Climate Change and Cities of the Future

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Abstract

60% of the global population is expected to be in cities by 2050. At the same time the climate is changing at an accelerated rate. In this short paper we discuss the conflation of these two phenomena and how it may change the cities of the future. We formulate this as an optimization problem that could help answer important questions such as where are they likely to be located? How are they to be pow- ered? What would be their demand for mobility and how might this be met? How over or under ground might these cities be? This paper first looks at a historical paradigm of cities in the absence of the climate crisis and then proposes the new paradigm to look at cities of the future faced by the challenge of the climate change crisis.

Historical Paradigm

Location-Resources-Energy-Mobility

Human societies have organized themselves in various configurations throughout history, with the primary goal being the exchange of goods (or resources) and ideas. Societies have tried to minimize spatio- temporal access to resources i.e. locate themselves close to resources to maximize productivity and facilitate exchange of ideas for their citizens. Energy is one such resource and Mobility another, which in turn needs energy, facilitates the exchange of goods, ideas and consequentially people.

Prior to the agricultural and industrial revolu- tions (1700-1900), the human population predom- inantly lived in rural areas. But the 20th century brought with it a change in this dynamic. Settle- ments characterized by a dense population, having a particular urban planning and function, are gener- ally called cities (urban areas). In 1900, 15% of the population lived in cities, currently, 55% of the population lives in cities [1,12]. The UN forecasts that by 2050, 68% of the world population is projected to live in urban areas. Cities are responsible for 80% of Gross Domestic Product (GDP), 2/3 of energy use and 70% of GHG [12].

Mathematical formulation: historical
For the context of this discussion, we will define some key parameters:
d_w: distance to fresh water,
d_r: distance to a resource (not water),
t_r: time to access a resource,
E: energy,
$M = f(E) = M_a + M_l + M_s$: mobility over air, land and sea,
r: resource,
i: ideas,

Mathematically, we could formulate these parameters as an optimization problem, where we could assume the objective function of human society has been to minimize spatio-temporal access to resources, with the constraints being energy availability and mobility options.

$$\begin{aligned} \min_{r,i} \quad & -f(r, i) \\ \text{s.t.} \quad & d_w \leq 100\text{mi}, \\ & d_r \leq 5\text{mi}, \\ & M \quad 6 \quad 3, \end{aligned} \tag{1}$$

As we see from this formulation, the role of mo- bility, which we defined as the ability to move people and resources, has a key role to play in the quality of life and decisions of where humans settle. His- torically, the maritime industry changed the way settlements were located and operated. More re- cently railroads, the automobile and air transport have caused dramatic shifts. For example, Denver Colorado, saw a 650% increase in population due to the transcontinental railroad that provided access to the resources between 1870 and 1880. In recent times, Dubai has seen its population increase by about 700% between 1985 to 2019, during which the

[1] https://www.emirates.com/us/english/

Emirates [1] airline was established and Dubai International Airport[2] has seen a rapid expansion.

Climate Change

Climate change, caused by increased warming in our atmosphere, is causing a number of unintended consequences to our earth. Since the industrial revolution, we have seen an increase in CO_2, CH_4 and other greenhouse gases in the atmosphere. Scientific studies have observed this [9,10,11] warming trend in the lower layer of the atmosphere, specifically through the detection of increases in concentrations of greenhouse gases and have established a correlation of this warming trend to human activities. Human activities that have a major contribute to climate change are electricity generation and transportation. The current model of development based on an intensive use of fossil fuels, which is at the heart of the world-wide energy system is producing dangerous waste, damaging biodiversity and polluting our soil and water. The industrial system has not developed efficient ways to absorb and reuse waste and by-products. If we continue to operate with business as usual methods, latest IPCC reports predict global warming is likely to reach between 1.5 degrees and 2 degrees C. These changes cause significant risks for natural and human systems[10]. Due to global warming we are noticing and anticipate diverse and escalating disturbances such as water stress, ecosystem extinction, food impacts, coastal damage from flood and storms, human health impacts and ocean acidification.

Climate Change Paradigm

Conflation of urbanization and population growth

We see the conflation of the issues of population growth and urbanization through the impact that climate change related phenomena are having on the cities. Under this new paradigm, the globe is witnessing the following impacts :

- Global mean sea level rise: By 2100 global mean seal level is projected to rise, this is a threat to cities and people living on the coast.
- Land: Impacts on biodiversity and ecosystems including species loss and extinction.
- Ocean temperature: Ocean temperature changes effect acidity of the oceans and decreases ocean oxygen levels. This causes potential risks to marine biodiversity, fisheries and ecosystems.
- Temperature increase : Mean global temperature is expected to increase by 1.5 degrees centigrade by 2100.
- Climate change related migration: Large movement of people as they face issues related to climate change.
- Air pollution : Increase in harmful gases (sulfur dioxide, nitrogen oxides, carbon monoxide, chemical vapors, etc.) that effect human health. - Infrastructure damage: Damage to infrastructure due to climate related extreme events.

New ideas such as smart cities [2] try to leverage Information and Communication Technologies (ICT) within city infrastructure to try to minimize environmental impacts. These smart try to integrate and synthesise data with the goal of improving the efficiency, equity, sustainability and quality of life in cities.

Mathematical formulation: Under climate constraints

Under this new climate change paradigm, cities now have to minimize their environmental impact. Under our mathematical formulation in (1), we now have to add a new constraint, which is the reduction of emissions and looking for new models of growth. Our objective function now becomes multi-objective. We can formulate problem using an ε-Constraint Method developed by [13] in which we keep just one of the objective and restricting the rest of the objectives within user-specific values i.e as constraint.

$$\begin{aligned} \min_{r,i} \quad & -f(r,i) \\ \text{s.t.} \quad & d_w \leq 100\text{mi}, \\ & d_r \leq 5\text{mi}, \\ & M \quad 6 \quad 3, \\ & C \quad 6 \quad \text{cmax, carbonconstraints} \end{aligned} \tag{2}$$

Cities of the future

Given this new paradigm due to the conflation of issues, how will it change cities of the future? The cities of the future are the cities of today in most cases. Therefore, there is a need to place existing cities on a more sustainable evolution path, realizing the climate as a common good. We still need to facilitate the exchange of goods(or resources) and ideas, but under climate constrains.

Location-Energy-Mobility-Materials

With new innovations in mobility and energy resources, this could shift the way we live in future cities. Just as we have seen how Denver, Colorado and Dubai City were transformed radically with the railroad and air travel in a very short period of time, we could hypothetically begin to re-

[2]https://www.dubaiairports.ae/corporate/about-us/dubai-international-(dxb)
[3]https://www.virgingalactic.com/, https://www.blueorigin.com/
[4]https://www.spacex.com/hyperloop

locate cities with a breakthrough in a mobility options. Innovators are trying to reach new frontiers with space travel [3] or the hyperloop [4]. Urban Air Mobility [5], could also revolutionize the location in where we live as urban centers need not have one downtown, but be connected by multi-central districts. Newer materials such that are recyclable are needed that adhere more to circular economy principles, taking an entire life-cycle perspective that will help reduce waste related issues. Cities of the future would need to optimize for carbon constraints, while still maintaining their fundamental configuration of facilitating the exchange of goods and ideas.

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