CIVI MATICS

INTERDISCIPLINARY MATHEMATICAL MODELLING MEETS CIVIC EDUCATION

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PROJECT INFORMATION

Project Acronym:	CiviMatics
Project Title:	Civic Education Mathematics
Project Number:	2020-1-DE01-KA203-005707
National Agency:	Deutscher Akademischer Austauschdienst (DAAD)
Project Website:	https://www.civimatics.eu
Authoring Partner:	Institut für Didaktik der Demokratie, Leibniz University Hannover
Document Title:	Methane emissions causing climate change: An interdisciplinary inquiry
Publishing Date:	July 2021

This project has been funded with support from the European Commission. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein. Submission Number: 2020-1-DE01-KA203-005707

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Content

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1. Introduction

The climate on our planet has changed constantly over geological time, with significant variations in global average temperatures. However, the current climatic warming is happening much more rapidly than past warming events. It has become clear that mankind has caused most of the warming of the last century by emitting greenhouse gases to power our modern lives. We do this through burning fossil fuels, agriculture and land use and other activities that drive climate change. The World Meteorological Organization (WMO) reported in 2017 that greenhouse gas emissions in Earth's atmosphere have reached the highest level ever in 800,000 years (Schlein, 2017). This rapid increase is a problem because it is changing our climate at a rate that is too fast for living organisms to adapt to. Climate change involves not only rising temperatures, but also extreme weather events, rising sea levels, changing wildlife populations and habitats, and a number of other impacts.

Education is an important agent in addressing the issue of climate change. The United Nations Framework Convention on Climate Change (UNFCCC) assigns responsibility to the Convention's parties to undertake educational and public awareness campaigns on climate change, and to ensure public participation in programmes and access to information on the issue. The UNFCCC maintains:

> *Education can encourage people to change their attitudes and behavior; it also helps them to make informed decisions. In the classroom, young people can be taught the impact of global warming and learn how to adapt to climate change. Education empowers all people, but especially motivates the young to take action. (Education is Key to Addressing Climate Change, n.d.).*

Teaching climate change can however be challenging for many teachers, as discussed in the article "Teachers' learning about climate change education" by Oversby (2015). These are sources of the complexity associated with climate change education he points to: knowledge claims in the field are based on modelling from uncertain and partial data that challenge traditional views of what a science is; its breadth encompasses subject matter knowledge in many disciplines; attitudes towards environmental issues and consumption are central, together with commitment to action; its strong links to personal and communal action, often political, may make development of climate change education in conventional classrooms controversial; and characterization of learning is multi-faceted and often beyond the expertise of many teachers.

The climate problem is a responsibility also for teacher educators. This paper reports from an inquiry by mathematics educators and civic educators into what we call "the methane problem". The study focuses on how emission of methane gas into the atmosphere affects the climate on planet Earth, on how social structures contribute to the problem, and points at some possible steps to reduce the problem. The inquiry is done under the auspices of the project CiviMatics (see www.civimatics.eu) and was set out to produce material that can be used in interdisciplinary modelling activities related to climate change in teacher education programmes. The paper is a resource for a special type of modelling, called *Study and Research Paths* (SRPs). The methodology of SRPs and the theoretical framework in which SRPs are rooted – the anthropological theory of the didactic – is presented in *Framework to develop normative modelling teaching materials* (Gildehaus et al., 2021).

Emission of methane gas into the atmosphere is an important factor in causing the greenhouse effect, which in turn is connected to climate change. We will investigate this phenomenon first from a mathematics education point of view, involving also knowledge from chemistry and biology, and then from a civic education point of view, discussing political aspects connected to methane emission. The generating questions studied from the two perspectives are, respectively:

> Q^M: *What is the contribution of methane gas to the greenhouse effect?*
>
> Q^C: *How can more awareness of the methane cycle be created/taught among citizens in order to make more informed decisions?*

These questions will generate new, derived questions which we will study in due course in order to develop answers to the problem at stake[1].

2. The methane problem studied from the perspective of Mathematics Education

We start with the generating question:

> Q^M: *What is the contribution of methane gas to the greenhouse effect?*

[1] In view of the scope of the paper, some derived questions will be presented but not studied here. However, these questions are material for SRPs to be implemented with student teachers at a later stage.

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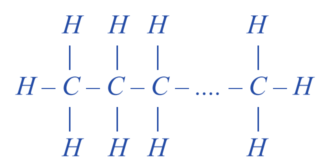
In order to answer this question, it is necessary to acquire some knowledge about methane, what it is, how it is generated, and what happens with it when released in the atmosphere. This will lead to a number of derived questions, which we will address as we go along. – and their perspectives on a complex issue such as climate change. Both principles of civic education, for example the principles of problem orientation, and mathematics education, with theories such as the ATD and its study and research paths or the modelling cycle, offer opportunities for interdisciplinary learning processes, which we will detail below.

2.1 METHANE – ITS NATURE AND BEHAVIOUR

In The first derived question is the following:

Q_1^M. What is methane and how is it related to other chemical compounds?

Hydrocarbons are compounds consisting only of the elements of hydrogen and carbon, and hydrocarbons are considered to be the simplest organic molecules. The least complex hydrocarbons have only single carbon-carbon bounds, and they are called *saturated*. Furthermore, if there are no carbon cycles, the hydrocarbon is referred to as *acyclic*. Acyclic, saturated hydrocarbons are called *alkenes*, and methane is the simplest of all alkenes. The general formula for an alkene is C_nH_{2n+2}2. This follows from the fact that all carbon-carbon bounds are simple. When the number of carbon atoms increases ($n \geq 4$), the number of possibilities for creating carbon chains increases. The different versions obtained in this way are referred to as isomers, and the simplest isomer for a given n can be illustrated as below:



Methane has only one carbon atom, hence the formula CH_4.

Alkenes form the basis for a number of other chemical compounds, such as alcohols, aldehydes and organic acids, to which they are transformed in oxidation processes. Removing one hydrogen atom from an alkene, gives a radical, the alkyl group, C_nH_{2n+1} (Kice & Marvell, 1974; Mahan, 1975). The alkyl group can combine to other groups of atoms (functional groups) giving new compounds. The simplest example is with the methyl group CH3 as the starting point, to add the hydroxyl group, –OH, to get CH3OH, methanol. Having placed methane in the chemical landscape, we will now turn to a discussion of how methane behaves in the atmosphere. This leads to the discussion of how methane is part of a cycle. Hence, the next question to pursue is:

Q_{12}^{M}. How can the flow of methane be described as a cycle?

As indicated above, the alkyl groups can combine with various functional groups to form new compounds, and this indicates that the alkenes are not stable. The heavier alkenes, such as propane (n = 3) and butane (n = 4) are commonly used for cooking and heating, since they burn easily, but not as fiercely as methane does. In the combustion process, the alkenes oxidise to CO_2 and water. Methane oxidises in the troposphere to CO_2 and water, and according to Wahlen (1993) this constitutes the major sink for methane. He writes that the atmospheric lifetime for methane is 8–12 years (p. 407). Another, small sink of methane is due to bacteria consuming atmospheric methane. These bacteria, called methanotrophs, constitute a group of bacteria that are capable of utilising single-carbon compounds, and methane is both the source of energy and the source of carbon for these bacteria (Bürgmann, 2011). The oxidation described above is aerobic oxidation. Methane is also consumed in anaerobic oxidation. This is an oxidation that takes place through reduction of sulphates or nitrites (Conrad, 2009). Chemically this process can be described as

$$CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^- + H_2O$$

or

$$CH_4 + NO_3^- \rightarrow CO_2 + NO_2^- + H_2O$$

with sulphates and nitrites, respectively. Similar processes exist with methane replaced by ammonium (NH_4). The nitrite-driven anaerobic oxidation of ammonium and methane is caused by certain groups of microorganisms. According to Reimann, Jetten and Keltjens (2015) these bacteria were only discovered about 20 years ago. Moreover, Wahlen (1993) indicates some important sources of methane:

> *Methane is produced by bacteria under anaerobic conditions in wet environments such as wetlands, swamps, bogs, fens, tundra, rice fields, and landfills. It is also produced in the stomachs of ruminants (cattle and other cud-chewing mammals), and possibly by termites. [...] Other sources of CH_4 are from leakage of natural gas upon drilling and distribution, and from coal mining. A further source is from biomass burning where CH_4 is a product of incomplete combustion. (p. 408)*

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Conrad (2009) attributes about 25% of methane sources to mining and combustion of fossil fuels or burning of biomass, about 69% to microbial processes, and about 6% to chemical production of CH_4 from plant material. According to this, microbial processes are the largest source of methane. This covers a wide range of sources, where some sources are more or less directly controllable by humans. Microbial metabolism takes place where organic matter is decomposed in the absence of oxygen or other oxidants. Wetlands are the largest individual source of methane but also rumen fermentation in cattle, sheep and other ruminants are an important source of CH_4 (Conrad, 2009). Figure 1 shows the percental distribution of methane sources.

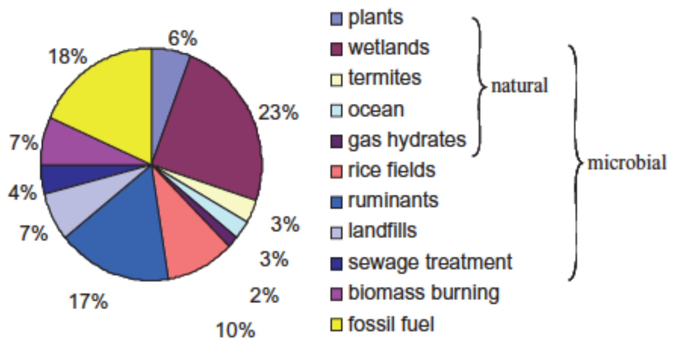

Figure 1. Global methane sources in percent of total (retrieved from Conrad, 2009, p. 286)

The figure shows that close to one quarter of the methane comes from wetlands. Conrad claims that there is little direct human influence on the source strength of methane from wetlands. The second largest sources, according to Conrad, are burning of fossil fuels and rumen fermentation, with each of these sources accounting for 17–18% of the total. Wahlen (1993, p. 416) presents a table based on four different studies from 1988–1991. According to this table, wetlands account for a share in the range of 22–25% and animals (enteric fermentation) account for a share in the range of 15–20%.

These figures are seen to be consistent with the figures that Conrad presents in his paper from 2009. Both sources indicate the total emission of methane to be around 500–600 tons per year. According to the website of the United Nations Economic Commission for Europa (UNECE), about 60% of global methane emissions are due to human activities (The Challenge, n.d.). Figure 2 shows a graphic of the different sources of human created methane emissions.

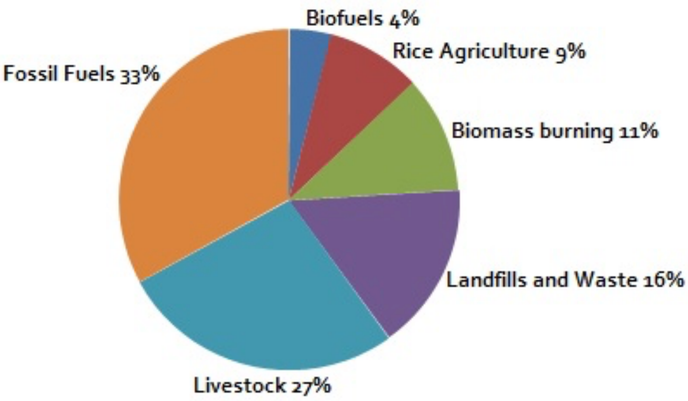

Figure 2. Sources of human created methane emissions (retrieved from The Challenge, n.d.)

Above we have identified some important sources and sinks of methane, the most important sink being the oxidation of methane to CO_2 and water. This interplay between sources and sinks makes it reasonable to talk about methane being part of a cycle. What affects the net emission of methane is obviously the difference between the total source strength and the total sink strength. The total sink strength has for a long time been smaller than the total source strength, causing an increase in the concentration of methane. However, the CH_4 sink strength increases proportionally with the increasing CH_4 concentration in the atmosphere, which to some extent neutralises the changes in source strength (Conrad, 2009).

2.2 METHANE AS A GREENHOUSE GAS

Now we turn to the issue of methane as a greenhouse gas, and this leads to the following question:

Q_3^M. What is the role of methane as a greenhouse gas?

According to Conrad (2009), methane is the second most important human caused greenhouse gas after CO_2 and that methane contributes about 30% to the total net human caused radiative forcing of 1.6 W/m2. Conrad further claims that the concentration of CH_4 in the atmosphere has been increasing from pre-industrial values of about 715 ppb (parts per billion, i.e., parts per 10^9 parts) to currently about 1770 ppb. The growth rate of atmospheric CH_4 was about 12 ppb/year in the 1980s, but has decreased since the early 1990s, with a value of about 4 ppb/year since 1999. Figures 3 and 4, taken from the European Environment Agency website (Trends in Atmospheric Concentrations of CO_2, CH_4 and N_2O, 2019), show respectively the lines of development of CO_2 and CH_4 in the atmosphere from 1800 to present. Furthermore, UNECE states that methane has a 100-year global warming potential that is about 30 times that of CO_2 and that this ratio grows to 84–86 times over a 20-year period (The Challenge, n.d.). However, as Figures 3 and 4 show, the concentration of methane is much lower than that of the CO_2 concentration.

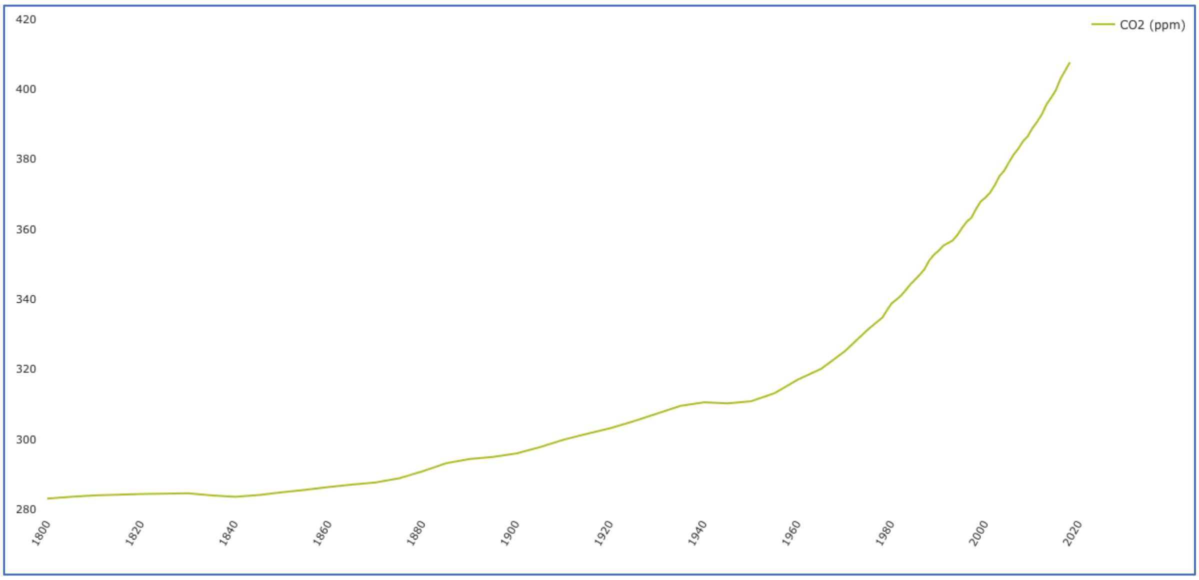

Figure 3. Concentration of CO_2 in the atmosphere

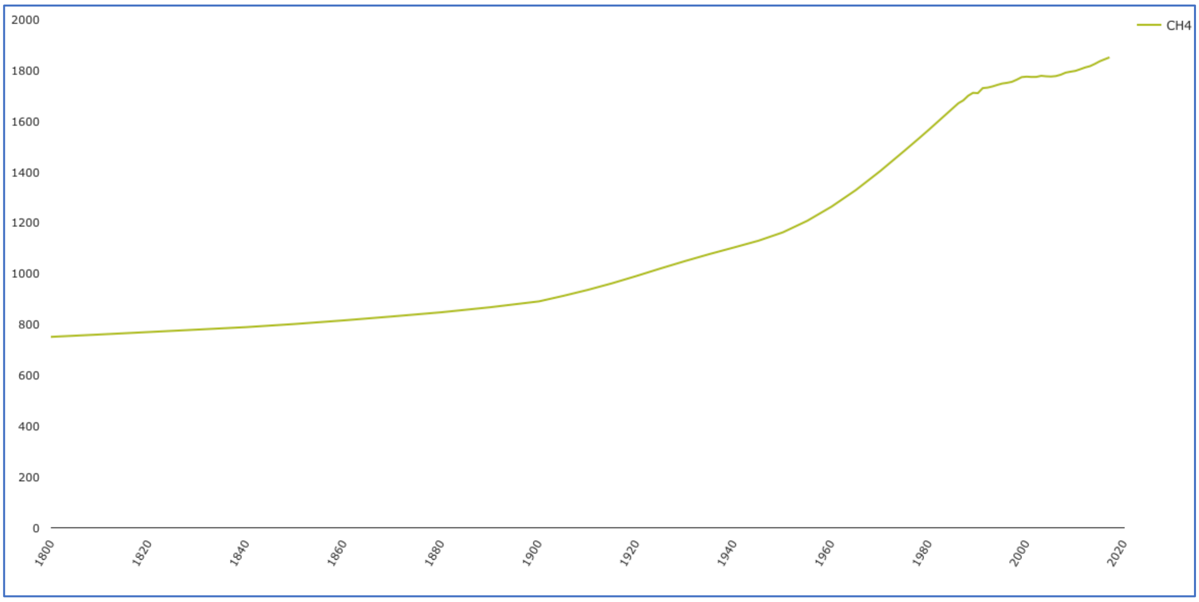

Figure 4. Concentration of CH_4 in the atmosphere

It appears that much of the knowledge regarding the methane cycle is relatively new. In 2009, Conrad listed a number of issues to be addressed for better understanding the ecology of methane-producing and methane-consuming microorganisms and their role in the methane cycle.

2.3 HOW METHANE IS PRODUCED BY RUMINANTS, AND HOW IT CAN BE REDUCED

The fact that 27% of the methane emissions comes from livestock (see Figure 2), makes it necessary to better understand its role in the methane cycle. We therefore go on to study the following question:

> Q_4^M. *How is methane produced by ruminants?*

Cows, goats, sheep and several other animals belong to a class of animals called ruminants. Ruminants have four stomachs and digest their food in their stomachs instead of in their intestines, as humans do. Ruminants eat food, regurgitate it as cud and eat it again. One of the characteristics of ruminants that makes them so interesting and advantageous for the human production is that they can convert otherwise indigestible cellulose-rich plant material into meat, milk, wool, and leather. Since they eat plants that humans cannot digest, they do not compete directly with humans for food. Their digestion is supported by a group of microbes, called methanogens, that form a subgroup of the domain Archea. These microbes live in the forestomach (reticulorumen, more commonly known as the rumen) of ruminants, and produce methane as a side product of the digestion process. In Figure 5 the process of the synthesis of methane in the digestion of a ruminant is shown in more detail.

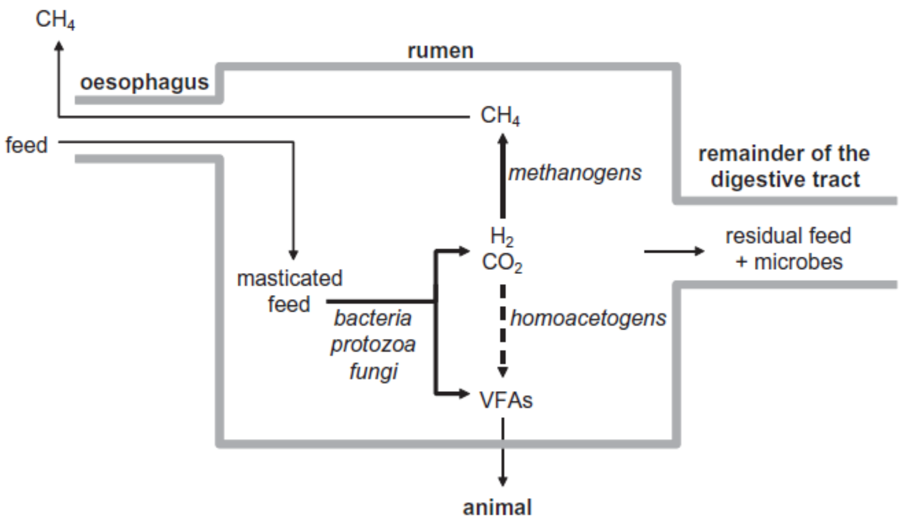

Figure 5. Synthesis of methane in a ruminant (retrieved from Buddle et al., 2011, p. 12)

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During the fermentation of the feed, several bacterial, protozoal and fungal species derive the energy from the feed in form of volatile fatty acids that the animal absorbs. Side products of this process are the gases H_2 (hydrogen) and CO_2. In a subsequent step, methanogens use these end products of the fermentation as substrates and produce methane at the end of the tropic chain. For an even more detailed chain describing the microbial fermentation process of feed polysaccharides and H_2 reduction in the rumen, see Figure 6.

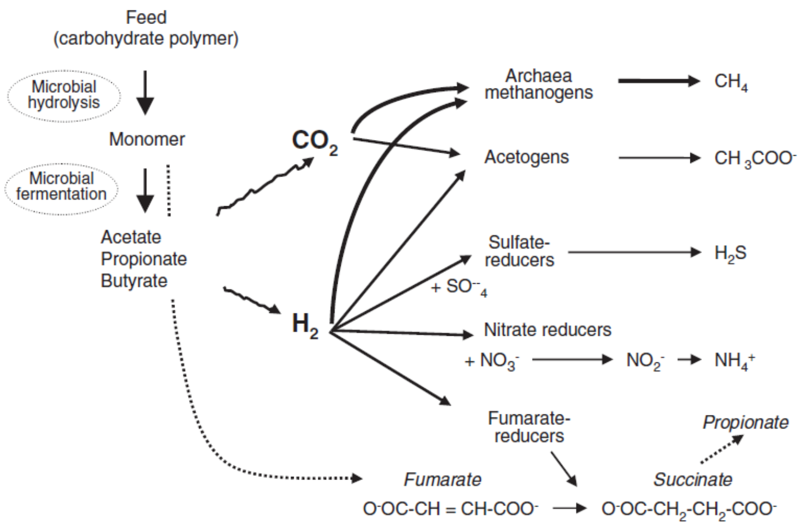

Figure 6. Fermentation of feed (retrieved from Morgavi et al., 2010)

Now having identified and explained how ruminants contribute to the emission of methane, and recognising the important role that ruminants play, a derived question to study is the following:

> *Q_5^M. How can production of methane from ruminants be reduced (without reducing the number of ruminants)?*

Reducing the microorganisms that produce methane in cows' digestive system is not only of interest to climate-friendly agriculture, but it would also increase cow productivity. According to a report commissioned by the European Commission on Environmental Economics, between 4% and 10% of the energy in cow feed is lost through methanogenesis and thus not available for digestion (Economic Evaluation of Quantitative Objectives for Climate Change, n.d., p. 28). Therefore, the reduction of microorganisms has long been the subject of scientific research. Basically, two approaches have delivered promising results: 1) reduction of enteric methanogenesis and 2) adaptation of the ruminants' diet. In the next section, we explain what these methods involve.

2.3.1 Reducing microorganisms in ruminants' digestive system

By reducing the number or activity of methanogens in the rumen, a vaccination against rumen methanogens can potentially reduce methane emissions (Wedlock et al., 2013). The great advantage of this approach is that it is likely to be inexpensive and one of the few options that would be viable with grazing animals. Vaccination of farm animals is already widely practiced for disease control and the adoption of this technology by veterinarians and farmers could be quick if it were shown to be effective at reducing methane emissions. So far however, the results are inconclusive, as vaccines are very specific to certain microbial strains and there are differences in efficiency (Patra et al., 2017). Another method involves adding substances to the cow's diet, which will influence the entire digesting process towards a lower percentage of methanogens and a higher percentage of microbes – this will produce more volatile fatty acids as an energy source used by the ruminant.

Probiotics can achieve just that. It has been shown that ionophore antibiotics like Monesin reduce methanogenesis, presumably by shifting the fermentation processes and reducing certain microorganisms (Russell & Houlihan, 2003). However, these findings have been debated and criticized (Grainger et al., 2008, 2010; Odongo et al., 2007). In some cases, organic acids such as malate, fumarate or acrylate have also been shown to reduce methane emissions, but the results of these studies vary widely and remain inconclusive (Bates, 2001; Jeyanathan et al., 2014). Many secondary plant compounds such as tannins, saponins or essential oils have been shown to directly reduce methanogens and hydrogen production in the rumen (Hess et al., 2006).

Oil such as coconut oil, and garlic powder are considered to be some of the most effective additives for methane control (Kongmun et al., 2010). One advantage of adding fats to the cows' feed is that it reduces methanogenesis without significantly affecting other rumen functions. Other substances such as bromochloromethane, 3-nitrooxypropanol or nitrates have also been shown to be effective in reducing methane emissions (Van Wesemael et al., 2019). Although many feed additives have the potential to reduce methane emissions, more research is needed to determine whether they are effective in the long run (or whether the rumen microorganisms

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adapt to them) and whether there are any potential risks, such as negative effects on the environment.

Recent studies suggest that replacing a grass-only diet with mixed feeds may be beneficial, as some plants, such as flowers, may have the potential to lower methane emissions as phytonutrients inhibit methanogenesis (Hammond et al., 2015; Haque, 2018). Tannin rich legumes like Sainfoin have also been reported to help reduce methane emissions (Stewart et al., 2019). In general, cows that receive grain silage emit less methane than cows that receive grass silage. The diet of cows is generally balanced between forage such as grass, hay and energy rich concentrates containing more sugar and starches. The more concentrates the cow feeds on, the lower the production of methane, in relation to the cow's productivity. This is because the main substrate for methanogenesis are fibrous carbohydrates. However, feeding large amounts of concentrates without the addition forage is not without risk and can for example lead to an acidic environment in the rumen which is bad for the cow.

A quite amazing case is from Australia, where farmers have been feeding cows pink seaweed to help combat climate change. A study in 2014 by Australia's national science agency, CSIRO, found that by adding the pink seaweed Asparagopsis to a cow's food they could reduce the amount of methane gas produced when cows burp and fart by as much as 99% (Climate Change, 2019). The special pink seaweed grows in Queensland in Australia, and now scientists want to set up special farms to make more of it. The reason why Asparagopsis is so effective in reducing methane production is because it contains a lot of bromoform (Hermans, 2020). A derived question here is the one below, which we will leave out to be considered at a later point in time:

> $Q_{51}{}^{M}$. *How can the effect of bromoform on methane production in ruminants be explained scientifically?*

Regardless of their diet, there is variation in the production of methane between individual animals. Depending on the feed efficiency of an animal, the relative amount of methane produced can be lower. There is some evidence that the level of methane production is a heritable trait in cows, which suggests that this trait may be selected for breeding (González-Recio et al., 2020). However, the fermentative processes in the digestive system depend on the community of microorganisms, so the extent to which these microorganisms depend on the genetics of the cow, is highly debated.

2.4. ESTIMATION OF EMISSION BUDGETS

So far, we have inquired into the nature and behaviour of methane and how methane emissions can possibly be reduced to help combat climate change. This section points at another aspect, to be explored further at a later stage: the estimation of emission budgets – that is, budgets giving an upper limit for total greenhouse gas emissions associated with remaining below a specific global average temperature. While anthropogenic warming is largely determined by cumulative emissions of CO_2, short-lived climate pollutants (SLCPs) – such as methane, soot and other aerosols – also play an important role. In climate budgeting, it is therefore crucial to develop models that take SLCPs into account in a proper way. Allen et al. (2018) show that methodologies using conventional Global Warming Potentials (GWP100, i.e., Global Warming Potential over 100 years) to convert SLCPs into so-called "CO_2 equivalent" emissions are misleading. In their article entitled "A solution to the misrepresentations of CO_2-equivalent emissions of short-lived climate pollutants under ambitious mitigation", Allen et al. provide a new methodology that allows the temperature forcing of CO_2 and SLCPs to be examined under a common cumulative framework. A modified form of GWP – GWP*, which relates cumulative CO_2 emissions with contemporary SLCP emissions – is shown to better model the future climate forcing of both long- and short-term pollutants (see also Lynch et al., 2020). This is based on comparing greenhouse gases by converting them into a "forcing equivalent" quantity of CO_2 (CO_2-fe, for short). Use of GWP* could improve climate policy design, benefiting mitigation strategies to achieve the Paris Agreement targets.

Figure 7 shows historical emissions and projected changes from 2015 following an ambitious mitigation scenario, RCP2.6[2], expressed as CO_2-e (Fig. 7a–b) and CO_2-e* (Fig. 7c–d)[3]. Left panels in the figure show annual emission rates, and right panels show cumulative (integrated) emissions. CO_2-e and CO_2-e* emissions of CO2 and N2O are identical, but annual CO2-e* methane emissions (Fig. 7c) track the *rate of change* of methane emissions, unlike CO_2-e (Fig. 7a), which track methane emissions themselves. We see that methane CO_2-e* emissions increased rapidly in the 1950s and decreased over the 1990s as the rate of increase in methane

[2] RCP2.6 stands for Representative Concentration Pathway 2.6 (where 2.6 refers to forcings for the scenario). This is one of four described scenarios which provide time-dependent projections of atmospheric greenhouse gas concentrations (Wayne, n.d.).

[3] CO_2-e stands for CO_2 equivalents using conventional GWP and CO_2-e* stands for CO_2 equivalents using GWP*.

emissions stopped. Dashed lines show global mean surface temperature (GMST) response to *radiative forcings*[4] associated with these emissions. Thin solid lines (Fig. 7d) show cumulative CO_2-fe emissions closely tracking GMST response. We see that cumulative CO_2-e* emissions closely track both cumulative CO_2-fe emissions and resulting temperature changes (Fig. 7d), while GWP100-based CO_2-e performs poorly for SLCPs, particularly when emissions are falling (Fig. 7b).

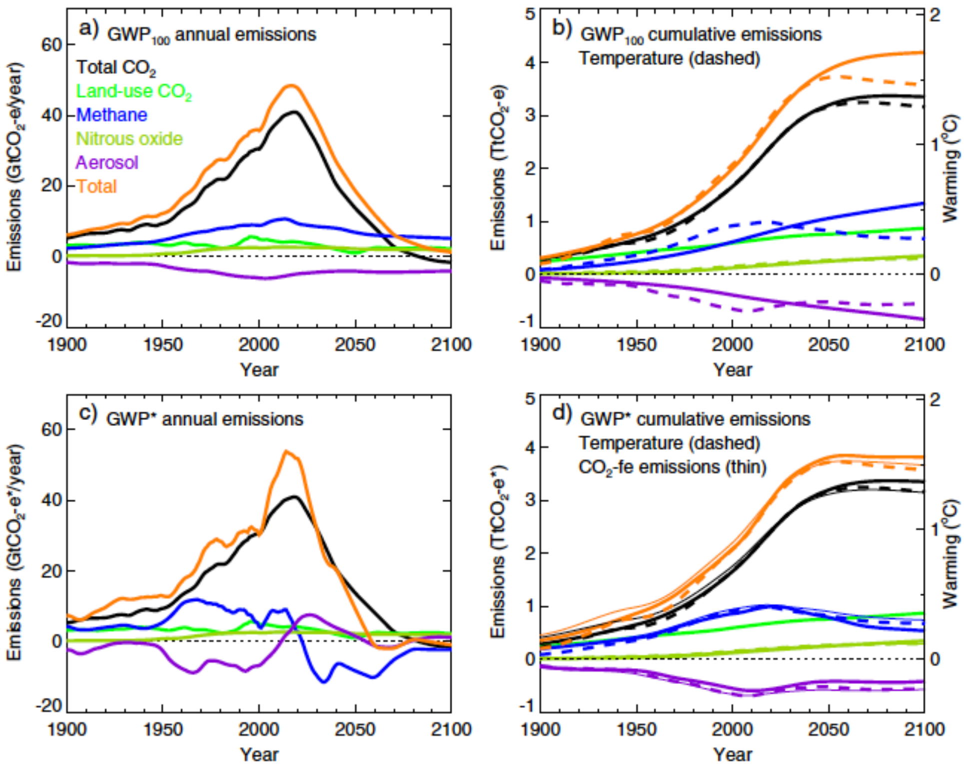

Figure 7. Historical emissions of greenhouse gases and projected changes from 2015 following the ambitious mitigation scenario, RCP2.6 (retrieved from Allen et al., 2018, p. 4)

The following question, to be studied in a future SRP, will provide knowledge about an up-to-date way of estimating emission budgets:

> *$Q_6{}^M$. What does the framework for temperature forcing of CO_2 and SLCPs using GWP* consist of, and what mathematics is involved in it?*

[4] Radiative forcing, measured in watts per square meter of surface, is a measure of the change in energy balance as a result of a change in a *forcing* agent (greenhouse gas, aerosol, etc.) to affect the global energy balance and contribute to climate change ("Radiative Forcing", 2021).

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In our inquiry we have up to now drawn upon natural sciences and mathematics. This has been necessary with regard to questions concerning the nature and behaviour of methane. Our discussion of methane mitigation is built on the same disciplines, but a complementary treatment of this topic is provided in Section 3, where the question of methane emissions is based on political science and sociology, taking into account the socio-political level and citizens' awareness of climate change. This we present next.

3. The methane problem studied from the perspective of Civic Education

3.1. Reducing methane emissions depending on socio-political conditions

The Amazon basin is an incredibly vast, naturally diverse and environmentally important region stretching over nine Latin American countries, hosting more than 30 million people – 9% of whom are indigenous people belonging to more than 350 different ethnic groups – and accommodating about 10% of the world's known biodiversity (Inside the Amazon, n.d.). In the last decades, however, the biological and cultural diversity of the Amazon basin has been seriously threatened by deforestation, wildfires, land seizures and land use changes, which have reduced 17% of its extension and might even risk of degrading the rainforest into a non-forest ecosystem (Lovejoy & Nobre, 2018). Despite the environmental and socio-political threats, these processes seem to have further increased under the leadership of Brazilian president Bolsonaro, who "has sabotaged environmental law enforcement agencies, falsely accused civil society organizations of environmental crimes, and undermined Indigenous rights" (Canineu & Téllez Chávez, 2021; see also Brazil: Accelerating Deforestation, 2020), in a country that hosts 60% of the rainforest. What are the reasons for the increasing deforestation?

Whether conducted through illegal means or perpetrated through state policies and actions, in the past decades deforestation has increased significantly to make way for soy plantations and, above all, cattle farming. While traditional agriculture in Latin America has remained relatively stagnant in previous decades, Pacheco (2012) has noted how commercial agriculture has soared, mainly due to growing global demand for commodities in the food, fodder and biofuel markets. In fact, in 2013 Brazil was the world's second biggest producer and the world's major exporter of soy, whose cultivation is "pushing settlement and cattle raising into the more remote areas of the Amazon, where land is cheaper" (Hoelle, 2017, p. 748). Similarly, while it is noted that

Amazon peasants usually possess a small number of cows for their own sustenance, the production of bovine meat – and the deforestation that goes with it to open up new spaces for cattle ranches – has skyrocketed over the past decades, making Brazil the world's largest exporter of this commodity (Kröger, 2020).

When looking at the methane problem from a Civic Education perspective, several interrelated socio-political issues connected to the efforts for reducing methane emission might inform the discussion, as the example above shows. A generating question for an SRP connected to the methane cycle in civic education could be the following:

> Q^C: *How can more awareness on the methane cycle be created/taught among citizens in order to make more informed decisions?*

To be able to answer this question it is necessary to discuss to what extent this problem is caused by society and which social structures contribute to it; how governments are responding to this issue; what the political consequences of this issue are; what kind of political decisions can be made to deal with the issue; and what the impact of such political decisions is. We will discuss these derived questions more in detail below

> Q_1^C: *What role does the capitalist cycle of extraction, production, consumption and disposal of goods have in the methane cycle?*

The methane cycle described above resembles, and seems to have many connections with another, fundamental cycle in our society: the capitalist cycle of extraction, production, consumption and disposal of goods. Although the methane production in cows is a natural process, everything else surrounding it – from the production of bovine meat at the global level to the increasing forest loss for cattle ranches, the extractive activities, and the consumption needs in developing and developed countries – is social and political. It is social, because it is deeply related to the way goods are produced, distributed, consumed and disposed of globally within the current capitalist system, and political, because it is established, negotiated, implemented and even contested at multiple levels. Not only can the causes of such processes be traced, but one can (and should) also look at the social, political and environmental consequences that such processes carry with them.

When it comes to the methane problem, the capitalist system seems to have a main impact. This connection between human activities and the emission and decomposition of methane gas into the atmosphere can be seen in the production sources of methane such as in the stomachs of ruminants, as well as connected to landfills, rice fields, leakage of natural gas upon drilling and distribution or from coal mining (Wahlen, 1993, p. 408). Zygmunt Bauman outlines in his book *Consuming Life*, published in 2007, that society has changed into a consumer society. Bauman (2007a) explains this change with the transition from a “society of producers” to a “society of consumers” (see also Bauman, 2007b, 2009). He describes as crucial the change from the production of durable goods to the fact that nowadays happiness is less associated with the satisfaction of needs, but with a constant increase and reinforcement of desires. There is a short-lived use of the things we buy, as we soon replace them with something new. According to Stengel (2011, p. 101) the transformation taking place in the West and East from deprivation to desire, from scarcity to abundance, from work to leisure, from production to consumption – characterises the change to a global consumer society. Consumer societies at the beginning of the 21st century are characterised by growth and consumption orientation and a high and increasing throughput of materials, products and energy, as well as by huge amounts of emissions.

3.2. SOCIETAL CHANGE AND ITS CONSEQUENCES CONCRETISED

In this section we illustrate the relationship between consumer society and climate change, by studying this derived question:

> *Q_2^C: What is an example of the impact of the capitalist cycle on the methane cycle?*

One example of the impact of the capitalist cycle on the methane cycle is the transformation of agriculture. The transformation of capitalism since the 1970s – driven by the continuous research of new markets especially after the economic crises of stagnation and inflation in western countries – has pushed the boundaries of production, circulation and consumption of goods at the global level, radically changing the economies of both developing and developing countries (Harvey, 2019). Agriculture has not been immune to such transformations: prompted by technological advancements, agriculture has developed from a subsistence activity for the satisfaction of local needs to an intensive, mechanised and profit-driven business for mass consumption and the needs of the global markets. Besides, as Hoelle (2017) points out in relation to the Brazilian case, the improvement of living standards has translated into a drastic change in con-

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sumer behaviour, with an increase in meat consumption and exotic products. An important aspect in this respect, therefore, would be to look at the intertwined relationships between production and consumption, at their transformations through time within global capitalism, and at their implications in relation to methane emissions.

As for the consequences, the excessive production of methane – far more destructive than CO_2 although less spread – might have important repercussions not only regarding climate change, but also for all of its corollaries, such as the potential increase in climate refugees. Stengel (2001, p. 102) points out that the consumer society must undergo a transformation, as decisive boundary conditions have changed. Climate change, scarcity of resources and species extinction show that this pattern cannot be continued for much longer. Therefore, awareness must be raised to secure consumers' influence and power. For example, Noleppa (2012) shows in his study that a reduction in meat consumption in Germany can have an influence on CO_2 emissions (see Figure 8).

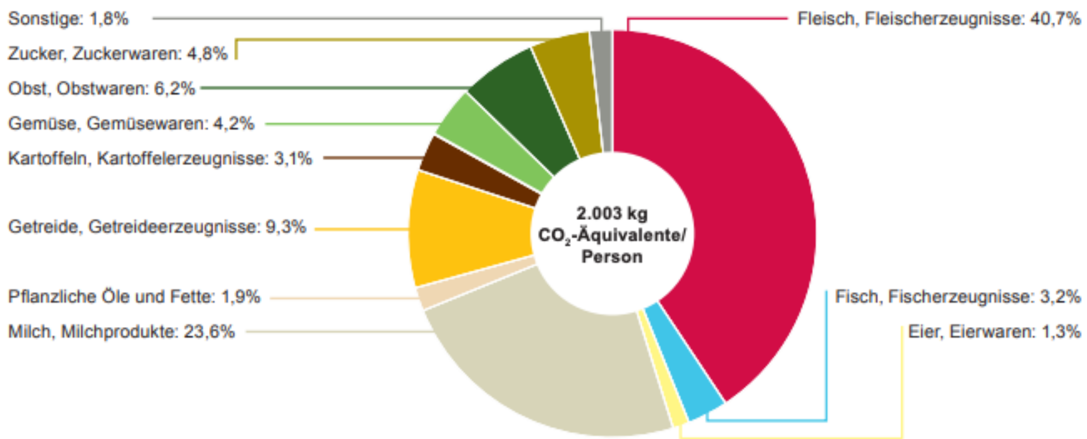

Figure 8. Direct greenhouse gas emissions from food in Germany per person (retrieved from Noleppa, 2012, p. 28)

Noleppa (2012) further shows how land and climate footprint could be reduced through healthier nutrition in Germany, using meat as an example. The prospect is based on a 44% reduction in meat consumption – in line with the nutritional recommendations (see Figure 9).

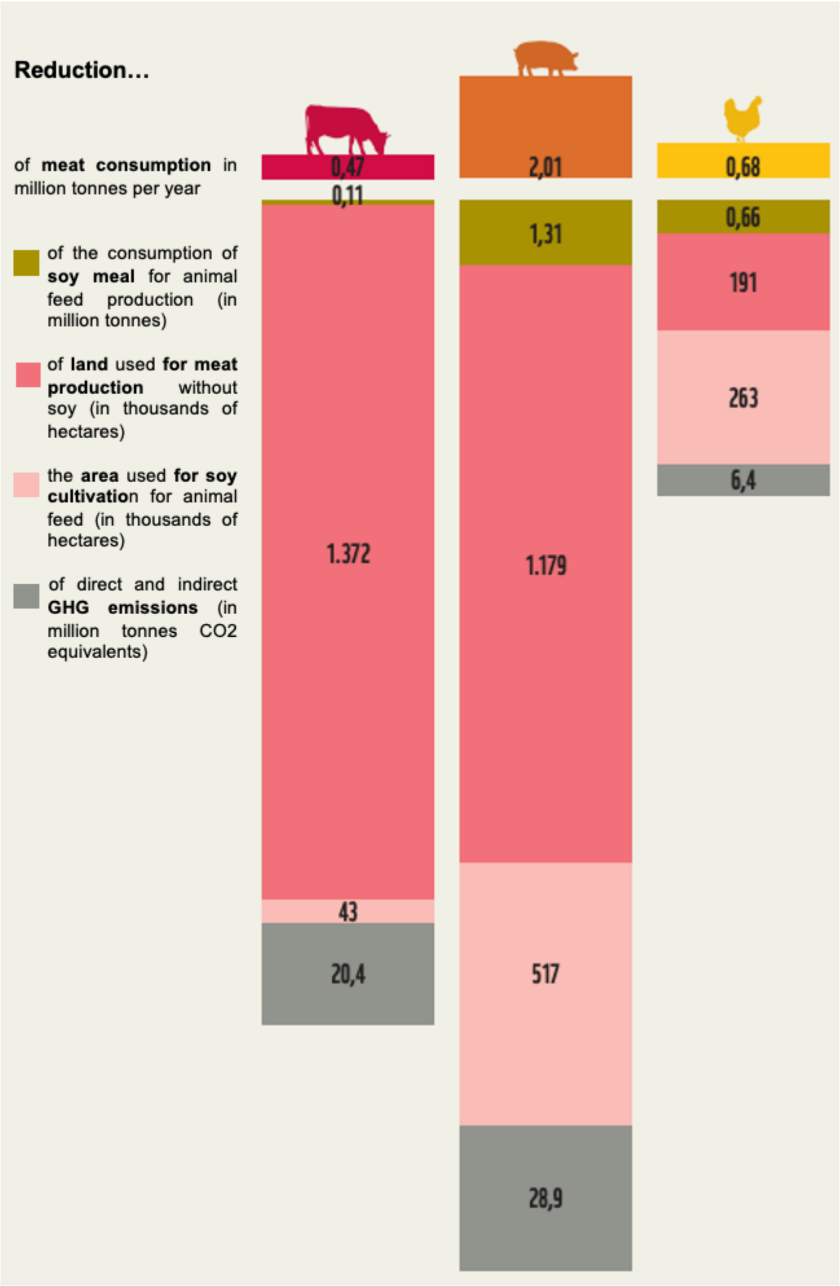

Figure 9: Reduction of the land and climate footprint through healthier nutrition in Germany (retrieved from Noleppa, 2012, p. 50, Authors trans.)

High meat consumption causes both increased land consumption and significantly more greenhouse gases (Noleppa, 2012, p. 4). Almost 70% of the direct greenhouse gas emissions of the German diet are due to animal products. Thus, changes in diet away from excessive meat consumption would reduce land consumption and the amount of greenhouse gas released. In 2015, the 2030 Agenda for Sustainable Development was adopted by 193 member states at the United Nations General Assembly. It contains 17 goals for sustainable development, which encompass social, ecological and economic aspects and aim to "transform our world". These are called Sustainable Development Goals (The Sustainable Development Goals, n.d.). One of these formulated goals is “responsible consumption and production”. Thus, responsible consumption and production is a crucial goal for climate protection.

3.3. The political level, and raising awareness

From a civic education perspective, it would be interesting to look either at what kind of political decisions can be made to deal with the issue of methane production or at how to raise awareness of the topic among citizens in order to make more informed decisions. What are the political consequences of this? How are governments responding? And how can we raise awareness of it? The first question to study is the following:

Q_3^C: Why is it important to raise awareness of methane emissions?

According to Ecker (2010), young people should reflect on the fact that a political signal can be set by conscious shopping if they want to. However, they must really see the political goal as their own. Creating awareness of exploitative working methods would be a sensible basis for further steps in this direction, for example, discussing the phenomenon involving goods being produced cheaply under inhumane working conditions in poor countries, to be later advertised and sold as luxury brands.

Ecker (2010) sees consumer history and current consumer behaviour of young people well suited as a topic for the new competence-oriented curriculum. This topic can be treated in a cross-curricular and project-oriented way in history, social studies and political education as well as geography and economics. However, it is important that this topic does not focus on moralising, but that young people learn to recognise that the role as a responsible consumer can bring them many advantages and general benefits in their future life. By making purchasing decisions, young people can consciously influence which products are sold in our markets. Products from companies that do not produce according to social or environmental standards could be boycotted. The consumption of products increasingly influences not only the economic and social situation of people, but also the state of the environment. Consequently, there is great potential for reducing environmental pollution in the sustainable use and manufacture of products (Nachhaltiger Konsum, 2021). The advantages of a sustainable lifestyle over a purely consumption-oriented lifestyle should be discussed and evaluated.

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Q_4^C: Why is it important to critically question approaches to solutions?

It would also be interesting to have a close look at the solutions provided by science and what consequences the implementation of these would have. For example, as mentioned in Section 2.3.1, coconut oil and garlic powder are considered to be some of the most effective additives for methane control (Kongmun et al., 2010). A pertinent question in this regard is whether reduction of methane-producing microorganisms in cows is environmentally sustainable in itself, or whether we should critically rethink the overall mechanisms of production, circulation, consumption and disposal of goods underlying global capitalism. What would the increase in coconut oil production mean for the local people? What impact does greater coconut oil production have on the environment? These are all questions that, we believe, are worth exploring in order to raise awareness on such issues and develop a critical consciousness of the global capitalist system in which we live.

4. WHY TEACH THE METHANE PROBLEM?

More than half of global methane emissions stem from human activities in three sectors: fossil fuels (35% of human-caused emissions), waste (20%) and agriculture (40%). According to a recent report from the United Nations Environment Programme (Ravishankara et al., 2021), reducing human-caused methane emissions is one of the most cost-effective strategies to rapidly reduce the rate of warming and contribute significantly to global efforts to limit temperature rise to 1.5° C. Available targeted methane measures, together with additional measures that contribute to priority development goals, can simultaneously reduce human-caused methane emissions by as much as 45%, or 180 million tonnes a year by 2030. Ravishankara et al. claim that this will avoid nearly 0.3°C of global warming by the 2040s and complement all long-term climate change mitigation efforts. It would also, each year, prevent 255,000 premature deaths, 775,000 asthma-related hospital visits, 73 billion hours of lost labour from extreme heat, and 26 million tonnes of crop losses globally.

We consider these facts and prospects encouraging for working with the methane problem in education, and we believe that this study will be useful for us in supervising inquiries with student teachers in the form of SRPs on this topic in the coming academic year.

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