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Abstract: Transport represents one of the highest contributing sources of oil use, pollutant and greenhouse gas emissions and therefore many countries and cities are investigating how to direct abatement activities into that sector. Some cities, like Paris, Madrid, Hamburg and Chengdu, are undertaking restrictive policies such as bans on internal combustion engine (ICE cars) and pedestrian zones and other policies that reduce driving. Several countries are considering national bans on new sales of ICE engine cars by 2040. We consider the literature on proposed policies to shift urban transport modes away from use of cars in urban regions. We then, with our own modeling, estimate the potential impacts of a combination of policies being put into practice to contribute to a peaking in oil demand. We find that combined, national level car bans, urban zone bans, and modal shift policies could contribute significantly to leveling off oil demand trends compared to a business as usual.  Subtracting for any overlap in impact, if applied widely around the world, these combined policies could cut oil use by over 9 mmB/D by 2050. The resultant lessening of oil use would save 0.66 gigatons in CO2 emissions by 2050, compared to a “baseline” type scenario.

# Role of Car-free Zones and Internal Combustion Engine Bans To Reduce Oil Use and Emissions in Urban Transport

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- **Emerging urban policies could contribute to peak in oil demand**
- **Bans on internal combustion engine technology under consideration**
- **Combining these complementary approaches can be effective by 2040**

**Abbreviations**
ASEAN, Association of South East Asian Nations
4DS, 4 Degree Scenario;
ICE, internal combustion engine;
EPA, Environmental Protection Agency;
GHG, greenhouse gas;
$CO_2$, carbon dioxide
EJ, exajoules
IEA, International Energy Agency;
*f,* fuels;
Km^2, square kilometers
MoMo, Mobility Model;
*m,* modes;
Mboe/d, million barrels of oil equivalent per day
Mtonnes $CO_2$eq, million tons of carbon dioxide equivalent
NDC, Nationally Determined Contributions;
OECD, Organization for Economic Co-operation and Development
PLDV, passenger light duty vehicles;
NO2, nitrogen dioxide
Pkm/y, passenger kilometer miles per year
SAV, shared autonomous vehicle;
Vkt, vehicle kilometers traveled
WTW, well to wheel

## 1. Introduction

By 2050, over 80 percent of the world's population will live in urban areas (Rose, 2016), giving cities a critical role in tackling climate change. Transport and buildings represent the highest contributing sources of greenhouse gas emissions (GHG) and therefore many cities are investigating how to direct abatement activities into those sectors (O'Shaughnessy, et al, 2016).

Cities are taking many different approaches to achieving CO2 reductions, from smart growth planning to expansion of public transit to pedestrian-only zones and other direct restrictions on driving. But a fundamental challenge to altering the climate performance of cities is their current configuration where much of the existing infrastructure is built to accommodate the use of individual passenger cars.

Falling costs of wind and solar power have empowered greenhouse gas abatement efforts in the electric power sector in recent years. However, in order to meet and exceed goals from the Paris Climate Accord, transportation systems must be dramatically transformed alongside electricity grids. Effective climate change mitigation depends on reducing oil consumption to power private cars which represent more than half of all emissions from transportation. Desire to address the public health crisis from air pollution in major global cities is also galvanizing change in urban transport approaches and creating a strong desire to reduce oil use (Nieuwenhuijsen, et al, 2014).

In the past year, several countries including France, the U.K., India and China, have announced plans to ban new sales of internal combustion engine (ICE) gasoline and diesel fuel cars by 2040. Other countries such as Ireland, the Netherlands, Norway, Slovenia, and India have set more ambitious timelines for banning ICE cars (IEA 2018). Reduction or outright bans of ICE engine cars in city centers is also catching on in many locations (Garfield, 2018). A number of major cities have pledged to restrict diesel and gasoline ICEs between 2024 and 2040 (IEA 2018).

In this paper, we survey the literature on the role of cars in cities and analyze potential strategies for countries and cities to cut oil use and $CO_2$ emissions. We examine whether these policies could contribute to an eventual peaking in oil use. The existing literature on peak oil demand focuses mainly on the role of energy efficiency improvements and alternative fuels in transport such as electricity in lowering requirements for all oil (conventional oil production and unconventional oil production) by 2070 (Brandt et al, 2013). Brown and Huntington 2017 note the importance of reducing world oil consumption as a means to enhance world oil security. Newman, Beatley, and Boyer 2009 argue that for cities to be resilient to climate change and other health challenges, they will need to reduce oil use.

We extend this literature by considering how newly emerging urban policies and outright engine bans could peak demand for all oil in an earlier time frame. Consultants McKinsey & Co. 2016 consider urban transformations as part of their study of peak oil demand. We further examine this framework by referencing the existing urban policy literature which covers a wide range of alternatives influencing travel demand, including transit-oriented development, accessibility, congestion pricing, vehicle bans, ride-sharing, electrification, and pedestrian centers that are influencing travel demand. We discuss these findings and identify two emerging strategies are starting to stand out as increasingly important policy levers: ICE car sales bans, implemented at a national or urban level, and car-free city centers, implemented at the urban scale. Increasingly, these two policies are being considered separately or together as complimentary approaches. They could both be widely deployed and are reinforcing, since one is primarily focused on urban travel behavior and the other on national travel and vehicle technology. We consider these policies specifically, because they are under broad discussion and implementation in many forward-looking communities around the world and represent a new area of analysis related to oil use. Other urban policies such as congestion taxes and expansion of transit services have received more attention and are well understood.

We utilize a widely respected third-party transportation and energy model to contribute to the literature by highlighting the volumetric potential that combining these two particular policies might have on oil use as a means to greenhouse gas mitigation. We blend insights from the existing literature into our analysis since restrictions for automobiles are most effective when they increase the use of transit, cycling or walking. We find that combining ICE engine bans and car-free city centers could be an effective policy to stimulate a peaking in oil use in the 2030s and thereby reduce greenhouse gas emissions from personal automobile use in the urban setting. However, for these policies to offer optimum impacts and to avoid unintended consequences, they need to be implemented in tandem with other urban sustainability approaches that increase accessibility by other means, such as cycling programs, public transit and land use policy.

### 1.1 Review of the Literature

There is a broad academic literature on urban sustainability that tackles the problem of mobility, air quality, and congestion. More recently, scholars are looking at urban policy as a means to lower oil use and carbon emissions globally. Urban innovations in transportation, land-use development, and building efficiency are increasingly seen as key solutions to climate change and rising energy demand. Roughly half of the world's population lives in cities today. By 2050, over 80 percent of the world's population will live in urban areas, giving cities a critical role in tackling climate change (Rose, 2016). Cities are particularly vulnerable to climate change impacts and, therefore, are politically incentivized and well positioned to lead. Cities can benefit from reducing oil use, especially in transportation, by extending budgets, improving air quality, and reducing congestion. The world's largest cities consume over two-thirds of the world's energy and are responsible for as much as 70 percent of global $CO_2$ emissions derived from energy use. In 2012, consultants McKinsey & Co. project that by 2025 one billion urban residents will be added to global middle class and will increase consumption of transport energy, among other goods and services. Since so much of the global population will be living in cities, understanding the levers that might lower oil use in urban regions offers insights into future global oil demand trends and related emissions.

Local governments are key players in infrastructure and land-use decision making. In the industrialized countries (OECD) local governments are responsible for as much as 70 percent of total public investment and over half of spending on environmental protection (Ter-Minassian, 2017). Ramaswami et al (2012) found that a combination of voluntary and regulatory actions by cities could contribute to a 1 percent annual reduction in carbon emissions in urban transport and buildings through improved building efficiency, transit mode shifting, and smart growth. Subsequent studies had similar findings that cities could play a major role reducing global carbon emissions (Broekhoff, 2015). Several of the largest U.S. cities have set ambitious official targets for lowering their carbon emissions, including New York, Chicago, and Atlanta, which have all pledged reduction goals of 80 percent or higher by 2050. The steps being taken to achieve carbon reductions are varied and include a wide range of programs such as smart growth planning, expansion of public transit, promotion of renewable energy, and enhanced energy efficiency standards.

Transportation is a particularly useful sector for reducing oil use and greenhouse gas emissions because the transport sector is responsible for roughly 20 percent of global emissions and is projected to increase in the coming decades. The IEA predicts that emissions from the global transportation sector will increase by a third by 2050 (IEA 2017). The question is what actions that are being taken by cities to reduce emissions might have significant impact on oil use.

Attempts to reduce emissions through increased transit development and accessibility are widespread. Increasingly, urban sustainability studies are focusing on accessibility, defined as "an indicator of the ability to reach oft-visited places" and accessibility is another tool to reduce carbon emissions by providing urban design that replaces long transportation grids with local accessibility to services and workplaces by combining proximity and mobility. (Cervero 2005.)[1] Ewing and Cervero 2002 argue that compact, mixed use development can substitute for physical movement "by shortening travel distances and prompting travelers to walk in lieu of driving." The emergence of transit-oriented development (TOD) as a potential solution to transit and urban development issues has gained currency within the last two decades. TOD is generally defined as the overlaying of multi-modal transportation options within compact, mixed-use urban settings, allowing for increase public transit and decreased congestion (GAO 2014). Haas, et al 2010 found that residents who lived within walking distance of transit options had emissions that were 43 percent lower than suburban residents.  Rode, et al 2014 present evidence that accessibility created through co-dependency between urban form and transport systems led to a 10-fold differentiation in transport related carbon emissions between compact, efficient cities and energy-intensive, sprawling cities. A suite of smart growth urban planning policies, including TOD, can have a sizeable effect on reducing vehicle use and congestion, with Salon et al 2013 estimating effects in the range of 20 to 30 percent reductions. O'Shaughnessy et al 2016 found smart growth policies could reduce emissions in the United States by 30 to 80 m tonnes of $CO_2$ per year, roughly 2.5 to five percent of on-road vehicle emissions. Litman 2018 concluded that

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[1] Susan Handy looked at some of the claims about the effect of smart growth design principles and sprawl. Her 2005 paper concluded that the new highway capacity does influence where development occurs and increases highway congestion a little. She also found that investment in light-rail will encourage increased urban densities, but only under certain conditions. Finally, smart growth strategies can make it easier to drive for those who already interested in driving less. Handy, S. *Smart Growth and the Transportation-Land Use Connection: What Does the Research Tell Us?*, International Regional Science Review
Vol 28, Issue 2, pp. 146 – 167, 2005.

although each individual design factor has a small percentage effect on vehicle travel and ownership, the incorporated and synergistic effects of these policies can reduce ownership and travel by twenty to forty percent. Portland, Oregon has been able to reduce personal vehicle use, congestion, and subsequently, emissions, through the combined use of an urban growth boundary that limits suburban sprawl and increased investment in transit corridors and biking lanes (Rose and Burkholder, 2009). Total daily vehicle use remained flat between 2014 and 2016, even though Portland grew by 3 percent annually. State-wide vehicle kilometers traveled (Vkt) peaked in 1999 and has been steadily declining since. (Oregon Department of Transportation, 2016)

Initial studies on the subject of new, disruptive technologies such as electrification, automation and shared mobility suggest that these technologies have the potential to promote significant impacts on $CO_2$ reductions, depending on how they are utilized (Fulton, et al, 2017). Levenson et al 2003 found that expansion of public transit can significantly reduce private vehicle travel. O'Shaughnessy et al 2016 found that public transit expansion measures in the United States could reduce carbon emissions by 60 to 110 m tonnes of $CO_2$ per year, roughly four to seven percent of on-road vehicle emissions.).

New studies are now highlighting the role that pedestrian centers can play in creating more sustainable landscape for cities. Many cities are taking incremental steps towards reducing use of PLDVs by offering incentives for public transit, limiting parking, restricting driving permits, implementing congestion pricing, and/or converting roads for exclusive use by bicyclists and pedestrians. To date, there are no large (>500,000 inhabitants) cities completely free of PLDVs (Nieuwenhuijsen and Khreis, 2016). Venice and the Medina of Fez in Morocco are among the best examples, but PLDV use in these cities is naturally limited by practical constraints (Wright

2005). Within the last few years, there has been growing interest among some cities in setting increasingly ambitious goals to restrict PLDVs from entering high-use areas (often referred to as car-free zones). Hamburg was the first city to announce that it will be free of private car use by 2034 (Reuters, 2015). Norway's capital, Oslo, quickly followed with a goal to become "car-free" by 2019. In reality, this policy restricts cars from only 1.9 km$^2$ of Oslo's downtown, in addition to an existing car-free waterfront promenade and central station. Similarly, Madrid has limited the number of visiting vehicles in its downtown and plans to completely pedestrianize its urban center (3.52km$^2$) by 2020 (Cathkart-Keays, 2015). In Europe alone, there are 32 cities considering implementation of a car-free zone (Tønnesen, 2016).

Vancouver, Canada, Quito, Ecuador, and Bogota, Colombia each have designated days per month when downtown streets become accessible to only bikes and pedestrians. New York City has been slowly converting strips of land in popular areas to pedestrian only use, as well as increasing the prevalence of green belts, bike share ports, and expanded subway lines. Congestion pricing offers another means of limiting cars in certain urban areas. London has had a congestion price on PLDVs entering roughly 21km$^2$ of downtown area since 2003, encouraging public transit use to reduce inner-city congestion. London's congestion pricing plan is generally considered to be a success, reducing traffic by a quarter and personal vehicle use by 40 percent. In addition, cycling and walking have increased dramatically (Mayor of London 2017). In one of the most extreme cases, Chengdu China has committed to redesigning the city of 800,000 inhabitants with the goal of pedestrians being able to walk 'anywhere in the city in less than 15 minutes" (Garfield, 2018). This emphasis on alternatives to the urban PLDV highlights a growing acceptance of the car-free lifestyle. Singapore, perhaps one of the most heavily urbanized countries in the world, has some of the strictest PLDV ownership requirements, including hefty fees, quotas, and congestion prices. In October 2017 the Land Transport Authority of Singapore announced that they would reduce the current 0.25 percent growth rate in PLDV ownership to zero in 2018, effectively capping private vehicle ownership at the current level of 612,000 vehicles (LTA 2017). In conjunction with this announcement, the government pledged to invest $20 billion in new rail infrastructure, $4 billion in upgraded rail, and $4 billion in bus contracting subsidies over the next five years.

In an effort to reduce both congestion and mitigate local air quality concerns, cities are restricting the use of PLDVs through even-odd license plate restrictions. Often these measures are emergency bans in order to deal with acute air quality issues, such as the Paris odd-even ban in March 2014 (New York Times, 2014). More long run bans have been implemented in Delhi, Mexico City, and Beijing, among others. A dozen major global cities, totaling more than 145 million people have some form of license-plate vehicle restriction (Davis, 2017). Results have been mixed. Davis 2017 found that Mexico City's Saturday vehicle ban for certain vehicles led to no discernable improvement in air quality. Notably, there was no evidence that residents shifted their transportation choices to public transit options. Instead, residents relied on second vehicles or taxis and ride-sharing. Viard and Fu, 2015, however, found that Beijing's driver restrictions did reduce particulate matter air pollution by as much as 20 percent, with residents choosing to stay home rather than shift to other transportation options.

Nieuwenhuijen, Khreis 2016 studied the impact on car-free zones on personal transportation choices. They found that small car-free areas did not stimulate dramatically higher use of public transit. In their case study on 3 European cities (Bologna, Italy, Lubeck, Germany, and Aachen, Germany) only 12 percent of people affected by the ban on PLDVs switched to public transit instead of driving and parking as close as they could get to the city center or using park-and-ride services. Still, despite the lower than expected mode shift, these three cities saw between a 40-80 percent reductions in PLDV travel from/to the city center.

A new area of research on urban mobility and emissions comes from emerging studies on ride-sharing services and their impact on travel behavior. Firnkorn 2015 estimates that 40 percent of urban car owners (randomized online survey distributed to citizens of Ulm, Germany) would sell their cars or decline to buy a future car if instantly summoned electric vehicles were available through ride-sharing services. But other studies have highlighted the potential negative effect of increased ride-sharing services. A recent study found that a third of San Francisco riders surveyed were using ride-sharing services instead of public transportation, rather than to supplement it (Rayle, et al, 2014). A survey of ride-sharing customers in the Boston area found that 42 percent of customers would have used public transit had ride-sharing not been available (Boston MAPC 2018). This suggests that a sizeable number of customers may be substituting ride-sharing in place of public transit.

Fagnant and Kockelman 2014 studied the potential of autonomous shared vehicle services on urban sustainability. They found that while one shared autonomous vehicle (SAV) could replace up to 11 conventional vehicles, the SAV adds 10 percent more travel distance, offsetting some but not all of the benefits of emissions reductions possible from greater fleet efficiency. Greenblatt also found that autonomous vehicle taxis could reduce emissions from urban transportation if they were smaller, high efficiency vehicles and electricity being utilized was low carbon (Greenblatt, 2013). More recent research by UC Davis details how cities can reduce emissions by as much as 80 percent below business as usual if they embrace vehicle electrification, automation, and ride-sharing (Fulton et al, 2018).

We extend the urban transportation and development literature by considering the outcomes of these previous studies to construct supplementary global oil use scenarios for the transportation sector in circumstances where car-free zones become widespread at the same time bans are imposed on internal combustion engines in key regions that are considering such bans. We add to the literature by illustrating the contribution these combined policies could have on reducing urban transport carbon emissions through reduced oil demand. We find that temporal and geographic aspects are important to the outcome in the relative effectiveness of this policy approach.

## 2. Methodology and Data

For the analysis of the two policies (urban modal shifts and national ICE vehicle sales bans) undertaken in this study, we developed scenarios and projections that are calibrated to those of a global model of urban passenger travel: the International Energy Agency's (IEA) Mobility Model (MoMo). This is a "what if" style spreadsheet model with detailed data and projections for urban travel, vehicle stocks and energy use around the world, broken into 32 countries and regions. This methodology results in forecasts that are based on very detailed data while concurrently allowing for a deeper understanding of underlying drivers. For the purposes of this analysis, we simplified the modeling by creating a standalone scenario tool, with detail level data related to vehicle adoption and use and other transport modes that are specifically needed for this analysis. Comparisons to base year data and "business-as-usual" projections are calibrated to the more comprehensive modeling outputs of MoMo. This approach allows us to illustrate isolated factors consistent with the IEA's general framework while still offering scenario insights contextualized in comparison to the more robust IEA published analysis.

Our specific analysis builds off IEA's "4DS", the 4 Degree Scenario, a type of baseline projection of car stocks and car travel that includes some policy changes but nothing as major as those considered in our analysis (Mason et al, 2015). We refer to this as the "Baseline".

In utilizing the model, we start from Baseline projections of vehicle sales by vehicle type and region and utilize the stock-turnover calculations to get from changes in sales to net stocks over time. It also uses projections of mode shares and travel per vehicle to estimate the effects of how changes in this travel could affect total vehicle travel. This in turn is linked to vehicle efficiency, energy use and CO2 emissions. To put this another way, these calculations and projections are based on the ASIF methodology, which relates vehicle stock, activity, efficiency, and energy content to emissions rate and energy consumption (Schipper). A generic form of the ASIF-based equations used within MoMo for passenger light duty vehicle (PLDV) projections is:

$$G = \sum_{m,f} P_{m,f} A_{m,f} C_{m,f} E_{m,f}$$

Where *G* is the total energy consumption, *P* is the vehicle stock, *A* is the level of activity per vehicle, *C* is the energy consumption rate per unit of service provided, and *E* is the energy density per unit of fuel, assessed across all modes (*m*) and fuels (*f*). Greenhouse gas emissions can then be calculated based on the carbon intensity of the fuel consumed. For use in this analysis, the baseline projection already contained in MoMo was used and new scenarios were constructed by altering this baseline, by changing specific assumptions regarding the sales (and energy technologies) of new vehicles at certain points in the future, and/or the travel of these vehicles in the urban context. Costs of substitution in modalities of travel and for electrification of vehicles are embedded in the MoMo model and are frequently updated. Fulton et al 2009 provides further description of methodologies for how costs are factored into substitution within the modeling framework. Another source for evaluating costs of the net increase in costs to transition away from ICE engine technology is found in Meszler, German et al 2016. Meszler, German et al 2016 found that passenger vehicles as low as 60 to 70 grams per kilometer (g/km) can be achieved with "either no or only modest levels of non-ICE vehicle penetration. Their study adds that passenger vehicle standards as low as 40 g/km can be achieved by 2030 for costs between 1,300 and 3,000 Euros per vehicle at 2014 currency values.

In our modeling exercise, travel behavior is adjusted based on a prior scenarios exercise conducted by two of this article's authors to reflect broader urban sustainability interactions when access to private automobiles is limited such as discussed in the paper **"**A Global High Shift Cycling Scenario: The Potential for Dramatically Increasing Bicycle and E-bike Use in Cities Around the World, with Estimated Energy, CO2, and Cost Impacts" (Mason et al 2015), By linking the reduction in vehicles miles traveled to increases in cycling and transit (in what way mathematically) we incorporate substitution affects from car bans by stimulating more travel by cycling, walking and transit in the modeling. The model allows us to eliminate car stocks from particular locations in the case of urban centers or to reduce their numbers in the case of ICE bans. We replace that travel in the spread sheet with comparable shifts to other modes using the parameters used in previous research (Fulton, Mason, and McDonald, 2016). Net cost differences in the Global High Shift Cycling Scenario are substantial, with savings of roughly $700 billion in decreased costs of road building and $200 billion in saved energy costs outweighing costs for public transit systems and e-bikes (Mason el al 2015). Full scale social cost of carbon calculations is outside the scope of our article but would be a good topic for future research since health and other benefits in the urban environment could be large.

## 2.1 IEA 4 Degree Scenario

We compare our scenario outcomes with similar component calculations in the Baseline Scenario that references the IEA's 4 Degree (4DS) scenario. IEA's scenario takes into account some existing pledges by countries to limit emissions and improve energy efficiency, including Nationally Determined Contributions (NDCs) pledged under the Paris Agreement. Shifts culminate to limiting the expected climate change to a 4°C rise by 2050. Energy consumption reductions in the 4DS come from improved logistics, increased energy efficiency, and policy that supports progressive modal choice behavior. The ensuing section will review some of the fundamental data supporting the 4DS projections as well as transportation relevant trends and assumptions made in the 4DS. Further detail regarding the 4DS scenario can be found in the IEA's Energy Technology Perspectives 2016.

In 2015, the transportation sector accounted for 28 percent of final global energy demand, 23 percent of global $CO_2$ emissions, and 65 percent of final global oil consumption (International Energy Agency). In total, this accounts for 113 EJ. The IEA 4DS predicts consumption to increase to 165 EJ by 2060. The bulk of this demand increase comes from road freight vehicles (36 percent) and passenger light duty vehicles (PLDVs) (28 percent). Additional sizable increases in consumption from 2015-2060 are seen in international transport via marine and aviation. In total, PLDVs accounted for the largest share of global oil demand in 2016 (27 percent). The next largest demand sectors were freight (17 percent), petrochemical feedstock (12 percent), and maritime and aviation (11 percent) (IEA 2017).

For the scenario analysis performed for this essay, a convergence factor is incorporated to account for the global interconnectedness of economic activity. This factor helps to account for the weakening relationship between wealth, car ownership, and GDP and their compounding impact of economic growth. The factor is assessed on non-OECD regions after the year 2020 with stronger impacts in future years to increase convergence of economic growth globally.

## 2.2 National ICE vehicle sales ban scenario

We define the parameters of an internal combustion engine (ICE) sales ban policy as one where non-plugin, ICE-powered vehicle sales go to zero in participating countries by 2040. Plug-in hybrids are assumed to be exempt from the sales ban, as well as commercial freight vehicles, emergency vehicles, and 2/3 wheelers.

In our analysis, we assume the policy begins to impact sales in 2030 as automobile manufacturers begin to gradually shift production. This predated response is consistent with modeling strategies done by BP on a similar topic (BP 2017). However, BP assumes that fuel efficiency gains for passenger vehicles will flatten comprehensively during the periods in question. Authors disagree with this premise among others in the BP assessment. Additionally, the idea of an anticipatory response to the policy is consistent with recent actions made by auto manufacturers after national commitments to phasing out ICEs were made public. For example, Volvo announced it will exclusively produce cars with some form of electric motor beginning in 2019 (Pham). While Volvo represents a niche player in the industry, giants such as General Motors and Renault-Nissan are poised to roll out many more electric models of their own. In October 2017, General Motors reported plans to offer at least 20 new fully electric models by

2023 (Davies). This shift is monumental due to GM's scale, but is not surprising given the trends unfolding in China, its largest market. China has aggressively pursued policies to increase the share of electric vehicles in the national PLDV stock. In 2017, more than 500,000 EVs were sold in China, with EVs making up 2.2 percent of total PLDV stock (IEA 2018). Renault-Nissan has pledged 20 percent electric vehicles by 2022. More strikingly, Volkswagen, the world's largest auto-manufacturer, is planning to launch 50 new electric models and 30 new hybrids by 2025 (Boston). Finally, a number of OEMs have pledged to cease production of all diesel powertrains within the next decade (IEA 2018).

We further assume that ICE bans are fully implemented by 2040 in covered countries. Thus, no non-plug-in vehicles may be sold after 2039. We further assume that countries (and consumers) see this date approaching and start to shift away from ICE cars much sooner, beginning in 2030. The period 2030-2039 is handled as a transition period with a steady decline in ICE vehicle market shares. We further assume that LDV mobility and vehicle ownership are fully conserved (overall new vehicle sales and Vkt remain consistent across all scenarios). We implement our ICE ban in four markets consistent with political statements that have been made public but have not yet turned into direct policy: OECD Europe, China, India, and California.

A Gompertz curve was used to model the decline in non-plug-in ICE sales starting in 2030. A Gompertz curve is a standard sigmoidal function that is traditionally used to model growth over time. The curve starts with slow and increasing growth rates which peak at an inflection point and tapper off again as cumulative growth reaches a maximum capacity, producing an s-shape. To adjust for the reduction in sales in ICE vehicles, an equal number of sales were added to alternative drivetrain vehicles as a function of the Baseline proportion of sales in that year.

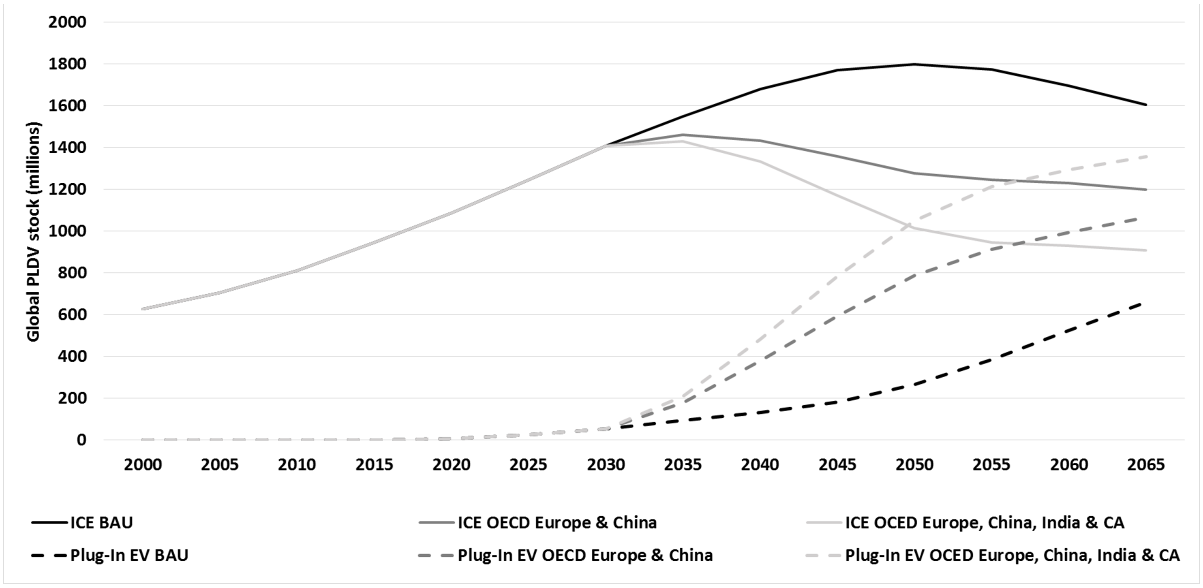

*Figure 1. Global PLDV sales shares as a function of drive train*

One reason for a fairly slow rate of impact of national ICE sales bans is the slow rate of vehicle stock turnover. The longevity of the existing car stocks in the countries in question (and other countries not affected by the bans) will lengthen the time frame before the policy's impact can be felt. Legacy ICEs sold prior to the ban will continue to operate globally for 1-2 decades after the ban is implemented.

Thus while a ban implemented in 2040 will not fully affect the fleet even in 2050, it is also possible that consumer practice might hasten the effect of an announced ban as it approaches, in the same fashion that European diesel car sales have plummeted since the Volkswagen scandal in 2015. Creative policies, such as the Obama administration's cash for clunkers program, might add muscle to the retirement of stocks of ICE vehicles, since it leads to faster phase-out of older vehicles. Our calculations incorporate calibrations for rebound effect patterns but more academic research needs to be done on oil price feedback effects of peak oil demand and increased use of ride sharing and automated vehicle services (Jaffe, 2017).

The ubiquity of national ICE bans (impacting both urbanite and non-urbanites) results in a meaningful reduction in oil consumption. As we attain results from our modeling of car-free city centers together with ICE engine bans, we must subtract urbanite vkt and car stocks from the overall ICE ban results to avoid double counting in impacts related to city center closures.

| PLDV Parc (millions) | 2015 | 2040 | 2065 | % Change (2015-2065) |
|---|---|---|---|---|
| **OECD Europe** | 421 | 486 | 504 | 20% |
| **USA** | 210 | 210 | 197 | -6% |
| **OECD North America ex USA** | 42 | 64 | 78 | 84% |
| **Other OECD** | 200 | 212 | 200 | 0% |
| **India** | 29 | 247 | 399 | 1286% |
| **China** | 140 | 421 | 363 | 159% |
| **Africa** | 31 | 88 | 216 | 606% |
| **Latin America** | 71 | 129 | 162 | 126% |
| **Middle East** | 34 | 85 | 106 | 216% |
| **Other Asia** | 59 | 222 | 388 | 555% |
| **Russia** | 33 | 47 | 40 | 21% |
| **non-OECD Europe** | 21 | 33 | 29 | 37% |
| **World** | 1292 | 2244 | 2683 | 108% |

*Table 1. PLDV Parc size by region*

### 2.3 "High Shift" travel changes in cities

In our urban travel "High Shift" scenario we create parameters that simulate (number) large municipalities that designate an area where PLDV travel is banned, regardless of drivetrain. This policy is already taking place and therefore begins before the 2040 ICE engine ban. In this early period, the closure of city centers to cars impacts only urban drivers, and only to a degree proportional to the size of the area where PLDV travel is banned. We begin our adjustments by considering one scenario where only the direct effects of a car ban are felt in terms of lost vkt for individual vehicles.

To achieve our car free city ban operationally in our spreadsheet calculations, the proportion of Vkt reduced was calculated based on the assumption that trips with destinations located within the car-free area would not be made with a PLDV, as well as any other linked trips. Assuming a uniform trip distribution across all urban traffic analysis zones and no internal trips, a 10 percent car-free center, for example, would result in a 10 percent reduction in Vkt. A 10 percent magnitude of car-free urban areas was selected based on a survey of Europe's largest car-free urban areas, seen in Table 1. This data shows that even the most ambitious municipalities are instituting very modest car-free areas. Our calculations are adjusted to be consistent growth trends, and we work on the assumption that these ambitious municipalities could achieve a 10 percent car-free level by 2030, leading other urban hubs along a similar trajectory. Although cities have only succeeded in cordoning off smaller geographic areas to date, mounting congestion is likely to direct urbanites to seek other avenues of transportation such as cycling, walking and transit, and cities and private developers are already responding to this new demand. We assume that the trend towards enhanced accessibility without increases in traffic will gain momentum as congestion worsens, making driving in private vehicles near impossible for the daily traveler. Bike sharing programs are becoming a more visible feature of many urban areas and some cities, notably New York and San Francisco are starting to consider restrictions on ride sharing vehicles.

| **City** | **City size (km^2)** | **Car free Area (km^2)** | **Percentage of City CF** | **Density (people/km^2)** | **Total Population** |
|---|---|---|---|---|---|
| **Oslo** | 148 | 1.9 | 1.28% | 4284 | 634,032 |
| **Copenhagen** | 90 | 0.6 | 0.67% | 6444 | 579,960 |
| **Groningen** | 81 | 0.3 | 0.37% | 2469 | 199,989 |

| | | | | | |
|---|---|---|---|---|---|
| **Zurich** | 92 | 0.3 | 0.33% | 4130 | 379,960 |
| **Freiburg** | 155 | 0.5 | 0.32% | 1419 | 219,945 |
| **Brussels** | 161 | 0.5 | 0.31% | 7172 | 1,154,692 |
| **Utrecht** | 99 | 0.2 | 0.20% | 3323 | 328,977 |
| **Nuremberg** | 186 | 0.3 | 0.16% | 2677 | 497,922 |
| **Strasbourg** | 224 | 0.3 | 0.13% | 1214 | 271,936 |
| **Gent** | 158 | 0.2 | 0.13% | 1589 | 251,062 |
| **Stockholm** | 215 | 0.2 | 0.09% | 4186 | 899,990 |
| **Munich** | 310 | 0.2 | 0.06% | 4839 | 1,500,090 |
| **Gothenburg** | 204 | 0.02 | 0.01% | 2662 | 543,048 |
| **Dublin** | 115 | 0.01 | 0.01% | 4591 | 527,965 |

*Table 2. Car free cities from throughout the European Union*

We then prepare a more ambitious version of a car-free scenario by integrating approaches found in the paper "A Global High Shift Cycling Scenario: The Potential for Dramatically Increasing Bicycle and E-bike Use in Cities Around the World, with Estimated Energy, CO2, and Cost Impacts" (Mason, 2015). In that study, authors developed a detailed model to estimate the impacts of a range of measures on modal shift, including high transit and cycling use, in cities around the world by 2050. The modeling and "High Shift" scenario development covered all urban areas worldwide with a population of 300,000 or greater.

The reader is referred to that report for most of the details and assumptions of that analysis, but in summary, the High Shift Cycling scenario includes cutting car travel in half in most cities around the world by 2050, with much of this travel shifted to other modes in addition to some reduction in travel due to shorter average trip lengths.

The one region where vehicle travel is not cut by half is North America, and in particular the United States, because it is not possible (or plausible) to re-allocate 50% of the travel to other modes in such a car-oriented situation. The applied North American shift is closer to 35% by 2050. But on average around the world, the reduction in personal vehicle travel is close to 50% by 2050, with much of this achieved by 2035.

In calculating oil demand results here, we use these results with slight adjustments for both the decrease in car travel and some increase in the use of buses, which use petroleum from the "High Shift" scenario. The use of electric rail cycles and walking in that scenario do not use oil are assumed as substitute effects but not explicitly used in the oil use calculations since neither require petroleum.

## 3.0 Results and Discussion

### 3.1 Urban "High Shift" scenario

A combination of significantly less driving, more cycling and greater reliance on transit can clearly cut oil use and associated carbon emissions from cities dramatically. from the projected shift of populations to urban areas. However, our analysis also indicates that it would take substantial, wide sweeping policies and societal changes to achieve this scenario.

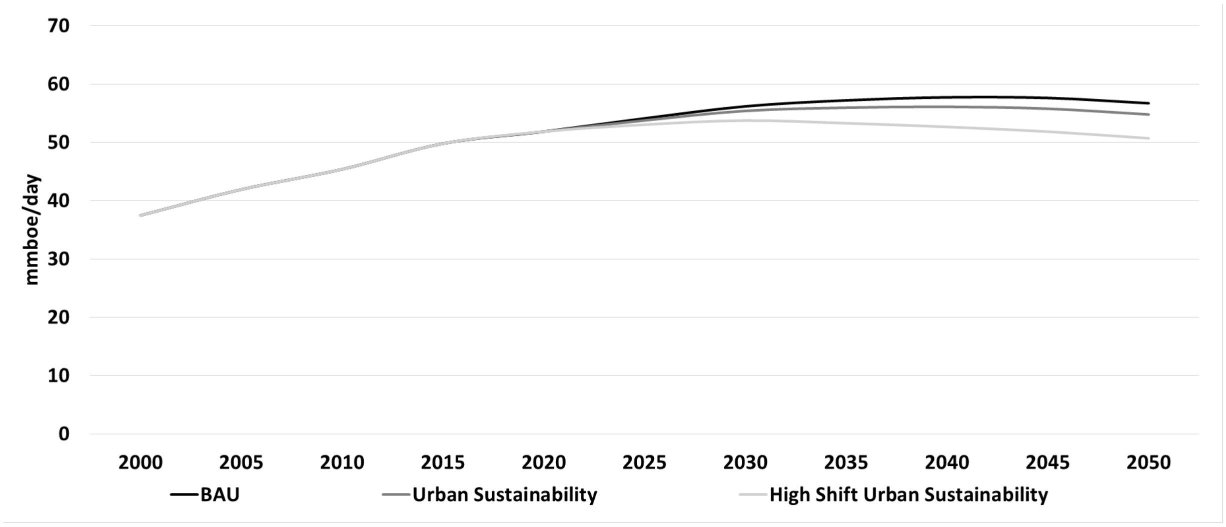

*Figure 2. Global PLDV oil consumption under Urban Sustainability Scenarios*

Figure 1 shows PLDV oil consumption under our "High Shift" scenario combined with an ICE engine ban in key countries. A swell in PLDV oil consumption continues through roughly 2035 and is indicative of the boom in middle class projected to occur in ASEAN and Africa. Middle class families typically own and operate PLDVs at a much higher rate than lower income households.

Given the underlying baseline projection of oil use (which flattens over time in any case), the shifts in urban travel would eventually help bring about a peak in global oil use. Our results find that the order of magnitude of close to 6 million barrels a day of oil use can be eliminated by 2050. In greenhouse gas emissions terms the effectiveness of the "High Shift" scenario is substantial, resulting in a global savings of over 1,000 MMT of $CO_2$ emissions compared to the Baseline.

The bottom line is that the "High Shift" policy can offer a strategy for expedited oil consumption reduction if cities are willing to take strong modal shift measures. These may include closing a large area to individual passenger cars and other measures to discourage car use, combined with highly developing transit and cycling infrastructure whose use is incentivized.

### 3.2 National ICE engine bans

In contrast to urban "High Shift" measures, national ICE car bans focused on a 2040 target date would have little possibility of affecting oil use or CO2 emissions before perhaps 2030, and even then only because of expected anticipatory behavior on the part of consumers and automakers. It is true that other policies are already in play that may shift purchase patterns toward electric vehicles in a substantial way by 2030, but we separate those effects out in our calculations of the direct impacts from a travel ban.

Another key factor is the geographic range of the ban – we assume it is implemented in major car producing regions such as the US, Europe, China, Japan and India. The rest of the world may eventually follow suit, but here we assume that the existing ICE vehicles are sent to those other regions through 2050 and that these other regions do not achieve strong trends away from such vehicles during the study period in question.

Finally, where ever ICE vehicles are banned and thus no longer sold, we assume that a vehicle purchase is still made but substituted by an electric vehicle. This has a direct, complete impact on oil use (as long as electricity generation uses no oil) but doesn't necessarily cut CO2 emissions completely, since electricity generation triggers some emissions. It is possible over time that individual car ownership trends might change over time, rendering our assumptions about car stocks too high. Automation may move some urban populations away from individual vehicle ownership to a higher reliance on "on demand" services that might reduce overall car stocks over time. For our electric transport emissions calculations, we use the IEA 4DS assumptions about grid carbon electricity and find that by 2050 most of the world's grids are deeply decarbonized. Thus, in fact, the CO2 reduction is close to a similar proportion as the oil use reduction.

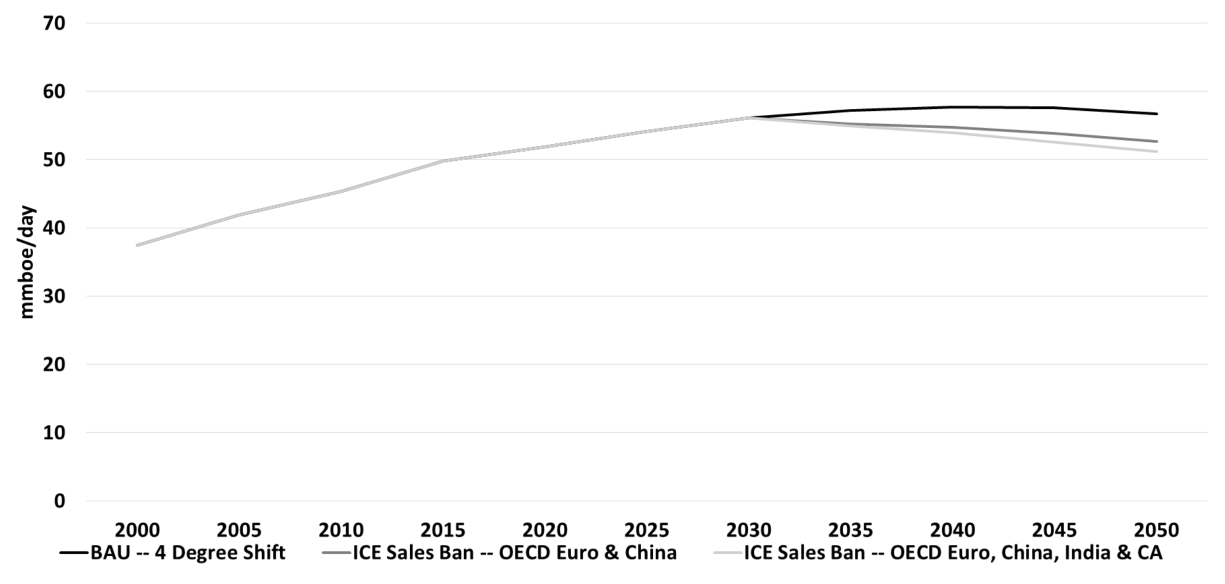

*Figure 3. ICE Sales Ban Oil Demand Implications*

The net effects are shown in Figure 2. The policy begins to save oil around 2030 and achieve significant savings after 2040. By 2050 it reaches around 6 million barrels per day and around 1 billion tonnes of $CO_2$. This is similar to the impacts of our High Shift scenario in cities, though the timing is somewhat later. This also does not take into account that there will be overlap between the two policies and they are not fully additive, as discussed below.

### 3.3 Combining the two policies

The "Hight Shift" and national ICE ban policies are certainly not mutually exclusive and it is interesting to consider the combined impacts if both were followed aggressively. To create the combined scenario, urban sustainability measures began in 2020 and develop in cities through 2030 following the same methods and logic as the High Shift Urban Sustainability scenario. In 2030, the ICE sales ban begins to impact the sales share of EVs in the implementation countries, displacing oil demand. To avoid double counting, the oil demand displacement impacts achieved by the High Shift Urban Sustainability policies were netted out of the ICE Sale Ban countries. In doing so, this method avoids assuming incremental oil displacement from removing a pure electric vehicle from the roads.

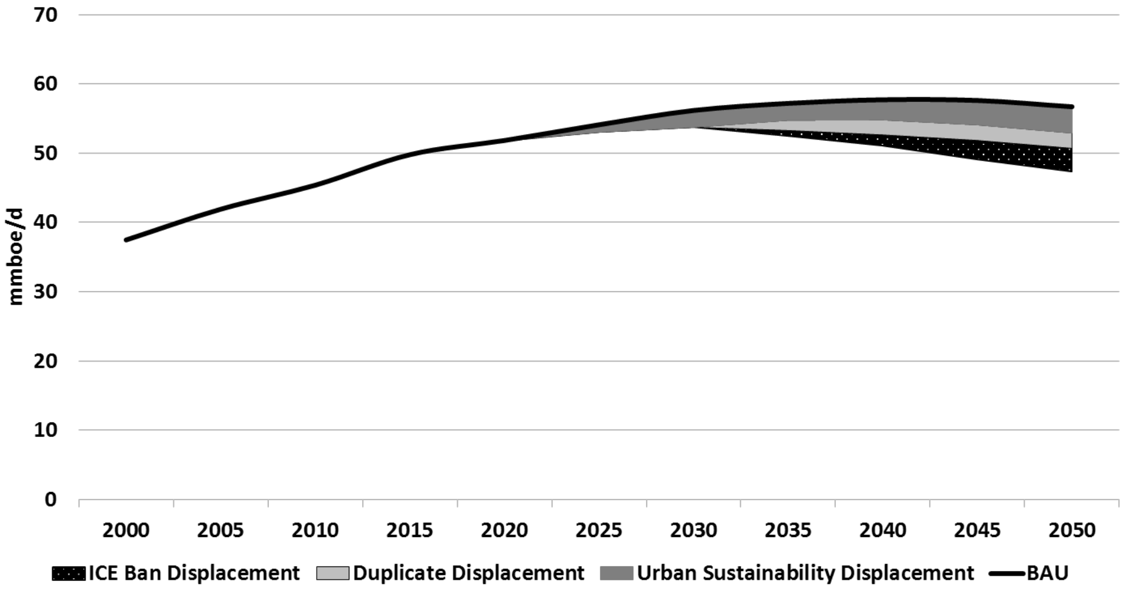

*Figure 4. Oil Displacement from combined ICE Ban and High Shift Urban Sustainability Policies*

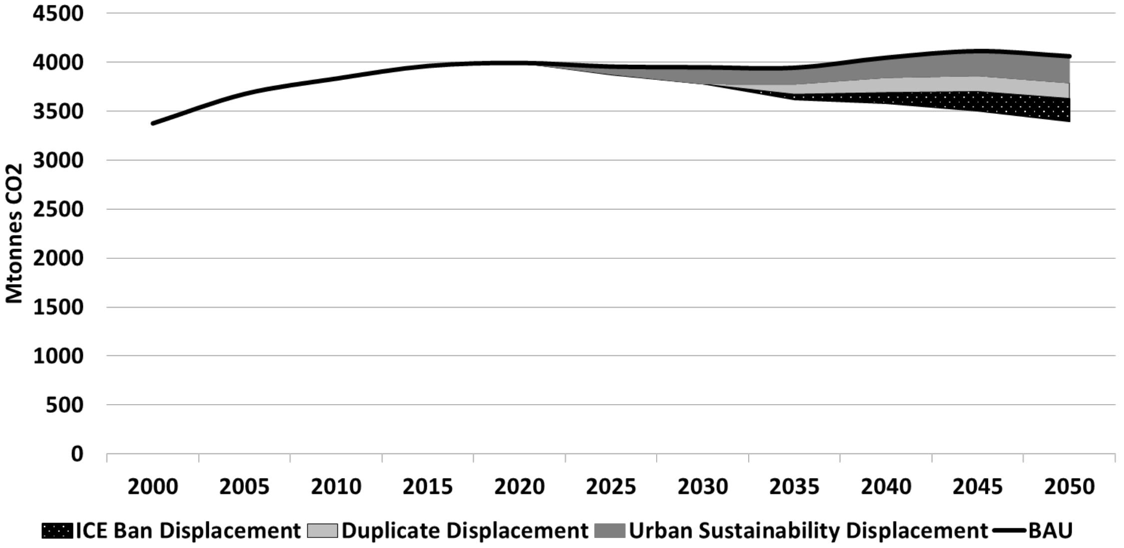

*Figure 5. Emissions reductions from combined ICE Ban and High Shift Urban Sustainability Policies*

| | | Global Transportation Oil Demand (mboe/d) | | | | Oil Displacement (mboe/d) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | BAU | ICE Sales Ban | Urban Sustainability | High Shift Urban Sustainability | Combined Policy | ICE Sales Ban | Urban Sustainability | High Shift Urban Sustainability | Combined Policy |
| **2025** | 54.1 | 54.1 | 53.8 | 53.0 | 53.0 | 0.0 | 0.3 | 1.1 | 1.1 |
| **2030** | 56.2 | 56.2 | 55.4 | 53.7 | 53.7 | 0.0 | 0.8 | 2.4 | 2.4 |
| **2035** | 57.2 | 54.9 | 55.9 | 53.3 | 51.0 | 2.3 | 1.3 | 3.9 | 6.2 |
| **2040** | 57.7 | 54.0 | 56.1 | 52.6 | 48.9 | 3.7 | 1.6 | 5.1 | 8.8 |
| **2045** | 57.6 | 52.6 | 55.8 | 51.8 | 46.8 | 5.0 | 1.8 | 5.8 | 10.8 |
| **2050** | 56.7 | 51.2 | 54.8 | 50.7 | 45.2 | 5.5 | 1.9 | 6.0 | 11.5 |

*Table 3. Scenario Comparison VS BASELINE: Global Transportation Oil Consumption*

Taking these differences and potential overlaps into account, we estimate that a combination of both policies would cut oil use by about 9.3 mmboe/d (rather than 11.5 million if the two were fully additive). Similarly, CO2 emissions reductions would be about .668 gigatonnes rather than the .826 it would be if they were fully additive.

| | | Global Transportation Oil Emissions (Mtonnes) | | | | Oil Emissions Abatement (Mtonnes) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | BAU | ICE Sales Ban | Urban Sustainability | High Shift Urban Sustainability | Combined Policy | ICE Sales Ban | Urban Sustainability | High Shift Urban Sustainability | Combined Policy |
| **2025** | 3956 | 3956 | 3931 | 3878 | 3878 | 0 | 25 | 79 | 79 |
| **2030** | 3949 | 3949 | 3895 | 3778 | 3778 | 0 | 55 | 171 | 171 |
| **2035** | 3945 | 3788 | 3858 | 3674 | 3518 | 156 | 87 | 271 | 427 |
| **2040** | 4048 | 3786 | 3934 | 3692 | 3430 | 262 | 114 | 356 | 618 |
| **2045** | 4114 | 3755 | 3982 | 3702 | 3343 | 359 | 132 | 412 | 771 |
| **2050** | 4062 | 3666 | 3924 | 3631 | 3236 | 396 | 138 | 431 | 826 |

*Table 4. Scenario Comparison VS BASELINE: Global Well-to-Wheels Passenger $CO_2$ Emissions*

Thus, though there would be some "losses" in combining the two types of policy, their combined effects would still be quite large and would lead to a stronger impact on peaking transport oil, sending transportation oil use into a negative trend after 2030. The combined impacts in transport oil use is sufficient to induce a reversal of the growth in total oil use globally, effectively instituting a peak in global oil demand starting in the 2030s (Figure 6).

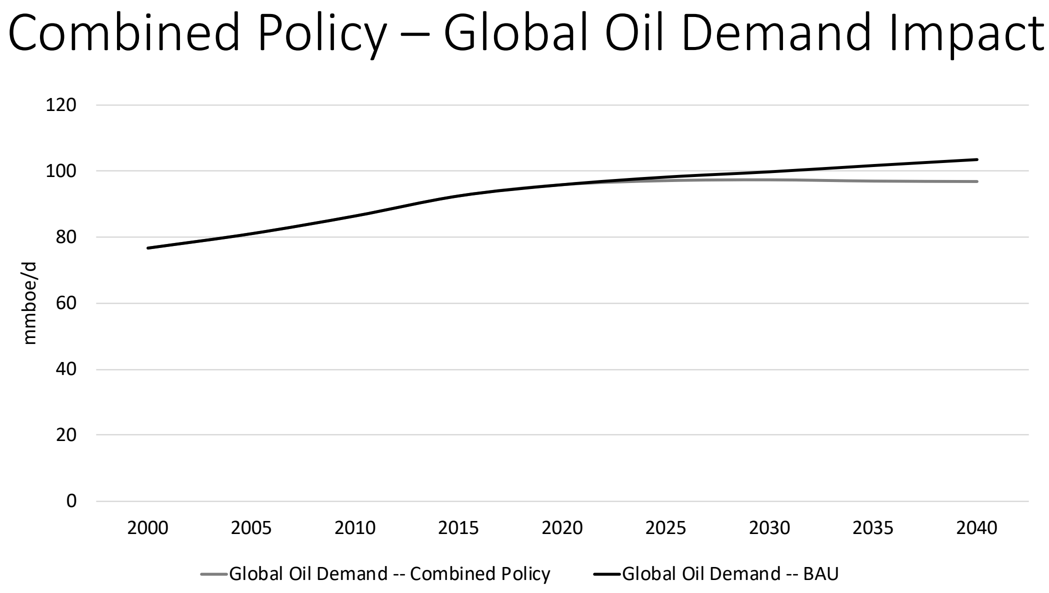

*Figure 6. Impact on Total Global Oil Use from combined ICE Ban and High Shift Urban Sustainability Policies*

## 4. Conclusion and Policy Implications

We survey the literature on urban sustainability policy and find that two policy levers, ICE engine bans and car free city centers, are gaining momentum. The literature suggests that these policy tools need to be considered together with a suite of approaches, including land use management, improved access to city cycling resources and public transit and tighter regulation of ride sharing.

We then utilize a scenario tool calibrated to the International Energy Agency's bottom-up, transport spreadsheet model MoMo to analyze the impact of combining urban sustainability "High Shift" policies and national bans on new sales of light-duty ICE passenger cars.

While each policy could eventually reduce about 5 to 6 mmboe/d of oil use, the combination could reach over 9 mmboe/d by 2050. It would have the potential to trigger peak transport oil use after 2030 and contribute to a significant reduction in greenhouse gas emissions.

The urban “High Shift” policy does provide earlier reductions; however, ICE engine bans may be easier to implement at scale. Small urban pedestrian centers closed to passenger car traffic in the geographic scale currently under implementation in Europe would not be sufficient to alter the upward trajectory for transport oil demand unless they are combined effectively with other approaches that influence mobility choices of urban residents to shift to other forms of transport.

We recommend that cities look at a wide array of policies to combine with a sustainable urban center in their efforts to reduce carbon emissions. GHG emissions rates correspond very strongly to the rate of oil consumption, and thus are impacted commensurately by the CFCC policy.

There are a number of potential subjects for future inquiry. One would be to better understand how quickly cities could transform themselves and rapidly cut car use, based on the fastest historical cases (such as Copenhagen). Another would be to consider how soon a national ICE ban would begin to affect behavior, i.e. if passenger vehicle owners would anticipate the ban and shift their purchases away from ICE engine cars up to a decade in advance of the target date, given the clear commitment. The pace of Europe’s current abandonment of diesel engine vehicles might shed some light on this notion. In Europe, sales of diesel engine cars have plummeted in the past year as Germany and other countries have mooted banning their use in urban settings.

In considering these results, we note that an effective global climate and energy policy regarding urban use of passenger vehicles should be set in parallel at both the national and municipal level and that each could support the other. This is currently taking place somewhat haphazardly but could be better integrated into global governance structures of global climate negotiations. In particular, nationally determined individual reduction pledges should include both realistic timelines for an outright or partial ban of ICE engines sales, increased investment for public transport expansion plans, car free zones, and smart urban design and transit-oriented development to increase accessibility while lowering dependence on individual passenger car use. We have shown this multi-faceted approach could be quite effective in accelerating a peaking in global oil use and bring about needed reductions in greenhouse gas emissions in the transport sector.

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