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# Estimating the health benefits associated with a speed limit reduction to thirty kilometres per hour: A health impact assessment of noise and road traffic crashes for the Swiss city of Lausanne

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ABSTRACT

Reductions of speed limits for road traffic are effective in reducing casualties, and are also increasingly promoted as an effective way to reduce noise exposure.

The aim of this study was to estimate the health benefits of the implementation of 30 km/h speed limits in the city of Lausanne (136′077 inhabitants) under different scenarios addressing exposure to noise and road crashes.

The study followed a standard methodology for quantitative health impact assessments to derive the number of attributable cases in relation to relevant outcomes. We compared a reference scenario (without any 30 km/h speed limits) to the current situation with partial speed limits and additional scenarios with further implementation of 30 km/h speed limits, including a whole city scenario.

Compared to the reference scenario, noise reduction due to the current speed limit situation was estimated to annually prevent 1 cardiovascular death, 72 hospital admissions from cardiovascular disease, 17 incident diabetes cases, 1′127 individuals being highly annoyed and 918 individuals reporting sleep disturbances from noise. Health benefits from a reduction in road traffic crashes were less pronounced (1 severe injury and 4 minor injuries). The whole city speed reduction scenario more than doubled the annual benefits, and was the only scenario that contributed to a reduction in mortality from road traffic crashes (one death per two years). Implementing 30 km/h speed limits in a city yields health benefits due to reduction in road traffic crashes and noise exposure. We found that the benefit from noise reduction was more relevant than safety benefits.

## 1. Introduction

Motorized transport provides great benefits in facilitating access to goods and services, including health services. However, the negative environmental, economic and health impacts of motorized transport related to congestion, air pollution, noise and greenhouse gas emissions are of increasing concern (Vienneau et al., 2015a). From a public health perspective, motorized transport is a leading cause of both injuries and non-communicable diseases - mediated by air pollution, noise, and low physical activity to name a few (Khreis et al., 2019; Sallis et al., 2016). A wealth of studies have linked short- and long-term air pollution exposure, including that from traffic, to mortality (Chen et al., 2013; Hoek et al., 2013) and morbidity, mainly via cardiovascular and respiratory diseases (HEI, 2010; Khreis et al., 2017a; WHO, 2013). Furthermore, noise exposure has increasingly been associated with negative impacts on health and well-being (WHO, 2018). Indeed, transportation noise and more specifically road traffic noise have been linked with ischemic heart disease (Babisch, 2014; van Kempen et al., 2018; Vienneau et al., 2015a), hypertension (van Kempen and Babisch 2012), diabetes (Clark et al., 2017; Eze et al., 2017; Sørensen et al., 2013), annoyance (Guski et al., 2017; Ragettli et al., 2015), and sleep disturbance (Basner and McGuire, 2018). At least for cardiovascular diseases, the effects of noise seem to be independent from the effects of air pollution (Gan et al., 2012; Héritier et al., 2019; Sørensen et al., 2012).

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Adverse health effects due to motorised transport are even greater in urban areas where both population and traffic densities are high and increasing. In this context, policy-makers face a real challenge in designing transport policies that take into account a wide range of potentially conflicting interests, such as mobility, efficiency, environmental sustainability, health and safety (Archer et al., 2008). Over the past 20 years, policy-makers have increasingly implemented 30 km/h zones in urban areas, mainly for safety reasons. The existing evidence shows that 30 km/h speed limits are effective in reducing road traffic crashes and casualties (Cairns et al., 2015; Grundy et al., 2009). More recently, there is a growing interest in introducing city- or town-wide 30 km/h speed limits (Pilkington et al., 2018) to improve population health and well-being. Less information exists regarding the potential benefits of speed limit reductions in terms of other health pathways, such as noise and air pollution exposures and physical activity patterns (Joffe and Mindell, 2002). Jones and Brunt (2017) estimated clear benefits from a country-wide change in speed limits from 30 to 20 mph (48.3–32.2 km/h) in Wales on road traffic casualties and health outcomes related to air pollution. To date, noise has not been quantified despite an increasing interest in promoting 30 km/h speed limits as an effective way to reduce noise exposure (Commission fédérale de lutte contre le bruit, 2015; Degraeuwe et al., 2012), and indications that traffic related noise and air pollution have similar public health impacts (Vienneau et al., 2015a).

In Switzerland, the introduction of 30 km/h speed limits is a source of controversy and opposition. Whereas the road safety argument is well appreciated in political discussions, knowledge about health benefits from noise reduction is scarce (Le Parlement suisse, 2017). For this reason, we aimed to conduct a comparative health impact assessment for the implementation of various 30 km/h speed limit scenarios in the city of Lausanne, to compare the potential health benefits in relation to noise and road crashes.

## 2. Methods

The study followed standard methodology used in quantitative health impact assessment to derive attributable cases. The following methodological steps were included: selection of the study area and the relevant scenarios for the study area, selection of exposure-response functions and health outcomes, modelling changes in population exposure under the different selected scenarios, and calculating the number of attributable cases for the predicted changes in exposure.

### 2.1. Study area and study population

The study area was defined as the administrative area of the municipality of Lausanne, which corresponds to the level at which speed management policies are decided and implemented. Population data were derived from the Swiss National Cohort (SNC) (Spoerri et al., 2010) to obtain residential coordinates needed for noise exposure assessment (Vienneau et al., 2019). Due to data availability, we used SNC data from 2014. In 2014, the 41,3 km$^2$ study area included 136′077 inhabitants. Observations for which residential coordinates were missing in SNC (n = 361) were excluded.

### 2.2. Selection of scenarios

We calculated the difference in health impacts between a reference scenario and three counterfactual scenarios. The reference scenario, called “no zones”, corresponds to the absence of 30 or 20 km/h zones. According to the counterfactual approach, we assumed that the target population and disease rates did not change. We defined the three counterfactual scenarios as follows:

1. “Current situation”, using the 30 and 20 km/h zones that existed in 2017 (Supplementary material Fig. S1)
2. “Whole city except cantonal roads”, 30 km/h speed limits for all the roads except main through roads (Supplementary material Fig. S1)
3. “Whole city”, 30 km/h speed limits for all roads.

For the purpose of our study, we considered road traffic crashes and noise based on clear evidence from the literature that speed reductions could influence these exposures (Egger et al., 2017; Grundy et al., 2009).

### 2.3. Selection of exposure-response functions and health outcomes

Following the recent Environmental Noise Guidelines for the European Region (WHO, 2018), we considered cardiovascular mortality and morbidity, diabetes incidence, annoyance and sleep disturbance. When available we used Swiss exposure-response functions from the SiRENE (Short and Long Term Effects of Transportation Noise Exposure) project (Héritier et al., 2017; Röösli et al., 2019), because the association between noise and health may depend on contextual factors and thus Swiss effect estimates are expected to be most accurate. For cardiovascular outcomes, we selected all cause cardiovascular mortality (Héritier et al., 2017). For diabetes, due to low statistical power of the Swiss study (Eze et al., 2017), we used a recent exposure-response function for road traffic noise exposure from a meta-analysis of three cohort studies including the Swiss study (Zare Sakhvidi et al., 2018). For annoyance and sleep disturbance we used logistic functions from a Swiss survey conducted within SiRENE (Brink et al., 2019a, 2019b). For road traffic injuries, we took the results from a controlled interrupted time series on the effects of 20 mph traffic speed zones in London between 1986 and 2006 (Grundy et al., 2009). Table 1 summarizes the exposure-response functions and outcomes used in our analyses.

### 2.4. Baseline health data

Baseline mortality and morbidity data were obtained from the Statistical Office and the Public Health Service of the Canton of Vaud (Table 1). Road traffic causalities (injuries and deaths) were provided by the Lausanne municipality police office. Number of incident diabetes cases were calculated by applying the incidence of diabetes from the baseline examination of the Lausanne population-based cohort study (CoLaus study) and the 2 follow-up studies performed between 2003–2006, 2009–2012, 2014–2017, respectively (Firmann et al., 2008).

### 2.5. Population exposure modelling

The population exposure to road traffic noise was obtained by assigning values from the 10 × 10 m Swiss sonBASE noise maps (year 2010) to the x, y coordinates in the SNC for persons residing within the municipality of Lausanne. In sonBASE the noise propagation from source to reception points is modelled taking into account building height, first order reflections and noise barriers. Road traffic noise emissions are calculated using sonROAD (Heutschi, 2004) while propagation is obtained via the StL-86 model (Federal Office for the Environment, 1987). The sonBASE model provides equivalent continuous noise level (Leq) for the day (06:00–22:00) and night (22:00–06:00) at the most exposed façade of each building per floor in Switzerland, with noise in 1 dB(A) increments from 30 to 80 dB(A) and also as 10 × 10 m noise maps (Karipidis et al., 2014; Vienneau et al., 2019). The Lden [dB] noise metric used in our study was obtained by applying the daytime noise also for the evening interval to calculate the 24 h weighted Lden average, with a penalty of 5 dB for evening hours and 10 dB for night hours.

In principle, we assumed that all people living within 25 m from roads would benefit from noise reduction due to speed limit reductions. However, individuals in areas along the railway corridor with modelled rail noise exceeding road traffic noise by 5 dB were excluded (n = 1′884) as they would not profit from a reduction in road traffic noise. Similarly,

**Table 1**
Selected health outcomes, exposure-response functions and baseline data for the estimation of mortality and morbidity due to road traffic noise and crashes.

| Health outcome | Age group | Population size | Exposure-response function | Source | Baseline health data | Baseline health data source |
|---|---|---|---|---|---|---|
| ***Road traffic noise related*** | | | | | | |
| Cardiovascular diseases | ≥30 years | 83′161 | RR[a] 1.025 (1.018–1.032) | (Héritier et al., 2017) | 330 deaths; 25′807 hospital days | ICD10 I00-I99: 2014 mortality rates (Statistical Office of the Canton of Vaud) and hospital days (collected by the Swiss Federal Statistical Office and provided by the Public Health Service of the Canton of Vaud) |
| Diabetes | 30–85 years | 79′595 | RR[b] 1.07 (1.02–1.12) | Meta-analysis of 3 cohort studies (Zare Sakhvidi et al., 2018) | 1′179 new cases of diabetes | Diabetes incidence extrapolated from CoLaus study (Firmann et al., 2008) |
| Highly annoyed (HA) | ≥18 years | 107′963 | %HA[c] = 1/ (1 + exp (-(-8.59010665 + 0.1108459**Lden*))) | Logistic function (Brink et al., 2019b) | | |
| Highly sleep disturbed (HSD) | ≥18 years | 107′963 | %HSD[d] = 1/(1 + exp (-(-7.1315 + 0.0976**Lnight*))) | Logistic function (Brink et al., 2019a) | | |
| ***Road traffic crash related*** | | | | | | |
| All casualties | All ages | | Percentage reduction (main analysis): 22.7% (15.3–30.1%) Percentage reduction (high estimate): 41.9% (36–47.8%) | (Grundy et al., 2009) | 2 deaths, 59 serious injuries, 273 minor injuries | Road traffic crashes provided by the Lausanne city police office |

[a] Relative risk (RR) with 95% confidence interval per 10 dB(A) increase in Lden.
[b] Relative risk (RR) with 95% confidence interval per 5 dB(A) increase in Lden.
[c] Percentage of the population "highly annoyed".
[d] Percentage of the population "highly sleep-disturbed".

individuals living within 150 m of the motorways were excluded if they were exposed to noise levels > 60 dB Lden (n = 3′708). In accordance with the results of the SiRENE project (Röösli et al., 2019), an effect threshold of 45 dB for Lden and 35 for Lnight was applied to all exosure-response functions. Thus people below these thresholds were assumed to not profit from a further noise reduction (n = 6′185).

For each of the above specified scenarios, including the reference scenario, we conducted a noise exposure assessment. We applied a 3 dB Lden reduction for areas with a speed limit of 30 km/h and a 5 dB reduction for areas with a speed limit of 20 km/h. These assumptions were based on a source approach specifically developed to estimate the noise level reductions related to the implementation of 30 km/h areas or roads in Switzerland (Egger et al., 2017). In brief, the approach combined measured noise emissions from different driving behaviours for a representative and up-to-date vehicle fleet, data from a statistical survey on actual driving behaviours in representative 30 km/h speed limit situations, and heavy vehicles noise emissions adapted from the European CNOSSOS model (Kephalopoulos et al., 2012). The assumptions for areas with a speed limit of 20 km/h were taken from the graphs in Egger et al. (2017), that also provide the noise reductions for this speed.

Road traffic casualties were computed according to their location and road speed limit using a geographical information system (GIS).

### 2.6. Calculation of health impacts

For health impacts, we calculated attributable fractions for each scenario using the corresponding noise exposure distribution and applied them to baseline health data. Attributable fractions ($AF_{pop}$) were calculated according to the formula $AF_{pop} = [p_p (RR - 1)]/[p_p (RR - 1) + 1]$, where $p_p$ is the proportion of the population exposed to noise and RR is the relative risk according to the exposure-response function for the health outcome under consideration (Perez and Künzli 2009). Attributable cases were then derived from attributable population fractions, by noise category. For road traffic crashes, the percentage decrease in the number of casualties, stratified per road speed limits, was applied according to the changes in road segment speed limits for the different scenarios. The age range used to calculate burden for each health outcome was selected to match the age range of the original population in the studies from which the exposure-response functions were derived (Table 1). For diabetes, we adapted the age range to match that of the CoLaus study on incident cases.

In order to express uncertainty of estimates, results were presented with point estimates and upper and lower 95% confidence intervals, derived from exposure-response functions.

### 2.7. Sensitivity analysis

A sensitivity analysis was performed to assess the influence of a minimal and a maximal reduction in noise exposure. For maximal noise exposure reductions, we applied a 6 dB and 7 dB Lden reduction to 30 km/h and 20 km/h speed limit areas, respectively (Egger et al., 2017). In theory, this is achievable in the presence of an acoustically neutral road pavement, a 2% share of heavy duty vehicles and if every car would adhere to the speed limits. For minimal noise exposure reductions, we applied a respective 2 dB and 3 dB reduction (Egger et al., 2017).

For road traffic crashes, we applied a maximal percentage reduction of 41.9% (95% CI 36.0–47.8%), taken from Grundy et al. (2009). No minimal assumption was applied to road traffic crashes.

## 3. Results

### 3.1. Current exposure

Of the 135′716 individuals living in the Lausanne area in 2014 and for which residential coordinates were available for exposure assessment, 130′124 were included in the impact calculations. Fig. 1 depicts the noise exposure distribution of the study population: 95% were exposed to noise levels greater or equal to Lden threshold of 45 dB. Furthermore, 34% were exposed to noise levels ≥ 60 dB.

### 3.2. Predicted exposure changes

Fig. 2 shows the distribution of the noise exposure for the reference and the three counterfactual scenarios. Considerably more people were

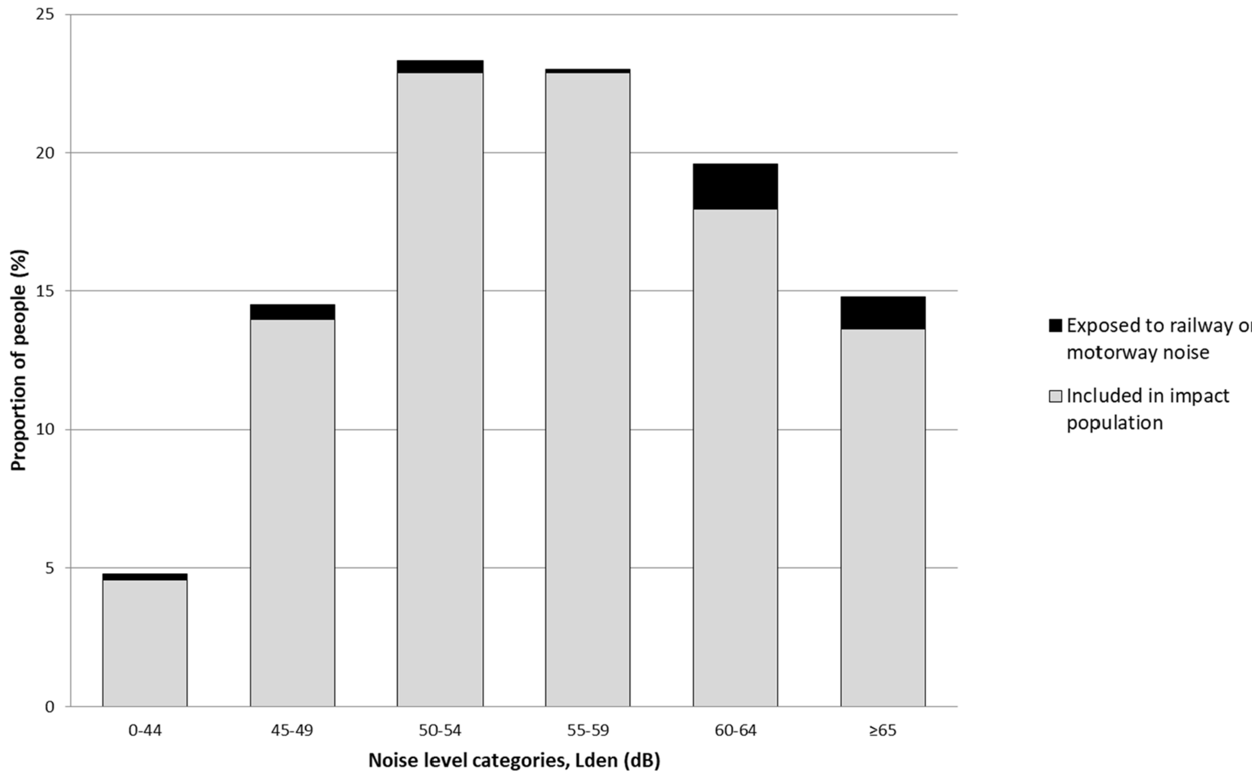


**Fig. 1.** Exposure to road traffic noise for the Lausanne population in 2014.

exposed to higher noise levels in the "no zones" reference than in the "current situation" scenario. The proportion exposed to noise levels ≥ 60 dB was 38.1%, 33.0%, 25.8%, and 24.5% in the "no zones", "current situation", "whole city except cantonal roads" and "whole city" scenarios, respectively. Mean Lden exposures under the respective scenarios were 56.8 dB, 55.5 dB, 54.0 dB and 53.8 dB. The difference in noise exposures between the two latter scenarios was small.

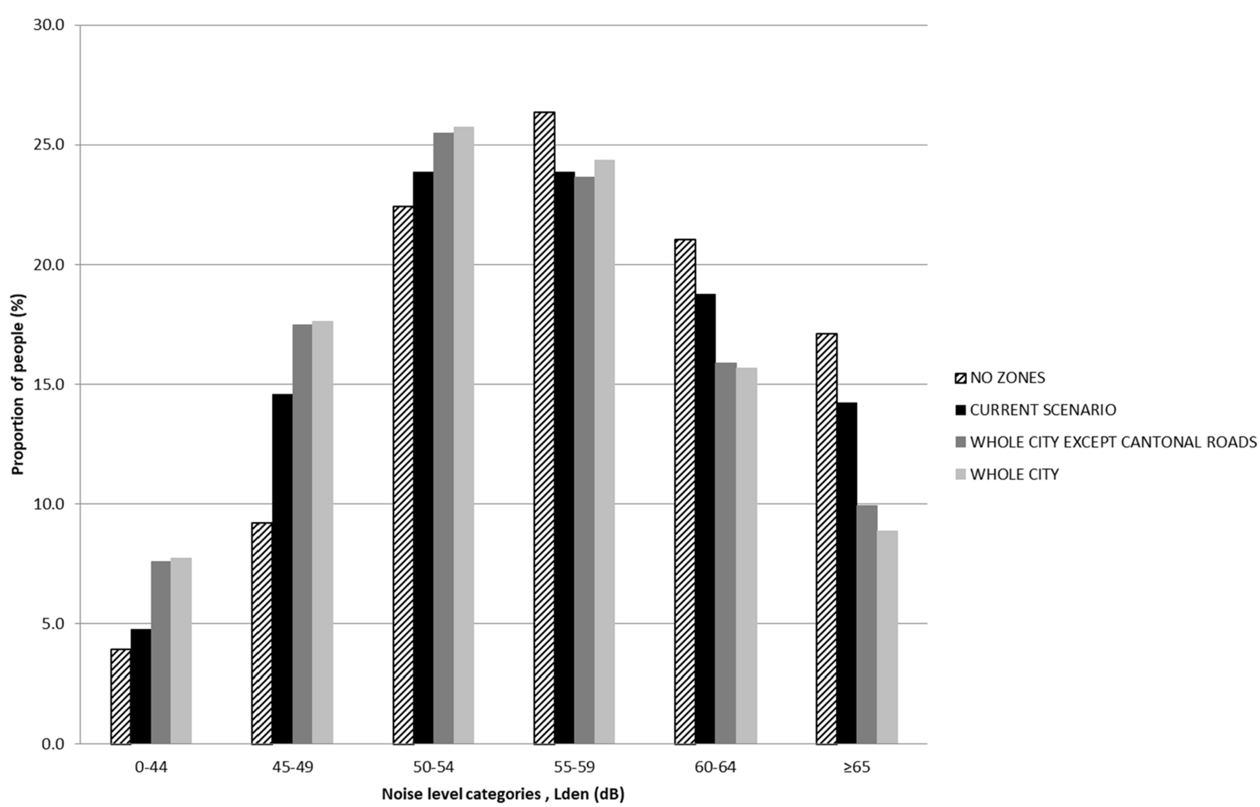


**Fig. 2.** Exposure to road traffic noise of the population under different scenarios.

### 3.3. Health impacts

The estimated health benefits in relation to the introduction of current speed limits, along with additional benefits that could be obtained by the implementation of additional 30 km/h speed limits compared to the reference scenario "no zones", are shown in Table 2. Due to the noise reduction, the "current situation" was estimated to have annually prevented: 0.9 deaths from cardiovascular disease, 72 hospital admissions from cardiovascular disease, 16.9 incident diabetes cases, high annoyance in 1'127 individuals, and high sleep disturbance in 918 individuals. Compared to the "current situation", further introduction of speed limits more than doubled the annual benefits due to noise reduction. Estimated health benefits in terms of a reduction in road traffic casualties were also observed, though to a lesser extent than benefits due to noise reduction: 0.9 severe and 3.9 minor injuries for "current situation" vs. "no zones"). For noise, there was only a minimal difference in estimated health impacts between the "whole city except cantonal roads" and "whole city" scenarios, whereas for road traffic crashes, the "whole city" scenario resulted in a substantial further reduction of mortality and injuries. Only the "whole city" scenario was found to contribute to a notable reduction in mortality from road traffic crashes.

**Table 2**
Estimated health benefits following the introduction of 30 km/h speed limits and according to different scenarios.

| Exposure | Health outcome | Scenario | Attributable number of prevented cases (95% CI) [a] | |
|---|---|---|---|---|
| Road traffic noise | Mortality due to cardiovascular disease (≥30 years) | Current situation | 0.9 | (0.7–1.2) |
| | | Whole city except cantonal roads | 2.0 | (1.4–2.5) |
| | | Whole city | 2.1 | (1.5–2.7) |
| | Hospital admissions for cardiovascular diseases (≥30 years) | Current situation | 72 | (52–92) |
| | | Whole city except cantonal roads | 153 | (111–195) |
| | | Whole city | 164 | (118–208) |
| | Diabetes | Current situation | 17 | (5–27) |
| | (30–85 years) | Whole city except cantonal roads | 36 | (11–58) |
| | | Whole city | 39 | (12–62) |
| | Highly annoyed (HA) | Current situation | 1127 | |
| | (≥18 years) | Whole city except cantonal roads | 2577 | |
| | | Whole city | 2804 | |
| | Highly sleep disturbed (HSD) (≥18 years) | Current situation | 918 | |
| | | Whole city except cantonal roads | 1977 | |
| | | Whole city | 2096 | |
| Road traffic crashes | Mortality | Current situation | 0.0 | (0.0–0.0) |
| | (all ages) | Whole city except cantonal roads | 0.0 | (0.0–0.0) |
| | | Whole city | 0.5 | (0.3–0.6) |
| | Severe injuries | Current situation | 0.9 | (0.6–1.2) |
| | (all ages) | Whole city except cantonal roads | 8.2 | (5.5–10.8) |
| | | Whole city | 13 | (8.9–18) |
| | Minor injuries | Current situation | 3.9 | (2.6–5.1) |
| | (all ages) | Whole city except cantonal roads | 38 | (25–50) |
| | | Whole city | 61 | (41–81) |

[a] Numbers below 10 have not been rounded to whole numbers.

### 3.4. Sensitivity analysis

Assuming a conservative noise reduction of 2 dB for 30 km/h and 3 dB for 20 km/h speed limits showed a ~30% reduction in noise-related health benefits compared to the results from the main analyses (Supplementary material, Table S1).

A maximal noise reduction of 5 dB for 30 km/h and 7 dB for 20 km/h speed limits resulted in a doubling of the health benefits (Supplementary material, Table S2). The same applied when considering a maximal reduction in road casualties of 41.9% (95% CI 36.0–47.8%) (Supplementary material, Table S2). The estimated changes in noise exposure for minimal and maximal noise reductions are shown in Supplementary material Figs. S2 and S3.

## 4. Discussion

Road traffic noise is associated with significant health impacts in terms of morbidity and premature mortality. A previous comparative risk assessment estimated that 4′700 years of life lost are attributable to road traffic noise in Switzerland (Vienneau et al., 2015a). A recent burden of disease study from Houston, Texas assessed 302 premature deaths attributable to transportation-related noise and 330 fatalities from motor vehicle crashes (Sohrabi and Khreis, 2020). Speed management is a common target for policy-makers, but it is also a source of controversy and debate. Our study shows that the implementation of 30 km/h speed limits in the city of Lausanne is expected to induce health benefits mainly through a reduction in noise exposure and, to a lesser extent, through a decrease in road traffic casualties. A city-wide 30 km/h default speed limit would double current noise-related health benefits and prevent a noticeable number of road traffic casualties.

Health impact assessments enable integration of health considerations into transport appraisals and contribute to evidence-based policy-making (Kjellstrom et al., 2003). Indeed transport policy interventions may considerably differ in terms of potential health impacts (Khreis et al., 2017b). To our knowledge, most previous health impact assessments of 30 km/h speed limits have focussed on road traffic crashes, demonstrating that traffic calming measures are effective for reducing injuries and deaths (Cairns et al., 2015; Grundy et al., 2009) and providing the greatest benefits to young children (Grundy et al., 2009). In a recent health impact assessment in Wales (3.2 million inhabitants), Jones and Brunt (2017) estimated that changing all 30 mph (48.3 km/h) speed limits to 20 mph (32.2 km/h) could prevent 6–10 deaths from road traffic crashes and 1200–2000 injuries. The authors suggested that 20 mph speed limits may contribute to other health benefits not included in impact calculations, for example through increasing levels of active travel, social inclusion, and by decreasing community severance (i.e. barrier effect of busy roads and transport infrastructure) (Jones and Brunt 2017).

Active travel is of major relevance from a public health perspective (Mueller et al., 2015). Yet, there is no convincing evidence on the effects of traffic calming measures including 30 km/h zones on physical activity (Cairns et al., 2015; National Collaborating Centre for Healthy Public Policy, 2011; NICE, 2018), which is why we have not included this aspect in our health impact assessment.

With regard to air pollution, 30 km/h speed limits have been shown to lower $CO_2$ emissions, but study results on other air pollutant emissions in urban areas provide conflicting results (Cairns et al., 2015;

Degraeuwe et al., 2012; Int Panis et al., 2011). As explained in Int Panis et al. (2011), the differences are mainly related to the use of macroscopic versus microscopic traffic modelling. Emission estimation methods based on macroscopic models use quadratic functions, and indicate that emissions increase when the average speed decrease from 50 to 30 km/h. Microscopic modelling methods, using real-life drive cycles (i.e. a specific speed trace used for testing vehicle performance) for a sample of vehicles, are considered more relevant in urban settings. Speed limits were found to improve traffic flow, resulting in less stop and go traffic with potentially less air pollution emissions (Egger et al., 2017; Transport Environmental Analysis Group, 2013). An analysis on a real drive cycle, on 20 mph and 30 mph roads in London, did not find negative effects on ambient local air quality from introducing 20 mph speed restriction (Transport Environmental Analysis Group, 2013). Due to these inconsistent findings, we opted not to consider air pollution in our analysis.

The study in Wales by Jones and Brunt (2017) considered air pollution, and estimated that deaths attributed to nitrogen dioxide would increase by 63 and those attributed to fine particulates may decrease by 753, respectively. The large difference results between the two pollutants were largely due to the finding that changes in specific pollutant emissions depend on both speed and the vehicle fleet. Emissions were derived from a London study showing that nitrogen oxides emission factors increase for petrol vehicles over 20 mph compared to 30 mph drive cycles, while for diesel vehicles they decrease (Transport Environmental Analysis Group, 2013).

Although it has been shown that speed reductions also reduce noise (Egger et al., 2017), to our knowledge, the health benefits from a reduction of noise exposure have not yet been considered in health impact assessment studies dealing with speed limit reductions.

In our study, we found no major health benefits from a further reduction in noise exposure between the "whole city except cantonal roads" and the "whole city" scenarios. This is due to the fact that cantonal roads in the city of Lausanne correspond to only few main road axes. Thus, although still relevant for affected residents, conversion to 30 km/h speed limits only provides a small reduction in noise exposure at the population level. In contrast, larger health benefits from a city-wide 30 km/h default speed limit are estimated for road traffic casualties, because a relative high number of casualties and deaths occur on the higher traffic cantonal roads. However, such conclusions do not consider that adopting a partial default 30 km/h speed limit could redirect some of the traffic to the main road axes - areas that are already exposed to heavier traffic, and where people of lower socio-economic status might be overrepresented - thus potentially creating greater inequalities (van Schalkwyk and Mindell, 2018).

As with all health impact assessments, our study provides estimates based on several assumptions, and is subject to some limitations. The analyses were based on modelled effects, and noise reductions were exclusively based on the effects from speed reduction. In reality, many other factors may contribute to the effectiveness of noise reduction such as road pavement, the share of heavy duty vehicles, and adherence to posted speed limits. Speed limits have a major influence on driving speeds, but without enforcement the decrease in average vehicle speed does not necessarily correspond to the change in posted speed limits (Elvik 2012). In the city of Lausanne, the introduction of a 30 km/h speed limit on two main roads during the night, without any further structural enforcement changes, was surveyed in order to plan for expanding the measure to other roads including main axes (Ville de Lausanne, 2018) Measurements demonstrated that the speed limit alone resulted in a decrease of the 85th speed percentile by approximately 6 km/h and an average noise decrease of 3.1 dB(A) and 2.5 dB(A) on these two roads (Ville de Lausanne, 2018). This is slightly higher than the assumption made in our sensitivity analysis for the minimal scenario. It is reasonable to assume that for a more definitive introduction, including enforcements, reductions in speed and noise would be higher and thus close to the assumption of our main analysis. Importantly, the trial in Lausanne was appreciated by a majority of residents and was well accepted by drivers (Ville de Lausanne, 2018). The reduction in noise emissions applied in our study has the advantage of being based on a representative and up-to-date vehicle fleet and observed changes in traffic speed. However, by adopting a counterfactual approach, our study does not include future or near future changes in vehicle fleet, transport systems or policy (e.g. a car ban in the city centre). The increasing share of electric cars, likely to be seen within the next years, will further fortify speed limit related noise reductions, because below 50 km/h the proportion of motor generated noise is most relevant whereas above, the traffic noise originates mainly from the tires (Rojas-Rueda et al., 2020). The implementation of intelligent transport systems could contribute to greater health benefits by reducing road crashes, but may also result in higher traffic volumes increasing noise exposure and thus making speed limits more efficient.

Our study used data from several years, due to data availability. The noise modelling, population data and the map of 20 and 30 km/h zones were from 2010, 2014, and 2017 respectively. However, temporal changes across this time period are expected to be small, and have only a minor impact on the estimated numbers.

Our approach assumes steady state conditions, and there are some uncertainties in relation to the time of occurrence of health benefits. Improvements in annoyance and sleep disturbance, as well as road traffic casualties, should occur quickly after implementation. Impacts on cardio-metabolic diseases may require more time, though timing is uncertain. Moreover, while diabetes and cardiovascular diseases affect adults, road traffic crashes disproportionately affect children and young adults (Grundy et al., 2009).

Considering the assumptions in our study, the results should be interpreted as a conservative estimation of health benefits. We included only health outcomes for which an exposure-response for road traffic noise exists, and omitted other possible noise-related outcomes such as cognitive impairment in children, depression and other metabolic disorders like obesity (Basner et al., 2014). We also applied an effect threshold of 45 dB although several studies reported health effects below this threshold (Vienneau et al., 2015b).

Concerning the interpretation of the results, the estimated benefits are rather small, and dominated by the reduction in noise exposure. Nevertheless, benefits are in the range of what can be expected for isolated transport policy measures, such as speed limit reductions on motorways, traffic reallocations or an increase in the share of electric cars (Schram-Bijkerk et al., 2009; Tobollik et al., 2016). Health benefits may be even higher through the increase in active travel (Mueller et al., 2015), if future studies demonstrate the effectiveness of 30 km/h speed limit in increasing the active transportation mode.

## 5. Conclusion

Road traffic is and will remain a major challenge in urban areas. This study provides estimates on the magnitude of the possible health benefits achieved by the implementation of 30 km/h speed limits in the city of Lausanne. It confirms that 30 km/h speed limits are effective in reducing road traffic casualties. Strikingly expected benefits due to the reduction in noise exposure are quantitatively even more important than benefits attributed to less road traffic casualties, which supports the implementation for 30 km/h speed limits not only for safety reasons.

## Credit authorship contribution statement

**Isabelle A. Rossi:** Formal analysis, Investigation, Writing - original draft, Funding acquisition. **Danielle Vienneau:** Methodology, Formal analysis, Writing - review & editing. **Martina S. Ragettli:** Writing - review & editing. **Benjamin Flückiger:** Visualization, Writing - review & editing. **Martin Röösli:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Funding acquisition.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2020.106126.

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