FIVE ASPECTS OF CLIMATE CHANGE REGARDING SUSTAINABILITY

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Selected aspects of global and regional climate change, including response by society and education are tackled. They answer to the following five questions: Does climate system respect the GAIA-hypothesis? Shall we expect more extreme events? Has energy- and carbon efficiency been increasing in Hungary? Does global warming affect our renewable energy potential? Can we support sustainability educating of and by climate change? The answers given by the study are: Several processes do not. Not all, for sure. Yes, considerably. Yes, but not too strongly. Yes, in both directions. Eight figures and three tables are included.

Keywords: GAIA-hypothesis, extreme events, Kaya-identity, renewable energy, education

Introduction

Recent climatic changes enhance the challenges of sustainability. Any long-term change would do so, but, as the scientific climate projections indicate, they will hardly be either advantageous, or quantitatively predictable, especially at the regional and local scales. The present study will tackle the following eight aspects of climate and sustainability:

- Does climate system respect the GAIA-hypothesis?
- Shall we expect more extreme climate events?
- Does global warming affect our renewable energy sources?
- Is energy- and carbon efficiency increasing in Hungary?
- Can we support sustainability by education of and by climate change?

The first two questions deal with climate science, followed by two ones related to the response by society. The last question is special, as education establishes the basis for the next generation's response. The paper is an essay, reflecting the authors' ideas in the questions.

Does Climate System Respect the GAIA-hypothesis?

The Gaia-hypothesis (Lovelock, 1972) postulates that the Earth is a self-regulating *system*, called Gaia (the ancient Greek goddess of the Earth), which tries to keep the physical and chemical environment optimal for contemporary life via biological and geological processes.

However, there are several processes in the climate system, which do not support this hypothesis in case of the present and future global warming. For example, cloudiness was considered as key regulator of our climate, for many years, keeping it stable through its effects on the atmospheric radiation balance. But, as *Figure 1* indicates, cloudiness expresses positive, i.e. enhancing feedback on the global mean temperature.

Spatial details of this behavior are seen in *Figure 2,* showing the expected changes of cloudiness. At the law and lower temperate latitudes, where the solar radiation is larger than the outgoing long-wave irradiation by the surfaces and clouds, decrease of cloudiness means even more radiation income, i.e. further warming the surface-atmosphere system. On the other hand, at the high and higher temperate latitudes, where cloudiness is increasing according to the models, steep rays of the Sun and the high initial amount of cloudiness make the incoming radiation smaller than the outgoing radiation. Hence, in these regions the increasing cloudiness means more energy retained by the system, i.e. further warming, again.

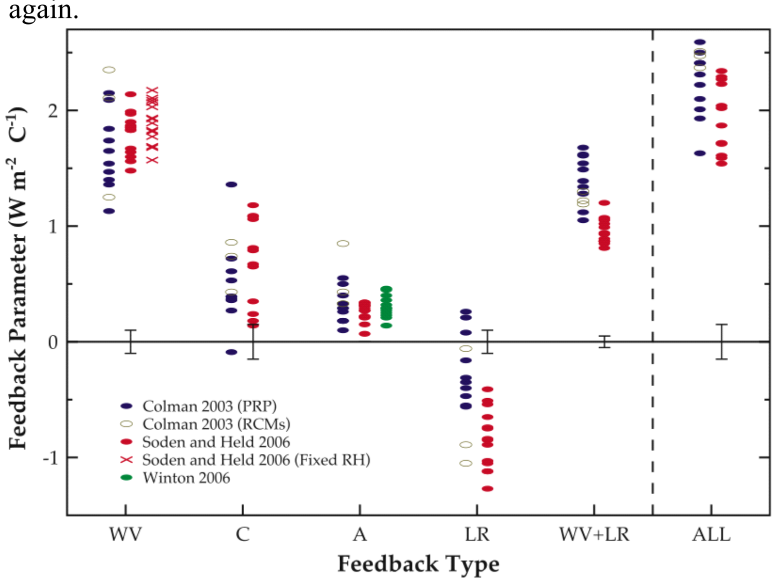

Figure 1. Effects of the key feedback mechanisms on the sensitivity parameter of climate. Data obtained from IPCC, 2007: Fig. 8.14.

Note. (λ) in the equation $\Delta Q = - \lambda \Delta T$, where ΔT is the change of the global mean temperature caused by the ΔQ modification of the Earth's radiation balance. Without any atmospheric feedback mechanisms, $\lambda = -3.2$ W $m^{-2}C^{-1}$. The involved feedbacks are the so called water vapor- (WV), cloud- (C), surface albedo- (A) and lapse rate (LR) feedbacks.

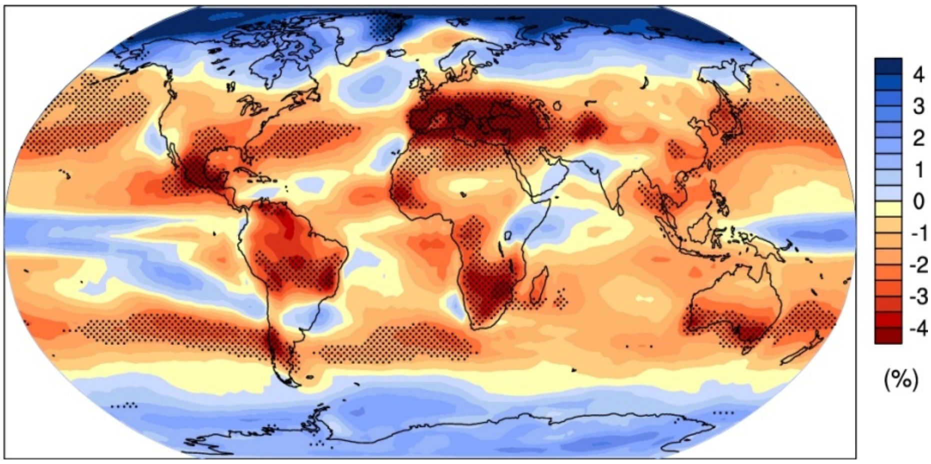

Figure 2. Average the projected changes in cloudiness (%) derived from the GCM results. Data obtained from IPCC, 2007: Ch. 10, Supplement.
Note. Areas of significant changes, compared to the inter-model variance, are marked by points.

Both figures exposing cloudiness are results of global climate models. But, are we sure that they are convincingly good to support so complex questions? *Fig. 3* shows the strongest argument for this statement. The observed variations of the global mean temperature are successfully simulated by the 14 global climate models, reproducing the past changes under influence of all known anthropogenic and natural climate forcing factors. But, if leaving out the anthropogenic ones, i.e. allowing just natural factors, like volcanic eruptions and solar activity to act, this simulation clearly departs from the fact. So, warming of the recent half-century was mainly driven by the anthropogenic factors.

Correspondence between the observed and simulated curves proves that global climate models simulate the climate changes fairly well at the global and continental scales. This is also the basis for further considerations on regional features and effects of future warming, as well as for the response by the society, i.e. adaptation to and mitigation of the changes. The IPCC (2007) states that anthropogenic origin of the recent 50 years is "very likely".

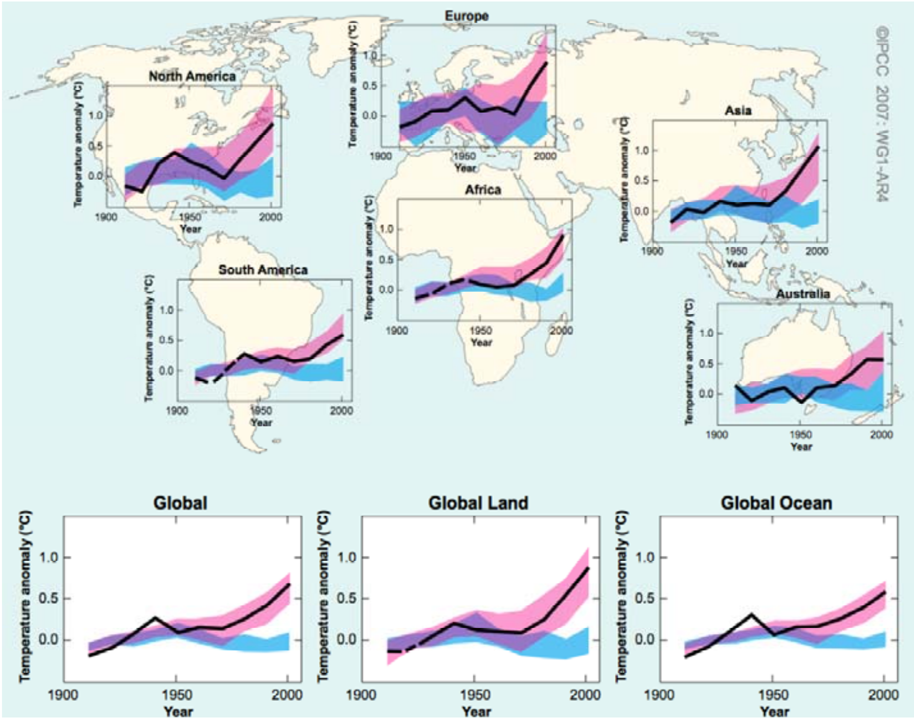

Figure 3. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by the climate models. Data obtained from IPCC, 2007: FAQ 9.2, Figure 1.
Note. Decadal averages of observations for the period 1906–2005 (black line) run parallel to the model runs using both natural and anthropogenic factors, but they definitely depart from those using only the natural forcing factors.

Of course, effect of cloudiness is neither biological, nor geological process, but after the recent IPCC (2007), two further positive feedback mechanisms of these categories became known. Weakening biological (and oceanic) sinks has lead to higher airborne fraction of the emitted CO_2, as it is seen in the right part of *Figure 4*. At the same time, the land-use changes have not contributed to stronger emission (*Figure 4b),* as they are slightly decreasing since 1990. The emission is dominated by the fossil fuels.

For the counter-GAIA geological processes, we can refer to the melting of permafrost, locking huge frozen carbon reservoirs (Bloom, et al., 2010). As large parts of permafrost became melted in the recent years over the Northern Hemisphere, the methane emission have been increasing, again, from ca. 2007, after a few years' stagnation since the turn of centuries.

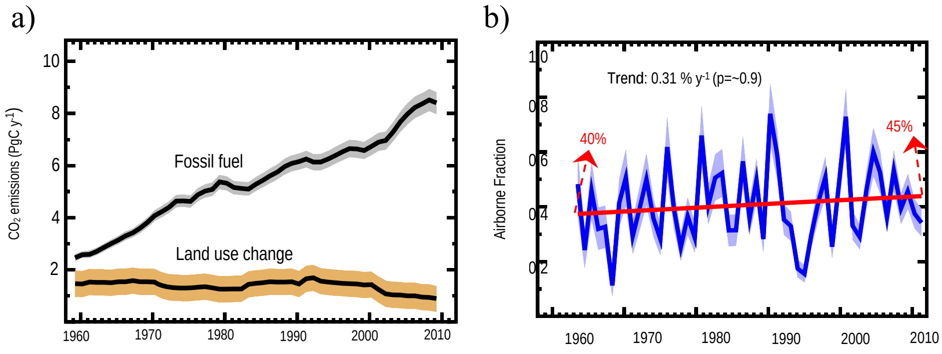

Figure 4. Trends in fossil fuel vs. land-use forms of anthropogenic CO_2 emission (a) and the fraction of CO_2 remained in the atmosphere (b) in 1960-2009. Data obtained from Global Carbon Project, 2010.

Shall We Expect More Extreme Climate Events?

There is little doubt that society has become more sensitive to extreme weather, since population and infrastructure continues to grow in areas vulnerable to weather and climate extremes. As it is seen in *Figure 5*, weather extremes play a sorrowful important role: The reasons not related to meteorology cause 31% of economical losses, but 55% of fatalities at the global scale. In Europe these numbers are 20 and 23%. Globally wet storms are the most dangerous (25% in the losses, i.e. equally dangerous with the floods, and 34% considering the deaths), whereas in Europe the storms (32%) and the hydrological extremes (25%) cause the most losses, but 55% of the fatalities were caused by the heat waves.

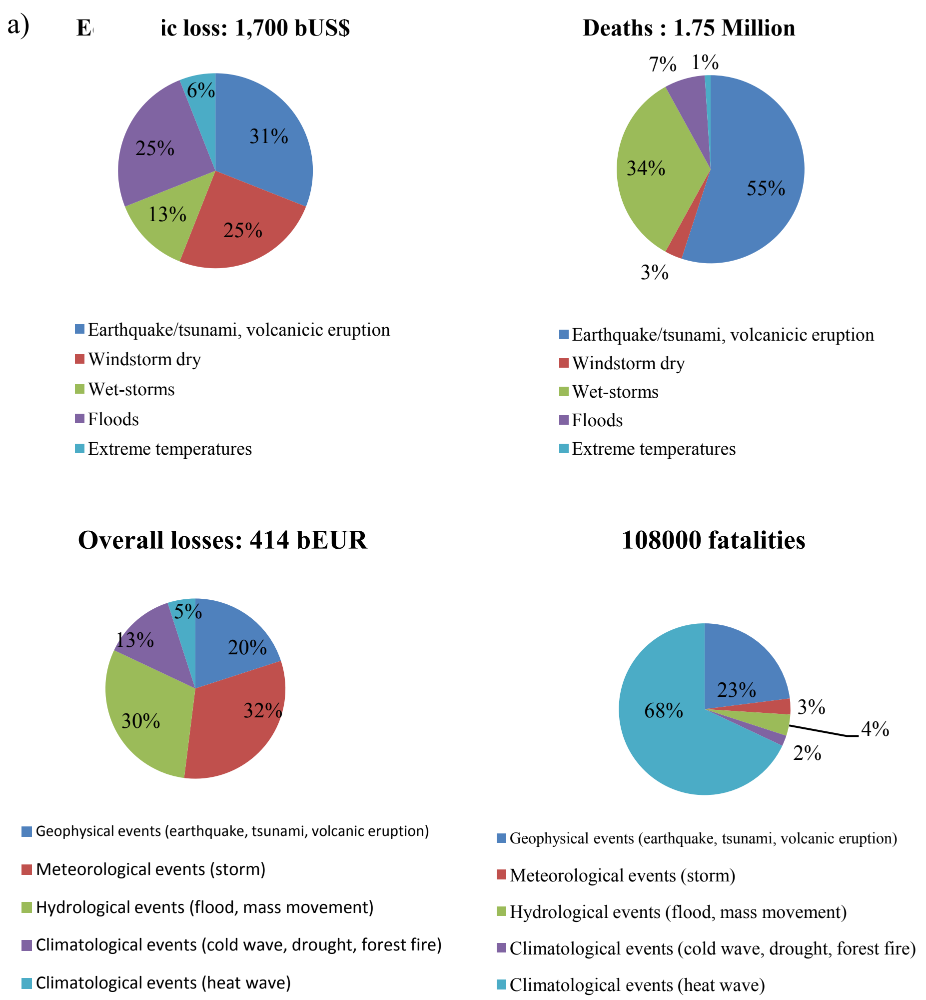

Figure 5. Relative distribution of economical loss (left) and number of fatalities (right) caused by natural disasters: a) Global mean in 1950-2005 (Hoeppe at al., 2006); b) Europe-mean (EU+5 countries) 1980-2009 (EEA, 2010).
Note. The grey-scaled colors, arranged in clock-wise order in the diagrams, correspond to left-to-right and up-to-down order in the legends.

The main question concerning the meteorological extremes is if the extremes become more frequent and more severe parallel to the global warming. Some statistical and physical considerations suggest that a warmer climate bears more meteorological extremes than the present one. Let us briefly survey these arguments (Mika, 2012).

Statistical considerations concerning the extremes: Frequency of an extreme event can generally be enhanced under climate change for two reasons. When the whole distribution is shifted to one direction, with no change in its variance, then the extremes of this direction become more frequent, whereas the opposite extremes become rarer. In the second case, when variance of the distribution changes with no shift in the mean, frequency of extremes on both sides moves in the same direction. Parallel occurrence of the two causes is of course, possible.

Physical considerations. Some physical processes support the hypothesis of increasing extremities parallel to global warming, but some others definitely question that. The most frequent argument for the more intense extremes is the increased energy content of the climate system, including the atmosphere. Having more thermodynamic energy in the whole system, the energy may be more easily cumulated in a given atmospheric object and region. Another reasonable assumption is that in a warmer world, water vapor content of the air is increasing, hence more latent heat may turn into kinetic energy. A third experience is that in a warmer world the average lapse rate is higher, which in turn supports formation of convective systems. Other considerations, however, may lead to less intensive extremes. For example, the experience that the high-latitudes warm faster than the lower latitudes project smaller horizontal temperature- and pressure-gradients in the process of global warming-up.

Both modeling and statistical approaches of estimating present or future trends of one or the other kinds of meteorological extremes have various methodological problems (Mika, 2012). However, there are some extremes tendency of which is generally accepted by the climate scientists. *Table 1* displays these major extreme events, indicating the 20th century tendencies and likelihood of the future trends. It indicates „warmer and fewer cold days and nights", as well, as „warmer and more frequent hot days and nights", over most land areas. Both statements are assessed "very likely" with over 90% of probability concerning their 20th century trends. For the future, continuation of the trends is virtually certain (99%). Heavy precipitation events at the temperate latitudes and increase of drought affected area are likely in many regions since the 1970s. Continuation of this process in the 21st century is "likely".

Recently, the IPCC SREX Report (2011) mainly approved these statements. E.g., for Central Europe they indicate 4-6 times more frequent occurrence in the thermal and ca. 1,5x in the precipitation extreme by 2045-2065, depending on the assumed emission scenario.

Table 1
Recent trends and projections of extreme weather events.

Phenomenon and direction of trend	Likelihood that trend occurred in late 20th century	Likelihood of trends projected for 21st century)
Warmer and fewer cold days and nights over most land areas	*Very likely*	*Virtually certain*
Warmer and more frequent hot days and nights over most land areas	*Very likely*	*Virtually certain*
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*Very likely*
Heavy precipitation events. Frequency mostly increases	*Likely*	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)	*Likely*	*Likely*

Note. Table adapted from IPCC(2007) Tab. SPM-2.

Is Energy- and Carbon Efficiency Increasing in Hungary?

Emission of CO_2 is a product of four general components according to identity by Kaya (1990):

$$CO2 = Pop \times (GDP/capita) \times (TPES/GDP) \times (CO2/TPES) \qquad (1)$$

They are: number of people on the Earth *(Pop);* average well being of humans (*GDP/capita)*; mean energy required to create one USD *(TPES/GDP)* and mean CO_2 emission required to produce a unit amount of energy *(CO2/TPES).*

As it is seen in *Figure 6*, the product of the first two components is increasing much faster than the already ongoing decrease of the third and fourth components. Though, it is also interesting, that the latter two components started to decrease far before climate-, or environment-awareness, due to technological development.

The options for reducing the CO_2 emissions include: reduction of energy use through increased end-use energy efficiency; replacement of fossil fuel with renewable energy sources; reversal of the current deforestation trend; shift of the fossil fuel mix from high- to low- CO_2 emitting fuels; and disposal of CO_2 beneath the Earth surface.

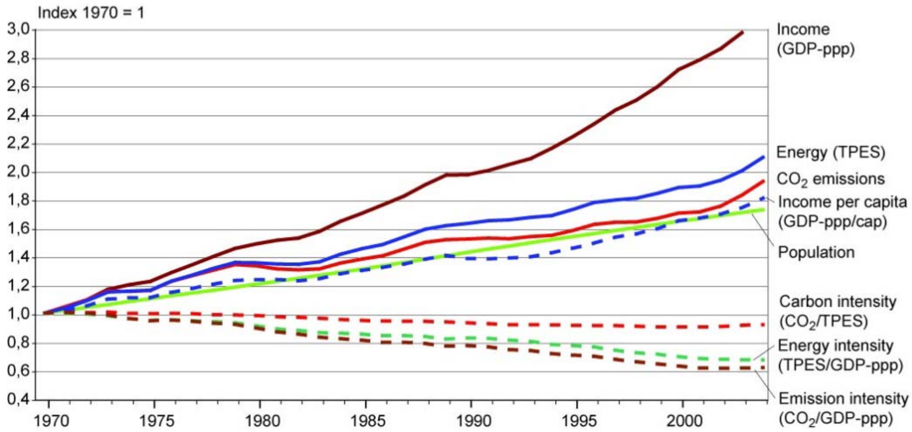

Figure 6. Trends in the components of CO_2 emission, according to Eq. 1, 1970-2004. Adapted from IPCC WG-III (2007) Fig. 1.5.
Note. In the right-side subscripts ppp stands for 'Purchasing power parity' at 2000 prices.

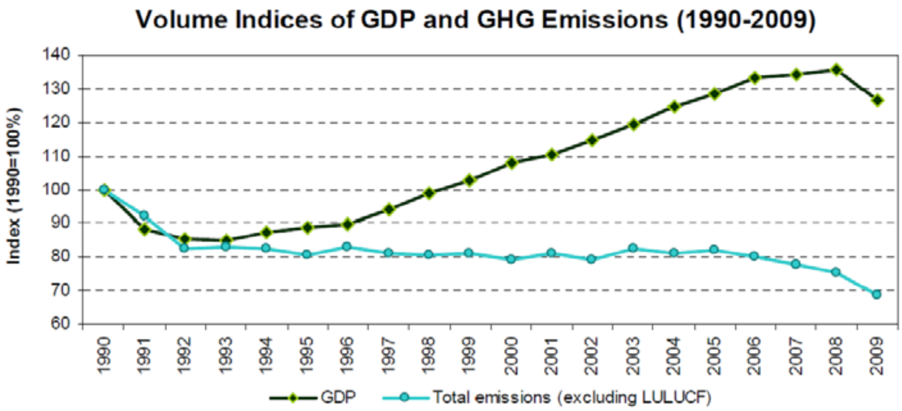

Figure 7. Comparison of trends in GDP and GHG emissions in Hungary in 1990-2009. National Greenhouse Gas Inventory (2011) Retrieved from http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/5888.php)

We do not know data on these possible factors for Hungary, but, as *Figure 7* indicates, the latter two factors of Eq. (1), i.e. product of energy intensity and carbon-intensity have been improved since the mid-1990s. The Figure shows strong decoupling between the GDP (1-2. components of Eq. 1) and GHG-emissions. One must add that in 2009 proportion of CO_2 was 75 % in the total greenhouse-gas emission, even excluding the biospheric emission.

Does Global Warming Affect Our Renewable Energy Potential?

The ongoing climate change and some other environmental considerations lead to enhanced interest in exploitation of renewable energy. One aspect of this process relates to the natural availability of these energy sources parallel to the climate change, itself.

In *Figure 8* the average changes in runoff, soil-moisture content sea-level pressure are presented. Except the pressure changes, all maps are related to the annual averages. Together with projected changes in the annual cloudiness (see above in Figure 2), they are the key meteorological parameters that help answering the question in the title of the present section.

The projected changes in cloudiness exhibit rather simple structure: With the exclusion of a few smaller low-latitude areas, the cloudiness is decreasing between the ca. 60th latitudes of both Hemispheres with increasing cloudiness in the rest of the Globe. The decreased cloudiness at the low and temperate latitudes contributes to enhanced solar energy. In Hungary the surplus is a few percent, as one may judge from Figure 2.

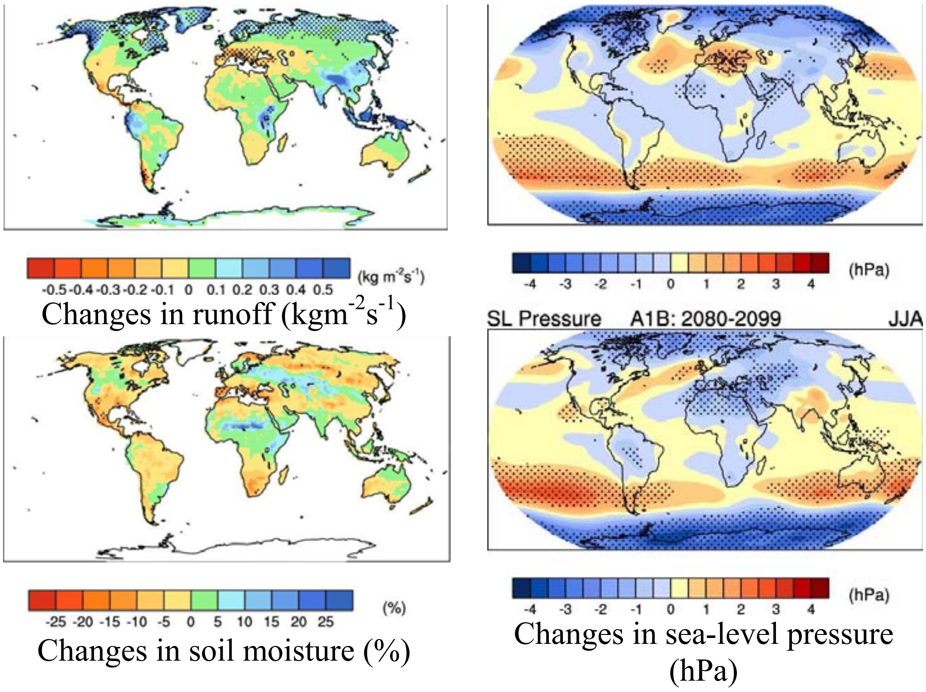

Figure 8. Averages of the projected changes in the selected indicators related to potential renewable energy sources derived from the model means. Data obtained from IPCC, 2007: Figures of Ch. 10, Supplement.

Note. In a part of the Figures area of significant changes are marked by points.

Patterns of changes in the sea-level pressure show complex structure. As expected from the law of mass conservation, there should be a spatial balance between the increasing and decreasing sectors of pressure over the Globe. For wide areas of Europe the significant increase of the pressure indicates more frequent anticyclones in winter. However, in summer the pressure is decreasing over most of the continent. The more anticyclones in winter imply weaker wind from the large-scale circulation and less intense convective activity, but in summer the tendencies are the opposite. Hence, over majority of Europe, including Hungary, the wind-energy potential will likely increase in summer, but decrease in winter.

Patterns of changes in runoff are patchy. Decrease of runoff is projected at the lower temperate latitudes expressed in decrease in the western and increase in the eastern parts of both Eurasia and Northern America. In Europe a clear zonal structure with increase in the northern and decrease in the southern parts of the continent is distinguishable. The decrease of runoff indicates even lower availability of water energy for Hungary than today.

Patterns of soil moisture changes are more or less of zonal structure with some tilt towards the lower latitudes in the middle of the continents. In Europe this means decrease of the soil moisture in majority of the area including Central Europe, as well. For the vegetation, it means decreasing water availability, which is the main limiting factor of plant development in Hungary, enjoying enough sunshine and sufficient temperature in the growing season. Hence, lower amount of green-mass, i.e. less source of biological energy can be expected.

From the above changes in available renewable energy sources in Hungary, one may conclude that only the solar energy would win from the expected warming, but none of the changes would be too strong in either direction. Hence, distribution of renewable energy will likely be determined by other factors than changes of resources caused by the global warming.

Education of and by Climate Change

Climate change is an exciting scientific and practical challenge of our era. The interest of pupils in climate change also provides good opportunity to present the related problems of environment, stemmed from the same anthropogenic over-consumption of the natural resources. There are two aspects which can not be expressed in detail due to space limitations, but which are important connections between school and everyday life. They are (a) *the intelligent adaptation to weather*, as ever-changing risk and resource for everyone and everywhere; and (b) *the energy-conserving way of life* in our homes, including motivations for using renewable energy. Both topics are good examples on those cases when fresh knowledge of the youngsters can guide the elder generation. (Note again, that weather extremes are not direct consequences of climate change, as it was already mentioned above.)

Besides that, the interest in climate change may also be used for bringing closer to pupils many topics of the various school subjects. Pajtók-Tari et al. (2011) collected a detailed list of such possibilities with their relation to broader topics of the subject, the reason for emphasis and relation to climate. Two examples from each subject are indicated in *Table 2*.

Table 2

Selected phenomena in various subjects, possibly educated by climate change

Phenomenon/process	Broader topic	Reason for emphasis	Relation to climate
		Physics	
Melting and freezing	Phase transitions	Melting of the ice caps, increase of the sea-level.	Global warming
Space-born images	Artificial planets, meteorological satellites	Monitoring of the climate changes.	Changing climate zones.
		Chemistry	
Photochemical reactions	Inorganic chemistry (oxygen)	Atmospheric processes	Ozone formation and decomposition
Gaseous air contaminants	Materials of the environment	Environmental pollution	Dry and wet deposition, ozone depletion.
		Biology	
CO_2 level in air, CO_2 absorption of plants	Plant physiology, assimilation	Assimilation processes, big cycles of Earth.	The effect of the increasing CO_2 level
High temperature, flood, drought, new diseases	Human Health	Exotic & native diseases, effect on human body	Extreme weather, higher temperature averages
		Geography	
Soil erosion, zonal and non-zonal soil's shift	Pedology (Soil Geography)	Soil degradation process and consequences	Intensive rains, likely more frequent in future
Population distribution. environmental migration	Population Geography	Requirements to sustain, inc. natural resources	Desertification, loss of Himalaya glaciers.

Note. Data based on Pajtok-Tari et al. (2011).

Finally, let us show another aspect of teaching, i.e. the so called key competences which mean ability to solve various problems of life, including response to climate change and sustainability. Development of nine key competences, established by the subsequent National Core Curricula (NCC, 2007; 2012), is a parallel and important goal for education. *Table 3* gives a list of possibilities to improve the competences in relation with climate change.

Table 3
Climate change to improve the key competences: examples

Key competence (KC)	Example of using climate change to develop the KC
Communication in the Mother Tongue	learn new words of climate, effect and responses
Communication in Foreign Languages	find extra motivation in understanding the CC disputes
Mathematical Competence	use CC as motivation to understand usefulness of math
Competences in Natural Science and Technology*	use CC to teach and integrate Natural Sciences
Digital Competence	besides the Internet, compilations and calculations in CC
Learning to Learn	use CC as a fast developing topic to learn for learning
Social and Civic Competences	weather extremes are good examples of cooperation
Sense of Initiative and Entrepreneurship	renewable- and low-carbon industry are good examples
Aesthetic and Artistic Awareness and Expression	nature itself provides picturesque examples in storms

Note. Competence in technology is added to the key competences by the new National Core Curriculum (2012).

Conclusion

The five investigated questions have been answered by study as follows:

Unfortunately, there are processes in the climate system, which work against the GAIA-hypothesis, i.e. they strengthen the global warming. It is not surprising, since the present, very likely anthropogenic warming is faster than the previous ones by 1-2 orders of magnitude. Hence, new and more effective mechanisms would be needed to counteract the warming and the corresponding changes of the environment.

Despite the common stereotype in the media, no unequivocal intensification of meteorological extremes should be expected. There are pros and cons to this assumption. Extreme events will likely change with the global warming, but as regional details of the changes are rather uncertain, projection of the extreme events' frequency and intensity distribution is unsettled at present stand of science.

Having studied the recent tendencies of greenhouse-gas emission in Hungary, a clear de-coupling between the GDP and the greenhouse-gas emission is established in Hungary since the economical recovery in mid-1990-s, after the transition.

From the projected changes of available renewable energy sources in Hungary, one may conclude that only solar energy would win from the expected warming, but none of the changes would be too strong in either direction. Hence, distribution of renewable energy will likely be determined by other factors than changes of resources caused by the global warming.

Finally, a few examples were shown to demonstrate, that enhanced interest of pupils in climate change and related aspects, including weather sensitivity and mitigation can be used both for teaching various topics of sciences and for developing the key competences.

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