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Driving change: A scoping review of psychological interventions to reduce engine idling and air pollution

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ABSTRACT

Emissions from stationary vehicles (i.e., engine idling) are a major contributor to air pollution, a serious environmental issue that also threatens physical and mental health. Engineering and technical sciences focus on tackling idling pollution through technological advancement but they mostly ignore the human factor (the vehicle driver). In contrast, psychological science has proposed and tested human-centered interventions aiming to influence drivers' behavior directly. Despite their crucial potential to inform strategies for improving public health, these tests have been relatively scarce and dispersed across time and place. Here we conduct a systematic literature search adhering to the PRISMA 2020 guidelines to establish a scoping review of behavior change interventions to reduce engine idling. A search of the Web of Science, Scopus, and PsychINFO databases yielded 26 relevant studies: 11 relying on individual training, 3 on feedback, 5 on community-based interventions, and 7 on psychological messaging. The review suggests that individual training may be effective but mostly in the short-term, with less systematic effects appearing in the longer term. Providing feedback on driving is also an effective approach, especially when used to signal undesirable behavior (i.e., via negative feedback). Community-based interventions emerge as a costly but effective approach, when they succeed to engage community members. Finally, theory-led psychological messaging may be especially effective but message content is key and not every message yields effects. The review summarizes the findings of the existing research, highlights strengths and limitations, and provides future research directions for efficient ways of tackling engine idling.

1. Introduction

Air pollution is a major threat to both human physical and mental health (Hautekiet et al., 2022) and the environment (Smith, 1992). Motor traffic is a major source of that pollution and also contributes significantly to greenhouse gas emissions (Dietz et al., 2009). In recent years, there has been a growing effort from policy makers, engineers, and researchers alike to address the challenge of reducing air pollution from motor traffic. Some strategies focus on reducing the number of individual journeys or on switching from private cars to public transportation. Others aim to make cars less polluting through technological advances. A third approach is to target drivers' behavior, based on the contention that technology can only help so far as the human using it allows. This approach includes different types of intervention, including efforts towards implementing "eco-friendly" driving. However, no single intervention has emerged as dominant in the literature and there is no clear consensus about the relative effectiveness of different strategies for changing drivers' behavior related to air pollution. To address this gap, the present paper presents a scoping review of the literature on psychological interventions aiming to change drivers' behavior, more specifically to reduce drivers' *engine idling* behavior.

Idling behavior has contributed substantially to excess pollutant emissions (e.g., Sharma et al., 2019) but is also a behavior on which drivers have direct control, entails no cost, and is in principle amenable to change. It is therefore a prime candidate for behavior change interventions. In the following sections, we briefly outline the impact of motor traffic and more specifically of engine idling on air pollution, before turning to the review of behavior change interventions tackling

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the issue.

1.1. Air pollution and motor traffic

Air pollution has been associated with cardiovascular and respiratory problems (Dominski et al., 2021), sleep deprivation (Chen et al., 2022), and depression (Bakolis et al., 2021; Latham et al., 2021), and generally with poor self-reported physical and mental health (Hautekiet et al., 2022). Therefore, it is not surprising that air pollution is linked with high morbidity (Tong, 2019) and mortality (Burnett et al., 2018; Engström & Forsberg, 2019; Holgate, 2017). Of importance, even relatively short exposures to air pollution can lead to devastating health consequences (Gawryluk et al., 2023; Weinmayr et al., 2010), especially if they occur repeatedly (Schultz et al., 2012). At the macro-level, air pollution also has a detrimental societal impact, leading to lower productivity and lower gross domestic product (Aragón et al., 2017; Behrer et al., 2023; Burney & Ramanathan, 2014; Fu et al., 2021). Strikingly, air pollution was estimated to result in over 350,000 premature deaths in Europe in 2022 (European Environment Agency, 2024), and over 4 million premature deaths worldwide in 2019 (World Health Organization, 2024). Despite the implementation of new air quality standards and an overall improvement in air quality in recent years, the most recent report from the European Environment Agency noted that 96 % of the EU's urban population is still exposed to unsafe concentrations of fine particulate matter (European Environment Agency, 2024). Finally, air pollution also has a substantial impact on the environment and local eco-systems (Smith, 1992), especially in terms of CO_2 emissions (European Commission: Directorate-General for Energy Transport, 2006).

Transport emissions are one of the largest contributors to air pollution (Bakolis et al., 2021; Engström & Forsberg, 2019; Harris et al., 2016), in particular in terms of PM (particulate matter), CO_2 (carbon dioxide), and NO_2 (nitrogen dioxide) emissions. Transport emissions, and especially that of road transport, for instance, account for a quarter of all greenhouse gas emissions in the EU (European Environment Agency, 2025). They have also been directly linked to poor physical and mental health (Bakolis et al., 2021; Freire et al., 2010; Harris et al., 2016; Li et al., 2022; Paul et al., 2020; Shankardass et al., 2015). For example, Engström and Forsberg (2019) found that traffic-related air pollution accounts for 23 % of the annual inhalation of NO_2 among commuters during rush-hour, resulting in increased risks of premature death.

1.2. Engine idling and potential for interventions

Researchers have pursued different approaches to address air pollution caused by motor traffic. Those working in technology and engineering typically aim to develop more efficient and less polluting vehicles (for a review, see Lust et al., 2008). Technological advancements do show promising impacts, especially for high-impact vehicles such as those used in mechanized agriculture (Varani et al., 2022) and service vehicles equipped with air conditioning and refrigeration devices (Khazraee et al., 2017). In addition, sophisticated idling detection systems have been shown to reduce idling behavior (Ando et al., 2010; Rolim et al., 2016; Xu et al., 2013). However, advanced technologies are challenging to implement in privately owned vehicles because of the decentralized and diverse nature of the car market. In addition, the transition to advanced and eco-friendly technologies involves logistical and financial challenges for individuals (Adnan et al., 2017; Li et al., 2017; Rezvani et al., 2015). Given the pressing nature of the air pollution problem worldwide, it is of vital importance to also devise and test non-technological interventions aimed at directly changing the behavior of individual drivers.

This latter approach is used by psychologists and social scientists who focus on changing people's habitual driving behavior that contributes to air pollution. For example, interventions have aimed to encourage citizens to reduce the number of individual car journeys (e.g., Tertoolen et al., 1998) or to switch from private cars to public transportation (e.g., González et al., 2021). Yet, these require effortful or costly lifestyle changes and are difficult to implement. Others have turned to the potential for less wholesale changes to the current behavior of car drivers as a means of substantially reducing air pollution whilst minimizing opposition.

One such behavior that has a huge impact on emissions of air pollutants is *engine idling* (i.e., leaving the engine on while being stationary, for instance, at stoplights or railroad crossings; Rahman et al., 2013; Shancita et al., 2014; Sharma et al., 2019). The emission of pollutants from stationary vehicles is particularly harmful, as these pollutants do not disperse easily, posing a substantial health risk for individuals in stationary vehicles (Barnes et al., 2018), residents, and passing pedestrians (Shancita et al., 2014). Turning off the engine while being stationary is a costless, easy-to-adopt behavior, and previous research suggests that while being told to eco-drive may induce some negative affective responses, engaging in eco-driving can increase drivers' self-esteem (Allison et al., 2022). In spite of technological developments making it both easier and more effective to turn off the car's engine, however, a considerable number of drivers continue to idle while being stationary (Abrams et al., 2021). Thus, there is substantial benefit to be gained from devising simple and effective methods to convince people to turn off their engines.

A number of studies have endeavored to reduce engine idling, testing various interventions. However, we lack a comprehensive overview of the existing evidence for the effectiveness of such interventions. The aim of the present review is to address this gap. Specifically, we aim to provide a scoping review of the literature on *behavior change* interventions (excluding purely technology-based ones) to reduce engine idling, investigating (1) the types of interventions most often studied and (2) their effectiveness.

2. Methods

2.1. Information sources and search strategy

This review adhered to the most recent PRISMA 2020 guidelines (Page et al., 2021). We conducted a systematic search of the literature on the two main databases of Web of Science (https://www.webofscience.com/) and Scopus (https://www.scopus.com/) on October 24th, 2023. The search included the following string of words, which were searched in the "keyword+" field: "engine idling" *or* "idling" *or* "car idling" *or* "driver behavior" *or* "eco-driving" *or* "fuel-efficient driving" *or* "anti-idling". The search resulted in 3,609 hits on the Web of Science and 12,829 on Scopus. Of those, we identified 618 duplicates (579 automatically identified based on the publications' DOI and 39 manually identified while conducting the review), leaving a first total of 15,820 unique publications.

Because a significant amount of time passed between our initial search and the writing of this paper, we later updated the search (May 6th, 2025). We searched again the Web of Science and Scopus with the same string of keywords. We also decided to expand the search to another database, PsychINFO (searching for all papers published up to the current date).[2] This new search resulted in 596 hits on the Web of Science, 14,578 on Scopus, and 533 on PsychINFO. Of those, we identified 655 duplicates (609 automatically identified based on the publications' DOI and 46 manually identified while conducting the review), leaving a second total of 15,052 unique publications.

[2] We initially reasoned that PsychINFO would show such an overlap with Web of Science that it was not worth including both. Indeed, our search showed 70 % duplicates for the first search period (till 2023) and 90 % for the second one (2023–2025). Thus, it seems that the overlap between both databases is important, and increasing.

2.2. Eligibility criteria and selection process

We sought to only include publications that (1) utilized a behavior change intervention (thus focusing on human-centered interventions that aim at changing the behavior of the driver behind the wheel, as opposed to, for example, technological advancement) and (2) specifically considered engine idling as an outcome (as opposed to, for example, general fuel-efficient driving behavior). We considered all studies that measured either time spent idling, whether the engine was turned off at a specific stopping location, fuel consumption rate due to idling, or pollutant emission from idling. We also decided to include the (very few) studies that considered engine idling intentions. We did not have a priori expectations as to the type of interventions that the review would reveal and therefore did not have a pre-determined plan how to group the studies for the synthesis. Publications were screened in several stages: one author first screened all publications based on their title to assert general relevance. The same author further screened the retained records based on their abstract. We then sought to retrieve these publications. A second author assessed all records that could be retrieved for eligibility.

2.3. Data collection process and items

Two research assistants independently read and coded the retained records. For each study, they coded the country in which the research was conducted, the population (e.g., truck drivers, car drivers, online sample) and sample size, the intervention being investigated, the outcome(s) under consideration, and the study's findings. The research team then met to discuss and resolve discrepancies in coding.

2.4. Effect measures and synthesis methods

Our last step was to group the studies into coherent categories of intervention. We sought to derive a small number of broad categories, describing what different types of interventions have been used in the literature. This would then allow us to compare their frequency in terms of number of publications but also their relative effectiveness. As the studies' outcomes varied widely (e.g., idling time, fuel consumption rate, whether the engine was turned off) and were not directly comparable, we decided to focus on a narrative description of the existing research, adopting a scoping review approach (Munn et al., 2018). Some studies considered several outcomes (e.g., idling time but also braking and accelerating, or knowledge about idling risk). We only focus here on those directly related to engine idling.

3. Results

3.1. Study selection

From the 15,820 unique publications initially identified in 2023, the first screening based on publications' title left 399 records, and the second screening based on abstract left 102. Seventeen records could not be retrieved. Based on full-text skimming of the 85 retrieved records, we retained 42. To this, 16 records were added that were identified through secondary citation search. These 58 papers were closely read. We excluded 27 papers because they did not focus on idling specifically (either idling was not considered, or it was only treated as part of a more encompassing measure such as overall eco-driving score or fuel consumption with no possibility to extract the idling component only); 3 papers because they presented a technical, not behavioral, intervention; 2 papers because they only presented descriptive or narrative results with no quantitative data on idling, and 1 paper because it included no original data. We thus retained 25 articles.

From the 15,052 unique publications identified in our second search in 2025, the first screening based on publications' title left 55 records, and the second screening based on abstract left 15. All records could be retrieved. Based on full-text skimming of the 15 retrieved records, we excluded 8 papers because they did not focus on idling specifically and 6 papers because they included no original data, retaining 1 paper. Our review thus focuses on the 26 articles (25 + 1) ultimately retained (for an overview, see Fig. 1).

3.2. Study characteristics and results of synthesis

The retained records were published in different fields, mostly in transportation science (8 papers) and psychology (applied or multidisciplinary; 6 papers), with smaller numbers coming from the public health, hospitality and tourism, engineering, business, and thermodynamics literature (see Table 1 for an overview). The majority studied car drivers (15 papers) while others focused on public bus drivers (3 studies), truck drivers (2 studies), or a mix of different driver/vehicle types. Many studies were conducted in English-speaking countries such as the USA (5 studies), the UK (5 studies), Canada (2 studies), and Australia (1 study), but others were conducted in typically underrepresented countries such as Serbia (3 studies), Portugal (2 studies), China (2 studies), Belgium, Croatia, Japan, The Netherlands, Norway, and the Philippines (1 study each). Thus, the studies covered varied geographical locations, although observations from South America and Africa were notably missing.

We identified four intervention approaches, two more individual-centered and two non-person-specific. On the individual-centered side, we first considered the *individual training* approach, which broadly refers to offering theoretical and/or practical training sessions for vehicle drivers (eco-driving). These sessions also at time include tailored advice and feedback on one's driving performance. In contrast, studies categorized under the *feedback* approach solely provide (delayed or real-time) feedback on driving behavior but no training or coaching. On the non-person-specific side, we considered *community-based campaign*, a broad type of participatory intervention including information sharing, participant pledge, and anti-idling messaging on key sites; and finally, the *psychological messaging* approach, which relies on persuasive messages drawing from a variety of theoretical perspectives. All studies included in the review fell under one of the approaches (see Table 1).

3.3. Individual eco-driving training

The systematic literature search identified 11 studies that had employed individual training, mostly under the framework of eco-driving training (Table 2). Eco-driving represents a mode of driving that is "ecological, economical, and safe" and has been integrated into public driving training courses since the mid-1990s (Rutty et al., 2014). Eco-driving initiatives encompass different elements such as strategic (e.g., vehicle maintenance), tactical (e.g., optimal choice of route), and operational decisions (e.g., driving style; Alam & McNabola, 2014). Of the latter, common recommendations include smooth and gradual acceleration and deceleration, maintaining a steady speed by anticipating traffic flow, and – most relevant for the present purpose – avoiding idling by turning off the engine when not in use (Rutty et al., 2014).

The mode and contents of individual eco-driving training substantially differed between studies although most had a duration of 1 day at most (two days for Wu et al., 2017, 2018; and a longer period of daily feedback between two-day sessions for Sigurjonsdottir et al., 2022). Some introduced training courses already developed by non-profit or professional organizations but most developed and executed original training courses, as reported in Table 2. There were two forms of training: theoretical and practical. Theoretical training included in-class seminars (e.g., Barić et al., 2013) and various presentations and courses about eco-driving (e.g., Wu et al., 2017). Practical training involved a driving instructor guiding participants (e.g., Basarić et al., 2017) or daily feedback (e.g., Sigurjonsdottir et al., 2022). Four studies considered the short-term effects of the intervention only, while three considered long-term effects only. Four considered both. All studies adopted a

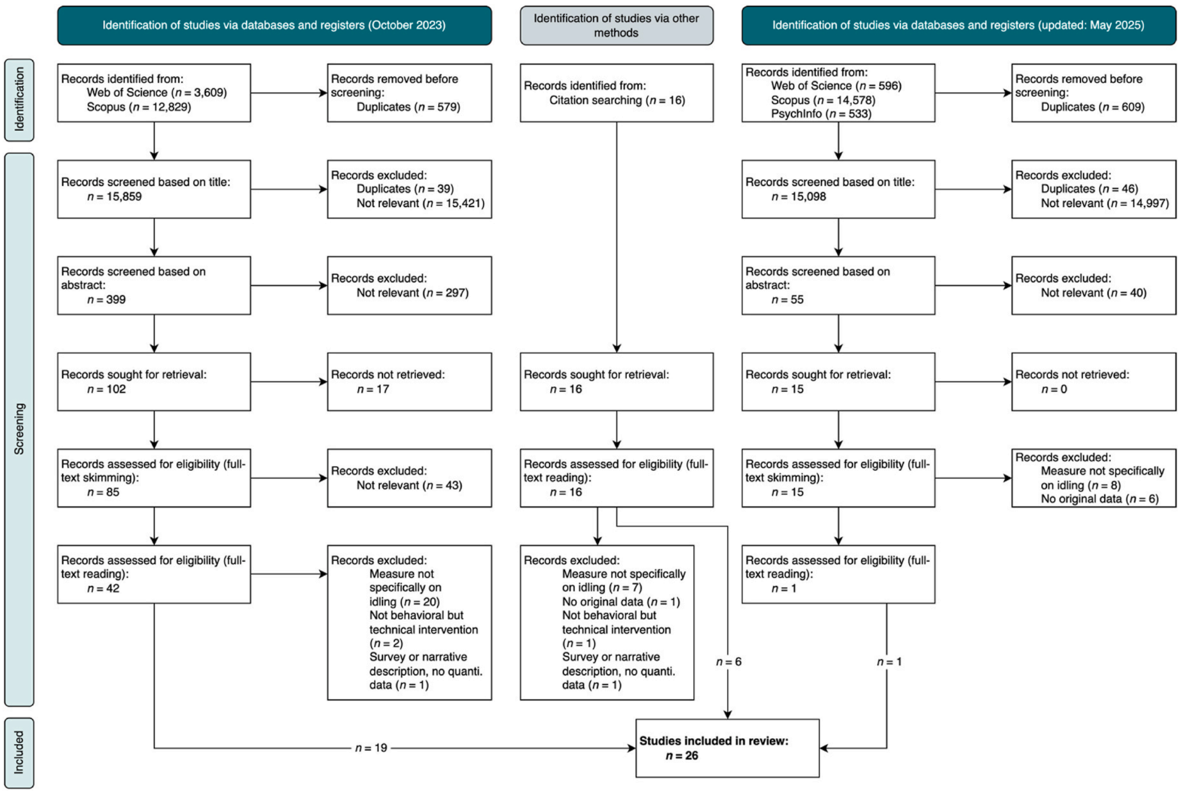

Fig. 1. Flow diagram of the systematic literature review.

longitudinal design, comparing idling behavior pre-/post-intervention within individuals. However, sample sizes were rather small, ranging 3 to 57 participants (median = 13.5).

Over the short-term, that is, directly following training, most studies found an improvement in idling rates. Specifically, fuel consumption rate from idling and time spent idling decreased on training day for the majority of participants in two studies (Abuzo & Muromachi, 2014; Barić et al., 2013). However, others found only a limited impact: in one study, half the drivers reduced their idling time but the other half increased it, leading to no difference overall (Savković, Gladović, et al., 2019). Another study suggests that it is mostly “extreme fuel consumers” who benefit from the training, whereas “low fuel consumers” may not improve and even show some rebound effect after training (Basarić et al., 2017). Although the number of studies is too small to draw definite conclusions, it seems that car drivers benefit from the training more than public bus drivers, potentially because of different constraints on driving behavior.

Studies with multiple intervention phases also afford additional insights into their respective efficacy: mere information was not sufficient to influence idling rates, but introducing feedback and/or specific instructions significantly reduced them from 20 % to 14 % (Sigurjonsdottir et al., 2022). Others found that an initial individual training already effectively reduced idling by up to 50 percentage points (noting that baseline idling rates were quite high in these studies, i.e., 78–82 %) and the effect strengthened after the second phase of training (with an additional 10–15 percentage points decrease; Wu et al., 2017, 2018).

Results on the mid- and long-terms are less conclusive. Some studies found a sustained effect of the training on idling rates over 15 days (Sigurjonsdottir et al., 2022), one month (Rutty et al., 2013; Savković, Miličić, et al., 2019), and a couple of months (Rutty et al., 2014; Savković, Gladović, et al., 2019). However, others found limited or no improvement over time. Abuzo and Muromachi (2014) report that only 10 in 40 participants decreased their actual fuel consumption from idling five days after training. Beusen et al. (2009) similarly found no significant difference in idling 10 months after training compared to before (although other indicators improved). One study even identified a boomerang effect with higher fuel consumption on idling three months after training compared to before (Barić et al., 2013).

In sum, eco-driving training seems to have the potential to influence drivers’ behavior in the short- and the long-term. Still, some studies suggest that behavior change is not uniform and that certain drivers may benefit from training more than others. It is also possible that motivational factors come to play. For example, the underlying intrinsic or extrinsic motivation to join the training may moderate its effectiveness – but none of the 11 studies directly assessed such factors. We also note that several studies relied on very small sample size, qualifying as case studies rather than actual experiments. In addition, they often did not offer details of their training in a way that their methods can be reproduced. The lack of open training materials thus hindered us from systematically investigating or quantifying the effectiveness of different training methods.

3.4. Feedback

Providing feedback has long been recognized as a powerful tool to encourage behavior change. Feedback effectiveness relies on both within- and between-individual mechanisms. At the within-person level, informative feedback may highlight discrepancies between one’s current state and their desired goal (Carver & Scheier, 1998) and increase self-awareness, be it related to the ideal or ought self (Higgins, 1987; Markus & Nurius, 1986). This motivates the individual to adapt their behavior to reduce the discrepancy. At the between-person level, comparative feedback may trigger social comparison dynamics, providing a benchmark for assessing progress, and fostering motivation to align with social norms or personal aspirations (see Festinger, 1954).

Three studies tested the effectiveness of (solely) offering feedback on driving behavior (Ando et al., 2010; Rolim et al., 2014, 2016; see Table 3). Two additional studies (Rutty et al., 2013; Sigurjonsdottir

Table 1
List and characteristics of the studies included in the review.

Study	Category	Country	Population	Total *N*	Outcome	Journal subject area	JCI 2023
Abrams et al. (2021)	Messaging	UK	Vehicle drivers	6049	Engine off (observation) + Air pollution monitoring	Psychology, Multidisciplinary	1.88
Abuzo and Muromachi (2014)	Individual training	Philippines and Japan	Car drivers	57	Fuel consumption rate due to idling (cc/s)	Transportation Science & Technology	0.36
Ando et al. (2010)	Feedback	Japan	Car drivers	50	Idling time (relative to stopping time)	Computer Science	n/a[a]
Barić et al. (2013)	Individual training	Croatia	Car drivers	n/a	Idling time + Fuel consumption while stationary	Transportation Science & Technology	0.16
Basarić et al. (2017)	Individual training	Serbia	Public bus drivers: one low, one moderate and one high cost-awareness	3	Idling time	Thermodynamics	0.29
Beusen et al. (2009)	Individual training	Belgium	Car drivers	10	Idling time	Transportation	1.63
Burgess (2019)	Community campaign	USA	Car drivers	617*	Engine off (observation) + Idling duration	Environmental Assessment	n/a[b]
Dogan et al. (2014)	Messaging	Nether-lands	Car drivers	305	Idling intentions (self-reported)	Business	0.39
Eghbalnia et al. (2013)	Community campaign	USA	Bus + car drivers from school community	184 (19 + 165)	Idling time	Public, Environmental & Occupational Health	0.12
Mahmood et al. (2019)	Messaging	UK	Car drivers	442	Engine off (observation)	Psychology, Multidisciplinary	1.88
Mahmoudi et al. (2025)	Messaging	USA	Car drivers	564	Idling intentions (self-reported)	Psychology, Multidisciplinary	1.88
Meleady et al. (2017)	Messaging	UK	Car drivers	541	Engine off (observation)	Psychology, Multidisciplinary	1.31
Mendoza, Bayles, et al. (2022)	Community campaign	USA	Vehicle drivers	908	Engine off (observation)	Transportation Science & Technology	0.57
Mendoza, Benney, et al. (2022)	Community campaign	USA	Car drivers	874	Air pollution monitoring	Meteorology & Atmospheric Sciences	0.56
Player et al. (2018)	Messaging	UK	Car drivers	419	Engine off (observation)	Psychology, Social	0.73
Rolim et al. (2014)	Feedback	Portugal	Public bus drivers	216	Idling time	Transportation	0.27
Rolim et al. (2016)	Feedback	Portugal	Car drivers	40	Idling time	Psychology, Applied	1.13
Rumchev et al. (2021)	Community campaign	Australia	Schools	10 school sites	Air pollution monitoring	Public, Environmental & Occupational Health	0.40
Rutty et al. (2013)	Individual training	Canada	Car drivers	15	Idling time + CO_2 emission from idling + Fuel consumption and cost from idling	Transportation	1.63
Rutty et al. (2014)	Individual training	Canada	Ski resort fleet drivers	14	Idling time + CO_2 emission from idling + Fuel consumption and cost from idling	Hospitality, Leisure, Sport & Tourism	1.60
Savković, Gladović, et al. (2019)	Individual training	Serbia	Public bus drivers	13	Idling time	Engineering	0.30
Savković, Miličić, et al. (2019)	Individual training	Serbia	Truck drivers	8	Idling time	Engineering	0.46
Sigurjonsdottir et al. (2022)	Individual training	Norway	Truck drivers	8	Idling time	Transportation	1.25
Van de Vyver et al. (2018)	Messaging	UK	Car drivers	455	Engine off (observation)	Psychology, Applied	1.13
Wu et al. (2017)	Individual training	China	Car drivers	22	Idling behavior (driving simulator)	Engineering	0.60
Wu et al. (2018)	Individual training	China	Professional + non-professional car drivers	30 (15 + 15)	Idling behavior (driving simulator)	Transportation	1.63

Note. * estimated number (not reported directly in the paper). JCI = Journal Citation Indicator (Clarivate). All papers were published in peer-reviewed journal except for [a] conference paper, and [b] Master thesis.

et al., 2022) tested the effectiveness of feedback combined with individual eco-training. However, in these studies feedback was only one component of a more encompassing intervention. We therefore decided to treat and describe them as part of the eco-driving training interventions (see Section 3.3 above).

In the three studies that solely focused on providing drivers with feedback, the methods of giving feedback varied greatly. Rolim et al. (2014) studied the impact of real-time sound signals whilst driving (one-year intervention). Ando et al. (2010) used delayed feedback on a daily basis, emailing vehicle drivers a brief summary of their trip and driving behavior (18-week intervention). Participants in their study could obtain further information from the web platform, including a radar chart of the evaluation of their driving (eco-friendliness, idling stop, non-steep acceleration, and non-steep handling), advice for improving these four behaviors, changes of the driving evaluation over time, etc. Furthermore, they offered participants rankings on eco-driving scores as well as a figure describing changes in their ranking results. Finally, Rolim et al. (2016) used delayed feedback on a weekly basis, sending drivers their personal driving statistics alongside customized improvement recommendations (three-month intervention). Here as well, more information could be accessed through a webpage but the authors noted this was barely used. All three studies adopted a longitudinal design with multiple measurement points during each phase of feedback and sample sizes ranged 40–216 (median = 50).

All three studies measured idling time (alongside other measures). The two studies that measured idling during the feedback phase found a reduction in idling time. Specifically, Ando et al. (2010) identified a linear decrease over the 18 weeks of intervention. Rolim et al. (2016) observed a significant decrease in average idling time over the three months of intervention, compared to the three months prior (baseline).

Table 2
Description and findings of studies investigating individual eco-driving training.

Study	Country	Population	Total *N*	Outcome	Training content	Training duration	Training development	Design	Other measures	Short-term effect	Mid- to long-term effect
Abuzo and Muromachi (2014)	Philippines and Japan	Car drivers	57	Fuel consumption rate due to idling (cc/s)	In-person training with an eco-driving expert (driving orientation, eco-driving training, driving test, driving evaluation) and eco-driving diagnostic report after the test drives	One day	Developed by non-profit/ professional organization	Pre/post-intervention	Driving behavior (acceleration, deceleration, constant speed) and subjective perception (questionnaire)	Fuel consumption rate on idling decreased on training day (0.13 cc/s difference); 40/57 participants improved.	Five days after training, real-world improvement is limited (10/40 participants improved); detail of cc/s consumption not reported.
Barić et al. (2013)	Croatia	Car drivers	n/a	Idling time + Fuel consumption while stationary (l)	Theoretical education and practical training onboard a vehicle	One day	Original	Pre/post-intervention	Driving behavior (braking, stopping, shifting gears) and total fuel consumption	Fuel consumption on idling (while stationary) and time idling decreased on training day (−22 % and −11 %).	Three months after training, fuel consumption on idling and idling time increased to greater values than pre-intervention: a boomerang effect (+57 % and +49 %). However, total fuel consumption decreased (mostly due to better brakes usage).
Basarić et al. (2017)	Serbia	Public bus drivers: one low, one moderate and one high on cost-awareness	3	Idling time	Theoretical and practical classes and two drives with monitored driving style (feedback on errors, suggestions and guidelines)	One day	Original	Pre/post-intervention	Driving behavior (braking, stopping, shifting gears) and total fuel consumption	On training day, idling time of the “extreme fuel consumer” driver reduced (−53min), but that of the “low fuel consumer” increased (+29min) with the “moderate” driver in-between (+8min). However, total fuel consumption decreased for all three drivers (mostly due to better average speed).	n/a
Beusen et al. (2009)	Belgium	Car drivers	10	Idling time	Four-hour course on fuel-efficient driving (drive test with and without guidance and fuel-efficient driving instructions)	One day	Original	Pre/post-intervention	Driving behavior (acceleration, deceleration, constant speed) and total fuel consumption	n/a	Over the following 10 months, no significant pre/post difference on idling time (−1 %) although fuel consumption and other indicators improved.
Rutty et al. (2013)	Canada	Car drivers	15	Idling time + CO_2 emission from idling + Fuel consumption	Theoretical education and individualized feedback on pre-	One day	Developed by non-profit/ professional organization	Pre/post-intervention	Driving behavior (hard acceleration and deceleration)	n/a	Over the following month, for gasoline/ hybrid vehicles respectively, idling time (−0.3h or −4

(*continued on next page*)

Table 2 (*continued*)

Study	Country	Population	Total *N*	Outcome	Training content	Training duration	Training development	Design	Other measures	Short-term effect	Mid- to long-term effect
				and cost from idling	intervention driving style						%/−0.3h or −10 %), CO_2 from idling (−1.1 kg/−0.6 kg), and fuel from idling (−0.5L/−0.3L) all decreased.
Rutty et al. (2014)	Canada	Ski resort fleet drivers	14	Idling time + CO2 emission from idling + Fuel consumption and cost from idling	Curriculum tailored to focus on the parameters where participants were the most inefficient pre-intervention (focus on idling)	One day	Original	Pre/post-intervention	Driving behavior (acceleration and deceleration)	n/a	Over the duration of the ski season, CO_2 emission (−8 %), fuel consumption (−8 %), and fuel costs (−8 %) due to idling, decreased in spite of an increase in daily drive time and distance driven (+17 %). Idling time during the first trip of the day (particularly targeted during training) also decreased (−27 %).
Savković, Gladović, et al. (2019)	Serbia	Public bus drivers	13	Idling time	Classroom training combined with on-road instructions by the instructor (test drive)	One day	Original	Pre/post-intervention	Driving behavior (speeding and braking) and total fuel consumption	Directly following training, half the drivers reduced their idling time (13–65 %) but the other half increased it (1–52 %), leading to no overall significant difference.	n/a
Savković, Miličić, et al. (2019)	Serbia	Truck drivers	8	Idling time	Classroom training combined with on-road instructions by the instructor (test drive)	One day	Original	Pre/post-intervention	Driving behavior (speeding and braking) and total fuel consumption	Idling time was reduced by 40 % in the month following training.	Three months after training, the reduction in idling time is sustained (−63 %).
Sigurjonsdottir et al. (2022)	Norway	Truck drivers	8	Idling time	Information about the intervention, instructions/ training, and feedback	One day information session + 19 days of daily feedback + one day instructions session	Original	Pre-intervention, after information, after feedback only, after instructions + feedback, post-intervention	Total fuel consumption	Compared to a 20 % idling rate at baseline, idling did not decrease significantly during the information phase (17 %) but did so during the feedback phase (17 %) and the instructions + feedback phase (14 %).	Over the following 15 days, the reduction in idling rates was sustained (12 %). Five out of the eight drivers significantly improved, two trended towards improving (ns) and one significantly worsened.
Wu et al. (2017)	China	Car drivers	22	Idling behavior (driving simulator)	Theoretical education (phase 1) followed by coaching: getting guidance and feedback about eco-driving behavior in a	2 × one day (education + practical training on different days)	Original	Pre-intervention, after education only, and after coaching (each 3 days apart)	Driving behavior in the simulator (efficient acceleration and deceleration, speed choice)	Percentage of idling behavior reduced from 82 % (pre-intervention) to 32 % after education (phase 1) and further to 21 % after training (phase 2). The	n/a

(*continued on next page*)

Table 2 (*continued*)

Study	Country	Population	Total *N*	Outcome	Training content	Training duration	Training development	Design	Other measures	Short-term effect	Mid- to long-term effect
					driving simulator (phase 2)					incremental benefit of training (phase 2) is more visible for longer stops of 30s and 60s (difference of 14 perc. points in both cases) than for shorter stops of 15s (5 perc. points).	
Wu et al. (2018)	China	Profes-sional + non-professional car drivers	30 (15 + 15)	Idling behavior (driving simulator)	Theoretical education (phase 1) followed by coaching: getting guidance and feedback about eco-driving behavior in a driving simulator (phase 2)	2 × one day (education + practical training on different days)	Original	Pre-intervention, after education only, and after coaching (each 3 days apart)	Driving behavior in the simulator (efficient acceleration and deceleration, speed choice)	Percentage of idling behavior reduced from 78 % (pre-intervention) to 28 % after education (phase 1) and further to 13 % after training (phase 2). The incremental benefit of training (phase 2) is only visible for professional drivers (gain of 27 perc. points) but not for non-professional drivers (2 perc. points) across shorter and longer stops (15s, 30s, 60s).	n/a

Table 3
Description and findings of studies investigating feedback.

Study	Country	Population	Total *N*	Outcome	Feedback type	Design	Other measures	Effect during feedback phase	Effect after feedback phase
Ando et al. (2010)	Japan	Company car drivers	50	Idling time (relative to stopping time)	Delayed feedback: driving stats are sent daily to the driver by email + available on a website. The website also provides customized advice and time comparison.	18 weeks of data collection with daily feedback	Driving behavior (starting, changing speed) and CO_2 emission per kilometer	Relative idling time decreased over the course of 18 weeks (linear regression).	n/a
Rolim et al. (2014)	Portugal	Public bus drivers	216	Idling time	Real-time feedback (sound signals)	1 year of receiving real-time feedback while driving + 1 year without feedback (prior to data collection, most drivers received 1 h of in-class training)	Driving behavior (hard stops and starts, braking, excess speed)	n/a (no pre-intervention data provided to contrast the figures from the feedback phase)	Idling time was lower in the second phase with no feedback than during the feedback phase (approx. −50 %). Younger short-term employees are the only group that did not change (+5 %).
Rolim et al. (2016)	Portugal	Car drivers	40	Idling time	Delayed feedback: driving stats are sent weekly to the driver alongside customized improvement recommendations + access to more information on a website (but this was barely used).	Experimental design: 2 feedback (between: with vs. without) × 2 phase (within: 3 months pre-intervention vs. 3 months intervention)	Driving behavior (hard stops and starts, braking, excess speed)	Idling time reduced during the feedback phase in the experimental group (−1.2 %) while the control group showed no significant difference between phases. Negative (but not positive) feedback led to reducing idling.	n/a

Looking at temporal effects from week to week, they also found that the improvement in idling times was linked to negative, but not positive, feedback received in the preceding week. The third study did not consider idling time prior to the intervention but rather contrasted idling time during the real-time feedback intervention (one year) to that of the following year (Rolim et al., 2014). It identified significantly lower idling time in the following year, after feedback had stopped. Yet, because the study did not include a control group, it is difficult to assess whether the effect represents a positive effect of the intervention, only one that is lagged in time (i.e., drivers do not improve during the feedback year but only later), or whether it indicates possible reactance to the relatively intrusive intervention (real time sound signals while driving) which disappears when the intervention stops.

3.5. *Community-based campaign*

In environmental psychology as in other fields, there is a growing push to actively engage with communities and involve them in the development of research-led interventions – i.e., make the intervention participatory rather than prescriptive (Trott et al., 2020). Such bottom-up processes are believed to increase community's understanding of the issue and to keep community members active and engaged (Holfelder, 2019; Jans, 2021). The Participatory Action Research (PAR) approach thus highlights a number of core building blocks required to develop successful community interventions, such as building relationships, establishing working practices, establishing a common understanding of the issue, observing, gathering and generating materials, collaborative analysis, and planning and taking action (Cornish et al., 2023).

Our review identified five papers that described such community-based campaign (Burgess, 2019; Eghbalnia et al., 2013; Mendoza, Bayles, et al., 2022; Mendoza, Benney, et al., 2022; Rumchev et al., 2021; see Table 4). The two papers by Mendoza and colleagues pertained to the same intervention as in Mendoza, Bayles, et al. (2022) focusing on engine idling observations and in Mendoza, Benney, et al. (2022) focusing on air pollution monitoring. All interventions were implemented at school sites, sometimes specifically the school's pick-up/drop-off lane.

In all cases, the community campaign had involved a collaboration between university researchers, a governmental body (Departement of public health and environment or Departement of health), and one or several schools (most of them public schools). Mendoza and colleagues reported an intervention with the greatest number of involved partners (i.e., the school principal, focus group (parents), survey respondents (school community: students, teachers, staff, bus drivers, and delivery truck drivers), students (Clean Air Champions), and volunteers for data collection), while Burgess (2019) had the fewest (only volunteers helping with data collection). This variation in partnership was reflected in the design of the interventions, which ranged from being designed entirely by governmental officials and merely brought to a school (Burgess, 2019), to being designed governmentally but then modified to suit community needs (Mendoza, Bayles, et al., 2022; Mendoza, Benney, et al., 2022), to being designed from the outset with the help of the community (Eghbalnia et al., 2013; Rumchev et al., 2021).

Although the interventions themselves varied widely to accommodate the specificities of their respective community, we identified several commonalities in their content. Three out of four interventions (all but Rumchev et al., 2021) included an anti-idling pledge with a form that was sent to school parents and/or staff. However, they differed in how the pledge was handled: Burgess (2019) only sent a pledge to parents (at home) and did not include any incentive for signing it. Eghbalnia et al. (2013) sent it to parents and school bus drivers, and included an incentive under the form of a small prize or gift for classrooms with most pledges. Mendoza and colleagues sent the pledge to the entire school community including a small gift as personal incentive for signing. They tracked the school-wide number of pledges received but explicitly refrained from making classroom-level comparisons.

Three out of four (all but Mendoza and colleagues) also included anti-idling messaging. In all cases those were health appeals focusing either on children only ("children breathing", Burgess, 2019; "young lungs at work", Rumchev et al., 2021), or on children and adults (Eghbalnia et al., 2013). Finally, we noted some components that were unique to one campaign. Eghbalnia et al. (2013) included an educational program for all school bus drivers, a staff educational challenge, and schoolwide educational assembly. Rumchev et al. (2021) sent information to parents, teachers and students (fact sheets and newsletters). Mendoza and colleagues provided daily feedback on air quality on school site and worked to facilitate positive contact between students (Clean Air Champion) and non-idling drivers.

In terms of outcomes, three studies focused on engine idling observations and time spent idling (Burgess, 2019; Eghbalnia et al., 2013; Mendoza, Bayles, et al., 2022). The other two monitored air pollution on school sites (Mendoza, Benney, et al., 2022; Rumchev et al., 2021).

All papers reported a positive impact of the community campaign (Table 4). Specifically, Eghbalnia et al. (2013) observed a reduction in idling times by school buses and private cars by approx. 3min on average. Mendoza, Bayles, et al. (2022) reported a decrease in both idling rates and idling time from before to after the campaign. Burgess (2019) also observed reduced idling rates across three schools. However, in this study the idling time (for vehicles still idling) decreased in two locations but *increased* in the third one, indicating possible reactance by some drivers and in some contexts. Of studies that included air pollution monitoring, Mendoza, Benney et al. (2022) reported an air quality increase with lower hourly PM2.5 concentration. Rumchev et al. (2021) also observed a decrease in particulate matter concentration by up to 45 % across 10 school sites, although concentration of other pollutants such as CO, NO, and NO_2, was not affected.

In summary, community-based campaigns demonstrate potential to influence engine idling behavior, therefore contributing to an amelioration of poor air quality. While the number of studies is too small to

Table 4
Description and findings of studies investigating community-based campaigns.

Study	Country	Population	Total *N*	Location	Official partnership	Community partners	Campaign design
Burgess (2019)	USA	Car drivers	617*	School pick-up/ drop-off lane	University + Department of public health and environment + Public schools	Volunteers (data collection)	Entirely designed by governmental office
Eghbalnia et al. (2013)	USA	Bus + car drivers from school community	184 (19 + 165)	School pick-up/ drop-off lane	University + Department of public health + Public schools	Campaign coordinator, school principal, school bus service company, NGOs, local TV station	Designed from scratch
Mendoza, Bayles, et al. (2022)	USA	Car + truck drivers	908	School site	University + Department of public health + Elementary school	School principal, focus group (parents), survey respondents (school community: students, teachers, staff, bus drivers, and delivery truck drivers), students (Clean Air Champions), volunteers (data collection)	Designed by governmental office and modified to suit community needs (parent-led)
Mendoza, Benney, et al. (2022)	USA	as above	as above	as above	as above	as above	as above
Rumchev et al. (2021)	Australia	Schools	10 school sites	School pick-up/ drop-off lane	University + Department of health + Public schools	Project advisory committee (researchers + gov. representatives), school principal, focus groups (parents)	Designed from scratch

	Pledge	Messaging	Other components	Outcome	Other measures	Effect
Burgess (2019)	Anti-idling pledge sent home (week 2), no incentive.	Anti-idling signs (week 1): Health appeal ("children breathing")	n/a	Engine off (observation) + Idling duration	–	Idling rates decreased following the anti-idling campaign in the 3 locations (−18 perc. points). Idling time (for idling vehicles) decreased in 2 out of 3 locations (−53 %) and increased in the 3rd (+19 %).
Eghbalnia et al. (2013)	Anti-idling pledge for parents (+ information) and school bus drivers. Incentive for classrooms with most pledges (small gift).	Anti-idling signs: Health appeal (for children and adults)	Educational program for all school bus drivers + staff educational challenge + schoolwide educational assembly	Idling time	Idling knowledge + anti-idling intentions of school buy drivers and staff	Idling time of school buses and private cars decreased after the anti-idling campaign (approx. −3min on average). Knowledge and anti-idling intentions also ameliorated.
Mendoza, Bayles, et al. (2022)	Pledge packet (educational flyer + pledge form) sent to school community. Personal incentive for signing (small gift) + tracking of # pledges received (school-wide benchmark).	n/a	Daily feedback on air quality, positive contact between students (Clean Air Champion) and non-idling drivers	Engine off (observation) + Idling duration	–	Idling rates (−8 perc. points) and idling time (−37 %) decreased after the anti-idling campaign.
Mendoza, Benney, et al. (2022)	as above	n/a	as above	Air pollution monitoring	–	Air quality increased post-campaign compared to pre-campaign (lower hourly PM2.5 concentration).
Rumchev et al. (2021)	n/a	Anti-idling signs: Health appeal ("young lungs at work")	Information to parents, teachers and students (fact sheets and newsletters)	Air pollution monitoring	–	PM concentration decreased in intervention schools following the anti-idling campaign (−45 % relative change), but CO, NO and NO_2 concentration did not.

Note. * estimated number (not reported directly in the paper).

Table 5
Description and findings of studies investigating psychological messaging.

Study	Country	Population	Total *N*	Outcome	Design	Delivery channel	Location	Other measures	Messaging detail	Effect
Abrams et al. (2021)	UK	Vehicle drivers	6049	Engine off (observation)	Three messages (rotated across two locations) compared to pre-intervention baseline	Printed on a placard, fixed to a lamppost by the railroad crossing	Railroad crossing	Measured concentrations of atmospheric particulate matter	Injunctive social norm vs. Outcome efficacy vs. Self-regulation (private self-focus)	The social norm (−12 perc. points) and outcome efficacy (−7 perc. points) but not self-regulation (−3 perc. points, ns.) messages decreased idling rates. Effectiveness of the social norm message increased with the volume of traffic.
Dogan et al. (2014)	Netherlands	Car drivers	305	Idling intentions (self-reported)	Two messages (between-participant design) compared to a control condition	Presented on computer screen (conversational information embedded in a vignette scenario)	Online (imagined scenario)	Other eco-driving intentions	Self-interest appeals: Financial vs. Environmental	Reducing idling was perceived as more 'worth the effort' when environmental impact (rather than financial, or control condition) was highlighted. Idling intentions were also reduced in both conditions compared to control (environmental: Cohen's $d = -0.56$, financial: Cohen's $d = -0.45$, no sig. difference between the two).
Mahmood et al. (2019)	UK	Car drivers	442	Engine off (observation)	Three messages compared to pre-intervention baseline	Printed on a placard, held by a research assistant on the sidewalk	Railroad crossing	–	Normative reputational concern vs. Outcome efficacy vs. Reflection on intentions	The outcome efficacy (−19 perc. points) and reflection on intentions (−14 perc. points) but not normative concern (−9 perc. points, ns.) messages decreased idling rates.
Mahmoudi et al. (2025)	USA	Car drivers	Study 1: 281. Study 2: 283	Idling intentions (self-reported)	Three/four messages (between-participant design) compared to a control condition (Study 1/2, respectively)	Presented on computer screen (message and image embedded in a vignette scenario)	Online (imagined scenario)	–	Study 1: Information vs. Injunctive social norm vs. Injunctive social norm + image. Study 2: Injunctive social norm + image, varying the Descriptive norm (1-2-4-8 cars described as idling right now)	Study 1: all messages decreased idling intentions compared to baseline, with norm + picture showing the greatest decrease at −4.21min (information: −2.14min, norm: −1.75min). Study 2: the injunctive norm decreased idling (average: −1.40min) as long as the descriptive norm was not too contradictory. At "8 cars idling", no significant difference with baseline.
Meleady et al. (2017)	UK	Car drivers	Study 1: 216. Study 2: 325	Engine off (observation)	Message/picture compared to a control baseline	Printed on a placard, held by a research assistant on the sidewalk	Railroad crossing	–	Study 1: Picture of watching eyes (= reputational concern). Study 2: Picture of watching eyes vs. Private self-focus message	Study 1: the 'watching eyes' picture did not significantly affect idling compared to baseline (+7 perc. points increase). Study 2: the 'watching eyes' again did not differ from baseline (−10 perc. points) but the private self-focus message decreased idling (−31 perc. points).
Player et al. (2018)	UK	Car drivers	419	Engine off (observation)	Three messages compared to a control baseline	Printed on a placard, held by a research assistant on the sidewalk	Railroad crossing	–	Descriptive norm vs. In-group prescriptive deviance vs. Outgroup prescriptive deviance	The in-group prescriptive deviance (−19 perc. points) message decreased idling rates but the outgroup prescriptive deviance (−9 perc. points, ns.) and descriptive norm (−13 perc. points, ns.) did not.
Van de Vyver et al. (2018)	UK	Car drivers	455	Engine off (observation)	Three messages compared to a control baseline	Printed on a placard, held by a research assistant on the sidewalk	Railroad crossing	–	Self-interest appeals: Financial vs. Health vs. Kin	All messages (financial, health, and kin-based self-interest) decreased idling rates (−17, −18, −19 perc. points, respectively).

draw any definitive conclusion, it seems that the risk of backfiring or just of an uneffective intervention may increase in cases of predetermined, 'one size fits all', interventions (Burgess, 2019).

We note a variety of designs, approaches, and activities, implicitly or explicitly drawing from the psychology literature. For example, the unexpected gift offered to non-idling drivers might have reinforced their positive behavior through self-perception processes (Lepper et al., 1973). Providing feedback on the number of pledges received or on air quality on site could also have reinforced social influence dynamics (e.g., Keizer & Schultz, 2018; Nolan et al., 2008). And health appeals may have activated a basic motivation for survival, encouraging drivers to protect themselves (Baldassare & Katz, 1992; Fritsche et al., 2010) and their kin (Palomo-Vélez et al., 2020) by changing their behavior.

3.6. Psychological messaging

An abundant literature on persuasion and attitude change supports the idea that psychological messaging is a powerful tool to influence people's thoughts and behaviors. Messaging may be particularly cost-effective given that, with minimal resources, it can potentially reach large audiences. Messages can vary greatly in their format, content, emotional tone, framing, etc., and their efficacy will depend in part on how people process them. Interventions based on psychological messaging may rely on a variety of theoretical approaches to determine the elements they want to emphasize. For example, dual-process models of attitude change suggest that argument quality is particularly important when people are both able and motivated to scrutinize the message whereas superficial cues such as characteristics of the source are more important when people only pay superficial attention to the message (Chaiken, 1980; Petty & Cacioppo, 1986).

Our review identified seven papers that utilized psychological messaging to encourage drivers to reduce engine idling (see Table 5). Five papers reported the results of field experiments (Abrams et al., 2021; Mahmood et al., 2019; Meleady et al., 2017; Player et al., 2018; Van de Vyver et al., 2018) and two were lab experiments (Dogan et al., 2014; Mahmoudi et al., 2025). The field experiments adopted a pre-post design, comparing average engine idling rates during the intervention to a baseline. The central outcome was observed rates of engine idling, with one study also reporting measured particulate matter levels as a secondary measure (Abrams et al., 2021). The experimental studies compared idling intentions following message exposure compared to a control condition. Sample sizes were notably larger than in the training and feedback studies reviewed above and ranged 216–6049 observations per study (median = 325).

All messages were theory-based and a variety of theoretical frameworks were used to design them. Four psychological constructs emerged repeatedly: social norms and reputation (Abrams et al., 2021; Mahmood et al., 2019; Mahmoudi et al., 2025; Meleady et al., 2017; Player et al., 2018), outcome efficacy (Abrams et al., 2021; Mahmood et al., 2019), self-regulation/reflection on intentions (Abrams et al., 2021; Mahmood et al., 2019; Meleady et al., 2017), and self-interest appeals (Dogan et al., 2014; Van de Vyver et al., 2018). Studies would often compare two to three different messages (relying on different psychological constructs) within the same experiment.

All studies reported some beneficial effects of at least one of the messaging interventions. First, self-interest appeals were generally found effective. Participants in an online study reported lower idling intentions when they had been exposed to a financial or an environmental self-appeal, compared to a control condition (Dogan et al., 2014). They also perceived reducing idling as more 'worth the effort' following the environmental self-appeal. Turning to actual behavior, Van de Vyver et al. (2018) found that health (i.e., emphasizing health-related benefits), kin (emphasizing benefits for children), and financial (emphasizing financial benefits) self-interest appeals all reduced idling rates at a railroad crossing by 17–19 percentage points compared to a no-message baseline.

Second, messages conveying outcome efficacy information (i.e., highlighting that the (non-)idling behavior of just one driver *will* affect air pollution in the area) effectively decreased idling rates by 7 and 19 percentage points in two studies (Abrams et al., 2021; Mahmood et al., 2019, respectively).

Messages relying on social norms showed potential but the effect depended on which specific norm the message referred to. One online study measuring idling intentions observed reduced intentions when participants had been exposed to an injunctive norm message and the effect was stronger when the text was accompanied by the image of a child coughing in a cloud of exhaust gas (Mahmoudi et al., 2025; Study 1). Interestingly, the positive effect of the injunctive norm only held as long as the descriptive norm did not contradict it (i.e., "there are 1/2/4 cars idling"). When the descriptive norm became pro-idling ("8 cars idling"), idling intentions were comparable to that of the control condition (Study 2). Turning to actual behavior, Abrams et al. (2021) reported a reduction of 12 percentage points in idling rates when displaying a message highlighting an injunctive social norm (i.e., that the local, socially responsible, behavior is not to idle). Furthermore, the effectiveness of this message was moderated by the number of vehicles queuing at the railroad crossing such that its impact increased as the number of vehicles increased, suggesting a moderating effect of the descriptive norm. Similarly, Player et al. (2018) observed a reduction of 19 percentage points in idling rates with a message highlighting ingroup prescriptive deviance (i.e., a manipulation to activate reactance, by differentiating drivers from other city residents who fail to switch off their engines). The same research found no effects on idling when the messages focused on outgroup prescriptive deviance (that it is visitors idle, implying an ingroup norm for residents not to do so) or simply on the descriptive norm (stating the real observation that most drivers idle). Highlighting social reputational concern (e.g., via the image of watching eyes; Meleady et al., 2017; or a message encouraging drivers to "show others they care"; Mahmood et al., 2019) also did not significantly affect idling behavior.

Finally, messages focusing on self-regulation/reflection on intentions yielded mixed findings. Encouraging drivers to reflect on their intentions ("When barriers are down do you intend to turn off your engine?") reduced idling rates by 14 percentage points (Mahmood et al., 2019). Activating a private self-focus ("think of yourself") also successfully reduced idling rates by 31 percentage points in one study (Meleady et al., 2017) but not in a second one (Abrams et al., 2021). An interesting difference is that in the first study, researchers stood on the sidewalk and held a placard with the message, while in the second study, the message was displayed on a fixed pole. It is thus possible that the human presence associated with the message moderates its effectiveness by triggering social dynamics that feed into the private self-focus process.

In summary, studies relying on psychological messaging mostly report successful reduction in idling intentions, engine idling rates and idling time, as well as significant reduction in particulate matter concentration. Studies relying on idling intentions solely must be interpreted with caution as those may not align with behavior in situ (Sheeran & Webb, 2016) as evidenced in the pilot study accompanying one of the field experiments (Abrams et al., 2021). Further, not all messages are effective, which suggests that their content (or underlying psychological construct) must be thought through carefully before designing an intervention. In general, we note that these studies tend to have larger sample size than those utilizing individual training and feedback reviewed above. However, they are mostly observational and only report on changes in idling rates during, or directly following, the intervention. None report mid- to long-term effects beyond the duration of the intervention, so from each individual study it is not possible to know whether the benefits of the intervention generalize to other driving contexts or persist through time.

4. General discussion

There are more than 2 billion 22 million vehicles registered worldwide (Global Health Observatory, 2020) which, as populations increase, contribute persistently and with growing impact to air pollution. Although switching to electric vehicles or renouncing to private vehicles altogether are effective ways to reduce some elements of air pollution, neither is likely to be achieved quickly or globally (Kukowski & Garnett, 2024). Thus, influencing drivers' behavior is a crucial element of efforts to limit pollution.

The present paper reviewed behavior change interventions to reduce engine idling – a behavior that largely contributes to traffic-based emissions but is relatively non-costly and amenable to influence. Because the evidence varies widely in terms of methods and outcomes, we chose to conduct a systematic narrative rather than meta-analytic review. Our analysis revealed four categories of interventions: individual training, feedback, community-based intervention, and psychological messaging. In the following sections, for each intervention category we summarize the main findings and discuss implications for policies and large-scale applications.

4.1. Individual training

Summary of findings. We identified 11 studies that evaluated individual training interventions tackling idling behavior. Overall, these studies obtained positive results with a reduction of idling rates immediately following training. Furthermore, introducing hands-on practice and direct feedback on driving behavior produced larger effects than mere education. Car drivers also seemed to benefit from training more than public bus drivers, potentially because of different constraints on driving behavior. However, few studies involved public bus drivers and more evidence is required to reach more definitive conclusions. Finally, evidence for the mid- and long-term was less conclusive. Some studies found effects of training were sustained for up to a few months but others found limited or no improvement after training, or even a boomerang effect.

Nine out of the eleven studies developed their own training methods, and it is likely these varied greatly across studies. Moreover, the majority did not fully describe the contents, mode, or exact duration of the training. Consequently, it is difficult to identify precisely why some interventions were more effective than others. A promising and necessary avenue for both researchers and practitioners in the future is to develop and test standardized individual training methods. This would establish a clearer insight into which component(s) of the training render it more or less effective, and also whether and when it might be useful to develop customized variants targeting specific groups of drivers (e.g., novice versus expert, professional versus private).

Implications for policy and practice. The greatest impediment to adopting an individual training approach may be its cost-efficiency. Individual training, especially if including practical training (which as we described may be key to efficiency), cannot easily target large numbers of drivers. One potential solution may be to rely on country-level policy and implement mandatory idling-related training in the standardized driving license training and practical tests. As such, the European Union made it mandatory to all member states to integrate eco-driving training in the private car (category B) driving test in 2013 (ECOWILL, 2013). However, other countries, notably the USA and the UK, have not implemented such measures and eco-driving training remains an optional component for interested drivers. In order to leverage the individual training approach to discourage engine idling as a large-scale intervention, we suggest that it is vital to closely work with policymakers to integrate eco-driving skills into their official driving license programs. However, while general training can help to frame the general awareness of the value of non-idling, we also recognize that engine idling is most often a choice and not regarded as an inherent part of driving skills or constrained by law, suggesting much of the variance in behavior will depend on altering motivation and habits.

4.2. Feedback

Summary of findings. Studies relying on a feedback approach have used in-vehicle devices to accurately monitor driving behavior and fuel statistics and provide drivers with graded information and verbal feedback. In addition, scholars have developed systems that summarize and send driving statistics to drivers. Our review identified three studies that adopted this approach in an effort to tackle engine idling. These studies were generally successful in reducing idling in the short term. The long-term effects of this approach, however, remain unknown. One paper found lower idling rates *after* the feedback than during it, but there were no baseline observations making it impossible to determine whether this was a lagged effect of the intervention or a form of reactance to the real-time feedback intervention which disappeared later. The other two studies implemented feedback phases of three and four-and-a-half months, respectively, and observed reduced idling rates over these periods. These findings are promising, but it is also possible drivers eventually habituate to the feedback and stop paying much attention to it.

Implications for policy and practice. In general, the feedback approach has several logistic implementation drawbacks. Vehicles need to be equipped with monitoring and feedback systems (Adnan et al., 2017; Li et al., 2017; Rezvani et al., 2015) which involve direct cost, inconvenience, and at least a minimal level of acceptance by the driver (else they deactivate it). Real-time feedback may be distracting and dangerous to the driver and requires careful design and safety assessment. Further, the exact content and format of the feedback would also require calibration. One study contrasted the immediate reactions to positive and negative feedback and found that idling rates reduced only after negative, but not positive, feedback. That people react to negative feedback and modify their behavior to compensate for a past lack of performance is not surprising and speaks to the basic mechanisms of feedback (Carver & Scheier, 1998). However, not only is negative feedback likely to deplete cognitive resources for other aspects of driving (e.g., Sommer et al., 2021), but positive feedback may actually backfire and lead drivers to relaxing their efforts at it effectively signals that they fulfilled their eco-driving goals – a self-licensing effect (Effron & Conway, 2015). Research from the moral and environmental psychology literature has identified a number of moderators of self-licensing on the basis of which we would advise that, so as to keep drivers motivated and avoid self-licensing, positive feedback should employ abstract rather than concrete terms (Conway & Peetz, 2012; Cornelissen et al., 2013), highlight eco-driving standards as an ideal rather than an obligation (Lalot et al., 2022), and reaffirm drivers' commitment to these standards (Fishbach & Dhar, 2005). Overall, however, while feedback can help motivated drivers to ensure they continue to respect their eco-driving standards, the feedback approach is likely to be difficult to implement at large scale.

4.3. Community-based campaign

Summary of findings. Community-based campaigns are one example of bottom-up process aiming at involving community members in the development of customized interventions to address local problems. We identified five papers that described this approach, with two papers pertaining to the same intervention. All campaigns revolved around school pick-up and drop-off zones. They involved a variety of actors but predominantly university researchers, a governmental office, and school representatives. The interventions themselves were either designed entirely by governmental officials, partly customized for a community, or designed from the outset with the help of the community. While the exact components vary, most interventions included a pledge campaign and anti-idling messaging (health appeals), among others. All studies reported a positive impact of the campaign in terms of reduced idling in the school vicinity and amelioration of air quality.

Implications for policy and practice. Community-based interventions demonstrate potential to influence engine idling behavior. They also entail significant cost and time-investment if they are to involve and coordinate between multiple partners so as to clearly define both the local problem and solution(s). This cost, however, seems likely to be worth bearing because research in different fields converges in showing that a 'one size fits all' approach is liable to be relatively ineffective and it is therefore important to tailor interventions to the specificities of the community (e.g., Apfelbaum et al., 2016; Aswani et al., 2017; Fontaine et al., 2024). While designing the campaign, it is also important to ensure that it remains evidence-based because lay-people's intuition about 'what works' may not be accurate. One notorious example is the underrating of normative social influence (e.g., Nolan et al., 2008, 2011). Community-based interventions thus have to be constructed as a real dialogue, bringing together strong empirical evidence and insights about the needs, desires, and resources of the community (see Cornish et al., 2023).

4.4. Psychological messaging

Summary of findings. The messaging approach builds on a long-standing literature on persuasion and attitude change to design communications. As such, it offers a complete contrast with the feedback approach: messaging is extremely cost-effective and can rapidly reach large audiences, but on the other hand, it cannot be customized to specific individuals. We identified seven papers that adopted the psychological messaging approach (testing a total of 23 theory-driven messages). These studies mostly reported successful reduction in engine idling rates and idling time, as well as significant reduction in particulate matter concentration. However, messages were not equally effective, which suggests that their content (or underlying psychological construct) must be considered carefully before designing an intervention.

Messaging based on outcome efficacy and (different types of) self-interest systematically yielded positive effects. Messaging based on social norms showed great potential but depended on the exact content of the normative information: greater effects emerged when the message highlighted that *not idling* was a socially desirable behavior (i.e., injunctive norm) and that although some ingroup members might not respect it, it was very important to do so (i.e., ingroup prescriptive deviance). On the other hand, messages that described an outgroup norm or highlighted a minority descriptive norm were not effective. Finally, messaging focusing on self-regulation/reflection on intentions yielded mixed findings.

We note that the psychological messaging studies have not so far assessed longer-term effects beyond the period of exposure to the message or the intervention. It remains unclear whether drivers might become desensitized if the messages were presented for longer periods or even permanently, leading to decay of impact over time (see Moore & Boldero, 2017). On the other hand, with more continuous, or repeated exposure to such messages, drivers may develop a habit of switching off their engine (Moore & Boldero, 2017), and this might persist and spread through descriptive normative influence. Given the promising results, future research should now turn to exploring the generalizability and robustness of these interventions across different locations and through time. More work is also needed to better understand in which contexts, and potentially which cultures, different messages may be more effective. For example, societies differ in the strength of societal norms and tolerance of deviance (i.e., tight vs. loose cultures; Gelfand et al., 2011) which might moderate the effectiveness of norm-based messaging (see e.g., Siemens et al., 2020).

Implications for policy and practice. Psychological messaging emerges as a cost-effective way to reduce engine idling. Given that the presence of road signs on public highway is generally regulated by the authorities, an efficient implementation of messaging strategy will require collaboration between authorities and scientists who design theoretically-sound messaging. Background research should also be conducted ahead of implementing such campaigns to ensure the local community is involved in and feels content with or welcomes the intervention.

4.5. Limitations and future directions

This review was conducted in accordance with the PRISMA 2020 guidelines, which enhances confidence in the reliability of its findings. However, we recognize certain limitations, such as the restriction to English-language publications. Broadening the scope to include studies in other languages could have improved the review's comprehensiveness and global relevance. The certainty of our conclusions is also constrained by the quality of the work included in the review, which varied. As noted above, some of the research relied on very small samples; some only provided limited information about their design and implementation; and some did not report inferential statistics. This being said, most of the papers reported sound science (24 were peer-reviewed with just 1 conference paper and 1 thesis; see Table 1) and some were published in top journals of their respective fields. Thus, we are confident of the reliability of our general conclusions but call nonetheless for further high-quality research to investigate psychological interventions to reduce engine idling.

In light of the findings reviewed here, we would like to point to the importance of community involvement in pursuing applied research to promote proenvironmental behavior. Currently, a large proportion of drivers leave their engine idling while stationary, reinforcing a harmful community descriptive norm. As pointed out by Cislaghi and Heise (2018), habits and cultural practices are self-protective and difficult to change from outside, and purely external interveners may experience backlash. We join Sloot et al. (2017) in arguing that community involvement and community-led initiatives are likely to be more effective in promoting sustainable behavior as they can trigger both individual- and group-level motivations and actions. Therefore, an important avenue for future work is to develop and test researcher-community collaborations to implement science-based, effective, and well-accepted psychological interventions.

In closing, it is important to note that the automotive industry is undergoing rapid technological change, with the growing implementation of more eco-friendly technology such as start-stop systems and a growing market of electric vehicles. At first glance, this might indicate that engine idling will soon cease to be a pressing concern – but we disagree. First, many developing nations only have a restricted access to such technology and rely on used (and thus older) vehicles imported from Europe and North America; furthermore, car ownership is on the rise in the Global South (UN Environment Programme; 2024). Second, as we noted in the opening, technology can only be efficient if humans allow it to be. Technology disuse is in fact widespread and underlined by many reasons (see Nordhoff, 2024). For instance, industry sources suggest that up to 40 % of drivers disable the start-stop technology in their cars – at least temporarily (Dunham, n.d.). Finally, and relatedly, very recent papers note that similar problems to diesel engine idling plague electric vehicles. Drivers' suboptimal use of their electrical vehicles ("idling energy consumption") creates important energy loss (e.g., Kushwah, 2025). Therefore, we argue that driver behavior is and will remain key to traffic-related environmental impact. The lessons learnt from the present review may continue to inform future behavior change interventions, even as the technology evolves.

CRediT authorship contribution statement

Fanny Lalot: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hirotaka Imada:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tim**

Hopthrow: Writing – review & editing. **Dominic Abrams:** Writing – review & editing, Supervision, Conceptualization.

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