Destroying the Earth by Using Tidal Energy

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Abstract

Sciences and technologies have been advanced to a level that they can be used to destroy the Earth, if in a wrong hand. However, you might be surprised to hear that the Earth may also be destroyed by using tidal energy, even with a positive intention!? Consuming tidal energy is actually taking, therefore reducing, the rotational energy of the Earth, which decelerates the rotation speed. Based on current pace of world energy consumption, if we were taking the rotational energy just to supplement 1% of world energy requirements, the rotation of the Earth could be literally stopped in about **1000 years**. As a consequence, one side of the Earth would expose to the Sun for much longer time than it is today. The temperature would be extremely high on this side, and extremely low on the opposite side. The environment would be intolerable and life would be wiped out from the Earth.

Introduction

Global warming has brought awareness to many people as a consequence of consuming fossil fuels. As a clean, renewable alternative, tidal energy has attracted more and more attention. Technologies have been developed and made it possible to collect tidal energy and convert it to electricity to supply the increasing energy requirements for the world's growing economies. However, it might be a surprise to many people that tidal energy is actually **not renewable energy** and using tidal energy will create more severe environmental problems than global warming.

To majority of people today, there is no question that tidal energy is a clean, renewable form of energy.[1-4] Imagine what responses you might face when talking about global warming a century ago. In a presentation to a class of graduate students in 1990, I was exploring energy sources alternative to fossil fuels. Contrary to common belief, I categorized the tidal energy as a form of non-renewable energy. It inspired an overwhelming discussion and I faced lots of challenges. One of the questions I was asked most was: how will consuming tidal energy cause environmental problem? Since then, I was thinking about how to make this issue clear and to help people to abandon the prejudice.

I put together a website on this topic in 1993 when the first web browser Mosaic was just available. The site did not receive much public attention initially until Google indexed the web pages several years later. Emails were sent to me from tidal turbine companies, asking me to take off the web pages since they were not in favor of their businesses.

Unfortunately, the website was not well maintained after I left the school where it was hosted. Googling “tidal energy” today, I was not able to find my pages. In response, I got lots of web pages that still list tidal energy as renewable energy together with other green energy, such as wind and solar power.

On the other hand, as more and more people become aware of global warming, industries have been pressured to search for clean alternatives. Tidal energy has become a favorable option. Now, more than ever, I sensed the necessity and urgency to warn people before it becomes too late.

Collecting Tidal Energy

Tides are the periodical rises and falls of the sea level observable almost any place along the coasts. Tidal energy is a form of hydropower converted from the energy obtained in tides into the useful forms of power, mainly electricity. A simple structure to collect tidal energy is to build an artificial reservoir with barrages.[5] Channels are opened for sea water to flow into the reservoir on the high tides. Gates in the channels can be closed to seize the water behind the barrages, creating the hydraulic water head between high and low tides. During low tides, the potential energy of the water in the reservoir drives hydraulic turbines to generate electricity.

There are also some other technologies that can be used to obtain tidal energy. Tidal stream generators make use of the kinetic energy of moving water to drive turbines, similar to wind turbines.[6] Coastal constrictions, such as straits or inlets, can create high velocity currents at the specific sites, which make it ideal for stream generators.

Dynamic tidal power exploits interactions between potential and kinetic energy in tidal flows. Very long dams are proposed to be built from coasts straight out into the ocean. Tidal phase differences are introduced across the dam, leading to a significant water-level differential in shallow coastal seas, featuring strong coast-parallel oscillating tidal currents such as found in China and Korea.

The world’s first large scale tidal power plant was the Rance Tidal Power Station in France, operation started in 1966. The largest tidal power station is Sihwa Lake Tidal Power Station in South Korea opened in 2011, generating 254 megawatts.

As fossil fuels are being exhausted, large scale and more effective tidal energy stations will be built for the increasing energy requirements. Like global warming, without restrictions, another fatal environmental crisis will be inevitable.

Tidal Formation

Tides are resulted in the rotation/spin of the Earth and gravitational forces from the Moon and the Sun. The combination of these effects produces tidal forces on the two sides of the Earth, pulling ocean water to form bulges, Figure 1. The bulges are stationary with respect to the rotation of the Earth. To a local observer on the Earth, he/she will see the periodical rises and falls of the see level.

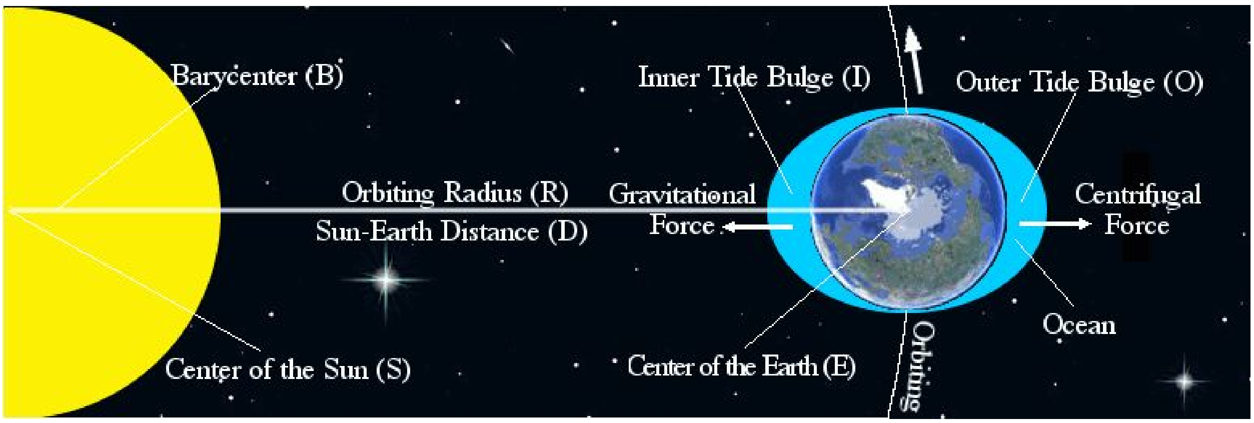

Figure 1: Formation of tides.

First, let's look into the physics of tidal forces. Gravity is the force of attraction between any two objects, given by:

$$F_g = GM_1M_2D^{-2}$$

$\mathbf{F_g}$ is the gravitational force, **G** is the gravitational constant, $\mathbf{M_1}$ and $\mathbf{M_2}$ are the masses of the two objects, and **D** is the distance between the mass centers of the objects.[7] It is this force that pulls the Earth, revolving around the Sun. To make the following discussion easier, let's also examine the centrifugal force. It is an inertial (or virtual) force that appears to act on an orbiting object, pushing away from the revolving center, provided by:

$$F_c = mW^2R$$

$\mathbf{F_c}$ is the centrifugal force, **m** is the mass of the object, **W** is the revolving angular velocity of the object, and **R** is the radius of the orbit.

Consider the Earth revolving around the Sun, Figure 1, viewing from space above the north pole. The Earth is actually orbiting around the barycenter **B**, the mass center of both Sun and Earth. The radius **R** is the distance from the center of the Earth **E** to the barycenter **B**. **D** is the distance between Earth's center **E** and Sun's center **S**, which is a little larger than **R**. The Earth revolves around, not falls onto, the Sun, because the overall gravitational force $\mathbf{F_g}$ is balanced by the centrifugal force $\mathbf{F_c}$. In particular, this is true for a point mass **m** at the center of the Earth: the gravitational force $\mathbf{F_{gc}}$ is equal to the centrifugal forces $\mathbf{F_{cc}}$. Thus, we have the following equation:

$$mW^2R = F_{cc} = F_{gc} = GMmD^{-2}$$

or

$$mW^2R = GMmD^{-2}$$

W is the angular velocity of the Earth revolving around the barycenter **B**. **M** is the mass of the Sun. Now, let's consider a point mass **m** to the inner (or the Sun's) side of the orbit. The revolving radius is **R-r** and gravitation distance is **D-r**, where **r** is the radius of the Earth. The gravitational force $\mathbf{F_{gi}}$ is greater than centrifugal force $\mathbf{F_{ci}}$ for the mass **m**, proved by the following inequality, where the middle portion is the above equation:

$$F_{ci} = mW^2(R-r) < mW^2R = GMmD^{-2} < GMm(D-r)^{-2} = F_{gi}$$

or

$$F_{ci} < F_{gi}$$

The unbalanced force ($\mathbf{F_{gi} - F_{ci} > 0}$), called tidal force, pulls the ocean water toward the revolving center **B**, producing the Inner Tidal Bulge, Figure 1. Similarly, for a point mass **m** to the outer side of the orbit, the revolving radius is **R+r** and gravitation distance is **D+r.** In this case, centrifugal force $\mathbf{F_{co}}$ is greater than the gravitational force $\mathbf{F_{go}}$, as a result of the following inequality:

$$F_{co} = mW^2(R+r) > mW^2R = GMmD^{-2} > GMm(D+r)^{-2} = F_{go}$$

or

$$F_{co} > F_{go}$$

The tidal force ($\mathbf{F_{co} - F_{go} > 0}$) will push the ocean water away from the revolving center **B**, creating the Outer Tidal Bulge. These bulges are stationary with respect to the gravity direction between the Sun and the Earth. As the Earth rotates along its axis, the bulges drift relatively in the opposite direction on the surface, forming high tides to stationary observers on the Earth and low tides in between the high tides. This is known as solar tides.

The Moon also exerts a similar force on the Earth, producing lunar tides. Because the Moon is closer to the Earth than the Sun, the lunar tides are actually more significant than solar tides. At the time when the Earth, Moon and Sun are aligned in a straight line, lunar and solar tides superimpose each other, creating the largest tidal effects, named King Tides.

Earth Deceleration

The rotation speed of the Earth is gradually decreased.[8] To make it easy to understand the process, let's take a look at how car's brakes work. Basically, in a car braking system, Figure 2, there is a rotor disc attached to a wheel and a caliper fixed on the body of the car. On normal driving, the caliper does not touch the rotor and the car moves freely on its wheels. As the brake pedal is pressed, the piston causes the calipers squeeze the rotor disc. The pads inside the caliper create friction that stops the car.

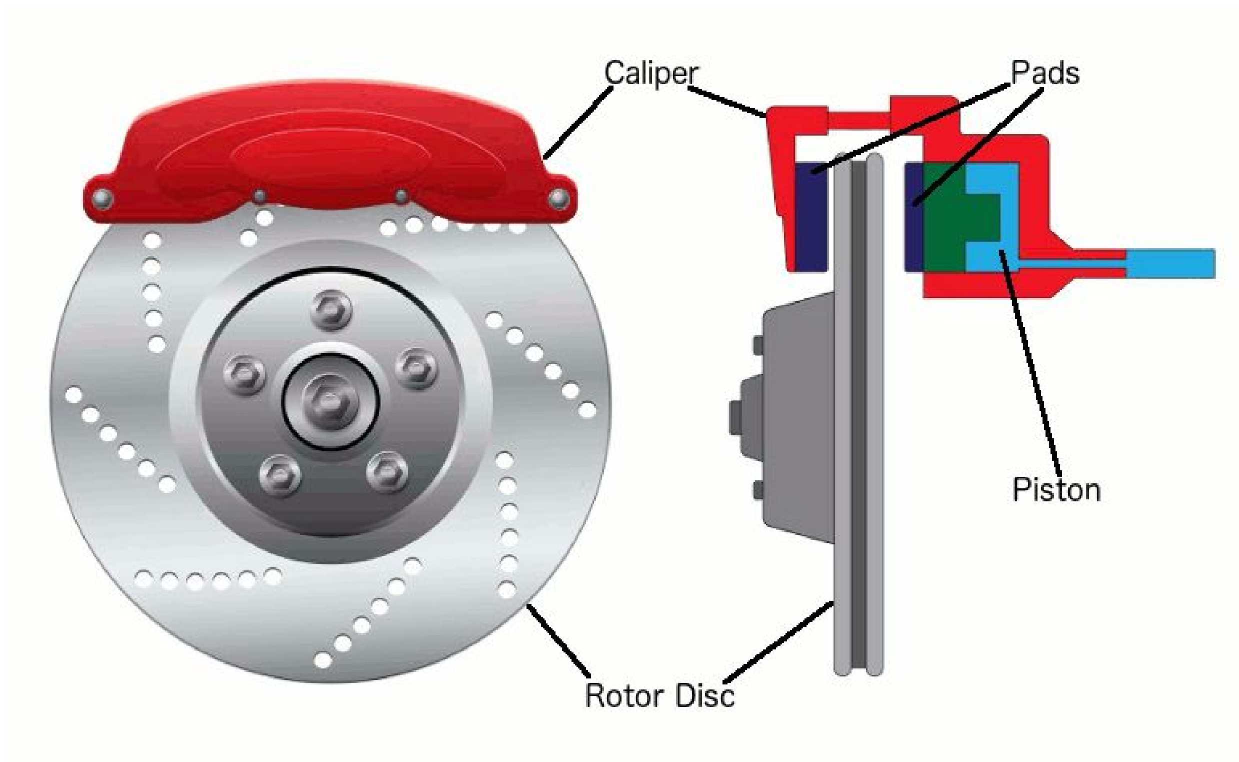

Figure 2: Car Brake System

Now, imagine the spinning Earth as a rotor and the two tidal bulges as stationary brake pads. Let’s assume that the Earth were covered entirely by water body and there were no friction between water and ocean floor. The Earth would rotate freely with respect to the tidal bulges on the surface, just like the free spinning rotor disc in a car. The tidal bulges would not affect the rotation of the Earth, even though there is relative motion between the Earth and the tidal bulges.

In reality, however, there is friction between water and ocean floor as the Earth rotates. The tidal bulges always apply a braking force on the Earth, decelerating its rotation. This model explains the situation in the southern hemisphere. However, in the northern hemisphere, there are continents blocking the travel of the tidal bulges respect to the rotation of the Earth. To understand this sinarior, let’s observe a ball moving freely in a bowl, Figure 3.

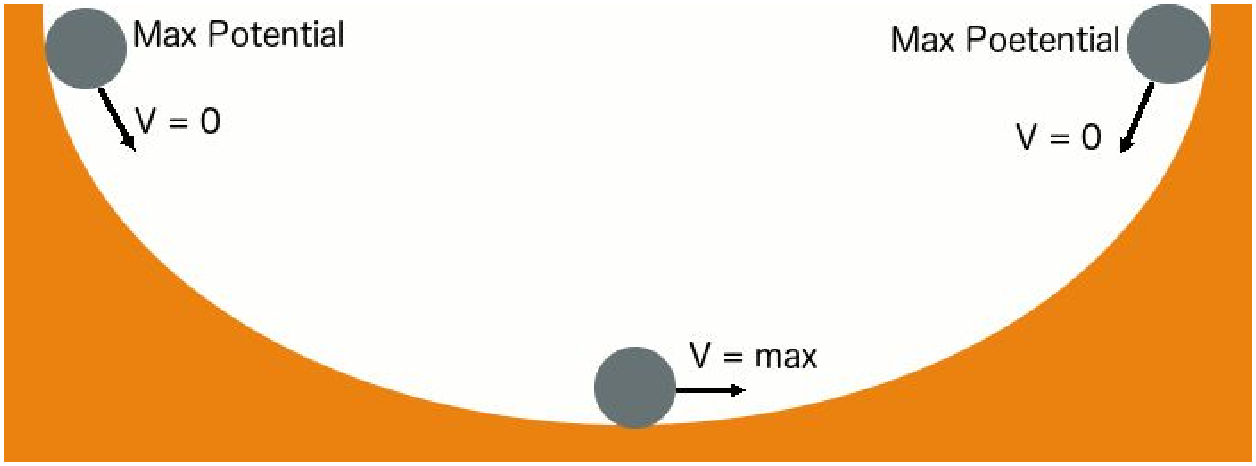

Figure 3: Conservative energy exchange

At the top of the left edge, the energy of the ball is all in the form of potential energy. As it moves down due to the gravity, the potential energy reduces and converts to kinetic energy with increasing speed. At the bottom of the bowl, all the potential energy converts to kinetic energy. The ball reaches the maximum speed. Inertia causes the ball to continue moving to the other side. As the ball moves up, its kinetic energy reduces and restores into potential energy, until all the kinetic energy converts to potential energy at the highest point on the right side. Then, the ball will move back. Without friction, there would be no energy loss in the system, kwond as a conservative system. The ball would oscillate in the bowl forever, where the energy exchanges between potential and kinetic forms.

In the northern hemisphere, the oceans are like huge bowls. Without friction, the water would oscillate in the bowls between high and low tides freely, exchanging the energy in potential and kinetic forms like the ball in Figure 3. There would be no energy loss in the system. The Earth's rotation would not affected in this ideal model.

However, friction exists between water and ocean floor as tidal bulges oscillate in the oceans. The energy in the tides is reduced by the friction and converted into heat that is lost eventually. If the Earth were stop rotation today, without dissipation/supplement of the rotational energy from the Earth, the tidal oscillation would decrease and eventually stop. The fact is that the Earth rotates continuously and tides drain energy from the Earth consistently. As a result, the rotation speed of the Earth is gradually reduced in these natural processes. The number of days in a year has been decreasing.

In addition, there is a tidal acceleration effect that the Earth exerts on the Moon, which transfers Earth's rotational energy to the Moon and causes it moves away from the Earth. This process also decelerates the rotation of the Earth. However, the effect is much less than tides, attributing to about 4% of the energy loss of the Earth's rotation.[9-11]

Tidal Locking

Looking through a telescope, you will notice that the landscape on the Moon's surface is always the same, no matter when you look at it. This is because that one side of the Moon is always facing the Earth. This phenomena is called Tidal Locking, also resulted from tidal effects.[12-13]

Just like the Moon exerts tidal force on the Earth, the Earth also applies a tidal force on the Moon. Even there is no water on the surface of the Moon, the tidal force that the Earth exerts on the Moon also results in tidal bulges to the solid body of the Moon, stretching the Moon into a footballish shape. Scientists call this solid tides. The effect also decelerates the rotation of the Moon. Eventually, the Moon's rotation is decreased to once per orbiting cycle. Thus, one end of the "football" faces the Earth all the time.[14]

At this point, the tidal force prevents the rotation from slowdown or speedup, named tidal locking or gravitation locking. The rotation is synchronous, also known as captured rotation. Similarly, the Earth will gradually decelerate its spin and eventually lock to the Moon. As a result, both of Moon and Earth will be locked face to face, revolving around their common barycenter as a binary system.[15]

Rotational Energy

Just as there is momentum or energy in a moving object, there is also momentum or energy in the rotation of an object. It is called angular momentum or rotational energy, which is a form of kinetic energy. The total rotational energy of the Earth is about **2.138×10^{29} Joules**.

To estimate the rotational energy for the Earth, we need to find out the moment of inertia of the Earth, first. The moment of inertia **I** for a solid ball can be calculated using this formula:

$$I = 0.4MR^2$$

R is the radius of the ball. Average radii of the Earth are about 6.371×10^6 meters.[16] **M** is the mass. Current best estimate for Earth's mass is 5.9722×10^{24} kilograms.[17] A simple estimate for the moment of inertia using the about formula would be 9.696×10^{37} kgm^2. However, the formula above applies to a homogeneous ball. The Earth is not homogeneous: inner martials are heavier than outer martials due to gravity and convection inside the Earth. The actual Earth's moment of inertia should be less than this estimate. A more accurate estimate for Earth's moment of inertia is 8.04×10^{37} kgm^2. Now, we are able to compute the total rotational energy for the Earth given by:

$$E = 0.5W^2I$$

E is the rotational energy and **W** is the angular velocity. The rotation period of the Earth is 23.93 hours, or an equivalent angular velocity of 7.29×10^{-5} rad/s. Put the moment of inertia 8.04×10^{37}

kgm^2 into the equation and we come to the total rotational energy of the Earth 2.138×10^{29} Joules.

How Much Time Left

When a car is braked, the kinetic energy of the car is lost into heat generated by the friction between the rotor disc and the brake pads. Similarly, the rotational energy of the Earth is also gradually dissipated into heat from the friction between tides and ocean floors. Given that there is a finite amount of rotational energy in the Earth, it will be depleted over a **billion years** as estimated next. So, the self rotation of the Earth will be stopped eventually in its natural process.

Here is a simple way to roughly estimate the decreasing rate of the Earth's rotational energy. Like the growth rings in a tree, there are also seasonal and daily growing patterns in coral reefs due to the rhythm of seasonal and daily change in light and nutrition supply in the ocean. Studying fossil reefs early and middle Silurian (444-419 million years ago), scientists discovered that there were 420 days in a year. The number of days per year in early Middle Devonian Period (419-358 million years ago) was 410. Similar researches through preserved fossil corals indicate there were 385 days per year in the early Carboniferous period, 350 millions years ago. More paleontological researches in this aspect can be found in Deines and Williams' publication.

For the last 400 million years, there is no evidence of significant changes in Earth's mass and orbit. So, it should be safe to assume that there is not much change in Earth's revolving period. Based on the above researches, let's consider that there were 420 days in the year around 430 million years ago. So, the angular velocity of the Earth at that time can be computed, 8.39×10^{-5} rad/s. Thus, the total rotational energy estimated using the formula described above was 2.83×10^{29}Joules. With the current rotational energy estimated above (2.138×10^{29} Joules), we found that there were 6.92×10^{28} Joules energy loss in the last 430 million years, or on average 1.73×10^{20} Joules per year.

At this rate, the current rotational energy (2.138×10^{29} Joules) will be depleted in 1.24 billion years. This is clearly an aggressive estimation because the depleting rate should decrease as the rotation speed of the Earth reduces. This number should be larger. Therefore, it should be safe to state that it takes more than a billion years for the Earth to cease the self rotation. In this case, there should be enough time for future generations to figure out solutions to prevent this catastrophe from happening.

Only 1000 Years Left

However, the story will be totally different if we are going to consume tidal energy in any form. As soon as we are tapping the tidal energy, the slowdown process will be accelerated. If we were taking the tidal energy just to supplement 1% of the world energy consumption, the self rotation of the Earth would be literally stopped in about **1000 years**.

To estimate the time, let's revisit the system in Figure 3 above. Without friction, there were no energy loss and the ball would oscillate in the bowl forever. Imagine, the ball is a bucket of water. At one side, the water is guided through a channel into a hydraulic turbine and the potential energy is used to generate electricity. Afterwards, the water is returned through a channel back to the bottom of the bowl. If the system is so efficient that all the potential energy is converted to electricity, the water reaches the bottom without any kinetic energy to move up to the other side. Otherwise, if the energy was not completely consumed, the remaining kinetic energy will move the water up to the other side, but not as high as in the previous time because part of the energy has been used in electricity generation. This effectively is the same mechanism employed as in a tidal power collection system. Energy does not come from nowhere. Every watt of electricity generated by tidal turbines comes from the energy in the tides that in turn is transferred originally from the rotational energy of the Earth.

Now, let's estimate how fast we can drain the rotation from the Earth. The world energy consumption was about 5.67×10^{20} Joules in 2013.[18] This number increases by more than 2% per year on average in the last 50 years. Average world's economy growth rate in the last 50 years was about 3%, which requires a corresponding increasement in the energy supply. So, the 2% growth rate for the world energy consumption should be a conservative estimation.

Based on this pace of the energy consumption, if we were tapping the tidal energy to supplement 1% of the world energy requirements, which is 5.67×10^{18} Joules, the total rotational energy of the Earth would be reduced in the next **N** years by this amount:

$$5.67 \times 10^{18} \times (1.02^1 + 1.02^2 + 1.02^3 + \ldots + 1.02^N)$$

or

$$5.67 \times 10^{18} \times (1.02^{N+1} - 1.02) / 0.02$$

At this rate, the current rotational energy of the Earth (2.138×10^{29} Joules) would be depleted in **1031 years**. Although, this is an very rough estimation, it demonstrates how fast we could decelerate the rotation of the Earth.

In The End

The Earth and the Moon will be eventually tidal locked into each other. The Earth will rotate at the same angular speed as its revolving velocity around the barycenter of the Earth-Moon system. A day on the Earth will be the same as a Month.

Due to the tidal acceleration, the Moon moves away from the Earth at a speed of 38.247 minimeter per year. This will increase the moment of inertia for the Earth-Moon binary system, and therefore, will reduce their orbiting speed. The time for a month will be longer than it is today. Thus, there will be fewer months, or less than 12 days (or months), in a year.

By that time, one side of the Earth will face the Sun for a long time, e.g. 30 times longer than it is today. The temperature on the surface will be raised very high, while the temperature on the opposite side will be extremely low. Most of the life on the Earth today will not be able to tolerate that extreme temperatures. The huge temperature difference between the two sides of the Earth will create pressure gradient, that in turn drive the air, resulting strong current. There will be huge storms all the time. The environment on the Earth will be intolerable. Life may be extinct.

Conclusions

Driven by the world's fast growing economies, industries are capable of developing efficient machineries and structures that can deplete the rotational energy of the Earth, therefore destroy the world, much faster than natural processes. In hundred years ago, no one had ever questioned that we could cause the global warning. The real problem today is that majority of people have not realized the potential danger and still believe tidal energy is renewable. So, heads up! To save the would, please do not use tidal energy, thus, to give enough time for future generations to avoid the catastrophe.

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