Comparative Analysis of the Possibility to Use Urban Organic Waste for Compost or Biogas Productions. Application to Rosario City, Argentina

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Abstract. The city waste is one of the main urban problems to be solved, since they generate large impacts on the environment, like use of land, contamination of the soil, water and air, and human diseases, among others. In Rosario city, placed in the Argentina Humid Pampa and having about 1 million inhabitants, the Municipality is developing different strategies in order to reduce the waste impact (295 000 Tons in 2016). One of the most important actions was the construction of the Bella Vista compost plant in 2012 (within the largest in South America). In the present work we analysed the possibility to use urban organic waste (that for Rosario city represents about 58% of the total waste in the last years) for: a) compost production and b) biogas production, with compost as a by-product. We determined the produced compost and biogas and the corresponding greenhouse gases (GHG) emissions, considering three possible scenarios: A reference scenario (S₀) where 24 100 Tons of urban solid waste per year is transported from the city houses and buildings to a transfer landfill and then to the a final disposal landfill; a scenario number one (S₁) in which the same fraction of waste is transported to the Compost plant and transformed to compost and a scenario number two (S₂) where the same quantity of waste is used for the production of biogas (and compost). Applying the IPCC 2006 Model, we compare the results of the annual GHG emissions, in order to select the best alternative: to expand the Compost plant or to build a Biogas (plus compost) plant. We also discussed the extension of the present analysis to the situation in which all the capability of the Compost plant (25% of the 2016 waste production of the city) is used and the impact these plants are having for a better quality of life of persons involved in the informal waste activity.

1. Introduction
One of the main problems of modern cities is the waste disposal, which is producing significant effects in human health, ecosystem and soil degradation. In the present study we consider the possibility to use the organic waste of a city for its transformation to compost and to use this compost to incorporate in the soil, as a source of Nitrogen (N) fertilization. In this way, it is expected that an important reduction in Greenhouse gases (GHG) emission will be obtained. For example, Luske [1] analyzed this possibility for a citrus farm in Egypt, obtaining very positive results, when N from compost was compared with N obtained from artificial ammonium nitrate (AN). We will also analyze the possibility to use the same
quantity of waste for biogas production. Consequently and following the method proposed by IPCC (2006), we will develop three different Scenarios, that will permit to compare the individual contributions to GHG emissions in the case of:

a) Landfill organic material left in the place (Sr reference scenario),
b) transformed to solid compost (S1 scenario) and
c) used for biogas production, with liquid compost as a byproduct (S2 scenario).

It will be applied the formalism to the particular case of the Rosario city, placed in the Argentina Humid Pampa and at the geographical site: 32° 57’ S, 60° 44’ W, 25 m asl. Its population can be estimated in 2016 at 970,000 inhabitants, taking into account the small variation in the number of citizens in the last decades and considering as a reference the 2010 census. This census determined that Rosario city had 948,000 inhabitants in this year, as indicated in the official web page of the Municipality of Rosario, Argentina [2].

2. Materials and methods

Rosario city produced in the 2016 year, $W_{\text{total,Rosario}(2016)} = 299,000$ Tones of solid (total) waste/year, that were transported to a landfill. The Municipality of Rosario [3] informed that this quantity of waste was maintained approximately the same the last years and that the fraction of organic waste, with respect to the total one, was $f_{\text{org,Ros}} = 0.584$. Consequently $W_{\text{org,Rosario}(2016)} = f_{\text{org,Ros}} \times W_{\text{total,Rosario}(2016)} = 174,600$ TnOrganicWaste/year.

Figure 1. Flux diagram of waste transportation and GHG emissions in the different Sr, S1 and S2 scenarios (see text). Note: The green arrows indicate waste and compost transportation and the curved arrows, GHG emissions, as indicated in the left top part of the figure. The red point arrow pointing to the bottom indicates the CO2 captured by the soil in the farm.
The city has one of the largest Compost plant in South America, called Bella Vista [4], with a potential capacity for processing waste material of 200 \( \text{TnWaste/day} \) when it will arrive at its final stage of development. In 2016, it processed a fraction \( f_{\text{Compost Plant,Ros}} = 0.0807 \) of the total amount, which corresponds to:

\[
W_{\text{Compost Plant,Rosario}}(2016) = f_{\text{Compost Plant,Ros}} \cdot W_{\text{total,Rosario}}(2016) = 24 \ 100 \ \text{TnWaste for Compost/year}
\]  

This mass quantity will be considered the same for all Scenarios in the present work, in order to have the possibility to compare the different results. In what follows, we present the model calculations for the different Scenarios, where the partial contributions of the greenhouse gases (GHG) emissions are indicated in Figure 1 with arrows (up for GHG emission and down for capture).

### 2.1 System definition, basic equations and results for the different scenarios

When was analyzed possibility to use the organic waste for solid compost production and consequent use as farm Nitrogen fertilizer or biogas production (with liquid compost as a byproduct), considering three Scenarios of GHG emissions: Carbon dioxide (CO\(_2\)), Methane (CH\(_4\)) and Nitrous oxide (N\(_2\)O).

#### 2.1.1 Reference scenario (Sr)

In most cities (that we will indicate in what follows with the \( Y \) symbol), the waste is transported by trucks to the landfill and deposited there. Then, the GHG are emitted in two steps: during transportation, \( T(\text{GHG})_{r,Y} \) (producing mainly \( \text{CO}_2 \)) and from chemical reactions in the landfill, \( L(\text{GHG})_{r,Y} \) (generating mainly \( \text{CH}_4 \) and \( \text{N}_2\text{O} \)). In Figure 1 we present a flux diagram of this and other Scenarios. The organic waste produced annually by the Rosario city (\( Y = \text{Rosario} \)) is transported to the landfill by trucks specially prepared for this activity. So, the formula for the GHG mass emitted to the atmosphere due to transportation from the city to the landfill, is the following (IPCC, 2006)

\[
T(\text{GHG})_{r,Y} = T(\text{GHG})_{r,Y} + T'(\text{GHG})_{r,Y} = N_1,Y \cdot \Delta d_1,Y \cdot \gamma_1 \cdot \lambda_{\text{GHG}} + N_2,Y \cdot \Delta d_2,Y \cdot \gamma_2 \cdot \lambda_{\text{GHG}}
\]  

[in TnGHG/year]  

(2)

where the first term in the sum corresponds to the mean transportation (go and return of the truck) from the city to the intermediate transfer landfill and the second one from this point to the Ricardone final deposition landfill, \( N_{1,Y} \) is the number of travels per year made by the trucks [in 1/year], \( \Delta d_{1,Y} \) and \( \Delta d_{2,Y} \) are the mean distances from the city to the transfer landfill (and return) and from the transfer landfill point to the final deposition landfill [in km], \( \gamma_1 \) and \( \gamma_2 \) the fuel (diesel) consumptions of the truck per unit of distance in each case [in litter of fuel/km], respectively. It is needed to include a \( \lambda_{\text{GHG}} \) conversion factor of the emitted GHG mass per litre of fuel used by the transport media [in TnGHG/liter of fuel]. The annual number of travels is obtained from the following relation:

\[
N_{1,Y} = \frac{W_{\text{total,Y}}}{m_{\text{transp}} \cdot \alpha},
\]

being \( m_{\text{transp}} \) the mean capacity of the transportation media [in tons]. In the case that not all this capacity is used (for example in case of low density materials), a correction factor \( \alpha \) (lower than 1), needs to be considered.

Since the transportation of the waste in Rosario city is made with special trucks for waste transportation of \( m_{\text{transp}} = 7.5 \text{ Tn (tons)} \) of capacity and \( \alpha = 0.95 \), then \( N_{1,Ros} = 3 \ 400 \text{ travels/year} \) (rounding to 3 significant figures) and \( N_{2,Ros} = 1 \ 900 \text{ travels/year} \). The main travelled distances are: \( \Delta d_{1,Ros} = 40 \text{ Km} \) and \( \Delta d_{2,Ros} = 30 \text{ km} \), the fuel consumption and conversion to GHG coefficients are, respectively: \( \gamma_1 = 3.5 \text{ litres of fuel/km} \), \( \gamma_2 = 0.66 \text{ litre of fuel/Km} \) and \( \lambda_{\text{GHG}} = 0.00292 \text{ TnCO}_2\text{e/litter of diesel, [5, 6]} \). Replacing these values in the first term in the sum of formula (2), we obtain for the \( \text{CO}_2 \) (since it is the main GHG contribution)

\[
T(\text{CO}_2)_{r,Ros} = 1 \ 400 \text{ TnCO}_2\text{e/year}
\]  

In the same way, we determine for the second term:

\[
T'(\text{CO}_2)_{r,Ros} = 90 \text{ TnCO}_2\text{e/year}
\]  

(4)
This result must be considered as a **lower limit** of CO2 emission per year due to transportation, since there are other sources of waste containing organic materials like industries, urban farms, etc. However, normally their contributions are rather low, with respect to the organic waste that goes to the landfill from the large number of houses and buildings.

The other GHG emission term is due to the Landfill itself (mainly CH4, since N2O is negligible, as shown for example in the report of IPCC, 2006)

\[
L(CH4)_{r,Y} = f_{CH4} * W * \text{CompostPlant}_{1, Ros}(2016) * \Omega_{CH4}
\]  

Here \( f_{CH4} = 0.064 \) is the ratio of the emitted CH4 gas per unit of waste [in TnCH4/TnWaste (tons of waste)] and \( \Omega_{CH4} (=21) \) is the CH4 global warming potential (GWP) with respect to CO2, as given by EPA [11]. For Rosario city, it results:

\[
L(CH4)_{r,Ros} = 32400 \ \text{TnCO2e/year}
\]  

Consequently, the annual total GHG emission within the (S1) **reference scenario** is the sum of the (3), (4) and (6) terms

\[
M(GHG)_{r,Ros} = T*(CO2)_{r,Ros} + T´(CO2)_{r,Ros} + L(CH4)_{r,Ros} = 33890 \ \text{TnCO2e/year}
\]

it can be defined

\[
M'(GHG)_{r,Ros} = T'(CO2)_{r,Ros} + L(CH4)_{r,Ros} = 32490 \ \text{TnCO2e/year}
\]

as the emitted GHG due to the solid waste that is used for compost production at the Bella Vista compost plant. Here \( \text{TnCO2e} \) means that all the GHG emissions were transformed to the equivalent CO2 emissions.

### **2.1.2 Scenario number one (S1)**

In this case, it is proposed that the organic waste is transformed into solid compost and then transported to the (mainly horticultural periurban) farms for N fertilization. Now there are four possibilities for the GHG emissions (see Figure 1): a) as in the previous case, the \textit{transportation from the city} contributions, \( T*(GHG)_{1,Ros} \) and \( T'(CO2)_{1,Ros} \) b) the \textit{compost production unit}, \( C(GHG)_{1,Ros} \), c) the \textit{transportation from the compost production unit to the peri-urban farm}, \( T''(GHG)_{1,Farm} \) and d) the \textit{farm}, \( F(GHG)_{1,Farm} \).

The contribution of each term to the total emission is

\textit{a) Transportation}

There are two terms, as defined before in formula (2). The first one is the same as given in formula (2), with the corresponding result displayed in (3)

\[
T*(GHG)_{1,Ros} = T*(CO2)_{r,Ros}
\]

The second term in formula (3) is, in this case

\[
T'(CO2)_{1,Ros} = N_{2,Y} * \Delta d_{2,Y} * \gamma_{2} * \lambda_{GHG} = 720(1/\text{year}) * 30\text{km} * 0.56(\text{lt/km}) * 0.002943\ \text{TnCO2e/lt} = 36\ \text{TnCO2e/year}
\]
C(GHG)\textsubscript{1,Ros} = [\varphi_1(CH_4)*\Omega_{CH_4} + \varphi_1(N_2O)]*\Omega_{N_2O}^* W_{\text{comp,Ros}} + R(GHG)\textsubscript{1,Ros} = 2 380 TnCO_2e/year \tag{11}

Here $\varphi_1(CH_4) = 0.004 \ TnCH_4/TnCompost$ and $\varphi_1(N_2O) = 0.00024 \ TnN_2O/TnCompost$, are the ratios of the emitted GHG gases to the unit of produced compost [8]. In the Bella Vista compost plant, in 2016, the produced compost was $W_{\text{solid comp, Ros}} = 14 240 \ TnCompost/year$. The value of the N_2O Global Warming Potential is $\Omega_{N_2O} = 310$ [8]. The last term $R(GHG)\textsubscript{1,Ros}$ corresponds to the refuse of solid waste separated in its different constituents and selecting the organic waste and is given by

$$R(GHG)\textsubscript{1,Ros} = f_r*W_{\text{refuse,Ros}}*\Omega_{CH_4} = 0.00064 (TnCH_4/TnCompost)*9 380 (TnCH_4/TnCompost)*21 = 126 \ TnCO_2e/year \tag{12}$$

where $f_r = 0.00064 \ TnCH_4/TnCompost$ is the fraction of the emitted quantity of CH_4 per Ton of compost (Bella Vista compost plant private communication).

The compost produced in this framework, from the initial considered organic waste (formula 1) is 2 650 TnCompost/year.

c) Transportation from the compost production unit to the farm

Applying formula (2), considering a similar transportation unit as that used for the transport from the transfer landfill to the compost plant and an equivalent distance, results

$$T''(CO_2)\textsubscript{1,Farm} = 8 \ TnCO_2e/year \tag{13}$$

d) Farm

The GHG emissions are mainly due N2O from soil and CO2 from compost application, then

$$F(GHG)\textsubscript{1,Farm} = \varphi_2*W^{*}_{\text{comp,Ros}} = 125 \ TnCO_2e/year \tag{14}$$

In this case, $\varphi_2 = 0.0477 \ TnCO_2e/Tn of compost$, as given by Luske and Van der Kamp [7]. Another term is due to the tractor use for the application of the compost

$$F'(GHG)\textsubscript{1,Farm} = \varphi_3*W^{*}_{\text{comp,Ros}} = 70 \ TnCO_2e/year \tag{15}$$

Here, $\varphi_3 = 0.027 \ TnCO_2eq/Tn of compost$, as also given by Luske and Van der Kamp (2009). A significant negative term arise from the incorporation of organic matter into the soil, that can be estimated from the work of Luske and Van der Kamp (2009) as

$$F(GHG)\textsubscript{1,Soil} = -\varphi_4*W^{*}_{\text{comp,Ros}} = -180 \ TnCO_2e/year \tag{16}$$

were, $\varphi_4 = 0.068 \ TnCO_2e/Tn of compost$. Then, the total farm contribution is

$$F(GHG)\textsubscript{1,Farm, total} = F(GHG)\textsubscript{1,Farm} + F'(GHG)\textsubscript{1,Farm} + F(GHG)\textsubscript{1,Soil} = 15 \ TnCO_2e/year \tag{17}$$

So, the annual total GHG emission within the $S_1$ scenario is the sum of the (9), (10), (11), (13) and (17) terms

$$M(GHG)\textsubscript{1,Ros} = T*(CO_2)\textsubscript{1,Ros} + M'(GHG)\textsubscript{1,Ros} = 3 840 \ TnCO_2e/year \tag{18}$$
where we introduced the term

\[ M'_{(GHG)} \_1,Ros = T'(CO2) \_1,Ros + C(GHG) \_1,Ros + T''(CO2) \_1,Farm + F(GHG) \_1,Farm,\text{total} = 2440 \text{TnCO2e/year} \]  

(19)

that corresponds to the emitted GHG due to: the transportation from the transfer landfill to the compost plant, the emissions in this plant and those produced (and captured) in the fertilized farm. The contribution of this term to the total GHG emission (formula 18) in the framework of the \( S_1 \) scenario is the largest one, being 63.5% of the total GHG emissions.

The compost produced in this framework, from the initial considered organic waste (formula 1) is

\[ m_{\text{solid compost}} = \rho_{\text{waste,solid compost}} \times W_{\text{solid compost}, Ros} = 0.11 \times 14240 \text{TnCompost/year} = 2650 \text{TnCompost/year} \]  

(Bella Vista compost plant private communication).

2.1.3 **Scenario number two \( S_2 \)**

This scenario corresponds to the production of biogas and compost as a byproduct. So, there are, as in the previous \( S_1 \) scenario, four possibilities to be analyzed (see Figure 1): a) as in the previous case, the transportation from the city contributions, \( T^*_{(GHG)} \_2,Ros \) and \( T'(CO2) \_2,Ros \) b) the biogas production unit, \( B(GHG) \_2,Ros \), c) the transportation from the biogas production unit to the peri-urban farm, \( T''(GHG) \_2,Farm \) and d) the farm, \( F(GHG) \_2,Farm \), in a similar way as for \( S_1 \) scenario, including a negative contribution due to Nitrogen capture by the soil.

Consequently, the contribution of each term to the total GHG emission in the \( S_2 \) scenario is

a) **Transportation**

\[ T^*_{(GHG)} \_2,Ros = T^*_{(CO2)} \_2,Ros \]  

(20)

as given in formula (2) and the result displayed in (3).

\[ T'(CO2) \_2,Ros = T'(CO2) \_1,Ros = 36 \text{TnCO2e/year} \]  

(21)

since we assume that the traveled distances and the type of vehicles are the same as before.

b) **Biogas (+ liquid compost) production unit**

\[ B(GHG) \_2,Ros = [\beta_{2(CH4)} \times \Omega_{CH4} + \beta_{2(N2O)}] \times \Omega_{N2O} \times W_{\text{comp,Ros}} + R(GHG) \_2,Ros = 365 \text{TnCO2e/year} \]  

(22)

Here \( \beta_{2(CH4)} = 0.0008 \text{TnCH4/TnCompost} \) and \( \beta_{2(N2O)} \sim 0 \) (assumed negligible), are the ratio of the emitted GHG gases to the unit of produced biogas [8]. The last term corresponds to the refuse of solid waste separated in its different constituents and it is given in formula (12)

\[ R(GHG) \_2,Ros = R(GHG) \_1,Ros \]  

(23)

c) **Transportation from the biogas production unit to the farm**

Applying formula (2) and assuming that the value determined in the previous \( S_1 \) scenario (formula 13) can be applied in the present case, but multiplied by a factor of two due to the water content of the liquid compost (Gropelli and Giampaoli, 2001), it results

\[ T''(CO2) \_2,Farm = 16 \text{TnCO2e/year} \]  

(24)
We like to point out that only the liquid compost is transported since it is assumed that the factory that will use the biofuel will be placed in the same zone as the Biogas plant, so in this case the transportation contribution, $T'(CO_2)_{2,Ros}$, can be considered negligible.

d) **Farm**

Here, the GHG emissions are mainly due to the emissions of N$_2$O from soil and CO$_2$ from compost application. Then, considering the same contribution of the farm terms as in the previous $S_i$ scenario, we have

$$F(GHG)_{2,Farm,total} = F(GHG)_{1,Farm,total} = 15 \text{ TnCO}_2\text{e/year} \quad (25)$$

So, the annual total GHG emission within the $S_2$ scenario is the sum of the (20), (21), (22), (24) and (25) terms

$$M(GHG)_{1,Ros} = T^*(CO_2)_{B,Ros} + M'(GHG)_{2,Ros} = 1830 \text{ TnCO}_2\text{e/year} \quad (26)$$

where the following term is introduced in the same way as before

$$M'(GHG)_{2,Ros} = T'(CO_2)_{1,Ros} + B(GHG)_{2,Ros} + T''(CO_2)_{2,Farm} + F(GHG)_{2,Farm,total} = 430 \text{ TnCO}_2\text{e/year} \quad (27)$$

It is the emitted GHG due to the liquid waste that is obtained from the biogas production process. The percentage contribution of this term (formula 27) to the total GHG emission in $S_2$ scenario (formula 26) is 23.5 %.

The biogas produced in this framework, from the initial considered organic waste (formula 1) is $V_{biogas} = e_{biogas} * W_{solid\ comp,\ Ros} = 232 \text{ (m}^3\ \text{biogas/TnCompost)} * 14240 \text{ TnCompost/year} = 3.3 \text{ Mn}^3\text{biogas/year}$ [9] and the liquid compost is $m_{liquid\ compost} = 2 \text{ (Lt of compost/Tn compost sólido)} * 5.3 \text{ M}\text{Lt of compost/year}$, [10].

### 3. Conclusions

The following conclusions can be derived from the present work.

- The contribution to GHG emissions of the waste transportation from the Rosario city to the Transfer waste plant is quite high, 1400 tons CO$_2$e/year. Since this quantity is the same for the three scenarios, it will not be considered in the following analysis of the GHG emissions corresponding to the $S_r$, $S_1$ and $S_2$ scenarios:

- In the $S_r$ reference scenario, the largest contribution came from the landfill GHG emissions, being 32400 TnCO$_2$e/year. The lowest one corresponds to the waste transportation from the Transfer waste plant to the Ricardone landfill (90 TnCO$_2$e/year).

- In the $S_1$ scenario, the main contribution came from the Compost production unit, 380 TnCO$_2$e/year, being rather small the other positive contributions coming from the transport from the transfer landfill to the Compost plant (8 TnCO$_2$e/year) and from the farm (15 TnCO$_2$e/year). In the last case, the low value is due to the compensation of the transport and labor terms by the Nitrogen fixation by the soil term. If the solid compost were all transported to the periurban horticultural farms for N fertilization, which amounts at 2650 TnCompost/year, it could have other benefits, like the inclusion of organic material into the soil, the elimination of (at least part of) the landfill near the Rosario city, etc.

- In the $S_2$ scenario, the main contribution came from the biogas production unit, 365 TnCO$_2$e/year, accounting for 85 % of the total contribution, being the rest terms quite small. The liquid compost that would be transported to the periurban horticultural farms for N
fertilization amounts at 5 300 TnCompost/year (double than in the $S_1$ scenario since it is partially diluted in water).

- Putting apart the term (3) corresponding to the transportation from the city to the Transfer landfill plant, that is the same in all scenarios, it results the following percentage relations for:
  
  a) $S_1$ scenario with respect to the $S_r$ one (see Figure 2)
  
  $$ \Delta S_r,S_1(\%) = 100\times \frac{M'(GHG)_{r,Ros} - M'(GHG)_{1,Ros}}{M'(GHG)_{r,Ros}} = 92.5\% $$ (28)

  b) $S_2$ scenario with respect to the $S_r$ one (see also Figure 2)
  
  $$ \Delta S_r,S_2(\%) = 100\times \frac{M'(GHG)_{r,Ros} - M'(GHG)_{2,Ros}}{M'(GHG)_{r,Ros}} = 98.7\% $$ (29)

Figure 2. Comparison of the GHG mass emissions [in TnCO$_2$/year] of the different $S_r$, $S_1$ and $S_2$ scenarios (see text) and percentage reductions indicated with green arrows pointing to the left, with respect to the $S_r$ reference scenario.

- The extension of the present analysis to the situation in which all the capability of the compost plant (25% of the 2016 waste production of the Rosario city) will be used, will produce higher compost, biogas and GHG emissions in the $S_1$ scenario, approximately in a ratio: 74 750 (TnWasteforCompost/year)/24 100 (TnWasteforCompost/year) = 3.1. However, this GHG emissions would be very small compared with those that would be produced if the same mass of organic waste would be disposed in the Ricardone landfill, amounting to the same 3.1 ratio.

- Another point to be considered is that, when the Bella Vista compost plant will produce compost at its full capacity, it will increase in about the same ratio the number of workers, with respect to 2016. This is important, since a large fraction of the present workers were cartoneros (persons dedicated to collect the waste that they can sold like paper, plastics, metals, etc.) and in this way they can improve significantly their quality of life. This is a social impact of the project that it is not easy to quantify, as the GHG emissions, but it must be taking into account by the Municipality authorities in an analysis of the impact of given actions, like those proposed in this work. So, from the present results of GHG emissions (directly related to Global Warming, [12])
plus the consideration of the social problem, the Municipality of Rosario will has the possibility to decide which will be the line of action to be selected.

In conclusion, the use of city waste for compost production or for biogas production with compost as a byproduct, is a very good possibility to reduce GHG emissions, producing the last one the largest reduction in these emissions.

Acknowledgements
The support of the following institutions are acknowledge: Municipality of Rosario, Argentina; CONICET, Argentina; RUAF (Resource Centres for Urban Agriculture and Food Security) Foundation, The Netherlands in and CDKN (Climate Development Knowledge Network), Great Britain in the first stages of the present work. Also, we acknowledge particularly to Marielle Dubbeling of RUAF Foundation, to Dr Wijnand Sukkel of Applied Plant Research, Wageningen University and Research Centre, Sustainable Farming and Food Systems, Wageningen University, The Netherlands and to Eng Cecilia Alvarez and Belén Gonzalez, members of the Bella Vista compost plant.

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