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Global climate impacts of agriculture: A meta-regression analysis of food production

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1. Introduction

Based upon the requirements of the UN's Sustainable Development Goals (SDG) (Hajer et al., 2015) and the Paris Agreement on Climate Change (Rogelj et al., 2016), knowledge of external effects and how to deal with them is becoming increasingly important (Wesseh et al., 2016). It is indisputable that negative external effects are still widespread in today's economy (Longo et al., 2008; Wei et al., 2014), although they should be avoided (Gaugler and Michalke, 2017; IMF, 2010). One of the most important external effects is the emission of greenhouse gas whereby their internalization is a crucial point. Hence, greenhouse gas emissions play an important role in the life-cycle assessment. In particular, ISO 14044 implies the measurement of the carbon footprint of products and services (Finkbeiner et al., 2006). To perform a life cycle assessment of products the knowledge about the external effects of products and services in generals as well as the carbon footprint in detail is inevitable. Hence, companies ground on reliable measure for external effects and greenhouse gas emissions in detail. The same is true for policymakers which try to internalize external effects. Without a reliable measurement of external effects their approaches are ought to be misspecified. Consequently, both sustainable acting companies as well as policymakers pledge for a reliable measurement of external effects.

However, looking at the same goods different publications lead to different external effects (Cimprich et al., 2017). This might partially be true due to different specifications of an inhomogeneous product, which is the result of customization. In case of agricultural products, homogeneity could be assumed (German, 2014), because the production of agricultural products worldwide follows a similar business model. Hence, we chose this subject of study. As a consequence, there are numerous

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results reported from throughout the world that were designed to measure the same aspects. However, again different studies assign different measures of external effects for the same agricultural product. In particular, a more detailed analysis reveals that studies – also determining the climate impact of agriculture – yield deviating results when determining the climate impacts of agriculture. ICPP (2014) reports the economic sector "agriculture, forestry and other land use" accounts for 11.75 gigatons (GT) of CO_2eq, which corresponds to 24% of the anthropogenic greenhouse gas emissions (see Table 1). Contrarily, Gilbert (2012) reports that one third of greenhouse gas emissions come from agriculture, whose products are important for processors in the food sector and also serve as energy sources or precursors of the industrial sector. However, increased scrutiny reveals reporting of significantly different emission figures in different studies. While, for example, the Food and Agriculture Organization of the United Nations states that 18% of global greenhouse emissions result from the livestock sector (FAO, 2006), the World watch Institute (2009) concludes that livestock products account for at least 51% of annual global greenhouse gas emissions. Existing literature often provides very heterogeneous emission values that are often not directly comparable, e.g. due to different regional foci.

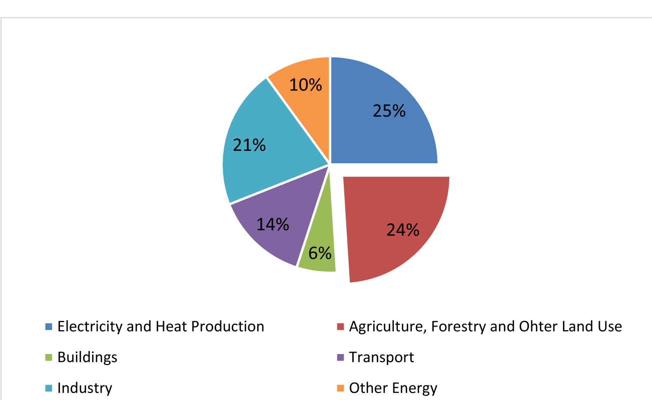
Agriculture is one of the main causes of climate change. After energy production, which accounts for 35% of global greenhouse gas emissions (17.15 GT CO_2e), the economic sector "agriculture, forestry and other land use" is seen as the second largest issuer (24%/11.75 CO_2e), according to ICPP (2014) (see Table 1).

Against this background, the authors of this article sought to achieve three objectives: First, heterogeneous emissions data should be collected and, based on this, a mean should be calculated. Second, answers to the question of how to explain the heterogeneity of the data should be found. Third, we aim to derive an understanding about the strengths of the main drivers. To achieve these goals, we apply the meta-regression analysis and adapt it innovatively to our research field. In the following we want to do a short contextualization of this method and its extension: To compare different studies and to identify common effects ("overall effects"), meta-analysis is normally used by default (Gurevitch et al., 2018). This method in general is designed to uncover mean effects and is applied in several disciplines like medicine, social science and environmental science. A recent, more advanced methodological strand based on meta-analysis is the meta-regression analysis. This is a common technique to analyze heterogeneity and is well established in economics as well as environmental economics. Both approaches use squared errors to account for the precision of the results. However, in our case, data is primarily reported without standard errors in underlying publications. Instead, only accurately measured values are reported and information on the precision of these values is missing. Thus, a classical meta-regression analytical approach to weight the examined studied cannot be applied. This circumstance has hindered the use of meta-regression analysis in the field of environmental performance measurement so far. In this article, we replace the standard error with a series of other quality measures for weighting the input data. Thanks to our newly established approach, we also make the meta-analysis operational in the context of environmental performance measurement. In determining the articles' quality, we have adopted established standards, such as the quality of the journal in which the study was published. We additionally used alternative metrics (altmetrics) as quality proxy. Following the path of including non-traditional bibliometric indicators, the "number of Facebook likes of the affiliation" could also be included in our weighting scheme. Thanks to the use of meta-regression analytical methods, it was also possible to determine which drivers have the greatest influence on agricultural emissions. In order to understand the global impact of agriculture in more detail, a meta-regression analysis is carried out which compiles fifty-three primary studies and covers the period from 1951 to 2015. In total, 1345 results on emitted amounts of CO_2e and SO_2e are documented, covering all countries or country groups worldwide. In particular, our study is designed to help us to understand the heterogeneity of the results reported so far.

Based on our research, we replicate the well-known result that (1) the livestock sector – and in particular cattle production – are strong drivers of emissions into the atmosphere. (2) More importantly, cultural specifics have explanatory power regarding the quantities emitted: the higher the "humane orientation" of a country, the lower the reported emission-level. In addition, (3) Publication characteristics play a decisive role: if the first author is affiliated to an NGO, higher emissions are reported. With "NGO related first author", we refer to the first named author of a study in case he is working for a non-governmental organization (NGO). The employment is apparent from the author's affiliation disclosed in the publication. With the help of our results we first contribute to the literature of measurement of greenhouse gas emission. Besides confirming the positive relationship between livestock density and emission levels (Hao et al., 2001; Godfray et al., 2010; Rzeźnik and Mielcarek, 2016) we identified with the results (2) and (3) two new determinants. Especially with the cultural variable we follow a pathway of publications which find out that cultural variables drive the sustainable management (Tilman and Clark, 2014; Vastola et al., 2017). Second, our insights support companies working in the primary sector, as well as in downstream supply chains or networks committed to sustainability, to measure external climate effects of their products. Lastly, our results are relevant for policy makers with the implementation of useful measures for reaching relevant Sustainable Development Goals (SDGs). There is also the question of how the Common Agricultural Policy (CAP) – i.e. the agricultural policy of the European Union (EU) – can be developed further. At 39%, it is the largest item in the EU's Multiannual Financial Framework (2014–2020) and has a major impact on how and which foods are grown in the EU and beyond.

For this purpose, we hereby report the scientific 'state-of-the-art' in section 2 and introduce our research design in section 3. To do so, we first address the operationalization (section 3.1) before we present our data and methodological approach (section 3.2). Section 4 is focused upon the main results, supplemented by different variations as well as robustness tests, and are completed

Table 1
Distribution of global anthropogenic greenhouse gas emissions (49 GT CO_2eq) to economic sectors (IPCC, 2014; EPA, 2016).



by sensitivity analysis. Section 5 concludes the work and motivates follow-up research.

2. The literature review

2.1. Agriculture in the context of sustainability and the anthropocene

An understanding of the need for sustainable action has grown significantly in recent decades. Already in 1983, the “World Commission for Environment and Development” set up by the United Nations developed the concept of sustainability. Since then, sustainable development has been defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). This vision was further developed into the “Agenda 21” by the United Nations’ Rio Summit on Environment and Development in 1992 (Momtaz and Kabir, 2018). Individuals, groups and organizations have been called upon to push global sustainability goals both ecologically and economically and socially. Sustainable thinking and action were concretized and operationalized in 2000 through the Millennium Development Goals (UN, 2009) and expanded by the UN’s Sustainable Development Goals (Sachs, 2012). Despite the fact that a large number of economic and social goals have been achieved over the past decades (UN, 2015), a number of ecological goals are showing a negative development (Rockström et al., 2009; Steffen, 2015). It is becoming increasingly clear that the influence of man on the environment as a whole is very negative. Therefore, in the scientific discourse there is now a consensus that man has become one of the most important factors influencing the biological, geological and atmospheric processes all over the world. In addition to climate change, the degree of human influence becomes obvious when looking at the global biomass distribution of mammals: humans account for 36%, livestock make up 60%, and wild animals represent only 4% of the mammalian biomass (Bar-On YM, 2018). As a consequence, the World Economic Forum’s annual risk map meanwhile states primarily environmental problems as the biggest risks for the global population (WEF, 2019). Due to the big human influence, a new age, the Anthropocene, is spoken of (Crutzen and Stoermer, 2000; Biermann et al., 2012). In this context, the agricultural sector is undoubtedly at the core of many global environmental problems: Besides its extensive contribution to global warming, agriculture is the single biggest land user with a share of over 37% of the global land area (FAO, 2016) and about 70% of global freshwater use (Chen et al., 2018). About 80% of the anthropogenically created reactive nitrogen comes from agricultural sources (Kanter et al., 2015), which is a major reason for eutrophic waterways and acidic airways (Stevens et al., 2014). The latest, most comprehensive report on species extinction by the UN concludes that agriculture has the biggest impact on species and habitat loss (Tollefson, 2019).

In the following, we first look at the emission of greenhouse gas in general and their theoretical mechanisms of action (section 2.2). Second we address the heterogeneity of previous publications (section 2.2).

2.2. Review of existing work on the climate impact of agriculture

The impact of industrial agriculture in the on current climate change, which is primarily caused by an everlasting increase in the emission of greenhouse gases, is not to be neglected (Steinfeld et al., 2006). The three main greenhouse gases emitted from agricultural activities are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Based on their specific impact intensity, these gases can be converted into CO_2-equivalents. The equivalent numbers express the gases’ Global Warming Potential (GWP) that combines the lifetime they remain in the atmosphere in this particular form as well as their energy-absorbing properties. Thus, CO_2 has the equivalent number of 1; the other gases are expressed in relation to their damage and are multiple times more potent: with a standard horizon of 100 years, CH_4 has a GWP of 25, N_2O has a GWP of 298 (EPA, 2018). Direct carbon dioxide emissions from agricultural sources arise through microbial degradation of animal residues and during the burning of waste such as the by-products of crop production. Land use change is another big source: CO_2 that was formerly bound in the ground or forests is released into the atmosphere when utilizing these areas for agricultural use. Agriculture is the biggest emitter of methane in the comparison of sectors with almost half of the global CH_4 emissions coming from the agricultural sector (FAO, 2017; Ritchie and Roser, 2017). CH_4 mainly develops during the enteric fermentation process of livestock, where bacteria in their digestive systems ferment the ingested feed and produce CH_4 as a by-product. Enteric fermentation is the biggest source of agricultural CH_4 and represents approximately half of the emissions (Gerber et al., 2013); it is, in fact, even the biggest source of anthropogenically emitted CH_4 globally (Yusuf et al., 2012). Other than the digestive process of ruminants, livestock’s waste management, rice cultivation, and agricultural waste burning are sources of CH_4 emissions (GMI, 2019). Almost three quarters of global nitrous oxide emissions can be traced back to the agricultural sector, making it the biggest emitter of this greenhouse gas by far with steadily increasing N_2O emissions. The biggest cause is an elevated use of mineral fertilizers and manure which leads to a nitrogen surplus in the soil. Such fertilizers are used excessively for enhancement of yield and therefore increase of sold produce, but they are used in such high amounts that the grown crop cannot retain all of the now available nutrients. Eventually emission of N_2O, amongst other compounds of reactive nitrogen, occurs over air or water ways. But also indirect sources, like the production of precursors, especially nitrogen fertilizers, are other sources of agricultural N_2O emissions (Mosier et al., 1998; Reay et al., 2012; Ritchie and Roser, 2017).

2.3. Heterogeneity of existing literature

To explain the heterogeneity of emissions from agriculture, numerous studies can be found in existing literature. Rześnik and Mielcarek (2016) conducted a review focusing on the three gases NH_3, N_2O and CH_4. Comparing the emission amounts of the two animal species pigs and dairy cows, they report big variations which they attribute to different geographical locations, feed compositions, housing and ventilation systems as well as the time of measurements. With the sole focus on greenhouse gas emissions, Hao et al. (2001) examine the impact of cattles’ manure composting, whereas Broucek (2017) addresses nitrous oxide production and investigates the scientific literature related to different drivers like microclimate, season, manure composition, microbial population, management, storage conditions, and the type of digestion. However, these relate primarily to different forms of husbandry and the resulting differences related to the amount of environmentally relevant emissions. These drivers are mainly related to the farms themselves and can – to some extent – be influenced by the farmer. This is where our research comes in, exploring drivers that go beyond drivers related directly to the farm-level. Following Crane et al. (2016) we accomplish “Theory Testing and Refinement” and thereby further develop existing theory. With our article, we therefore aim to better understand the heterogeneity of the emission levels reported in the individual studies and their drivers. This requires a differentiation of existing literature:

Whereas some studies refer to global agriculture (Verge et al., 2007; Rees, 2012), other contributions examine regions (De Vara and Jayet, 2011; Brown et al., 2012; Notarnicola et al., 2017), or specific countries (Björklund, 1999; Jongeneel et al., 2016; Fantin et al., 2017). Due to the differences between underlying areas and population figures in each study, a direct comparison of the amount of emissions seems difficult. In addition, countries differ in mechanization levels and the associated intensification of agriculture. Developed countries tend to use more technology, enabling higher yields and thus a smaller proportion of the population working in the primary sector. There are also differences in terms of geographic and climatic conditions and the associated potential yields. A trend towards higher amounts of agricultural climate emissions is reported for economically-developed countries compared to developing countries, when considering the factors highlighted above. In addition, publications can differ from one another regarding the different agricultural intensities of the regions studied. In some more populous countries land is used more intensively for agricultural purposes, in comparison to usage in other, geographically larger countries. In addition, regional cultivation or usage patterns differ. A good example is in the US state of California, where water management is of particular importance (Smart et al., 2011), whereas in rainy regions like the Philippines, wetland rice fields are the focus of research (van den Gon, 1996). Some regions are characterized by high production rates of livestock, which is also reflected in the focus of the publications (Flachmann and Mayer, 2014).

Publications differ regarding the underlying method used for determining emission levels. Some publications emphasize the development and application of specific methods. Winiwarter (2005) uses the Greenhouse Gas Airpollution, Interactions and Synergies (GAINS) model, based on the Regional Air Pollution Information and Simulation (RAINS) model, which estimates impact on the environment via emissions forecasts. The National Emissions Model for Agriculture (NEMA), used in the Netherlands, is based on a deterministic flow model that focuses on ammonia emission values of thirty-five different livestock species (Coenen et al., 2014). The DeNitrification-DeComposition model was developed particularly for the UK, and the four sub-models framing this process-oriented simulation relate to soil climate, plant growth, degradation, and denitrification (Brown et al., 2002). Other publications use proprietary methods applied to a multitude of countries, but for which no distinct method name has been established (Subak et al., 1993; EUROSTAT, 1997). Yet other studies use data resulting from existing evaluations as inputs for their own quantifying methods (Atkinson, 2004; O'Neill, 2007; Kundermann, 2014). Some publications identify individual agricultural sectors (agricultural soils, enteric fermentation, rice cultivation, manure management, other agricultural sources), without a detailed description of the assessment-process of emission quantities (EPA, 1999; EPA, 2006). In order to compare these figures with other total agricultural emissions, the amounts of the individual sectors are summed up. It is found that many publications refer to methods based on the IPCC (Tegtmeier and Duffy, 2004; Brown and Petrie, 2005; Tubiello et al., 2013; Jongeneel et al., 2016) – an intergovernmental organization initiated in 1988 by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO).

Another possibility for differentiation is cultural specifics. Cultural aspects seem to be important as the demand behaviour of consumers differs due to their cultural characteristics (Mullie et al., 2009). Exemplarily we refer to Tilman and Clark (2014) as they examine the specific role of India, where the consumption of food of animal origin is relatively low for religious reasons.

Publications can also be differentiated with regard to the publishing institution. In addition to academic research (Oenema et al., 2001; Tegtmeier and Duffy, 2004), national state organizations (Subak et al., 1993; Brown et al., 2005; Coenen et al., 2014), international state organizations (OECD, 2001; Leip et al., 2010), and non-governmental organizations (NGO) (Baumert et al., 2005; Goodland and Anhang, 2009) publish content concerning the environmental impacts of agriculture.

Considering the different emphases of previous studies, the authors aim to draw an overall picture of the actual extent of agricultural climate impacts and their drivers. Due to the numerous previous investigations a large number of results are available, which also differ greatly from one another. Therefore, conducting a meta-regression analysis is a suitable methodology. Meta-regression analysis, an extension of traditional meta-analytical techniques, which was initially established in the 1970s and was originally used in medical research, is an important method for developing research synthesis, particularly in the field of environmental performance measurement.

3. Research design

3.1. Operationalization

The authors focus upon the climate effects of global agricultural production and we investigate those using meta-regression analytical methods. We decided to create a meta-regression analysis to aggregate individual publications appropriately. Through the application of an innovative meta-regression analytical method, we were able to incorporate the individual publications on a weighted basis into our overall results. In addition, our approach makes it possible to identify influencing factors that explain the great heterogeneity of the individual study results. In accordance with the definition from Glass (1976, p. 3) we conduct a statistical analysis of a large collection of results from individual studies to integrate the findings. In order to appropriately quantify the effects of climate change resulting from agriculture, the term "global warming potential" (GWP) is a useful measure. The climate-damaging effect of CO_2, CH_4, and N_2O is measured in carbon dioxide equivalents (CO_2e). In the measurement of agriculture-related acidification potential, Sulphur dioxide (SO_2), nitrogen oxide (NO_x), and ammonia (NH_3) play central roles. To obtain information about the amounts of these gases resulting from agriculture as well as about the emitting countries, the following electronic databases and platforms are used for research: Google Scholar, the Electronic Journals Library, Journal-specific internet portals, and German Interlibrary Lending. To extract relevant publications, the following keywords are used individually and in combination: external effects, externalities, agriculture, greenhouse gas (emission), global warming (potential), agriculture, agricultural sector analysis, and economic evaluation. The search items are used in both singular and plural forms. In addition to the English terms, their equivalents in German language are also utilized. In the following step, we perform a forward search (via the "cited by"-option in Google Scholar) as well as a backward searches and therefore screen the reference lists of the studies initially identified relevant. From a total of 311 publications, 258 publications are found to be unsuitable because of their solely qualitative nature and the resulting absence of quantitative qualitative data. Additionally, several articles are purely model-theoretical. In part, the focus is not on specific countries, but rather for example, e.g. on the climate impacts of small regions or only specific cultivation or farming methods. In some cases, the climate impacts are not measured in quantities of CO_2e or SO_2e, but in monetary terms. Finally, 53 publications referring to 165 countries are identified as relevant and thus are included in our meta-analysis. Each of these studies focuses on one or more countries resulting in a total number of 1345 observations, which we manually collected. The investigation period of the different studies covers articles from 1951 to 2015 and was performed from December 2016 to March 2017. As described above, our goal is to explain the heterogeneity of the different results of studies that deal with agricultural emissions. Based on existing literature, we distinguish between the emissions variables (variables to be explained) and five categories of potential drivers (explanatory variables) (see Table 2 for an aggregated list of the drivers).

Determinants of greenhouse and acidification gases: Global warming and acidification potential are of primary importance when investigating agricultural effects on the atmosphere (Brentrup et al., 2004). To examine global warming it is crucial to investigate the emission quantities of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). To measure global acidification potential, Sulphur dioxide (SO_2), nitrogen oxide (NO_x), and ammonia (NH_3) are the drivers to be considered (Brentrup, 2001; Goulding, 2016). Although scientific consensus exists on agriculture's significant and overall negative impacts on the environment (Matson et al., 1997; Foley et al., 2005), only recently-published research differentiates the scientific landscape, including both input factors (e.g. energy-, water or land use) as well as output and emission factors (Poore and Nemecek, 2018).

Quantitative country determinants: Furthermore, agricultural systems in different countries vary greatly. On the one hand this is due to the differing numbers of inhabitants, and on the other hand to the different areas of the countries. The countries are also very different in terms of their economic development (OECD, 2018). The specific level of food supply is closely linked to the economic performance of a country. Often, the primary sector in poorer, mostly African countries provides a very low level of food security in comparison to wealthier countries, with partially less than the minimum of 1800 kilocalories being supplied there. In contrast, most of the western population consumes more than 3600 kilocalories per day (FAO, 2018a). Significant differences concerning dietary composition are evident as well. Tilman and Clark (2014) report that meat consumption increases with higher income even though it decreases after reaching a certain threshold in some western countries (Gaugler, 2015). Against this background, we hypothesize that developed countries are characterized by higher per capita emissions. Furthermore, we hypothesize that a high number of inhabitants per area (and the associated nutritional needs) implies a higher amount of emissions.

Determinants of livestock and crops: In addition to economic differences, diverse climatic and geographical conditions are relevant factors. In the case of food of animal origin, cattle farming, pig farming, and poultry farming are particularly important. The five leading beef producers are the USA, Brazil, China, Argentina, and Australia. By far the largest producer of pigs is China, followed by the USA, Germany, Spain, and Brazil. The largest quantities of poultry are produced in the USA, China, Brazil, Mexico, and India (FAO, 2018b). In order to compare different livestock species that differ in their live weight, a conversion into animal units (AU) (which corresponds to the live weight of one cow) is common. Dividing AU from the country-specific area results in units of livestock density (EU, 2017). High livestock densities are associated with intensive livestock farming, while low livestock density is referred to as extensive livestock farming. Conversely, the main products of plant production are corn, wheat, and rice. The USA, China, Brazil, Argentina, and Mexico are the largest corn-growing countries, while most wheat is grown in China, the USA, India, Russia, and Indonesia. Rice cultivation is primarily conducted in China, India, Indonesia, Bangladesh, and Vietnam (FAO, 2018c). Related to this category, we derive two hypotheses: In terms of crops, we assume that the agricultural area and the amount of emissions have a positive correlation. In terms of livestock, current literature agrees that the production of animal-based foods is – on average – significantly more resource-intensive and causes bigger environmental impacts than the production of plant-based foods (Steinfeld, 2006; Garnett, 2011; Clune et al., 2017). Thus, we hypothesize that the amount of livestock kept is positively correlated with the amounts of agricultural emissions.

Culture-related country determinants: Culture can be defined as "shared motives, values, beliefs, identities and interpretations or meanings of significant events that result from common experiences of members of collectives and are transmitted across age generations" (House et al., 2004, p. 15). Cultural influences on the attitudes and behaviour of inhabitants of different regions and countries were already investigated in the 1960s by Hofstede's cultural dimensions (Hofstede, 1980). Their number has been increased from the original four to six dimensions (Hofstede et al., 2010).

A further differentiated understanding is presented in the GLOBE-study, which uses nine variables to define and operationalize cultural differences among different countries (House et al., 2004): The dimension of (1) power distance measures the degree to which members of a collective expect power to be distributed equally. (2) Uncertainty avoidance is a measure for the extent to which a society, organization, or group relies on social norms, rules, and procedures to alleviate unpredictability of future events. The dimension of (3) humane orientation indicates the degree to which a collective encourages and rewards individuals for being fair, altruistic, generous, caring, and kind to others (Hoppe, 2007). The additional dimensions are (4) institutional collectivism, (5) in-group collectivism, (6) assertiveness, (7) gender egalitarianism, (8) future orientation, and (9) performance orientation (Hoppe, 2007). We assume that not all of the dimensions quantified by GLOBE are directly related to the amount of agricultural emissions. Nevertheless, we hypothesize two correlations: First, we expect that a higher degree of future orientation is negatively correlated with the amount of emissions, as these have a negative effect on human livelihood (i.e.: regarding climate and environment) in the medium and long term. On the other hand, we hypothesize that a higher level of human orientation is associated with greater awareness of sustainability (Parboteeah, 2012) and thus is associated with lower emissions.

Determinants of publication characteristics: Authors of many meta-analyses emphasize the influence of publication-characteristics on the heterogeneity of the studies' results. First and foremost, the varying measurement methods used in those studies can often explain the differences in reported results (Hang et al., 2018). But other characteristics indicating conclusions on the quality of the particular studies are also reported. For example, whether the results are published in a reputable journal (what e.g. can be measured by the SJR-impact factor) could be one focus and could shed light on the existence of a publication bias: biased values (i.e. high emission amounts) could be reported, facilitating publication in high ranked journals. Furthermore, by evaluating the article's citation number, it can be identified to which extent its results are considered for further scientific discussion (Hang et al., 2017). Another possible differentiation could occur on the level of authors belonging to distinct affiliations. Lastly, the time period of investigation can influence the results as well (Valickova et al., 2015), as scientific progress in agriculture could help reduce emissions rates. By exploring the relationship between publication characteristics and agricultural emission levels, we enter uncharted scientific territory and refrain from putting forward any hypotheses. Accordingly, we have marked the corresponding expected signs in Tables 3–6 and Table 8 (in the Appendix) with indifference ($\pm$).

Table 2
The used explanatory variables and the results of the descriptive statistic (minimum, maximum, mean, median, standard derivation) of our meta-regression are compiled here.

	Unit	Dummy	Min.	Max.	Mean	Median	Standard Deviation
Quantity of Greenhouse and Acidification gases [QU]							
Carbon dioxide	t/km^2		1.00	212.83	22.50	11.27	41.94
Methane	t/km^2		1.09	18.02	3.58	2.84	2.56
Nitrous oxide	t/km^2		1.00	3.70	1.18	1.11	0.26
Carbon dioxide equivalents	t/km^2		1.02	650.93	117.54	96.17	102.75
Sulphur dioxide	t/km^2		1.01	2583.87	861.96	1.01	1491.21
Nitrogen oxide	t/km^2		1.00	1.11	1.03	1.01	0.03
Ammonia	t/km^2		1.01	3086.96	73.88	2.12	470.43
Carbon dioxide	%	X[1]	0.00%	100.00%	11.30%	0.00%	0.32
Methane	%	X[2]	0.00%	100.00%	27.14%	0.00%	0.44
Nitrous oxide	%	X[3]	0.00%	100.00%	27.66%	0.00%	0.45
Carbon dioxide equivalents	%	X[4]	0.00%	100.00%	28.18%	0.00%	0.45
Sulphur dioxide	%	X[5]	0.00%	100.00%	0.22%	0.00%	0.05
Nitrogen oxide	%	X[6]	0.00%	100.00%	2.30%	0.00%	0.15
Ammonia	%	X[7]	0.00%	100.00%	3.20%	0.00%	0.18
***Quantitative* Country data [QC]**							
Inhabitants[8]	# (log)		13.95	21.01	17,22	17,46	1,47
Area[9]	km^2 (log)		6,58	16,65	12,94	12,79	1,89
Inhabitants/area	#/km^2		1,39	7,061,20	186,61	92,28	610,21
GDP[10]	US$ pc (log)		5,55	11,22	9,34	9,91	1,29
Country: USA	%	X[11]	0,00%	100,00%	7,58%	0,00%	26,48%
Country: Germany	%	X[12]	0,00%	100,00%	4,46%	0,00%	20,65%
Country: United Kingdom	%	X[13]	0,00%	100,00%	5,35%	0,00%	22,52%
Country: Netherlands	%	X[14]	0,00%	100,00%	3,87%	0,00%	19.29%
Data on Livestock and Crops [LD][15]							
Livestock: Cattle	#		2.78	1263.19	251.83	163.93	246.13
Livestock: Chicken	#		0.02	45.90	3.80	2.10	5.77
Livestock: Pig	#		0.02	4458.72	432.47	176.16	803.83
Livestock: Animal Units	AU/km^2		0.00	2480.09	417.77	249.12	497.73
Crops: Area harvested	km^2		0.02	37.58	10.63	9.15	8.12
Crops: Permanent crops	t		0.00	1.50	0.04	0.00	0.16
Crops: Grain	t		0.00	34.78	7.23	4.48	7.00
Crops: Others	t		0.00	6.87	1.22	0.83	1.16
Crops: Biomass	t		0.00	15.24	2.13	1.86	2.19
Culture Related Country Data [CC][16]							
Globe 1: Assertiveness	–		2.66	5.56	3.72	3.68	0.62
Globe 2: Institutional collectivism	–		3.83	5.65	4.65	4.59	0.47
Globe 3: In-group collectivism	–		4.94	6.52	5.62	5.67	0.31
Globe 4: Future orientation	–		4.33	6.20	5.34	5.31	0.39
Globe 5: Gender egalitarianism	–		3.18	5.17	4.73	4.83	0.41
Globe 6: Humane orientation	–		4.49	6.09	5.46	5.48	0.24
Globe 7: Performance orientation	–		5.17	6.58	5.92	5.90	0.28
Globe 8: Power distance	–		2.04	3.53	2.67	2.70	0.30
Globe 9: Uncertainty avoidance	–		3.16	5.61	4.36	4.26	0.62
Publication Characteristics [PC]							
First author supra-national	%		0.00%	100.00%	81.34%	100.00%	38.97%
First author NGO	%		0.00%	100.00%	7.43%	0.00%	2.73%
Reference year (RY)[17]	#		5.00	32.00	17.56	15.00	7.15
SCImago Journal Rank[18]	–		0.00	2.03	0.14	0.00	0.44
Google Scholar: citations/year[19]	#		0.03	2.27	0.22	0.29	0.14
Method 1: Addition of data	%	X[20]	0.00%	100.00%	49.14%	0.00%	50.01%
Method 2: Study-specific method	%	X[21]	0.00%	100.00%	13.98%	0.00%	34.69%
Method 3: GAINS, NEMA, etc.	%	X[22]	0.00%	100.00%	0.07%	0.00%	2.73%
Method 4: Based on other studies	%	X[23]	0.00%	100.00%	0.52%	0.00%	7.20%
Publication Quality (alternatives)							
Factor weighted	–		0.29	0.68	0.51	0.60	0.12
First factor	–		−444,800.66	4625.54	−160,672.78	−234,921.71	99,222.71
Two factors	–		−416,486.61	288,33	−157,883.34	−230,911.22	97,450.42

GDP = Gross Domestic Product; pc = per capita.
[1] 1 if the study investigates only carbon dioxide emissions, 0 otherwise.
[2] 1 if the study investigates only methane emissions, 0 otherwise.
[3] 1 if the study investigates only nitrous oxide emissions, 0 otherwise.
[4] 1 if the study investigates only carbon dioxide equivalent emissions, 0 otherwise.
[5] 1 if the study investigates only Sulphur dioxide emissions, 0 otherwise.
[6] 1 if the study investigates only nitrogen oxide emissions, 0 otherwise.
[7] 1 if the study investigates only ammonia emissions, 0 otherwise.
[8] Referring to the reference years of the underlying studies. Source: https://data.worldbank.org/indicator/SP.POP.TOTL.
[9] Source: https://data.worldbank.org/indicator/AG.LND.TOTL.K2.
[10] Referring to the reference years of the underlying studies. Source: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD.

[11] 1 if the study investigates only the USA, 0 otherwise.
[12] 1 if the study investigates only Germany, 0 otherwise.
[13] 1 if the study investigates only the United Kingdom, 0 otherwise.
[14] 1 if the study investigates only the Netherlands, 0 otherwise.
[15] Sources: http://www.fao.org/faostat/en/#data/QA, http://www.fao.org/faostat/en/#data/QC.
[16] Source: House et al. (2004).
[17] Reference: Number of years since 1980.
[18] Source: https://www.scimagojr.com/.
[19] Google Scholar-based number of citations per year are measured as log (2 + cit)/(2018-RY).
[20] 1 if the study investigates only Method 1, 0 otherwise.
[21] 1 if the study investigates only Method 2, 0 otherwise.
[22] 1 if the study investigates only Method 3, 0 otherwise.
[23] 1 if the study investigates only Method 4, 0 otherwise.

Table 3

The main results presented in this table are structured as follows: The left half of this table applies to the base case, in which the quality of all examined publications is rated due to their average yearly Google citations as well as the first, best factor. Beta-values are stated in first column; p-values are shown in the second and third columns. For estimating p-values we first use clustered standard errors (SE) at the study level. The third column is based on clustered standard errors on study and country levels. Variables with an error-probability lower than 1% (p-value = 0,00) and 1% (0,00 < p-value < 0,01) are highlighted in bold letters. In the right half of this table results are represented when they underlie the inhabitants per area. Analogous to the base case, first the Google citation number and second the first, best factor is used as the measure of quality.

		Base Case						Inhabitants / Area					
		# Google Citations			1st Factor			# Google Citations			1st Factor		
	Exp. sign	Beta	Cluster SE Study P-value	Cluster SE Study and Country P-value	Beta	Cluster SE Study P-value	Cluster SE Study and Country P-value	Beta	Cluster SE Study P-value	Cluster SE Study and Country P-value	Beta	Cluster SE Study P-value	Cluster SE Study and Country P-value
Carbon dioxide		255.55	0.18	0.02	177.79	0.05	**0.01**	76.30	0.37	0.32	-57.69	0.21	0.24
Methane		227.26	0.21	0.02	167.24	0.06	0.02	47.31	0.42	0.38	-68.44	0.17	0.20
Nitrous oxide		234.43	0.21	0.02	165.21	0.07	0.02	54.64	0.41	0.36	-70.45	0.16	0.19
Carbon dioxide equivalents		351.67	0.11	**0.00**	269.06	**0.01**	**0.00**	171.63	0.24	0.16	33.44	0.32	0.35
Sulphur dioxide		1921.60	**0.01**	**0.01**	1452.14	0.05	0.06	1740.00	0.02	0.02	1213.95	0.08	0.09
Nitrogen oxide		256.32	0.19	0.02	154.27	0.08	0.03	76.19	0.38	0.34	-81.25	0.13	0.17
Ammonia		417.27	0.17	0.06	146.05	0.09	0.03	236.53	0.28	0.23	-89.68	0.10	0.14
Google Scholar: citations / year	+/-	2.34	0.44	0.42	0.00	0.03	0.03	3.11	0.42	0.40	0.00	0.04	0.03
SCImago Journal Rank	+/-	12.88	0.16	0.05	-2.22	0.36	0.39	11.57	0.18	0.06	-1.55	0.40	0.42
Reference year (RY) since 1980	+/-	0.91	0.21	0.11	-0.19	0.16	0.17	0.89	0.22	0.12	-0.24	0.08	0.10
Livestock: Animal units / area	+	0.07	**0.00**	**0.00**	0.07	**0.00**	**0.00**	0.07	**0.00**	**0.00**	0.09	**0.00**	**0.00**
GDP	+	-0.49	0.46	0.44	3.06	0.04	0.08	0.43	0.47	0.46	5.32	**0.00**	**0.00**
Inhabitants / area	+	2.75	0.04	0.08	0.84	0.16	0.18						
Globe 1: Assertiveness		1.24	0.32	0.37	-3.22	0.05	0.14	5.36	0.02	0.05	0.86	0.29	0.33
Globe 2: Inst. collectivism		3.47	0.28	0.34	-0.32	0.46	0.48	8.81	0.05	0.09	5.85	**0.01**	0.08
Globe 3: In-group collectivism		-24.78	0.04	0.04	-14.21	0.02	0.05	-22.39	0.05	0.08	-10.66	0.05	0.17
Globe 4: Future orientation	-	31.21	0.08	0.05	4.85	0.27	0.31	38.17	0.06	0.02	12.74	0.06	0.06
Globe 5: Gender egalitarianism		2.82	0.36	0.37	2.87	0.19	0.30	0.69	0.46	0.47	-1.74	0.29	0.38
Globe 6: Humane orientation	-	-38.38	0.04	**0.00**	-30.05	**0.00**	**0.00**	-18.71	0.14	0.11	-9.37	0.06	0.17
Globe 7: Performance orientation		-14.64	0.14	0.04	-3.33	0.24	0.28	-15.88	0.12	0.04	-4.64	0.16	0.20
Globe 8: Power distance		-7.00	0.34	0.24	-6.49	0.18	0.13	6.03	0.33	0.26	7.01	0.06	0.04
Globe 9: Uncertainty avoidance		-14.58	0.13	0.11	4.01	0.14	0.23	-15.69	0.13	0.12	4.21	0.13	0.21
First author supra-national	+/-	-35.94	0.28	0.24	-0.76	0.45	0.46	-37.63	0.27	0.23	-1.20	0.42	0.44
First author NGO	+/-	67.97	**0.00**	**0.00**	93.36	**0.00**	**0.00**	69.99	**0.00**	**0.00**	94.71	**0.00**	**0.00**
Method 1: Addition of data		43.27	0.18	0.21	-10.06	0.10	0.17	43.79	0.18	0.21	-9.09	0.12	0.18
Method 2: Study-specific method		9.48	0.31	0.31	-1.95	0.39	0.40	8.51	0.32	0.32	-2.86	0.35	0.36
Method 3: GAINS, NEMA, etc.		38.50	0.24	0.28	-17.64	0.02	0.04	40.18	0.24	0.27	-14.99	0.04	0.08
Method 4: Based on other studies		-184.44	0.02	0.03	-138.89	0.14	0.13	-178.57	0.02	0.04	-128.24	0.16	0.15
Crops: Area harvested	+	-0.11	0.45	0.42	0.57	0.03	0.07	-0.30	0.38	0.27	0.34	0.12	0.14
R^2		0.42			0.63			0.43			0.64		
F-test		35.11			79.21			35.32			82.01		
Number of observations		1345			1345			1345			1345		

3.2. *Data*[1] *and methodology*

Based on these theoretical preparatory works, we operationalize our five categories as follows:

The agricultural quantity of greenhouse and acidification gases [QU] (based on the reference year) reported in the examined publications is differentiated as follows: (1) the amount of carbon dioxide CO_2, (2) the amount of methane CH_4 and (3) the amount of nitrous oxide N_2O. The emission masses of these three gases can be aggregated to (4) carbon dioxide equivalents (CO_2e). Moreover, (5) the amount of Sulphur dioxide SO_2, (6) the amount of nitrogen oxide NO_x, and (7) the amount of ammonia NH_3 are collected – as far as they are reported. These compounds are combinable to (8) Sulphur dioxide equivalents (SO_2e) (see aggregation schemes for CO_2e and SO_2e later in this paragraph, short after Table 2).

Quantitative country data [QC] extends to (9) the country name, (10) the number of inhabitants of the country in the reference year (meaning the year the emission data was collected), (11) the area of the country and – in combination – (12) the inhabitants per area. These variables are necessary to compare the levels of emissions reported for different countries. We measure economic development by (13) the countries' GDP (in billion US-dollars), again based on the specific reference year.

The third category covers data on livestock and crops [LD]. We distinguish between plant production and animal production, as the production systems – as well as their expected emission levels – differ widely. In addition to (14) the number of cattle and (15) chickens, we also included (16) the number of pigs of the examined country and the reference year of each publication. Thus, we cover about 95% of the terrestrial animals consumed worldwide (FAO, 2018). The livestock numbers refer to live animals. To distinguish

[1] The authors collected data with highly esteemed support of Marie Mehrens.

Table 4

The first variation, in which countries with more than 30 study results were further analysed, is structured as follows: Analogous to the evaluation process used in Table 3, the average yearly number of citations of an article on Google scholar is used as a quality measure (left half of the table). As a different measuring tool, we use the first, best factor (right half of the table). For the estimating process we use clustered standard errors on the study-level as well as clustered standard errors on study and country levels. Again, variables with an error-probability lower than 1% (p-value = 0,00) and 1% (0,00 < p-value < 0,01) are highlighted in bold letters.

		Inhabitants					
		# Google Citations			1st Factor		
		Beta	Cluster SE Study	Cluster SE Study and Country	Beta	Cluster SE Study	Cluster SE Study and Country
	Exp. sign		P-value	P-value		P-value	P-value
Carbon dioxide		-10.05	0.46	0.46	24.29	0.36	0.39
Methane		-44.46	0.32	0.33	13.54	0.42	0.44
Nitrous oxide		-36.57	0.35	0.36	11.52	0.43	0.45
Carbon dioxide equivalents		81.83	0.20	0.21	115.53	0.05	0.09
Sulphur dioxide		1641.56	0.01	0.02	1277.56	0.07	0.08
Nitrogen oxide		-1.60	0.49	0.49	-5.17	0.47	0.48
Ammonia		151.71	0.27	0.26	-8.07	0.46	0.46
Google Scholar: citations / year	+/-	-8.19	0.34	0.36	0.00	0.05	0.04
SCImago Journal Rank	+/-	14.88	0.11	0.04	-7.29	0.15	0.19
Reference year (RY) since 1980	+/-	0.63	0.25	0.17	-0.28	0.04	0.05
Livestock: Animal units / area	+	0.02	0.18	0.20	0.05	**0.00**	**0.00**
GDP	+	2.53	0.16	0.20	4.77	**0.00**	**0.01**
Inhabitants / area	+	-1.14	0.26	0.20	-0.82	0.11	0.13
Globe 1: Assertiveness		3.73	0.08	0.12	-0.86	0.29	0.37
Globe 2: Inst. collectivism		11.20	**0.01**	0.14	5.60	0.02	0.20
Globe 3: In-group collectivism		-7.72	0.15	0.14	-2.63	0.27	0.29
Globe 4: Future orientation	-	7.76	0.21	0.19	-4.88	0.19	0.22
Globe 5: Gender egalitarianism		2.10	0.37	0.40	-2.89	0.17	0.33
Globe 6: Humane orientation	-	-10.81	0.05	0.12	-14.35	**0.01**	0.03
Globe 7: Performance orientation		-10.04	0.07	0.12	-0.89	0.42	0.45
Globe 8: Power distance		11.00	0.05	0.21	2.02	0.32	0.35
Globe 9: Uncertainty avoidance		-0.38	0.47	0.48	7.85	**0.00**	0.11
First author supra-national	+/-	-34.47	0.29	0.25	-0.59	0.46	0.47
First author NGO	+/-	87.02	**0.00**	**0.00**	82.22	**0.00**	**0.00**
Method 1: Addition of data		47.39	0.17	0.20	-9.23	0.12	0.19
Method 2: Study-specific method		9.72	0.30	0.29	-3.87	0.30	0.29
Method 3: GAINS, NEMA, etc.		59.01	0.21	0.23	-34.32	**0.00**	**0.00**
Method 4: Based on other studies		-195.82	0.03	**0.01**	-165.97	0.10	0.09
Crops: Area harvested	+	0.68	0.03	0.07	0.90	**0.00**	0.02
USA		25.57	0.05	0.21	2.63	0.32	0.38
Germany		37.93	**0.00**	**0.00**	26.55	**0.00**	**0.00**
UK		-8.49	0.37	0.27	26.26	**0.00**	**0.00**
Netherlands		137.91	0.09	**0.00**	82.29	**0.00**	**0.01**
R^2		0.43			0.64		
F-test		31.45			71.79		
Number of observations		1345			1345		

between the different animals, the data is combined to (17) livestock units with factors of 1 (per cattle), 0.39 (per pig), and 0.0106 (per chicken). Furthermore, we determine (18) the agricultural acreage (in km^2)) of the publications' underlying countries. To ensure similar coverage of plant production, the acreage of the 15 most important plant species for the reference year are considered. The importance of the individual species is measured by the worldwide production quantity of plant produce. Additionally, plant produce is aggregated in the following categories: (19) permanent crops, (20) grains, (21) others, and (22) biomass.

To provide insights into possible differences among inhabitants of different countries related to their specific attitude or behaviour, we include culture-related country data [CC] resulting from scores of the GLOBE study (House et al., 2004). The country-specific GLOBE-indicators used include: (23) assertiveness, (24) institutional collectivism, (25) in-group collectivism, (26) future orientation, (27) gender egalitarianism, (28) humane orientation, (29) performance orientation, (30) power distance, and (31) uncertainty avoidance.

To determine whether publication characteristics — related to the publishing journal, to the authors as well as to a specific publication — provide information about the heterogeneity of the reported emission quantities, the following possibly explanatory variables [PC] are employed: (32) the title of the publications, (33) the reference year of the inherent data, (34) the authors, and (35) the affiliation of the leading author. Therefore, we distinguish between (35a) a University, (35b) a national state organization, (35c) a supra-national state organization, (35d) a non-governmental organization (NGO), or (35e) a different or not ascertainable organization. Furthermore, we include — as far as possible — (36) the publishing journal of the underlying publication as well as (37) the journal's SJR indicator (SCImago Journal Rank) at the time of publishing. Moreover (38) the absolute number of citations (Google scholar) is referenced as well as (39) the investigation method of the emission data. Due to the resulting variety of methods used, we decided to use following five methodical approaches: approaches of (39a) perform a summation of different data collected within the publication itself (i.e. "method 1"). With approach (39b) inherent

Table 5

In the second variation, various animal species and plant crops are examined in more detail: Analogous to the evaluation process used in Tables 3 and 4, the average yearly number of citations on Google scholar is used as a quality measure (left half of the table). As a different measuring tool, we use the first, best factor (right half of the table). For the estimating process we again use clustered standard errors on the study-level as well as clustered standard errors on study and country levels. Again, variables with an error-probability lower than 1% (p-value = 0,00) and 1% (0,00 < p-value < 0,01) are highlighted in bold letters.

		Livestock and Crops					
		Google Citations			1st Factor		
	Exp. sign	Beta	Cluster SE Study P-value	Cluster SE Study and Country P-value	Beta	Cluster SE Study P-value	Cluster SE Study and Country P-value
Carbon dioxide		268.76	0.20	0.04	161.81	0.04	**0.01**
Methane		238.83	0.23	0.05	151.57	0.05	0.02
Nitrous oxide		246.60	0.23	0.05	149.61	0.05	0.02
Carbon dioxide equivalents		364.12	0.14	**0.01**	253.69	**0.00**	**0.00**
Sulphur dioxide		1929.95	**0.01**	**0.01**	1428.84	0.06	0.06
Nitrogen oxide		266.59	0.22	0.05	131.57	0.08	0.03
Ammonia		431.54	0.19	0.06	131.23	0.08	0.02
Google Scholar: citations / year	+/-	-0.08	0.50	0.50	0.00	0.05	0.05
SCImago Journal Rank	+/-	13.33	0.14	0.05	-5.16	0.22	0.29
Reference year (RY) since 1980	+/-	0.79	0.23	0.13	-0.32	0.03	**0.01**
Livestock: Animal units / area	+						
GDP	+	1.48	0.39	0.33	5.77	**0.00**	**0.00**
Inhabitants / area	+	2.43	0.13	0.23	-0.66	0.19	0.29
Globe 1: Assertiveness		-1.26	0.36	0.30	-5.12	**0.00**	**0.00**
Globe 2: Inst. collectivism		7.16	0.07	0.12	3.16	0.09	0.15
Globe 3: In-group collectivism		-8.98	0.20	0.27	6.57	0.09	0.21
Globe 4: Future orientation	-	10.51	0.20	0.20	-15.88	**0.00**	**0.00**
Globe 5: Gender egalitarianism		-1.31	0.42	0.42	-4.23	0.05	0.05
Globe 6: Humane orientation	-	-29.05	0.09	**0.01**	-16.62	**0.00**	**0.00**
Globe 7: Performance orientation		-27.60	0.09	**0.01**	-18.55	**0.01**	0.05
Globe 8: Power distance		-3.60	0.41	0.32	-2.40	0.34	0.30
Globe 9: Uncertainty avoidance		-10.42	0.22	0.20	10.42	**0.00**	**0.01**
First author supra-national	+/-	-35.81	0.28	0.24	-1.96	0.37	0.39
First author NGO	+/-	66.29	**0.00**	**0.00**	86.83	**0.00**	**0.00**
Method 1: Addition of data		44.20	0.18	0.21	-8.68	0.12	0.20
Method 2: Study-specific method		10.73	0.28	0.29	-4.89	0.26	0.27
Method 3: GAINS, NEMA, etc.		37.75	0.27	0.29	-27.37	**0.00**	**0.00**
Method 4: Based on other studies		-221.73	**0.01**	**0.01**	-183.73	0.08	0.07
Livestock Cattle	+	0.09	**0.00**	**0.00**	0.12	**0.00**	**0.00**
Livestock: Chicken		0.59	0.32	0.32	0.29	0.25	0.33
Livestock: Pig		0.02	0.10	0.02	0.01	**0.00**	**0.00**
Bananas, palm	-	8.27	0.13	0.16	12.53	**0.00**	**0.00**
wheat, barley, rice	-	-0.77	0.29	0.07	-0.02	0.48	0.48
Rest (vegetable etc.)		2.31	0.19	0.20	5.42	**0.00**	**0.00**
Potatoes, corn, watermelon, sugar cane	+	2.94	0.08	0.03	1.79	**0.01**	0.03
R^2		0.43			0.64		
F-test		29.97			71.60		
Number of observations		1345			1345		

methods specific to the publication are aggregated ("method 2"); in (39c) rarely used methods (e.g. GAINS, NEMA Model, phase II methodology, UK-DNDC) are summarized ("method 3"). (39d) combines approaches that use the database of various studies for their own quantifying methods ("method 4"). Lastly (39e) describes publications that use IPCC-based methods (1990, 1992, 1996, 1997, 2000, scenario IS92a, tier 1, tier 2), which differ in release dates and the variety of scenarios used ("method 5").

The majority of studies — covering 165 countries in total — are based on CO_2, with the most data available for the USA, followed by Germany, the United Kingdom, and the Netherlands. Results show that the underlying studies have a low average ranking and that most of the studies are issued by supranational organizations. Since studies refer to worldwide data, there is great heterogeneity in the cultivated agricultural products and livestock results (Table 2).

Our method is delineated and presented in detail below. Attention should first be drawn to the aggregation of the different emitted gases. In order to compare the climate impacts of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), they are set in relation to the climate impact of CO_2 as follows: based on an observation period of 100 years, the greenhouse gas potential of CH_4 is 25 times higher than that of CO_2. The emission of one ton of N_2O has a greenhouse gas effect 298 times higher than the same amount of CO_2 (EPA, 2018). To assess acidification potential the emission quantities of Sulphur dioxide (SO_2), nitrogen oxide (NO_x), and ammonia (NH_3) are significant. In order to aggregate the effects of these gases into SO_2e, their specific acid formation potential is calculated and set against the reference substance SO_2. This results in factors of 1 for SO_2, 0.7 for NO_x, and 1.88 for NH_3 (Brentrup, 2001). The primary goal of our empirical analysis is to explain the heterogeneity of external effects in different primary studies. Hence, a meta-regression analysis is applied in order to regress the

Table 6
In the third variation, we focus on CO_2 equivalents: Analogous to the evaluation process used in Table 3, Table 4, and Table 5, the average yearly number of citations on Google scholar is used as a quality measure (left half of the table). As a different measuring tool, we use the first, best factor (right half of the table). For the estimation process we use clustered standard errors on the study-level as well as the clustered standard errors on the study and country level. Again, variables with an error-probability lower than 1% (p-value = 0,00) and 1% (0,00 < p-value < 0,01) are highlighted in bold letters.

		Carbon dioxide					
		Google Citations			1. Faktor		
		Beta	Cluster SE Study	Cluster SE Study and Country	Beta	Cluster SE Study	Cluster SE Study and Country
	Exp. sign		P-value	P-value		P-value	P-value
Carbon dioxide							
Methane							
Nitrous oxide							
Carbon dioxide equivalents		659.38	**0.00**	**0.00**	547.19	**0.01**	**0.00**
Sulphur dioxide							
Nitrogen oxide							
Ammonia							
Google Scholar: citations / year	+/-	-52.71	0.24	0.19	0.00	0.15	0.27
SCImago Journal Rank	+/-	-0.13	0.50	0.50	-14.27	0.06	0.08
Reference year (RY) since 1980	+/-	-0.06	0.44	0.44	-0.43	0.13	0.14
Livestock: Animal units / area	+	0.16	**0.00**	**0.00**	0.17	**0.00**	**0.00**
GDP	+	6.77	0.02	0.10	9.61	**0.00**	0.03
Inhabitants / area	+	0.42	0.41	0.41	1.09	0.26	0.28
Globe 1: Assertiveness		-2.92	0.25	0.30	-5.52	0.10	0.20
Globe 2: Institutional collectivism		4.57	0.28	0.40	2.72	0.36	0.43
Globe 3: In-group collectivism		-51.85	**0.00**	0.02	-37.98	**0.00**	0.03
Globe 4: Future orientation	-	33.63	**0.01**	0.12	15.14	0.12	0.26
Globe 5: Gender egalitarianism		11.30	0.12	0.27	7.88	0.15	0.30
Globe 6: Humane orientation	-	-79.89	**0.00**	**0.00**	-75.11	**0.00**	**0.00**
Globe 7: Performance orientation		-17.31	**0.01**	0.08	-10.41	0.11	0.23
Globe 8: Power distance		-14.96	0.15	0.23	-15.54	0.14	0.15
Globe 9: Uncertainty avoidance		-6.21	0.23	0.34	6.52	0.19	0.32
First author supra-national	+/-	-30.54	**0.00**	**0.00**	-11.77	0.16	0.16
First author NGO	+/-	54.94	**0.00**	**0.00**	53.04	**0.00**	**0.00**
Method 1: Addition of data		10.51	0.14	0.10	5.34	0.18	0.25
Method 2: Study-specific method							
Method 3: GAINS, NEMA, etc.							
Method 4: Based on other studies		143.22	**0.00**	**0.00**	132.96	**0.00**	**0.00**
Crops: Area harvested	+	1.16	0.01	0.14	1.61	**0.00**	0.06
R^2		0.88			0.86		
F-test		133.12			106.57		
Number of observations		379			379		

external effects on explanatory variables (sometimes referred to as moderator variables) (Stanley and Jarrell, 1989). The latter comprise regional differences, data characteristics, differences in variable operationalization publication characteristics as well as the theory-guided factors influencing external effects that can be measured on study level (see Table 2). Altogether, this results in the following regression equation:

$$ee_{ij} = \sum_{l=1}^{7} \beta_{0,l} D_{ijl} + \beta_1 pq_j + \sum_{k=1}^{K} \gamma_k Z_{ijk} + \varepsilon_{ij},\ \varepsilon_{ij} \sim N(0;\ SE) \quad (1)$$

The meta-dependent variable ee_{ij} is the external effect of the i-th estimate from the j-th primary study, D_{ijl} is a dummy for the respective emission "l" inspected, $pq_j$is a measure of publication quality, Z_{ijk} represents the matrix of k explanatory variables defined in Table 2, and ε_{ij} is the error term. It is important to note that – instead of one constant – different constants for different emissions l are used.

In contrast to standard meta-regression analysis (Stanley et, 2008) the dependent variable in our procedure is not an estimate generated by inferential statistics, but mostly a value derived by geophysical measurement. In that sense it is subject to measurement error, which is not disclosed in more than 95% of the primary studies. As such, in contrast to classical meta-regression analysis, the standard error of our dependent variable external effects is not included in our regression equation. However, following van Ewijk et al. (2012) we use several variables as proxies for the standard errors of the dependent variable in our primary studies. First in accordance with Haase et al. (2016) the logarithmized number of Google citations per year is used in our analysis as a measure of the publication quality, pq_j. To avoid undefined numbers for non-cited publications we add the constant 1 to each number of citations before converting it to a logarithmic value (see Tables 3–6). Second, again following Haase et al. (2016), we construct an index for publication quality; in so doing, four categories which measure the publication quality are defined. Besides classical citation measures of the article and the publication source, we include the quality of the abstract, the quality of the main body of the publication as well as the scientific reputation of the first author and her institution in our factor (see Table 8 in the Appendix). We normalize all determinants on the unit interval, calculate the arithmetic mean of the determinants in the different categories, and use the sum of equally-weighted means of the categories as a measure of publication qualitypq_j. Since determinants are highly correlated among themselves, this procedure is applied to avoid their over-weighting in our factor. Third, instead of using a deductively-derived weighting scheme, we inductively deduce a weighting scheme with the help of a principal component analysis (Jolliffe, 2002), with the resulting first factor explaining more than 90% of the variation in determinants of the publication quality. Hence, we use the first factor as a proxy for publication quality and consequently as a proxy for standard error (see Table 3 to Table 6). Fourth, in addition to the first factor, the second factor is included to calculate our proxy. To this end, we combine the first and second factors linearly, weighting by the explanatory power of both factors. Hence, our fourth proxy explains more than 95% of variations in the determinants of publication quality (see Table 7).

To account for the fact that some external effects contain a higher precision, we follow Stanley and Doucouliagos (2015) and use a weighted least square estimation of our equation (1), leading to:

$$\frac{ee_{ij}}{1/pq_j} = \sum_{l=1}^{7} \frac{\beta_{0,l}}{1/pq_j} D_{ijl} + \beta_1 pq_j^2 + \sum_{k=1}^{K} \frac{\gamma_k}{1/pq_{j_k}} Z_{ijk} + \varepsilon_{ij}^{'},\ \varepsilon_{ij}^{'} \sim N(0; SE) \quad (2)$$

Thus more precise results are given a larger weight (the weight is increasing with an increasing publication quality) in the meta-regression estimation (Hedges and Olkin, 2014).

In accordance with to Egger et al. (1997), we use the *t*-test of the slope coefficient β_1 as an indicator of possible publication bias. In general, we apply different estimators to calculate the standard errors of the regression coefficients for our t-statistics. Due to the fact that studies in our sample routinely report more than one external effect, within their-study inter-dependencies probably occur. Hence we apply standard errors clustered at the study level (Doucouliagos and Stanley, 2013). Moreover, dependencies might arise from the fact that different researchers collect data from the same country. To account for this, we alternatively use standard errors clustered at the country level as well as a dual clustering for study and country levels at the same time (see Tables 3–6). Regarding robustness checks, we also used the White-robust standard errors accounting for possible heteroscedasticity bias (Table 8 in the Appendix).

Last but not least in order to interpret our effect size as an external effect, we develop a mean model and deviations from the mean model (Hang et al., 2017), thus inserting means for all variables. In the following we alter different variables e.g. by setting the dummies to one or zero or changing the mean by one standard deviation to derive the impact of the different variables in our best practice setting (Table 7).

4. Results

As a result of our literature analysis, the global climate impact of agriculture is opened up. A total of 1345 pollution values (CO_2, CH_4, N_2O, respectively CO_2e and SO_2, NO_x, NH_3, respectively SO_2e) can be identified, each relating to a country or region. In the first evaluation of the base scenario, we choose the average annual number of Google citations of a study as a proxy for its quality. In the second evaluation – structurally identical to the first one – we establish the first, best factor as a measure of the quality of the examined publications. In the third and fourth evaluation, inhabitants per area are alternatively used as reference (i.e. we calculated the emissions per head). Analysing the secondary data, we obtain the results compiled in Table 3.

When taking all evaluations into account it appears that three main factors are highly significant: the number of livestock units per area, the affiliation of the leading author to an NGO, and the humane orientation. By including the beta coefficients it becomes clear that a high number of animal units correlate with high emissions of air pollution. For example, the status of the publication's leading author working for a non-governmental organization is ultimately linked with a higher reported amount of pollution. It is evident that countries which – based on the GLOBE-study – show high values in the dimension of humane orientation have lower amounts of agricultural CO_2e- and SO_2e-emissions. Far weaker or only partly provable significances are found for the gross domestic product (GDP) per capita, the crops-acreage, the quality of the article, the use of databases of various studies for their own quantifying methods (method 4), and GLOBE's in-group collectivism.

In subsequent steps we conduct variations with three different main emphases. Firstly, an analysis focusing on major countries was carried out. Therefore, we included dummy variables to identify countries with the most study results (i.e. an effect size of more than 30). As a result, we conclude that the animal unit (per area) and the NGO-variable as well as the humane orientation continue to be significant. The GDP per capita shows partially – but in comparison to significant findings rather rarely – a significantly positive coefficient to the amount of emissions. The Netherlands and Germany show very high significance-values compared to other countries.

As a second main emphasis, we differentiate between various animal species and plant crops. For animals we limit data collection to cattle (milk- and meat-cattle), pigs, and chickens, because these three species represent the vast majority of all meat-supply. For crops we collect data for the 15 plant-species with the highest sales – bananas, barley, cassava, maize, oil (palm fruit), potatoes, rice (paddy), soybeans, sugar beet, sugar cane, sweet potatoes, tomatoes, vegetables (fresh), watermelons, and wheat – and integrate those into our examination. Both numbers for animals as well as for plants are collected specific to the respective country, based on the reference year in the examined publications.

The results show that the characteristic of "leading author related to an NGO continues to be still highly significant. In comparison to this finding, the characteristics of humane orientation,

Table 7
Expected change of the average emission quantity "mean of all" (in t/km^2) resulting from variations of different variables by one standard deviation.

Subject	Mean of all	Variation of variable	Emission change (t/km^2)
Base case	45.36	First author NGO	87.04
Base case	45.36	Publication quality	−7.31
Base case	45.36	Livestock	36.08
Base case	45.36	Humane orientation	−14.08
Base case	45.36	Acreage	4,61
Livestock and Crops	44.89	Cattle	29.45
Livestock and Crops	44.89	Pigs	10.10
Livestock and Crops	44.89	Maize	3.93
Countries	33.11	Netherlands	76.32
Countries	33.11	Germany	20.58

quality of the article, and rarely used methods that we have summarized by the term “method 3” are only partly significant. The differentiated examination of single animal and plant species indicates that the number of cattle is highly significant: the more cattle the higher the emission amount. The impact of pigs and chickens is documented to be relatively low or not significant. Significance, although strongly attenuated, can be found in the plant-category, which has a high nutrient extraction rate from the soil (potatoes, corn, watermelons, and sugar cane).

As a third variation, we focus solely on CO_2e emissions since the emission amounts of this variable is most often reported (also because equivalents could calculated if data was not directly available from the outset). Examining the results, it is documented that the livestock units continue to have a highly significant positive impact on the amount of CO_2e emissions. The significant relationship with humane orientation, which is one of the GLOBE dimensions, as well was the influence of the first author NGO-affiliation on the reported emission level has to be emphasized. There is no consistent picture of the methods, whereas acreage possibly has a positive impact on the level of CO_2e emissions.

In addition, we conducted several robustness tests to examine the validity of our results. Therefore, we varied the quality measure of the studies. To alternatively measure publication quality, the studies were compared and evaluated using four equally weighted criteria. Beside (1) classical citations measures of the article and the publication source, we included (2) the quality of the abstract, (3) the quality of the main body of the publication as well as (4) the reputation of the first author and her institution in our factor. To examine the quality of the abstract, we checked the existence of the following five components: thematic classification, method, data specified, results, and relation to the overall research question. To examine the quality of the main body of the study, the existence of the following points was checked: literature review, method, data, results, as well as the number of references. In addition, we used the overall number of citations of the fist author and the number of Facebook-likes of the affiliation as novel measures. In addition, we use simple White-robust standard errors accounting for a possible heteroscedasticity bias. The results of these robustness tests show the stability of our results (see Appendix 1 for a detailed depiction of the robustness tests).

A central goal of our article is to provide information about the strength of individual drivers. While single articles are only of limited significance, our meta-regression -analytical aggregation and evaluation of the results of individual studies also allow valid statements about the reactivity of specific drivers. Therefore, we conduct a sensitivity analysis to measure the responsiveness of the emission quantity (endogenous variable) to the change of individual (exogenous) variables. Starting from the base case and its variations, the results of a ceteris-paribus variation of different variables by one standard deviation each − corresponding to a change of about one third − is summarized in Table 7.

A variation of the variable “first author NGO” by one standard deviation results in an expected change of the total average emission quantity of $+87.04$ t/km^2 (first author NGO). Accordingly, the increase of animal units leads to an increase of emissions by 36.08 t/km^2. In contrast, the increase of humane orientation is associated with a decrease of emissions (-14.08 t/km^2). Recapturing variations (II) and (III), we conclude that, in particular, a change in the number of cattle results in a significant change of emission levels in the same direction ($+29.45$ t/km^2). Our model reacts strongly to changes in the Netherlands and Germany. Both countries are examined more than 30 times in the studies evaluated (see variation (I)).

The comparison of our results with the existing literature shows the following, differentiated picture. In parts, we could confirm the results of the existing literature: our first highly significant finding, namely that livestock farming (and especially cattle farming) has a negative impact on the agricultural emissions level (“the more livestock, the more emissions”), coincides with existing literature (Tilman and Clark, 2014; Borsato et al., 2018; Poore and Nemecek, 2018; Garnett, 2011). In addition, we were able to expand the state of science in the following areas: On the one hand, the inverse connection between the cultural dimension human orientation and the amount of emissions is not present in previous literature. A theoretical approach that may explain this relationship is based on Parboteeah et al. (2012), who show a positive correlation between human orientation and the awareness for sustainability. On this basis, our findings might be explained and classified in the following way: the higher the human orientation − and the more pronounced the awareness of sustainability − the lower the emission levels. Our third highly significant finding was, that studies conducted by a first author related to an NGO report significantly higher agricultural emissions levels, which is a novelty in the scientific literature related to agriculture. It is due to this fact that there is no explanatory relation to existing literature until now. For our investigations we have used meta-regression analytical methods. Due to our innovative approach, this methodology can now also be applied to environmental performance measurement. It is thus possible to include the quality of the individual publications in the analysis. On the basis of the methodology used, we were able to make consistent statements about the reactivity of individual drivers (i.e. how strongly changes in individual parameters affect the overall emission level). On the other hand, we have been able to identify driver categories, such as to identify the affiliation of the authors, who so far could not be identified for the area of agricultural emissions.

5. Discussion and conclusion

This study is designed to examine the heterogeneity of global climate impacts related to food production, as reported by different studies. Therefore, we analyze the primary sector's worldwide emissions in a meta-regression analysis. Our results go beyond the often limited to farming conditions studies on agricultural emissions (cp. section 2.3). The results document that the production of plant-based foods is related to relatively low climate impacts. In contrast, production of livestock has a significantly high impact on the amounts of emissions. Particularly, cattle-production is linked to high emissions of CO_2e and SO_2e and therefore causes strong negative external climate change-related effects. Furthermore, the cultural background of countries examined in the relevant underlying studies seems to influence the amount of emissions. Relating GLOBE's cultural dimensions to found emission factors we document that nations with a high level of humane orientation − defined as the degree to which a collective societal will encourages and rewards individuals for being fair, altruistic, generous, caring, and kind to others (House et al., 2004) − report lower agricultural emission amounts. The publication's characteristics are also found to be of importance as well: To estimate the quality of examined studies we test new measuring methods which − amongst others examined the first author's affiliation. While performing these analyses we find big differences in published emission factors depending on the first authors' affiliation. Studies whose first author is related to an NGO especially tend to publish significantly higher emission factors than is the case for members of academia or (supra-)national state organizations. Following up on this observation, a strengthening of the scientific exchange between NGOs and university research seems sensible, in order to identify reasons for the currently observable differences in the amount of emissions reported. In addition, such an exchange could help to improve their specific methods and thus reduce the heterogeneity of future publications' results.

With our article, we focus on the meta-regression analytical study of the climate impacts of agriculture. Although we can contribute to the scientific debate with this approach and the results, our study has several limitations that should not be ignored. The fact, that our results are consistently based on average values can be judged critically, as there are large differences in the production of food, especially in countries with large territory and different climatic or geographical zones. This restriction results from the basic studies and also affects our meat analysis. In addition, the country-based average analysis used has the disadvantage that different forms of cultivation and livestock farming are not taken into account. Our average assessment is vulnerable, as biologically produced foods are in most cases associated with lower climate impacts. Furthermore, we do not take into account the extent to which the food produced in one country is directly consumed by the respective population. The role of food imports and exports is therefore not examined in more detail. In addition, food production impacts that go beyond climate impacts are not taken into account. This includes content that relates to the social dimension of sustainability, such as the number of people employed in food production and their working conditions or health issues that may arise from under- or malnutrition. A limitation of our study is the anthropocentric perspective. We take this fact into account by adding the following section: Our focus on climatic impacts should not deceive about the fact that food production also causes far-reaching further implications. Noteworthy here are questions of animal welfare, especially with regard to the mass production of food of animal origin, as well as the current, mostly negative impact of agriculture on biodiversity. Against this background, the anthropocentric view (and the focus on "human" orientation in this article) should be relativized in favor of a shift towards a stronger ecocentrism (cp. Gribben and Fagan, 2016) in subsequent studies.

For political decision-makers, our results concerning the reactivity of individual drivers are of particular importance. In order to take appropriate economic policy measures, it makes sense for state intervention to be targeted at those places, where the effects of a reduction are most evident. Based on our results, we see this potential – across national borders – especially in animal husbandry. For this, state interventions that affect fertilizer management and contribute to increasing nitrogen efficiency appear useful. In addition to these technical measures, polluter-taxation of high-emission foods could reduce the consumption of these foods. As a further measure for the reduction of emissions, state campaigns that help to avoid food waste appear useful. For companies working in the primary sector as well as downstream supply chains or networks who are committed to sustainability, it is advisable to anticipate or consciously take action beyond these public policies. For example, food producers could substitute animal ingredients with less harmful substitutes. When purchasing intermediate products, companies in the food industry could also use biologically produced alternatives that are associated with lower emissions. In a country-differentiated analysis, our results show that the reduction of agricultural emissions would have a significant positive impact especially in the Netherlands and Germany.

By gaining a better understanding of the drivers of agricultural environmental impacts and their specific intensity, our findings can help to achieve the UN Sustainable Development Goals (SDGs). In particular, it can help to promote sustainable agriculture (SDG 2), to ensure sustainable consumption and production practices (SDG 12), to protect land ecosystems (SDG 15) and, in particular in the high impact areas, to take immediate action to combat climate change and its effects (SDG 13). Our results provide a good basis for working on and implementing effective measures to curb agricultural-induced climate change, both at government level and at company level. Knowing our results, future articles might continue to focus on the identification and evaluation of measures for the reduction of environmental consequences resulting from the production of groceries (cp. Huisingh et al., 2015; Sala et al., 2017). Thus, a contribution can be made to achieve the commitments of the Paris Agreement. Against the background of our results and the big impact of food production on the climate, government funding programs for environmentally friendly management seem sensible. In terms of the EU'sCommon Agricultural Policy, strengthening the relevant funding programs (in the so-called second pillar) seems as useful as clearly orienting all government funding to their contribution to reducing negative climate impacts. This could also include influencing consumption habits towards the consumption of foods with less environmental impact.

While publication bias analysis shows a rather mixed picture, our article quality variable is partly significant, thus suggesting that the emission effects of better studies are lower. Therefore, further research should be done in fields without available inference statistics as well. Because we could not observe standard errors in the primary studies, we try to operationalize study precision or article quality by alternative measures. This could be a starting point for more intensive discussion of the measurement of article quality. Meta-analyses are usually based upon primary studies by applying inference statistics to a self-collected or given data set. The aforementioned positive effect is that the primary studies usually disclose their statistics. In contrast many environmental studies, which measure physical variables, suffer from non-disclosure of their measurement errors. Although the measurement processes of these studies are different, the general approaches are similar. Hence, we see a necessity: the results of those studies should also be aggregated by meta-(regression) analysis and then analysed with respect to their heterogeneity. Here the relevant meta-analytic tools should accordingly be further developed. In addition, the analysis of attributable reasons for emissions levels of different food-categories will require more detailed investigations (cp. Pairotti et al., 2015). Furthermore, we currently focus on climate impacts resulting from agricultural production. Since producing foodstuff affects other environmental aspects (e.g. water) or rather results in such aspects (e.g. nitrogen-pollution), phosphorous-pollution, pesticide-pollution, species-diversity decline consequences, etc., the effects reported in different studies need to also be analysed in regard to these and other direct human health impacts of many pesticides.

In this article, we have focused on external effects of agriculture and their drivers. As shown, this sector has a huge impact on the environment. However, it should not be forgotten that other sectors, such as energy generation, the industrial sector and also transportation are largely responsible for the emergence of negative external effects, too. There is also a need for scientific action in these sectors in order to identify the main drivers there as well. The necessary "rapid decarbonisation" (Rockström et al., 2017) can only be achieved if further research and action is carried out in each of these economic sectors.

Author contribution

All authors contributed equally to the work.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table 8
The results of our robustness tests are structured as follows: Focusing on the base case, an alternative measure of quality is used; in addition, the second-best factor is now included (left side of the table). To measure publication quality, the studies are compared and evaluated using four equally-weighted criteria. Besides (1) classical citation measures of the article and the publication source, we include (2) the quality of the abstract, (3) the quality of the main body of the publication as well as (4) the reputation of the first author and her/his institution in our factor. To examine the quality of the abstract, we check the existence of the following five components: thematic classification, method, data specified, results, and relation to the overall research question. To examine the quality of the main body of the study, the existence of the following points is checked: literature review, method, data, results, as well as the number of references. In addition, we use the overall number of citations of the first author and the number of Facebook-likes of the affiliation as novel measures. In the right third of the table, we use simple White-robust standard error accounting for a possible heteroscedasticity bias. In addition, we use clustered standard errors on the country level. Again, variables with an error-probability lower than 1% (p-value = 0,00) and 1% (0,00 < p-value < 0,01) are highlighted in bold letters.

		Base Case & alternative measure for paper quality						Base Case & other SEs		
		Weights			1st and 2nd Factor					
	Exp. sign	Beta	Cluster SE Study P-value	Cluster SE Study and Country P-value	Beta	Cluster SE Study P-value	Cluster SE Study and Country P-value	Beta	White-robust SE P-value	Cluster SE Country P-value
Carbon dioxide		297.70	0.05	**0.00**	178.03	0.05	**0.01**	255.55	0.15	0.02
Methane		281.65	0.06	**0.00**	167.54	0.06	0.02	227.26	0.18	0.02
Nitrous oxide		279.56	0.06	**0.00**	165.53	0.07	0.02	234.43	0.18	0.02
Carbon dioxide equivalents		391.14	0.02	**0.00**	269.35	**0.01**	**0.00**	351.67	0.09	**0.00**
Sulphur dioxide		1131.55	0.09	0.09	1444.73	0.05	0.06	1921.60	0.10	**0.01**
Nitrogen oxide		301.37	0.07	**0.00**	155.45	0.08	0.03	256.32	0.20	0.02
Ammonia		392.12	0.09	**0.01**	146.28	0.09	0.03	417.27	0.15	0.06
Google Scholar: citations / year	+/-	1.43	0.49	0.48	0.00	0.04	0.02	2.34	0.45	0.42
SCImago Journal Rank	+/-	-4.68	0.36	0.22	-1.20	0.43	0.44	12.88	0.15	0.05
Reference year (RY) since 1980	+/-	0.60	0.19	0.15	-0.19	0.16	0.17	0.91	0.18	0.11
Livestock: Animal units / area	+	0.07	**0.00**	**0.00**	0.07	**0.00**	**0.00**	0.07	**0.00**	**0.00**
GDP	+	0.79	0.40	0.34	3.05	0.04	0.08	-0.49	0.46	0.44
Inhabitants / area	+	1.46	0.08	0.12	0.84	0.16	0.18	2.75	0.05	0.08
Globe 1: Assertiveness		-1.36	0.26	0.32	-3.23	0.05	0.14	1.24	0.34	0.37
Globe 2: Institutional collectivism		-1.83	0.32	0.36	-0.33	0.46	0.48	3.47	0.31	0.34
Globe 3: In-group collectivism		-17.24	**0.00**	0.02	-14.22	0.02	0.05	-24.78	0.06	0.04
Globe 4: Future orientation	-	18.04	0.04	0.04	4.87	0.27	0.31	31.21	0.09	0.05
Globe 5: Gender egalitarianism		2.74	0.25	0.30	2.88	0.19	0.30	2.82	0.38	0.37
Globe 6: Humane orientation	-	-36.53	**0.01**	**0.00**	-30.11	**0.00**	**0.00**	-38.38	0.03	**0.00**
Globe 7: Performance orientation		-10.27	0.13	0.06	-3.38	0.24	0.28	-14.64	0.12	0.04
Globe 8: Power distance		-15.00	0.11	**0.00**	-6.56	0.18	0.12	-7.00	0.32	0.24
Globe 9: Uncertainty avoidance		-6.34	0.18	0.17	3.99	0.14	0.23	-14.58	0.12	0.11
First author supra-national	+/-	-23.61	0.17	0.12	-1.15	0.43	0.44	-35.94	0.28	0.24
First author NGO	+/-	72.53	**0.00**	**0.00**	92.68	**0.00**	**0.00**	67.97	0.14	**0.00**
Method 1: Addition of data		8.10	0.20	0.30	-10.18	0.10	0.17	43.27	0.18	0.21
Method 2: Study-specific method		4.64	0.34	0.32	-1.00	0.45	0.45	9.48	0.28	0.31
Method 3: GAINS, NEMA, etc.		-3.49	0.39	0.44	-16.51	0.04	0.05	38.50	0.32	0.28
Method 4: Based on other studies		-96.55	0.19	0.22	-136.66	0.14	0.13	-184.44	0.20	0.03
Crops: Area harvested	+	0.11	0.42	0.40	0.56	0.03	0.08	-0.11	0.45	0.42
R^2		0.36			0.63			0.42		
F-test		25.89			79.39			35.11		
Number of observations		1345			1345			1345		

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