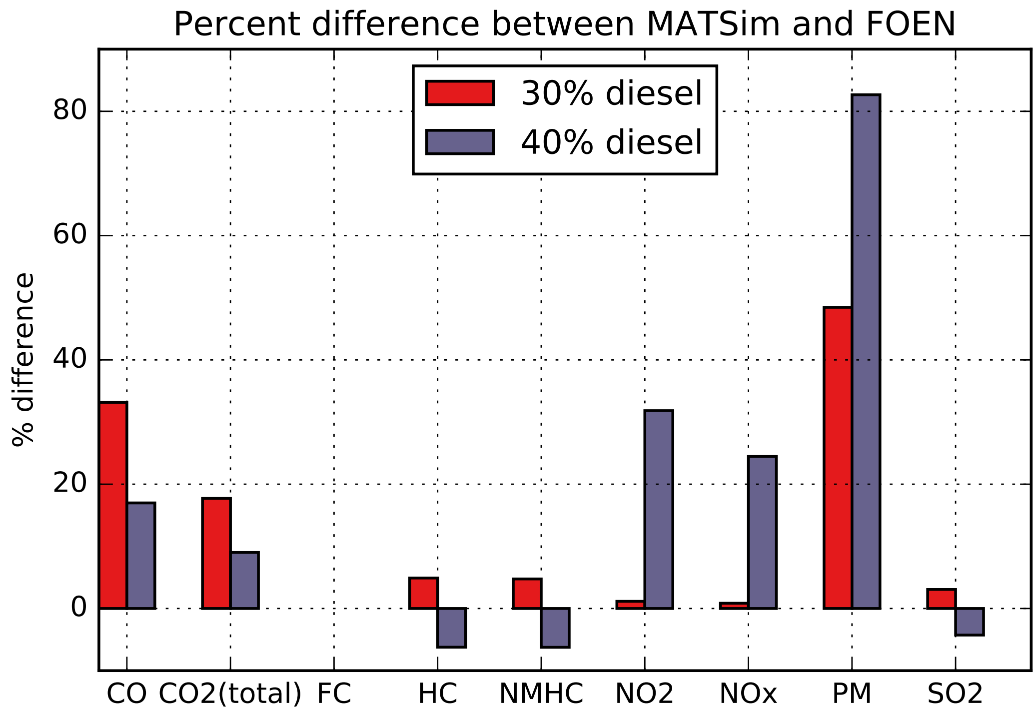
Pollutant	FOEN	MATSim			
		30% diesel		40% diesel	
	t/a	t/a	%	t/a	%
CO_2 (total)	10 687 911	12 580 738	17.71	11 651 538	9.02
FC	0	4 130 052	—	3 823 821	—
CO	67 424	89 789	33.17	78 879	16.99
NO_x	16 496	16 635	0.85	20 530	24.46
HC	9 546	10 014	4.90	8 952	-6.23
NMHC	9 037	9 467	4.76	8 473	-6.24
NO_2	4 127	4 175	1.15	5 441	31.83
PM	418	621	48.46	764	82.67
SO_2	59	61	3.06	56	-4.28

PM are within 40% of the reported values; the values for NO_x, NO_2 and PM increase with an increase in the diesel engine ownership share. These deviations are possibly due to the fact that emissions factors depend on the exact type of petrol or diesel engine. Indeed, in the MATSim model, only one type of petrol and diesel engine is considered, whereas in reality, these are further subdivided into specific subtypes with different emission standards. Further calibration of the vehicle engine types to the appropriate subtypes could possibly lead to a better fit in emissions values. Nevertheless, the estimed values coincide with the previously reported values, thereby demonstrating that MATSim provides a reliable means of estimating emission values for pollutants.

3.1.2 Congestion

Contrary to emissions, congestion and delays caused and experienced cannot directly be estimated from GPS traces alone, since information on how many other drivers were present on the road at that given moment is lacking. It is precisely for this reason that MATSim is used to estimate congestion throughout a typical workday. Therefore, it is crucial that the estimated aggregate congestion values are consistent with other previous estimates. As before, these values are calculated using a 10% MATSim scenario for Switzerland and are aggregated into hourly time bins per road link. These estimates are again first analyzed temporally and spatially to assure the plausibility of the output before being compared to the values from Keller and

Figure 5: MATSim and FOEN estimated emission value comparison



Wüthrich (2016).

The typical total caused and experienced delays pattern per hourly time bin estimated from the MATSim scenario is shown in Figure 6. As was the case for emissions, total delays also expectedly coincide with typical commuter patterns, with fewer delays the early morning and at night, two distinct peaks corresponding to morning and evening rush-hour and midrange values at midday. One notices in Figure 6 that there are higher caused delays than experienced delays at the start of the peaks whereas the opposite is true towards the end of the peaks, a manifestation of the fact that delays first need to be caused before they can be experienced. Nonetheless, the total duration of both caused and experienced delays are equal and sum up to just under 250 000 hours.

Figure 7 shows the spatial distribution of the total daily experienced delays over entire Switzerland. The heatmap is generated by summing the total experienced delays with a 1 km radius around each point. Following an anogolous reasoning as for emissions, longer delay times are observed in and around larger cities and within highly populated cantons, where more people live and commute to.

Figure 6: Hourly total caused and experienced delays for Switzerland

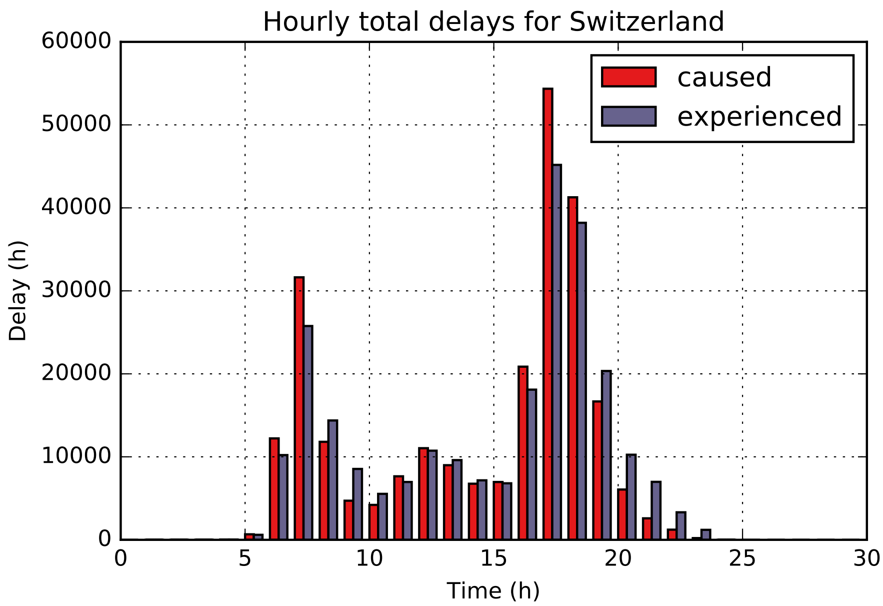


Figure 7: Spatial distribution of total experienced delays in Switzerland

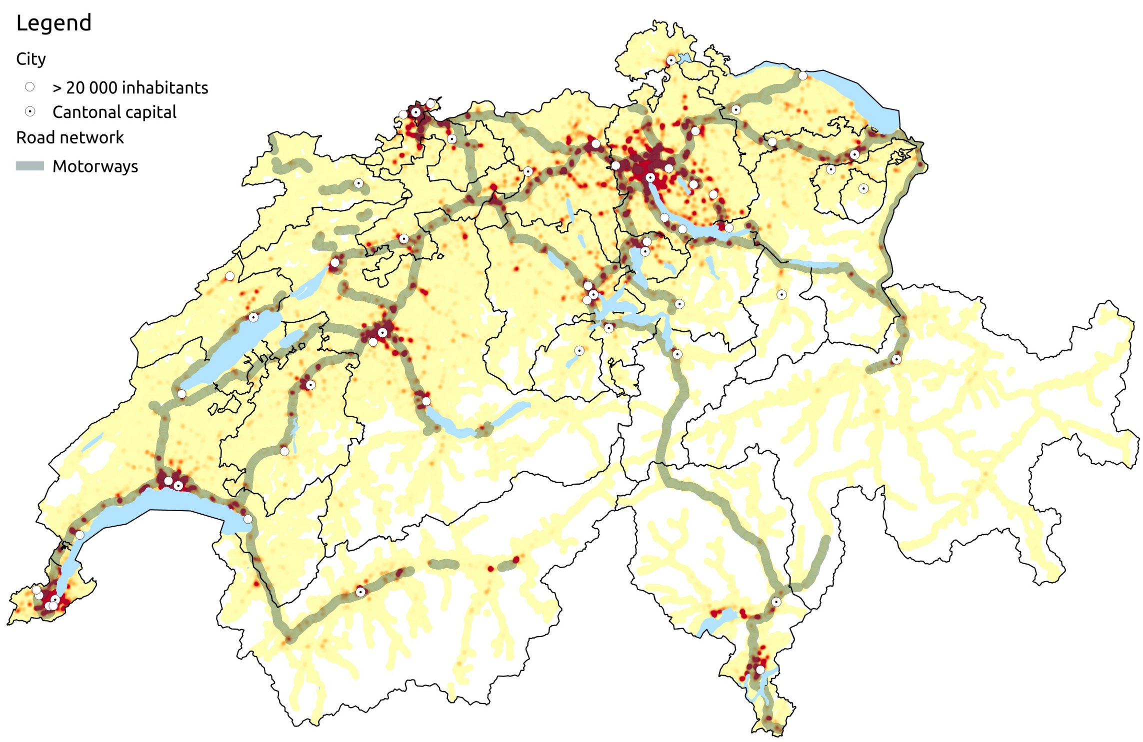


Table 4: MATSim and Infras / MK Consulting congestion comparison

Road type	MK/Infras (Mveh-h/a)	MATSim (Mveh-h/a)	%
Motorway	16.62	8.33	-49.89
Non-motorway	11.23	95.00	745.98
Total	27.85	103.33	271.03

The MATSim computed delay values are then compared to those calculated by Keller and Wüthrich (2016). The same scaling operations are performed as in the case of emissions: multiplication by 10 to account for the population sampling, then by 365 days and finally by an additional scale factor such that the total traveled distance matches the one reported by Keller and Wüthrich (2016) for 2014. The values are reported in Table 4.

The total vehicle hour delay per year values are estimated to be much higher in MATSim than in Keller and Wüthrich (2016). However, the authors do indeed state that they have taken an "at-least" approach in estimating delays and that the values for non-motorway segments are highly underestimated. On the other hand, our model only simulates passengers vehicles. Therefore, it neither accounts for the effects of the interaction of cars with trucks on motorways nor does it captures extraordinary circumstances such as accidents and holiday traffic which could increase the vehicle hours of delay. A combination of these effects could be the underlying cause of the deviation between the estimates and should be further investigated.

3.2 Green Class Emission Reductions

A core component of the Green Class pilot project was the availability of an electric car to subscribers. These cars were covered by renewable energy certificates, negating the need to consider the energy generation makeup in calculating the emissions reductions. For the analysis, it is assumed that for trips performed with an electric vehicle, the driving style, route choice and trip timing is independent of the choice of vehicle. Additionally, the possibility that the availability of electric vehicles generated mode shifts away from other modes (i.e. train travel, cycling or car sharing) is excluded. The effects of having an additional vehicle in multi-car households are also excluded.

Table 5 presents the reduction of various emissions over the course of the program due to the availability of the E-car. A clear immediate reduction in daily CO_2 emissions is observed in

Table 5: Reduction in emissions due to the availability of an electric vehicle

	Car	Ecar	Reduction (%)
CO (kg)	45.51	37.26	45.02
CO_2 (T)	11.32	8.97	44.20
FC (T)	3.60	2.85	44.20
HC (kg)	4.53	3.68	44.80
NMHC (kg)	4.27	3.46	44.80
NO_x (kg)	24.18	19.34	44.43
NO_2 (kg)	4.12	3.28	44.37
PM (kg)	1.22	0.97	44.29
SO_2 (kg)	0.06	0.05	44.20

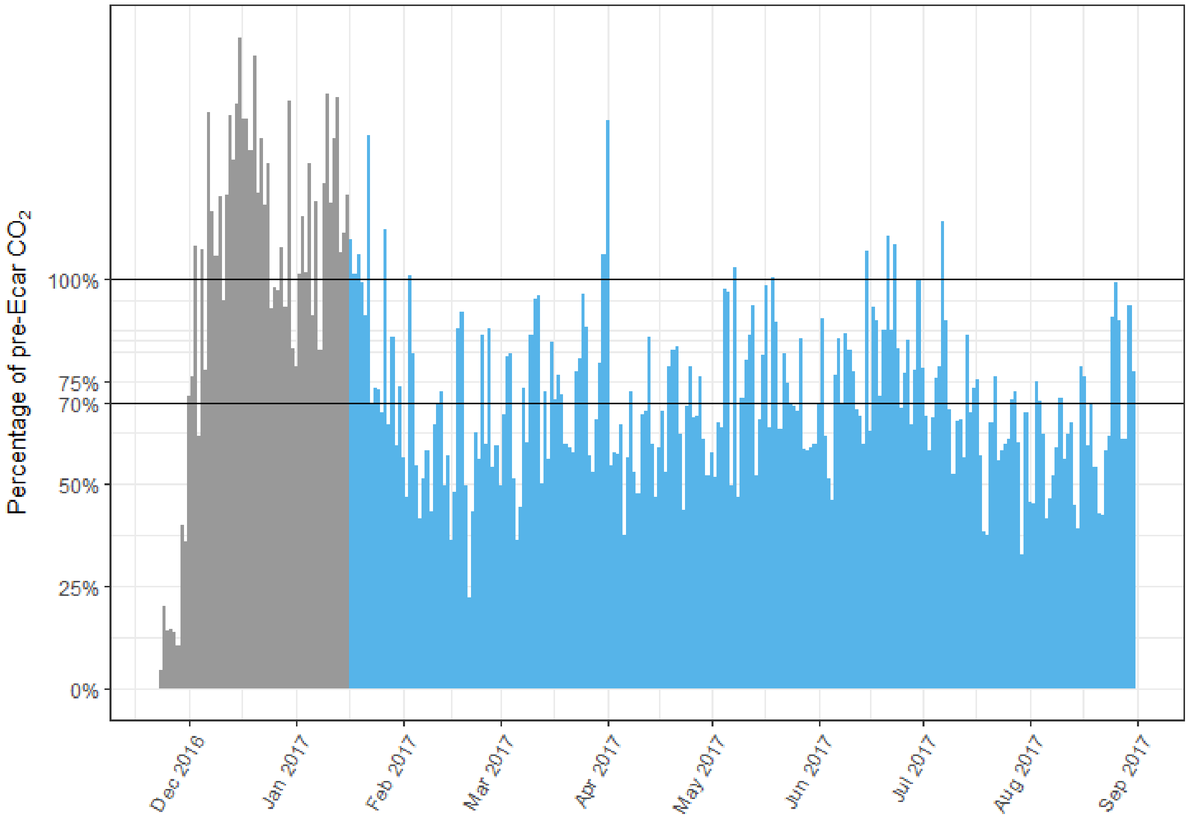
Figure 8. Overall, a reduction of 30% can be observed with respect to the pre-Ecar period. There are however some noticeable outliers, particularly April 1st, 2017. During the course of the pilot program, subscribers had unrestricted access to both their personal vehicle and the provided electric vehicle. As such, on days where many subscribers choose to use their personal vehicles, emissions will naturally be nearer to the pre-program levels. A particular reason for such a choice would be public holidays where many subscribers are likely to want to travel further than what the range of the electric vehicle permits.

The 139 subscribers were not representative of the general population, due to the high cost (12,200 CHF) and selective nature of the pilot program. Nevertheless, these results demonstrate the environmental benefit of having an electric vehicle, and that persons with access to both will significantly reduce their emissions by using the electric vehicle.

4 Conclusion

This paper presented a methodology for imputing the externalities on GPS traces using the MATSim framework. The 2015 MATSim Switzerland scenario was used to provide hourly aggregate estimates for experienced and caused congestion, and pollutant emission factors were taken from the Handbook for Emission Factor Analysis (HBEFA). The suitability of the MATSim scenario for this purpose was evaulated by validating the Switzerland-wide externalities against published offical values. The agent-based aspect of MATSim allows for a much finer calculation of externalities by taking into account the heterogenity in both the population

Figure 8: Percentage of pre-electric vehicle CO_2 produced per day. EV's were provided on January 16, 2017.



and travel behaviour. The validation indicated that the 2015 scenario is mostly suitable for such purposes with some caveats. Firstly, the emission results are highly dependent on the composition of the national car fleet. Therefore, further work will incorportate a car ownership model for Switzerland into the scenario. Secondly, the total delay hours in the scenario are lower than the offical numbers for motorways, but higher for other roads. While the errors are most likely introducted from simplifications on both sides, more work needs to be done to identify the sources of these discrepancies. The analysis of the SBB Green Class project with the proposed methodology demonstrates the environmental benefits of electric vehicles in mobility schemes, even when convential alternatives are still available. Ongoing work will explore the experienced and caused congestion of subscribers, and identify how such information can be communicated to respondents to influence their travel behaviour. Furthermore, the externalities with be monetized based on standards from the VSS norms and the Federal Office of Spatial Development ARE (2016).

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