Planet Earth

We only have one planet. We should thus be careful with it. In this chapter, we're going to look at how our planet is doing.

1 Basic principles of sustainability

What does sustainability actually mean? And how do we accomplish it? We will first exam these basic ideas.

1.1 Sustainable Development

Sustainable Development (SD) is a development that meets the needs of the present. However, it also makes sure that future generations can meet their needs. To achieve a Sustainable Development, we should aim to reach an **equilibrium**. The load we put on our environment should be equal to its ability to recover from it.

An important principle for SD is the **precautionary principle**. Let's suppose there is some action or policy that might cause serious harm to the public. The precautionary principle now states that those in favor of the action/policy need to prove that it's safe. In other words, you can better be safe than sorry.

1.2 Ideas of sustainability

The Earth may seem like something that has always been present, and will always be present as well. But when you go up into space, your view on matters will change. You will see that not space is unique, but the Earth is. It is our space ship, and we need to take care of it.

At the moment, we're more or less destroying our own Earth. This needs to change. To accomplish this, everyone should want to change. The basic idea behind the change is to work with nature, rather then against.

2 Keeping the Earth in balance

The Earth is a unique planet. Its temperature is ideal to support life. It would be nice to keep this temperature level in balance. What factors influence this level?

2.1 Energy entering and leaving our planet

The sun emits a lot of light towards planet Earth. This light arrives with an intensity (called the **solar intensity**) of $S_0 = 1372 W/m^2$. Planet Earth has a reflection of approximately $\alpha = 30\%$. (This is called the **albedo**.) It thus absorbs 70% of S_0, which is $960 W/m^2$. We can even say that, in total, our planet absorbs

$$E_{in} = (1\alpha) S_0 A_{sun} = (1 - \alpha) S_0 \pi R^2, \tag{2.1}$$

where A_{sun} is the area which is shined on by the sun. Also, $R = 6371 km$ is the Earth radius.

Our planet doesn't only absorb energy. It also emits it. The total outgoing energy is given by **Boltzmann's law**. It states that

$$E_{out} = \sigma T^4 A_{earth} = \sigma T^4 4 \pi R^2, \tag{2.2}$$

where A_{earth} is the surface area of the Earth, and T is its temperature. Also, $\sigma = 5.670 \cdot 10^{-8} W/m^2K^4$ is **Stefan's constant**. If we equate $E_{in} = E_{out}$, then we would find that the **equilibrium temperature** of the Earth is $T_{eq} = -18°C$. Luckily, this isn't the actual temperature of our planet. This is because of the **greenhouse effect**.

2.2 The greenhouse effect

To see how the greenhouse effect works, we need to examine the way our Earth is heated. First, we receive electromagnetic waves (which include visible light) from the sun. These waves occur mainly in the visible spectrum. Since our atmosphere is transparent for these waves, they can reach the planet's surface, thus heating it.

The Earth also emits radiation back into space. However, this radiation mainly occurs in the infra-red part of the spectrum. And our atmosphere can absorb this kind of radiation. Most of the radiation thus doesn't make it into space. It only warms up the atmosphere, which, in turn, warms up the planet surface again.

The greenhouse effect isn't necessarily bad. Without it, we'd have a temperature of $-18°$. However, we can insert too many greenhouse gases into our atmosphere. (**Greenhouse gases**, like **carbon dioxide** (CO_2), cause our atmosphere to absorb even more infra-red radiation.) If we do this, the planet's temperature will increase. And that's not very good, since it may cause our climate to change.

2.3 Climate change

The term **climate** refers to the the average state of our environment. If we talk about **climate change**, we mean the variation of this climate over time. We only take into account long-term variations, spanning at least a few decades. A specific example of climate change is **global warming**.

To prevent climate change, the **United Nations Framework Convention on Climate Change** (UNFCCC, or shorter, FCCC) was created. It is an international environmental treaty. Almost all countries on Earth have agreed upon it. (Sadly, the USA tends to be rather stubborn.) Its goal is to achieve the right level of greenhouse gas concentrations in the atmosphere.

There is also the **Intergovernmental Panel on Climate Change** (IPCC). The task of this panel is to examine the risk of climate change, caused by human activity. The IPCC does not carry out research itself. Instead, it publishes reports, based on published scientific literature. The most important conclusion of the IPCC, is that the temperature of the Earth is increasing. This temperature increase then causes all sorts of bad effects.

2.4 Natural causes of climate change

Let's ask ourselves, what natural phenomena can cause climate change? The **Milankovitch Theory** describes some of these causes. It states that climate change is caused by changes of Earth's orbit. This happens in multiple ways. First of all, the eccentricity of our orbit changes periodically. The Earth rotation axis (with respect to the orbital plane) also shifts slightly over time. Finally, Earth's orbit is subject to a minor precession (rotation in the orbital plane). All these changes occur periodically. Earth's climate thus also changes cyclically.

Next to the Milankovitch Theory, also other causes of climate change are known. The **continental drift** is known to cause climate changes as well. As the continents shift, the Earth can reflect more/less radiation. This thus shifts the Earth's energy balance.

The Milankovith Theory and the continental drift both cause long-term climate changes. There are also short-term natural climate changes. These are mainly caused by variations in the solar intensity. This, in turn, is often caused by so-called **solar spots**. Finally, big **vulcanic eruptions** and **large scale weather systems** (like El Niño) are also known to cause climate change.

2.5 Human causes

Not all climate changes are caused by natural phenomenon. Humanity also influences the climate. We do this in many ways. Sadly, most of these ways aren't understood.

However, one cause of climate change that is understood, is the greenhouse effect. In previous centuries, the concentration of greenhouse gases used to be a steady $280PPM$. (PPM means parts per million.) However, over the past century, this concentration has risen to $390PPM$. This rise has caused the average temperature of the Earth to rise by almost an entire degree Centigrade.

3 Monitoring planet Earth

To know how to save the Earth, we first need to know what's wrong. We thus need to observe the Earth. To accomplish this, several projects are currently active. (Is the Ozone hole growing? How is El Nino doing? Are the rain forests and the ice caps still shrinking?) But how do those projects work? How do we acquire data about our environment?

3.1 Going back into history

There are many ways in which we can find out something about the history of our environment. Of course, there are scientific records for the past century. But if we want to have data about our world centuries, or even millennia ago, we need different methods. If we are only interested in a few centuries, we can examine **tree rings** and **plant remains**. If, however, we want to go back several millennia, we have to examine **isotopes** and **fossiles**.

3.2 Detecting water isotopes

Let's consider an example. We will examine water. Water has one oxygen molecule O and two hydrogen molecules H. It is thus described by H_2O. Usually, H has an atomic weight of $1u$ and O an atomic weight of $16u$. H_2O thus weighs $18u$. However, some water molecules (about 0.21%) have an O atom with an atomic weight of $18u$. (This atom has two more neutrons.) We call this variant the ^{18}O-variant. (It is also possible for water molecules to have a ^2H deuterium atom. The working principle for this is the same. We won't consider this specific case though.)

There is a way to find the percentage of ^{18}O-variant molecules. To do this, we use a **mass spectrometer**. The working principle of this is as follows. First, we ionize the molecules, so they become HO^-. (They lose a hydrogen atom.) We then send a beam of these ionized water molecules into an electric field. This field bends the trajectory of these particles. The ^{16}O-variant and the ^{18}O-variant have the same charge. So the same Lorentz forces are acting on them. However, the ^{18}O-variant is more heavy than the ^{16}O-variant. It therefore bends off less. In this way, the percentage of ^{18}O-molecules can be found.

3.3 The meaning of the water isotopes

You may wonder, what's the use of examining water isotopes? To find that out, we define

$$\delta^{18}O = \frac{\left[\text{Percentage } ^{18}O\text{-variant in vapor}\right] - \left[\text{Percentage } ^{18}O\text{-variant in water}\right]}{\left[\text{Percentage } ^{18}O\text{-variant in water}\right]}. \tag{3.1}$$

Usual values for the above equation are

$$\delta^{18}O = \frac{0.208\% - 0.210\%}{0.210\%} \approx -0.01 = -1\% = -10 \text{ promille.} \tag{3.2}$$

In general, we have $\delta^{18}O < 0$. Now let's ask ourselves, why? To find that out, we look at the energy of a molecule. It is given by

$$E = \frac{1}{2}kT = \frac{1}{2}mV^2, \tag{3.3}$$

with k a constant, T the temperature, m the mass and V the velocity. The temperature (and thus the energy) of the molecules in a fluid is generally equal. So we must have

$$\frac{1}{2}m_{16}V_{16}^2 = \frac{1}{2}m_{18}V_{18}^2. \tag{3.4}$$

The ^{18}O-variant has a higher mass. So it must have less velocity. It thus escapes less easily from water. This means that it evaporates less easily than the ^{16}O-variant. This explains why $\delta^{18}O$ is negative.

Now let's examine the effects of temperature. If the temperature T increases, also the velocities of the molecules increase. At these high velocities, the difference between V_{16} and V_{18} is less important. So the two variants evaporate at a more equal rate. This means that the magnitude of $\delta^{18}O$ is smaller for high temperatures. $\delta^{18}O$ is therefore (relatively) highly negative on the poles.

By using this trick, we can find the temperature of our planet over the past centuries. Every year, layers of snow are forming on the poles. As these layers are compressed to ice, small bubbles of air are trapped in them. Both the snow and the trapped air have a set value of δ^{18}. We can then drill up several layers of ice from the poles. For every layer, we can then find the temperature at the time the layer was formed.

Next to using surface ice, it is also possible to use **ocean sediments**. You then have to start drilling in the ocean floor.

3.4 Using carbon contents in plant remains

Let's suppose we find plant remains. How do we know how old they are? To do that, we can use a method called **carbon dating**. In the atmosphere is not only the normal ^{12}C carbon variant, but also ^{14}C. The isotope ^{14}C is radioactive, but it decays only very slowly.

A living plant, being in contact with the atmosphere, has the same $^{14}C/^{12}C$ ratio as its surroundings. However, when a plant dies, it won't replenish its supply of ^{14}C anymore. Over time, the ^{14}C is subject to radioactive decay. The $^{14}C/^{12}C$ ratio will thus decrease. This happens in a negative exponential way. From this ratio, scientists can derive how long ago the plants have died.