Green Wave

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Contributor: Georg Jäger

The concept of a Green Wave, i.e., the coordinated switching of traffic lights in order to favor a single direction and reduce congestion, is often discussed as a simple mechanism to avoid breaking and accelerating, thereby reducing fuel consumption. On the other hand, making car use more attractive might also increase emissions.

Keywords: traffic modelling ; traffic flow optimisation ; urban CO2 emissions ; green wave ; agent-based modelling

1. Introduction

Climate change is one of the biggest challenges society currently faces [1][2][3]. In particular, human-induced CO_2 emissions, of which 88% come from the consumption of fossil fuels, are a decisive factor in this context [3]. Although GHG emissions indicate a decreasing trend in some sectors, this is not the case for the transport sector [4]. In the European Union, for example, road transport causes around a quarter of GHG emissions and a fifth of CO_2 emissions [4]. Consequently, CO_2 emissions from the transport sector accounted for 21% of total CO_2 emissions in the EU in 2017 [5], and the total emissions from the transportation sector rose by 36% compared to 1990 [4]. Globally, there is a transition towards a low-carbon, circular economy, which means that the European Union must also take action to remain competitive and meet people's needs for enhanced mobility [6]. As part of this, the Commission's low-emission mobility strategy was launched in July 2016 [5]. The aim of this strategy is to reduce GHG emissions from the mobility sector by at least 60% by 2050 compared to 1990 levels [5].

Cities and urban areas play a significant role in this context. Between 71% and 76% of the world's energy-related CO_2 emissions, and 67–76% of the world's energy consumption are associated with cities and will be further increased due to the rising number of people residing in urban areas [2][7][8][9]. Forecasts predict that 6.7 billion people, equivalent to 68% of the world's population, will settle in cities by 2050 [7]. In addition, the IPCC report (2014) states that in several urban areas, there are barriers to advancing sustainable development and minimising energy and carbon use. These include a lack of political will, as well as institutional and financial capacity constraints [2]. Nevertheless, studies indicate that government-imposed regulations can have an effect on the climate impacts of urban areas [2]. As a result, cities have the potential to counteract climate change [10].

Due to the continuing increase in the number of private vehicles worldwide, with the US having the highest number of passenger cars per 1000 inhabitants, followed by the EU and Japan, which indicates a trend in the undesirable direction, attention is focused on PMT [11]. Since it is difficult for people to change their behaviour—for example, an annual visit to the dentist is an effort, or they lack the persistence to lose weight through diets and regular activity—humanity cannot be required to withdraw their own needs in order to help the common welfare or mitigate climate change in the future [12]. For instance, restricting mobility in the sense that people should refrain from using their own cars would lead to reluctance. Therefore, the core literature on climate change deals with the search for technological solutions [13]. Among others, there is a portfolio of actions by Pacala and Socolow [14] that would contribute to mitigating emissions. The majority of these measures are based on technological solutions, but eliminating car use by half represents a behavioural approach. According to Pacala and Socolow, however, achieving this solution involves additional behavioural changes, which in turn makes technological instruments preferable.

The introduction of a Green Wave offers a rare occasion to both enhance personal comfort and reduce emissions. This technological solution can avoid a social dilemma that describes a conflict of short-term personal interest with long-term societal goals [15]. Traffic light strategies subsumed under the term Green Wave can be rather complex [16][17], and their implementation depends on many factors of the existing traffic system and of the users of that system. However, the main idea of such strategies is the same: the green phase of each traffic light starts with a time delay that is equal to the travel time between the traffic lights in a certain direction. In a simplified way, vehicles that drive in this direction with the recommended speed will only encounter one red light, while all other lights will then switch to green shortly before the cars arrive at the intersection. This has the aim of reducing the mean stopping times of vehicles and consequently optimising the traffic flow [18][19]. Improving the flow efficiency of the street system reduces stop-and-go traffic [19], which saves emissions [20]. Especially when accelerating, the vehicle needs more fuel and causes increased CO_2 emission levels, which is decreased when driving at constant speeds [20]. A reduction in stopping times also cuts overall travel time, but it potentially raises the attractiveness of driving. Thus, optimising traffic flow may lead to an undesirable feedback or even a negative overall effect.

2. The Risks of Rebound Effects When Implementing “Green” Policies

Using an agent-based model, based on data provided by a mesoscopic traffic model[1][21][22][23] , we studied the effect of a Green Wave in terms of emission reduction and difference in travel time. We found that in the road section we investigated, introducing a Green Wave has the potential to reduce emissions by 5% to 7%, which is a significant yet not a radical improvement.

A major effect we have to keep in mind is that a Green Wave can also increase the attractiveness of car use. Since alternatives to car use are nearly always lower in CO_2 emissions than personal car use [24][25], this could easily compensate the benefit in emissions. Although the most important factor for attractiveness is travel time (and it was possible to keep travel time constant in this system), other factors are relevant as well. For example, stop-and-go traffic as well as having to stop at red lights decreases attractiveness, even if it would have no effect on the actual travel time. Thus, we cannot conclude that a Green Wave always has an advantage in terms of GHG emissions.

This phenomenon of increased attractiveness becomes even more problematic if we consider the area outside the boundaries of the model. We only model a small section of an urban road. However, since this road is mainly utilized by commuters, effects of increased attractiveness are multiplied here. One per cent more cars on this road increase emissions inside the system by one per cent. However, it also means that more people commute to the city by car. In terms of emissions, the journey to the city is more costly than the journey within the city, and the Green Wave offers no benefit outside the city. Depending on the number of commuters on the road, availability of public transport to the city limits, and the average commuting distance of the city, a minimal increase in attractiveness of just 1% might be enough to effectively increase GHG emissions overall.

To conclude, we find that although introducing a Green Wave has the potential to reduce emissions by optimising traffic flow, this potential is limited. Only if a road

- currently offers a higher speed limit,
- is used highly asymmetrically, and
- is not used by many commuters coming from far away from the city by car

can a Green Wave have an beneficial impact on GHG emissions. If this cannot be guaranteed, investing in alternatives to private car use or making the existing alternatives more attractive will be more effective and more efficient in decreasing CO_2 emissions.

Parts of these findings are not specific to the strategy of a Green Wave. Every measure or policy that reduces emissions inside the city limits by optimising traffic flow has the potential to increase overall GHG emissions due to the increased attractiveness of personal car use. While traffic flow optimisation can still play an important role in the reduction of traffic emissions, it is paramount to include all its effects, even if they appear outside the investigated system. Such a holistic view can minimize the risk of policies that lead to a rebound effect and offers the possibility to find solutions for the challenge of ever rising GHG emissions related to traffic and transportation.

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