**Mathematical Modelling Report**

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**Introduction:**

Carbon dioxide emissions contribute to around 60% of our growing global warming concerns. Cars and vans accounting to 10% of our global carbon dioxide emissions. This poses a significant risk to our environment as more heat is being trapped in our atmosphere, inevitably raising the atmospheric temperature of our Earth and causing global warming. This forces the loss of species and increases the rate of natural disasters, causing a disruption to the balance of our ecosystem. So, what can we do about it?

**Aim:**

 For my report I decided to investigate “How many trees need to be planted each year to offset the carbon emissions from driving a car?”

**Assumptions:**

1. The rise of bushfires is turning our forests into major carbon sources, producing 1.76 trillion kilograms of carbon dioxide, in only Australia alone. As global warming worsens, countries like Australia are sending all this CO 2 back into our atmosphere, so this is why it is crucial that in this experiment our trees remain in an undisturbed forest. With this we no longer have to worry about the effects of natural disasters, as they are too unpredictable to add into my calculations.
2. Petrol will be the main fuel type in this experiment as over 90% of all US cars are petrol operated, and with the US being one of the countries with highest car to person ratio, I have presumed other countries are relatively similar.
3. For the experiment Ponderosa pine trees will be the focus as they have a fast growth rate and are large, providing an excellent CO 2 absorber.
4. The dry weight of a tree includes all parts of the tree, excluding the water content, which is evaporated through conventional kilns and solar drying
* Etifor | Valuing Nature, [Which Tree Absorbs the Most Carbon?](https://www.etifor.com/en/updates/carbon-removals/#:~:text=Evergreen%20species%20such%20as%20Pinus,large%20canopies%20and%20dense%20wood), (Unknown)
* IER, [Petrol Cars in the US](https://www.instituteforenergyresearch.org/fossil-fuels/gas-and-oil/new-registrations-of-gasoline-vehicles-are-still-growing-despite-the-ev-push/), December 21, 2023
* Nation Master, [Top Countries in Vehicle Use](https://www.nationmaster.com/nmx/ranking/vehicles-in-use), (Unknown)

**Problems:**

1. My research also does not account for the fact that larger and much smaller cars are also driven regularly around the world. This includes countries such as Taiwan that had around [14.38 million](https://tribune.net.ph/2022/11/25/motorcycles-and-transportation-in-taiwan/) registered motorcycles in 2023. It is also important to note that the average emission factor of car varies depending on factors such as the size and model.
2. Although 40 trees will theoretically absorb all the carbon released by a car per year, it does not consider the 5600kg of CO 2 emissions released throughout the manufacturing process of a car.
3. Another problem with this proposed forest is that trees eventually die and decay. Once they die or are harvested for use, they will release all the carbon that it has absorbed of its lifetime. This will essentially reverse all the good it has done, challenging the purpose of this experiment.
* How Many Cars Are There in The World In 2024? [How Many Cars in Taiwan](https://hedgescompany.com/blog/2021/06/how-many-cars-are-there-in-the-world/), (Unknown)

**Strategy:**

 When I began my research, I went in with the idea that in order satisfy this question there would have to be around 10 trees planted per person. My plan was to find how much the average person travels by car, then calculate the amount of carbon emissions. I would then continue my research by finding out how much carbon a tree absorbs by the time it reaches full maturity.

**Car Emissions:**

For cars, we use the following calculation:
Greenhouse gas emissions by car = total distance travelled multiplied by the average emission factor for a car in an urban environment. A standard passenger vehicle, which has an average fuel efficiency of 10.6L/100km, typically emits an average of 2.3 kg of CO₂ per Liter. If this car travels approximately 15,000 kilometres each year, it will release around 3657 kilograms of CO₂ annually per person.

* $10.6 ×2.3 =24.38kg/100km$
* $24.38 ÷100= 0.2438kg/km$
* $0.2438 ×15000=$ 3657kg
* Australian Government, [Fuel economy of Australian passenger vehicles](https://www.bitre.gov.au/sites/default/files/is_091.pdf), 2018
* National Transport Commission, [Carbon Dioxide Emissions](https://www.ntc.gov.au/sites/default/files/assets/files/Carbon%20dioxide%20emissions%20intensity%20for%20new%20Australian%20light%20vehicles%202018.pdf), June, 2019
* [Zane Dobie](https://www.drive.com.au/about-drive/our-journalists/zane-dobie/), [Average Travel Distance](https://www.drive.com.au/caradvice/how-many-kilometres-is-good-for-a-used-car/), 29 February 2024

**Carbon Dioxide in Trees:**

 However, because CO 2 is a compound element, for every 2 oxygen, there is only 1 carbon atom. If the atomic weight (at. wt.) for oxygen is 16amu and the weight of carbon is 12amu, then carbon is only 27.27% of a CO 2 molecule.

* Atomic weight of oxygen is 16amu
* Atomic weight of carbon is 12amu
* There is 2 oxygen in every carbon
* The atomic weight of a carbon dioxide molecule is 44amu

 Thus: $\frac{12}{44} ×100 $= 27.27%

In order to calculate what percent of a CO 2 molecule carbon is, you must divide the atomic weight of the whole molecule by the at. wt. of a singular carbon atom.



**If carbon is only 27.27% of** $CO\_{2}$**, how much carbon is released by a car?**

In order to calculate how much carbon a standard sized vehicle used per year on average, you must first start by multiplying how much carbon there is in a singular CO 2, by how much carbon dioxide a car releases per km

* $\frac{12}{44}×0.2438= 0.06649090909kg carbon/km$
* $0.06649090909×15000 ≈997.36kg $

Next you must multiply your previous finding by how much a car travels per year on average. Thus, we now know that a standard sized passenger vehicle that used petrol will produce roughly 997.36kg of carbon annually.

**How To Calculate:**

It is crucial you find the dry weight of wood as trees contains large amounts of water in them, so measuring the mass of wood after it has fully dried out removes any inconsistency. This process is most effective when the leaves and roots are excluded from the measurement. Most foresters typically go by the rule of thumb that 50% of the wood's dry weight is carbon.  So first you must find the dry weight of a singular Pine tree at full maturity, which for a Ponderosa is 35 years, then divide that in half to calculate the total carbon content.

* Hyne Timber, [Age and Carbon Content](https://tour.hyne.com.au/plantation#:~:text=Each%20tree%20takes%20between%2028,to%20resume%20that%20capturing%20process), (Unknown)

**How Much Carbon Can a Pine Tree Absorb?**

A harvested Pine Ponderosa with a dry weight of 1059.592kg, will absorb around 530kg in a 35-year life span.

* $1059.592 ÷2=5$29.296 $≈530kg$

With these findings we can now estimate that a pine tree will absorb roughly 15kgCO2/year based on the average age of pine maturity. However, this would not be a uniform average as the tree will absorb more carbon the closer it gets to full maturity.

* $530÷35= 15.1428571429 ≈15kgCO\_{2}/year$
* The Shodor Education Foundation, Inc. 2002, [Dry Weight](http://www.shodor.org/succeedhi/succeedhi/weightree/help/Dry-content.html)

**How Many Trees Need to Be Planted?**

I came across the problem when writing my final answer as I realised that my calculations only consider the carbon emissions of a car for a year, whereas the trees will need 35 years to counter it. This means that in order to successfully answer my question, I will have to find how much carbon dioxide is released from a car in the span of 35 years.

This is how much carbon will be released by a standard sized passenger vehicle every 35 years

* $997.36 ×35 ≈34907.6kg of CO\_{2}$
* $34907.6÷530= 65.8633962264≈66$

If 34907kg of carbon is emitted by cars every 35 years, and pine trees can absorb 530kg of carbon during the same period of time, then 66 pine trees will have to be planted per vehicle

**Conclusion:**

Based on the research and calculations I have conducted; I am confident that planting 66 Pine Ponderosa trees for every car will effectively compensate for the annual emissions produced by vehicles by the year 2059. Although this will offset the carbon emissions, it does not reverse the impacts fossil fuel has on our environment.

**Is My Answer in Line with Estimate And/or Information Online?**

My hypothesis was that “if 10 trees are planted per car, it will offset the carbon emissions released by a car per year, because trees continue to absorb carbon throughout its entire life”. Compared to other estimates made by other people, my answer of 66 trees is close to what I initially predicted. Multiple reports I have read suggest that around 200 trees will have to be planted in order to offset the carbon emissions from cars. The information I found online tend to vary, however most of them a couple hundred off to my answer. However, one report stated that we would need to plant 17 trees per person, which is the closest answer to my own. They used a similar calculation process to me, except they found the average driving distance of a car is 16,000km and that their tree will absorb 268kg of CO 2 over its lifetime, instead of 530kg, like what I found.

I believe this may have occurred because previous theories may have focused, they might have focused on a larger vehicle or based their averages on a vehicle that travels more or burns more fuel per km. Also, two reports I read stated that they also included the carbon released by electric cars. Next time I will try and focus on a specific model of car because I believe by finding overall averages of thing, I have created some inconsistency in the information I have retrieved. For example, if I found the average distance travelled by Australians, but the fuel efficiency of a car from the US, the data might not line up.

**How Else Can This Be Used?**What if the Australian government decided that they wanted to completely offset the carbon emissions released by drivers? How much land will it take to plant this forest and where might we find the room?

Here’s how I found out that the Australian government would have to cover more than $\frac{1}{3}$ of Switzerland in pine trees to offset the carbon emissions of all the registered standard sized passenger vehicles in Australia.

**[CALCULATIONS NEXT PAGE]**

**CO 2**  **released per vehicle**

In Australia, there are approximately 15.33 million registered passenger vehicles. Each vehicle consumes about 10.6Lof fuel/100km and emits 180.9 grams of CO 2 /km. Given that the average standard passenger car travels around 13,800 kilometers annually, we can calculate the total environmental impact to be:

* 10.6 x 180.9 = 1917.54 / 100 = 19.1754kg/100km
* 19.1754 / 100 = 0.191754kg/km
* 0.191754 x 13,800 = 2646.2052 kg

**Carbon Released**

* $\frac{12}{44}×0.191754= 0.05229654545kg of carbon $
* $0.05229654545 ×13800= 721.69kg carbon per car annually $

**Number of Trees Needed**

* $721.69×35 = 25259.15kg $
* $25259.15kg ÷530 ≈ 48$
* $48×15,330,000 = 735840000$ trees needed

**How Much Space Will They Require?**

If a pine tree needs anywhere between 3-6 meters between each one, then we will say each tree spaced 4.5 apart and each row also being 4.5m apart, a tree needs a recommended 20.25$m^{2}$ of space. Therefore, to calculate how many trees are able to be planted in 1 hectare (ha), you divide the number of square meters in a hectare by the number of square meters required by each tree.

If approximately 494 trees can be planted per hectare and 735.84 million trees need to be planted, then $1,489,555ha$ will be required

* $10000m^{2}÷20.25m^{2}≈494 trees/ha$
* $735840000÷494≈ 1,489,555ha$

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**4.5m**

**4.5m**

* Our World Data, [Land Areas In Hectares](https://ourworldindata.org/grapher/land-area-hectares?tab=table), retrieved on 17/11/2024
* [Lauren Youngcourt](https://plantaddicts.com/authors/lauren-youngcourt/), [Planting Pine Trees](https://plantaddicts.com/planting-pine-trees/#:~:text=Pine%20Tree%20Spacing&text=Planting%20pine%20trees%20too%20close,10%2D20%20feet%20is%20suitable), 4/7/2023
* Australian Automobile Association, [Average Distance Travelled](https://www.aaa.asn.au/wp-content/uploads/2016/08/sgs-report-aaa-transport-affordability-index.pdf), August, 2016
* Australian Government, [Vehicle Emissions](https://www.greenvehicleguide.gov.au/pages/UnderstandingEmissions/VehicleEmissions#:~:text=A%20vehicle's%20that%20uses%20more,kilometre%20(g%2Fkm)) retrieved on 17/11/2024
* Australian Government, [Fuel Efficiency](https://www.bitre.gov.au/sites/default/files/is_091.pdf), 2018
* [Christopher Hughes](https://www.statista.com/aboutus/our-research-commitment/1934/christopher-hughes), [Registered Australian Vehicles](https://www.statista.com/statistics/683552/australia-number-of-vehicles-by-type/#:~:text=As%20of%20January%202023%2C%20the,about%203.95%20million%2C%20came%20next) , 4/14/2024