Environmental and economic feasibility of an integrated community composting plant and organic farm in Malaysia
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Abstract
Waste prevention and management become the major issue worldwide to achieve sustainable development. Similar to many developing countries, Malaysia has faced serious problems in waste management due to its rapid economic growth and urbanisation. The municipal solid waste (MSW) production rate in Malaysia had increased significantly in a recent year, ranging from 0.8 – 1.25 kg/person∙d. The wastes generated contain a high amount of organic portion and moisture content. Imperfect MSW management practice or delayed in waste collection and transportation can lead to severe health issues. This paper presents a case study in Johor Bahru, Malaysia in which a composting prototype is used as the waste management technology to recycle the food and vegetable wastes. The greenhouse gases (GHG) mitigation and economic feasibility of the integrated composting and organic farming in this study are reported. This study showed a reduction of 32% of GHG by diverting the food and vegetable wastes from landfilling to the composting plant. Higher reduction rate can be achieved with a better planning of waste collection route and applying the mitigation strategies during the composting process. High revenue can also be obtained from the sale of compost generated and vegetable. This study provides an insight of the feasibility and desirability to implement a pilot-scale composting for organic waste management to achieve the low carbon and self-sustain community.

1. Introduction
Municipal solid waste (MSW) is defined as the refuse or unwanted product that derived from human activities and discarded by the society. With the rapid population growth, urbanisation and industrialisation, the generation of the municipal solid waste (MSW) have increased over the years. According to the Department of Statistics (2016), Malaysian population reached 31.7M in 2016 with an annual growth rate of 1.5 % where 71 % of the total population has resided in the urban area in tandem with the rapid development. From 2012 to 2014, the MSW generation increased from 22 kt/d to 30-33 kt/d. Landfilling and open dumping remained the main disposal method; about 94.5 % of the collected wastes are disposed in the landfills or open dumpsites, with a recycling and composting rate of 5.5 and 1 % (Periathamby et al., 2009), despite the fact that 57 % of the waste is made out of organic solid waste (Saeed et al., 2009).

Solid waste management encompasses all the activities from generation to the final disposal. These include the control, generation, storage, collection, transfer and transportation, processing and disposal of solid waste consistent with the best practices of public health, economics, and finance, engineering, administration, legal and environmental considerations (Johari et al., 2014). In developing country such as Malaysia, the over-reliance on landfilling and open dumping can lead to some severe issues, including the emission of greenhouse gases (GHG) from the site as well as the limited land area for waste disposal. It is essential to develop a more sustainable and effective MSW management in Malaysia.

Composting can be an alternative waste management strategy in overcoming this issue. Composting is a biological process which converts organic wastes into a stable organic product with high humic substances that last longer in soil (Wang et al., 2016). It involves a relatively low processing cost and less complicated
technology as compared to other MSW management technology. Composting transforms the organic wastes into compost that can be used to improve soil quality, minimise soil erosion, and promote plant growth. Compost without a detectable level of pathogens and heavy metals can act as a soil conditioner or organic fertiliser to plants. It also provides the soil with a large amount of organic matter and nutrients, improves the soil texture and chemical buffering, and water-holding capacity of the soil. With the presence of a high population of beneficial microorganisms in compost, the suppression of several plant diseases can be achieved with the application of compost. Composting has been widely practised in many developing countries. However, the replacement ratio of compost for chemical fertiliser is still low due to the inconsistency in the end quality of compost (Fan et al., 2016), unclear definition of system boundaries, incomplete impact assessment and lack of sensitivity analysis (Laurent et al., 2014).

This study presented an interesting case study at Johor Bahru, Malaysia. The pilot-scale composting plant is integrated with the concept of community farming to enable self-sustaining. The compost produced is being used directly on the family farm. The economic analysis demonstrated a potential high-return of this community-composting model that is a determinant factor to sustain the composting site. There have been several studies reported on the environmental and economic analysis of industrial composting plant. However, application of such a community composting model has not been addressed in details (Lim et al., 2016). The main objective of this study is to quantify the cost and benefit analysis (CBA) and the GHG emission regarding kg CO₂eq through inventory analysis of a community composting prototype located in Johor, Malaysia. The analyses are conducted based on two scenarios. Scenario 1 comprises the baseline scenario where the waste is sent to open dumping (OD); Scenario 2 represents the waste treatment in the community composting plant (CCP). This paper fills in the gap in the feasibility studies of a novel community-composting model.

2. Method

2.1 Community-composting site and waste sources

Study site comprises of a composting facility and an organic farm. The composting plant is currently handling around 2.5 to 3 t/d of food and vegetable waste. It is a community farm preaches to produce healthy and organic crops to close to 70 families who support the farm.

2.2 Scenario analysis

2.2.1 Scenario 1: Baseline scenario – open dumping (OD)

Scenario 1 represents the current waste management practice where the food waste is collected and disposed at a landfill around Kulai, Johor. A total of 288 t/y of food waste (FW) on the generation rate of 24 t/mth is disposed to the landfill. As for the fruit and vegetable retail market, the vegetable waste is currently sent to the open dumpsite in a farm located at Ulu Tiram, Johor.

2.2.2 Scenario 2: Community-composting plant (CCP)

Scenario 2 represents the current pilot-scale composting being operated by the organic farm. Different types of waste are collected using a 2t-truck and transported to the farm. A total of 84.6 t/d of waste is composted with a production of 32 t/mth of compost.

2.3 Environmental assessment – GHG inventory analysis

The life-cycle inventory analysis for scenarios 1 and 2 was conducted for the estimation of GHGs emission regarding kgCO₂eq. This analysis aims to identify and quantify the environmental performance related to the system through the inputs and outputs of the two scenarios within the system boundary.

The system boundary of this study included the transport of waste to the disposal area, process emission from the decomposition of organic waste during the treatment and replacement of chemical fertiliser as well as carbon sequestration through compost application. The functional unit (f.u.) is defined as 1 t of waste entering the treatment facility.
2.3.1 Scenario 1

The GHG emission factor for landfilling and open dumping is calculated based on the non-sanitary landfill emission from IPCC model (2006). The GHG emission only considered the fuel consumption for the transportation of the wastes from the hotel and the fruit and vegetable retail to the open dumpsite, as well as the emission from the anaerobic digestion of waste at the open dumpsite. The CH₄ generation potential from landfill (IPCC, 2006) was calculated using Eq. (1):

\[ L_0 = MCF \times DOC \times \frac{DOC}{F} \times SF \]  

(1)

where \( L_0 \) is the methane generation potential (t CH₄/t waste), MCF is the methane correction factor (fraction), DOC is the fraction of degradable organic carbon of the waste (weight fraction), F is the fraction of methane in landfill gas, SF is the stoichiometric factor.

The CO₂ emission from diesel combustion is calculated using Eq. (2) (U.S. EPA, 2016):

\[ E_{CO2} = EF \times \text{volume of diesel consumed} \]  

(2)

where \( E_{CO2} \) is the CO₂ generation potential, EF is the emission factor for diesel combustion which is 2.70 kg CO₂/L diesel.

2.3.2 Scenario 2

The GHG inventory in Scenario 2 accounted for the emission of CH₄ and N₂O from the composting process, GHG emission from the diesel consumption for biomass transportation, shredding, mixing and screening of materials. The processes that contributed to carbon savings included the substitution of chemical fertiliser, carbon storage factor from compost to soil and carbon sequestration. The key assumptions made included:

- The biogenic CO₂ emissions from the composting process are considered to be carbon neutral, but the emission from CH₄ and N₂O were included with 21 times and 310 times higher GWP than CO₂ based on 100-year time horizon.

- The GHG emissions from the operation of on-site machinery included CO₂, CH₄ and N₂O.

- The input data is a mixture of on-site data and literature data from other similar studies

- the total FW and VW generated was 24 t/mth and 54 t/mth

- the GHG savings from the compost production was based on the amount of compost produced

The following limitations were applied:

- The application of compost was equivalent to the chemical fertiliser but excluded the potential N₂O emission from the compost application in soil.

- The emission from water usage and in the form of leachate was excluded.

- The emissions from the waste materials other than food and vegetable wastes were excluded.

CH₄ and N₂O emissions from composting may be calculated using the total mass of waste composted and the emission factors (U.S. EPA, 2011) as listed in Eq. (3) and (4):

\[ E_{CH4} = EF_{compost, CH4} \times M_{compost} \]  

(3)

\[ E_{N2O} = EF_{compost, N2O} \times M_{compost} \]  

(4)

\( E_{CH4} \) and \( E_{N2O} \) are the CH₄ and N₂O generation potential, \( EF_{compost, CH4} \) and \( EF_{compost, N2O} \) is the emission factor for CH₄ and N₂O, \( M_{compost} \) is the mass of material added or fed to the composting process (wet weight basis) (t/mth). The \( EF_{compost, CH4} \) and \( EF_{compost, N2O} \) are 4 kg CH₄/t waste and 0.3 kg N₂O/t waste.

CH₄ and N₂O emissions from the nonroad vehicle (agricultural equipment) are calculated using Eq. (5) and (6) (U.S. EPA, 2016):

\[ E_{CH4} = EF_{diesel, CH4} \times \text{volume of diesel consumed} \]  

(5)

\[ E_{N2O} = EF_{diesel, N2O} \times \text{volume of diesel consumed} \]  

(6)

\( E_{CH4} \) and \( E_{N2O} \) are the CH₄ and N₂O generation potential, \( EF_{diesel, CH4} \) and \( EF_{diesel, N2O} \) is the emission factor for CH₄ and N₂O, which are 0.00038 kg CH₄/L diesel and 0.00033 kg N₂O/L diesel.

2.4 Cost and benefit analysis (CBA)

The CBA assessed the economic feasibility for the two scenarios studied. Such analysis provides useful information to the local authorities or other investors to set up a community composting plant.
2.4.1 Scenario 1

The major cost for Scenario 1 is the diesel consumption for waste collection and transportation to the landfill and open dumpsite.

2.4.1 Scenario 2

On-site data collection was conducted to conduct the CBA for Scenario 2. The costing in this scenario includes the infrastructure and site construction, equipment purchase, diesel consumption for waste collection and on-site operation, workforce, sample analysis, and utility cost. The cost benefits of this scenario included the saving from the compost utilisation (replacement of chemical fertiliser) and the selling of vegetables. Figure 1 shows a common system to calculate the cost to produce 1 kg of compost for the community composting plant (CCP).

![Figure 1 Key data to compute the cost of the community composting plant (CCP) for Scenario 2.](image)

3. Results and Discussions

3.1 GHG Inventory analysis

The environmental impacts of the two scenarios by evaluating the GHG emissions by kg CO\(_2\)-eq for both scenarios are presented in Table 1 and 2.

**Table 1 Input data for GHG calculation in Scenario 1 landfilling/ open dumping.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane correction factor, MCF</td>
<td>0.6</td>
<td>IPCC (2006)</td>
</tr>
<tr>
<td>Degradable organic carbon (fraction), DOC</td>
<td>0.15</td>
<td>IPCC (2006)</td>
</tr>
<tr>
<td>Fraction of DOC decomposed (fraction), DOC</td>
<td>0.5</td>
<td>Food waste (IPC C, 2006)</td>
</tr>
<tr>
<td>Fraction by volume of CH(_4) in landfill gas, F</td>
<td>0.5</td>
<td>Food waste (IPCC, 2006)</td>
</tr>
<tr>
<td>Stoichiometric actor, SF</td>
<td>16/12</td>
<td>Food waste (IPCC, 2006)</td>
</tr>
<tr>
<td>Methane generation potential, L(_0)</td>
<td>30 (kg CH(_4)/t waste)</td>
<td>Calculated from Eq. (1)</td>
</tr>
</tbody>
</table>

**Table 2 GHG inventory for Scenarios 1 and 2.**

<table>
<thead>
<tr>
<th>Input</th>
<th>Scenarios 1</th>
<th>Scenarios 2</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>I) Feedstock and compost (t/mth)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FW to open dumpsite</td>
<td>24</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>VW to open dumpsite</td>
<td>54</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FW to composting site</td>
<td>0</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>VW to composting site</td>
<td>0</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Onion and garlic waste to composting site</td>
<td>0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Fishery waste to composting site</td>
<td>0</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Compost produced</td>
<td>0</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>II) GHG calculation (kg CO(_2)-eq) for both scenarios</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A) CO(_2) generation potential based on the feedstock input (kg CO(_2)-eq/t material)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO(_2) generation potential from FW and VW</td>
<td>630</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>CO(_2) generation potential from co-composting of FW and VW</td>
<td>0</td>
<td>177</td>
<td>U.S. EPA (2010)</td>
</tr>
<tr>
<td>Total A: total CO(_2) generation potential for feedstock</td>
<td>630</td>
<td>177</td>
<td></td>
</tr>
</tbody>
</table>
The results from Table 2 show that composting (Scenario 2) provides a promising outcome in GHG saving with approximately 32% of GHG mitigation compared to the open dumping (Scenario 1). Seng et al. (2013) and Bong et al. (2016a) also observed the similar finding (over 60% saving of GHG) when composting was used as waste treatment compared to landfilling.

For both scenarios, the diesel consumption for waste collection and transportation contributed significantly to the GHG emissions among all inventory items. A more efficient wastes collection flow is required to reduce the GHG emissions. The current wastes collection flow is not efficient, it is time and diesel-consuming and leading to high GHG emission. This can be improved by combining several trips and reduced the trip frequency between the waste source and the farm. For the vegetable waste collection, instead of going twice per day, the two trips can be combined and collected only in the afternoon. This re-planning of the waste collection route is dependence on the maximum capacity of the truck. This issue highlights the importance of optimising the location of the composting site that could minimise the transportation distance and the GHG emissions to the composting facility (Seng et al., 2013) and more recently (Bong et al., 2016a).

Apart of emission due to waste transportation, the emission from the waste degradation can be critical if the pile is not well managed. CH₄ and N₂O are emitted during composting. Both GHG contributes 21 times and 310 times higher global warming potential (GWP) than CO₂ based on the 100 y time horizon. Failure of monitoring the composting process can cause a higher emission of these GHG compared to landfilling and open dumping. The mitigation of GHG emission from composting process can be achieved by applying different amendment strategies (Bong et al. (2016b). The GHG emission from the composting process could be measured directly from the pile to show the real GHG emissions of the compost piles. The GHG emission from the process ranges within 4 to 8,000 kg CO₂-eq/t wastes when different composting approaches were applied (Bong et al., 2016a; Lim et al., 2016). Amendment made during composting can improve the compost quality as a high nutrient soil-enhancer. The GHG calculation for machinery on composting site was calculated based on the diesel consumption from all the on-site activities. Due to the lack of data availability, the electricity consumption is not included in this study for GHG emission.

The greatest GHG saving recorded for Scenario 2 came from the avoided GHG emission from the production of N fertiliser, followed by the avoidance of K and P fertilisers production (Table 2). The application of compost also resulted in the GHG savings from soil carbon sequestration, a process that retains and increases the carbon storage in soil. As mentioned in Section 2.1, the compost produced in this study is...
consumed locally; the avoidance of the transportation to and from the farm site can significantly contribute to the GHG savings.

3.2 Cost and benefit analysis (CBA)

Table 3 shows the cost and benefit analysis (CBA) of the two scenarios. In this section, the total costs of the two scenarios on a yearly basis were calculated with the capital cost being normalised into 10 y. All the costs were reported in MYR/mth unless otherwise stated.

Table 3 Costing breakdowns, saving, and revenue gained from the two scenarios.

<table>
<thead>
<tr>
<th>Item</th>
<th>Scenarios</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>I) Cost breakdown and compost revenue (MYR/mth)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A) Capital cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site construction</td>
<td>0</td>
<td>450,000 Accommodation for workers, workshop and seedling area; farming area; composting site with leachate collection</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>0</td>
<td>98,700 Site with water and electricity supply</td>
</tr>
<tr>
<td>Tractor</td>
<td>0</td>
<td>70,000 2-t truck</td>
</tr>
<tr>
<td>Screener</td>
<td>0</td>
<td>20,000</td>
</tr>
<tr>
<td>Shredder</td>
<td>0</td>
<td>2,500</td>
</tr>
<tr>
<td>Bobcat</td>
<td>0</td>
<td>40,000 Model: S175 from Teck Soon Sdn Bhd</td>
</tr>
<tr>
<td>Waste collection bin</td>
<td>0</td>
<td>16,000 MYR 160 × 100 units</td>
</tr>
<tr>
<td>Chimney system</td>
<td>0</td>
<td>1,000</td>
</tr>
<tr>
<td>Tilling machine</td>
<td>0</td>
<td>1,800 Model: VMT500</td>
</tr>
<tr>
<td>Total A</td>
<td>0</td>
<td>700,000</td>
</tr>
<tr>
<td>B) Operational cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>i. Labour cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composting process monitoring</td>
<td>0</td>
<td>2,000 1 worker × MYR 2,000/mth</td>
</tr>
<tr>
<td>Farming</td>
<td>0</td>
<td>8,000 4 worker × MYR 2,000/mth</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>10,000</td>
</tr>
<tr>
<td>ii. Fuel cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation (diesel, L/mth)</td>
<td>1,040</td>
<td>900</td>
</tr>
<tr>
<td>On-site machinery (diesel, L/mth)</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Total</td>
<td>1,038</td>
<td>1,100 Diesel cost = MYR 2.10/L</td>
</tr>
<tr>
<td>iii. Miscellaneous cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laboratory analysis</td>
<td>0</td>
<td>1,050</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>2,000 Utility cost (electricity and water bill and maintenance fee)</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>3,050</td>
</tr>
<tr>
<td>Total B (MYR/mth)</td>
<td>1,038</td>
<td>14,150</td>
</tr>
<tr>
<td>C) Saving from compost utilisation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical fertiliser</td>
<td>0</td>
<td>-139.8 MYR 120/ 50 kg fertiliser</td>
</tr>
<tr>
<td>Pesticide &amp; Herbicide</td>
<td>0</td>
<td>-300.00 MYR 100/ 100 cc pesticide &amp; herbicide</td>
</tr>
<tr>
<td>Total C (MYR/mth)</td>
<td></td>
<td>-339.80</td>
</tr>
<tr>
<td>D) Revenue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Membership</td>
<td>0</td>
<td>-27,000 Membership = MYR 2,000/ 6 mth-family</td>
</tr>
<tr>
<td>Total D (MYR/mth)</td>
<td>0</td>
<td>-27,000</td>
</tr>
<tr>
<td>II) Final costings (MYR/yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost A</td>
<td>0</td>
<td>+100,000 Normalised for 10 years</td>
</tr>
<tr>
<td>Total cost B</td>
<td>+12,456</td>
<td>+169,800</td>
</tr>
<tr>
<td>Total cost C</td>
<td>0</td>
<td>-4,077.60</td>
</tr>
<tr>
<td>Total cost D</td>
<td>0</td>
<td>-320,000</td>
</tr>
<tr>
<td>Total D (final) (MYR/mth)</td>
<td>+12,456</td>
<td>-54,277.60</td>
</tr>
</tbody>
</table>
As reported in Table 3, the investment for a composting facility (Scenario 2) offers good return potential with the incorporation of community agriculture, especially with the adaptation of the membership concept. Although composting had a relatively low investment and capital cost, it brought a lesser revenue and a longer payback period compared to other waste management technologies (Blumenstein et al., 2012; Bong et al., 2016a; Yoshizaki et al., 2012). The membership subscription concept plays a critical role in this case study in maintaining a substantial cash flow. This liquidity allows the purchase and upgrading of the on-site facilities to improve the composting process further. It is expected that a minimum of 100 families is required to sustain the operation of this composting side. Current subscription capacity is limited by the crop yield which is not enough to provide sufficient crops to 100 families. This limitation is expected to be solved in another few years’ time when the soil gets more fertile over the years.

As reported by Galgani et al. (2014), in Northern Ghana, composting was not viable without external subsidies, although some successful cases in Bangladesh and Indonesia were recorded in which subsidies was not required in running the composting project. The economic viability of a composting project is hard to be estimated since it can be affected by many factors. Including the capital cost, the technology selected, the scale of the project, the supply and demand chain of the wastes and the mature compost, available facilities and equipment, and the composting site selection. In this study, besides the membership concept, the family-run business model also allow the early payback of this project, where big support has been provided during the early set up of the composting facility. These included the land, free supply of wastes, volunteer of dump-site and bobcat drivers, and on-site operator. To facilitate more ventures in the composting business, the government would need to provide financial incentives to overcome the financial barrier, most notably the setup cost which was reported to be nearly MYR 700,000 (Table 3). The cost will be higher if either the purchasing or rental cost of the land is included. Some mechanisms include soft loan, green technology scheme, tax exemption for imported machinery, buy-back mechanism from local council (i.e. to be used for landscaping), quality assurance for safe utilisation, and technical assistance to produce good quality compost should be considered by the local government to relieve the financial and technological barrier of the investors.

As recorded by the Food and Agriculture Organization (2016), world fertiliser consumption rate had increased from 98.7 to 119.9 kg/ha of arable land from the year 2002 to 2013. In the same period, the statistic rose from 1,177.0 to 1,726.6 kg/ha of arable land in Malaysia. This can be reduced with the performing of composting and through compost utilisation. The organic farm farm had demonstrated a successful composting-economic model while other composting facilities could have limited land and workforce to run an organic farm. A joint effort between compost facilities and farmers should be established, especially with the help of the government unit.

4. Conclusion

This study showed a community composting project as a viable waste management technology to reduce the amount of organic waste to the landfill. The pilot scale composting facility presented by the organic farm was capable of reducing up to 32% of GHG and able to generate revenue compared to open dumping. Most of the GHG emissions from composting were recorded to be contributed by diesel consumption from transportation and the on-site operation of composting process (including the emission from diesel consumption for on-site machinery and the composting process alone. However, the GHG emission can also reduce by a better planning of waste collection route where the later can be improved by implementing some mitigation strategies such as improve aeration, the addition of a bulking agent, cover with mature compost, and the addition of microbial inoculants. The composting-economic model demonstrated by the organic farm can be applied as a successful strategy with the adaptation of membership concept. More families can be fed through the up-scaling of the composting facility and the expanding of the agricultural land. Income can also be generated by the mature compost sale. Further investigation is needed for better understanding the supply-demand chain of wastes and mature compost to minimise the GHG emission during the process as well as amplify the revenue from running a composting facility.
As a conclusion, composting is proof to be a cleaner and sustainable technology compared to open dumping that reuses the organic wastes to produce bio-fertiliser for agricultural purposes. The relatively low investment cost and simple technology in composting also allow the better development of the composting project in developing country.

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