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Opinion

Role of Resource Circularity in Carbon Neutrality

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Abstract: With the help of circular strategies, products can be used longer (i.e., reuse, repair, and refurbish). Products that are difficult to use will be recycled efficiently. The present paper provides actionable guidelines for reducing environmental impact at all stages of a product's life cycle, including the manufacture and assembly of the materials that make up the product, environmental impacts during use, and environmental impacts at final disposal, as well as specific actions and evaluation mechanisms. The circular economy is a concept that encompasses specific actions and their evaluations. To clarify the contribution of this circular economy to carbon neutrality, the present paper highlights how it is important to recognize the role of carbon as both an energy carrier and a material. CO_2 is a waste product from burning and powering carbon. CO_2 must be disposed of like any other waste product, but carbon itself is also an energy carrier. Thus, when promoting the carbon cycle, it is important to harmonize carbon's function as a material with its role as an energy carrier. The further introduction of renewable energy and societal shift towards circular economy would contribute to carbon neutrality and more resource efficient use in a mutually complementary manner.

Keywords: resource circularity; circular economy; thermodynamics; energy carrier

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1. Introduction

The most important global environmental issue today is climate change. Climate change, also known as global warming, is primarily caused by mankind's excessive emissions of greenhouse gases (CO_2, methane, and chlorofluorocarbons (CFCs)). Although CO_2 does not have very significant global warming potential [1], excessive emissions of CO_2 make it the most significant factor in this phenomenon, and there is a growing worldwide movement to curb CO_2 emissions.

The recycling of resources has long been considered a useful human activity. In recent years, the objective of recycling has come to include not only curbing emissions of hazardous substances and the excessive waste of resources but also promoting reductions in CO_2 and CFC emissions, which have a strong impact on global warming, in response to growing awareness of climate change.

International communities have long discussed ways to improve resource efficiency [2], which is now reflected in many practical targets, including the sustainable development goals (SDGs). The core of this concept is "decoupling", which refers to the decoupling of resource consumption (including all resources, energy, bioresources, minerals, and water) and human well-being (or more realistically, economic development). Although not entirely uncontroversial in concept, this guiding principle alone did not lead to actual actions and had the weakness of being unable to articulate concrete activity guidelines. The circular economy was proposed as a means to overcome this factor [3]. The essence of this concept is to promote the circular use of all goods. For example, products should be used longer (reuse, repair, and refurbish), and hardly reusable End of Life products should be recycled efficiently. In other words, the circular economy provides actionable guidelines for reducing environmental impacts at all stages of a product's life cycle, including the manufacturing of the materials that make up the product, product assembly, environmental impacts during use, and environmental impacts at final disposal, as well as specific actions and their evaluation mechanisms.

With the development of a circular economy, the conventional industrial structure of mass production, mass consumption, and mass disposal will be transformed. However, since the system of mass production and mass disposal has its own economic rationality, in order for the circular economy to be more feasible, it is necessary to change human behavioral guidelines and circularize the industrial structure. In this sense, international standardization of the circular economy is currently underway [4]. However, attention must be paid to the positioning of waste management. While it is important to build a value chain that takes reuse and recycling into account, it is impossible to achieve 100% reuse and recycling without generating residues for all products. Therefore, from the perspective of environmental protection, it is necessary to implement safe and environmentally friendly waste management. If we consider the ideal state of the circular economy and ignore the realities, we may face significant challenges. In addition, when manufacturing products, energy is also needed to control and curb the generation of environmentally hazardous substances during production and use since some raw materials also employ hazardous substances. Figure 1 illustrates the tradeoffs involved in this concept.

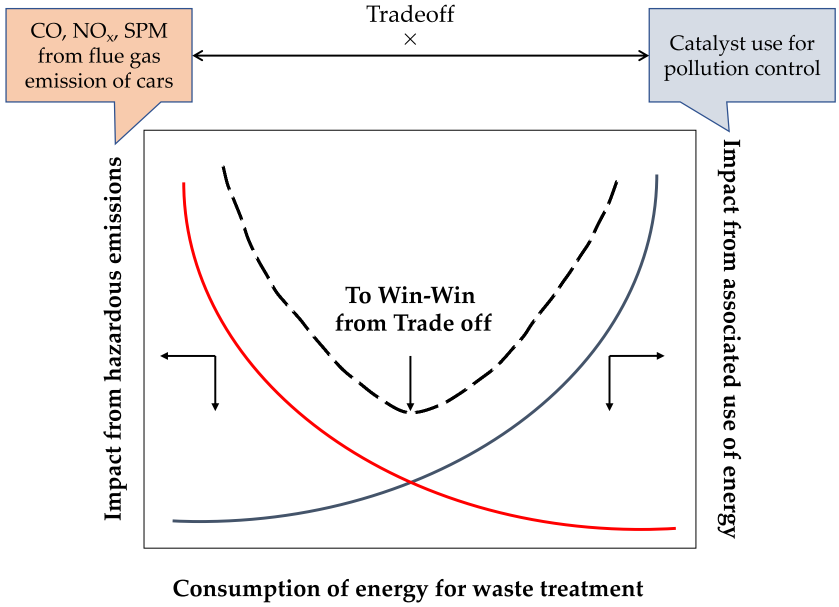

Figure 1. Tradeoff relationship between impacts from hazardous emissions and energy use for mitigation. Red: left axis, Blue: right axis.

Even today, there are many examples of such tradeoffs throughout the world. Figure 1 shows an example of a catalyst for purifying automobile exhaust gas. Here, a ternary catalyst using platinum group metals is used to purify unburned carbon, nitrogen oxides, and CO gas in the exhaust gas. Platinum group metals are very scarce, and only a few ppm of such metals can be found in ores [5]. For this reason, considerable amounts of rock and sand are stripped and mined, and a great deal of energy is spent to produce these metals. This process requires a large amount of energy and emits considerable CO_2 gas. Many other similar examples can be found, such as the inability to recover energy from exhaust gases to control dioxins generated during recycling.

The addition of active carbon or decomposition techniques using catalysts is very popular to eliminate dioxins. This process, however, leads to large energy losses, which, in turn, generates extra CO_2 emissions. Of course, technological development should move in the direction of eliminating such trade-offs, but it is not easy.

2. Macroscopic Overview of Energy Supply and CO_2 Emission Problems

This section describes the basic issues necessary to understand the problem of excess CO_2 generation and resource circulation.

2.1. What Are Energy Resources?

Energy refers the ability to do work and comes in many forms. For example, there is thermal energy, kinetic energy, chemical energy, internal energy, and nuclear energy. In classical mechanics, the kinetic energy of an object with mass m and velocity v is $\frac{1}{2}\,mv^2$, so the corresponding dimension is ML^2T^{-2}. However, calories and joules are often used as units, and the dimension of time is not included in the visible form. This is another important factor when considering energy resources. Electrical energy cannot be stored, but an energy resource can only be considered an energy resource if it can be stored.

Figure 2 provides a brief description of the sources of energy resources.

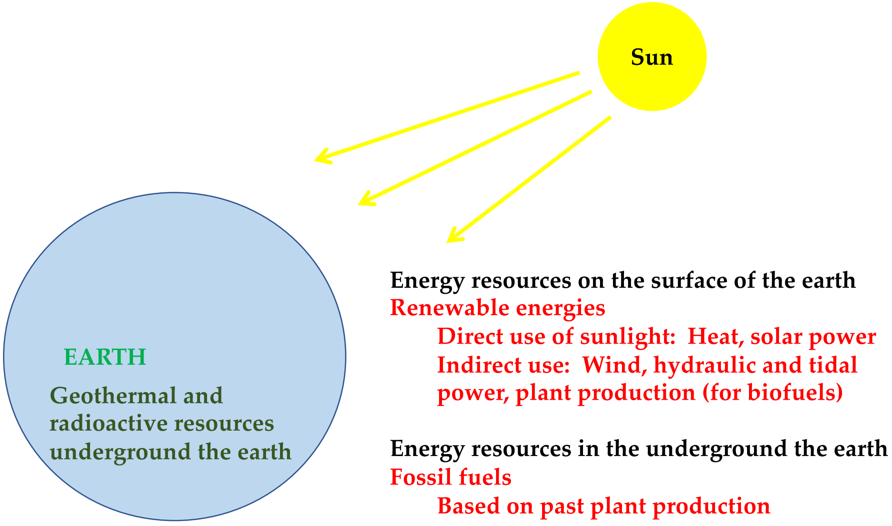

Figure 2. Major energy resources used by humankind.

A primary energy resource is the ability to produce energy or, more precisely, the ability to convert energy. However, a primary energy resource must also have the property of being storable. Petroleum became the leading primary energy resource of 20th century because of its presence in underground reservoirs and its storability above ground. Since energy is often used for generating power, it is important that it can be stored in small portions for specific uses. Cars still run on internal combustion engines that use fossil fuels because that method is by far the most advantageous. Incidentally, both fossil fuels and biofuels, which are gaining attention for their carbon neutrality, are produced through photosynthesis. The crucial difference between these two fuels is that fossil fuels were formed very long ago. Hydroelectric and wind power generation, which convert the movement of water and wind into electricity, are also indirectly influenced by the sun through weather phenomena. Solar power generation, of course, converts energy from the sun directly into electricity. Most energy currently used by humankind is obtained from the sun. The only irrelevant energies are geothermal and nuclear power. This recognition is important when considering carbon neutrality.

At this point, we need to rethink "what is electricity?" Electricity is thought of as the energy carrier that supports modern society. However, electricity itself is not energy. Electricity is usually expressed in kWh. When considering energy resources, however, the unit of time is often not taken into account. In other words, energy resources correspond to the potential of materials, which is why it is important to be able to store energy easily. In other words, electricity is a “raw” resource and must be used once it is created. Electricity can only be stored through materials and cannot be converted into energy. For this reason, materials for storing electricity have been invented and used since ancient times. The most familiar component of electricity generation is the battery, which appears essential in the effective use of electric power. To rationally link energy and electric power and use in daily life without contradiction, it is necessary to link energy with materials. This concept is illustrated in Figure 3.

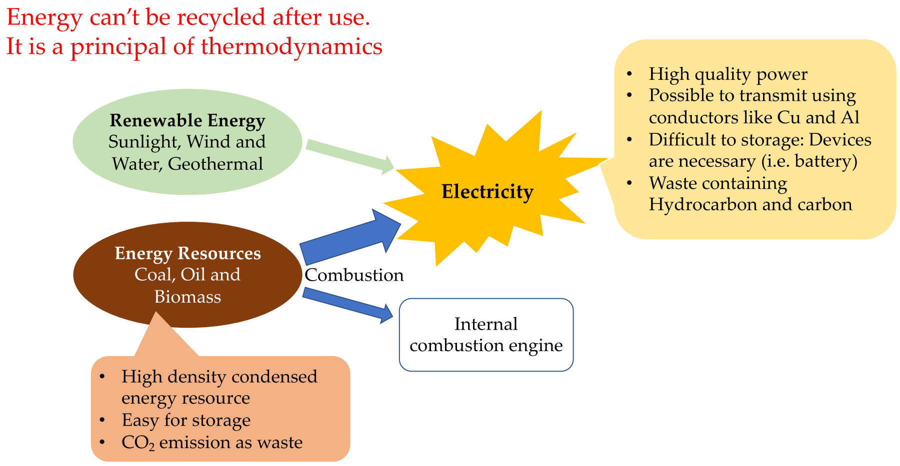

Figure 3. Relationship between power, energy, and energy resources.

However, with the free availability of electricity, we have become increasingly less aware of the connection between energy and material. In order to solve the social problems caused by energy issues, such as climate change, we need to reaffirm the relationship between material and energy and solve energy problems based on the material cycle.

While it is positive to aim for a large-scale carbon cycle and fixation, the energy needed to achieve this goal must, at a minimum, be provided by renewable energy sources, not by fossil fuel-derived electricity. As a practical answer, we need to define what kind of energy can be used for carbon fixation and with what efficiency.

The only way to promote a carbon economy is to obtain a supporting energy supply by means other than carbon oxidation reactions.

2.2. The CO_2 Problem from the Viewpoint of Chemical Thermodynamics

To solve a problem, one should always understand the cause of the problem and address that cause specifically. Carbon is a component of the skeletons of living organisms, especially plants. Biotic resources, including large amounts of fossil fuels, are consumed in human activities as energy carriers and raw materials for biological or polymeric materials. One factor that distinguishes humans from other animals is that humans are not afraid of fire and can make good use of it. Thus, human activity is based on the use of carbon as an energy source and energy carrier. Here, carbon used as energy is oxidized in the following reaction, which provides significant energy through the heat of oxidation [6]:

$$\mathrm{C\ (s) + O_2\ (g) = CO_2\ (g)},\ \Delta H = 394\ \mathrm{kJ} \quad (1)$$

Equation (1) describes a typical oxidation reaction of carbon, but from the perspective of oxygen, it is actually a reduction reaction. The reaction equation shown here is a redox reaction, with electrons moving in and out. In this case, carbon provides four electrons to become CO_2, and the oxygen atom accepts four electrons to become CO_2. By chemically completing Equation (1), this reaction produces a large amount of energy (394 kJ), some of which can be used as heat.

The rate of the oxidation reaction of carbon here is generally fast, which is analogous to the combustion of fossil fuels. However, are reduction reactions different? The most famous reduction reaction involving carbon is photosynthesis, the rate of which is much slower than that of oxidation reactions [7]. From a physicochemical point of view, the product of carbon oxidation is gaseous CO_2. This product easily leaves the reaction field, and, even in large quantities, the reaction is rarely inhibited. On the other hand, in the reduction reaction of CO_2, the product is carbon, which remains at the reaction interface. In this way, the reaction is easily inhibited. This relationship is shown in Figure 4.

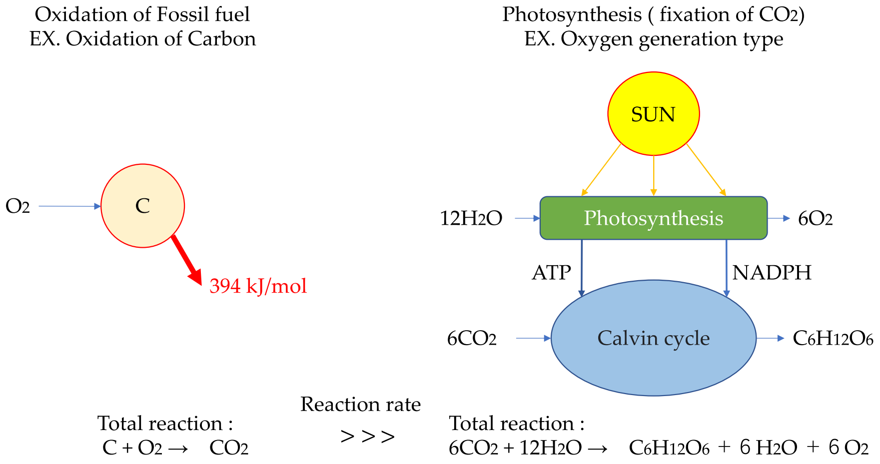

Figure 4. Rough illustration of oxidation carbon and photosynthesis.

In this figure, the oxidation reaction of carbon is compared to the reaction of carbon-fixing photosynthesis. It should be fully understood that the oxidation reaction of carbon is much faster than the rate of fixation of carbon compounds under photosynthetic reactions.

As noted earlier, when humans do not actively consume energy, both generation and absorption primarily occur in vivo, and the rates are easily balanced. The quantitative difference between the rate of carbon fixation by photosynthesis and the rate of carbon combustion reactions cannot be clearly demonstrated, but it is likely to be at least several orders of magnitude. Fortunately, for human beings, the reaction field of photosynthesis is much larger than the reaction fields of the energy generators used by humanity. This amount is very hard to quantify, but the International Energy Agency (IEA) reports [8] that the rate of increase in atmospheric CO_2 in recent years represents a difference about 900 million tons of carbon equivalents, assuming that all CO_2 is generated by human activities. The goal of the Paris agreement is to limit global warming to well below 2 degrees Celsius and preferably 1.5 degrees Celsius compared to pre-industrial levels by thoroughly reducing the generation of CO_2 and other greenhouse gases.

Thermodynamics simply refers to the study of experience. The first is the law of conservation of energy, the second is the law of increasing entropy (entropy increases as the state changes), and the third is the law of determining entropy at any other temperature. More precisely, the third law states that entropy is zero at an absolute zero temperature. Additionally, the second and third laws are related.

The first and second laws are important when considering real-world events in thermodynamics. The conservation law of energy is sensibly accepted by many people. If we were to find macroscopic events that do not obey this law, then perpetual motion engines could also be realized. The second law states that “any process that transfers heat from a low-temperature object to a high-temperature object and causes no change other than a change in temperature is not feasible.” Simply put, “entropy always increases as the state changes.”

3. Carbon Neutrality and the Resource Cycle

How can resource recycling and decarbonization be compatible? Let us consider the necessary conditions. First, the following relationship must be established.

CO_2 emissions for material production from primary resources > CO_2 emissions from secondary resources.

The comparing the direct CO_2 emissions for the material production processes with primary resources to the CO_2 emissions from secondary resources is very simple. However, when calculating CO_2 emissions from manufacturing from primary resources and CO_2 emissions from secondary resources, it is important to consider not only the CO_2 emitted during direct operations but also the indirect CO_2 emissions impacted by the processes throughout the value chains. (Scope 3 of the carbon footprint accounting). However, including Scope 3 of the carbon footprint is not easy. In particular, CO_2 emissions from related processes such as collection, transportation, separation and recovery are sometimes high and may depend on the social systems. CO_2 for transportation is also highlighted quite often.

It is necessary to build a rational social system for circulation by seeking the best geographical combinations of scrap generation, recycling facility, and their users. Additionally, the introduction of many examples of resource recycling that contribute to environmental issues such as decarbonization and increase the public's interest in this field are very important. This will encourage private businesses from different industries to cooperate in resource recycling. And then, the government will promote subsidies in terms of taxation and technological development. Below, we consider this goal qualitatively. Products made of metals consume considerable energy in the process of manufacturing metal materials. Thus, recycling is said to be effective in realizing a low-carbon society [9]. Although the figures are very rough, an existing study shows the extent to which this effect is falling. The results are presented in Table 1. This table shows the energy consumption and carbon footprint for the production of iron, aluminum, and copper both from primary and secondary resources. It can be seen that for all three metals, production from secondary raw materials is more energy efficient and creates fewer CO_2 emissions. While this rule generally applies, it is not always the case. For example, for aluminum, hydroelectric power can be used in the high-temperature molten salt electrolysis process, which consumes the most energy when creating products from primary raw materials. When this production happens, the process using primary raw materials is extremely low in CO_2 emissions. In this case, the process using secondary feedstock may have higher CO_2 emissions. In addition, these values for secondary resources do not consider waste collections, transportations or some parts of sorting.

Table 1. Comparison of energy requirement and carbon footprint for primary and secondary materials production [10].

	Primary		**Secondary**	
Material	**Energy [TJ/100,000 t]**	**CF [ktCO$_2$/100,000 t]**	**Energy [TJ/100,000 t]**	**CF [ktCO$_2$/100,000 t]**
Aluminum	4700	383	240	29
Copper	1690	125	630	44
Ferrous	1400	167	1170	70

Importantly, the discussion here remains general. A diagram of the value chain in which goods and information circulate from resources to waste is shown in Figure 5. The start of the chain is the mining of natural resources, followed by the production of materials, ingredients, components, and goods. Then, the product is made by the final manufacturer, passed on to the general public, disposed of, and lastly recovered as a material base by a recycler. The end result is a residue that cannot be used anywhere and can be safely disposed of as waste, often in landfills.

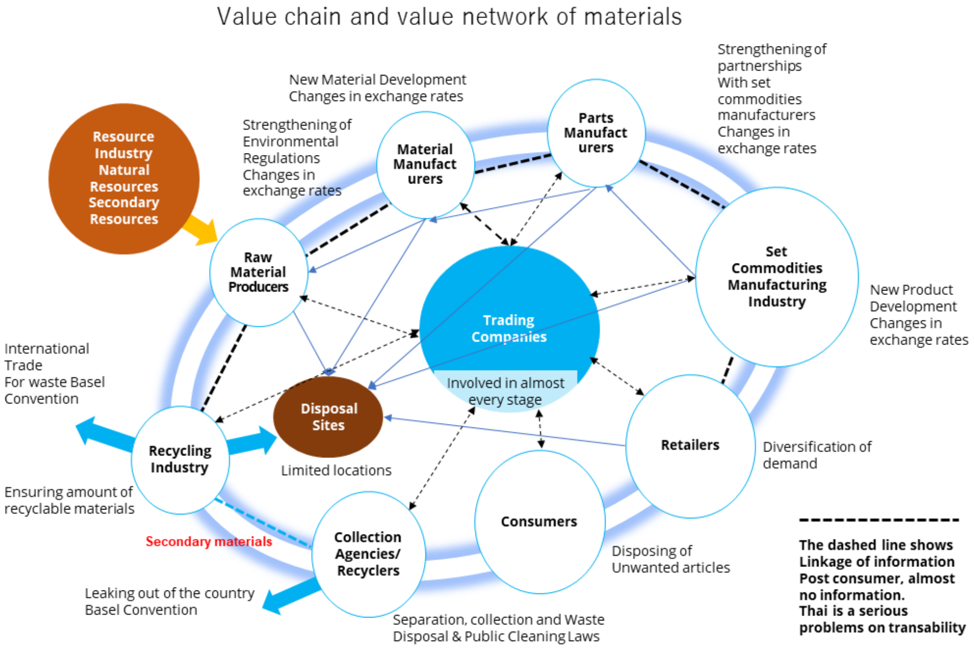

Figure 5. General value chain of materials and information on the market.

A smaller circulation cycle is more desirable. The circulation cycle includes the exchange of information with neighboring sectors and, for set makers close to the final goods, the reuse of parts and other materials. In particular, reuse and repair take place in the movement of the final goods to the user and among users. In addition, trading companies play an important role in connecting each sector in terms of both goods and information.

In order to link decarbonization and resource recycling, it is necessary to make the loop of circulation as small as possible. To achieve this, it is effective to promote easy disassembly design and/or to construct a new process that does not distinguish between recycling and reproduce processes. This goal is difficult to achieve by simply recycling materials. We use final products in our daily lives, but we give those products away for a variety of reasons. Depending on how we give those products away, the form of effective use will vary. Some products can be easily reused with simple rework or repair, while others are difficult to reuse in any way. Furthermore, even if reuse is possible, it will not be possible if the item is incorrectly disposed of. Generally speaking, the 3Rs (to reduce, reuse, and recycle) refer to using a product for a long period of time and then reconfiguring it for reuse. Finally, for recycling, we need to know where recycling takes place, by whom, and what items are no longer needed. In the past, such information was only available to a small segment of society, but thanks to advances in information technology, it is now possible to obtain the details of unwanted items in real time [11,12]. By attaching a value to such objects, they can be easily reused. This measure alone is effective, but unfortunately the effects are not readily visible. It would be more effective if software were designed to show how effective this trade is in reducing CO_2 emissions. Therefore, when considering a social circulation system, it is important to consider reuse first and foremost and build a collection system that fully takes this factor into account [13].

To illustrate the environmental impacts of reuse, recycling, and other forms of circulation in more detail, the environmental and economic effects of each type of resource circulation are shown in Figure 6.

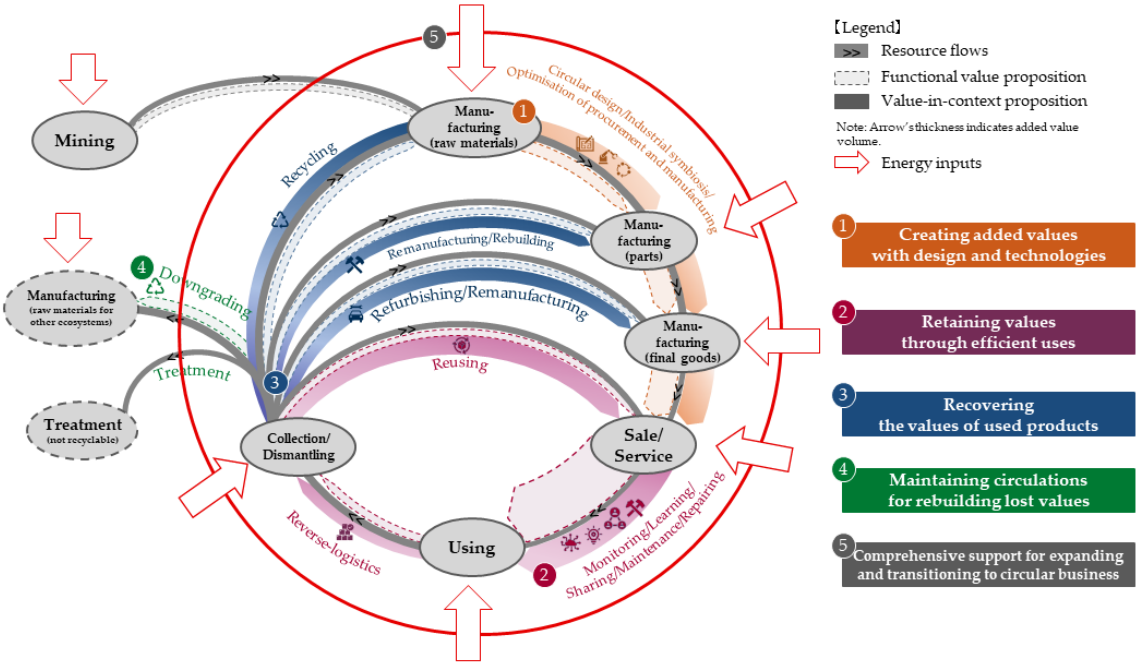

Figure 6. Environmental and economic effects of each resource cycle.

Figure 6 shows the environmental and economic effects of each resource circulation. For example, lithium-ion batteries [14] and photovoltaic panels [15], which have a significant impact on both resource circulation and carbon neutrality, should be designed for circular economy based on exactly these concepts. In this figure, the environmental effects are shown as materials lost from resource circulation and energy inputs as the origin of greenhouse gas emissions. Although only depletable resources are circulated, it can be seen that each role contributes to the following five factors:

1. Creating added value with design and technologies (maximization of value in the value chain);
2. Retaining value through efficient use (maximization of value through product value utilization);
3. Recovering the value of used products (maximization of residual product value);
4. Maintaining circulations for rebuilding lost value (minimization of resource loss);
5. Comprehensive support for expanding and transitioning to circular business.

In a circular economy, organizations are required to maintain a circular flow of resources and recover, retain and add to their value. Some primary research [16–21] reviewed circular business cases and classified their actions into several types: recycling, reusing, sharing, refurbishing, remanufacturing, performance-based approaches, and industrial symbiosis. These actions can be divided into three categories: maximization of value, minimization of resource losses, and comprehensive support for other actions. Value types for maximization can be segmentalized into various types of value in the value chain, value through product utilization, and residual product value. One criterion for the transition to circular business is a value proposition in relation to the use of resources. Without an appropriate value proposition, all the actions supporting a circular business will fail to function.

From an environmental perspective, resource losses and energy inputs must be minimized in the business ecosystem for the circular economy.

While the above cannot be simplified, it is possible to understand what underlies circular behavior.

The first is reuse, which must be fully considered. Naturally, it is efficient to reuse objects that can be reused in order to maximize the value of resources. However, reuse does not always work well for products related to the ever-evolving information and communications field. Of course, it is problematic to encourage consumption by offering new products unnecessarily, but it is also true that reuse does not work well when new products are introduced through essential technological innovations. Moreover, this case is more complicated, and issues such as patent infringement must be considered.

Recently, the concept of "Mobility as a Service (MaaS)" [3] was applied to automobiles, and the idea of cloud-enabling transportation using ICT and considering transportation means other than private cars as one service has been considered, regardless of the operator and whether such alternatives are forms public transportation. The concept of "transportation as a service" is also attracting attention. This change represents a shift from "goods" to "services", accompanied by the adoption of subscription methods and changes in the way that business is conducted, which may further promote recycling. Notably, recent studies have shown that reuse does not always contribute more to the environment than recycling.

In the context of resource decoupling, both reuse and recycling increase resource productivity by extending the residential time of the resources. However, new business models of Product Service System (PSS), such as subscription and sharing, do not necessarily extend a product's lifespan; instead, they increase the operating ratio. For example, one purchased product could be used once a month with a product life span of 5 years. However, rental may allow a different product to be used twice a week with a product life of 1 year. In this case, the latter may save material resource inputs for production per service if the other conditions remain the same. However, we cannot expect the same mitigation effects for CO_2 emissions. If the rental requires transportation between the users and service providers every single use twice a week, CO_2 emissions may even increase considering the huge emission potential of transportation. As shown in [22], CO_2 mitigation impacts depend on a combination of product types and services. Roughly speaking, for products whose CO_2 emissions in the production phase are huge, the corresponding services generally have positive effects on CO_2 emission reductions.

The surrounding social system has a large impact on the CO_2 emission differences between reuse and recycling. Unfortunately, reuse is not very common in developed economies. Consequently, the logistics for reuse are generally less efficient compared to those for recycling. Here, less efficient logistics reflect not only a longer transportation distance but also several other differences. For example, product inventory management usually requires more careful handling than products disposed of in a scrap yard, as well as careful packaging and less loading efficiency in transportation. All these factors have undesirable effects. Notably, reuse can avoid the material production process. The comparison result depends on the materials' carbon footprint and reuse market, and all related social systems.

Reuse and recycling, however, are not mutually exclusive activities. In the short term, some consider the two activities to be opposites since more reuse means less recycling. While idealistic, such a world does not reflect progress. There will always be a time when reuse is no longer possible, at which point it becomes desirable to recycle efficiently, rather than simply dispose of the product. Therefore, we need to consider recycling (partial disposal) as a backup to the reuse system.

First, products are composed of many parts, which themselves are composed of many more materials. If products are reused, it may take a considerable amount of time for them to be recycled. Since recycling is done with materials, the materials used in new products will change over the life of the product, creating the possibility that even if materials are successfully recovered, they will no longer be used in that final product. Base metals that have been used in large quantities for a long period of time, such as iron and aluminum, can be retained in their original form, but materials used in a wide variety of functional contexts, such as polymeric materials and critical metals, often change, making it difficult to create a reuse > recycle process. Another difficulty is collection. Recycling also refers to the creation of resources, so a certain amount of mass processing is necessary to make recycling economically rational. Unlike natural ores and petroleum, it is quite difficult to recover large quantities of emissions in a way that makes effective use of them.

4. Introduction of a Circular Economy

The circular economy is not just about recycling. However, for materials, this concept refers to recycling, while for products, lifetime extension is the priority and has a significant decarbonizing effect. There is also difference between energy conservation and decarbonization, which used to be completely synonymous. Decarbonization means not using conventional fossil fuels. Thus, using renewable energy sources such as wind and solar is still decarbonization, even though the energy efficiency is a bit lower. The ultimate goal of resource recycling is not to decarbonize but to reduce the consumption of finite and depletable resources such as mineral resources and ultimately build a truly sustainable society from which all resources can be recycled. The ultimate goal of decarbonization is to eliminate climate change and stop global warming. There is a strong sense that decarbonization has been a priority in the last few years, but both concepts are not inherently superordinate and should be achieved at the same time. Much of recycling is fundamentally a type of resource-saving that contributes to energy conservation and saves energy. Moreover, since the two concepts can act without trade-offs in many cases, they should always aim to achieve each other's goals simultaneously. However, if we focus on a specific goal, we may not be able to see the whole picture. Instead, it may be preferable to fully explore only one issue.

The introduction of resource recycling must be accompanied by changes in industrial structures and social systems, such as promoting the reuse of products as close to the market as possible, in order to reduce environmental impacts and solve energy issues at the same time.

Biobased resources can be used as food or as materials. Because such resources contain carbon, they also serve as another energy carrier. Biomass power generation, which has been gaining momentum recently, uses wood chips to generate electricity. Since wood is created through photosynthesis, it is balanced with atmospheric CO_2 and can be described as safe. However, if one is not careful, trees take a long time to grow and become a forest through photosynthesis, whereas power generated through biomass is consumed in an instant. Thus, when the time frame is considered, there is no balance. Agricultural and pastoral production, food supply, and the disposal of the corresponding waste are all crucial factors in biological systems. Humans are living organisms and need food. As is often said, considerable plant resources are needed to produce meat, and it is from this perspective that the development of bio-meat (soybeans and other crops processed and flavored with the nutrition and taste of meat) began. Again, the balance between production and consumption is important, but unlike the production of energy, the use of food is not as unbalanced. There remain temporary and regional imbalances, but since humans also belong to the biosystem in the sense that they are living, such imbalances are unlikely to represent a major problem.

Moreover, for humans, animal excrement and food loss (including processing loss) are enormous. In the past, bacteria in the soil worked and cycled biosystems through photosynthesis, but the situation is not as simple today. Today, we actively use fermentation technology to produce methane and other substances, which are then converted into a synthesis of chemical products and energy known as methane fermentation technology. In this case, the waste cannot be completely recycled, but most of it is turned into liquid fertilizer and fermentation gas that can be effectively utilized. However, although this type of recycling is an effective use, the methane gas generated is ultimately converted into CO_2 when it is burned and converted into energy, which does not contribute to decarbonization. This factor represents a core difficulty in the cyclical use of bio-based materials.

What clearly differentiates the circular economy from the traditional cycle of depletable resources is its emphasis on the circulation of biological resources. An early report by the Ellen MacArthur Foundation, which actively promotes the circular economy, describes the famous butterfly diagram [3] as the circulation of artifacts on the one hand and the circulation of biological resources, such as food, on the other. Considering these two cycles is very important and significant, as the biogeochemical cycle is directly related to energy issues and, ultimately, climate change. While it is qualitatively understandable that conventional cycles of man-made resources reduce the energy consumption of human activities and reduce CO_2, a greenhouse gas, it is difficult to understand how and to what extent these resources contribute to the cycle. On the other hand, it is easy to understand that bio-based systems also include food and lead to more direct CO_2 reductions. There are two components to the circulation of bio-based systems: one part that circulates for a short time and one part that circulates for a very long time. Figure 7 shows a slightly modified version of both circulations, leaving both circulations in place but taking into account differences in the time scale. Specifically, to express the difference in time, a logarithm of time was employed on the horizontal axis in Figure 7. Of course, the absolute value of this axis is not necessarily accurate for the activities and phenomena shown in the figure. However, it is well known that the biochemical cycles in the original biosphere occur over a very long-term horizon, and, as discussed below, photosynthetic rates are important when discussing global warming. Thus, it is necessary to consider the time axis since it is unreasonable to assume that all biological cycles function at the same rate as inorganic ones.

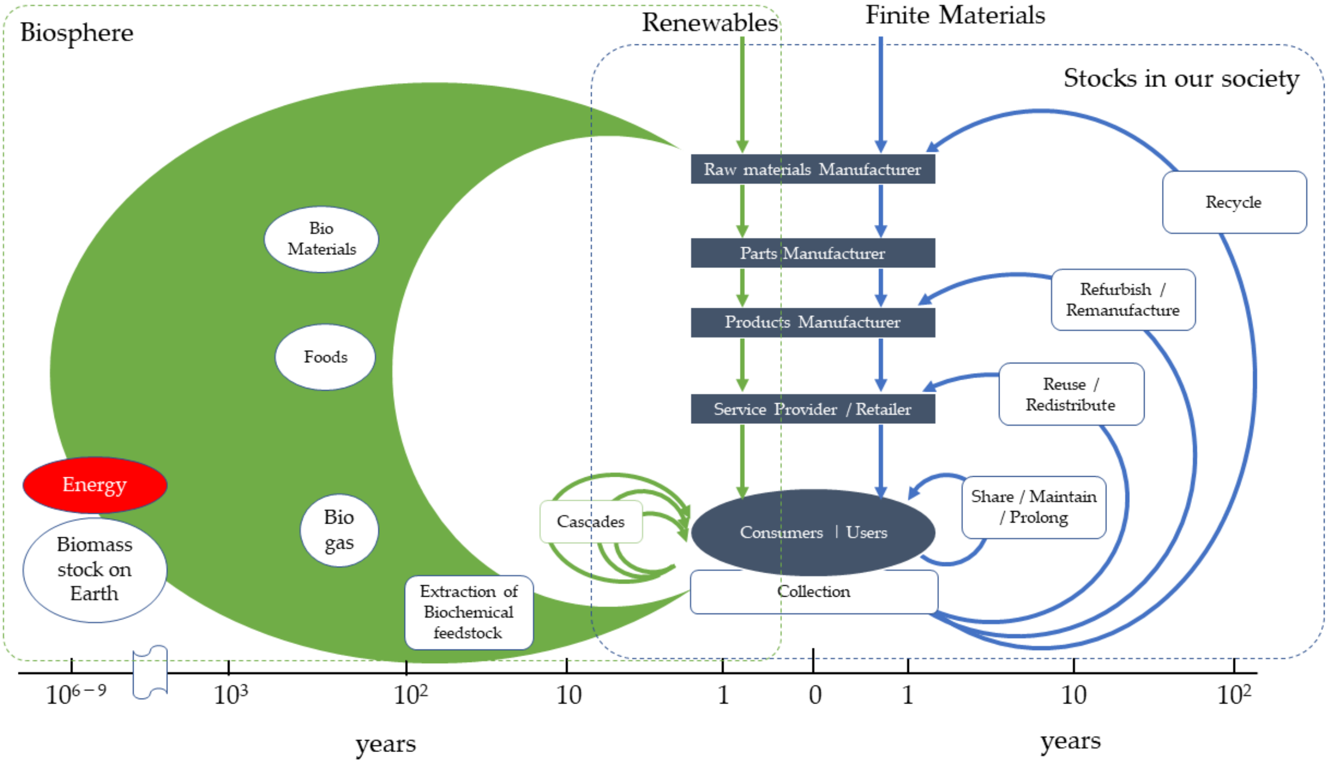

Figure 7. Modified illustration of the CE concept originally produced by Ellen Macarthur Foundation [3].

5. Contribution of the Circular Economy

Based on the above discussion, we offer one suggestion. This suggestion is not particularly new but should be promoted as a high-priority industrial policy.

As generally discussed, renewable energy sources, such as solar power and wind power, are positive to use because they provide the highest quality of relatively direct power in the form of electricity. As mentioned earlier, electricity refers to the motion of the electric charge and is not energy itself; rather, it is an energy carrier. Therefore, electricity must be conserved in order to be used efficiently. This mass conservation of electricity is a key technology for building a decarbonized society. Much research has been done in this area but has yet to yield satisfactory results.

The circular economy cannot by itself yield CO_2 reduction effects. As a review article [22] indicates, even in one circular strategy, the GHG mitigation effect varies and may even have a high risk of backfire effect. We may even consider integrating multiple strategies into one service. Therefore, a new evaluation axis is needed to assess circular economy activities and determine, at a minimum, what kind of energy was used and how much fossil fuel was consumed in the process. Of course, it is not possible to immediately provide an index of such usage for all products, but it is necessary to understand the resources circularity with the help of Material Flow Analysis (MFA) and evaluate the whole cycles using Life Cycle Assessment (LCA) as much as possible.

When performing an evaluation on a small individual scale, it is necessary to examine the whole picture and what it means on a global sustainability.

Once we have reached this point, we will be able to determine the technological issues that humanity needs to tackle with total commitment. In other words, we need to understand the extent to which renewable energy can be used, build social infrastructure based on this understanding, and promote technological development that can be linked to the systems that will make a circular economy possible.

The most necessary technology development process is as follows:

(1) Develop technologies that enable small units (individual homes, buildings, commercial facilities, etc.) to be almost entirely powered by renewable energy;
(2) Examine what carriers can be used to supplement energy between these small units and develop specific technologies for this purpose;
(3) Estimate the energy consumption intensity of larger areas (municipalities, local governments, and the national government), in the above-mentioned development areas in particular;
(4) Develop a system that can ultimately be controlled on a national basis;
(5) Enact fiscal policies to make the above feasible.

It is essential for any organizations to determine which model is suitable for themselves, taking into account its geographical characteristics and political stability, and to present that model and promote activities to support it as much as possible (e.g., linking that model to investments).In conclusion, the Circular Economy could make a significant contribution to carbon neutrality, if renewable energy will be increasingly adopted. However, the introduction of renewable energy itself may demand unprecedented mineral material resources and other resources. At that time, these mineral resources should be covered by recycling, at least in the future. Thus, the introduction of the circular economy and renewable energy are mutually complementary for carbon neutrality and efficient use of resources, and should be continuously expanded while being properly evaluated.

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