Multi-Level Perspective as a Method to Explore Potential Mitigating Strategies Regarding Environmental Harm from Consumer Electronics and Transitioning to a Better System

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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I. Introduction: Managing a Seemingly Impossible Problem

According to Electronic Hardware Sustainability at the Ohio State University, "Approximately 40 million metric tons of electronic waste consisting of discarded televisions, phones, computers, and other electronic hardware are produced globally." This causes a considerable amount of pollution to poison the air, including 580 metric tons of carbon dioxide in 2020 alone, according to University of California, Irvine researchers (UCI study finds 53 percent jump in e-waste greenhouse gas emissions between 2014, 2020). Nancy Wagner of TechWalla also asserts that the mass creation of consumer electronics is problematic to the environment because much of that harm is due to the fact that nearly every single one product of consumer electronics is made of rare earth metals or elements, which themselves are mined by processes that use a great deal of fossil fuels (What Materials Are Used to Make Cell Phones?, 2021). Furthermore, according to Abu Bakar Siddik, Arman Shehabi, and Landon Marston of the Environmental Research Letters, the next big culprit is the fact that data centers are instrumental to the efficiency of data. Data centers that run on fossil fuels are used to store all digital information transmitted between devices (Siddik, A. B., Shehabi, A., & Marston, L., pg. 1, 2021). Considering the sheer quantity of consumer electronics used by people in everyday life, it stands to reason that the negative impact on the environment is considerable. There is a common way to think about this problem: find solutions that address the impacts of consumer electronics after they have been created and used. This is the common perspective amongst novices in the field. However, an those who are experienced in the field would suggest to address the issue at its source, or in this case, sources, as the life of consumer electronics causes harm to the environment along the whole way, not just in the end. At different stages of its life, there are unique environmental problems to address, meaning the problem is multidimensional. There is no one-size fits all solution, rather a multidimensional solution.

By having all this information, it can be deduced that the most effective STS framework and approach to use is Geel's "Multi-Level Perspective on Sustainability Transitions". Through Geel's work, I had found that it would be beneficial to understand the patterns of sociotechnical transitions, particularly the emergence, acceptance, or rejection of newly developed technology. Geels lays out a series of conditions that are ideal for the "Transitions to sustainability". These conditions are goal-oriented transitions "...in the sense of addressing persistent environmental problems", and solutions that "... do not offer obvious user benefits..." (Geels, F. W., pg. 25, 2011). This paper will explore the most optimal solutions based on these two conditions that Geels' framework lays out: specifically, the solutions of creating energy efficient data centers and mining practices, and relying on people detoxing from their products, as media becomes more and more invasive (*Freshmen give up cellphones for one week*, 2020).

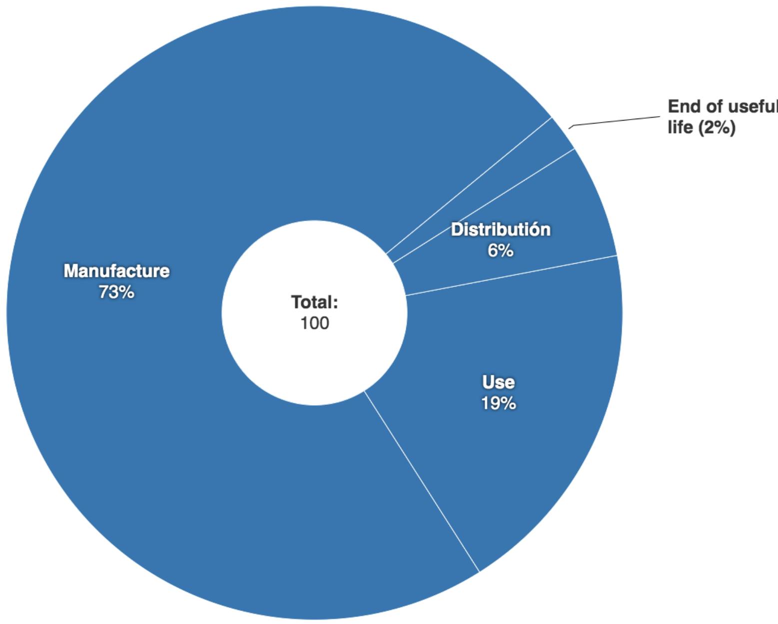
II. Problem Definition: Leveraging the Known to Determine a Framework for Potential Mitigating Strategies

As has been already established, the already known main issue is that consumer electronics have a negative impact on the environment, and the numbers are immense. Chris Barnes of Nottingham Trent University explains how from the perspective of waste, it is known that "...E-waste is the world's fastest growing household waste stream, negatively affecting the planet and draining global resources; 53.6 million metric tons of e-waste were generated worldwide in 2019" (Barnes, pg. 7, 2021). Even just from the use of electronics, the non-renewable materials found in them "...can spread the air and sea to other continents – widening the impact of the problem" (Barnes, pg. 7, 2021). These facts illustrate that it is unequivocally true that there is significant harm to the environment from consumer electronics. Especially since there are hardly any renewable materials used in consumer electronics, the lifecycle of almost all products end at waste and are never recycled. A look at this lifecycle can be more clearly seen below from the Tecnologia Libre De Conflicto.

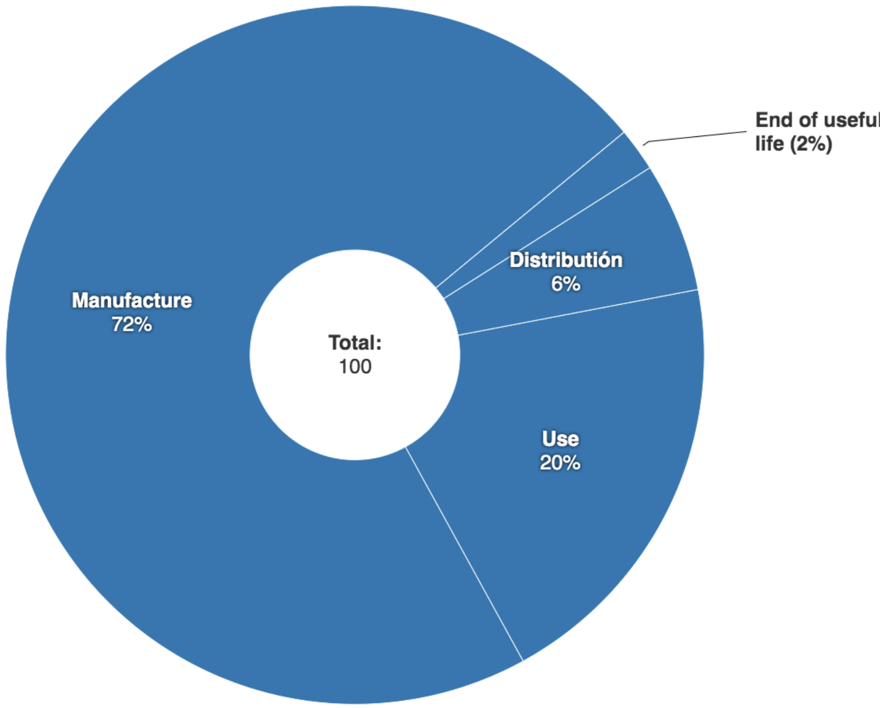
1. The Life Cycle of Electronic Devices
(*The Environment and Electronic Devices,* 2017)
This illustrates the path to waste for consumer electronics

This diagram illustrates that as soon as a product is created from raw materials and manufactured in a factory that runs on fossil fuels, it inevitably ends up as waste almost every time, and is not conventionally recycled, which would be more beneficial to the planet.

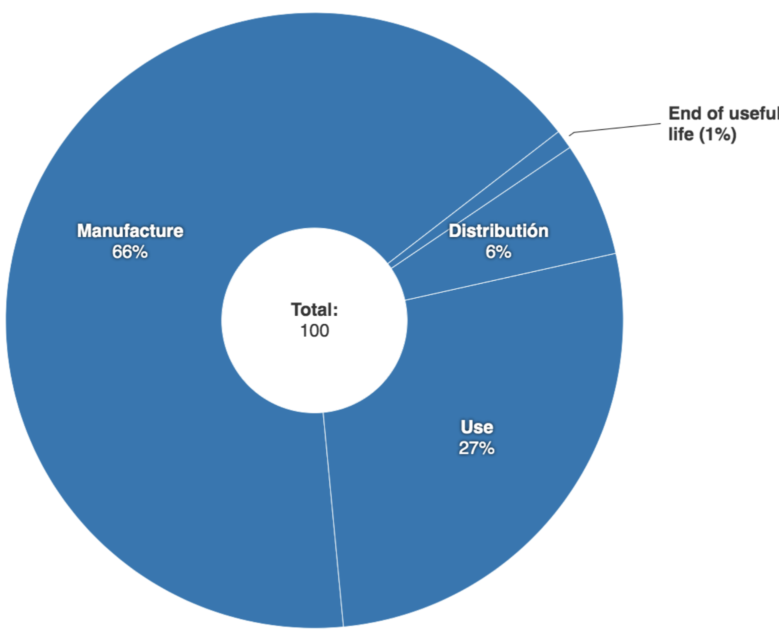
Furthermore, another known issue regarding consumer electronics is the amount of CO2 emissions they leave, and that their respective data centers emit a high amount of greenhouse gasses. The amount of CO2 that has been emitted is steadily rising, and has been for years now. In fact, Shui Bin and Hadi Dowlatabadi of Energy Policy explain that "...in the US for 1997, the industrial sector was the most energy-intensive (38% of US total) and CO2-intensive (33%)..." (Bin, S., & Dowlatabadi , H., pg. 197, 2005). This only covers the industrial sector, which means that these are the statistics in regards to just creating consumer electronics. As mentioned before, creating consumer electronics requires a great deal of mining via methods that use fossil fuels. These very same methods are responsible for the numbers in these statistics, and have been an ongoing issue since the late nineties. Furthermore, the harmful CO2 effects do not stop there. Even while the products are in use, CO2 emission is still taking place, as illustrated by the figures below, also below from the Tecnologia Libre De Conflicto. Upon analyzation of said figures, it can be observed that the largest culprit in CO2 emission is the manufacturing, followed by use and distribution. If any solutions are to be made, it would be beneficial to address those parts of the diagrams.



2. CO2 Emission by Life Phase of a Smartphone
(*The Environment and Electronic Devices,* 2017)
This illustrates the high amount of carbon emission from smartphones.

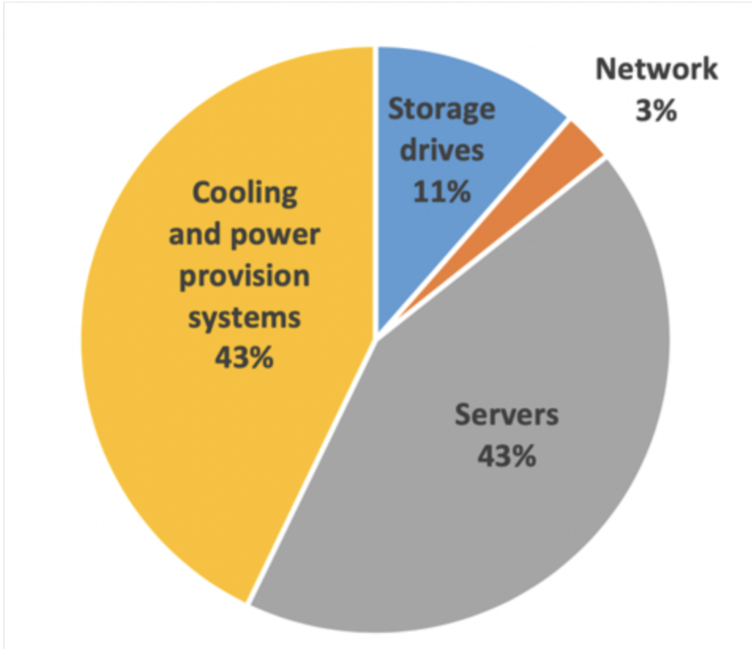


3. CO2 Emission by Life Phase of a Laptop
(*The Environment and Electronic Devices,* 2017)
This illustrates the high amount of carbon emission from laptops.



4. CO2 Emission by Life Phase of a Computer
(*The Environment and Electronic Devices,* 2017)
This illustrates the high amount of carbon emission from computers.

As just mentioned previously, the respective data centers of consumer electronics emit a high amount of greenhouse gasses. According to Shehabi and Marston at the Environmental Research Letters, “Approximately 0.5% of total US greenhouse gas emissions are attributed to data centers” (Siddik, A. B., Shehabi, A., & Marston, L., pg. 1, 2021). Although 0.5% is a very small percent, this is only taking into account the US (an easier way to visualize this has been provided in the figure below from Energy Innovation that gives a breakdown). It does not take into account any other country on the planet. If one was to take into account the percentages of greenhouse gasses from data centers in other countries, especially developed countries, the global percentage is tremendously high. It is also known that “Data centers require a tremendous amount of energy to operate, accounting for around 1.8% of electricity use in the United States” (Siddik, A. B., Shehabi, A., & Marston, L., pg. 1, 2021). Again, this does not take into account any other country on the planet. If one was to take into account the percentages of electricity use from data centers in other countries, especially developed countries, the global percentage would also be tremendously high.



5. Fraction of U.S. Data Center Electricity Use in 2014
(*How much energy do data centers really use?,* 2020)
This illustrates the high amount of power used from data centers.

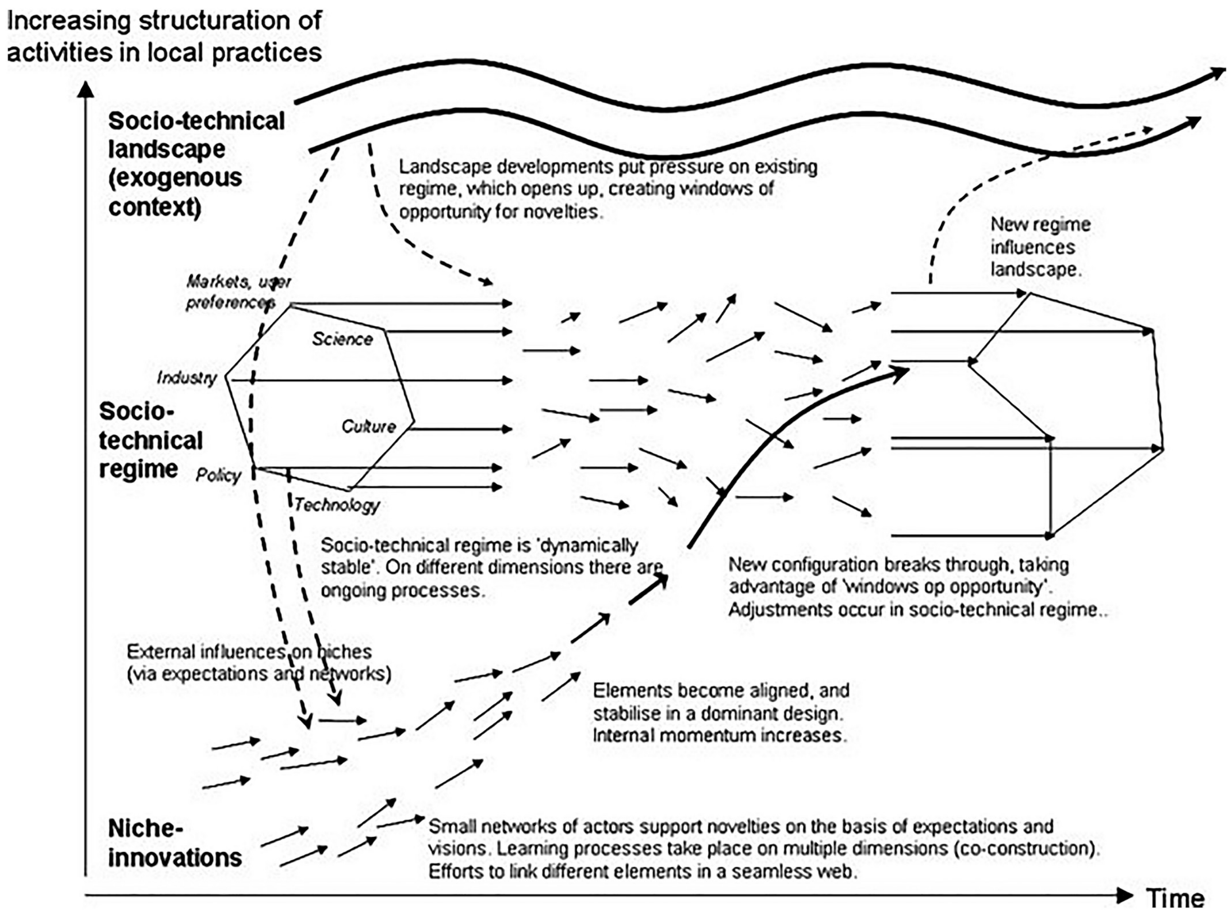
Despite all these knowns regarding the issue, there is still one glaring unknown that throws a wrench in finding a solution to this issue. Out of all the environmentally harmful innovations that have been made, it is unknown if consumer electronics pose the most harm to the environmental out of all other technological innovations. The Carnegie Cyber Academy at Carnegie Mellon University mentions how cars are also extremely widespread in society, but not everyone has one. However, there are enough that carbon emissions have made air lesser in quality (Carnegie Mellon University, Green computing – environmental issues - The Carnegie Cyber Academy, 2022). By extension of cars, air planes also have a similar effect on the environment as cars, and are also used extensively worldwide. The amount of carbon emissions caused by air travel is multiple orders of magnitude higher than the carbon emissions generated by cars. One could make the opposing argument that it could be better to mitigate vehicular and air travel as opposed to consumer electronics, as the former can be perceived to cause more harm to the environment.

According to Energy Policy, “In the past two decades, the role of consumers and their consumption patterns have attracted increasing attention of and discussions among researchers” (Bin, S., & Dowlatabadi , H., pg. 197, 2005). Perhaps there lies a solution here, by trying to change consumption patterns so that they are socially engineered for the benefit of the environment. The ultimate bridge that needs to be gapped with research is finding an appropriate STS framework that lays out specific conditions whereby effective solutions can come about. The understanding that the research seeks to fill is that after finding out what the methods of minimizing the environmental impacts of consumer electronics are, what is the most realistic way to implement them on a large scale? As mentioned earlier, there are high level solutions, which address the issue from the end stages of a product’s life, and low-level solutions, which address the issue from the sources (or each individual lifecycle stage). The issue with the high level is that it is not comprehensively effective, as it only addresses the symptoms, not the problems. This is why a one-size fits all solution will not work: there are unique solutions for unique lifecycle stages, or what the experts would say, “heterogeneous”.

As per the intellectual framework of Geels, there are two conditions that must be met in order for solutions to facilitate a transition to a better system. Based on the conditions that Geels identifies, there are ways to determine which potential mitigating strategies are more desirable than others. This is the evaluation criteria. In other words, this will be how it is decided where to focus our attention in this broad domain of consumer electronics. I will investigate options that are worth pursuing, ideally ones relatively easier to implement and get results.

III. Methods: Geels’ Conditions in the Multi-Level Perspective to Transition to a Better System

In his “Multi-Level Perspective”, Geels lays out a way to facilitate environmental sustainability transitions by using solutions based on specific conditions; this is the most optimal and realistic approach when finding potential strategies for mitigating environmental harm from consumer electronics and getting to a better system. Within a system, there are many different concepts that are important to identify, as each has a unique role. One of the important key concepts in this realm is niches. In the context of the subject of this research paper, niches refer to the role that each entity has in the sociotechnical system. For example, the niche of tech companies is to identify the wants of the customers (or in this case, society), and develop and create new products to satisfy those desires. The niche of individuals who use consumer electronics is to use the products that tech companies make for them, and to provide feedback to those companies so they always know what their customers want. Another key concept in this realm is socio-technical regimes. This is defined as the meso-level formed by engineering practices and routines, as well as dominant technologies linked together. Maria Morgunova of The Extractive Industries and Society asserts that social practices, scientists, policy makers, and other independent groups help shape the regime level (Morgunova, pg. 2, 2021). As an example, Facebook and Google are social-technical regimes. They have a set of established engineering practices and routines that they abide by and they specialize in certain technologies. The last key concept in this realm is the socio-technical landscape. This is defined as the broader contextual developments that influence the socio-technical regime and over which regime actors have little or no influence (Geels et al., pg. 465, 2017). The prime example of this in modern society is the aforementioned social conditioning of society. Over time, as consumer electronics became more and more advanced, people have allowed their devices to become almost like an extension of themselves, whereby it is imperative to have a device for your daily tasks. In other words, the landscape has changed as technology became more advanced, which has caused tech companies to continue to feed into that social conditioning. A visual representation of the complex structure of social dynamics is seen below from Adam Sheingate from the Policy Studies Journal.



6. Visualizing Network Relationships and Processes in the Context of Sociotechnical Systems
(*Policy Regime Decay,* 2021)
This image illustrates the relationships in sociotechnical systems.

As mentioned earlier, Geels specifies certain conditions that must be met as prerequisites if any potential solutions for an environmentally sustainable transition to a better system takes place. In the "Multi-Level Perspective", Geels mentions that those conditions "...imply that sustainability transitions are necessarily about interactions between technology, policy/power/politics, economics/business/markets, and culture/discourse/public opinion" (Geels, F. W., pg, 25, 2017). When coming up with specific potential solutions, all four of these entities must be considered. Those solutions ought to have implications on all these entities. In order to transition to a better system, there must be change happening at each of those entities, otherwise the system will likely stay the same. When change happens at each of those entities, then the proceeding interactions between all entities will lead to a better system.

It can be deduced that since there are multiple different entities at play here, it stands to reason that any potential solutions will ideally consider the different facets of sustainability transitions. Geels asserts that “Researchers therefore need theoretical approaches that address, firstly, the multi-dimensional nature of sustainability transitions, and, secondly, the dynamics of structural change” (Geels, F. W., pg, 25, 2017). The problem of consumer electronics and the environment is a multi-dimensional one as well. As illustrated in the first figure on page 2, each product goes through a lifecycle. Each stage in the lifecycle causes its own environmental problems. Based on the approach outlined here by Geels, it would be effective to come up with possible mitigation strategies at each stage in the lifecycle so that the problem overall is being addressed at the source. By taking this approach, we would be addressing a multi-dimensional problem by using a multi-dimensional solution. With respect to structural change, the problem is that “...many existing (unsustainable) systems are stabilized through various lock-in mechanisms...” (Geels, F. W., pg, 25, 2017). Some examples of lock-in mechanisms that Geels provides are infrastructure, shared beliefs and discourses. By addressing a multi-dimensional issue with a multi-dimensional solution, these lock-in mechanisms can be chipped away at and potentially slowly changed over time. By treating the issue at the sources, it becomes more in the realm of possibility that these lock-in mechanisms will change into other lock-in mechanisms.

Given this understanding of how to move from one system to another system that is better, there’s two conditions which were earlier alluded to that Geels lays out that relate to the problem. The first condition is that “...sustainability transitions are goal-oriented or ‘purposive’... in the sense of addressing persistent environmental problems” (Geels, F. W., pg, 25, 2017). This condition from Geels’ framework is directly applicable to this issue, as there is a goal in mind here: to mitigate the persistent environmental impacts from consumer electronics. Any possible solutions must be congruent with that condition. The second condition is that “...most ‘sustainable’ solutions do not offer obvious user benefits (because sustainability is a collective good)...” (Geels, F. W., pg, 25, 2017). This condition also applies to this issue, because consumer electronics are inherently made for users. If steps are being taken to ensure mitigated environmental impact, it is very likely that it will come at the expense of product quality, specifically, the physical quality. Products made of lesser “valuable” materials do not offer obvious user benefits.

As an overview of the scope, the overall method can be summed up in the following way. Every product has a lifecycle. A lifecycle is composed of different stages of the products life from the gathering of raw materials all the way to disposal/waste. Instead of looking the issue of the negative impacts of consumer electronics on the environment from the end, I will look at it from each step in the lifecycle, effectively addressing it at the sources. Within each step of the lifecycle, potential mitigating strategies will be explored, as opposed to mitigating strategies to the issue as a whole from the end only. Each potential mitigating strategy in its respective spot in the lifecycle will adhere to the two aforementioned conditions that Geels lays out.

IV. Results: Potential Mitigating Strategies Congruent with Geels’ Conditions

As mentioned above, potential mitigating strategies will be discussed per each stage of a product’s lifecycle. Each strategy will be explained in alignment with the aforementioned conditions from Geels' framework. When referring to the first figure in this research paper, it is seen that the first stage of a product's lifecycle is to gather raw materials. The consumer electronics of today are almost always made up of rare earth minerals such as cobalt and tellurium. In order to gather these types of rare earth minerals, it requires mining. The issue with mining is that it is a method that requires a great deal of fossil fuels. The use of large amounts of fossil fuels are widely known to be a great deterrent of environmental health. Instead of using fossil fuels, a potential strategy that would mitigate harm to the environment would be to use renewable energy instead when mining for rare earth minerals/metals. A renewable energy source will not have the negative implications of fossil fuels such as air pollution and toxic emission. This strategy aligns with Geels' condition of having goal-oriented action when addressing persistent environmental problems. In this case, the goal is to mitigate environmental harm.

Furthermore in regards to raw materials, it must be acknowledged that although the mining of rare earth minerals with renewable energy is a step in the right direction, there is one step that can be taken in order to reach another level: products made of recycled materials. This way, instead of mining at all, recycled plastic or aluminum can be used to just make new products. The issue with this potential solution is that it would force users to get used to products of lesser quality than what they use now. For example, when you buy a new iPhone, it has a substantial premium feel to it that stems from the physical materials. If you were to get a new iPhone that was made of recycled plastic, you would likely be less than enthusiastic. Although this a tough solution to implement, it is not impossible, and it aligns with Geels' conditions. Specifically, this aligns with the condition of not all solutions having obvious user benefits. Using a plastic smartphone is not a benefit to the user, but it would be a potential mitigating strategy of environmental harm.

The second stage of a product's lifecycle in the first figure is the factory phase, or in other words, the manufacturing phase. During the manufacturing phase, a product is being physically made. For example, a laptop is being put together, or maybe a smartphone. All the raw materials are being formed up in such a way that leads to the physical form of the product in question. At the factories in which this takes place, there also exists a great deal of air pollution. This has become the norm with industrialized areas. Since both mining and manufacturing have a relatively similar nature, they both have similar issues. That said, they both have similar possible solutions as well. Much like with switching mining practices to use renewable energy, factories can do the same. The thing with factories is that the extent of their impact is significantly larger than mining based on pure scale. If factories switched to renewable energy, then it is possible that less harm will come to the environment. This also aligns with Geels' condition of goal-oriented action to address environmental problems, as using renewable energy is a move that proactively mitigates harm to the environment.

Another aspect of factories can also be addressed: waste. Factories produce a great deal of waste in order to create their products. Instead of tossing everything out, materials can possibly be evaluated in such a way where it can be determined if they can be reused. It is possible that a certain material cannot just be reused in the manufacturing process, but it can possibly be used at another point in the factory. If waste materials have no further use in the factory, perhaps another option is to get in touch with different nearby communities, facilities, or institutes to see if they have any use for that material. This all boils down to efficient recycling. If a factory can do these things, it can possibly be a mitigating strategy from environmental harm. Efficient recycling also aligns with the conditions Geels lays out, specifically, the first one: goal-oriented action to address environmental problems. Recycling is inherently an eco-friendly action. If it is used as a way to help the environment, then it is a potential way to reduce the harm generated from waste.

The next stage in a product's lifecycle is the brand, or more specifically, the item being on the store shelf and marketed to potential customers. This stage does not have any substantial harm to the environment, if at all, but it is a stage that is noted in the lifecycle diagram in the first figure of the research paper. This is shown as the third stage in the lifecycle.

The fourth stage in a product's lifecycle is the consumer, or the user of the product. At this stage, the product is in active use by the consumer. When we use consumer electronics, they require data centers to store everything being exchanged in the digital space such as phone calls, text messages, FaceTime messages, etc., and these massive data centers run on fossil fuels. If the harm from data centers is to be mitigated or minimized, there must be a strategy where they run on other forms of energy that are less harmful to the environment. Instead of running on fossil fuels, it would be better if like factories, data centers ran on renewable energy sources as well. This way they would not also contribute to air pollution. This potential mitigating strategy aligns with Geels' conditions about goal-oriented action. Much like with factories, the action of using renewable energy at data centers is goal-oriented, specifically the goal of mitigating harm to the environment.

The last stage in the product lifecycle is waste. This is the stage after the consumer is done using the product. There a multitude of different ways consumers manifest electronic waste. One example is when a person upgrades his or her smartphone, usually they throw out his or her old one, even though it may only be a few years old and still functional. The same can be said for computers and televisions. Even though a user's previous one was outdated, it is still functional, yet it is very common for people to discard of their previous products in local trash sites. When electronics are not disposed of properly, this can lead to hazardous materials such as mercury being released into the environment. The negative impacts do not end there. Electronic waste can also cause air pollution, water pollution, soil contamination, and animals can easily mistake electronic parts for food. The potential solutions for electronic waste are to donate old products that are still functioning, so that maybe others can make use of them, and recycle electronic waste at reputable recyclers so that materials are recycled properly. Both these mitigating strategies align with Geels' conditions. Both are actions based on goal-oriented purposes to make the environment healthier. Also, neither really offer any obvious user benefit. To give away an item brings no tangible benefit to the user, and neither does recycling.

V. Conclusion

When finding solutions to address the negative environmental impacts of consumer electronics, often times it is instinctually thought to address the issue from the end and come up with a one size fits all solution. However, the results of a Multi-Level Perspective analysis demonstrate that in order to move from one socio-technical system to a better one, it would likely be much more efficient to address the unique environmental impacts at each individual stage of a product's lifecycle. Designers and researchers should use this information to recognize the individual stages, what the environmental ramifications are at each stage, and come up with solutions that address each ramification at each stage. Designers and researchers can additionally use the Multi-Level Perspective analysis to realize that a one size fits all solution from the end of the problem is not the most efficient way to go about solving it; rather, addressing the issue at the sources could give a more comprehensive and effective outcome.

In this paper, I only examined consumer electronics through the lifecycle of the most conventional products. In other words, the lifecycle that I was referring to throughout the paper, and its respective stages, only applies to the most common consumer electronic products, such as smartphones, tablets, laptops, etc. It is possible that the more obscure products have a similar, but different lifecycle with different stages. This paper did not take those products into account. This is because the broad category of consumer electronics covers only many different types of products, which it makes it difficult to analyze a lifecycle that includes all stages of all types of products. However, as alluded to earlier on this research paper, the lifecycle that I analyzed is comprehensive of the majority of consumer electronics products. Therefore, the insights gained from this Multi-Level Perspective analysis can be applied to the majority of products.

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