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Methods and tools for integrated assessment of land use policies on sustainable development in developing countries

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ABSTRACT

For stimulating sustainable development in developing countries, land use patterns and land use changes are considered critical, and therefore effective and efficient land use policies are needed. In this paper we present a methodological framework that has been developed in a joint European and developing countries project (LUPIS – Land Use Policies and Sustainable Development in Developing Countries), to assess the impact of land use policies on sustainable development in developing countries. An illustrative application is presented for a case study in China, where water pollution due to agriculture in Taihu Basin is a major problem.

We argue that an integrated assessment is required, considering multiple drivers and indicators that determine the objectives and constraints of the stakeholders involved. Therefore, the sustainability impact assessment (SIA) is based on the concept of Land Use Functions (LUFs), and impacts on these LUFs are discussed with stakeholders based on a multi-criteria analysis. LUFs comprise economic, environmental and social indicators relevant for stakeholders at multiple scales. Instead of focusing only on the indicators that determine the problem (e.g., nutrient leaching in the Chinese case study), we take a broader perspective (considering also social, economic and institutional objectives and constraints), such that feasible policy options can be recommended. Stakeholders have a large role in discussing the selection of indicators and policies (pre-modelling), evaluating the impacts on indicators (modelling), and the weighing of indicators and LUFs (post-modelling). For the assessment of impacts on indicators (modelling), quantitative and qualitative approaches are combined. We present and discuss an impact assessment of policy options in Taihu Basin, for the current situation and towards 2015. The methodological framework as presented here proved to be useful to guide a sustainability impact assessment in China and six other case study regions.

1. Introduction

To enhance sustainable development, various commitments and interventions have been implemented in the delineation (September 2000) and assessments (September 2005) of the Millennium Development Goals (MDGs). World leaders committed their nations to stronger global efforts for poverty reduction, universal education, woman's empowerment, health, environmental sustainability and development partnership. For promoting sustainable development in developing countries, land use patterns and land use changes are considered critical (e.g., Tilman et al., 2002; Foley et al., 2005; Turner et al., 2007). Land reforms are vital for sustained productivity, food security, poverty alleviation, nature conservation and the environment (Reid et al., 2005). Land use policies are thus key to the achievement of the MDGs (UN, 2009).

The successful implementation of land use policies is often hampered by the fact that we do not know enough about their impact on sustainable development in different contexts. The potential

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role that land use policies could play is usually not assessed considering environmental, economic, social and institutional aspects in an integrated way (Kates et al., 2001; Robinson, 2004; Reid et al., 2005; Wood and Lenné, 2005; Kates and Dasgupta, 2007). A range of research tools have been applied for sustainability impact assessment (Ness et al., 2007), but generic and flexible concepts and tools to perform policy impacts assessments, that allow an integrated analysis at multiple scales and can be applied and compared in different contexts in developing countries, are not available.

For an integrated assessment of the impact of land use policies on sustainable development, a systems approach is required (e.g., Ewert et al., 2009). The problems to be studied are highly complex as they relate to multiple scales, dimensions, sectors and stakeholders. At higher scale levels, computer simulation models, performing a comprehensive analysis of the land-use system, appear to be indispensable research tools (Bouma et al., 2007). This was acknowledged by the European Commission, who introduced Impact Assessment Guidelines and promotes the use of modelling tools to make policy development better informed and improve the quality of European policies (EC, 2005; Bäcklund, 2009; Thiel, 2009). This resulted in a large number of studies on impact assessment of land use, policies and sustainable development (e.g., Boulanger and Bréchet, 2005; Rossing et al., 2007; Hacking and Guthrie, 2008; Walter and Stützel, 2009; Binder et al., 2010).

Policy analysis is typically concerned with a large unit of analysis, i.e. the regional or national level. Before the 1990s agricultural research was usually focused on the plot, field or farm level. In 1995, the Ecoregional Fund was initiated, with the aim of sponsoring methodology development projects in support of ecoregional research initiatives in various parts of the world (Bouma et al., 2007). This resulted in several successful studies, in which for example multi-objective programming was linked with GIS mapping to show the potential of agricultural activities in different locations (Roetter et al., 2005), and biophysical models were linked with econometric techniques to assess trade-offs between, e.g., agricultural production and soil erosion (Stoorvogel et al., 2004). Progress has thus been made, but thorough theoretical and empirical research into the effects of land use policies on the sustainable development of developing countries is still very much needed if we are to ensure the achievement of the Millennium Development Goals. Such understanding from assessments is vital to explore notions that, for example, the importance of trade is often underestimated (e.g., Dawe, 2001), agricultural intensification can both lead to an increase (less area needed) and loss in biodiversity and ecosystem service provision (Mooney et al., 2005; Reidsma et al., 2006; Glendining et al., 2009), and intensification leads to soil mining (e.g., Smith et al., 2000).

Kates et al. (2001) argue there is an information gap between developed and developing countries. This leads to knowledge differences, which should be bridged by collaborations among developed and developing countries to discuss key questions, appropriate methodologies and institutional needs. Numerous studies have shown that investments in research and development typically rank first or second in terms of returns to growth and poverty reduction, along with investments in infrastructure and education (Von Braun et al., 2008). Besides collaboration between developed and developing countries, other requirements to improve sustainability science (Kates et al., 2001) are to connect to the policy agenda, and focus on nature–society interactions and the pathways that lead to sustainability considering these interactions.

The aim of this paper is to present a methodological framework for sustainability impact assessment of land use policies in developing countries, considering the issues listed by Kates et al. (2001) above. The framework is multi-scale, integrated (economic, environmental, social and institutional) and involves stakeholders. Stakeholders include farmers, experts, policy-makers, researchers and other individuals, groups and organizations that are directly affected by decisions and actions or have the power to influence the outcomes of these decisions. Nine operational Land Use Functions (Pérez-Soba et al., 2008) are addressed to provide a holistic perspective. In the next sections we will present and discuss the methodological framework, and illustrate its applicability in a case study in Taihu Basin, China, where water pollution due to agriculture is a major problem. This paper focuses on presenting the approach while details of the case study modelling work are presented elsewhere.

2. Methodological framework

In the frame of a joint European and developing country project (LUPIS – Land Use Policies and Sustainable Development in Developing Countries), seven case studies have been selected in seven developing countries (China, India, Indonesia, Brazil, Tunisia, Kenya, Mali) for performing ex ante impact assessments of land use policies (McNeill et al., 2011). Each case study has its own specific land use problem, and each problem requires targeted land use policies. In order to assess these consistently, a methodological framework for sustainability impact assessment (SIA) has been developed that allows ex ante assessments including (i) multiple land use sectors, (ii) multiple dimensions of sustainability, and (iii) multiple scales (Reidsma et al., 2011). The framework is meant to be generic and flexible, so that it can be applied across a range of issues and countries. It builds upon two complementary methodologies (SEAMLESS and SENSOR), developed in the European context, but has been enhanced and adapted to the context of developing countries. SENSOR (Sustainability Impact Assessment: Tools for Environmental, Social and Economic Effects of Multifunctional Land Use in European Regions; Helming et al., 2008) developed ex ante impact assessment tools at regional scale for EU policies related to land use, with a focus on cross-sectoral trade-offs and sustainability side-effects. SEAMLESS (System for Environmental and Agricultural Modelling: Linking European Science and Society; Van Ittersum et al., 2008) concentrated on the agricultural sector and targeted at assessing agricultural and environmental policies and technological innovations at multiple scales. Using these two methodologies as building blocks, allows addressing a wide variety of land use problems, with a focus on agriculture, which is at the core of sustainable development in developing countries.

The SIA procedure has been adapted from the SEAMLESS methodology (Ewert et al., 2009) whereas the evaluation of sustainable development is based largely on the SENSOR approach (Helming et al., 2008; Pérez-Soba et al., 2008). The SIA procedure is subdivided into three main phases (Fig. 1), a pre-modelling phase (problem and scenario definition), a modelling phase (assessing the impacts of policies on indicators) and a post-modelling phase (evaluating impact of policies on sustainable development). Modelling is at the core of the framework and refers to computer-based models, but also includes qualitative approaches. Ex ante impact assessments require models (whether quantitative or qualitative) that can give forecasts for the future.

Involving stakeholders in the SIA is important to understand the regional and local problems and constraints, build trust, and have impact on policy making processes (Lebel et al., 2006; Bouma et al., 2007; Van Paassen et al., 2007; Giller et al., 2008). Part of the framework is therefore to organize policy fora with stakeholders in each phase of the process. In the pre-modelling phase discussions focus on problem identification, selecting relevant indicators and

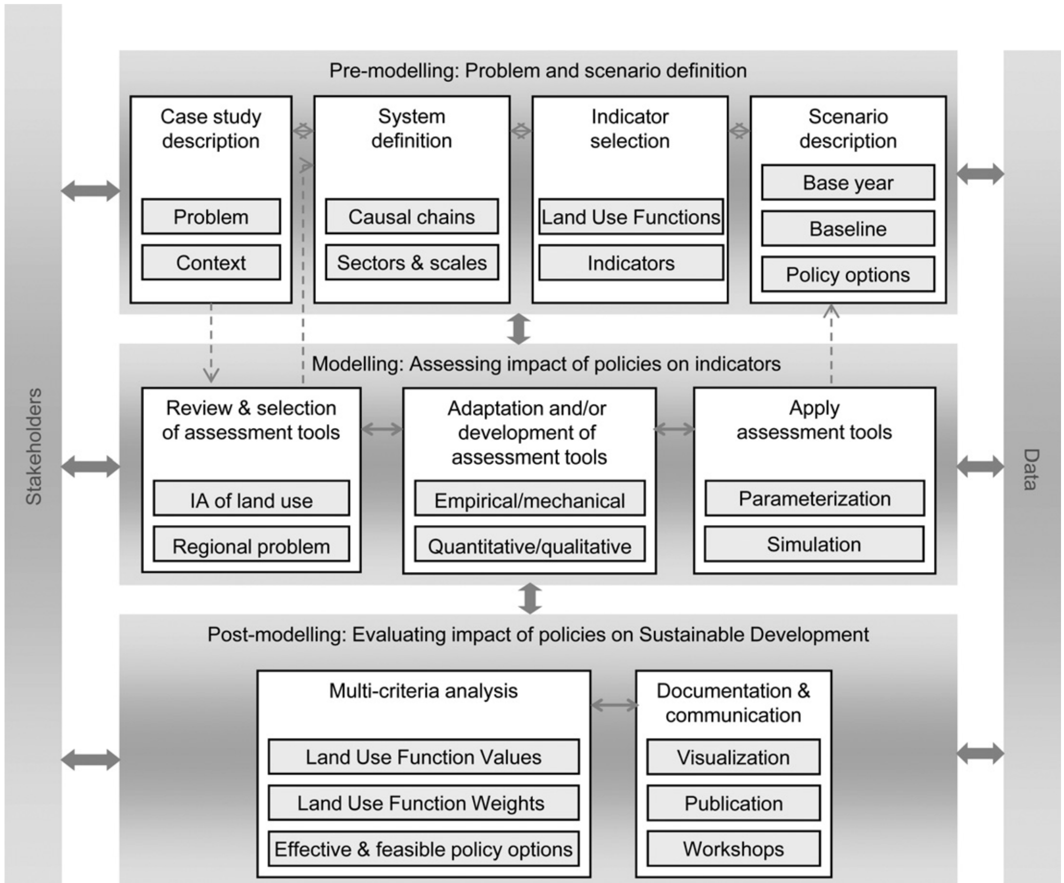

Fig. 1. Methodological framework for sustainability impact assessment (SIA) of land use policies in developing countries. The whole framework is iterative as mentioned by the two-way arrows. Where specific iterations are required, extra (dashed) arrows are included.

selecting policy options that have the potential to reduce the problem and improve sustainable development. In the modelling phase the stakeholders are approached to provide expert knowledge on driver-impact relationships and expected changes in indicators according to scenarios. In the post-modelling phase the main aims are to discuss the modelling results and assign weights to indicators in the multi-criteria analysis (MCA).

Although pre-modelling is logically performed before modelling, performing a SIA is an iterative process requiring refinement throughout the process, as indicated in Fig. 1 by the arrows. In the following sections we will describe each phase of the SIA, using the Chinese case study as an illustration.

3. Pre-modelling

3.1. Case study description

3.1.1. Problem definition

A major land use problem in China is the water pollution due to agricultural sources in Taihu Basin. Taihu is one of the five major lakes in China. It is a well-known place for tourists with beautiful lake and mountain landscape views. It also serves many other purposes, such as a source of drinking water, storage of flood water, shipping, irrigation and aquaculture. Due to rapid economic development in Taihu Basin since the 1980s and the lagging environmental protection, the water quality of major rivers running into the lake and the lake itself is now seriously polluted (Jin et al., 2006). Industry, domestic sewage and agriculture are the major sources increasing nutrient levels of the rivers that run into Taihu. It is expected that due to the internal restructuring of industry and the production processes in China, emissions from industries will continue to decline. Pollution from domestic sewage is being reduced by wastewater treatment plants. Agricultural non-point sources are projected to continue growing for a long time, because they are extensive and complex to manage, and governments have limited control (Zhang et al., 2001).

3.1.2. Context

Taihu Basin is located in the east of China, between the end of Yangtze River and the Qiantang River and Hangzhou bay (Fig. 2). Taihu Basin crosses through three provinces and one city, which are Jiangsu province, Zhejiang province, An-hui province and Shanghai city. Its total area is 36,500 km^2. Taihu Basin is an agriculturally productive and economically important region in China. The land area of Taihu Basin comprises 0.4% of China, population is less than 3%, but the GDP accounts for 12% of China. Population density is high, with 1100 inhabitants per km^2. It is a subtropical region, with an average temperature of 14.9–16.2 °C, July having the highest temperatures (27.7–28.6 °C) and January the lowest (1.7–3.9 °C). Mean annual precipitation is 1010–1400 mm, gradually increasing from north to south. Although agriculturally productive, agriculture has only a small share in the GDP (2.8%), mainly due to high economic growth in the last decades.

Besides reviewing the geographic, socio-economic and environmental context, we gave specific attention to the policy and institutional context. The policies currently in place and their effectiveness determine feasible policy options for the future. A land use policy typology was developed that distinguishes between

Fig. 2. Map of Taihu Basin, China.

objectives of the policies (Bonin et al., 2009). For Taihu Basin, twelve resource oriented, six sectoral and four integrated polices were identified and reviewed (Feng et al., 2011). The common purpose of most of the policies characterized as resource oriented in Taihu Basin is the appropriate development, utilization and protection of water and soil resources. These include the "Zero-clock Action", which was implemented in 1998 by the State Environmental Protection Bureau, and initiated integrated pollution control in Taihu. After that, several regulations on reducing water pollution have been implemented at national, provincial and basin level. Most resource oriented policies have not yet achieved their goals, because they were mainly formulated to deal with the consequences of the pollution, and not with the actors who cause the pollution. The purpose of the sectoral policies is mainly to reduce environmental pollution from agriculture (e.g., pesticide control, ecological agriculture). Important for the development of agriculture are the five-year plans; for 2006–2010 this was the 11th five-year plan for the construction of modern agriculture in Jiangsu province (2006–2010). Goals are ambitious, but due to lack of implementation and dissemination, the awareness on the need for environmental protection is still low. Integrated policies include land use planning at provincial, town, and country level, which are generally formulated to support economic, environmental and social development jointly. In general we observed that many policies have been formulated, but that lack of implementation, dissemination and monitoring prevent achieving the targets.

3.2. System definition

3.2.1. Causal chains

Within the methodological framework for SIA other frameworks were used for specific steps. The Driver, Pressure, State, Impact, Response (DPSIR) framework was used to analyse the causal relationships between the various economic, environmental, social and institutional aspects of the situation (OECD, 1993; Helming et al., 2008). Fig. 3 gives a summary overview including an example for the Chinese case study. This example includes iterations with the remaining steps in the pre-modelling phase (Fig. 1); the identified causal chains provide a good basis to define the most relevant scales and sectors, indicators and policy options.

Proximate drivers (Geist and Lambin, 2001) of land use change and associated impacts on water pollution are agricultural intensification and demand for food. Together these determine the demand for agricultural land and how this is managed (Pressure). Industrial pollution and domestic sewage are also proximate drivers of the problem; the contribution of agriculture to water pollution should be seen in context of these sources. Changes in these proximate drivers are influenced by underlying drivers such as economic development, technological development and population growth, and by policy and institutional factors. Land use and land use intensity do not influence sustainable development as such, but they affect the state of relevant social, environmental and economic indicators, including nitrogen (N) leaching, farmers'

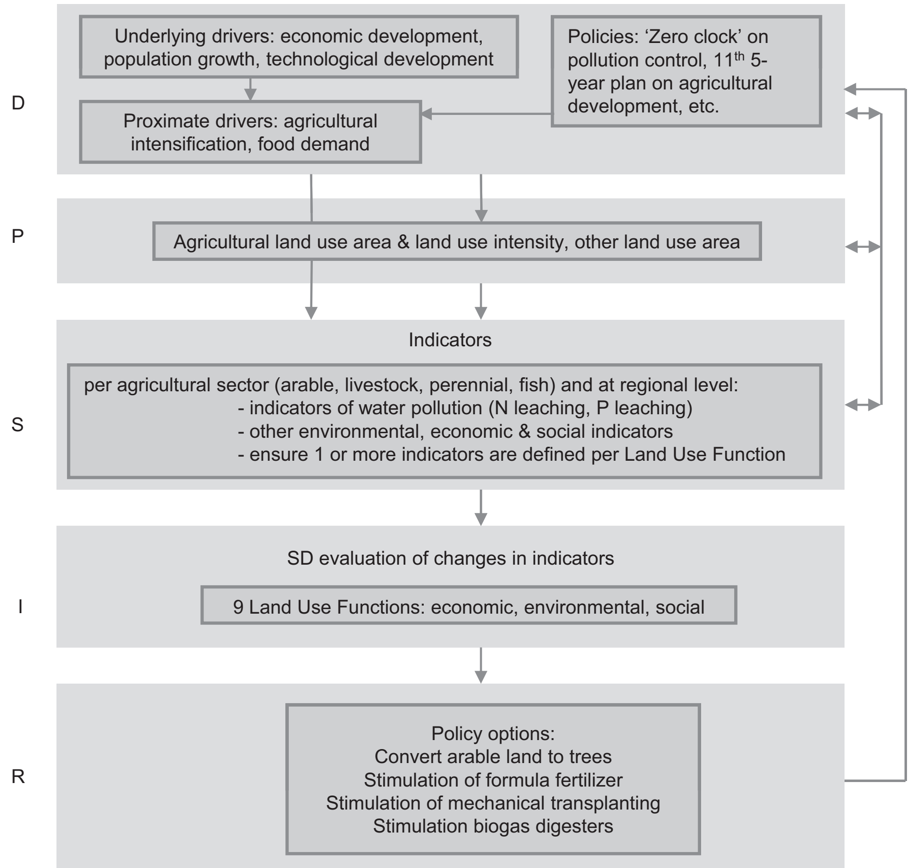

Fig. 3. Summary of the causal chain analysis of the Chinese case study using the Driver-Pressure-State-Impact-Response (DPSIR) framework. The causal chains of the problem 'water pollution due to agriculture' are identified. The State indicators are the most important indicators per Land Use Function, which are used to evaluate the Impacts. To clarify linkages between indicators and Land Use Functions, these are detailed in Fig. 5. Considering the review of causal chains DPSI, feasible policy options relevant for ex ante assessment are identified as Responses. In the ex ante assessment, these will also be considered as drivers. As relationships are not one-directional, but feedbacks occur between Drivers, Pressures and Indicators, and direct relationships exist between Indicators, extra arrows are included.

income and labour use. The impacts on sustainable development are measured by thematically grouping them into Land Use Functions as further explained in Section 3.3. Based on the causal chain analysis, feasible policy options (responses) can be identified (Section 3.4.3).

The arable sector has the largest contribution in N leaching and run-off to surface water towards Taihu. Grontmij (2005) estimated a contribution of 58,200 tons/yr from paddy and dryland fields compared to 5500 tons/yr from livestock and 2600 tons/yr from fish farming. The contribution to phosphorus (P) load was estimated to be small (around 0) compared to livestock (1250 tons/yr) and fish (300 tons/yr), but experiments show that due to long-term high P application and extreme rainfall events, the arable sector also contributes to P losses (Cao and Zhang, 2004; Guo et al., 2004; Xie et al., 2004). To improve water quality, it is essential to reduce emissions of both nutrients. As the lake is currently P limited, in the short-term the reduction of P emissions is more effective than the reduction of N. However, as P emissions from industry and domestic sewage have largely been reduced already due to effective policies, in the longer-term reducing N becomes more important. Clearly, N and P leaching are important indicators, but land use and intensity change also affect other indicators of sustainable development, such as crop production, food security, farmers' income, labour use and biodiversity. Using the DPSIR, most relevant indicators (State) and Land Use Functions (Impacts) were selected, which is further explained in Section 3.3.

3.2.2. *Sectors and scales*

The main land use sector that was assessed is the agricultural sector. Earlier studies have performed a more general assessment, estimating the relative impact of agriculture (Yang and Wang, 2003; Grontmij, 2005); here we go into more detail to search for effective and feasible policy options. Therefore different agricultural sectors were distinguished: arable, perennial, livestock and fish. In this paper we focus on the arable sector.

Water pollution is worst in North-west Taihu Basin, due to the direction of river flow and the large agricultural land area in this part. The regional assessment is therefore restricted to this area (Fig. 4), and is further divided into three municipalities (Wuxi, Changzhou and Zhenjiang). Within the municipalities and per agricultural sector, farm types are distinguished. For the arable sector 320 farms have been surveyed and cluster analysis was used (Köbrich et al., 2003), obtaining 4 farm types differing in farm size and contribution of off-farm employment to household income (influencing labour and capital availability). Farm types can choose among different agricultural activities, which are defined as rotations with a certain technology on a soil type. There are clay, loamy and sandy soil types observed in the Basin with the majority of farms operating on clay soils (57% of area of surveyed farmers). As the assessments for different sectors and at different scales are extensive, in this paper we present the assessment at agricultural activity level (i.e., field). Results at this level form the basis for higher level results. Rice–wheat is the major rotation (90% of the

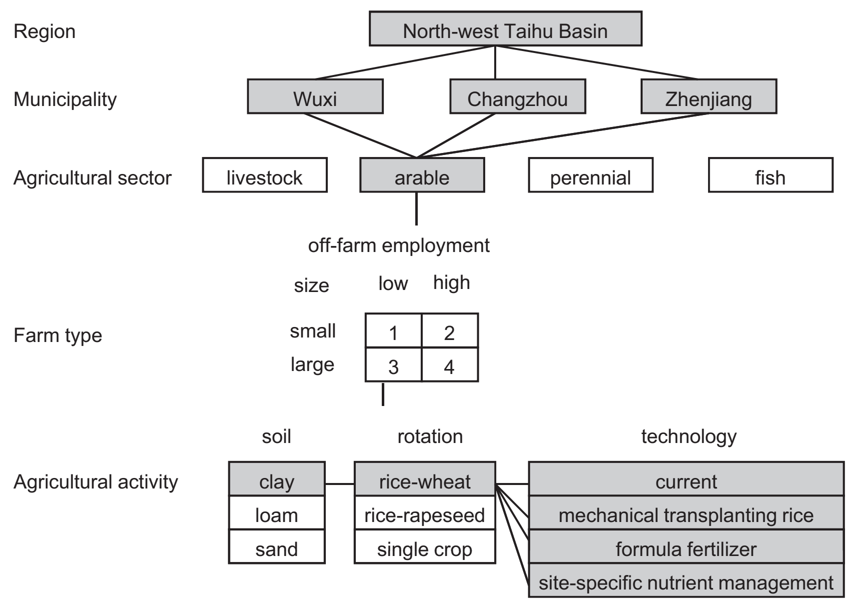

Fig. 4. Scales and land use sectors assessed in the Chinese case study. The boxes addressed in this paper are highlighted in grey.

area of surveyed farmers). The technologies in Fig. 4 relate to the policy options that are explained in Section 3.4.3.

3.3. Indicator selection

In order to translate a notion of sustainable development into a balanced set of indicators (Alkan Olsson et al., 2009), an indicator framework has been developed. The LUPIS indicator framework builds upon the concept of Land Use Functions (LUFs), as developed by Pérez-Soba et al. (2008). Nine LUFs are identified, i.e., three per dimension (i.e., economic, environmental and social), that represent regional sustainability in an integrated way. LUFs illustrate most relevant sustainability issues and are defined as goods and services associated with land use (e.g., economic: land-based production; environmental: maintenance of ecosystem processes; social: provision of work/livelihood). They refer to regional preferences with regard to the functionality of the land and therefore to the extrinsic value of the land. LUFs are a pragmatic way for stakeholder-driven sustainability assessment of land use changes (Schößer et al., 2010).

Fig. 5 illustrates the LUPIS indicator framework, which we explain here starting with clarification of Sustainable Development (SD) targets in Taihu Basin, which direct towards most relevant LUFs and result in a selection of indicators per LUF. LUFs can comprise multiple indicators (Paracchini et al., 2011), but as aggregation is not straight forward and presentation is not transparent, for this paper we select one indicator per LUF. For 2010, environmental policy targets were to reduce the use of pesticides and nitrogen (N) by 30% and 20%, respectively (Feng et al., 2011). The agricultural emission of total N and total phosphorus (P) to the lake should have reduced at least with 50%. New policy plans towards 2015 will likely further strengthen these targets. In 2015, water quality should reach class III (the concentration of COD and NH_3–N should be below 20 mg/l and 1.5 mg/l). These targets mainly refer to the environmental LUF 'maintenance of ecosystem processes'. N leaching, which was identified as an important indicator in Section 3.2.1, was selected to represent the LUF 'maintenance of ecosystem processes'. P leaching is also an indicator of this LUF, and impacts can additionally be presented, but we prefer not to aggregate these two indicators. The LUF 'maintenance of ecosystem processes' is supported by abiotic and biotic resources. As the application of N fertilizer compared to P and especially potassium (K) has been too high in the last decades (based on Janssen and de Willegen, 2006, Tian et al., 2007 and own data), reducing the contribution of N compared to K will improve the ideal soil fertility (the main reason to introduce 'formula fertilizers', Section 3.4.3) and hence the LUF 'abiotic resources'. Lastly, the N input can serve as an indicator for biodiversity loss and hence the 'biotic resources' (Kleijn et al., 2009; Asai, 2009). Maintaining biotic resources is an important LUF to ensure sustainable development, and therefore this should be addressed. Impacts on N inputs can additionally provide insights in reasons for changes in N leaching.

The main economic targets aim to increase the production of rice and other products, to increase the income of rural households, and to reduce the rural-urban income gap (Feng et al., 2011). These are related to the LUFs 'land-based production' (rice + wheat yield), 'economic production' (net income) and 'industry and services' (input use). Although a high input use is not necessary positive, money spent on machinery, fertilizers, pesticides and other inputs does represent the stimulation of other business activities. Social targets aim to ensure food security, a healthy environment including safe drinking water, and the provision of work/livelihood to the rural households. These were related to the indicators rice yield, a biocide residue index (Ponsioen et al., 2006) and the labour use. As off-farm employment gives higher profitability than agriculture, a reduction in labour use was considered positive.

The impact of a policy on sustainable development can be assessed based on environmental, economic and social indicators. Whether a policy is likely to be implemented, monitored and successful, also depends on the institutional context or governance. Governance includes laws, regulations, discursive debates, negotiation, mediation, conflict resolution, elections, public consultations, protests, and other decision-making processes (e.g., Lebel et al., 2006). As the institutional context is cutting across the three dimensions of sustainable development, its assessment is different and therefore often omitted. In our framework the ability to implement policies is important in the review of the policy and institutional context and the selection of policy options in the pre-modelling phase, and in the SD evaluation in the post-modelling phase. Institutional indicators can be defined to assess

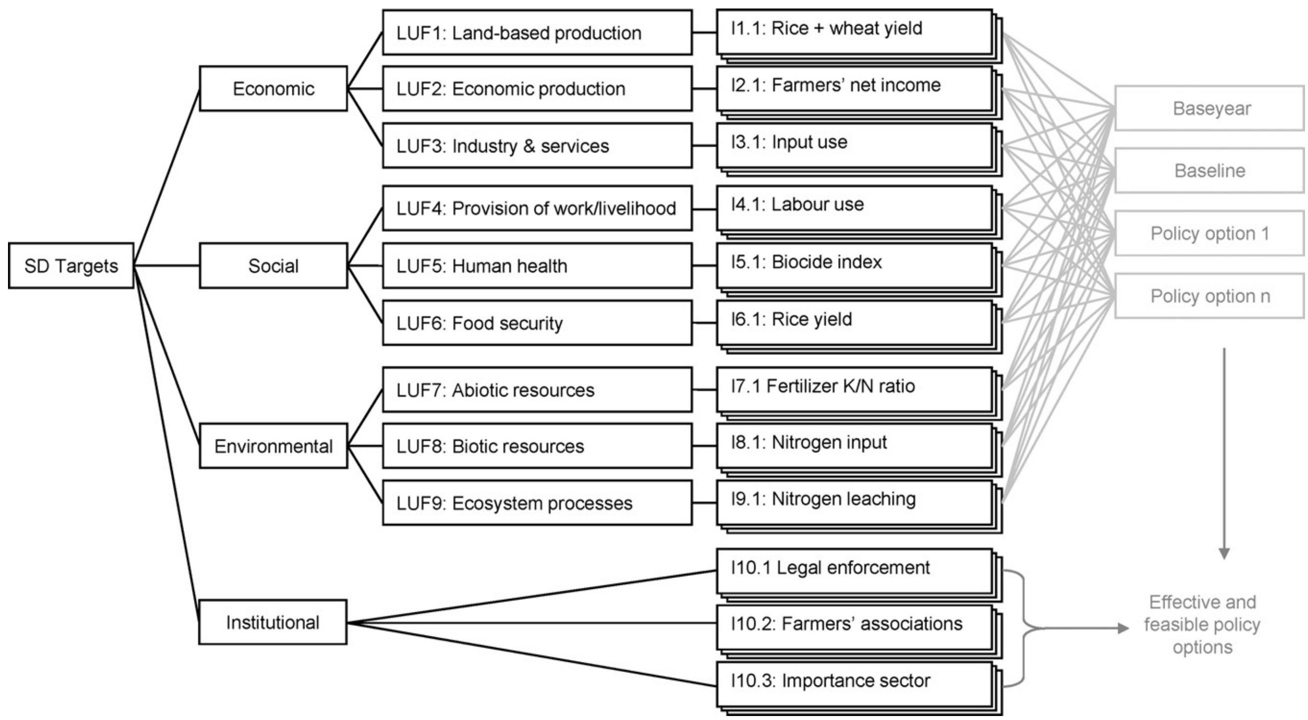

Fig. 5. The indicator framework for sustainability impact assessment (SIA) using Sustainable Development (SD) targets, Land Use Functions (LUF) and indicators. All environmental, economic and social indicators are assessed for different scenarios, and combined with institutional indicators, these assess the feasibility of policy options (in grey). Selected LUFs and indicators at field level in Taihu Basin, China, are presented.

(quantitatively or qualitatively) the ability to implement policies (Theesfeld et al., 2010), and hence the impact of a policy on SD targets. The review of the institutional context showed that implementation and monitoring of policies in the case study area should be strengthened, which can be measured by the indicator 'law enforcement'. Also public awareness and participation should be improved, which can be related to 'membership in farmers' associations'. Another important indicator is the economic importance of the agricultural sector, which influences the willingness to use economic instruments such as subsidies and taxes. Theesfeld et al. (2010) present ways of quantitatively measuring such indicators using data from f.e. the World Bank. In this study we judged these indicators qualitatively based on the policy review.

3.4. Scenario description

3.4.1. Current situation

A farm survey has been held on 320 arable farms, in 16 different villages in the 3 municipalities in 2008, which is considered as the base year. Data on cropping patterns, input use, technologies, outputs, objectives and constraints which are relevant to assess the selected indicators were collected. These data were complemented with soil and climatic data from regional sources. For the base year scenario the available data were used to assess a conventional rice–wheat rotation on clay (2008 BASE).

3.4.2. Baseline scenario

The target year for ex ante assessment is 2015. For policy makers and other stakeholders this short time horizon is relevant, as it directly links to current policies. For an assessment of sustainable development in the longer term it is relevant to have a more distant horizon to complement the assessment (e.g., 2025), but forecasts will be more difficult to validate. When the focus of the analysis is on the impact of policies, these should be evaluated against a baseline, a so-called 'business-as-usual' scenario where currently observed trends persist in the future. The DPSIR framework presented in Fig. 3 helps to shape the scenarios. For the arable sector in Taihu Basin, trends in crop yields, input and output prices and subsidies were estimated based on historical trends. These were used to forecast how a conventional rotation of rice–wheat on clay (2015 BASE) will perform in the baseline scenario.

3.4.3. Policy options

In the case study definition and case study description, relevant policies and their impacts have been reviewed. Based on this review of policies, and discussion with stakeholders, policy options that have the potential to improve sustainable development towards 2015 were identified and specified. Three policy options have been selected that (i) have potential to reduce water pollution, (ii) have impact on sustainable development at large, (iii) have been adopted already by farmers and implementation is therefore plausible and (iv) can be simulated with the models selected (therefore iterations with the modelling phase are needed; Fig. 1).

The first policy option refers to the stimulation of the use of what locals call 'formula fertilizers', generally known as site-specific nutrient management (SSNM). Based on soil samples and nutrient balance calculations, extension officers give site specific recommendations on nutrient management (Dobermann et al., 2002; Wang et al., 2007). A better formula for fertilizers and a better timing will reduce nutrient pollution, and may also have positive side-effects on crop yields and net income. To asses the impact of this policy in the base year 2008, we firstly assessed the rice–wheat rotation on clay with SSNM as currently applied by farmers using formula fertilizer according to average data (2008 FF). Secondly, optimal SSNM aiming for a zero nutrient balance as advocated by research (2008 SSNM) was assessed. This has not been observed much in practice yet. The 2015 FF gives a projection if policies with regard to improved nutrient management are continued as currently applied. The rotation with SSNM (2015 SSNM) presents what is feasible in terms of crop yields and nutrient losses according to experiments (Jing et al., 2007).

The second policy option relevant for arable farming is the stimulation of mechanical transplanting. Mechanical instead of hand transplanting of rice does not directly reduce nutrient leaching, but improves labour use efficiency, which is important in this region with increasing labour costs; it can thus facilitate adoption of SSNM. It furthermore reduces land use for seedbed and pesticide use, and increases yields. For the base year, this scenario was based on average data and current subsidies (2008 MT), the 2015 MT refers to stimulation of mechanical transplanting of rice fully subsidizing the rent of machinery use.

The third policy option considers the conversion from arable land to trees in areas close to rivers and the lake. Farmers who have land in these areas get compensation payments, but cannot grow crops anymore on these lands. These riparian buffer zones can reduce nutrient leaching, but will also influence the income and livelihoods of farmers.

4. Modelling

4.1. Review and selection of assessment tools

Tools for sustainability impact assessment were categorized by Payraudeau and Van Der Werf (2005) and Ness et al. (2007), including ex post approaches based on empirical data, and ex ante approaches based on modelling. For ex ante assessment, the generic approaches developed in the European context in the SEAMLESS (agriculture, multi-scale) and SENSOR (land use, regional) projects, can be used as a starting point. Although these generic approaches provide a basis for SIA in developing countries, the selection of models depends on the case study objectives. The models should allow assessment of the identified causal chains between drivers, policies and indicators as identified in the pre-modelling phase. As each land use problem involves different drivers, policies and indicators, we did not develop a modelling framework, but a framework that allows selecting appropriate models and approaches. Table 1 gives an overview of methods that have been applied in the case study in Taihu Basin, China. The table includes models at other scale levels and for other agricultural sectors to which results presented here are linked in order to assess the relative contribution to water pollution in Taihu.

4.2. Adaptation and/or development of assessment tools

When models are claimed to be generic, this does not imply that they can be readily used to assess indicators. When a specific model is used for another type of application or in another context, data needs to be collected as input in the model and often adaptations to the model structure need to be made. A bio-economic farm model was used to assess the impact of policies on farm performance in the arable sector, based on the Farming Systems SIMulator (FSSIM) developed in SEAMLESS (Louhichi et al., 2010). FSSIM is a generic model that can also be used outside the European context. However, although the generic structure is re-usable, several components needed to be adapted to the Chinese context. This can partly be done by using models and insights from similar regions. Models developed for a neighbouring region, Pujiang, were used to adapt regional agricultural structure (e.g., Hengsdijk et al., 2007; Van den Berg et al., 2007). For example, instead of rotations having one crop each year as in Europe, in Taihu Basin, rotations include multiple crops within one year.

A major requirement as input into bio-economic models, is the quantification of agro-ecological relationships. For this, we used the Technical Coefficient Generator developed for South-East Asia, TechnoGIN (Ponsioen et al., 2006). TechnoGIN simulates input-output relationships of agricultural activities on a hectare basis. TechnoGIN was adapted to serve as a technical coefficient generator and at the same time as a database hosting all the necessary input data for FSSIM. Farm survey data was used together with other data from literature and expert knowledge to feed TechnoGIN and FSSIM. Statistical analyses were performed on the data to ensure reliability, and to empirically analyse relationships between for example education and fertilizer use (e.g., Che, 2009).

Other agricultural sectors, including livestock, perennial and fish farming, have been assessed using response functions and knowledge rules (Sieber et al., 2008), constructed on the basis of available data and econometrically quantified relationships.

4.3. Application of assessment tools

An integrated assessment requires the application of multiple tools at multiple scales. In this paper it is not feasible to describe all tools, assumptions and results. As an example, we present the model application at field level using TechnoGIN, which is at the basis of results at farm and regional level. TechnoGIN was applied for each agricultural activity, including different rotations, soil types and technologies in line with the policy options (Section 3.4.3). The rice–wheat rotation on clay soils is presented, for which average data on inputs and outputs (on f.e. crop yields, fertilizer use) from three municipalities was used (Kang, 2009; Van Loon, 2010).

When assessing current activities including 2008 BASE, 2008 FF and 2008 MT, the data collected on nutrient application and obtained yields served as inputs, while TechnoGIN calculated nutrient losses (leaching and run off, denitrification, volatilization, fixation) using the built-in model QUEFTS (Janssen et al., 1990). When assessing alternative activities aiming for optimal nutrient management (2008 SSNM), the yearly fertilizer applications were calculated by balancing the inorganic and organic nutrient pools, so that the fertilizer applications and target yields can be repeated for many years without mining the soil or building up a soil nutrient reserve. Other indicators (Fig. 5) were calculated based on data collected on input requirements, input costs, crop yields and output prices. For 2015 BASE, 2015 FF and 2015 MT it was assumed that nutrient applications stay constant while yields increase according to historical trends. For 2015 SSNM it was assumed that with training and education the highest yields obtained in experiments and by farmers, can be obtained by the average farmers, while nutrient requirements were calculated by the model.

5. Post-modelling

5.1. Multi-criteria analysis

5.1.1. Land Use Function values

In the post-modelling phase, the changes in indicator values associated to the corresponding LUFs for the different scenarios were evaluated for (i) the impact on the problem, and for (ii) sustainable development in the wider context. In Fig. 6, results from the modelling example (Section 4.3), conventional rice–wheat rotation on clay, are presented for 9 indicators linked to Land Use Functions for the base year (2008 BASE), and % change relative to 2008 BASE for the policy stimulating the use of formula fertilizer (2008 FF), the potential of a policy improving site-specific nutrient management (2008 SSNM), and the policy stimulating mechanical transplanting of rice (2008 MT). The +/− indicates whether an increase was considered positive or negative; accordingly an

Table 1
Models used for sustainability impact assessment of land use policies in Taihu Basin, China.

Model type	Agricultural sector	Scale	Classification[a]	Reference (e.g.)	Indicators (e.g.)
Ex post					
Econometric/regression models	Arable Livestock	Farm Region	Quantitative Empirical	Liu and Wang (2005)	Fertilizer use Adoption of environmentally friendly technologies Fertilizer use efficiency Animal waste management
Ex ante					
Technical Coefficient generator	Arable Perennial	Field	Quantitative Mechanistic	Ponsioen et al. (2006)	Crop yield N leaching Net income
Bio-economic model	Arable	Farm type	Quantitative Mechanistic	Louhichi et al. (2010) Janssen and van Ittersum (2007)	Land use pattern Crop production N leaching Farm income
Response functions using DPSIR	Livestock Perennial Fish Arable	Agricultural sector	Quantitative Empirical	Sieber et al. (2008): mainly based on quantitative information	Indicators not included in other models used, but for which quantitative data are available
Knowledge rules using DPSIR	Livestock Perennial Fish Arable	Agricultural sector	Qualitative Empirical	Sieber et al. (2008): mainly based on qualitative information	Indicators for which no quantitative data are available

[a] The classification refers to research approaches as presented in Bouma (1997) and Stoorvogel and Antle (2001). Qualitative methods refer to stakeholder and expert knowledge, while quantitative methods refer to data analysis and modelling. Empirical methods are based on data analysis, while mechanistic methods are based on process-based models.

SD dimension	Land Use Functions	Indicator	Unit	2008 BASE	
Environmental	Abiotic resources	Fertilizer K/N ratio	kg K/kg N	0.20	+
	Biotic resources	N input	kg N/ha	634	–
	Ecosystem processes	Nitrogen leaching	kg N/ha	133	–
Economic	Land-based production	Rice + wheat yield	tons/ha	12.0	+
	Economic production	Net income	yuan/ha	8607	+
	Industry & services	Input costs	yuan/ha	11543	+
Social	Provision of livelihood	Labour use	days/ha	258	–
	Human health	Biocide index	-	641	–
	Food security	Rice yield	tons/ha	7.0	+

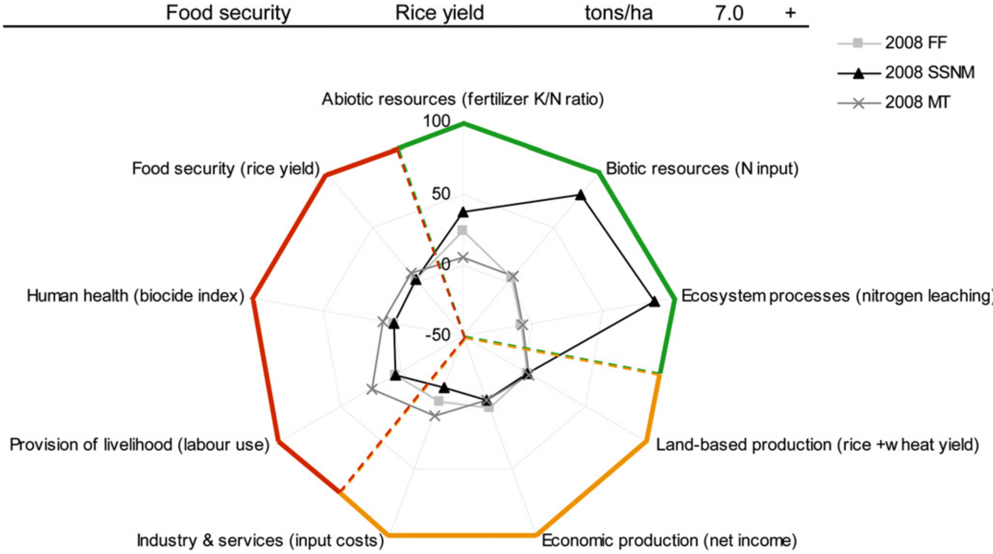

Fig. 6. Modelling results for 9 indicators linked to Land Use Functions for a conventional rice–wheat rotation on clay at field level using TechnoGIN in the base year (2008 BASE), and % change relative to 2008 BASE for the policy stimulating the use of formula fertilizer (2008 FF), the potential of a policy improving site-specific nutrient management (2008 SSNM), and the policy stimulating mechanical transplanting of rice (2008 MT). The +/– indicates whether an increase was considered positive or negative; accordingly an increase in the area of the spider diagram indicates a positive influence on SD. To show the different impacts on environmental (green), economic (yellow) and social (red) LUFs, these are distinguished by colour. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

SD dimension	Land Use Functions	Indicator	Unit	2015 BASE	
Environmental	Abiotic resources	Fertilizer K/N ratio	kg K/kg N	0.20	+
	Biotic resources	N input	kg N/ha	634	–
	Ecosystem processes	Nitrogen leaching	kg N/ha	133	–
Economic	Land-based production	Rice + wheat yield	tons/ha	12.9	+
	Economic production	Net income	yuan/ha	8939	+
	Industry & services	Input costs	yuan/ha	16916	+
Social	Provision of livelihood	Labour use	days/ha	263	–
	Human health	Biocide index	-	641	–
	Food security	Rice yield	tons/ha	7.3	+

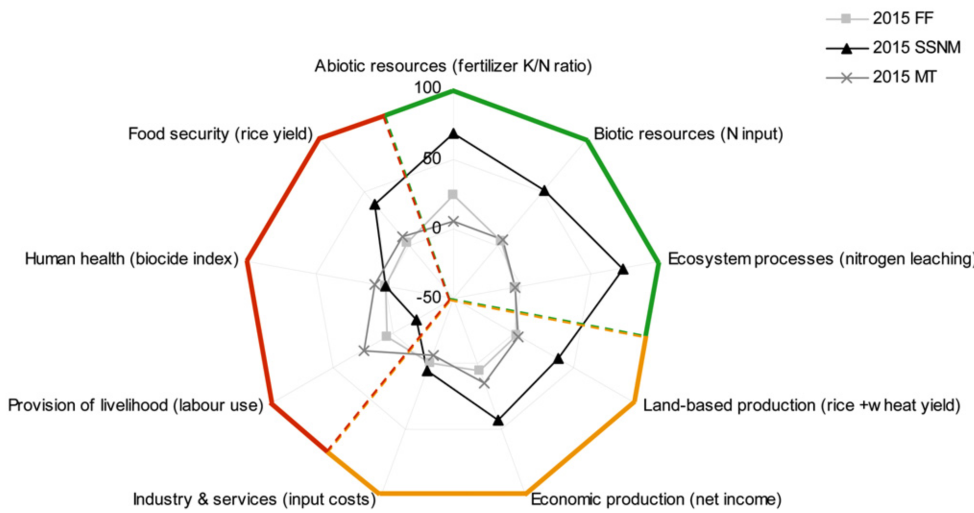

Fig. 7. Modelling results for 9 indicators linked to Land Use Functions forecasting baseline changes towards 2015 for a conventional rice–wheat rotation on clay at field level using TechnoGIN (2015 BASE), and % change relative to 2015 BASE for a continuation of the current policy stimulating the use of formula fertilizer (2015 FF), the potential of a policy improving training and education on site-specific nutrient management (2015 SSNM), and a policy completely subsidizing machinery for mechanical transplanting of rice (2015 MT). The +/− indicates whether an increase was considered positive or negative; accordingly an increase in the area of the spider diagram indicates a positive influence on SD. To show the different impacts on environmental (green), economic (yellow) and social (red) LUFs, these are distinguished by colour. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

increase in the area of the spider diagram indicates a positive influence on SD. Fig. 7 presents the projections towards 2015.

In Fig. 6 it can be observed that in 2008, farmers that were stimulated by the policy to apply formula fertilizers (FF) changed the K/N ratio of fertilizers, but they did not reduce total N input (farm survey data) and therefore N leaching was not reduced compared to the conventional application (simulated). The indicator for abiotic resources thus improved (contribution of N:P:K in fertilizers was more in line with what is needed considering the soil), but this was not associated with lower values of indicators representing biotic resources and ecosystem processes. With improved SSNM considering the same target yield, TechnoGIN shows that the contribution of K relative to N in fertilizers can be further increased (+38%), while total N, P and K input should be reduced, resulting in considerable lower impacts on the environment (80% less N input and 86% less N leaching). The impact of mechanical transplanting is mainly in the reduction of labour use, leaving more time for off-farm employment (or to improve nutrient management).

In the current situation, according to the farm survey data, on average 25% of the farms use formula fertilizer (FF) of which only a minor fraction applies it according to principles of SSNM, while 31% of the farmers use mechanical transplanting. The sustainability at farm and regional level depends on the results as presented in Fig. 6 and the degree to which a certain agricultural activity is adopted. Considering that rice–wheat on clay is the major agricultural activity, we can conclude that average indicator values at regional level are close to the ones presented for BASE 2008. The bio-economic farm model gives more details on diversity at farm type level (not shown).

The average net income of 8607 yuan/ha is more than the compensation payments for the buffer zones in Wuxi (6750 yuan/ha) and Changzhou (7500 yuan/ha), but lower than what farmers receive in Zhenjiang (9000 yuan/ha). Buffer zones are said to reduce N and P leaching with more than 80% (e.g., Klok et al., 2002) and are therefore effective to reduce water pollution, but whether the compensation payments cover the income loss of the farmers, depends on the municipality and the individual performance of the farmers.

When looking ahead towards 2015 (Fig. 7) for improved SSNM (2015 SSNM) rice yields can increase to 10 tons/ha. Higher crop yields require more N inputs (twice as much as 2008 SSNM, but still half of 2008 BASE), but as these will mainly be taken up by the crops, N leaching is low. The only negative impact is on labour use (i.e., more labour is required), reducing time available for off-farm employment. As mechanical transplanting reduces labour use, combining both technologies may be the best option having positive impacts on environmental and economic LUFs, and also being socially feasible for the farmers. However, for 2008 mechanical transplanting (2008 MT) results on average in less profit than hand transplanting (−2%, Fig. 6). With completely subsidizing machinery (2015 MT) net income can be increased (+20%, Fig. 7).

5.1.2. Land Use Function weights

Comparing indicator values and their trade-offs is one part of a multi-criteria analysis (MCA) (Saaty, 1980). A second part is to give weights to the different indicators/LUFs, given the preferences of stakeholders and expert knowledge. Normalizing LUFs and aggregating them using weights defined by stakeholders, summarizes multiple indicators into single scores, thereby indicating which scenario scores best. It can be argued that all LUFs should have the same weight, but the different preferences of stakeholders can influence the feasibility of a policy option to be implemented. Researchers, government officials, extension officers and farmers in Taihu Basin discussed the SD dimensions, considering the LUFs and associated indicators, and attributed weights for their importance in the region. Although the weights of the three dimensions were similar, different stakeholders had different views on the importance. Summarized, according to researchers the ranking was social (36%) > economic (33%) > environmental (31%); government officials and local extension officers thought that the sequence should be economic (50% and 45%) > environmental (33% and 35%) > social (17% and 20%); and according to farmers it should be environmental (37%) > social (33%) > economic (30%). It showed that all stakeholders are aware of the multiple land use functions of agricultural land use, and that besides food production, also LUFs like provision of work and ecosystem processes are considered important. The high importance researchers gave to the social dimension was mainly due to the weight given to food security, which is important at regional level. For farmers, this is less important as they are not dependent on food produced on-farm. Farmers gave a high importance to the environmental dimension, which was largely due to weights given to the indicators biocide use and (aquatic) biodiversity. They were unaware of the impacts of their own management practices on nutrient leaching and did not consider N and P leaching important for (aquatic) biodiversity.

A full MCA is mainly interesting for discussions with stakeholders. It reveals the understanding of stakeholders on indicators and may improve this. Caution should however be taken with presenting results as scientific, as the reliability depends on this understanding, and the stakeholders selected. Furthermore, for deriving a single score per scenario, indicators should be normalized considering their targets and thresholds (Paracchini et al., 2011). These are generally difficult to establish. They can be based on policy targets, ecological thresholds, general trends and expert knowledge. Which value is considered as sustainable determines the normalized indicator and hence the importance for the SD evaluation. Nevertheless, as Rockström et al. (2009) argue, even though uncertain, especially for environmental indicators it is important to estimate the safe operating space, i.e., the thresholds between which we can operate. Although in 2015 SSNM the 74% decrease in nitrogen leaching may seem to have more impact than the 19% increase in labour requirements, the latter has more impact on SD at farm level and is hence a reason not to adopt SSNM (although environmental LUFs were given most weight, thresholds for social and economic LUFS often appear to be tight). If at regional level reducing nitrogen leaching is considered to be important for SD, policies are required that also consider labour requirements. Due to the uncertainty, we do not present a scientific exercise here, but will further discuss the indicator values, weights and targets and thresholds with stakeholders.

5.1.3. Effective and feasible policy options

Concluding on the effectiveness and feasibility of the policy options based on Figs. 5–7, we can write that creating buffer zones is an effective policy, as legal enforcement is high, effects on reducing N and P leaching to water bodies are high, and compensation payments are good compared to the average net income. Other indicators (Fig. 5) were not specifically assessed for this policy option, as these are all zero at the field level (i.e., in buffer zones there is no fertilizer, biocide and labour input, and no crop production). Legal enforcement is more difficult for changing technologies such as SSNM, which is exemplified by the 2008 FF scenario. More education and training is needed to optimize SSNM, which should be organized by farmers' associations and extension services, while legal enforcement may be improved by recording amount and timing of nutrient management as done in for example the Netherlands. Mechanical transplanting is not always profitable, so providing more subsidies would help farmers to use the machines. As it is important for the government to keep up rice production and in the meantime to reduce the rural-urban income gap, providing more subsidies seems to be a solution.

5.2. Documentation and communication

In communication with policy makers and other stakeholders, clear visualization and documentation of results as well as scenarios and associated assumptions are of major importance. Different ways of visualization are presented in this paper. A dataportal is used within the project to systematize and compare results across seven country-specific applications (http://lupis.cirad.fr/). Policy briefs have been distributed to disseminate the objectives and results of the project, during the national and the international policy forums, to the EC commission, and on other occasions. Stakeholders expressed interest in 'their own case', but also in the other cases within the same continent. Some country teams translated the briefs to national languages to promote reading for a larger group of people. The briefs were an important means to share information of problems and issues in a broad range of cases in Africa, Latin America and Asia along with the LUPIS framework for ex ante impact analysis of land use policies. Furthermore, national policy fora and stakeholder workshops have been specifically useful in discussing the steps throughout the process, and will continue to be important to present results and to have impact in the policy arena.

6. Discussion and conclusion

In Europe, ex ante IA studies boosted the scientific literature in recent years (e.g., Helming et al., 2008; Tscherning et al., 2008; Van Ittersum et al., 2008; Thiel, 2009), due to the introduction of the Impact Assessment (IA) Guidelines in the European Union (EC, 2005). Besides other objectives, these were introduced in order to make policy development more transparent and improve the quality of European policies (Bäcklund, 2009). In developing countries such incentives from policy makers are few, and hence impact assessments of policies are usually of ex post nature (e.g., Fan et al., 2008). Ex ante assessments in developing countries generally explore potential technological or policy options instead of forecasting the impacts of more immediate and feasible options (e.g., Van Ittersum et al., 1998; Van den Berg et al., 2007; Tittonell et al., 2009). The projections in this study had a short time horizon (2015) due to its relevance to the 5-year planning strategy adopted in China.

The roles of models in societal problem solving can be (i) heuristic, improving understanding; (ii) symbolic, putting an issue on the political agenda; and (iii) relational, creating a community (Sterk et al., 2009). Although the impact of models has been less than aimed for in many cases, positive effects on social learning, such as adapted problem definitions, direction setting, representation and management of boundaries and negotiation strategies, have been shown (Bouma et al., 2007; Pahl-Wostl et al., 2007). Involving policy makers and stakeholders throughout the modelling process is important to contextualize the modeling work, to create confidence in the work and to increase changes for the actual use of results (Sterk et al., 2011). In the LUPIS methodological framework the pre-modelling phase and the involvement of stakeholders have therefore received much attention.

Policies that are currently in place and relevant to the problem have been extensively evaluated (Bonin et al., 2009). In the Chinese case study, before the first national policy forum and the evaluation of policies, stimulating organic farming and green manure application were seen as attractive policy options, assuming that they reduce water pollution and other environmental impacts. It appeared however that due to the low fertilizer prices and off-farm employment, few farms cultivate organically and they are not interested in converting in the near future. Ex ante impact assessment was therefore shifted to options that are considered feasible in the near future.

Interaction with stakeholders in the modelling phase for the Chinese case was mainly related to consultation on inputs and outputs of the models, including parameters, constraints and objectives. In many developing countries, data are lacking to parameterize process-based models. In several case studies of the project, we therefore applied the Framework for Participatory Impact Assessment (FoPIA; Morris et al., 2008), among which Indonesia (König et al., 2010), in which the whole methodological framework is followed and a qualitative impact assessment is done based on the expert knowledge of stakeholders. FoPIA does not substitute a quantitative analysis, but it provides a good starting point to guide for the most intriguing sustainability problems and can be used as a qualitative impact assessment tool where quantitative approaches and models fail (e.g., in the case of poor data availability, cross-disciplinary knowledge integration, stakeholder participation). Exercises in LUPIS using multi-criteria analysis to assess the impact of climate change on sustainable development in the case studies in Mali and Brazil (Verburg et al., 2009) also show that qualitative approaches can improve understanding among scientists and stakeholders. The use of LUFs in sustainable development evaluation helps to understand the importance of land use for sustainable development and to stimulate discussions among stakeholders. Methods have been developed to aggregate multiple indicators into LUFs (Paracchini et al., 2011), but as this can be complex and less transparent, in this paper we chose to select one indicator per LUF. Although these indicators may not completely represent the full sustainability picture, understanding and comparing 9 indicators is already much, both for decision-makers and other stakeholders, and for researchers. When well selected, 9 indicators should be sufficient.

The assessment of policy options regarding site-specific nutrient management, mechanical transplanting for rice and buffer zones, show that it is feasible to simultaneously increase food production, increase net income and reduce impacts on the environment; main indicators related to the Millennium Development Goals and to Chinese policy documents. The methodological framework has proven useful in structuring and performing a sustainability impact assessment of land use policies (McNeill et al., 2011). It has been applied in six other LUPIS case studies with different land use problems, SD targets and modelling tools. Although the case studies diverge enormously in nature of local issues that are studied (e.g., agrarian crisis leading to suicides in India, land degradation and poverty in arid regions in Tunisia; www.lupis.eu), the flexibility of the framework has allowed applying it for different situations and its generic feature facilitates comparisons between case studies.

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