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Sustainable value assessment of farms using frontier efficiency benchmarks

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Appropriate assessment of firm sustainability facilitates actor-driven processes towards sustainable development. The methodology in this paper builds further on two proven methodologies for the assessment of sustainability performance: it combines the sustainable value approach with frontier efficiency benchmarks. The sustainable value methodology tries to relate firm performance to the use of different resources. This approach assesses contributions to corporate sustainability by comparing firm resource productivity with the resource productivity of a benchmark, and this for all resources considered. The efficiency is calculated by estimating the production frontier indicating the maximum feasible production possibilities. In this research, the sustainable value approach is combined with efficiency analysis methods to benchmark sustainability assessment. In this way, the production theoretical underpinnings of efficiency analysis enrich the sustainable value approach. The methodology is presented using two different functional forms: the Cobb–Douglas and the translog functional forms. The simplicity of the Cobb–Douglas functional form as benchmark is very attractive but it lacks flexibility. The translog functional form is more flexible but has the disadvantage that it requires a lot of data to avoid estimation problems. Using frontier methods for deriving firm specific benchmarks has the advantage that the particular situation of each company is taken into account when assessing sustainability. Finally, we showed that the methodology can be used as an integrative sustainability assessment tool for policy measures.

1. Introduction

Sustainable development is now an important priority for many countries. Two economic paradigms of sustainable development can be distinguished: weak sustainability and strong sustainability. Weak sustainability is based on the idea that natural capital can to a certain extent be substituted as a direct provider of utility for the production of consumption goods. However, proponents of the strong sustainability view refuse this paradigm because they regard natural capital as non-substitutable. While weak sustainability could be seen as an extension to neoclassical economics, strong sustainability calls for a paradigmatic shift away from neoclassical environmental and resource economics towards 'ecological economics' (Neumayer, 2003). Ecological economics sees the human economy as part of a larger web of interactions between economic and ecological sectors (Constanza et al., 1991). Adherents of the weak sustainability paradigm favour marginal forms of analysis and tend to pay less attention to the concepts of the scale of an economy in relation to its resource base (Norton and Toman, 1997). Daly (1990) was an important architect of the strong sustainability view that advocates that resource substitutability is very limited and the sustenance of specific resource sectors is important (Pezzey and Toman, 2002). Daly (1991) states that: "Just as firms or households of the economy operate as a part of the aggregate economy, so the aggregate economy is likewise a part of a larger system, the natural ecosystem. Therefore, optimal allocation of a given scale of resource flow within the economy is one thing; optimal scale of the whole economy relative to the ecosystem is an entirely different problem."

The sustainable value approach developed by Figge and Hahn (2004a, 2005), on which this paper builds, leaves the total amount of each resource unchanged on the macro level and it can therefore be seen as an approach to measure strong sustainability. The focus is on the scale of an economy or part of an economy in relation to its resource base. In addition, the 'sustainable value' approach can be seen as a value-orientated impact assessment of economic

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activities (Figge & Hahn, 2004b). Value-orientated approaches integrate economic, environmental and social aspects with respect to the return that they generate rather than the burden that they cause, and analyse how much value is foregone when a bundle of resources is used. In other words, the value-orientated approach can guide where resources should be allocated; it addresses the question how much value would have been created with a specific set of resources if they had been used by more sustainable efficient firms (real companies or not). Note that other approaches use a burden-orientated logic by concentrating on different environmental (and social) impacts in order to measure the overall damage ('the burden') caused by economic activity (e.g., Pretty et al., 2000; Tegtmeier and Duffy, 2004). Burden-orientated approaches focus on the relative harmfulness of environmental and social impacts. In other words, burden-orientated approaches analyse how resources should be substituted by each other by assessing the combination of environmental impacts compared to another set of environmental impacts.

In our research contribution, we propose an approach that prefers a lower resource use to a higher resource use, all other things being equal, because in this way we can produce the same amount of output (e.g. food) with a smaller amount of resources (e.g. labour, capital, energy/water use, carbon dioxide emission, etc.). In other words, we aim to use the most 'sustainable' combination of resources within systems. In fact, less sustainable resource use should be (partly) substituted by more sustainable resource use. However, it is also important to analyse and to compare sustainability between systems. Improvements in sustainability may also be found by means of substituting companies that use their resources in an unsustainable way by companies that use their resources in a more sustainable way. The value-orientated sustainable value approach therefore assesses sustainability between systems by comparing the resource productivity of a system with the resource productivity of a benchmark (=the opportunity cost) and this for all resources considered. Policy makers and company managers can use the sustainable value approach to measure, monitor and communicate their sustainability performance. Furthermore the sustainable value approach can be used to identify characteristics of out- and underperformers (as in Van Passel et al., 2007; Hahn et al., 2007). Moreover, future performance scenarios can be constructed to compare possible firm or policy actions. Policy makers can use the simulation results to take well founded decisions within a sustainability framework.

The choice of the most appropriate benchmark is important, especially within the scope of policy analysis but also for choosing the appropriate actions to realise the firm objectives. Hence, using best performance or performance targets of each resource as a benchmark can be very useful to analyse the efforts of firms in their aim to reach sustainability (Van Passel et al., 2007). To determine the firms' benchmark, frontier methods can be applied. Such methods can be used to assess sustainability within systems (as in Reinhard et al., 2000). This research will use frontier methods to determine the sustainable value, and thus to assess sustainability between systems (or companies). Frontier methods (and efficiency analysis) can reveal linkages between the output and the resources used by firms, and in that way enrich the sustainable value approach. The approach compares the resource productivity of a company with the maximum feasible resource productivity of that company.

In the following section (Section 2) the theoretical background is formulated and the research objectives are explained. In a third section, the theoretical integration of frontier methods with the sustainable value approach is explained using two functional forms. In Section 4, the proposed methodology is applied using two empirical applications (one for each functional form). Furthermore, the possibility of using the approach to support policy making is tested on a dataset of Flemish dairy farms. Finally in Section 5, conclusions and suggestions for further research are made.

2. Theoretical background

Economic, social and environmental efficiency can be seen as a necessary – but not sufficient – step towards sustainability (Callens and Tyteca, 1999; Templet, 2001). Sustainability can be enhanced by strategies which promote resource use efficiency in economic systems (Templet, 1999). Efficient use of resources forms the keystone of policy, planning and business approaches to sustainable development but there are a wide range of potential interpretations of the efficiency concept (Jollands, 2006a,b). Jollands and Patterson (2004) show that efficiency is important within economics, thermodynamics and ecology with the consequence that the term represents a multiplicity of meanings (Jollands, 2006a). Note that all efficiency concepts are relative and context-dependent (Stein, 2001). Several concepts of efficiency are used in our methodology (e.g., technical efficiency, productivity, eco-efficiency). In order to avoid misunderstanding, we start by explaining these concepts in Section 2.1. After defining the efficiency key concepts, the sustainable value approach and the objectives of the research are explained.

2.1. Defining key concepts

There are several definitions of productivity, efficiency and eco-efficiency. In our research commonly accepted definitions within production economics are used. Productivity is calculated by dividing output by input. Farell (1957) defines efficiency as the actual productivity of a company compared to the maximum attainable productivity.

Besides productivity and efficiency, one can measure performance also in terms of eco-efficiency. A broadly accepted criterion for corporate sustainability is the eco-efficiency measure (e.g., Schmidheiny, 1992; OECD, 1998; WBCSD, 2000). Eco-efficiency, standing for a better management of the economy with less environmental pressure, is a well-known sustainability approach (Bleischwitz and Hennicke, 2004). There is a wide and diverse variety of terminology referring to eco-efficiency. A well-known definition of eco-efficiency is the ratio of created value per unit of environmental impact. In fact, this variant of eco-efficiency can be seen as environmental productivity (Huppes and Ishikawa, 2005), and is similar to the definition of productivity in economics.

So far, we used the terms 'input' and 'output'. Output can be expressed as total production (total revenue) or as value added (total output minus intermediate consumption). To obtain value added as output, economics traditionally distinguishes land, labour and capital goods as inputs. These inputs are also called factors of production, which are resources used in the production of goods and services in economics. In a more or less similar way, the concept of capital can be used to identify resources used to produce output. Land, capital goods and labour can be seen as capital forms. In order to assess corporate sustainability, a much broader interpretation of the concept of capital than traditionally used by economists, is needed (Dyllick and Hockerts, 2002). Pfeffer and Salancik (1978) define a resource as the means that an organisation needs in order to survive. In fact, the core argument of their resource dependency theory states that (i) organisations will respond to demands made by external actors or organisations upon whose resources they are heavily dependent and (ii) organisations will try to minimize that dependency when possible (Pfeffer and Salancik, 1978; Pfeffer, 1982). Frooman (1999) even states that the resource dependency theory defines a resource as basically anything an actor perceives as valuable. In the language of traditional strategic analysis, firm resources are strengths that firms can use to conceive of and implement their strategies that improve their efficiency and effectiveness; firm resources include all assets, capabilities, organisational processes, information, knowledge, etc. (Barney, 1991). Therefore, we do not make any distinction between conventional economic resources (inputs or production factors) and environmental and social assets. Physically speaking, certain environmental assets are (undesired) outputs rather than inputs. However, because companies do have an environmental impact in the production of value-added goods, these environmental aspects can be seen as resources from an economic point of view (Figge and Hahn, 2005). Mind that the effective management of the use of all resources is crucial in providing sound economic performance. Furthermore, Claver et al. (2007) stress that the connection between environmental management and economic performance should be seen in a broader perspective that includes the relationship between environmental strategy and firm performance. Also SMEs undertake a range of environmental strategies from reactive regulatory compliance to proactive pollution prevention and environmental leadership (Aragón-Correa et al., 2008). Porter and Van der Linde (1995a,b) state that increasing investment in environmental technology can obtain a competitive advantage, while reducing the negative environmental impact. The so-called Porter Hypothesis gave rise to an interesting scientific discussion about the existence of win–win opportunities (e.g. Murty and Kumar, 2003), possibilities of environmental regulation, spillover effects of environmental performance on productivity (e.g. Galdeano-Gómez et al., 2008), strategic quality competition (e.g. André et al., 2009), etc. In the context of this paper, the focus will lie on the integrated assessment of environmental and economic performance, although we recognize the important interlinkage with (firm) strategy.

We will call all capital forms (or aspects derived from capital forms) in the remainder of this paper 'resources', because we assume that they all contribute to the production of value added in a system. We use the term resources over the terms inputs or production factors or capital forms (economic, social and environmental) to indicate the assets that are used to create value in a broad context. A more detailed discussion about the treatment of environmental and social resources as inputs or as undesired outputs falls beyond the scope of this paper. We refer for this to Färe and Grosskopf (2003) and Hailu (2003).

2.2. The sustainable value approach

The sustainable value approach is developed by Figge and Hahn (2004a, 2005) and applies the logic of opportunity costs to the valuation of resources. Using the capital approach (e.g., Atkinson, 2000), all resources (economic, environmental and social) are needed to create value. Using the sustainable value approach, we consider that a firm contributes to more sustainable development whenever it uses its resources more productively than other companies and the overall resource use is reduced or unchanged.

The following steps are required to calculate the sustainable value of a company. First, the scope of the analysis needs to be determined. In other words, which economic activity or activities or entity or entities will be chosen? Second, the relevant resources to take into account (e.g., labour and land) need to be determined. Theoretically, the choice should include those resources that are critical for the sustainability performance of the company within the chosen scope. Third, the benchmark level needs to be determined. The choice of the benchmark determines the cost of the resource needs of a company, in other words the productivity that a company has to exceed. The benchmark choice reflects a normative judgement and determines the explanatory power of the results of the sustainability assessment.

Table 1 shows the calculation of the sustainable value for a dairy farm with a value added of € 80 000. This company represents a dairy farm with 55 milk cows, 30 ha of land and a milk quota of 300 000 litres.

The amount used of every resource can be found in column A of Table 1. The productivity (or return on capital) of each resource can be calculated (column B). For example, the return on land is € 2667 per hectare of land (€ 80 000/30 ha). In the same way the productivity of the benchmark (column C) can be determined, these are the opportunity costs. In this example, we choose as benchmark the average return on capital of a large sample of dairy farms (as in Van Passel et al., 2007). For the farm gate N-surplus, we choose a performance target (150 kg N/ha) as benchmark, which is an objective performance target for sustainable dairy farming in Flanders (Nevens et al., 2006). N-surplus is calculated as the N-input (e.g. concentrates, straw) minus the Nitrogen off take (e.g. milk, crops) at the farm gate. Note that Langeveld et al. (2007) stress the importance that to evaluate farm performance N-surplus should be supported by other indicators or model calculations. Agri-environmental indicators should be applied in an integrated evaluation (such as the sustainable value approach), at a scale that reflects the firm's spatial variability (Langeveld et al., 2007). In this context, farm typologies (e.g. specialist grazing livestock) can serve as an interesting tool for comprehensive assessment (Andersen et al., 2007).

In a next step, the value contributions of each resource can be calculated ($(B - C) \times A$ in Table 1). A positive value contribution indicates that the resource is used in a value-creating way by that company. This means that a positive value contribution is only obtained if the resource productivity of the firm is higher than the resource productivity of the benchmark. In other words, resources are only used in a value-creating way if the opportunity costs of the resources are at least covered. To determine how much value is created by the entire bundle of resources, the sustainable value can be calculated by summing up all value contributions and by dividing this value by the number of resources. The sustainable value approach indicates how much more or less return has been created with the resources available in comparison with the benchmark. To take the company size into account, ADVANCE (2006) suggests calculating 'the return-to-cost ratio'. This ratio was called 'sustainable efficiency' in Figge and Hahn (2005) and in Van Passel et al. (2007), but the term return-to-cost terminology is more consistent with the efficiency and productivity concepts. The return-to-cost ratio is calculated by dividing the value added of a company by the cost of the sustainability capital. The cost of sustainable capital is given by the difference between the value added and the sustainable value. The return-to-cost ratio equals unity if the value added corresponds to the cost of all resources. A return-to-cost ratio higher than one means that the company is overall more productive than its benchmark. In our example the return-to-cost of the farm is 1.04 (=€ 80 000/(€ 80 000 − € 3067)).

Table 1
Example of the calculation of the sustainable value.

Resources[a]	Amount used by the company	Productivity (80 000/A)		Value contribution (€)
	(A)	Company (B)	Benchmark (C)	
Land	30 ha	2666.67	2600.00	2000.00
Labour	1.00 fte	80 000.00	50 000.00	30 000.00
Non-land capital	300 000 Euro	0.27	0.27	0.00
Energy use	1 000 000 MJ	0.08	0.07	10 000.00
N-surplus	6000 kg N	13.33	17.78	−26 680.00
		Sustainable value =		3064.00

Fte: full time equivalent.
[a] Remind that we define resources as capital forms (economic, environmental and social) or aspects derived from capital forms.

The return-to-cost ratio shows by which factor the farm exceeds or falls short of covering its cost of economic, environmental and social resources or in other words by which factor it exceeds or falls short of the benchmark productivity.

Remember that the sustainable value approach does not claim that the benchmark is sustainable. In other words, the approach does not indicate whether the overall resource use is sustainable, but only how much a company contributes to a more sustainable use of its resources than the benchmark. Another drawback is that the utility of the methodology is limited by the available data on corporate capital use and the opportunity cost of the different resources (Figge and Hahn, 2005). Moreover, even if certain aspects are measurable, it is not always straightforward how to take these aspects into account. An interesting example is farm subsidies. Van Passel et al. (2007) found that the more a farm depends on subsidies, the lower the return-to-cost ratio. In Van Passel et al. (2007) farm subsidies are seen as an important determinant to explain differences in sustainability performance. However, another possibility is to use subsidies to calculate the sustainable value by assuming that subsidies are relevant resources to realise value added. Another drawback of the sustainable value approach is the fact that it does not take qualitative aspects of sustainability into account. All relevant aspects should be quantified in a meaningful way. However, the sustainable value approach allows integrating economic, environmental and social performance. Rather than looking at how burdensome the use of resources is, it compares the value that can be created with the resource by different economic actors. The sustainable value approach is the first value-based methodology that allows an integration of different resources of companies and thus can be used to compare sustainability between companies.

2.3. Objectives

As already explained, the choice of the most appropriate benchmark is essential when using the sustainable value approach, because the benchmark determines the opportunity costs of each relevant resource. Moreover, the choice of the benchmark depends on the particular research objective. For example to assess the sustainability performance of BP, Figge and Hahn (2005) used the UK economy as a benchmark. Within the ADVANCE project the sustainable value of 65 European manufacturing companies was calculated, although only environmental resources were considered. The EU-15 benchmark was used to calculate the sustainable value of each company. Assuming that environmental resources are not yet used in a sustainable way in the EU-15, a second benchmark was applied using performance targets. In this way the future performance scenario shows which companies will continue to create sustainable value under the more stringent future performance targets (ADVANCE, 2006). Van Passel et al. (2007) used the weighted average return of capital of a large sample of dairy farms to explain differences in farm sustainability. The results of their analysis were also compared using other types of benchmarks. Van Passel et al. (2007) showed that the benchmark choice had an important impact on the absolute level of the sustainable value but not on the ranking of the sustainability performance of the farms.

Because benchmarks can give valuable indications to all decision makers, a well defined benchmark is essential. Otherwise decision support systems can give wrong signals. In fact, an ill-considered choice of the benchmark may result in inappropriate and misleading results in light of the initial decision situation and research question. Furthermore, it is important that a benchmark is realistic and feasible for each company but it is also preferable that a benchmark is ambitious.

Benchmarks using best performance or specified targets can be very useful to analyse the efforts of farms in their aim to improve their results (Van Passel et al., 2007). In our example in Table 1 we choose the weighted average return on capital of a large sample as benchmark. Van Passel et al. (2007) opted for this benchmark because their study tried to understand why farms differ in their creation of sustainable value. Using for example the best performance of each resource as benchmark will result in other value contributions. In fact, all value contributions would be negative; a value contribution of zero would indicate that the observation is the best performance. In this case, the aim of all companies would be to get value contributions of zero. If all value contributions are zero, then the sustainable value of that company would be zero (or the return-to-cost ratio would be equal to one), which is the maximum achievable score. A sustainable value of zero would mean that the 'super-company' exists or in other words that such a company has the highest productivity for all resources. Using a basic best performance benchmark, Van Passel et al. (2007) found a maximum return-to-cost ratio of 0.7, showing a large scope for improvement.

However, the basic best performance benchmark using the best performance of each resource has important shortcomings. As indicated by Fig. 1, such a basic benchmark is not necessarily the best option to assess the performance of companies. Using a basic benchmark for all companies (independent of the actual resource use and combination) can result in a misleading measurement of the resource performance of a company. The unit isoquant *K* in Fig. 1 shows all the ways of combining two resources X_1 and X_2 to produce a given level of output *Y*. Points on the unit isoquant are efficient because their actual productivity equals the maximum feasible productivity. Observation '*a*' can improve the productivity of resource X_1 while observation '*r*' has the maximum productivity level. In fact, it seems very clear that in this case observation '*r*' is an accurate benchmark for observation '*a*' (even for both resources X_1 and X_2), the peer of observation '*a*' is observation '*r*'. The productivity level of observation '*a*' for the resource use of X_1 equals $0X_1^r/0X_1^a$. However, when looking to observation '*c*', the peer for observation '*c*', using the basic best performance benchmark, would be observation '*r*' but with the actual combination of resources X_1 and X_2, this is not always a feasible target. Therefore, a better peer for observation '*c*' would be observation '*s*' (Fig. 1). This is an accurate benchmark for a given ratio of different resources.

To analyse the efforts of companies towards more sustainable practises, the use of a best performance benchmark within the calculation of the sustainable value of firms is very promising.

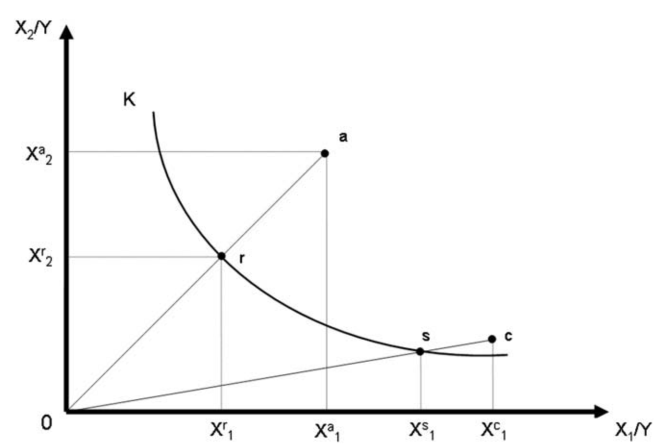

Fig. 1. Unit isoquant *K* for resources X_1 and X_2 for a given level of output *Y*.

However, the basic best performance benchmark has major shortcomings and therefore using a benchmark as in Fig. 1 would be an important improvement to benchmark firm sustainability because in this case the value contribution of each resource is dependent of the use of the other resources. The sustainability of each company would be assessed in comparison with the relevant peers of that company. In applications, benchmark units (peers) can play an important role by facilitating diffusion of best practises from efficient units to inefficient ones (Kuosmanen and Kortelainen, 2005).

In this research, we will use frontier methods to construct a best performance benchmark to assess the sustainable value. The idea of using production economics (frontier methods) in sustainability assessment is not new. Tyteca (1996) used production economics to define standardised, aggregate environmental performance indicators. These indicators do not require the specification of any a priori weight on the environmental impacts that are being aggregated (Tyteca, 1996). Callens and Tyteca (1999) and Tyteca (1999) worked out indicators of sustainable development using the principles of productive efficiency. In fact, they developed a model using an approach that is similar to one normally used to quantify output, input or overall productive efficiency. In our approach we start from a sustainability assessment method (the sustainable value approach) and use frontier methods to benchmark the value of firm resources.

Notice that the focus in Fig. 1 (and in this research) is only on technical efficiency and not on allocative efficiency. Remember that as in earlier applications of the sustainable value approach, we assume that there are no scale effects, for example the Cobb–Douglas production assumes constant returns to scale. In contrast, the translog functional form is more flexible and can take into account scale effects. In this research, we discuss both functional forms as benchmarks within the sustainable value approach.

Furthermore, we assume a constant relative ratio between all resources, meaning that we only capture efficiency improvements that do not change the relative rate by which different resources are used by a firm. In other words, we assume that companies are not able to change the relative weight of the different resources within the set of resources they are using. Our approach has the advantage that we take into account the fact that the use of different resources makes them interdependable, but this rules out differences in technology. In other words, we assume that all companies use a similar production technology. However, we only assume a constant ratio between all resources in defining a benchmark for each resource. After defining the benchmark using efficiency analysis, we use these benchmarks within the sustainable value in a similar way as in previous applications. While the basic best performance benchmarks (used by Figge & Hahn, 2005; ADVANCE, 2006; Van Passel et al., 2007) assume a linear production technology, we apply other kinds of production technologies. Which production technology (linear or non-linear) is preferable depends on the particular situation (sector, resources considered) and on the research question.

Hence, the most important advantage of using 'frontier method' benchmarks is that in this way the sustainable value approach takes production linkages into account. This is because production functions (estimated by frontier methods) show the link between the output produced and the resources used (including environmental and social resources). Therefore, in this research we will develop and test a methodology to improve the sustainable value method with frontier methods to construct a sound benchmark. We are aware that other types of benchmarks go along with different implications and assumptions. Frontier benchmarks broaden the possibilities of the sustainable value approach. In this way, more applications are possible.

3. Methodology

As indicated in the previous section, we use the sustainable value methodology and opt for a benchmark which (i) compares the combination of resources with other resource combinations and (ii) selects the most appropriate peer as benchmark for each company. The most appropriate peer can be defined as a comparable company that uses fewer resources to produce the same amount of output. This benchmark can be constructed using frontier methods. In this way, production theory is integrated with a value-orientated assessment method.

3.1. Formulation of the benchmark

In the frontier literature, two broad classes of approaches are considered, namely the parametric and the non-parametric approaches. Parametric approaches (e.g., stochastic frontier estimations) take possible measurement errors and other noise upon the frontier into account. The disadvantage is that the researcher has to select a functional form for the production frontier. Non-parametric approaches are robust to the kind of specification error that may arise in the choice of functional form, but the properties of the inefficiency estimates cannot be determined. In this research we prefer to work with a parametric approach for estimating the production frontier, because in our empirical application farm data is used and we expect that data noise could play an important role in the estimation of an agricultural production function (Coelli et al., 1998). Note, however, that our approach is also compatible and operational with non-parametric approaches.

Consider the following production function:

$$\ln(y_{it}) = f(x_{it}, \beta) + v_{it} - u_i \quad (1)$$

where y_{it} is the output of the ith firm in year t; x_{it} are the input quantities in the production process used by the ith firm in year t; β is a vector of unknown parameters; v_{it} accounts for measurement error and random errors while the second error term u_{it} measures the technical inefficiency. The efficient amount of x_{it} can be expressed as:

$$x_i^{\text{efficient}} = g(y_i, x_1, \ldots, x_n, u_i) \quad (2)$$

In traditional production economics, the inputs are for example labour and capital. The strategy of most parametric studies has been to include environmental effects in the output vector (e.g., Pittman, 1983; Färe et al., 1989; Ball et al., 1994; Hetemäki, 1996). As in Cropper and Oates (1992) and Reinhard et al. (1999, 2000) we model the environmental assets as a conventional input rather than as an undesirable output, because this fits completely in the sustainable value approach. A second reason (also rather pragmatic) is the fact that environmentally detrimental input use is easy to measure (e.g., excess nitrogen use), which is not the case with environmental impacts (Reinhard et al., 1999). Nevertheless as briefly discussed in Section 2.1, we are aware that the question of whether environmental factors are inputs or outputs can be relevant e.g., with respect to returns to scale. This question has been recently debated by Färe and Grosskopf (2003) and Hailu (2003), but this discussion falls beyond the scope of this paper.

We therefore specify the stochastic production frontier as:

$$\ln(\text{VA}_i) = f(x_i, z_i, \beta) + v_i - u_i \quad (3)$$

for all companies indexed with a subscript i; VA_i denotes the value added; x_i is a vector of conventional economic inputs. Intermediate consumption is not considered as an economic input, because we choose the value added as output and not the total value of returns. z_i is a vector of environmental and social assets; β is a vector of unknown parameters; v_i is a random error term intended to capture events beyond the control of the managers; u_i is a non-negative random error intended to capture technical inefficiency. The efficient amount of x_i and z_i can be expressed as:

$$x_i^{\text{efficient}} = g(\text{VA}_i, x_1, \ldots, x_n, z_1, \ldots, z_n, u_i)$$

$$z_i^{\text{efficient}} = g(\text{VA}_i, x_1, \ldots, x_n, z_1, \ldots, z_n, u_i)$$

As mentioned in Section 2.1, no distinction is made between conventional economic inputs (x) and environmental and social assets (z). We assume that they all contribute to the production of value added in a sustainable system. Therefore, we introduce the term resource r which includes economic, environmental and social capital forms (and aspects derived from capital forms):

$$r_i^{\text{efficient}} = g(\text{VA}_i, r_1, \ldots, r_n, u_i) \tag{4}$$

Note that the sustainable value of a company with n different resources can be calculated as:

$$\text{sustainable value}_i = \frac{1}{n}\sum_{s=1}^{n} r_i \times \left[\left(\frac{\text{VA}}{r}\right)_i - \left(\frac{\text{VA}}{r}\right)_{\text{benchmark}}\right] \tag{5}$$

where r_i stands for a resource (economic, environmental and social capital forms) of company i and VA_i for value added of company i.

Using efficiency analysis, we propose the following benchmark:

$$\left(\frac{\text{VA}}{r}\right)_{\text{benchmark}} = \frac{\text{VA}_i}{r_i^{\text{efficient}}} = \frac{\text{VA}_i}{g(\text{VA}_i, r_1, \ldots, r_n, u_i)} \tag{6}$$

Bringing equation (6) into equation (5) gives us the calculation of the sustainable value of a company i with a company specific benchmark:

$$\text{sustainable value}_i = \frac{1}{n}\sum_{i=1}^{n} r_i \times \left[\left(\frac{\text{VA}}{r}\right)_i - \left(\frac{\text{VA}_i}{r_i^{\text{efficient}}}\right)\right] \tag{7}$$

Note that the benchmark is different for each company, because the benchmark depends on the amount and combination of resources of that company (as in Fig. 1). To summarize, the benchmark calculation using frontier methods takes inefficiency of the resource use and initial resource use into account.

3.2. Formulation of the framework using functional forms

Before estimating the production frontier the researcher has to choose a functional form. An important step in any parametric empirical application is the selection of the appropriate functional form for the production function. A commonly used functional form is the Cobb–Douglas functional form. The simplicity of this functional form is very attractive, but a drawback is that the Cobb–Douglas production function assumes constant input elasticities, constant returns to scale for all firms and an elasticity of substitution to be equal to one. A number of alternative functional forms exist, such as the translog functional form (Christensen et al., 1973). An advantage of the translog form is that it imposes no restrictions upon returns of scale or substitution possibilities (Coelli et al., 1998). In the following sections, we use both forms.

3.2.1. Methodology using the Cobb–Douglas functional form

Assume a Cobb–Douglas technology with two resources r_1 and r_2 to produce VA (value added). Company i does not use its resources 100% efficiently, in other words u_i differs from zero.

We formulate the Cobb–Douglas stochastic production frontier model as:

$$\ln \text{VA}_i = \beta_0 + \beta_1 \ln r_{i1} + \beta_2 \ln r_{i2} + v_i - u_i \tag{8}$$

To perform the calculation, we first have to purge the output measure (VA) of its noise component (v_i) so that we can work in a deterministic framework:

$$\ln \widetilde{\text{VA}}_i = \beta_0 + \beta_1 \ln r_{i1} + \beta_2 \ln r_{i2} - u_i$$
$$\text{with } \ln \widetilde{\text{VA}}_i = \ln \text{VA}_i - v_i \tag{9}$$

We are looking for the input-orientated technically efficient resource $r^{\text{efficient}}$ for a given level of value added ($\widetilde{\text{VA}}$). This can be derived by simultaneously solving equation (9) and the resource ratio $(r_1/r_2) = k$. Note that the solution of the simultaneous system of equation is made after the parameters of the production frontier have been estimated using maximum likelihood methods. After estimation we get:

$$\ln \overline{\text{VA}}_i = b_0 + b_1 \ln r_{i1} + b_2 \ln r_{i2} \quad \text{and}$$
$$\text{with } \ln \widetilde{\text{VA}}_i = \ln \text{VA}_i - v_i = \ln \overline{\text{VA}}_i - u_i$$

Notice that $\overline{\text{VA}}$ is the predicted frontier output and VA is the observed output.

The $r^{\text{efficient}}$ are:

$$r_{i1}^{\text{efficient}} = \left[\widetilde{\text{VA}}_i \times \exp(-b_0) \times k_i^{b_2}\right]^{\frac{1}{(b_1+b_2)}}$$
$$r_{i2}^{\text{efficient}} = \left[\widetilde{\text{VA}}_i \times \exp(-b_0) \times k_i^{-b_1}\right]^{\frac{1}{(b_1+b_2)}} \tag{10}$$

Bringing equation (10) into equation (7), we can calculate the sustainable value of company i using only 2 resources and assuming Cobb–Douglas technology as:

$$\text{sustainable value}_i = \frac{1}{2}\left\langle r_{i1} \times \left[\left(\frac{\widetilde{\text{VA}}_i}{r_{i1}}\right) - \left(\frac{\widetilde{\text{VA}}_i}{\left[\widetilde{\text{VA}}_i \times \exp(-b_0) \times k_i^{b_2}\right]^{\frac{1}{(b_1+b_2)}}}\right)\right] + r_{i2} \times \left[\left(\frac{\widetilde{\text{VA}}_i}{r_{i2}}\right) - \left(\frac{\widetilde{\text{VA}}_i}{\left[\widetilde{\text{VA}}_i \times \exp(-b_0) \times k_i^{-b_1}\right]^{\frac{1}{(b_1+b_2)}}}\right)\right]\right\rangle$$

Because the Cobb–Douglas functional form has a constant elasticity of substitution (and equal to one), we can simplify the calculation of the sustainable value for company i as:

$$\text{sustainable value}_i = r_{i1} \times \left[\left(\frac{\widetilde{\text{VA}}_i}{r_{i1}} \right) - \left(\frac{\widetilde{\text{VA}}_i}{\left[\widetilde{\text{VA}}_i \times \exp(-b_0) \times k_i^{b_2} \right]^{\frac{1}{(b_1+b_2)}}} \right) \right] = r_{i2} \times \left[\left(\frac{\widetilde{\text{VA}}_i}{r_{i2}} \right) - \left(\frac{\widetilde{\text{VA}}_i}{\left[\widetilde{\text{VA}}_i \times \exp(-b_0) \times k_i^{-b_1} \right]^{\frac{1}{(b_1+b_2)}}} \right) \right]$$

The suggested benchmark offers two improvements. First, the benchmark incorporates inefficiency. This is because we considered (in)efficiency (as u_i) in our estimation of the production frontier using stochastic frontier analysis. Second, the benchmark allows identification of a benchmark considering the initial resource use of each company. In fact, each company can benchmark its resource use with the most appropriate peer.

Note that in this case, we only considered technical (input-orientated) efficiency and not allocative and economic efficiency. Economic efficiency is the combination of technical efficiency and allocative efficiency. Assuming Cobb–Douglas technology, the economic efficiency input vectors can be calculated, because the Cobb–Douglas function is self-dual. For this, price information of each resource is needed, which is not always possible (and relevant) for all resources, especially for environmental and social aspects.

3.2.2. *Methodology using the translog functional form*

In this section we use a translog functional form to benchmark the sustainable value. Assume a translog functional form with two resources r_1 and r_2 to produce VA (value added). Company i does not use its resources 100% efficient, in other words u_i differs from zero.

We formulate the translog stochastic production frontier model as:

$$\ln \text{VA}_i = \beta_0 + \beta_1 \ln r_{i1} + \beta_2 \ln r_{i2} + \beta_3 (\ln r_{i1})^2 + \beta_4 (\ln r_{i2})^2 + \beta_5 (\ln r_{i1} \times \ln r_{i2}) + v_i - u_i \quad (11)$$

To apply the calculation, again we first have to purge the output measure (VA) of its noise component (u_i) so that we can work in a deterministic framework:

$$\ln \widetilde{\text{VA}}_i = \beta_0 + \beta_1 \ln r_{i1} + \beta_2 \ln r_{i2} + \beta_3 (\ln r_{i1})^2 + \beta_4 (\ln r_{i2})^2 + \beta_5 (\ln r_{i1} \times \ln r_{i2}) - u_i \quad \text{with} \quad \ln \widetilde{\text{VA}}_i = \ln \text{VA}_i - v_i \quad (12)$$

We are looking for the input-orientated technically efficient resource $r^{\text{efficient}}$ for a given level of value added ($\widetilde{\text{VA}}$). This can be derived by simultaneously solving equation (12) and the resource ratio $(r_1/r_2) = k$. Note that the solution of the simultaneous system of equation is made after the parameter of the production frontier has been estimated using maximum likelihood methods. After estimation we get:

$$\ln \overline{\text{VA}}_i = b_0 + b_1 \ln r_{i1} + b_2 \ln r_{i2} + b_3 (\ln r_{i1})^2 + b_4 (\ln r_{i2})^2 + b_5 (\ln r_{i1} \times \ln r_{i2})$$

Notice that $\overline{\text{VA}}$ is the predicted frontier output and VA is the observed output.

The $r^{\text{efficient}}$ are:

$$r_{i1}^{\text{efficient}} = \exp \left[\frac{-(b_1+b_2) \pm \sqrt{(b_1+b_2)^2 - 4\left\{ -\ln \widetilde{\text{VA}}_i + b_0 - (b_2+b_5)\ln(k_i) + b_4 (\ln k_i)^2 \right\}\left\{ b_3+b_4+b_5 \right\}}}{2(b_3+b_4+b_5)} \right]$$

$$r_{i2}^{\text{efficient}} = \exp \left[\frac{-(b_1+b_2) \pm \sqrt{(b_1+b_2)^2 - 4\left\{ -\ln \widetilde{\text{VA}}_i + b_0 + (b_1+b_5)\ln(k_i) + b_3 (\ln k_i)^2 \right\}\left\{ b_3+b_4+b_5 \right\}}}{2(b_3+b_4+b_5)} \right] \quad (13)$$

Once this is obtained, the same approach as in the Cobb–Douglas case can be followed by bringing the $r^{\text{efficient}}$ (equation (13)) for every resource into equation (7). In this way the sustainable value can be calculated.

4. Empirical applications

In this section, the methodology considered is applied using empirical data. First, the Cobb–Douglas functional form is used, and second the translog functional form is used as benchmark to calculate the sustainable value. Finally, the impact on the sustainable value will be estimated for different policy options to illustrate how the approach may be used as a decision support system.

4.1. *Cobb–Douglas functional form as benchmark*

The first application uses the data of a large sample of Flemish dairy farms. As in Van Passel et al. (2007) we consider five different resources: (i) farm labour, (ii) farm capital, (iii) farm land, (iv) nitrogen surplus and (v) energy consumption (direct and indirect). Capital, land and labour can be seen as traditional economic resources, while nitrogen surplus and energy consumption are important environmental aspects in dairy farming. The dataset contains information of 645 Flemish dairy farms during the period

Table 2
Descriptive statistics.

Variable	Mean	Minimum	Maximum	Std. deviation
Total output (Euro)	150 293	20 445	622 791	68 765
Land use (ha)	31.73	6.72	83.08	11.28
Labour (full-time equivalent)	1.48	0.63	3.50	0.34
Farm capital (Euro)	284 466	37 338	789 404	152 140
Intermediate consumption (Euro)	66 361	13 600	295 465	31 535
Energy consumption (MJ)	1 248 410	268 185	3 803 592	522 292
Nitrogen surplus (kg N)	8884	1934	25 570	3879

1995–2001. Some descriptive statistics of the data sample can be found in Table 2.

As explained in Section 2.1 we use conventional economic and environmentally detrimental resources to estimate a production function. The value added of the farms is used as dependant variable. Furthermore, time dummies are added to indicate the different years. This leads to the following Cobb–Douglas functional form:

$$\mathrm{VA}_i = \exp(\beta_0)\cdot \mathrm{Labour}_i^{\beta_1}\cdot \mathrm{Capital}_i^{\beta_2}\cdot \mathrm{Land}_i^{\beta_3}\cdot \text{N-surplus}_i^{\beta_4} \cdot \mathrm{Energyconsumption}_i^{\beta_5}\cdot \exp\left(\sum_{j=1}^{n}\gamma_j\cdot \mathrm{Yeardummy}_i^j\right) \cdot \exp(v_i - u_i) \tag{14}$$

We can rewrite equation (14) in logarithmic form as:

$$\ln \mathrm{VA}_i = \beta_0 + \beta_1 \ln(\mathrm{Labour})_i + \beta_2 \ln(\mathrm{Capital})_i + \beta_3 \ln(\mathrm{Land})_i + \beta_4 \ln(\text{N-surplus})_i + \beta_5 \ln(\mathrm{Energyconsumption})_i + \sum_{j=1}^{n}\gamma_j \cdot \mathrm{Yeardummy}_i^j + v_i - u_i \tag{15}$$

The estimation results of equation (15) using maximum likelihood methods can be found in Table 3.

We apply the methodology as explained in Section 3.2.1. First the output measure is separated from its noise component to work in a deterministic framework (as in equation (9)). Then we calculate the input-orientated technically efficient resource for each resource considered using the estimated coefficients of equation (15) and the resource ratios. After we obtained the input technically efficient amount of each resource for each company, the sustainable value can be calculated using those values as benchmarks. Notice that in this application the technical input-orientated efficiency is used. Farms can improve their efficiency by reducing their amount of resources and producing the same amount of output (value added). We chose for an input-orientated efficiency because Flemish dairy farms have milk quotas and have to pay high levies in the case of exceeding their milk quota. Farms have to obtain an extra milk quota if they want to increase their production level.

Table 3
Estimation coefficients of the Cobb–Douglas production frontier.

Variables	Coefficient	St. error	Variables	Coefficient	St. error
Constant	0.5297	0.4344	D_1995	0.0057	0.0358
Labour	0.2886***	0.0510	D_1996	−0.0519	0.0340
Farm capital	0.2496***	0.0220	D_1997	0.0602*	0.0355
Farm land	0.2184***	0.0479	D_1998	0.1757***	0.0398
N-surplus	−0.1828***	0.0462	D_1999	0.3842***	0.0414
Energy-consumption	0.6147***	0.0545	D_2000	0.1545***	0.0356
Number of observations		645	Iterations completed	20	
Sigma		0.3975			

*Significant at 10%; **significant at 5%; ***significant at 1%.

Table 4
Actual and technical efficient resource use of a sample farm for achieving a value added of 149 283 Euro.

Resource	Actual use (r)	Technical efficient use ($r^{\text{efficient}}$)
Labour (fte)	1.50	1.23
Farm capital (Euro)	244 039	200 024
Farm land (ha)	50.09	41.09
N-surplus (kg N)	13 308	10 908
Energy consumption (MJ)	1 950 770	1 598 926

Fte = full time equivalent.

Table 4 illustrates the results of one of the observations in our dataset. This farm uses five resources to produce a value added of 146 448 Euro. Correcting this for random errors (in other words subtracting v_i) the value added becomes 149 283 Euro. The actual use as well as the technical efficient use of the resources is calculated in Table 4.

In our example the farm uses 50 ha of land, while the same amount of value added could be produced using only 41 ha agricultural land (Table 4). Notice that the ratio of the technical efficient use to the actual of the resources is the same for all resources (=0.80 or 80%). This is due the choice of the Cobb–Douglas formulation as functional form. As already mentioned the Cobb–Douglas functional form has an elasticity of substitution equal to one.

The sustainable value of all observations of the dataset can be calculated using the input efficient resource use as benchmark. In Fig. 2 the sustainable value of all our observations from low sustainable value to high sustainable value is represented.

It is quite obvious that for all farms the sustainable value is negative. In fact, a sustainable value of 0 would indicate that the farm uses all its resources in the most productive way. Such a super farm does not exist in our sample. Nevertheless, large differences are observed ranging from dairy farms with a sustainable value of € −2000 to € −94 000. Farms can improve their sustainable value by applying their resources in a more productive way, in other words, by moving towards the production frontier. Farms can improve their sustainable value by replacing more sustainable value-creating resources by resources with low value contributions.

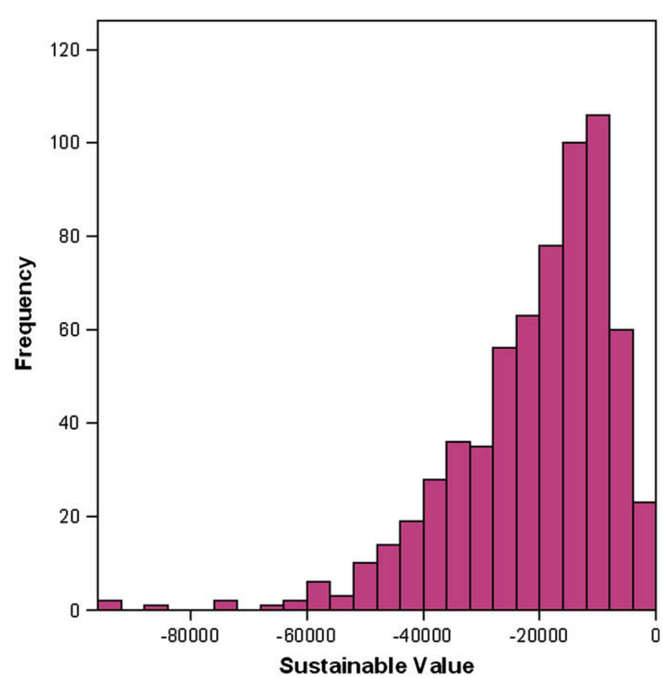

Fig. 2. Histogram of the sustainable value of all observations.

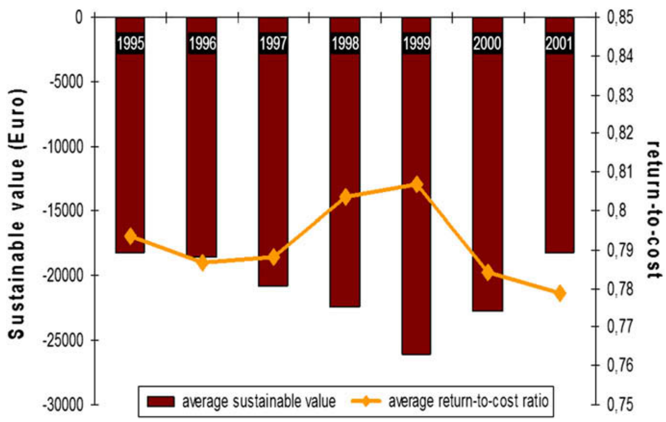

Fig. 3. The evolution of the average sustainable value and return-to-cost ratio of Flemish dairy farms.

The value contributions of all capital forms are equal using the Cobb–Douglas functional form as benchmark, because of the constant elasticity of substitution. Hence, using the Cobb–Douglas functional as benchmark cannot identify substitution possibilities because the assumption of constant elasticity of substitution. That is the reason why all value contributions of all resources are equal.

Fig. 3 shows the development over time of the sustainable value and the return-to-cost of the dairy farms in the data sample between 1995 and 2001. Notice that in this case we used a balanced panel data sample, in other words only the farms with data for all seven consecutive years (1995–2001) are used in Fig. 3. The average sustainable value of the farms fluctuates between € −18 000 and € −23 000, except in 1999. In 1999 the average sustainable value of our dairy farms was over € −26 000. As already explained, the sustainable value calculations do not take the farm size into account. Therefore, we use a size independent ratio: the return-to-cost ratio. The return-to-cost ratio relates the value added created by a farm to the opportunity costs it causes. The average return-to-cost is calculated as the sum of the return-to-cost ratios of all observations in one year divided by the number of observations in that year. Using the Cobb–Douglas production frontier as benchmark, a maximum return-to-cost of 0.96 has been found. The minimum return-to-cost of an observation in our data sample is 0.51. That farm uses its resources only half as productive as the benchmark (the maximum attainable production), more specifically that farm uses a double amount of resources to produce its output. We do not observe large yearly average return-to-cost shifts (Fig. 3). Note that in this case a low average sustainable value certainly does not mean a low average return-to-cost ratio, moreover the reverse is true. For example, in 1999, we observe a low average sustainable value and a high average return-to-cost ratio in comparison with the other years. This is not very surprising given the fact that the average value added in 1999 was high (resulting in a high return-to-cost). Note that although the productivities of the different resources in 1999 were in general higher in comparison with other years, the benchmark productivities were also higher, because the farms could achieve higher productivities due to beneficial circumstances (e.g., weather conditions) that result in a lower sustainable value for the farms in 1999.

As indicated by Fig. 1, we suggest using a frontier benchmark instead of using a simple best performance benchmark. In Van Passel et al. (2007) different benchmark types were used to analyse the robustness of the result. The rank correlation between the return-to-cost ratio using the weighted average return on resource as a benchmark and the return-to-cost ratio using the basic best performance on each resource form as a benchmark was very high (Spearman's rho = 0.9967). The use of a feasible benchmark for each company (applying frontier methods) results in a different ranking. We found a much lower rank correlation (Spearman's rho = 0.2327) between the return-to-cost ratio using the simple performance on each resource as a benchmark and the return-to-cost ratio using a Cobb–Douglas production frontier as a benchmark. This confirms our point that the sustainable value approach can differ by using frontier methods to benchmark the resource use of companies. The benchmark using frontier aspects takes underlying production aspects (e.g., initial resource use) into account. Hence, each farm is compared with a realistic but ambitious peer. That is why we call this 'frontier' benchmark approach more complete than the 'basic' benchmark approach.

4.2. *Translog functional form as benchmark*

Important drawbacks of the Cobb–Douglas functional form are the restrictive properties such as the constant input elasticities and a substitution elasticity equal to unity. The translog functional form does not impose these restrictions upon the production structure: it is a more flexible functional form. But this is at the expense of having a form which is more difficult to estimate and which can suffer from degrees of freedom and multicollinearity problems (Coelli et al., 1998). Using for example five different resources as in Section 4.1 will result in a production function with 21 variables. A lot of observations are needed to estimate such an equation. Estimations with only 645 observations (as in Section 4.1) were inadequate. Therefore, we will use an extended data sample (2651 observations) with only two resources (farm labour and farm capital). We will use only economic resources because in our extended data sample information about environmental resources was not available yet. We are aware that the lack of environmental variables implies that the application will not be suitable for a sustainability assessment. In this section, it is not our objective to make a sustainability assessment of Flemish agriculture but to test the methodology using an empirical application. Our data sample contains 2651 observations of Flemish dairy farms during 1989–2002. Note that in this example farm capital includes land capital.

In this case the translog functional form can be written as equation (11):

$$\begin{aligned}\ln \mathrm{VA}_i = {} & \beta_0 + \beta_1 \ln(\mathrm{Labour})_i + \beta_2 \ln(\mathrm{Capital})_i + \beta_3 (\ln(\mathrm{Labour})_i)^2 \\ & + \beta_4 (\ln(\mathrm{Capital})_i)^2 + \beta_5 \ln(\mathrm{Labour}_i \cdot \mathrm{Capital}_i) \\ & + \sum_{j=1}^{n} \mathrm{Yeardummy}_i^j + v_i - u_i \end{aligned} \tag{16}$$

The estimation results of equation (16) using maximum likelihood methods can be found in Table 5. We apply the methodology as

Table 5
Estimation coefficients of the translog production frontier.

Variables	Coefficient	St. error	Variables	Coefficient	St. error
Constant	9.2995***	0.1262	D_1994	0.1641***	0.0350
Labour	1.0696***	0.1802	D_1995	0.1156***	0.0346
Capital	0.3573***	0.0849	D_1996	0.0559	0.0358
Labour^2	0.2141**	0.1046	D_1997	0.1582***	0.0359
$\mathrm{Capital}^2$	0.0448***	0.0155	D_1998	0.3453***	0.0395
Labour × capital	−0.2125***	0.0634	D_1999	0.5452***	0.0411
D_1990	−0.1018***	0.0298	D_2000	0.2681***	0.0373
D_1991	−0.0654**	0.0303	D_2001	0.1693***	0.0433
D_1992	0.0155	0.0323	D_2002	0.0998**	0.0390
D_1993	0.2577***	0.0347			
Number of observations		2651	Iterations completed		28
Sigma		0.5179			

*Significant at 10%; **significant at 5%; ***significant at 1%.

Table 6
The actual and technical efficient resource use of a sample farm for achieving a value added of 67 602 Euro.

Resource	Actual use (r)	Technical efficient use ($r^{efficient}$)
Labour (fte)	1.55	0.88
Total farm capital (Euro)	298 571	225 942

Fte = full time equivalent.

explained using a two resource example in Section 3.2.2. First we separate the output measure with its noise component to work in a deterministic framework (as in equation (12)). Then we calculate the input-orientated technically efficient resource for each resource considered using the estimated coefficients of equation (16) and the resource ratio. After we obtained the efficient resource amount to produce the value added for each resource and for each company, the sustainable value can be calculated using those values as benchmarks.

Table 6 illustrates the results of one of the observations in our dataset. This farm uses two resources to produce a value added of 76 949 Euro. Correcting this for random errors (in other words subtracting v_i) the value added becomes 67 602 Euro. The actual use and the technical efficient use of the resources can be found in Table 6.

In our example the farm uses for example 1.55 full-time equivalent (fte) units of labour, while the farm could create the same amount of value added using only 0.88 fte of labour (Table 6). Note that the relation between the actual use to the technical efficient use of the resources is not the same for all capital forms (in contrast with the Cobb–Douglas functional form). Our results indicate that farms use labour less efficiently than capital. However, our analysis does not take allocative efficiency into account. In other words, the prices of the inputs are not considered.

The sustainable value of all observations of the dataset can be calculated using the input efficient resource use as benchmark. In this case the (negative) impact of labour capital will be higher than the (negative) impact of total farm capital in the calculation of the sustainable value (see Fig. 4). Farm capital is used in a more value-creating way (in fact a less value-wasting way) than labour capital. As explained in Section 2.2, a resource is defined as value-creating if the resource productivity of the firm is higher than the resource productivity of the benchmark On the other hand, we can define a resource as value-wasting if the resource productivity is lower than the benchmark. Given that our suggested benchmark is an estimated best practice benchmark, all resources are categorized as value-wasting (or value-neutral if the firm come up to the level of the best practice). Nevertheless, some resources are less value-

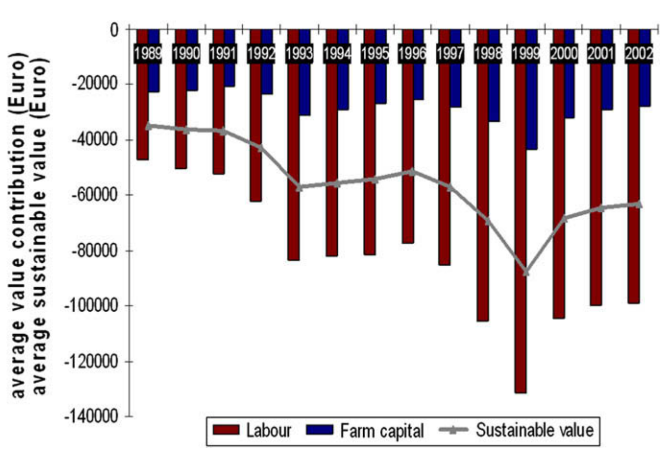

Fig. 4. The evolution of the average value contributions and sustainable value of Flemish dairy farms.

wasting because the distance to the benchmark is smaller. Fig. 4 shows the average value contributions of farm capital and labour and the average sustainable value of a balanced panel set of Flemish dairy farms (55 dairy farms during 1989–2002). We observe a decrease in sustainable value till 1999. Starting from 1999 we see a rather limited increase in sustainable value creation.

Farms can improve their sustainable value by applying their resources in a more productive way. They can increase their technical efficiency by moving towards the production frontier. On the one hand, farms can decrease the amount of resources used while producing the same amount of output. On the other hand, farms can change the composition of resources, value-wasting resources can be partly substituted by value-creating resources (or less value-wasting resources). In our restricted empirical application, this means that farms could replace a small amount of labour by a small amount of capital to increase the sustainable value. The sustainable value methodology using the translog production frontier as benchmark considers both possibilities. In other words substitution effects between resources are clearly taken into account to determine the opportunity cost (or benchmark) of each resource. A major drawback is the data requirements to estimate the translog production frontier (a lot of observations are needed). The more resources are considered as critical capital forms to assess firm sustainability, the more data is needed.

4.3. Benchmarking sustainability assessment for policy evaluation

The sustainable value approach discusses the need to conserve resources in order to generate higher return. It is interesting to know which firms are creating greater value considering economic, environmental and social resources, but it is even more crucial to know the impact of (future) decisions on the sustainable value. If a company or policy maker has to choose between several options, it is important that in terms of sustainable development that the option is selected which increases the sustainable value of the company, sector or region. In this section, we explain how the suggested approach may be used to support policy making. We illustrate the approach for the Flemish dairy sector using a large accountancy data sample (see Section 4.1). Assume that policy makers consider improving the sustainability performance of the Flemish dairy sector based on the two following policy options. We make the implicit assumption that both options have identical costs. The first option is to provide subsidies to improve the energy use (direct and indirect) of dairy farming (e.g., decrease in concentrate use or electricity use). Assume that these measures will result in an average decrease of 10% energy use while the value added remains the same. The second option is to provide subsidies to invest in labour saving techniques (e.g., time management tools, removing administrative burden). Again we assume that these measures will result in an average decrease of 10% labour use while the value added remains the same. Because policy makers have a limited budget, they have to choose between option A (energy use decrease) and option B (labour use decrease).

To support policy makers, the sustainable value (and return-to-cost ratio) of both options can be simulated. To do so, we use the balanced panel data of dairy farms as in Fig. 3, and we simulate the sustainable value of every farm in the sample for a future year for three options: option A, option B and the base scenario. We use the estimated Cobb–Douglas functional form as benchmark. The base scenario is a simulation of the sustainable value without a policy intervention (business as usual). As in Section 4.1 five different resources are selected: labour, farm capital, farm land, energy consumption and N-surplus. The resource use is calculated as the average of the seven preceding years. Furthermore, the

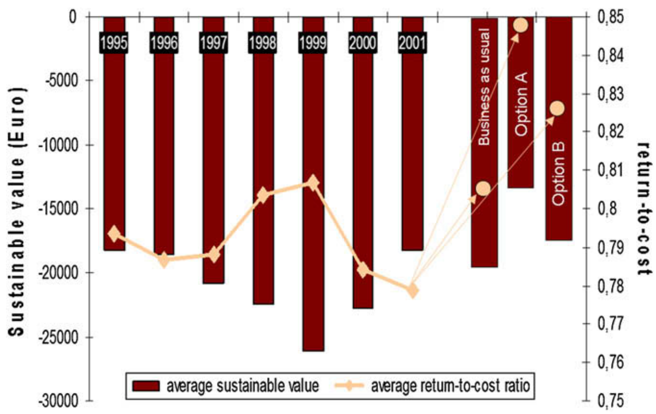

Fig. 5. The evolution of the average sustainable value and return-to-cost ratio of Flemish dairy farms including the simulation results of the policy options (business as usual, option A: energy use decrease; option B: labour use decrease).

value added and the yearly variation (indicated by the coefficients of the year dummies in Table 3) are fixed on the average values of the preceding years. To calculate the impact of the options, the energy use and labour use are decreased by 10% compared to the calculated average (or base scenario) for option A and option B respectively.

The simulation results can be found in Fig. 5. As expected (given the assumptions) the average sustainable value and the return-to-cost ratio increase for the two options. More interesting is the fact that subsidizing a decrease in energy use results in a higher increase of sustainable value than subsidizing a decrease in labour use. In other words, these results suggest that policy makers should support energy use reduction instead of labour use reduction.

Furthermore, we can analyse the simulation results considering characteristics of the farm manager. Table 7 shows that the return-to-cost ratio is higher for young, educated farmers with certainty about their succession. Furthermore, we found in each case a similar trend as in Fig. 5: option A is preferred over option B which is better than business as usual.

We are aware of the simplicity of the suggested policy options. To support policy makers, the suggested options have to be refined in more detail (e.g., differentiating among farmers receiving a subsidy). Furthermore, the impact of the suggested policy measures on all different resources and on the value added must

Table 7
Average return-to-cost considering managerial farm characteristics for the different policy options.

	Return-to-cost ratio Business as usual	Return-to-cost ratio Option A: energy use decrease	Return-to-cost ratio Option B: labour use decrease
Education of farmer			
No education (34%)	0.766	0.809	0.786
Education (66%)	0.826	0.872	0.847
Age of farmer			
Young (≤39 year) (34%)	0.814	0.860	0.835
Middle (40–46 year) (37%)	0.803	0.848	0.824
Old (≥46 year) (29%)	0.798	0.842	0.818
Succession of farmer			
No successor (37%)	0.811	0.857	0.832
Doubt about succession (59%)	0.797	0.842	0.818
Successor (5%)	0.858	0.906	0.880

Number of dairy farms: 41.

be studied and estimated before incorporating these results within the sustainable value approach. Our assumption of equal value added while decreasing the energy or labour use is for example not very realistic. Nevertheless, these results show that the suggested approach can be very useful to support decisions of policy makers and company managers and that the impact of potential decisions can be evaluated within an integrated sustainability framework.

5. Conclusion

The performance of companies is usually defined in terms of return on capital and profit. Recently, the view on performance has been broadened. To create value, companies do not only need economic capital but also environmental and social resources. This means that all relevant firm resources should be considered when assessing firm performance. In this broad view, high performance, indicating efficient use of all resources, is similar to improved sustainability.

Different assessment tools have been developed to assess firm sustainability. An interesting approach is the one developed by Figge and Hahn (2004a, 2005), who apply a value-orientated methodology to calculate the cost of sustainability capital. Their approach is based on the notion of strong sustainability, because it assumes that the amount of each resource remains unchanged on the macro level (Figge and Hahn, 2005). This means that firm performance is analysed as a scale issue rather than as the optimal efficient allocation of resources. The approach considers the total amount of resources rather than just the change in resource use. Thus, the sustainable value approach introduces scale-sensitivity into the performance analysis. Note that value- and burden-oriented impact assessments are necessarily complementary and both need to be considered to arrive at an optimal allocation of resources (Figge and Hahn, 2004b). A diverse use of methodologies to assess sustainability fits with the definitional diversity of sustainability.

The sustainable value methodology as shown in this paper allows flexibility in the use and choice of benchmarks. It should be noted that the choice of benchmark does not (and cannot) make any statement on the absolute sustainability of the benchmark as a status. Rather, sustainable value assessments will only indicate contributions to a more sustainable resource use depending on the actual benchmark chosen.

In Van Passel et al. (2007) the sustainable value and the return-to-cost ratio of a large sample of Flemish dairy farms were calculated and differences in the return-to-cost ratio were detected and explained. For this, the weighted average return on capital was chosen as benchmark. However, within the scope of policy analysis the choice of an accurate benchmark is important, because for policy makers a benchmark indicating the maximum attainable productivity level is more useful to analyse the efforts of firms in their aim towards best performance.

Choosing the most appropriate benchmarking is important. From a production perspective point of view, using frontier efficiency benchmarks can be useful for the following reasons. First, improvement in eco-efficiency (as measured by the sustainable value approach) is often the most cost-effective way of reducing environmental pressures (Kuosmanen and Kortelainen, 2005). Efficiency improvements can be seen as the first important step towards sustainability. Therefore, it makes economic sense to exploit these options as much as possible. Second, policies targeting efficiency improvements tend to be more easily adopted than policies that restrict the level of economic activity (Kuosmanen and Kortelainen, 2005).

Our approach combines the sustainable value approach, which can be seen as an indicator for eco-efficiency, with the frontier approach to benchmark the possible improvement. Using maximum feasible production possibilities as benchmark offers several advantages. First, the constructed benchmark takes inefficiency of the considered resources into account. Second, using frontier methods to construct benchmarks provides specific benchmarks for each company adjusted to the particular situation of the company (in other words to the actual resource use). The sustainability of each company is assessed in comparison with its relevant peers. Feasible targets can help to motivate decision makers (managers (e.g., farmers) and policy makers) to take realistic but ambitious measures towards sustainability. Third, our approach can be used to simulate and estimate the impact on firm sustainability of possible policy measures. In this way, this method can be used as an integrative sustainability assessment tool for policy measures. The main limitation of the suggested method is its extensive data requirement. As in Kuosmanen and Kortelainen (2005), our method is based on relative efficiency assessment of comparable units. Hence, data must be accurate and reliable, and the sample size must be sufficiently large.

The methodology using frontier methods to benchmark the sustainable value of firms has been illustrated with two functional forms: the Cobb–Douglas and the translog functional forms. The Cobb–Douglas functional form is very attractive because it is easy to estimate and to interpret. However, a major drawback of using the Cobb–Douglas functional form is the lack of flexibility. The value contributions of the different resources are identical because of the fixed elasticity of substitution (equal to 1). A possible solution is using the translog functional form, which is more flexible and allow substitution between resources to be taken into account. Our example for Flemish dairy farms shows that labour is used less productively than farm capital. Farm capital is used in a more value-creating way, or better in a less value-wasting way, than labour capital. A disadvantage of the use of the stochastic translog functional form is the data requirement, as many data are needed to avoid estimation problems such as multicollinearity problems. We therefore recommend that frontier methods (and especially more flexible forms such as the translog functional forms) are used to benchmark the sustainable value of firms if sufficient and sound economic, environmental and social data is available. With the increased collection of data on several resources, the possibilities of using frontier methods to benchmark the sustainable value increase.

Note that the suggested approach does not claim that current resource use is sustainable. It still is a relative measure of sustainability. Only quantifiable resources can be taken into account. Furthermore, the approach assumes a competitive market (price-taking, no transaction costs, perfect information and rational behaviour). Using frontier methods to benchmark the sustainable value assessment implies the assumption of similar production technology and constant relative rate by which different resources are used by a firm. Only the translog functional form (and not the Cobb–Douglas functional form) takes scale effects into account. Finally, as already mentioned, frontier estimation requires a sufficient amount of observations.

The described methodology seems very promising to assess system sustainability and can also be used to support policy makers. The sustainable value approach has the advantage of not looking from a negative externality view point but from the value-added point of view. Therefore, we think that our methodology may be a powerful tool, not only to assess firm sustainability, but also to guide companies towards sustainability. Starting from the available resources and looking at their contribution to the value added of a firm, the dependencies and possible substitutions in the resource base are analysed without reducing the economic output. This makes the options for sustainability improvement more concrete, interesting and realistic for both firm managers, seeking a private economic optimum, and for policy makers, seeking a more social welfare optimum.

To make the sustainability assessment tool fully operational, more research is needed such as testing other techniques to estimate the frontier (e.g., data envelopment analysis, 'goal' frontiers) or other functional forms. Furthermore, the possibilities for both back casting as forecasting, taking into account the impacts of different policy instruments, should be explored. Our rather simplistic example shows that this is possible but that this approach should be further expanded based on more detailed information about costs and benefits of the suggested policy options. Therefore additional data (combining different data sources) and complementary approaches such as cost–benefit analysis and life cycle analysis could be applied. Finally, besides the choice of the benchmark, we have to determine the scope of the analysis and incorporate the relevant resources to calculate the sustainable value of a company. At present, the relevant resources were based on literature and the availability of data. But with the increased collection of data on several environmental and social aspects (e.g., CO_2 contribution, animal welfare) the scope for further research analysis will certainly become wider. Furthermore, more research is needed how the variation of return and resource use (risk aspects) can be incorporated to assess sustainability in a world with uncertainty and risk. Finally, the sustainable value approach could be extended by defining sustainability from a systems' perspective: resources will have to be redefined by incorporating capacity constraints. In this way the resource use relates to sustainability at super- and subsystem level.

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