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BENGT STEEN*, RAUL CARLSON,
FREDRIK LYRSTEDT, GUY SKANTZE

** Corresponding author, Department of Environmental Systems Analysis*

CPM – Center for Environmental Assessment of Product and Material Systems
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Bengt Steen*, Raul Carlson, Fredrik Lyrstedt, Guy Skantze,

Department of Environmental Systems Analysis, Chalmers University of Technology, SE-412 96 Göteborg Sweden

Abstract

In 1991 the World Business Council for Sustainable Development were looking for a single concept to sum up the businesses influence on sustainable development. They found eco-efficiency to be suitable. Since then this concept has been used in many ways. This article reviews the conceptual understanding of eco-efficiency, formulates success criteria for an eco-efficiency indicator, gives an example of an eco-efficiency indicator, uses it in a case study, evaluates its compliance with success criteria and indicates its use in sustainability management. It concludes that 1) linking eco-efficiency to economic accounting and the budget process allows for monitoring and management of sustainable development of a business unit and 2) using monetised environmental externalities as a measure of environmental impact in eco-efficiency indicators increases understanding, in that it offers more benchmarks than conventional physical impact measures.

Keywords: Eco-efficiency; LCA; LCC; Case studies

1. Goal and scope

This article aims at improved sustainability management of economic activities through the use of eco-efficiency indicators. This is done by reviewing current ideas of the eco-indicator concept, defining success criteria for a useful eco-efficiency indicator, giving an example of one indicator that meets these criteria, assessing values based on this indicator for a number of products and, finally, demonstrating a way of using eco-efficiency indicators for management of economic activities. The demonstration is made on product life cycles, but it could as well have been done on companies. The system boundaries are different, but the principles are the same.

2. Introduction

The corporate world has an immense impact on the environment and plays an important role in the holistic context of sustainable development. This is one of the focal motives for the development of the concept of eco-efficiency. Eco-efficiency is commonly measured by the ratio product or service value/environmental influence (e.g. Michelsen et. al., 2006; Maxime et. a.l, 2006; Tahara et. al., 2005; Jollands et al, 2004). The term eco-efficiency was first used by Shaltegger and Sturm (1989) and made widely known by the world business council for sustainable development (WBCSD).

EE is primarily suited for management. It's most important feature is to guide decisions toward improving environmental performance, not necessarily to describe all the aspects of environmental impact: there need only to be a correlation between the EE measure and the relevant impact characteristics. The correlation needs to be verifiable in order to give the EE-measure sufficient legitimacy.

In 1991 the World Business Council for Sustainable Development (WBCSD) were looking for a single concept to sum up the businesses influence on sustainable development, and the term eco-efficiency emerged (Lehni, 2000). Eco-efficiency can be described as a continuous process of change in order to make, for instance, the exploration of resources, direction of investments, or the orientation of technological development consistent with future and present needs. The concept is comprised of three broad objectives (Lehni, 2000): reducing the consumption of resources, reducing the impact on nature and increasing product or service value. The most frequently used definition of eco-efficiency comes from the WBCSD (Jollands et. al., 2004):

"Eco-efficiency is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the earth's estimated carrying capacity" (DeSimone & Popoff, 2000).

Throughout the businesses world, setting targets and monitoring performance with indicators is an accepted management approach, important in evaluation of corporate progress (Verfaillie & Bidwell, 2000). According to Wisén & Karlsson (2002) it is critical to have easy to use and cost-efficient measurement tools that can be applied in various decision-making situations related to management of business operations and product development. One important factor to consider with such tools is that they facilitate the communication of environmental performance in an understandable way. There are several reasons why companies are interested in measuring eco-efficiency. Such reasons may include tracking and documenting performance with regard to policies and strategies, identifying resource savings and business benefits, and identifying and prioritising opportunities for improvements (Holliday et. al., 2002). Attempts have been made to capture eco-efficiency analysis in one single dimension. In order to add up its several different components it is necessary to have a systematic way of weighing the importance of these different components in relation to each other, i.e. a weighting system (OECD, 1998). The eco-efficiency measure is important as an interpretation tool in evaluating performance and other reported environmental data. Eco-efficiency is helpful as a tool to explain the meaning of data and figures to peers and in relation to different environmental targets (Verfaillie & Bidwell, 2000). However, there is a wide variety of opinion concerning how to interpret a specific eco-efficiency measure, depending on definitions and methods to describe environmental and technical systems, the actual application for which the measure was developed, on the individual person who developed the measure, etc. (Huppes & Ishikawa, 2005).

To sum up, we can say that eco-efficiency has been regarded either as a process (e.g. continuous improvement), a state (e.g. better than a benchmark, or within the earth's carrying capacity) or a quantity (e.g. value added per environmental impact value). In this article we focus on quantitative eco-efficiency as a characteristic of an event, concerning product life cycles, recycling or circular flows.

3. What makes an eco-efficiency indicator effective?

The basic idea underpinning eco-efficiencies is to express how specific economic activities influence the natural environment relative to creating value. Hence, basic success criteria for eco-efficiency indicators are those that guide us towards the largest actual environmental quality improvement per economic value created. Therefore, self-evident requirements for an effective EE indicator are that it has:

- environmental relevance in its application
- value relevance in its application

Considering that an effective EE indicator is also to be useful on an industrial scale, in different organizations, for different decisions, with financial and commercial implications, some additional requirements are necessary. For example, Carlson (Carlson 2006) describes the requirements needed for environmental information to support decision making in achieving actual environmental improvements. Expressed in terms of eco-efficiency the indicator must have:

- a specified application and scope,
- sufficient communication capability to be used,
- feasible data requirements,
- credible and legitimate methods.

These criteria are addressed in various ways in the literature on sustainability indicators. (Palme 2007). In the eco-efficiency literature we find four basic requirements for eco-efficiency:

1. it should describe the relation between economy and environment,
2. it should increase with improved environment at unchanged economy and
3. it should increase with improved economy at unchanged environment,

Besides, as a general requirement for quantified efficiency: efficiency is a ratio of useful output to useful input

3.1 A specified application and scope

Considering that EE is a management tool a specific EE indicator needs to be relevant in a specific management situations. For example, there is a substantial difference between product development at a chemical company and developing cars in an automotive company, or between internal management at a private company and in a public policy management context. There are also differences between EE indicators intended for strategic decisions and those intended for daily operation or product development. Hence, to develop and effectively use an EE indicator we need to consider its application domain and scope. There is a risk that the guidance provided by the indicator will lead in the wrong direction if it is applied in a domain for which it was not originally intended.

To fulfil the requirement of a specified application and scope means to specify:

- the intended user,
- the intended use,
- definition of sustainability,

- system boundaries for the value system,
- system boundaries for the environmental system,
- weighting principles for the value impact, including discounting if monetary value measures are used,
- weighting principles for the environmental impact – if any and
- if the environmental impact is expressed in monetary terms - principles for value transfer between generations, cultures, countries and objects.

3.2 Environmental relevance of the EE indicator to its application

The consequences of a financial management decision may influence, for example, resource use, human health, and biodiversity. Hence, the environmental relevance of a specific economic activity means to simultaneously take account of several environmental areas. An EE indicator should address the environmental areas relevant to the specific management situation and produce a balanced view to guide management in minimizing the complex of environmental influences.

To fulfil the requirement of environmental relevance, the environmental measure in the eco-indicator has to be in accordance with the specified requirements for the application and scope of the indicator. It is particularly important for the comprehensiveness in description of impacts within the environmental system boundaries and any weighting factors applied to be in accordance with the requirements. For instance, the system boundaries for the environmental system and the value system should be compatible.

One would wish that an improved eco-efficiency would mean an improved environment. As eco-efficiency addresses a confined system, this may not always be the case in practice. For example, an improved eco-efficiency may lead to larger product volumes and a net decline of environmental quality.

3.3 Value relevance of the EE indicator in its application

A business may have different values to different actors. And to a specific actor there may be different types of values, such as monetary and functional. For monetary values there are several ways of discounting future costs and incomes to a net present value (NPV) and for functional values there may be several functions to choose between.

To fulfil the requirement of value relevance, the value measure in the eco-indicator has to be in accordance with the specified requirements for the application and scope of the indicator. In particular the comprehensiveness in description of impacts on the value system itself should be in accordance with the requirements.

3.4 Sufficient communication capability to be used

To be useful an EE indicator has to have sufficient communication capability. This means that the indicator must be truly meaningful to the person who wants to communicate it, it should be relatively easy to compile an indicator value, and it should be possible to predict the receiver's interpretation of an EE indicator report.

Meaning, ease and interpretation should also all be understood in the light of possible educational support activities.

To fulfil the requirement of communication capability:

- the efforts to compile an indicator value should be realistic for the application,
- it must be meaningful to the user, i.e. using the EE indicator should increase the users job performance in the organisational context,
- there should be several benchmarks, to which indicator results can be compared

3.5 Feasible data requirements

An effective EE indicator expresses the environmental performance of a range of management decisions within its intended application and scope. An EE indicator can only be effective if it is constructed so that there is available data to reasonably cover the range of decisions. This is a strong trade-off requirement, since there are many relevant environmental and value issues to consider for any management situation, but it is only meaningful to include those for which it is worthwhile to acquire data. This means that when construing an EE indicator it is important not only to include all important issues in it, but also to consider its practical use in daily management situations. A highly effective EE indicator is constructed from data already available in the organisation.

To fulfil the requirement of feasible data, the cost of data collection must be significantly lower than the value of the EE management. It is therefore advisable to use an iterative assessment of the EE indicator, where approximations of data are used initially.

3.6 Credible and legitimate methods

Most people who compile EE-indicators, take decisions on the basis of them, or let their business life in general be guided by them do not want to learn the maths and mechanics inside the concept of the indicator. To these “ordinary users” it is crucial that the indicator is a non-controversial value with the support of most experts and peers. As far as possible it is therefore valuable if the methods for compiling, reporting and interpreting an EE indicator is standardised and are represented by frequent and non-contradictory occurrences in the scientific literature. Since business indicators are based on common understanding and simple communication, it is also important that they are frequently used by credible organisations. This increases the credibility of any such indicator.

To fulfil the requirement of credible and legitimate methods:

- it should be published in a scientific journal,
- it should be subject to published consensus, available to its users,
- it should be used. This is, of course, impossible for new methods, but it is possible to estimate the “market” for the indicator. It is also possible to show if the new method is based on credible and legitimate components and methods.

3.7 Technology acceptance model (TAM)

The TAM method was originally developed in computer science, but is also used to study emerging technologies. It was used by Steen et al. (2008) to evaluate interpretation keys for certified environmental product declarations (EPDs). In the TAM method, user groups state their opinions on (1) perceived usefulness (e.g the user's subjective probability that the use will increase his or her job performance in an organisational context, (2) perceived ease of use (e.g. the extent to which the user expects the target application to be free of efforts of use and able to contribute to increased performance through saved efforts on behalf of the user), (3) behavioural intention (e.g. the user's intention to actually use the application) and (4) perceived attractiveness (e.g. the user's positive feelings towards the application).

The TAM method has not been used directly in the work reported in this paper, as it performs best when there are two or more alternatives to compare, but its basic questions have been considered in the evaluation structure of sections 3.1 – 3.6.

4. An example of an eco-efficiency indicator

When designing a specific eco-efficiency indicator, there are a lot of choices to be made, largely subjective and based on the context and on the developer's conceptual understanding of eco-efficiency, sustainable development and environment. The specific eco-efficiency indicator used below is based on a view of eco-efficiency as an environmental sustainability assessment of values created by business. This means that the long term influences on the environment are emphasized, which broadly implies impacts on different types of natural resources and service capabilities. The sustainability aspect of the concept of sustainable development mainly concerns the sustainability of the natural environment, i.e. nature's capability, conservatively, to continue providing mankind with valuable resources and services. However, within this concept of sustainable development the sustainability of the social and economic dimensions does not carry the same conservative connotations, since development and progress of both economic and social features are required to cope with the challenges that mankind faces in the future. An eco-efficiency indicator based on principles and criteria that take this idea of environmental resource sustainability as its starting point was designed by Steen (2004).

The useful output in this indicator is the environmental impact adjusted economic value of the business products (equal to customer value + value changes in the environment), and the useful input is the economic resources added to the business (income). The method makes use of the established life cycle concepts LCA and LCC. The LCA indicator is environmental damage cost (EDC). Customer value, V, is estimated by life cycle cost for the customer (LCC). For reasons of consistency the same product system boundaries are used for the LCC and the LCA.

For a product, the income to the business is equal to the cost for the customer, which also is an estimate of customer value. Using cost as an estimate for value may be controversial. See evaluation below under 6.

$$\frac{V - EDC}{V} = 1 - \frac{EDC}{V}$$

The algorithm depicts an eco-efficiency of 100% when the EDC is negligible as compared with the value. Furthermore, the eco-efficiency is less than zero when the EDC exceeds the value, and more than 100% in cases when the EDC is negative, i.e. creates a surplus value for the environment.

4.1. Environmental Damage Costs (EDC)

The environmental damage cost of a product or a process is a monetary valuation of the damage of emissions and resource use caused by a product or process. The method used for monetary valuation in this study is the EPS 2000d method (environmental priority strategies in product development). The EPS 2000d method is based on the Rio Convention (Steen 1999), and the values used are obtained from the average WTP (willingness to pay) among OECD inhabitants, to avoid the environmental damage. It includes impacts on a number of safeguard subjects: human health, biodiversity, abiotic natural resources and recreational values.

In this study we have used LCA data from certified environmental product declarations (EPD) for emissions and resource use. They are expressed as category indicators of several impact categories as presented in table 1.

Table 1
Environmental damage costs of emissions and resource consumption

Product or process			Damage per unit
Impact Category	Category indicator	Indicator Unit	EUR/Indicator Unit
Greenhouse gases	CO_2-eqv.	kg	0.108
Acidifying gases	H^+ -eqv.	Mole	0.01
Ozone-depleting gases	CFC-11-eqv.	kg	5.41E+02
Gases contributing to ground level ozone	Ethene-eqv.	kg	3.20
Emissions contributing to eutrophication	O_2-eqv.	kg	0.00112
Consumption of non-renewable resources	Mass of resource	kg	Depends on type of resource

The EDC for each impact category is the amount of each category indicator multiplied by its damage cost per unit value, to yield the total EDC for the specific impact category. At present, EPDs only include six impact categories, and so the real EDC may be greater than the one obtained from the EPD. It is therefore important to consider the surrounding environment of the product system and add e.g. possible toxic substances or heavy metals, to attain a more complete view of the EDC of a specific product system.

4.2. Life Cycle Costing (LCC)

LCC is commonly used in the same type of situations as LCA, for instance decision-making situations concerning design, development, and purchase of products, processes, or activities, and the corporate and public policies associated with them (Huppes, 2005). The LCC may include both internal and external costs. The LCC is viewed in this method of calculation as the WTP (and thereby the value) of a product or a process. The WTP principle is thus applied in the numerator as well as in the denominator of the equation. Hence the efficiency measure is dimensionless.

5. Case study

Case studies are carried out to scrutinize the utility of the method of calculation, used throughout this study. The environmental information for the different products is predominantly gathered from certified environmental product declarations from Environdec (2005). For those products where no certified EPDs can be found, existing LCA studies are used. In the eco-efficiency calculation for the energy using products, a Swedish mix of electricity is used in the usage phase. Because the Swedish mix consists primarily of nuclear and hydropower, it does not contribute CO_2 emissions to the same extent that e.g. a European mix of electricity does (SPINE LCI Database, 2001). If the calculation for the pumps or the electric motors is made with a European mix of electricity, the eco-efficiency will decrease significantly.

5.1. Results of our case study

The results from the different analyses are summarised in table 2. The table depicts the eco-efficiency of a number of products within seven different product groups, to provide a wide spectrum of merchandise. The values of different products depend on various environmental factors such as air emissions and the use of non-renewable resources as well as on the type of product. Articles of consumption for example, tend to have low financial values and thereby show relatively low eco-efficiency values than more expensive merchandise such as photocopiers or LCD-TVs. Additionally, the eco-efficiency for the different products and services should not be considered as precise values because of the small number of samples. However, they give a rough indication for the different sub-groups.

Table 2 Examples of eco-efficiency related to different products

Product group	Eco-efficiency
Machinery and equipment	(%)
Sink Mixer	37
Submersible Pumps 1.3-32 kW	74-81
Electric Motor 1278 kW	81
White Goods	
Washing machine	84
Refridgerator	68
Freezer	70
Electricity, Gas and Water supply	

Nuclear Power	97
Hydropower	99
Wind Power	93
District Heating, (Gothenburg)	45
Other non Metallic Mineral products	
Cement	11
Sodium chlorate	57
Radio, Television & Communication equipment	
LCD TV	90
Fax machine	96
Photocopier	97
Pulp and Paper products	
Particle board	87
Incontinence products	29-45
Furniture, Curtain rails	
Nickel plated Steel	96
Solid Birch	98
Powder coated Steel	83
Anodised Aluminium	79
Stainless Steel	7
Food and Beverage	
Pork	86
Beef	76
Chicken	81
Milk	85
Potato	96
Drinking Water (Gothenburg)	94

The examples in table 2 show eco-efficiencies varying between 7 and 97 %. They are not necessarily representative of their product groups as they each have a specific life cycle including a specific method of end of life treatment. Some decisions will be choices between products with similar functions, but the eco-efficiency concept used here also allows for comparison between products with different functions. Given the budget constraints of an actor, (s)he may chose to save some money on the food account and use it to buy a washing machine. By using efficiency numbers like the ones in table 2, the actor may determine the net environmental adjusted value obtained by multiplying the money spent on each product type by its related eco-efficiency and then summing up the totals.

6. Evaluation of the eco-efficiency indicator used in our case study

In section 3, a number of performance criteria were formulated for an effective eco-efficiency indicator. Table 3 shows an evaluation of how the suggested indicator meets these criteria.

Table 3 Compliance with performance criteria

Performance criteria	**Way of compliance**
A specified application and scope	
The intended user	Anyone with some environmental or economic training
The intended use	Decision support in industry, policy and consumption
Definition of sustainability	Environmental resource aspect
System boundaries for the value system	All income to the business system
System boundaries for the environmental system	Human health, biodiversity, bio-productivity, natural resources, and cultural values are included. Global reach, no temporal boundaries.
Weighting principles for the value impact, including discounting if monetary value measures are used.	Monetary values. Discounting has to be defined for each case.
Weighting principles for the environmental impact – if any.	Willingness to pay for avoiding changes in the environment. According to EPS2000d (Steen 1999)
If the environmental impact is expressed in monetary terms - principles for value transfer between generations, cultures, countries and objects	No discounting, the same values are used for impacts in different countries, cultures and similar objects.
Environmental relevance of the EE indicator in its application	
The EE indicator has to be in accordance with the specified requirements for the application and scope of the indicator.	The EPS2000d method is used as required.
Value relevance of the EE indicator in its application	
The EE has to be in accordance with the specified requirements for the application and scope of the indicator.	The surplus value to the customer is not included
Sufficient communication capability to be used	
The efforts to compile an indicator value should be realistic for the application	The algorithm is simple
It shall be meaningful to the user, i.e. using the EE indicator will increase the users job performance in the organisational context	This need to be assessed from case to case, and from time to time, but if the user uses EE indicator values, like those in table 2, to decrease his or her total environmental impact, the use of the EE indicator is likely to be meaningful
There should be several benchmarks, to which	There is as shown in chapter 7 below.

indicator results can be compared	
Feasible data requirements	
The cost for data collection must be significantly lower than the value of the EE management.	In the cases in table 2 we use public, certified EPD data, which are acquired at low cost. The value of the EE management can be estimated from the achieved improvement in EE indicator values times the monetary flow.
Credible and legitimate methods	
It should be published in a scientific journal or similar publication	It is introduced by Steen (2006) and Steen et.al. (2008), and described in this article.
It should be subject to a published consensus, available to its users	No compliance yet
It should be used.	No compliance yet

A criticism to the value relevance of the LCC indicator is that it does not include the surplus value to the consumer. If the value to a consumer is seen as the surplus value (WTP minus the LCC), an increase of the price of a product will mean that the value decreases from this perspective, but increases using LCC as a value measure. However in an LCC perspective, this change of the value to the buyer is exactly compensated by a value change to the seller, so there is no net change.

It is of course being an advantage if the surplus value could be included in eco-efficiency measures, but in practice, such data would be too time-consuming and uncertain to collect.

As the basic idea behind the eco-efficiency is to guide in sustainable development, the value indicator as well as the environment impact indicator should be designed to change in the same way as “global” change. Sustainability is not primarily a personal issue. A too narrow system boundary may fool the user of an eco-efficiency indicator.

The value indicator should therefore express a value to the society. In society there is a budget restriction. If money is not used in one place it will be used in another. This means that there is causalities not caught by a normal LCA or a LCC.

In summary, the EE indicator used in the case study complies with most of the requirements, but there is a need for a consensus process and education to further improve the compliance.

7. Use of EE for management

Most impacts on the environment are caused by economic activities. If all the economic activities decrease their impact per monetary unit more than economic growth (decoupling), there will be a net improvement of the environment.

A reasonable allocation of responsibilities for sustainable development could be that all economic actors increase their eco-efficiency more than is required with respect to economic growth.

Applied to our example of an EE indicator, we find that if a single activity, i, has an eco-efficiency of EE_i, and the value of V_i, the overall impact of activities within a budget is equal to

$\sum EE_i*V_i$

The target for a business activity would therefore be to have an impact for the year 2 of less than year 1, and equal to $(\sum EE_i*V_i)/g$, where g is the annual economic growth in a country or other community.

There could also be other benchmarks than the year-by-year comparison of the own activity. It is obvious that an eco-efficiency above 0 is needed for a product to be useful to society. Otherwise the environmental damage cost will be greater than the benefit for the user.
Other reference values are

- the average eco-efficiency in the global society, which is about 87%. This figure is determined from the global GNP and the global emissions and use of resources (Steen, 1999),
- the average of an industry branch or a product group,
- the efficient use of capital. If a net return on investments of a% is wanted, an eco-efficiency of 90% would require a net return of 10 + a% to be an efficient use of capital for society.

The more point of reference, the easier the evaluation of the indicator value.
There are of course several types of uncertainties involved in the eco-efficiency analysis. As the environmental impact is based on LCA, specific and local impacts is very difficult to foresee. The value of eco-efficiency is therefore more of a strategic kind than of an operative. A good eco-efficiency is a good starting point for environmental care.

8. Discussion

The eco-efficiency indicator used in the examples is different from traditional eco-efficiency indicators in that it mixes environmental and economic entities in the nominator. Traditional eco-efficiency indicators have an environmental indicator value in the nominator and an economic indicator in the denominator or vice versa. The indicator we used may be confusing to the expert community but probably less confusing to laymen, who is used to see 100% efficiency as something without losses.

The eco-efficiency values in table 2 are examples, representing different specific product systems. They also represent specific methods of calculating environmental damage cost and the product value.

The eco-efficiency values may vary considerably depending on what type of electricity is used, how recycling is done, etc. Such variation indicates the potential benefits of the use of eco-efficiency as an indicator for improving environmental performance.

The damage cost may be calculated in different ways. In the EPS 2000d method there is no discounting of future damage and there is a WTP for damage representing OECD countries. There are, however, alternative ways of calculating damage costs. If normal rates of discounting is used and the WTP of the people affected by the damage, the damage cost of CO_2 almost disappears, as well as the damage cost for depletion of ores.

However, the WTP is too difficult to determine to be of practical for use as the value of the product. If the requirements for simplicity and ease-of-use are not fulfilled the eco-efficiency indicator will not be used, and hence will not contribute to an improved environment. But will the present indicator design contribute? It is possible to think of situations where it will not. For instance, if the price is reduced, sales will increase. If the product system is beneficial to the environment or even merely better than the average product system, then there is a likely overall improvement of the environment although the eco-efficiency decreases. This is, however, not a specific problem for eco-efficiency. Most types of efficiency measures may have this property. If you increase the efficiency of a car engine, you may consume more fuel as there is a number of trips you considered too expensive before. So in order to make eco-efficiency a good environmental performance indicator, it should be supported by an analysis of its relation to the larger systems of which it is a part.

9. Conclusions

Linking eco-efficiency to economic accounting and the budget process allows for monitoring and management of the sustainable development of a business unit.

Using monetised environmental externalities, e.g. damage costs, as a measure of environmental impact in eco-efficiency indicators increases our understanding of its relative significance.

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