

IMMC 2019 International Round

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Carrying Capacity: Are We Past The Limit?

Summary

The Earth's population is rapidly increasing, to the point where many people are concerned about whether our increasing population can survive in the future, and whether we have exceeded Earth's carrying capacity. Overpopulation will lead to problems such as scarcity of resources and eventually large-scale conflicts over necessities. As such, knowledge of the carrying capacity of the Earth, i.e. the maximum population size it can sustain indefinitely, can allow us to acknowledge how much resources we should save to avoid overexploitation and what measures we can implement to increase our carrying capacity.

In this report, we identified freshwater, food, and carbon emissions as the major factors affecting carrying capacity. Next, we developed a mathematical model based on these factors, going through several stages. Firstly, we found the world's consumption or emission of the above factors, as well as the current resources available or the maximum amount the Earth can sustain. Then, using the data, we calculated the maximum population the above factors could support respectively. Finally, we took the smallest number as the real carrying capacity of Earth. We calculated both the carrying capacity under an ideal scenario (equal distribution of resources and no waste) and that of a more realistic situation (taking resource disparity and waste into account).

Through this model, we found that the carrying capacity of Earth is approximately 4.09 billion, with the limiting factor of this carrying capacity being carbon emissions. The maximum populations our freshwater and food resources can support are about 11.6 billion and 17.7 billion respectively, under a realistic situation where we take wasted food and water into account. Under an ideal situation, our freshwater and food can support about 37.0 billion people and 31.7 billion people respectively.

As such, we propose various solutions to increase our resources. One of them with the most significant impact would be switching to clean renewable energy, which can hypothetically reduce our carbon emissions to 0 and therefore increase Earth's carrying capacity, up to 11.6 billion (31.7 billion under an ideal situation), at which point the constraining factor becomes freshwater supply (or food supply for an ideal situation). Last but not least, we also would like to highlight the massive difference made by eliminating resource wastage. By cutting back on waste, we can more than double the population those resources can support.

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Introduction

The carrying capacity of Earth, or the maximum population it can support indefinitely, is a concept important to understand how an increasing population will affect both human society and the planet. The carrying capacity depends on four things, availability of resources, the rate of consumption of those resources, the rate of damage to the environment, and the rate of recovery of the environment.

In the following report, we will identify the major constraining factors determining Earth's carrying capacity, calculate the carrying capacity based on our analysis, and offer suggestions with regards to increasing carrying capacity. Moreover, we will separate the problem into 2 parts: one assuming that all resources are used equally and without waste, and one assuming that the resources are used according to current habits. This will offer a clearer picture of Earth's carrying capacity.

Based on this, we will then anticipate future conditions and give suggestions as to how to increase Earth's carrying capacity. We will also analyze the feasibility of some common proposals that claim to be able to increase our planet's carrying capacity.

Last but not least, we will test the sensitivity of our model by changing the various parameters, thus allowing us to understand how our model's results will change with different data inputs.

Restatement of Problem

In this problem, we are required to do 3 main tasks:

1. Find factors that have a major impact on Earth's carrying capacity for humans
2. Create a model that can calculate the current carrying capacity of Earth for humans
3. Give suggestions for increasing Earth's carrying capacity for humans in the future

This can be further split into subtasks:

Task 1

- a. Identify the basic needs of humans/human society
- b. Identify factors that support those basic needs
- c. Identify factors that are detrimental to humans/human society

Task 2

- a. Find data relating to the factors identified
- b. Calculate how many people each individual factor can support/how many people can be supported before the detrimental factor becomes too much
- c. Calculate the final carrying capacity based on the individual carrying capacities calculated

Task 3

- a. Predict what the future will be like based on the factors identified
- b. Based on the factors identified and our predictions, come up with suggestions to increase carrying capacity

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Variables

Definition of Variables

Variable	Description
K_i	Carrying capacity of Earth in an ideal situation
K_r	Carrying capacity of Earth in a realistic situation
K_{wi}	Carrying capacity of Earth in an ideal situation, based on water
K_{wr}	Carrying capacity of Earth in a realistic situation, based on water
K_{Fi}	Carrying capacity of Earth in an ideal situation, based on food
K_{Fr}	Carrying capacity of Earth in a realistic situation, based on food
K_c	Carrying capacity of Earth based on carbon emissions
N	Current population of Earth
W	Global accessible renewable freshwater, measured in km^3/year
w_i	Global consumption of water in an ideal situation (without wastage), measured in km^3/year
w_r	Global consumption of water in a realistic situation, measured in km^3/year
F	Global average food supply, measured in kcal/capita/day
F_c	Global average crop supply, measured in kcal/capita/day
F_l	Global average livestock supply, measured in kcal/capita/day
f_i	Average food required per capita in an ideal situation, measured in kcal/capita/day
f_r	Average food required per capita in a realistic situation, measured in kcal/capita/day
E	Global carbon emissions per year, measured in tonnes/year
A	Amount of carbon emissions absorbed by the Earth, measured in tonnes/year
C	Total carbon in atmosphere, measured in tonnes
t	Time

General Assumptions

Firstly, in this paper, we assume that the current conditions and technology do not change, as per the question stipulations. This implies that the production of food, withdrawal of freshwater, and emission of carbon per person will remain the same, i.e. technology or scarcity of resources will not impact the production of those resources. This is because it is too difficult to measure and quantify human behavior in such a situation.

Secondly, we assume that the usage of resources and carbon emissions are linearly related to the world's population. Since food produced is consumed by humans and humans only, it can be reasonably assumed to be linearly related to population. Water, on the other hand, is mainly consumed by humans only and can be shown to be roughly linearly correlated to human population (See Fig. 4 in Appendix). Similarly, carbon emissions roughly correlate with population, as they are approximately related to the energy use of humans (See Fig. 3 in Appendix). By assuming a linear relation among population and the 3 factors, we can obtain a useful and mostly accurate approximation of reality, without making calculations too difficult.

Thirdly, we will not consider the effect on the economy or society. Even though an increase in population would lead to economic and social breakdown long before we reached the carrying capacity, leading to an effective decrease in resources (as they will cease to be exploited), we assume this to not be the case, as again it is too difficult to quantify human behavior in such a scenario. Predicting the global economy and social condition is out of the scope of this question.

Fourthly, we will not take astronomical time spans into consideration, i.e. we assume that "indefinite" does not refer to time scales of billions of years or more. This is because the Sun will eventually burn out and the universe will eventually experience an end of some sort. If we consider time scales of this magnitude, the carrying capacity will be zero, because the planet cannot support any population indefinitely. Therefore, we will assume this to not be the case.

Last but not least, we will assume that all the planet's accessible resources will be used to support a hypothetical "maximum population". This includes untapped potential for renewable energy sources and uncultivated arable land. This is because at present technology, we are capable of utilizing these resources, but we are unwilling to do so because of their relatively large cost. When calculating the carrying capacity, these resources/potentials should also be taken into account, as they represent resources that are accessible "at current conditions".