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Greenhouse Gas Management and Sustainable Development

Municipal Solid Waste and Climate Change: Engaging Cities Through Composting Techniques

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Definition

Generation and destination of solid waste in cities has caused worldwide diverse socio-environmental problems, among them the emission of greenhouse gases (GHG) resulting from the decomposition of the organic fraction of this waste, which can collaborate in a significant way to climate change. In this scenario, organic waste composting may be an important alternative for techniques that seek to reduce greenhouse gases emissions, thus helping to achieve the goals of sustainable development.

Introduction

The generation and inadequate management of municipal solid waste (MSW) has become a major environmental problem faced in contemporary times, due to the large volumes generated daily in local, regional, and global scale. The economic model and production in which society is guided, responsible for excessive consumption, the production that generates various wastes, through the planned obsolescence of goods and by the impulsive consumption habit, directly results in excessive generation of solid waste.

This reality, coupled with the absence of proper treatment and inadequate waste disposal, as well as the shortcomings of solid waste management programs and environmental education, causes many negative impacts on the physical environment, due to environmental contamination. Some secondary effects of this situation are: the creation of unsanitary conditions in the streets and final disposal of waste sites; the increase in the proliferation of pests and disease vectors; the silting of rivers and the contribution to the increase of flooding in urban areas; the change of surface hydric bodies and general conditions of the watersheds; the change of groundwater, due to disposal of waste in direct contact with the ground, allowing that the manure generated scrolls and reaches groundwater table; air pollution; among other.

W. Leal Filho (ed.), *Encyclopedia of Sustainability in Higher Education*,
https://doi.org/10.1007/978-3-319-63951-2_376-1

As to adverse effects associated with inadequate management of waste, there is a problem that sometimes seems neglected – the contribution of this sector to the emission of greenhouse gases (GHG) and the process of climate change. During the process of decomposition of the organic fraction of waste are generated GHG such as methane (CH_4) – in larger amounts – and carbon dioxide (CO_2) – in smaller amounts – which, if left untreated in their generation source, are released directly into the atmosphere (ICLEI 2009).

According to the studies of Marengo (2007), the greenhouse gases (GHG) are the main agents that contribute to the process of rising global temperature averages, a phenomenon that has triggered effects such as melting ice caps, climate change, the increased occurrence of extreme weather events – such as heavy rainfall, drought, and frost – and others.

Confirming the relevance of GHG emissions and climate change, one of the Sustainable Development Goals (SDGs) presented by Agenda 2030 – agenda that sets programs, actions, and policies that will guide the work of the United Nations (UN) for the period between 2016 and 2030, aiming at sustainable development – focuses specifically on this topic. This is the SDG13 entitled Global Action on Climate Change (UN 2018).

The Agenda was completed in 2015, and in addition to the above SDG, it has other 16 SDG. These 17 main goals include 169 goals ratified by delegates, members of the UN, and together they seek to address key issues so that a global sustainable development process can be put into practice (UN 2018).

This entry discusses directly the SDG13, given the importance of the topic on a global scale and magnitude of the impacts caused by increased anthropogenic emissions of greenhouse gases. More specifically, it addresses the role of the waste sector as a source of emission of these gases. This approach takes into consideration the fact that the decomposition of organic waste presents GHG emission rates that vary substantially depending on the destination to which this material is subjected. As an example, you can compare the delivery of organic waste for composting with the alternative of arranging it in landfill. For the first allocation – composting, it is estimated that decomposition of the organic waste presents a GHG emission rate about 90% lower than if this waste were disposed of in a landfill (EMBRAPA 2010).

For that matter, the objective of this study is to investigate the relevance of potentially avoidable GHG emissions from shipment of organic waste generated in the State of São Paulo, Brazil, for composting instead of arranging it in landfill.

Solid Waste and Emissions of Greenhouse Gases

The process of decomposition of the organic residue, when disposed in landfill, controlled landfill, or garbage dump occurs with the action of microorganisms, which in contact with this material, initiates a series of chemical reactions responsible for biogas generation. This gas mixture consists mainly of CH_4 and CO_2, and other gases are present in minor proportions, such as ammonia (NH_3), hydrogen (H_2), hydrogen sulfide (H_2S), nitrogen (N_2), and oxygen (O_2) (ICLEI 2009; Barbosa 2011).

The biogas production takes place mainly in two stages: an aerobic and an anaerobic reaction. The first phase is initiated after the disposal of waste in the landfill and is basically due to the availability of organic matter and presence of oxygen. At this stage, CO_2 is produced predominantly. In the second phase, triggered after consumption of oxygen that was available, starts anaerobic reaction. At this moment, as the environment has low amount of O_2 and high amount of CO_2, the production of CH_4 occurs (ICLEI 2009; Barbosa 2011).

According to Mendes and Sobrinho (2005), the amount of biogas that is produced in a landfill as a function of a volume of waste disposed is quite variable. This amount depends on a few factors such as the amount of waste deposited, the percentage of this material that is organic, its moisture content, and pH level. In general, biogas emissions are initiated 6 months after the disposal of waste and can remain occurring for up to a century.

As mentioned above, the two principal compounds of the biogas – CH_4 and CO_2 – are the GHG that have contributed the most to the process of intensification of global temperature averages as well as to the occurrence of climate change (Marengo 2007). The importance of GHG emissions from waste decomposition can be seen in the extent to which the Intergovernmental Panel on Climate Change (IPCC) addresses this as one of four major emission sectors that contribute to the intensification of GHG atmospheric concentration – Waste, Energy, Agriculture, and Change of Land Use and Forest (IPCC 2016).

However, there are options to mitigate the impacts of the biogas generation and emissions in landfills. These options depend on, first, the collection of biogas, promoted through underground drains in the landfill, which direct the gases to external outputs. Once collected, the biogas can be used as an energy source, given their relevant calorific value. This is because the mixture containing methane as its main component, a gas that in contact with oxygen, reacts by generating an exothermic reaction and may generate heat – that is flammable and can cause explosions. Because of these characteristics, their energy use arises as a sustainable option for electricity generation, thermal energy, vehicle fuel, and gas lighting (ICLEI 2009).

These alternatives are configured as advanced technological standard options for mitigating the impacts caused by the emission of biogas. Another option – less technological – widely used is the biogas flared at the exit of the ducts from landfills. In this case, the burning of biogas results in reducing the amount of CH_4 that would be emitted to the atmosphere as well as in enhancing amount of CO_2. According to the Environmental Protection Agency (EPA 2018), CH_4 has a global warming potential (GWP) 21 times higher than CO_2 – this way, firing biogas process, which reduces the concentration of CH_4 and increases the emitted CO_2 results in a reduction in GWP associated with the gas mixture sent to the atmosphere.

However, all the alternatives presented so far relate only to mitigate the impacts caused by biogas generated by the waste disposed in landfill. For that matter, we must highlight the importance of another option that, unlikely, refers not to send the organic waste to the landfill, submitting it to the recycling process. It is estimated that this replacement reduces the GHG emission rate associated with the decomposition of the organic residue of about 90% (EMBRAPA 2010).

This reduction is due to the fact that the composting is an aerobic process of degradation of organic solids, resulting in a lower amount of CH_4 emitted per ton decomposed organic residue (in this case, CO_2 formation predominates). On the other hand, in systems that provide an anaerobic organic matter degradation, such as landfill, there is a high CH_4 emission rate with little generation of CO_2. As CO_2 has a capacity to increase the greenhouse effect 21 times lower than CH_4 (EMBRAPA 2010), it explains the benefit regarding processes that reduce CH_4 emissions and increases the emission of CO_2 in similar amounts.

Therefore, with regard to the combat against greenhouse gas emissions, the 21st United Nations Conference on Climate Change (COP 21), held in 2015, established reduction targets whose years for compliance with the agreement initiated in 2020. The member countries of the agreement have committed themselves to investing in renewable energy sources and reduction of carbon emissions, considering the threat of climate change, and aimed at sustainable development of global society (UN 2018).

In this sense, it should be noted that solid urban waste management is an important step towards achieving these goals. According to Hall et al. (2009, p. 2), "Cities are concentrations of vulnerability to the harmful impacts of climate change. They are also, directly and indirectly, responsible for most of the world's greenhouse gas emissions. 50% of the world's population lives in cities, a number that is set to increase to 60% by 2030. For all these reasons, cities are on the front line in responding to the threats of climate change."

Themelis and Ulloa (2007) also address the issue of methane gas as a by-product of municipal solid waste (MSW) in landfills. This is a major problem regarding global warming, as most of the MSW in the world is dumped in unregulated landfills and the generated methane is emitted into the atmosphere. Thus, according to the IPCC, landfills are the largest source of GHG emissions within the "waste" sector. In addition, this sector accounts for about 4.3% of total GHG emissions in developing countries – and up to 3% in developed countries (Bogner et al. 2007).

Thus, according to Otto and Lopes (2017), problems related to MSW have been shown to be relevant on a global scale, both in developed countries and in developing countries, for contributing to the complex phenomena of global warming and climate change.

In view of the above, it is evident the need and urgency in more sustainable proposals of management and destination for solid urban waste, with the aim of developing and applying techniques and methodologies that collaborate to minimize impacts related to climate change, such as composting of organic waste – an alternative that will be discussed more fully below.

Case Study: Avoidable Emissions in the State of São Paulo

The following is a case study involving the municipality of Atibaia and São Paulo state, Brazil, aiming to estimate the extent to which composting of organic waste generated in cities – avoiding their disposal in landfills – can contribute to reduce GHG emissions. Firstly, the justification for the choice of Atibaia as the standard scenario of waste generation in the state is presented. Next, the main methodological questions related to the estimation are presented. Then, the calculations are briefly shown. Finally, we discuss the relevance of avoidable emissions in the State of São Paulo.

City of Atibaia as São Paulo Standard Scenario

To estimate the potentially avoidable emissions in the state of São Paulo, a city of medium size – Atibaia – was used to estimate the average rate of per capita preventable emissions. First, is was estimated the rate of preventable emissions per capita of Atibaia. Thereafter, this rate was used to estimate the avoidable emissions in each of the 645 municipalities in the state, multiplying it by the number of inhabitants in each city. Finally, the sum of avoidable emissions from all municipalities provided the total amount of potentially avoidable emissions in the state by sending the organic fraction of MSW for composting.

The option to use a medium-sized city, to determine the rate of preventable emissions per capita, was due to the pursuit of an intermediate reality when it comes to the issue of the waste generated profile in the state. It is known that this profile – which is the percentage of organic waste, percentage of residue, which is recyclable average amount of waste generated by each inhabitant, etc. – varies greatly depending on the size of population of each municipality. Therefore, the choice of a medium-sized city to estimate the rate of preventable emissions per capita across the state reduces the possibility of major distortions. That is, the profile of the waste generated in the city is not very different from the reality of a large city – or a small town – considering its intermediate position.

The municipality of Atibaia is located in the Atlantic Highlands, characterized by a wide range of high and mountainous terrain with elevation above 800 m. It has an estimated area of 478,517 km^2 and population density estimated at 264.57 km^2, with a population of about 132,017 inhabitants (Atibaia 2015).

Based on the information contained in the Integrated Solid Waste Management Plan of Atibaia (2015) – generated amount of MSW, percentage of MSW that is organic and number of people – and considering the GHG emission factors associated with composting and disposal of organic wastes in landfill, we developed a GHG emission study regarding these two different organic waste destination.

The company Environmental Sanitation Atibaia (SAAE) held, in 2014, a gravimetric study to identify the physical composition of MSW generated in the city. In this study, were considered as the organic matter the food remains added to the biomass – also called green waste from pruning, mowing, and weeding (Table 1) (Atibaia 2015).

Greenhouse Gas Management and Sustainable Development, Table 1 Municipal solid waste material types

Organic matter (food remains + biomass)
Plastics (hard plastic, soft, pet bottle, etc.)
Papers (files, cardboard, etc.)
Glass
Metals (iron and aluminum)
Textile materials/leather/shoes
Disposable diapers
Long life packaging
Wood
Construction waste
Specials (electronics, batteries, and lamps)
Others (mattresses, tires, Styrofoam, etc.)

Source: Authors, based on Atibaia (2015)

This study indicated that, in 2014, the fraction of MSW corresponding to the organic matter was 44%. In this category, the recyclable group also participated with 44% of the total analyzed, and the waste comprised 11% of MSW. There were also 1% residues not addressed by the analysis classified as other (Fig. 1).

Also, according to the survey conducted by SAAE, the total volume of MSW generated in Atibaia was about 27,516.37 megagrams (Mg). Therefore, the amount of organic waste generated in the city, in 2014, was 27,516.37 × 0.44. = **12,107.20 Mg**.

Methodology: CO_2 Equivalent and Emission Factors

Estimates of GHG emissions use the CO_2 equivalent method (CO_2 eq) to standardize the comparison basis. According to Brazilian Agricultural Research Corporation – EMBRAPA (2010), "CO2 equivalent emission is obtained by multiplying the emission of a GHG by its Global Warming Potential for a given time horizon."

Emissions were estimated using the emission factors presented by the methodology Avoidance of methane emissions trough controlled biological treatment of biomass (AMS.III.F) adopted by the United Nations Framework Convention on Climate Change – UNFCCC (EMBRAPA 2010). Therefore, it is considered the following default emission factor for waste landfills: 1.0 Mg of food waste emits about 0.85 Mg CO_2 eq – Methane emissions converted to CO_2 eq – in a period of 10 years. According to the methodology, the same amount of waste in the same time interval, issuing around 0.084 Mg CO_2 eq. This material is subjected to the composting treatment, rather than disposed in landfill – that is, this substitution disposal the organic residue provides a reduction of approximately 90% of GHG (EMBRAPA 2010).

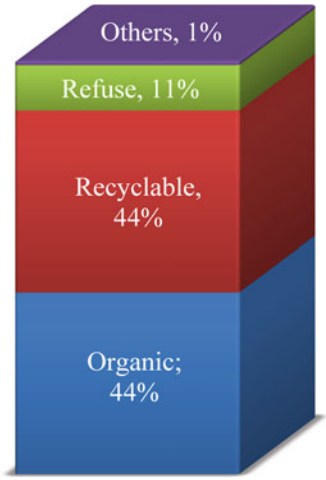
Calculation

Considering the volume of ≅ 12,107.20 Mg of MSW generated in 2014 in the first scenario – in landfill disposal – the emissions result is: 12,107.20 × 0.85 ≅ 10,291.12 Mg CO_2 eq in a period of 10 years. In the second – composting, with the same volume of waste and the same period, the result is: 12,107.20 × 0.084 ≅ 1017.00 mg CO_2 eq.

Therefore, submission of Atibaia organic waste for composting, at the expense of disposal in a sanitary landfill, presents an emission reduction potential of about 90%, in terms of absolute unnecessary emissions account for approximately 11,090.20 Mg CO_2 eq.

One way to investigate the relevance of this amount of potentially avoidable emissions is by checking their expressiveness before the reduction target set by the State of São Paulo. The goal presented in the State Policy on Climate Change (SPCC) is 20% emission reduction by 2020, considering for comparative purposes the 2005 scenario (São Paulo 2009). In 2005, total emissions of CO_2 eq state corresponded to 139,811 gigagrams (Gg) (CETESB 2008). Considering the target shown in SPCC, the amount of emissions avoided in 2020 must therefore be 139,811.00 × 0.2 ≅ 27,962.20 Gg CO_2 eq.

One must check now the representativeness of potentially avoidable emissions by sending organic waste for composting. Considering the result of preventable emissions in the city of Atibaia (11,090.20 Mg CO_2 eq) and its population (139,683) (IBGE 2017), we obtain a rate of avoidable emissions per capita equal to 11,090.20 / 139,683 = 79.39 kg CO_2 eq.



Greenhouse Gas Management and Sustainable Development, Fig. 1 Gravimetric study result in MSW of Atibaia (2014). (Source: Authors, based in Atibaia (2015))

Knowing the number of inhabitants of all 645 cities of São Paulo, it is possible to estimate the potentially avoidable emissions in each of them, applying this per capita rate. Finally, the sum of avoidable emissions in all municipalities provides the total estimation of potentially avoidable emissions in São Paulo from shipment of organic waste for composting. This calculation was performed using the number of inhabitants supplied by the Brazilian Institute of Geography and Statistics (IBGE 2017).

Therefore, considering the number of inhabitants in each municipality in the State of São Paulo and the rate of preventable emissions per capita due to the sending of organic waste for composting – based on waste generation from a medium size city of the state (Atibaia) – it was estimated a total of avoidable emissions of approximately 3580.32 Gg CO_2 eq across the state.

Avoidable Emissions Relevance

The total avoidable emissions estimated (3580.32 Gg CO_2 eq) represent about 13% of the state's emission reduction target, shown in SPCC (São Paulo 2009) (3,580.32 / 27,962.20 = 0.128).

To check the relevance of this emission reduction potential associated with the delivery of organic waste for composting São Paulo – 13% of the state presented by the reduction target, one may want to use a parameter that can provide a consistent basis for comparison. For that matter, the share of waste sector to total emissions of CO_2 eq occurred in the state is shown as a suitable option. In 2005 – the base year from which is based on the goal of SPCC reductions (São Paulo 2009), the waste sector accounted for 6.7% of the state's emissions, as shown in Table 2.

Therefore, even with the waste sector accounting for only 6.7% of total emissions of GHG state, it is estimated that sending the organic fraction for composting at the expense of disposal in landfills can contribute about 13% reduction target emissions shown in SPCC (São Paulo 2009). This is an important data; however, it may be questioned due to the difficulty to enable the sending of 100% of the organic waste generated in Sao Paulo for composting.

This consideration raises the need to investigate the relevance of the emission reduction potential in the case of organic residue lower rates take the path of composting as a disposal. For example, if only half of this type of waste is composted, it is estimated that the total amount of emissions would be avoided in the state would be 3580.32 / 1790.16 2 = Gg CO_2 eq. In this case, this amount of emissions avoided represents approximately 6.5% of the target reductions of Sao Paulo (1790.16 / 27,962.20 = 0.064).

That is, even the waste sector accounting for about 6.7% of GHG emissions that occurred in the State of São Paulo, it is estimated that sending only half of the organic fraction of this waste for composting would contribute to the fulfillment of approximately 6.5% of the reduction target established by the state. There is, therefore, substantially expressive relevance regarding the potentially avoidable emissions from sending organic waste for composting.

Final Considerations

Waste sector contributes to the global GHG emissions more in developing countries than it does in developed countries. It occurs because, in developed countries, there is an increasing process of landfill CH_4 recovery, landfilling decreasing, and

Greenhouse Gas Management and Sustainable Development, Table 2 GHG emissions in the State of São Paulo and Brazil in 2005

	SÃO PAULO	
	Emission	Participation
Sector	(Gg CO_2 eq)	(%)
Energy	80,017	57.2
Industrial processes	20,610	14.7
Agriculture and cattle raising	29,818	21.3
Waste	9,366	6.7
LULUCF[a]	0.0	0.0
Total	139,811	100

Source: Authors, based in CETESB (2008)
[a]Land Use Land-Use Change and Forestry

waste generating decreasing, due to the improvement of local waste management in these countries. This way, waste sector is responsible for about 4.3% of GHG total emissions in developing countries – and 2–3% in developed ones (Bogner et al. 2007).

In this sense, the case study highlights the strong potential of developing countries to mitigate this situation. GHG emission estimates showed that organic waste composting is a treatment that can be considered highly relevant to the mitigation of emissions, addressing the state of São Paulo as study scenario. More specifically, it can be inferred, therefore, that the composting process contributes directly to the achievement of Sustainable Development Goal 13 of Agenda 2030 – Global Action on Climate Change, given its GHG emissions mitigation capacity.

Moreover, it is a technologically simpler process and less energy-intensive than the solutions proposed to mitigate the impacts of the biogas generated by the organic waste disposed in landfill. That is, in addition to offering significant benefits with respect to the issue of GHG emission reduction, composting also reveals good indicators regarding the economic perspective.

Therefore, in order to mitigate the environmental impacts associated with the waste sector, the treatment of its organic fraction through composting seems to be one of the preferred alternatives for this specific kind of waste material. In this sense, it is worthy to emphasize the significant rate of GHG emissions reduction that can be achieved by sending the organic waste to be composted instead of sending it to the landfill – 90%.

Finally, it raises, as challenge for the exploitation of this strong potential, the need to investigate mechanisms that can leverage the amount of organic waste sent for composting.

Cross-References

▶ Energy Efficiency Processes and Sustainable Development
▶ Pollution Prevention for Sustainability
▶ Quality of Life and Sustainable Development
▶ Recycle Relevance and Sustainable Development
▶ Recycling Methods for Sustainability
▶ Social Responsibility and Sustainability

References

Atibaia (2015) Plano Municipal de Gestão Integrada de Resíduos Sólidos Atibaia – SP 2014/2015. http://arquivos.ambiente.sp.gov.br/cpla/2017/05/atibaia.pdf. Accessed 02 Jan 2018

Barbosa RV (2011) A questão dos resíduos sólidos urbanos em Caraguatatuba, Litoral Norte Paulista: Uma abordagem energética e ambiental. Dissertação de mestrado, Universidade Estadual de Campinas – Uincamp. http://repositorio.unicamp.br/bitstream/REPOSIP/264599/1/Barbosa_RebecaVeiga_M.pdf. Accessed 12 Jan 2018

Bogner JM et al (2007) Waste management. In: Metz B et al (eds) Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK/New York, pp 585–618

CETESB-Companhia Ambiental do Estado de São Paulo (2008) 1º Inventário de Emissões Antrópicas de Gases de Efeito Estufa Diretos e Indiretos do Estado de São Paulo. http://cetesb.sp.gov.br/inventario-gee-sp/wp-content/uploads/sites/34/2014/01/Sumario-Executivo.pdf. Accessed 05 Feb 2018

EMBRAPA-Empresa Brasileira de Pesquisa Agropecuária (2010) O papel da compostagem de resíduos orgânicos urbanos na mitigação de emissões de metano. Rio de Janeiro. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/35983/1/documentos-127.pdf. Accessed 20 Feb 2018

EPA-Environmental Protection Agency (2018) Atmospheric lifetime and global warming potential defined. https://www.epa.gov/climateleadership/atmospheric-lifetime-and-global-warming-potential-defined. Accessed 12 Jan 2018

Hall JW et al (2009) Engineering cities: how can cities grow whilst reducing emissions and vulnerability? Newcastle University, Newcastle

IBGE-Instituto Brasileiro de Geografia e Estatísticas (2017) Conheça Cidades e Estados do Brasil. https://cidades.ibge.gov.br. Accessed 10 Feb 2018

ICLEI-Governos Locais pela Sustentabilidade (2009) Manual para aproveitamento do biogás, vol 1. Aterros Saninários, ICLEI, São Paulo. http://www.resol.com.br/cartilha12/manual_iclei_brazil.pdf. Accessed 13 Jan 2018

Intergovernmental Panel on Climate Change (2016) Sixth assessment report (AR6) products, outline of the methodology report (s) to refine the 2006 guidelines for national greenhouse gas inventories. https://www.ipcc.ch/meetings/session44/l3_adopted_outline_methodology_report_guideline.pdf. Accessed 15 Feb 2018

Marengo JA (2007) Mudanças Climáticas Globais e seus Efeitos sobre a Biodiversidade. Brasiília. http://www.mma.gov.br/estruturas/chm/_arquivos/14_2_bio_Parte%201.pdf. Accessed 17 Jan 2018

Mendes LGG, Sobrinho PM (2005) Métodos de estimativa de geração de biogás em aterro sanitário. Rev ciênc Exatas 11(2):71–76. http://revistas.unitau.br/ojs-2.2/index.php/exatas/article/viewFile/358/480. Accessed 7 Feb 2018

Otto HR, Lopes JCJ (2017) Estimativa das emissões de ch4 em aterro sanitário: o caso do aterro Sanitário de municipal de campo grande – MS. In: Anais do 8° Congresso de Gestão Ambiental, Universidade Católica Dom Bosco, Campo Grande, 27–30 November 2017

São Paulo (State) (2009) Lei n 13.798, de 9 de novembro de 2009. Institui a Política Estadual de Mudanças Climáticas – PEMC. São Paulo, Diário Oficial do Estado de São Paulo

Themelis NJ, Ulloa PA (2007) Methane generation in landfills. Renew Energy 32(7):1243–1257

United Nations (2018) Transforming our world: the 2030 Agenda for Sustainable Development. https://sustainabledevelopment.un.org/post2015/transformingourworld. Accessed 06 Jan 2018