# Varsity Neg

## Framework

### My value is morality for two reasons

1. The resolution’s use of the word “unjust” implies a moral question.
2. Morality allows us to perceive what is inherently good or bad. It’s the value upon which we can conceptualize all other values, thus it must be prioritized.

### My criterion is environmental justice

#### Environmental justice means ensuring the planet remains livable

Bolte et al. 11, [Bavarian Health and Food Safety Authority, Oberschleissheim, Germany,] 3-3-2011, "Environmental Justice: Social Disparities in Environmental Exposures and Health: Overview," Elsevier B.V., <https://www.sciencedirect.com/science/article/pii/B9780444522726006851> PM

Introduction There is growing evidence that the gap in environmental resources and health has recently been widening not only between north and south, but also within industrialized countries (e.g., USA and Europe). The great number of multidisciplinary studies in this field is just beginning to make it clear that health disparities are inextricably linked with inequalities in the social, physical, and manmade environmental conditions across economic strata. To reach a better understanding of ethnic and socioeconomic inequalities in health and well-being, one must examine the conceptual and practical aspects of environmental justice as a dimension of the social causes of environmental inequality. Environmental injustice becomes evident from the disproportionate exposure to environmental hazards that affect mainly economically disadvantaged populations and communities of ethnic minorities with low capability for adjustment, rendering them more vulnerable. Early efforts to address various forms of structurally embedded environmental racism and social injustice were started in the USA during the 1980s by environmental organizations, social movements, and primarily locally based (grassroots) groups. The community of environmental justice activists has grown quickly over the past three decades in several countries, popularizing its concept and goals. The movement has attracted increasing public awareness, supported by substantial research, and to some extent political acceptance. In addition, methodological considerations mainly in the area of epidemiology were one recent cause for the growing interest in social disparities in environmental exposures and health. Definition and Main Features of Environmental Justice Environmental justice, environmental equity, and environmental racism are different phrases that describe and explain central features of the environmental justice movement, focusing on the disparate impact of hazardous waste sites and other polluting facilities located in or near distressed neighborhoods with high concentrations of ethnic minorities and economically disadvantaged populations. Because the concepts and contexts associated with each of these labels are complex and multidimensional, the meaning of environmental justice and injustice has changed over time and can differ considerably. Following the core definition from the Environmental Protection Agency (EPA), environmental justice seeks the equitable treatment and involvement of people of all races, cultures, incomes, and educational levels in the development, implementation, and enforcement of environmental programs, laws, rules, and policies. Therefore, the concept of environmental justice as a term with a more political connotation implies justice on a distributive, procedural, and precautionary level. Distributive justice requires an equitable distribution of the costs of environmental risks and of the benefits of environmental values across the demographic and geographic scales. Considerable emphasis is placed on procedural justice defined as the extent to which political decisionmaking processes are applied fairly and people are empowered to control and influence the decisions that affect them (e.g., higher fines for dumping waste in white versus minority communities). The precautionary principle is based on the attitude that uncertainties in short- or longterm environmental impacts resulting from deteriorating conditions in the everyday environment where people live and work call for decision-making to keep public health from harm. 459 With recent distributional challenges of globalization, urbanization, and environmental degradation (e.g., ozone depletion, water security, declining biodiversity, and deforestation) as well as climate change, the environmental justice concept has moved toward a broader understanding, now including generational and international environmental justice. Generational environmental justice refers to the concept of sustainability (including global ecological integrity and global environmental justice) and the responsibility of current generations to ensure a healthy and safe environment for future generations. (‘‘We’re only borrowing the world from our children.’’) It implies avoiding environmental degradation, which brings injustice on future generations for the sake of short-term economic gains in the present. As more environmental resources become ever scarcer, the increasing burden in hazardous environmental conditions imposed by more affluent countries on developing countries touches on an important issue of international environmental justice. Therefore, the concept of environmental justice has been taken up by many countries.

## Contention 1 is Innovation

#### Outer Space as a private sector is growing significantly right now

Weinzierl 21, 2-12-2021, "The Commercial Space Age Is Here," Harvard Business Review, <https://hbr.org/2021/02/the-commercial-space-age-is-here> PM

There’s no shortage of hype surrounding the commercial space industry. But while tech leaders promise us moon bases and settlements on Mars, the space economy has thus far remained distinctly local — at least in a cosmic sense. Last year, however, we crossed an important threshold: For the first time in human history, humans accessed space via a vehicle built and owned not by any government, but by a private corporation with its sights set on affordable space settlement. It was the first significant step towards building an economy both in space and for space. The implications — for business, policy, and society at large — are hard to overstate. In 2019, [95%](https://brycetech.com/reports) of the estimated $366 billion in revenue earned in the space sector was from the space-for-earth economy: that is, goods or services produced in space for use on earth. The space-for-earth economy includes telecommunications and internet infrastructure, earth observation capabilities, national security satellites, and more. This economy is booming, and though [research shows](https://hbsp.harvard.edu/product/716037-PDF-ENG) that it faces the challenges of overcrowding and monopolization that tend to arise whenever companies compete for a scarce natural resource, [projections for its future](https://hbsp.harvard.edu/product/720027-PDF-ENG) are optimistic. Decreasing costs for launch and space hardware in general have enticed new entrants into this market, and companies in a variety of industries have already begun leveraging satellite technology and access to space to drive innovation and efficiency in their earthbound products and services. In contrast, the space-for-space economy — that is, goods and services produced in space for use in space, such as mining the Moon or asteroids for material with which to construct in-space habitats or supply refueling depots — has struggled to get off the ground. As far back as the 1970s, [research](https://ntrs.nasa.gov/citations/19780004167) commissioned by NASA predicted the rise of a space-based economy that would supply the demands of hundreds, thousands, even millions of humans living in space, dwarfing the space-for-earth economy (and, eventually, the entire terrestrial economy as well). The realization of such a vision would change how all of us do business, live our lives, and govern our societies — but to date, we’ve never even had more than [13 people](https://www.space.com/6503-population-space-historic-high-13.html) in space at one time, leaving that dream as little more than science fiction. Today, however, there is reason to think that we may finally be reaching the first stages of a true space-for-space economy. SpaceX’s [recent achievements](https://www.nasa.gov/press-release/nasa-s-spacex-crew-1-astronauts-headed-to-international-space-station/) (in cooperation with NASA), as well as upcoming efforts by [Boeing](https://www.nasa.gov/feature/boeing-s-starliner-makes-progress-ahead-of-flight-test-with-astronauts), [Blue Origin](https://www.blueorigin.com/news/nasa-selects-blue-origin-national-team-to-return-humans-to-the-moon), and [Virgin Galactic](https://spacenews.com/virgin-galactic-prepares-to-transition-to-operations) to put people in space sustainably and at scale, mark the opening of a new chapter of spaceflight led by private firms. These firms have both the intention and capability to bring private citizens to space as passengers, tourists, and — eventually — settlers, opening the door for businesses to start meeting the demand those people create over the next several decades with an array of space-for-space goods and services. Welcome to the (Commercial) Space Age In our [recent research](https://www.hbs.edu/faculty/Publication%20Files/jep.32.2.173_Space,%20the%20Final%20Economic%20Frontier_413bf24d-42e6-4cea-8cc5-a0d2f6fc6a70.pdf), we examined how the model of centralized, government-directed human space activity born in the 1960s has, over the last two decades, made way for a new model, in which public initiatives in space increasingly share the stage with private priorities. Centralized, government-led space programs will inevitably focus on space-for-earth activities that are in the public interest, such as national security, basic science, and national pride. This is only natural, as expenditures for these programs must be justified by demonstrating benefits for citizens — and the citizens these governments represent are (nearly) all on earth. In contrast to governments, the private sector is eager to put people in space to pursue their own personal interests, not the state’s — and then supply the demand they create. This is the vision driving SpaceX, which in its first twenty years has entirely upended the rocket launch industry, securing 60% of the global commercial launch market and building ever-larger spacecraft designed to ferry passengers not just to the International Space Station (ISS), but also to its own promised [settlement on Mars](https://www.spacex.com/media/making_life_multiplanetary_transcript_2017.pdf). Today, the space-for-space market is limited to supplying the people who are already in space: that is, the handful of astronauts employed by NASA and other government programs. While SpaceX has grand visions of supporting large numbers of private space travelers, their current space-for-space activities have all been in response to demand from government customers (i.e., NASA). But as decreasing launch costs enable companies like SpaceX to leverage economies of scale and put more people into space, growing private sector demand (that is, tourists and settlers, rather than government employees) could turn these proof-of-concept initiatives into a sustainable, large-scale industry. This model — of selling to NASA with the hopes of eventually creating and expanding into a larger private market — is exemplified by SpaceX, but the company is by no means the only player taking this approach. For instance, while SpaceX is focused on space-for-space transportation, another key component of this burgeoning industry will be manufacturing. [Made In Space, Inc.](https://madeinspace.us/capabilities-and-technology/archinaut/) has been at the forefront of manufacturing “in space, for space” since 2014, when it 3D-printed a wrench onboard the ISS. Today, the company is exploring other products, such as high-quality fiber-optic cable, that terrestrial customers may be willing to pay to have manufactured in zero-gravity. But the company also recently received a [$74 million contract](https://www.nasa.gov/press-release/nasa-funds-demo-of-3d-printed-spacecraft-parts-made-assembled-in-orbit) to 3D-print large metal beams in space for use on NASA spacecraft, and future private sector spacecraft will certainly have similar manufacturing needs which Made In Space hopes to be well-positioned to fulfill. Just as SpaceX has begun by supplying NASA but hopes to eventually serve a much larger, private-sector market, Made In Space’s current work with NASA could be the first step along a path towards supporting a variety of private-sector manufacturing applications for which the costs of manufacturing on earth and transporting into space would be prohibitive. Another major area of space-for-space investment is in building and operating space infrastructure such as habitats, laboratories, and factories. Axiom Space, a current leader in this field, recently [announced](https://www.theverge.com/2021/1/26/22250327/space-tourists-axiom-private-crew-iss-price) that it would be flying the “first fully private commercial mission to space” in 2022 onboard SpaceX’s Crew Dragon Capsule. Axiom was also [awarded](https://spacenews.com/nasa-selects-axiom-space-to-build-commercial-space-station-module/) a contract for exclusive access to a module of the ISS, facilitating its plans to develop modules for commercial activity on the station (and eventually, beyond it). This infrastructure is likely to spur investment in a wide array of complementary services to supply the demand of the people living and working within it. For example, in February 2020, Maxar Technologies was awarded a [$142 million contract](https://www.builtincolorado.com/2020/02/03/maxar-technologies-142m-nasa-contract) from NASA to develop a robotic construction tool that would be assembled in space for use on low-Earth orbit spacecraft. Private sector spacecraft or settlements will no doubt have need for a variety of similar construction and repair tools.

#### The US commercial space industry is booming – private space companies are driving innovation

**Lindzon 21** [(Jared Lindzon, A FREELANCE JOURNALIST AND PUBLIC SPEAKER BORN, RAISED AND BASED IN TORONTO, CANADA. LINDZON'S WRITING FOCUSES ON THE FUTURE OF WORK AND TALENT AS IT RELATES TO TECHNOLOGICAL INNOVATION) "How Jeff Bezos and Elon Musk are ushering in a new era of space startups," Fast Company, 2/23/21, https://www.fastcompany.com/90606811/jeff-bezos-blue-origin-elon-musk-spaces-space] TDI

In early February, Jeff Bezos, the founder of Amazon and one of the planet’s wealthiest entrepreneurs, dropped the bombshell announcement that he would be stepping down as CEO to free up more time for his other passions. Though Bezos listed a few targets for his creativity and energy—The Washington Post and philanthropy through the Bezos Earth Fund and Bezos Day One Fund—one of the highest-potential areas is his renewed commitment and focus on his suborbital spaceflight project, Blue Origin. Before space became a frontier for innovation and development for privately held companies, opportunities were limited to nation states and the private defense contractors who supported them. In recent years, however, billionaires such as Bezos, Elon Musk, and Richard Branson have lowered the barrier to entry. Since the launch of its first rocket, Falcon 1, in September of 2008, Musk’s commercial space transportation company SpaceX has gradually but significantly reduced the cost and complexity of innovation beyond the Earth’s atmosphere. With Bezos’s announcement, many in the space sector are excited by the prospect of those barriers being lowered even further, creating a new wave of innovation in its wake. “What I want to achieve with Blue Origin is to build the heavy-lifting infrastructure that allows for the kind of dynamic, entrepreneurial explosion of thousands of companies in space that I have witnessed over the last 21 years on the internet,” Bezos said during the Vanity Fair New Establishment Summit in 2016. During the event, Bezos explained how the creation of Amazon was only possible thanks to the billions of dollars spent on critical infrastructure—such as the postal service, electronic payment systems, and the internet itself—in the decades prior. “On the internet today, two kids in their dorm room can reinvent an industry, because the heavy-lifting infrastructure is in place for that,” he continued. “Two kids in their dorm room can’t do anything interesting in space. . . . I’m using my Amazon winnings to do a new piece of heavy-lifting infrastructure, which is low-cost access to space.” In the less than 20 years since the launch of SpaceX’s first rocket, space has gone from a domain reserved for nation states and the world’s wealthiest individuals to everyday innovators and entrepreneurs. Today, building a space startup isn’t rocket science. THE NEXT FRONTIER FOR ENTREPRENEURSHIP According to the latest Space Investment Quarterly report published by Space Capital, the fourth quarter of 2020 saw a record $5.7 billion invested into 80 space-related companies, bringing the year’s total capital investments in space innovation to more than $25 billion. Overall, more than $177 billion of equity investments have been made in 1,343 individual companies in the space economy over the past 10 years. “It’s kind of crazy how quickly things have picked up; 10 years ago when SpaceX launched their first customer they removed the barriers to entry, and we’ve seen all this innovation and capital flood in,” says Chad Anderson, the managing partner of Space Capital. “We’re on an exponential curve here. Every week that goes by we’re picking up the pace.”

#### Innovation brought about by space helps to mitigate climate change

**ESA 20,** (European Space Agency ) 7-16-2020, "Space technology helps mitigate climate change", Esa, https://www.esa.int/Applications/Telecommunications\_Integrated\_Applications/Technology\_Transfer/Space\_technology\_helps\_mitigate\_climate\_change PM

Space technologies have led to a number of inventions that benefit the environment and save energy. Satellite-based systems are reducing vehicles’ carbon dioxide emissions, remote-sensing technology is making wind turbines more efficient, and information from weather satellites is helping solar cells to produce more energy. These are just some examples of how spin-offs from space technology and satellite services can make a difference. Over the years, ESA’s Technology Transfer Programme and its Business Incubation Centres have fostered and supported many innovative technologies and business ideas that contribute to new services and products to mitigate climate change. To maximise the amount of electricity from new wind turbines, the French company Leosphere developed a small instrument to measure wind speed and direction from the ground up to heights of 200 metres. The ‘lidar’ technology is similar to that which ESA will use on its Aeolus satellite to provide global observations of wind profiles from space. ESA’s expertise from this mission was important for Leosphere and was used to improve their instrument during the company’s start-up phase at ESA’s Business Incubation Centre (BIC) in Noordwijk, the Netherlands. More instruments based on the same technology have followed and these are now being used in more than 100 countries. By using data from weather satellites, ‘SolarSAT’ from Italian company Flyby can accurately predict the power output of photovoltaic power plants. This information is used to design improved systems and quickly identify faults in operating photovoltaic plants – faults that can reduce energy production by more than 10% a year. This system has already been installed on several photovoltaic systems in Italy. Miniaturised ceramic gas sensor technology, developed originally for measuring oxygen levels around spacecraft reentry vehicles, is now being used in systems that accurately control heater combustion, one of the major sources of pollutants. “It can reduce exhaust gases that are harmful for the environment and ensure that heating systems work at an optimum level. It also reduces fuel consumption by 10–15%,” explained Rainer Baumann from TU Dresden. Supported by ESA’s Technology Transfer Programme and its partner MST, this technology is now used by the German company ESCUBE in systems controlling industrial heaters. Conventional satnav systems help people to find their way. Now, several innovators have come up with interesting developments that use the same information to reduce fuel consumption and pollution by cars. Repeated rapid acceleration and abrupt braking increases the fuel consumption of even the greenest car. Alex Ackerman and Yossef Shiri have developed the intelligent GreenDrive system that combines information on the type of car, its location and the road conditions to advise the driver on the most economical driving style to use: when to accelerate, when to brake and when to keep the speed constant. On average, this can result in a 15–25% fuel saving. Another system proposed by Prof. Gerhard Güttler for the European Satellite Navigation Competition is Galileo-Ecodrive. This uses data on a road’s geodetic height profile provided by satnav systems to optimise the operation of auxiliary devices such as electricity generators, air conditioning, power steering, the deep freezers used on trucks for perishable goods and the moveable parts of a cement mixer –devices that consume up to 20% of the fuel. This could amount to savings of up to 2 billion litres a year across Europe, avoiding the emission of 5 million tonnes of carbon dioxide.

## Contention 2 is Mining

#### There is enormous potential in realistic space mining

**Carter 21,** 10-19-2021, "Space Mining: Scientists Discover Two Asteroids Whose Precious Metals Would Exceed Global Reserves", Forbes, <https://www.forbes.com/sites/jamiecartereurope/2021/10/19/the-age-of-space-mining-just-got-closer-as-scientists-discover-two-asteroids-whose-precious-metals-would-exceed-global-reserves/?sh=2b189574713b> PM

16 Psyche, the large metallic asteroid ideal for space mining. We know the age of private space travel is here, but what about the wider commercial space industry? “Space mining” has been talked-up in recent years, but the hype-cycle has peaked with the realization that the technology to fetch rare-Earth metals from distant asteroids is some way off. That’s not stopped NASA’s plans to launch, in 2022, its “Psyche” mission to a large metallic asteroid called 16 Psyche that’s thought to be largely metallic—and so ideal for space mining. However, the NASA plans to merely orbit and document 16 Psyche, and in any case won’t reach the asteroid—situated in the asteroid belt between Mars and Jupiter—until 2026. Now researchers have uncovered two metal-rich near-Earth asteroids (NEAs) that could one day be mined for iron, nickel and cobalt could for use on Earth or in space. They’re reckoned to be 85% metal and one is thought to contain enough iron, nickel and cobalt to exceed Earth’s reserves. Published in the Planetary Science Journal, the paper documents the examination of two asteroids, 1986 DA and 2016 ED85, whose light appears to be similar to asteroid 16 Psyche. The researchers used the NASA Infrared Telescope Facility on the island of Hawaii. The NASA Infrared Telescope Facility, Keck I, Keck II, and Subaru Telescopes at the Mauna Kea ... [+] Observatories On the Big Island of Hawaii The largest metal-rich body in the solar system, Psyche is about 230 million miles/370 million kilometers from Earth and about 140 miles/226 kilometers wide. Possibly made of iron and nickel, it’s thought to be the leftover core of a planet that failed during its formation. In comparison, 1986 DA and 2016 ED85 are tiny—just a few miles wide, yet thought to be the result of the cores of developing planets like 16 Psyche being destroyed early in the Solar System’s history. Crucially, they’re far closer to Earth than Psyche, so would be better targets for mining. “Our analysis shows that both NEAs have surfaces with 85% metal such as iron and nickel and 15% silicate material, which is basically rock,” said lead author Juan Sanchez, who is based at the Planetary Science Institute in Arizona. “These asteroids are similar to some stony-iron meteorites such as mesosiderites found on Earth ... it is rewarding that we have discovered these “mini Psyches” so close to the Earth.” A 164-foot/50-meter metallic object similar to the two asteroids 1986 DA and 2016 ED85 studied ... [+] created the Meteor Crater in Arizona. So could we mine these “mini Psyches?” The paper explored the mining potential of 1986 DA and found that it’s 85% metal—and that its iron, nickel and cobalt could exceed the global reserves of these metals. It’s also possible that the researchers have stumbled on to a seam of metal-rich asteroids. By studying the orbits of 1986 DA and 2016 ED85 they identified four possible asteroid families in the main asteroid belt—home to 16 Psyche. “We believe that these two “mini Psyches” are probably fragments from a large metallic asteroid in the main belt, but not 16 Psyche itself,” said David Cantillo, an undergraduate student in the Department of Geosciences at the University of Arizona. “It’s possible that some of the iron and stony-iron meteorites found on Earth could have also come from that region in the Solar System, too.” Wishing you clear skies and wide eyes.

#### Asteroid mining – even when resources are sent back to earth – is more environmentally sustainable than earth mining.

Hein 18, (Andreas M. Hein, PhD, Associate Professor at the University of Luxembourg), 10-10-2018, "Exploring Potential Environmental Benefits of Asteroid Mining," arXiv, <https://arxiv.org/abs/1810.04749> PM

Abstract Asteroid mining has been proposed as an approach to complement Earth-based supplies of rare earth metals and supplying resources in space, such as water. Existing research on asteroid mining has mainly looked into its economic viability, technological feasibility, cartography of asteroids, and legal aspects. More recently, potential environmental benefits for asteroid mining have been considered. However, no quantitative estimate of these benefits has been given. This paper attempts to determine if and under which conditions asteroid mining would have environmental benefits, compared to either Earth-based mining or launching equipment and resources into space. We focus on two cases: Water supply to cis-lunar orbit and platinum mining. First, we conduct a state-of-the-art of current environmental life cycle assessment for the space domain and platinum mining. Second, a first order environmental life cycle assessment is conducted, including goal and scope definition, inventory analysis, and impact assessment. We compare water supply to cis-lunar orbit with and without asteroid mining and go on to compare terrestrial with space-based platinum mining. The results indicate that asteroid water mining would have environmental benefits, as soon as the amount of water supplied via mining is larger than the mass of the spacecraft used for mining. For platinum mining, we find that by comparing the operations phase of terrestrial and space mining, space mining would have a lower environmental impact, if the spacecraft is able to return between 0.3 to 7% of its mass in platinum to Earth, assuming 100% primary platinum or 100% secondary platinum, respectively. For future work, we propose a more detailed analysis, based on a more precise inventory and a larger system boundary, including the production of the launcher and spacecraft. Keywords: asteroid mining, environmental life cycle analysis, ecological impact, sustainability, rare earth metals, platinum 1. Introduction Mining asteroids, and in particular mining Near Earth Asteroids (NEAs) has been frequently proposed as a source of resources for space and terrestrial applications [1]–[3]. Two broad categories of resources can be distinguished: volatiles and metals. Ross [4] identifies a variety of applications for these resources such as construction, life support systems, and propellant. Volatiles such as water are of particular interest for inspace applications, due to their abundance in carbonaceous (C-type) asteroids and their relative ease of extraction. For example, Calla et al. [5] explore the technological and economic viability of supplying water from NEAs to cis-lunar orbit. Regarding the supply of resources for terrestrial applications, only resources with a high market value are interesting, due to the high transportation cost. Hence, expensive metals such as rare earth metals and in particular the subgroup of platinum group metals have been the subject of asteroid mining studies [6]. The supply of platinum group metals is crucial for many terrestrial “green technologies” such as fuel cells and catalyzers [7]–[10]. However, there are two major concerns regarding platinum group metals. First, current supplies of platinum group metals are dominated by only a few countries, namely, South Africa, Russia, and Canada, which introduces political uncertainties into the supply chain [11]. The second concern is regarding the environmental impact of mining platinum group metals. Mines tend to go deeper and deeper, as resources in upper layers are depleted, which increases already high greenhouse gas emissions (currently ~40,000t CO2 per ton of platinum) [11], [12]. Mitigating these issues has led to initiatives for recycling rare Earth metals and investigating substitutes [13]–[15]. In addition, the local environment is severely impacted due to the use of hazardous substances during the extraction process [11]. Despite the potential environmental benefits of asteroid mining, either by reducing the number of launches into space or moving terrestrial industries into space, no dedicated studies for exploring these benefits has been conducted to the authors’ knowledge. Existing research on asteroid mining has mainly looked into its economic viability [2], [6], [16], [17], technological feasibility [2], [18]–[23], cartography of asteroids [24], [25], and legal aspects [26]–[28]. More recently Hennig [29] and MacWhorter [30] have introduced environmental arguments for asteroid mining, in particular with regards to platinum group metals. They refer to the benefits of asteroid mining for the Page 2 of 7 environment and sustainability, but do not provide any analysis or quantitative backing. This article addresses this research gap by providing an initial, first-order estimate of the potential environmental benefits of asteroid mining, exemplified via the case of water and platinum mining. 2. Literature survey Two different research streams are relevant for an environmental life cycle assessment of asteroid mining: The environmental life cycle assessment of space systems and platinum. 2.1 Space systems life cycle assessment The environmental life cycle assessment (LCA) of space systems is a rather recent domain. Environmental life cycle assessment is an approach for assessing the sustainability of products or systems. Chytka et al. [31] present an integrated approach to life cycle assessment, however, environmental aspects are not taken into account. Ko et al. [32] provide an overview of impacts of space activities on the space and Earth environment. They conclude that existing LCA approaches are insufficient for addressing impacts to space and suggest the development of additional impact categories. Neumann [33] applies LCA to launchers and provides a detailed inventory of inputs and outputs. However, the environmental impact from combustion exhausts is not taken into account. Austin et al. [34] present an overview of ESA activities on adopting LCA for space systems and mention their application to EcoSat, Ariane 5, Vega, Ariane 6, and four complete space missions. Wilson and Vasile [35] present a framework for integrating LCA into a concurrent engineering environment. De Santis et al. [36] present a methodology for a cradle-to-grave LCA for the European space sector and applied to the Astra 1N and MetOp A missions. The ESA Space system Life Cycle Assessment (LCA) guidelines [37] introduce an LCA approach based on the ISO 14040 / 14044 standard, tailored to the European space sector. Although LCA has been applied to several case studies in the space domain, its introduction is recent and no application to asteroid mining could be found. 2.2 Platinum mining life cycle assessment Platinum mining LCA studies are routinely performed by platinum mining companies, primarily for the estimation of their carbon footprint. The reported values are usually limited to greenhouse gas emissions and energy consumption. The global warming potential of emissions is commonly expressed in carbon dioxide equivalent or in short CO2eq over a period of 100 years [38], [39]. Although not a lot of detail is given for how the LCA is conducted, we assumed that a carbon footprint analysis of either Scope 1 (emissions are direct emissions from owned or controlled sources) or Scope 2 (indirect emissions from the generation of purchased energy) has been performed [40]. Several reports on the carbon footprint of primary platinum production exist, such as Bossi and Gediga [41], Montmasson-Clair [42], Cairncross [43], and by the Science Advice for the Benefit of Europe [44]. Glaister and Mudd [45] present qn extensive comparison of the environmental impact of platinum mining, based on CO2eq values reported by various platinum mining companies. CO2eq values for platinum from secondary production (recycled platinum) is available, for example, in the LCA database Impact 2002. Saidani [12] estimates a mean value of 40 tons CO2eq of greenhouse gas emissions per kg of platinum from primary platinum production, based on a literature survey. For secondary production, a value of 2 tons CO2eq per kg of platinum is estimated. We will use these values as a reference. 3. Asteroid mining environmental life cycle assessment We perform a first-order cradle-to-gate (extraction to factory gate) life cycle assessment of water and platinum asteroid mining, limited to greenhouse gas emissions. 3.1 Goal and scope definition The scope and functional unit define the reference against which mining activities on Earth and space are compared. The functional unit quantifies the service delivered by the product system. For our two cases of water mining in space and platinum mining on Earth and space, we use the following functional units: • 1 kg of water delivered to cis-lunar orbit. • 1 kg of platinum supplied to the Earth. In terms of scope, we limit our analysis to greenhouse gas emissions, as data is available from various sources. Furthermore, our system boundary is drawn to include the operations phase, which includes E1, launch and commissioning phase, E2, utilisation phase in space, and F, disposal, according to the ESA lifecycle assessment guidelines [37]. Contrary to the guidelines, in our case we interpret F not as disposal but re-entry of platinum to Earth. For an Earth-based mine, the operations phase would essentially include the operation of the mine post installation. Furthermore, the boundary is drawn around the direct production and refining system of platinum or water. The reason for the limitation to the operations phase is that the publicly available sources of LCA data for platinum mining is limisted to the operations phase, which contains extraction and refining. One could argue that for space-based mining, only E2 should be taken into consideration, as the Page 3 of 7 production of the mining infrastructure is not taken into account for Earth-based mining. However, we interpret the launch infrastructure with launch pads, fuel depots, etc. as part of the infrastructure as well as launchers, and spacecraft. We therefore consider operations in the wider sense of operating this whole infrastructure, eoncompassing both E1 and E2. Consistent with carbon footprint analysis, we take Scope 1 (emissions are direct emissions from owned or controlled sources) and Scope 2 (indirect emissions from the generation of purchased energy) into account, in order to arrive at results that can be compared with platinum LCA results from the literature. 3.2 Lifecycle inventory For the lifecycle inventory, fuel for the launcher and electricity for the launch infrastructure are considered as inputs. The output is limited to greenhouse gas emissions, for the simple reason that it is rather easy to find values for platinum mines. The values for electricity consumption for a launch of a Falcon Heavy-class rocket in Neumann [33] indicate that it is rather negligible compared to the greenhouse gas emissions from fuel combustion during ascent. Neumann [33] does not take greenhouse gas emissions from fuel combustion into account. However, we use the LCA conducted for kerosene by [46], where the greenhouse gas emissions from combustion is the dominant contribution to greenhouse gas emissions in the kerosene supply chain. In the following, we use a rough value of 3 kg CO2eq per kg of Kerosene combusted. 3.3 Bootstrapping factor We use the bootstrapping factor b as a figure of merit, which we define as kg of payload mass launched into space vs. kg of resources delivered to the target destination. = (1) indicates the mass of resources mined and supplied to the target destination and the mass of the payload launched into space for the mining operation. For the case of water, the bootstrapping factor allows for a comparison between launching water from Earth and supplying mined water to a target destination. For example, a 500 kg spacecraft (wet mass) is launched into space for mining an asteroid and the spacecraft delivers 1000 kg to its target destination, the bootstrapping factor is 2. When a 500 kg spacecraft carrying water is launched into space, delivering 200 kg of water to its target destination. b is 0.4. Comparing the water asteroid mining example with direct water delivery yields a ratio of 5. In order to make environmental sense, b for mining has to be larger than the b for direct water delivery. In the example above, this means > 0.4. We can therefore write: = \_ \_ > 1 (2) For linking b with environmental impact on Earth, a multiplier needs to be added, which converts the payload mass in a destination in space with a common payload reference, such as payload to LEO. Using the ratio from (2) and introducing the mass-specific environmental impact yields the following equation for the mass-specific environmental impact of asteroid mining, compared to the direct delivery of a resource. ‑­‑­ = ∗ "‑ #$ = %&'( (3) "‑ #$ indicates the mass-specific environmental impact of direct delivery of a resource. )\*­#+ is the massspecific environmental impact during launch. Equation (3) is not only valid for water mining but also for the case of mining and returning resources from space to Earth, such as platinum. For the latter, ‑­‑­ needs to be smaller than ‑­‑­ \_,) $+ , the mass-specific environmental impact of mining on Earth: ‑­‑­ < ‑­‑­ \_,) $+ (4) 3. Results 3.4 Asteroid water mining For the nominal case of supplying water to cis-lunar orbit, the environmental impact of launching 1 kg of water from Earth to a cis-lunar orbit is calculated. Based on a previous analysis for asteroid water mining in Calla et al. [5] and Hein & Matheson [16], a range for ‑­‑­ can be estimated between 0 and lower two-digit numbers. We calculate a lower bound for the CO2eq of launching 1 kg of water to cis-lunar orbit, which only includes the CO2 released from the combustion of kerosene, using Falcon Heavy data from Spaceflight 101 [47]. About 30 kg of kerosene is burned per kg of payload to cis-lunar orbit. We multiply this value by 3 kg CO2eq per kg of kerosene burned, a factor introduced in 3.2. We therefore get a value of 90 kg of CO2eq per kg of water delivered to cis-lunar orbit as a lower bound. Furthermore, it is assumed that all of the kerosene of the first stage and boosters are burned within the Earth’s atmosphere. It is assumed that the second stage has no impact in terms of CO2 emissions on Earth’s atmosphere. Using the bootstrapping factor ‑­‑­ , we get CO2eq values for the case where an asteroid mining spacecraft is launched and returns per kg of spacecraft mass b-times its mass. Table 1 shows the resulting Page 4 of 7 values. It can be seen that substantial savings in greenhouse gas emissions can be achieved. Table 1: CO2eq values for delivering 1 kg of water to cislunar orbit, with respect to the bootstrapping factor b ./01012 CO2eq [kg per kg of water] only Kerosene 1 90 5 18 10 9 20 4.5 30 3 40 2.3 3.5 Asteroid platinum mining For the case of platinum, Earth-mining is the reference and the impact of returning platinum to Earth needs to be taken into consideration. It is known that during re-entry a spacecraft releases H2O and NOx in the Earth’s upper atmosphere via the re-entry shock wave and material released via ablation [48], [49]. N2O has a global warming potential of between about 265–298, 310 times CO2 [39], [50]. Park and Rakich [51] estimate that about 17.5±5.3% of the Space Shuttle mass is released in the form of NOx during re-entry. As a conservative estimate, we use 20% and assume that predominantly N2O is released. Furthermore, we assume that for 1 kg of platinum, about 1 kg of additional mass is required for reentry (heatshield, GNS, parachute etc.). Hence, roughly 0.2 kg of N2O is released per kg of platinum returned to Earth, which translates into roughly an equivalent of 60 kg of CO. As a result, we get a total kg CO2eq per kg Pt of 150 kg. Given various uncertainties, we see that the total CO2eq of an asteroid mining mission is on the order of dozens to hundreds of kg CO2eq per kg of platinum returned. If we compare these rough estimates with the CO2eq values for Earth-based platinum mining, we immediately see that the global warming effect of Earth based mining is several orders of magnitude larger, even for secondary platinum. Table 2 shows the ratio between the Earth-based platinum mining emissions and the space-based mining emissions. A difference of two orders of magnitudes for primary platinum and one order of magnitude for secondary platinum is observed. For a mixture of primary and secondary platinum, we get values with two orders of magnitude difference. Table 2: Comparison of space and Earth-based platinum mining greenhouse gas emissions ./01012 CO2eq / kg Pt Ratio Earth reference (40 t / kg CO2eq) vs. space Ratio Earth reference (2 t / kg CO2eq) vs. space Earth: 33% secondary, 66% primary platinum vs. space 1 150 267 13 182 5 78 513 26 350 10 69 580 29 396 20 65 620 31 424 30 63 635 32 434 40 62 643 32 439 Although the CO2eq values used for space-based platinum mining represent a lower bound, we can estimate that even one order of magnitude higher emissions would lead to one order of magnitude savings, compared to Earth-based mining. 3.6 Carbon tax effects A straight-forward consequence of greenhouse gas emissions is that they have an economic effect, once carbon tax is introduced. Given the large differences in CO2eq emissions for Earth and space-based platinum mining, Earth-based mining would be penalized with the introduction of carbon tax. As shown in Table 3, using the value of 50 t of CO2eq per kg of platinum mined in 2030, extrapolated from its current value of 40 and a conservative carbon tax value of €70 per ton, we obtain a carbon tax of €3,500 per kg of platinum. Given today’s price levels for platinum and assuming that these remain similar, a penalty of ~10% needs to be added on top of the cost of Platinum production. Currently, the platinum mining industry is operating at low profit margins or even at a loss. The 10% tax could be compensated via a higher efficiency of the mining process and a potentially higher degree of renewable energy sources for electricity supply, as the majority of greenhouse gas emissions are generated by burning hard coal, at least in the case of South Africa [41]. However, it is unclear how much platinum mining companies might influence decisions that concern the energy mix on a country level. Page 5 of 7 Table 3: Estimates of carbon tax for platinum production Year t CO2eq/kg Pt Carbon Price (€) Carbon Tax (€) / kg Pt 2017 40 5 200 2030 50 70 3500 2050 60 120 7200 5. Discussion The results of the asteroid mining LCA show that for a broad range of bootstrapping factors ‑­‑­ , substantial environmental benefits could be reaped for both, water and platinum mining. The range of ‑­‑­ is consistent with the values for ‑­‑­ presented in Hein and Matheson [16] and should cover realistic mining scenarios. As with LCA in general, this result depends on the initial scope of the assessment. There are several limitations to the analysis presented in this article. For example, the environmental impact of rocket launchers could be reduced by applying eco-design principles, such as the use of “green propellants”, the reuse of components such as rocket stages etc. Some of these options are discussed in Neumann [33]. Furthermore, only greenhouse gas emissions have been considered, and a more extensive LCA would require the consideration of further impact categories. Of particular relevance for launchers is ozone layer depletion, as combustion products are directly released above the troposphere. Hence, adding midpoint and endpoint impact categories would create a more complete picture of the environmental impact of an asteroid mining mission. However, at least for the case of platinum mining, we are limited by the availability of LCA data beyond CO2eq and energy consumption. Another limitation is that emissions from spacecraft operations have not been considered. Sending 1 kg of water into cis-lunar orbit takes less time than an asteroid mining mission, a few days versus hundreds of days to years. Emissions from ground station operations are proportional to the duration of the mission and could change the result in favour of launching water. The impact of off-nominal behaviour has also not been considered. For example, the environmental impact of a failed launch within the Earth atmosphere would be much larger than for a successful launch, as the entire propellant would be burned within the atmosphere, including that of the upper stage(s). A topic that merits further investigation is the assessment of the in-space impact of asteroid mining. Such an assessment could be extended to trade-offs between terrestrial and space impact. The recent literature on in-space impact assessment could provide a starting point [32], [52], [53]. 6. Conclusions This article provides a first-order analysis of the potential environmental implications of asteroid mining, with a focus on greenhouse gas emissions. We introduce a bootstrapping factor, the ratio of resources delivered to the target destination and the payload mass launched into space that allows for a comparison of various asteroid mining missions. The results for the case of in-space water supply and platinum mining indicate that for typical values of the bootstrapping factor, asteroid mining generates substantial environmental benefits compared to its alternatives. For future work, a more extended LCA for asteroid mining missions would provide a more extensive picture of its environmental impacts. Further, combining economic and environmental assessment seems to be promising for identifying mining architectures that show a good performance with respect to both criteria. Another interesting topic would be a framework for conducting trade-offs between terrestrial and in-space environmental impacts such as the generation of space debris and the occupation of orbits.

# Case

### AT Debris

#### No impact to space debris

Lee A. Paradise 15, writer for Science Clarified encyclopedia. July 29 2015 "Does the accumulation of "space debris" in Earth's orbit pose a significant threat to humans, in space and on the ground?" www.scienceclarified.com/dispute/Vol-1/Does-the-accumulation-of-space-debris-in-Earth-s-orbit-pose-a-significant-threat-to-humans-in-space-and-on-the-ground.html

Considering the small size of objects like satellites or the shuttle placed against an environment as vast as space, **the risk of severe collisions is minimal**. Even when an object in space is hit by space debris, the damage is typically negligible **even considering** the high rate of speed at which the debris travels. Thanks to precautions such as debris shielding, the damage caused by space debris has been kept to a minimum. Before it was brought back to Earth via remote control, the MIR space station received numerous impacts from space debris. None of this minor damage presented **any significant problems** to the operation of the station or its various missions. The International Space Station (ISS) is designed to withstand direct hits from space debris as large as 0.4 in (1 cm) in size.¶ Most scientists believe that the number of satellites actually destroyed or severely damaged by space debris is extremely low. The Russian Kosmos 1275 is possibly one of these rare instances. The chance of the Hubble Space Telescope suffering the same fate as the Russian satellite is approximately 1% according to Phillis Engelbert and Diane L. Dupuis, authors of The Handy Space Answer Book . Considering the number of satellites and other man-made objects launched into space in the last 40 years, the serious risk posed to satellites is astronomically low.¶ In fact, monitoring systems such as the Space Surveillance Network (SSN) maintain constant track of space debris and Near Earth Orbits. Thanks to ground-based radar and computer extrapolation, this provides an early warning system to determine if even the possibility of a collision with space debris is imminent. With this information, the Space Shuttle can easily maneuver out of the way. The Space Science Branch at the Johnson Space Center predicts the chance of such a collision occurring to be about 1 in 100,000, which is certainly not a significant enough risk to cause panic. Soon the ISS will also have the capability to maneuver in this way as well.