The impact of human and livestock respiration on CO_2 emissions from 14 global cities

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Abstract

Background

The CO_2 released by humans and livestock through digestion and decomposition is an important part of the urban carbon cycle. But this part is reraly condidarded in the stuties of city carbon budget since its annual magnitude is lower than that of fossil fuel emissions within the boundaries of cities. However, human and livestock respiration may be substantial compared to fossil fuel emissions in areas with high population density such as Manhattan or Beijing. High-resolution datasets of CO_2 release from respiration also have rarely been reported on a global scale or in cities globally. Here, we estimate the CO_2 released by human and livestock respiration at global and large city scales and then compare it with the carbon emissions inventory from fossil fuels in 14 cities worldwide.

Results

The results show that the total human and livestock respiration is up to 38.1% of fossil fuel emissions for Delhi among the studied cities. The proportion could be larger than 10% in cities of Sao Paulo, Cape Town and Tokyo. In other cities, it is raletivily small with a proportion around 5%, while Washington DC has the least proportion in 2.8%. In addition, almost 90% of respiratory carbon comes from urban areas in most cities, while up to one-third comes from suburban areas in Beijing on account of the siginificant livestock production.

Conclusion

The results suggest that the respiration of humans and livestock represents a significant CO_2 source in some cities and is nonnegligible for city carbon budget analysis and carbon monitoring.

1. Introduction

Currently, approximately 55% of the world's population (The World Bank: Urban population, 2019) occupies only 0.37% of the global land surface [2, 3]. From the viewpoint of the process of urban material metabolism, the total harvested carbon transported into an urban system releases CO_2 through the processes of human and livestock metabolism and constitutes a part of the global CO_2 cycle (Fig. 1) (Luo et al., 2008; Pataki et al., 2006, Churkina, 2008, Churkina et al., 2010).

However, CO_2 from human and livestock respiration is often neglected due to its perceived small magnitude compared to fossil fuel emissions (FFE) from the burning of fuels for electricity, heating and industrial purposes, other industrial processes and ground transportation within city boundaries [7, 8]. Some researchers have considered human respiration as a significant contribution only in street-scale or residential areas, where CO_2 emissions from power plants and industry can be ruled out [9–11]. Others have regarded biogenic emissions to be a nonnegligible contribution at night or even during winter [12–15] but have not included CO_2 release from humans and livestock respiration (HLR).

However, human and livestock respiration may could be important in cities with high demands for food and feedstuff consumption. From the viewpoint of comparisons of bottom-up and top-down approaches, human and livestock respiration could represent 1.2% – 30% of FFE in densely populated regions (Table 1), such as some typical cities of Beijing, Greater Paris and Mexico City [16–22]. Thus, accurately estimating the amount of HLR could improve the atmospheric CO_2 flux inversion approach for estimating FFE and for comparison with the bottom-up technique [20, 22, 23]. However, the published studies (in Table 1) only focus on individual cities, and the HLR in few cities has be clearly

calculated. Moreover, only the studies of Zhao et al. and Gurney et al. included the livestock [21, 22], while the CO_2 release from respiration in other studies is from human.

Table 1
CO_2 release from respiration compared with total fossil fuel emissions.

City	Respiration to fossil fuel proportion (%)	Reference
Phoenix, AZ, USA	1.9%[1]	Koerner and Klopatek, 2002
Beijing, China	30%	Ciais et al., 2007
Shanghai, China	12%	
Chicago, Illinois, USA	1.2%	West et al., 2009
Mexico City, Mexico	6.4%[1]	Velasco and Roth, 2010
Greater Pries, France	8%	Bréon et al., 2014
Marion County, Indiana, USA	2.9%	Gurney et al., 2017
Nanjing, China	6.8%[1]	Zhao et al., 2014

1. Estimation of CO_2 emissions through a pure bottom-up technique. The proportion is converted from the respiration contribution to total CO_2 emissions to the respiration to fossil fuel proportion (Velasco and Roth, 2010), or estimated from CO_2 emissions for different sources of CO_2 [16, 21].

From the above, in areas with high population density, detailed estimation of the HLR is necessary for CO_2 monitoring and CO_2 flux inversion. However, a high-resolution dataset of HLR has rarely been reported on a global scale or in cities globally. Thus, the purpose of this study is to establish high-resolution datasets of global human and livestock carbon production and to compare it with CO_2 from FFE within large cities/metropolitan areas around the world. Excluding food loss/waste and livestock feed from local sources, the harvest carbon from crop production should correspond to the total human and livestock consumption of carbon. The fourth section discusses these carbon budgets and presents an uncertainty analysis.

2. Data And Methods

2.1 Study area and in-boundary FFE

The 14 reported global major cities according to the research of Chen et al. [24] are selected as the study area and include Bangkok, Beijing, Shanghai, Delhi, Cape Town, Sao Paulo, Tokyo, Greater Paris, Greater London, Los Angeles, Manhattan, New York City, Washington D.C., and Greater Toronto (see Table 4 and Additional file 1: Figure S1). The definitions of the 14 cities ranges from ‘district’ to ‘metropolitan’ (see also Table 4) [25]. The CO_2 from human and livestock respiration is directly emitted within global city boundaries, which is equivalent to scope 1 [26]. To compare the CO_2 emissions from human and livestock respiration within these global cities, we retrieved the in-boundary anthropogenic FFE from Chen et al. [24], who estimated the total FFE directly within the city boundaries of these 14 cities and metropolitan areas around the world.

Our study also separated city areas into two subcategories, urban and suburban. The urban extent of each city is based on the 1:10 m urban areas shapefile from Nature Earth (https://www.naturalearthdata.com), which is derived from [illegible] urban areas are defined in this study as urban and built-up

areas with high population densities, high radiance levels in commercial/industrial areas and high-density residential land cover, instead of being based on impervious surfaces (Schneider et al., 2009).

2.2 Estimate methods for HLR

The CO_2 release from respiration of per person (HR) or per head of livestock (LR) is obtained according to the basal metabolic rate (BMR). The BMR refers to the minimum level of energy required to sustain vital functions of organs at complete rest in a neutrally temperate environment and in a fasting state. It is measured by heat production or oxygen consumption and can be expressed as Cal m^{-2} h^{-1}, Cal kg^{-1} h^{-1} or O_2 g^{-1} h^{-1} for individuals [29,30]. For various mammals, the oxygen consumption rate per body mass consistently decreases with increasing body size, while the rate of oxygen consumption for individuals against body mass tends to decrease along regression lines in logarithmic coordinates (birds have a similar equation to mammals) [31]. Additionally, oxygen is combined with carbon according to the respiration reaction. Therefore, based on the BMR of each species, we can estimate the CO_2 produced by respiration according to the oxygen consumption.

The BMR of humans was given as 6279 kJ day^{-1} per person by Johnstone et al. [32] (minimum=4301 kJ day^{-1}, maximum=10455 kJ day^{-1}), which was the mean of seven experiments including 155 adults between the ages of 21 and 64. We also estimated the human BMR as 5698 kJ day^{-1} per person (minimum=4778 kJ day^{-1}, maximum=6612 kJ day^{-1}), which was the weighted average for different age groups and for both sexes from the daily BMR of 92 individuals predicted by the FAO (Additional file 1: Table S1) [33]. The fractions for different ages and both sexes for the global total population come from the World Bank (The World Bank: Featured indictors of Health, 2019). We take the average of the two sources as the globally averaged BMR and convert the heat production (kJ day^{-1}) into oxygen consumption (L O_2 day^{-1}) by introducing the thermal equivalent of oxygen (20.2 kJ L^{-1}). Finally, the HR is approximately 57.97 kg C yr^{-1}.

The BMR (ml O_2 g^{-1} h^{-1}) of mammalian livestock and chickens are measured values from previous experimental results that controlled the environmental temperature, nutrition, age and activity level [35–37]. The LR is estimated from the following equation:

$$LR = \frac{(BMR_l \times Body\_weight_l \times \frac{M(O_2)}{V_m} \times \frac{12}{32} \times 24 \times 365)}{10^6} \quad (1)$$

where BMR_l is the BMR, with units of ml O_2 g^{-1} h^{-1}; $Body\_weight_l$ is the average of different breeding ages and genders; is the molecular mass of O_2 in g mol^{-1}; and V_m is the molar volume of gas in 22.4 L mol^{-1}. The ratio of carbon (C) and O_2 is set to 12/32 according to the processes of respiration, which can be expressed by the following chemical equation [38]:

$$CH_2O + O_2 \rightarrow H_2O + CO_2$$

where CH_20 represents the composition of biological material.

The amount of LR represents the total carbon released during the days the animals are alive (see Table 2). Therefore, the life span of pigs is half a year [39,40], and that all species

except poultry and pigs live for more than one year.

Table 2. The parameters of eight types of livestock.

Livestock	BMR ($kg\ O_2\ yr^{-1}$)	LR [1] ($kg\ C\ yr^{-1}$ per head)	Global total production (million head in 2010)[2]	References
horse	813.43	305.04	59.66	M. A. Elgar and P. H. Harvey (1987)
pig	103.24	19.36	974.41	
cattle and buffalo	578.66	217.00	1603.86	
goats	85.60	32.10	910.83	
sheep	127.65	47.87	1076.36	
chicken and duck	26.95	1.25	22311.21	B. M. Freeman (1963)

1. LR is the CO_2 release from respiration of per head of livestock.
2. Data coms from FAOSTAT, http://www.fao.org/faostat/en/#home.

What's more, concerning the metabolic enhancement caused by exercise metabolism and other factors, the physical activity level (PAL) was defined in terms of three levels of physical activity [41]. For simplicity, we assume that the WHO recommended PAL=1.55 could be used as an uniform parameter for global countries and for different gender and age groups for both human and livestock [42]. Finally, the HR is 89.90 kg C yr^{-1}.

The total HLR is estimated by multiplying the CO_2 emission of each individual by the total population/livestock production within city boundaries. Since the population and livestock production are reported as high-resolution datasets (see sector 2.3), the HLR in grid *i* is estimated by HR and LR, as well as the population/production in each grid based on the following equations:

$$\mathrm{HR\ (i)} = \sum Population(i) \times HR_h \qquad (2)$$

$$\mathrm{LR\ (i)} = \sum Livestock(i) \times LR_l \qquad (3)$$

where *h* is for humans; *l* is for the species of livestock with a total of eight in this study; and *Livestock(i)* is the total production of each species of livestock in grid *i*.

2.3 Datasets of humans and livestock

The HLR in each city are extracted from high-resolution vector datasets (see Table 3). The Gridded Livestock of the World (GLW) datasets include global distributions of eight major livestock species (also see Additional file 1: Table S2). It should be noted that the total cattle and poultry production in Beijing from the high-resolution datasets is 17 times higher than the statistical data from the National Bureau of Statistics of China (NBS, http://data.stats.gov.cn/english/),

while cattle production is consistent with census statistics for Shanghai, Delhi and Sao Paulo (Additional file 1: Table S3-S4). As the detailed cattle census statistics of Beijing for GLW were mined from statistical yearbooks of China, we consider the values from official source of China are more reliable. Thus, we first corrected the livestock production in each grid in Beijing according to the spatial distribution from GLW and the total livestock production from NBS.

The city boundaries we used in this study come from the database of Global Administrative Areas (GADM) version 2.0 (http://gadm.org/). The shapefile with polygon features of 14 cities was first converted to a high-resolution vector-form dataset at a resolution of 30 arc-second and can be used as a region mask to extract values for population and livestock production within different cities.

To match the years with FFE in 14 cities from Chen et al [24], we used linear interpolation to obtain the annual human respiration after extracting the total CO_2 release from each city every 5 years. For livestock, we assume that the trend of livestock production in each city is close to that of the country (for the data, please see Table 3). We obtained the livestock respiration in each country through the method described in section 2.1. Finally, the total annual livestock respiration within cities is scaled from that of each country.

Table 3. Sources of data on humans and livestock

Data	Data source	Resolution	Time range
Gridded Population of the World, Version 3 (GPWv3)[2]	Socioeconomic Data and Applications Center (SEDAC)	2.5 arc-minute regridded to 30 arc-second	1990, 1995
Gridded Population of the World, Version 4 (GPWv4)[2]		30 arc-second	2000, 2005, 2010, 2015
Gridded Livestock of the World (GLW)[1]	FAO	5 arc-minutes regridded to 30 arc-second	2010
Livestock production[3]	FAOSTAT	national total	1960-2014

1. Gilbert et al., 2018b, 2018c, 2018a, 2018d, 2018e, 2018f, 2018g, 2018h
2. Center for International Earth Science Information Network - CIESIN - Columbia University, 2018; Center for International Earth Science Information Network - CIESIN - Columbia University and Centro International de Agricultural Tropical - CIAT, 2005
3. FAO. FAOSTAT, 2017

3. Results

3.1 Global CO_2 release contributed by livestock and human respiration

The annual mean carbon from human respiration was approximately 0.59 Gt C during 1995-2015 (approximately 0.62 Gt C in 2010). In terms of global total carbon from livestock respiration, it was approximately 0.81 Gt C in 2010, with the majority contributed by cattle, followed by sheep and buffalo, accounting for 60.2%, 10.6% and 8.1% of the total livestock carbon, respectively (Additional file 1: Figure S2 (b)).

3.2 Carbon release from livestock and human respiration in 14 cities

Based on the high-resolution gridded data, we extracted the value of HLR in 14 large cities and metropolises. Figure 3 shows the variation in total HLR in the 14 cities. The highest HLR in 2014 occurred in Beijing and Shanghai, followed by Delhi, with values of 2544.0, 2506.0 and 1659.8 kt C yr^{-1}, respectively. Washington DC featured the lowest HLR, with a value less than half that of Manhattan.

From the viewpoint of the variation trend, all 14 cities have an increasing trend over the studied 25 years. CO_2 emission increased by approximately 53.9 kt C yr^{-1} with a total increase of 87.7% over 15 year Shanghai, while Beijing and Delhi increased by 50.2 and 34.5 kt C yr^{-1} (with total increases of 100.3% and 91.5%), respectively. Most of the other cities increased by approximately 10.0 kt C yr^{-1} (with totals of 33.6% on average), while the trend of Washington DC was only 0.2 kt C yr^{-1} (6.1%). Among the total HLR in 14 cities, humans contribute much more than livestock, and the trend of HLR is also dominated by increasing population (see Figure 3 and S3).

For the values of human respiration, the differences among cities are noticeable. The values in Beijing are 4 times those of Delhi and Shanghai and might be related to cattle farms in the southern and northeastern portions of Beijing. Among the 14 cities, 9 cities had a descending trend from 1990 to 2014, including Ile De France, Los Angeles, Cape Town, Tokyo, Bangkok, Greater London, Washington DC, New York City and Manhattan (Additional file 1: Figure S3 (b)).

Figure 4 shows the spatial distribution of HLR in the 14 cities. In most of the cities, the human respiration is more than one order of magnitude larger than that of livestock (Additional file 1: Figure S4 and S5); thus, the spatial distribution of total HLR is dominated by the spatial distribution of humans and is very similar to that of the population (Additional file 1: Figure S1 and S4). In most of the cities, the total livestock respiration in each grid is less than 10 t C yr^{-1}. The areas around Paris have somewhat higher values, with values of almost 10 t C yr^{-1}. Moreover, the livestock respiration in eastern Beijing were greater than 60 t C yr^{-1} and might be contributed mainly by cattle.

3.3 Comparison with FFE

Figure 5 shows the HLR compared with the FFE in cities with different areas and populations (the actual value of HLR is shown in Table 4). The HLR amounts to up to 40% of the FFE in Delhi, with human respiration amounting to almost 34.7% of the FFE. Sao Paulo has the second highest proportion for FFE (nearly 36.2%), almost all of which is contributed by humans. The high proportion to FFE in Delhi and Sao Paulo is mostly due to the relatively low amounts of FFE and their large populations. The contribution of humans and livestock in other cities is approximately 4-10% relative to FFE.

We also compares the ratio of total respiration to in-boundary FFE associated with other sectors (Figure 6), including heating and industrial fuels, industrial processes, ground transportation, and large point sources, according to the results from Chen et al. [24]. Based on the average of the 14 cities, the average contribution of human and livestock respiration is comparable to that of large point sources (in-boundary) and is greater than that of industrial processes.

Moreover, we separated the source of HLR into urban and suburban. In the 14 cities overall, the HLR from urban areas is approximately 90% of the total HLR, and that from suburban areas varies from 0.4% to 33.3% (Additional file 1: Figure S6 and Table S5). In cities with relatively large proportions of HLR of FFE such as Delhi and Cape Town, the HLR from suburban only accounts for approximately 3.4% and 3.2% of the total in-boundary FFE. As for Sao Paulo, although HLR is 36.3% of total FFE, the HLR from suburban is only 0.4% of total FFE. What's more, the HLR from suburban areas in Beijing accounts for up to one-third of the total HLR (2.1% of total FFE). Such relatively high proportion is mainly contributed by the significant livestock production in suburban, where accounts for 80% of the total area. Therefore, in

studies with CO_2 concentration measurements, the stations located in suburban areas of cities such as Beijing, Delhi and Cape Town should also be taken into consideration.

In addition to the 14 selected cities, we provide a supplementary dataset on the HLR within other 118 world urban areas larger than 100 km^2, which were selected on the basis of being capitals or areas with large populations (greater than 1 million) or that have carbon monitoring sites, as a reference for carbon monitoring and carbon emission research (Additional file 2: Table S7). Among the 118 selected urban areas, approximately 11 urban areas have proportions of total respiration to FFE greater than 50%, and 48 urban areas have proportions greater than 10% (Additional file 1: Figure S7).

Table 4. Definition, population and carbon emissions of the 14 cities and metropolitan regions in this study.

City or metropolitan region	Year	Definition	Area (km^2)	Population (thousands)	Total in-boundary FFE (Mt C)	Human Respiration		Livestock Respiration	
						kt C	%	kt C	%
Bangkok	2005	Bangkok Metropolis	1,568.45	5659	7.5	**675.2**	**9.0**	3.1	0.04
Beijing	2006	Beijing Municipality	16,387.60	15810	31.4	1548.3	4.9	483.6	1.5
Cape Town	2005	City of Cape Town Metropolitan Municipality	2,443.63	3497	1.7	**291.9**	**17.5**	9.3	0.6
Delhi	2000	Metropolis	1,500.84	13200	3.5	**1199.7**	**34.7**	118.5	3.4
Greater London	2003	Greater London	1,601.83	7364	8.8	661.2	7.5	6.1	0.07
Greater Paris	2005	Ile de France	12,026.70	11532	13.7	**1032.2**	**7.5**	43.9	0.3
Greater Toronto	2005	Greater Toronto	7,610.32	5556	12.1	**506.2**	**4.2**	35.1	0.3
Los Angeles	2000	County	10,587.20	9519	21.2	**857.7**	**4.1**	11.4	0.05
Manhattan	2005	Borough	67.61	1570	2.4	**135.59**	**5.7**	0.1	<0.01
New York City	2005	City	739.51	8170	11.8	**582.3**	**5.0**	0.3	<0.01
Sao Paulo	2011	Municipality	1,520.90	11300	2.9	1049.4	36.2	1.7	0.06
Shanghai	2006	Shanghai Municipality	6,884.65	18150	49.1	1830.9	3.7	142.4	0.3
Tokyo	2006	Tokyo Metropolis	1,804.78	12678	10.9	1142.7	10.5	3.0	0.03
Washington DC	2000	District of Columbia	177.71	572	1.9	**51.6**	**2.8**	0.5	0.03

1. The population data for Manhattan were adopted from NYC Open Data (https://data.cityofnewyork.us/City-Government/New-York-City-Population-by-Borough-1950-2040/xywu-7bv9), and the population data for the other 13

cities were obtained from Kennedy et al. [54,55].

2.The human respiration in bold is directly extracted from GPW high-resolution population data, and that in black font is from linear interpolation.

3. The values (in %) in bracket show the proportion of human and livestock respiration compared with total FFE.

4. The livestock respiration in Beijing was corrected with livestock production from the National Bureau of Statistics of China.

4. Discussion

Carbon monitoring in urban areas has shown that the CO_2 released by the human metabolism can partially explain the diurnal pattern in measured CO_2 fluxes in densely populated urban areas [56, 57]. Moreover, the research of Ciais et al. [23] shows that, in total, humans and livestock contribute 5% to FFE in urban extent globally, and the CO_2 release from respiration is even larger than oil burning in India and larger than FFE from gas in Chinese cities. Thus, the HLR is not a negligible contribution in some populated cities. An accurate estimation of human and livestock respiration could improve the accuracy of monitoring FFE in cities. We compared the HLR with in-boundary FFE via a bottom-up method. The uncertainty in this study mainly comes from the uncertainty in the assumptions of the parameters of BMR and PAL.

4.1 Uncertainty Associated With The Parameters

The BMR is affected by a variety of factors, such as age, gender, exercise, body temperature, nutritional status, or lactation [30, 58–61]. Although several equations have been developed to predict BMR [30, 36, 62] and often take into account weight, height, age, gender and other factors, considering the high-resolution data of population and livestock production used in this study, it is difficult to distinguish the above factors on this spatial scale. Therefore, we assume that for each species (mammalian livestock, poultry and humans), individuals of different ages and genders and in different areas are assigned the same value of BMR.

In fact, BMR is only the lowest estimate of metabolic rate, and the actual respiratory intensity of each individual is related to climate and daily activity. The PAL recommended by the FAO/WHO/UNU Expert Committee in 1985 was defined in three levels: the minimum was set at 1.55 and 1.56 BMR for men and women, while the highest was defined as 2.10 and 1.82 BMR for men and women, respectively [41]. Considering that humans spend approximately one-third of their day asleep and that most people do not have long-term high-intensity activity, we roughly assume that the average daily activity is at the lowest level.

The carbon emissions from respiration per individual in this study are only a first-order approximation based on the above assumption. The CO_2 emission from one person is assumed to be 89.90 kg C yr^{-1} in this study but varies over a range of 52.9–160 kg C yr^{-1} (Additional file 1: Table S6) in other studies based on different methods or without considering different age groups and gender [16, 18, 63, 20–22, 64]. The value used by Huang et al. is much higher than other studies. As a result, their estimated annual averaged global carbon emissions from human respiration are approximately 1.2 Gt C yr^{-1} [64] from 1990 to 2005, which is much greater than the value estimated in this study (0.81 Gt C yr^{-1}). Additionally, their estimation of livestock respiration is approximately 0.8 Gt C yr^{-1} [64], which is comparable with this study (0.62 Gt C yr^{-1}).

4.2 The Budget Of Harvested Crop Carbon

The processes that release CO_2 (human and livestock respiration) and the processes of crop carbon harvest result in fluxes of CO_2 to and from the atmosphere and constitute a part of the global CO_2 cycle. In this section, we will briefly discuss the budget of the carbon cycle from the bottom-up approach and top-down approach.

Based on the results in the previous sections, humans and livestock together released 1.43 Gt C in 2010 (0.62 and 0.81 Gt C, respectively). Forage grass is a local feed resource of horses, sheep and goats, as well as a portion of the feed for poultry, pigs and housed cattle in developing countries [17]. We follow the assumption of Ciais et al. that only 20% of poultry, pigs and cattle in developing countries received grain-based feeds, whereas 100% of these livestock in developed countries received grain-based feeds. Other livestock received local feed resources in our assumption. Based on the livestock production in each country from the FAO [53], we find that the carbon emissions from livestock utilizing local feed sources was approximately 0.64 Gt C (approximately 79% of total livestock respiration) in 2010. Hence, we assume that approximately 28% of the carbon released by livestock respiration comes from grain-based feeds.

Here, we also considered food waste. According to the FAO, approximately one-third of food produced by humans is lost or wasted globally every year (Gustavsson et al., 2011). Crop production is estimated to have been approximately 1.50 Gt C in 2010 based on crop production from the FAO [66], which is slightly larger than the human and livestock consumption estimated in this study.

The budget of harvested crop carbon is constructed as follows:

$$P - W = R_{human} + R_{livestock} \times 0.28$$

4

where P is crop carbon production via the top-down modeling method, W is the lost and wasted crop production, R_{human} and $R_{livestock}$ are the carbon releases from human and livestock respiration estimated by the bottom-up approach, and only 0.28 of $R_{livestock}$ comes from grain-based feeds. Based on the above discussion, we estimate that W is approximately 0.5 Gt C. Excluding food loss and waste, crop production is approximately 1.00 Gt C, which has the same magnitude and is comparable to human and livestock consumption (0.79 Gt C, excluding livestock feeding on local forage grass).

In addition, we should note that the carbon released by livestock respiration in 14 cities also includes local feed sources. In particular, in Delhi and Beijing, the percentages of livestock respiratory carbon are 3.4% and 1.5% relative to fossil fuel. Considering livestock fed with local feed, livestock respiration should have less influence on city carbon emissions.

5. Conclusions

In this study, we used the global population and livestock production, as well as the parameter of BMR, to estimate the amount of carbon released by human and livestock respiration from 1990–2014. Then, we calculated the carbon emissions from human and livestock respiration in 14 of the world's largest cities and compared them with the in-boundary FFE. The results showed that the proportion of total carbon release from humans and livestock is up to 38.1% relative to FFE in Delhi and is approximately 5%-10% in most of the 14 typical cities. Consequently, measuring only FFE may severely underestimate the carbon sources in some cities, such as Delhi, Sao Paulo and Cape Town. In studies monitoring FFE from ground stations or satellites, the significant proportion of human/livestock emissions relative to

the evaluation of the FFE trend [23]. In addition,

approximately 90% of the respiratory carbon is released in the urban areas of most cities, while the carbon released by humans and livestock respiration in suburban areas contributes up to 18%-33% of city's total respiratory carbon emissions in Beijing, Cape Town and Greater Toronto. This means that the setup of carbon monitoring sites should not neglect suburban areas in those cities. We should note that this study used global unified values for BMR and PAL. To estimate the carbon from human and livestock respiration more accurately and to compare it with FFE, it is better to adopt parameters appropriate for regional or national climate and livestock feeding conditions.

Declarations

Availability of data and materials. The datasets supporting the conclusions of this article are included within the article and its additional files. High-resolution data are available upon request to corresponding author.

Competing interests. The authors declare that they have no conflicts of interest.

Author contributions. NZ conceived and designed the study. QC and PH collected and analyzed the datasets. QC led the paper writing with contributions from all coauthors.

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Supplementary Information Legends

Additional file 1. Supplementary information including additional tables and figures

Additional file 2. Table S7.xlsx

Title of Table S7: The HLR within 118 world urbans.

Notes of Table S7: The 118 world urbans are selected on the basis of area larger than 100 km^2, being capitals, with populations greater than 1 million or have carbon monitoring sites.

Figures

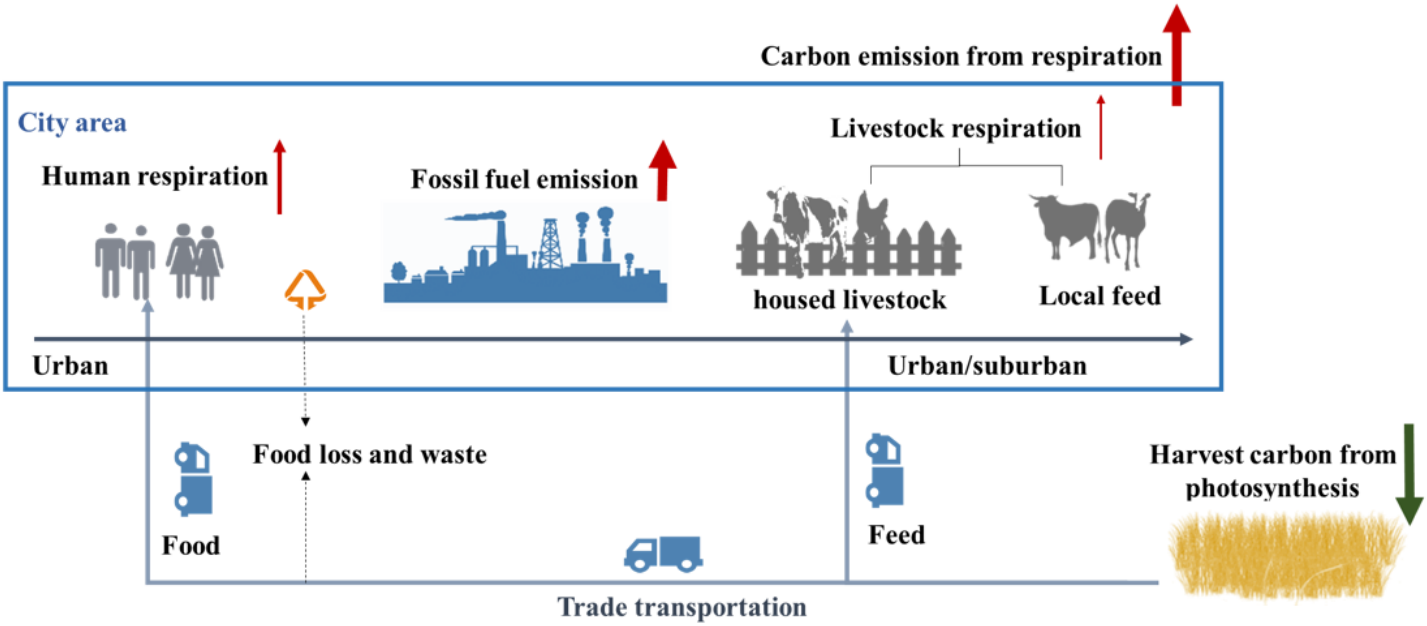

Figure 1

The process of urban material metabolism with crop production, the digestion of food and feedstuff by humans and livestock, and finally the release of carbon to the atmosphere via respiration.

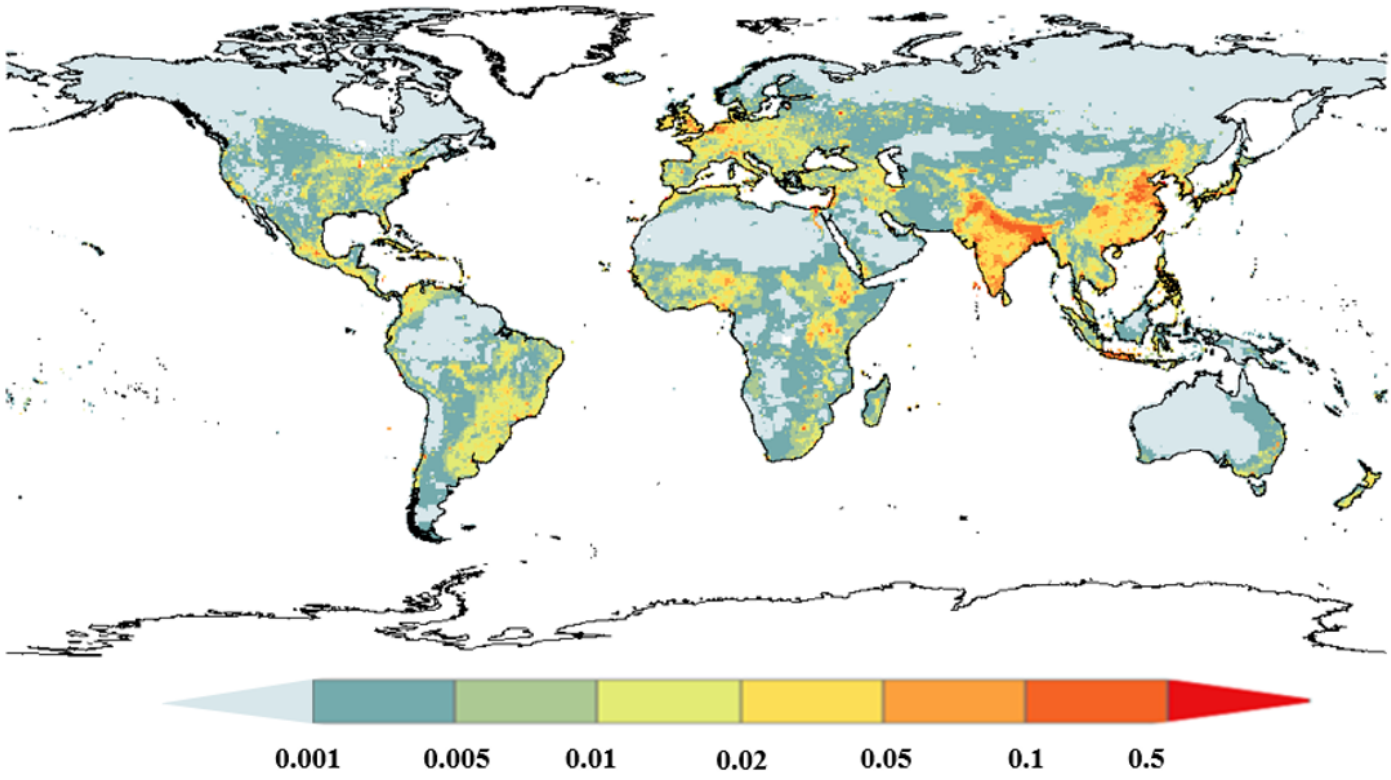

Figure 2

The spatial distribution of total CO2 release from human and livestock respiration (HLR) (kg C m-2 yr-1). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion

whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

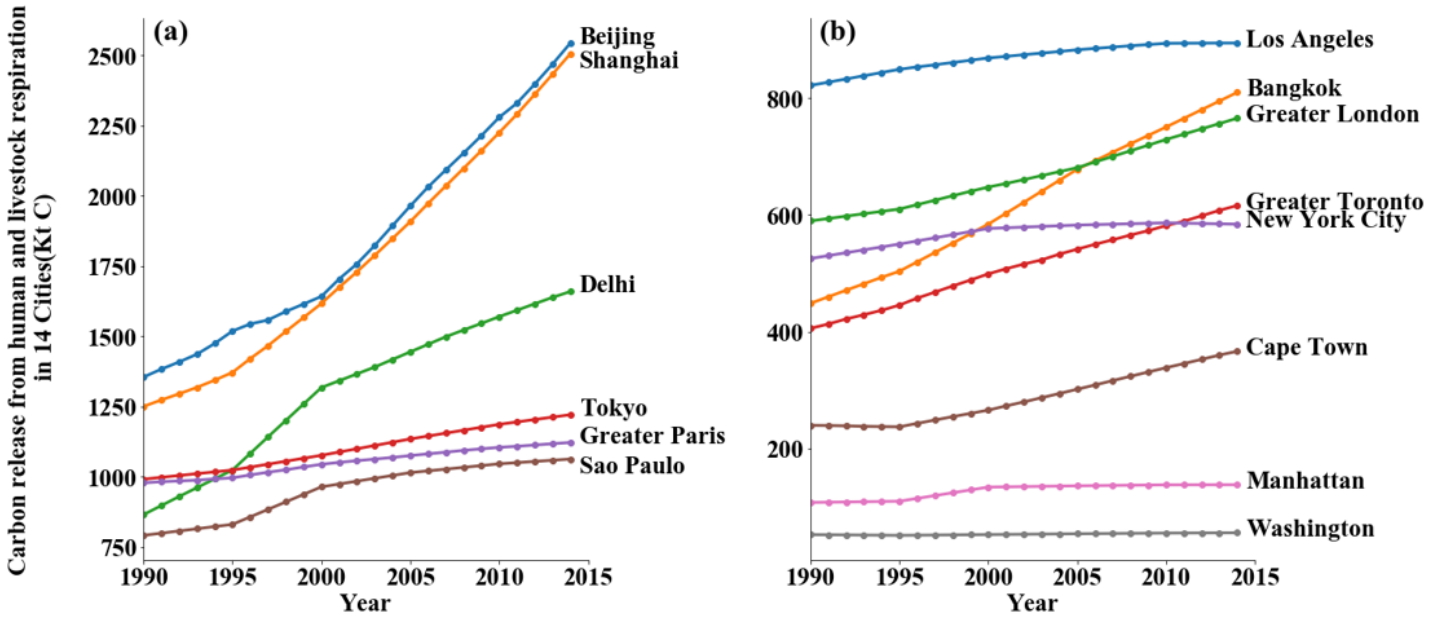

Figure 3

Variation in the total HLR in 14 cities. (a) Greater than 1000 kt C yr-1 in 2014, (b) less than 1000 kt C yr-1 in 2014.

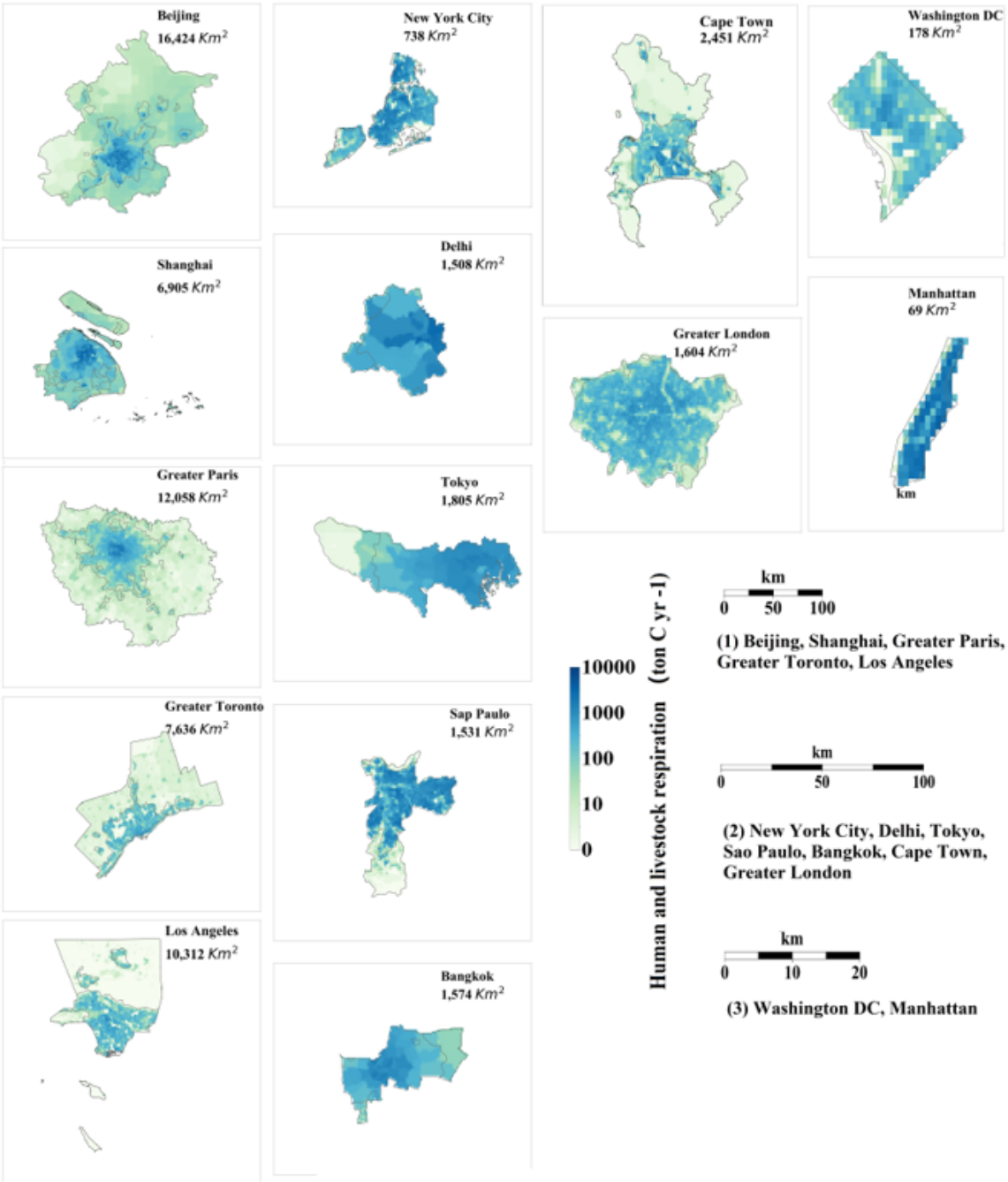

Figure 4

The HLR in 14 cities and metropolitan regions in 2010 at a resolution of 1 km (t C yr-1). The areas within the gray line show the urban extent. Three scale bars are included. Scale bar (1) corresponds to Beijing, Shanghai, Greater Paris, Greater Toronto and Los Angeles; scale bar (2) corresponds to New York City, Delhi, Tokyo, Sao Paulo, Bangkok, Cape Town and Greater London; scale bar (3) corresponds to Washington D.C. and Manhattan.

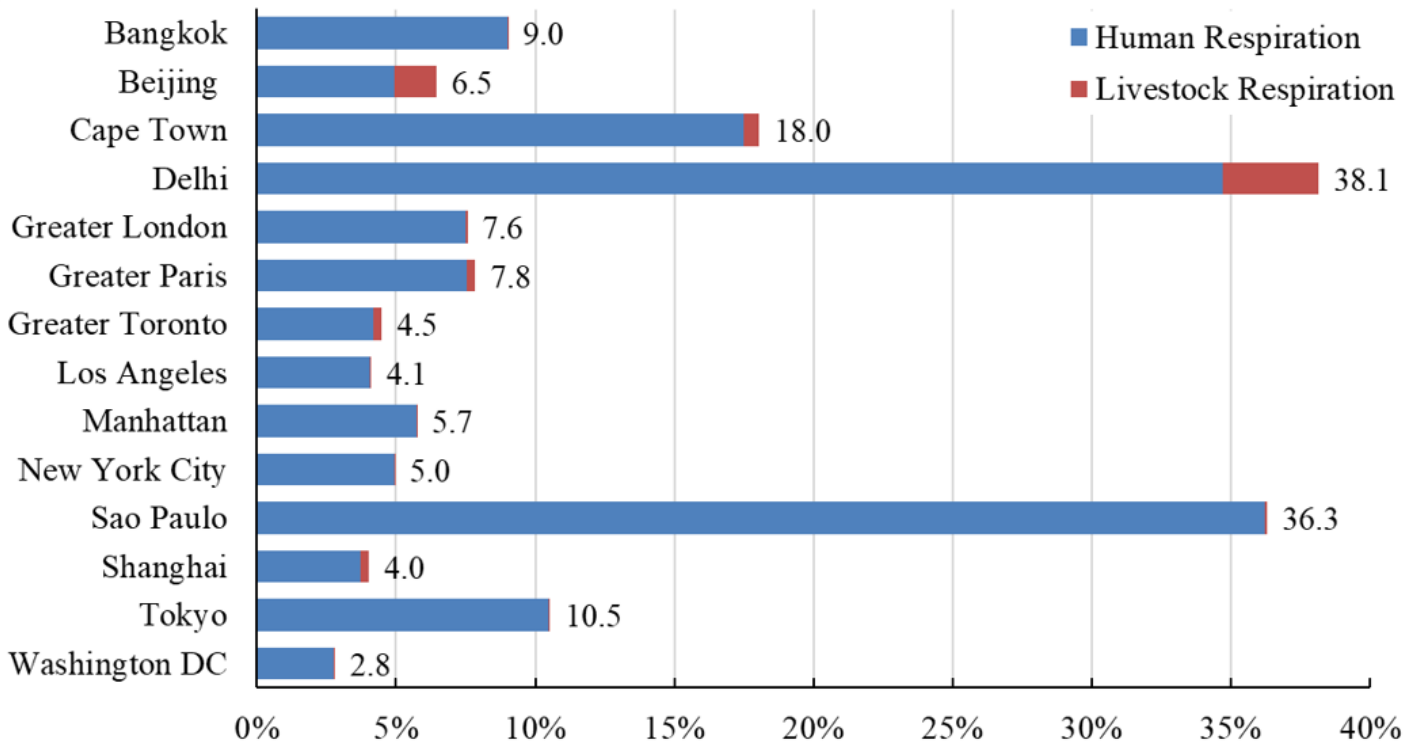

Figure 5

The proportions of HLR to FFE (in %). The values beside the bar show the sum value of the proportion of human and livestock respiration.

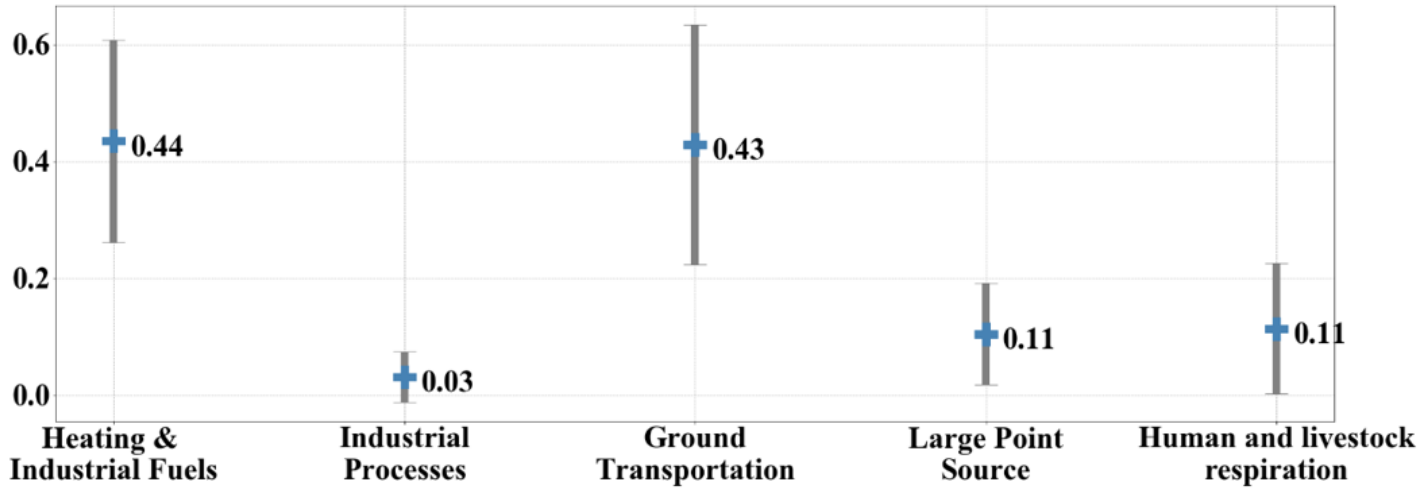

Figure 6

Comparison of the ratio of each sector to in-boundary FFE. The blue point represents the average ratio for the 14 cities, and the gray line is the error bar for the 14 cities.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- FigureS7b.png
- FigureS7a.png
- TableS7.xlsx
- Additionalfile1.docx