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# Ethical aspects in the economic modeling of water policy options

ABSTRACT

*Model-based ecological-economic studies on water management can be a valuable source of information for policy decisions on water-related issues; however, disputable normative assumptions may be involved. Deliberately or unintentionally, such assumptions can make these studies policy-prescriptive. Using the conceptual design of a spatially explicit agro-economic model as an example, this article introduces and employs a framework for analyzing normative assumptions in applied economic studies to increase transparency. We argue that the many value-laden issues identified in the studies cannot be - and should not be - avoided. Instead, if used properly and transparently, they can increase the policy-relevance and usability of model-based studies without being policy-prescriptive or "subjective." This requires analyzing and comparing the practical consequences of alternative policy goals or other value-laden assumptions. Therefore, this article secondly demonstrates, through an example, how researchers can deal more constructively with normative assumptions; our model calculations indicate different consequences of alternative ethical assumptions on how water-intensive agricultural products could be globally distributed. Finally, we argue that applied economic studies can improve their coverage of the ethical aspects of water policy, including (1) social equity, (2) inter-generational justice and (3) ecological sustainability.*

Keywords:

Normative assumption, Agro-economic model, Policy analysis, Water management

## 1 Introduction: Policy-relevance without policy-prescription?

Agriculture has a significant impact on freshwater resources; 70% of global withdrawals are used for irrigated agriculture (Molden 2007). The growing population, changing consumption patterns (Pingali 2007), climate change and economic growth will most likely increase pressure on water resources for agricultural production in the future (Rosegrant and Sombilla 1997, Vörösmarty 2000, Gerten et al. 2011). Water policy options in the context of agricultural production include the enhancement of (i) water-use efficiency in irrigated and rain-fed systems, (ii) overall agricultural productivity, (iii) water infrastructure and access, and (iv) trade for better allocation of agricultural production. Being well informed about the policy options at stake, as well as their possible practical consequences including costs, risks and trade-offs, is decisive for responsible policy decisions in this field.

Regarding the high complexity, trade-offs and socioeconomic importance of the future scarcity of water resources in the context of agricultural production, quantitative scientific analyses (e.g., Fader et al. 2013) are valuable for policy-making in this field. Advanced tools for such policy-relevant analyses are models that integrate biophysical, agricultural and economic systems in a single framework (e.g., Hertel 1998, Rosegrant et al. 2001, Lotze-Campen et al. 2008, and Havlik et al. 2011). Such models can be helpful for better understanding possible future developments of regional water scarcities, as well as their drivers and consequences, and for directly evaluating different water management options to tackle these scarcities on different scales. This is why science should aim to achieve policy-relevance, in the sense of providing scientific expertise that informs the discussion on public policy priorities and options.

However, there are considerable perils and pitfalls. In particular, non-transparent normative assumptions in model-based applied economic studies may - usually unintentionally by scientists - lead to the misguided political use of expertise. Sometimes, experts even deliberately act as “stealth advocates” for particular policy options through their studies (Pielke 2007). Under the guise of allegedly value-free facts, experts can impose, deliberately or unintentionally, their ethical values or interests on others by being policy-prescriptive in a concealed manner (Jasanoff 1990, Schneider 1997, Sarewitz 2004, Pielke 2007, Douglas 2009, Ackerman et al. 2009). In the case of water management, many controversial ethical values and sectional interests are advocated for by various stakeholders through their political standpoints (Armstrong 2006), even though most players would probably agree on the central, yet unspecified, goal of reducing water scarcity. To mention just a few examples, some advocate for economic welfare maximization, while others emphasize liberty rights, social equity and the integrity of the environment. Thus, the perils of non-transparent biases towards particular viewpoints in scientific studies for policy are obvious from a democratic point of view.

Cash et al. (2003) argue that, due to the value-ladenness of policy issues, researchers often make trade-offs between (a) achieving valuable policy relevance and (b) being politically unbiased, which suggests that the latter is easier to achieve when scientists focus on “pure” science rather than policy analyses. Yet, even when scientists do not intend to inform policies through their publications, public officials might be aware of these publications, and articles frequently find their way into large-scale scientific assessments for policy (WWAP 2012, UNEP 2012, IPCC 2007, etc.) where they become politically relevant. Moreover, “pure science” can sometimes imply ethical values and can quickly lose political innocence and neutrality as many studies show (e.g., Pielke 2007, Putnam 2004, Douglas 2009).

With that said, making disputed ethical assumptions transparent is certainly among the minimum and widely accepted requirements for scientific studies (van der Sluijs 2002, Pielke 2007, Ackerman et al. 2009, Kloprogge et al. 2011, Hall 2011). Although there is much literature on the ethical aspects of economic models (e.g., Streeten 1950, Sen 1988, Schneider 1997, Hausman and McPherson 2006, Hof et al. 2008, Peil and van Staveren 2009, Beckerman 2011, Putnam and Walsh 2012) and on the policy-relevance of applied economic models and scenarios in general (e.g., White et al. 2010, M'barek 2012), considerable research gaps still exist. First, specific normative assumptions in water-related ecological-economic models are rarely identified and discussed in the literature, also because there is a lack of an appropriate conceptual framework to identify value-related biases. Kloprogge et al. (2011) present a convincing framework to identify, review and prioritize value-laden assumptions in model-based environmental assessments jointly with stakeholders and the public, and Robert and Zeckhauser (2011) provide a useful taxonomy of disagreement at the science-policy interface. These helpful frameworks can, however, be enhanced by a typology of normative assumptions that is systematically based on the philosophy of science; some relevant normative assumptions might otherwise be missed both in the large-scale assessment processes and the underlying model-based studies.

Second, beyond the need for transparency and public participation in scientific knowledge production (e.g., Maasen and Weingart 2005), it is still unclear for many researchers how they can deal more precisely with and make legitimate use of value-laden issues in applied economic modeling in order to overcome the trade-off between policy-relevance and politically unbiased research (Cash et al. 2003). This may also be due to a fundamental philosophical confusion about the nature and treatment of normative issues in scientific research (Hands 2001, Putnam 2004, Douglas 2009).

Based on these two interrelated research gaps, the dual goal of this paper is first to help avoid the pitfalls of concealed policy-prescription and ethical bias in model-based ecological-economic analyses of water policy options. For this, we introduce a novel framework and typology that facilitates increased transparency of normative assumptions there. At the same time, we also aim to enhance the valuable political and societal potential of such model-based studies by proposing a strategy for dealing with normative assumptions based on recent findings in the science-policy literature, thus addressing the second research gap identified above. Both the typology and the strategy of normative assumptions will be systematically explored and exemplified in this article using the land- and water-use model MAgPIE.

The purpose of this paper is neither to criticize MAgPIE or similar models (rather, their socio-political utility shall be enhanced), nor to discuss the appropriateness of individual normative assumptions. Instead, we aim to provide a useful method for researchers to better identify and more constructively deal with normative assumptions in their studies.

# 2 The MAgPIE model and its relevance to water policy

## 2.1 MAgPIE model description

This article uses the Model of Agricultural Production and its Impact on the Environment (MAgPIE), an agroeconomic model, to exemplify both the identification and the improved treatment of normative assumptions in such models. MAgPIE is a global, spatially explicit, economic land and water use model that solves in a recursive dynamic mode (Lotze-Campen et al. 2008) (a flow-chart of the model can be found in the Appendix (*Figure 2*)).

The model distinguishes between 10 world regions on the demand side and solves grid-specific (aggregated units of 0.5 degree resolution) on the supply side. With income and population projections (based on van Vuuren et al. 2009) as exogenous inputs, required demand is projected for the future.
The model simulates time steps of 10 years and uses the optimal land-use pattern from the previous period as the initial condition. On the biophysical side, the model is linked to the grid-based dynamic

vegetation model LPJmL (Bondeau et al. 2007) which simulates potential crop yields depending on climatic conditions on a 0.5 degree resolution. LPJmL also transfers information, such as water availability and requirements per grid cell and crop type, to MAgPIE; based on this, the model can calculate spatial patterns of agricultural production.

The objective function of MAgPIE is to minimize global costs, which include production costs for agricultural commodities, technological change costs and land expansion costs. Production costs are derived from the GTAP database (Narayanan and Walmsley 2012). The endogenous implementation of technological change (TC) is based on a surrogate measure for agricultural land-use intensity (see details in Dietrich et al. (2012)). Expanding croplands is the alternative to increasing the production level. The expansion involves land-conversion costs for every unit of cropland, which account for the preparation of new land and basic infrastructure investments (Krause et al. 2012). Land conversion costs are based on country-level marginal access costs generated by the Global Timber Model (GTM) (Sohngen et al. 2009).

To allocate the demand to supply regions, international trade is considered in MAgPIE by using flexible minimum self-sufficiency ratios at the regional level. Self-sufficiency ratios describe how much of the regional agricultural demand quantity is produced within a region (see details in Schmitz et al. 2012). A detailed representation of areas of blue water scarcity is possible through a spatially explicit representation of water supply and agricultural water demand for irrigation, using LPJmL. The simulated water shadow prices - which indicate how much global agricultural production costs would decrease if an additional unit of water was available - can be interpreted as an agro-economic water scarcity indicator that considers both economic forces and biophysical limitations in the agricultural system.

### 2.2 A MAgPIE-based study on water policy options

With MAgPIE and similar models, certain water policy options can be scientifically explored. Schmitz et al. (2013) have conducted a water-related, MAgPIE-based study which we will refer to below when analyzing normative assumptions. Schmitz et al. (2013) use MAgPIE to investigate the effects of potential future trade liberalization and of a potential change in global diets on local water scarcity. The authors compare a scenario where trade barriers are reduced by 10% per decade from 2015 until 2045 with a scenario where no additional trade liberalization takes place. Additionally, they look at the impacts of a less meat-intensive global diet, by assuming that every citizen on earth will derive only 20% of their daily calories from livestock-based products until 2045. To estimate the impact of these potential future changes on water scarcity, the authors use the MAgPIE-generated water shadow price.

When comparing a business as usual scenario to one with liberalized trade in 2045, the authors find that water scarcity is alleviated almost everywhere. This positive effect results from the possibility of water-scarce regions to import water intensive agricultural goods from places where water is less scarce; hence, the pressure on scarce water is reduced and the water shadow price decreases.

The study also finds that if the amount of livestock-based products in the global diet converges until 2045 and the total consumption of livestock-based products is reduced in such a way, water scarcity would be generally alleviated. Here, the effect can be explained by the relatively high necessary input of resources (such as water) for the production of a calorie of livestock products compared with the necessary input of resources for the production of a plant-based calorie.

# 3 Identifying and dealing with normative assumptions

### 3.1 Framework for making normative assumptions transparent

The transparency of normative assumptions in such or other model-based applied economic studies is important to avoid concealed policy-prescription. By normative assumptions in scientific studies, we mean ethical assumptions that tell us what to do (e.g., in public policy) or how to evaluate a certain situation or policy option. They can be ethical beliefs, cultural and social norms, or individual and sectional interests—or are at least based on them. Moreover, normative assumptions can occur in the form of policy objectives (i.e., policy ends). Like other model assumptions, virtually all normative assumptions in studies on water management options have implications for the key results of these studies. Hence, one-sided normative assumptions can influence the results and render these studies policy-prescriptive, in the broad sense that such studies indirectly prefer specific policies to others. Although other types of normative implications in scientific studies exist (e.g., epistemic and cognitive values, see Douglas 2009), the above type, on which we focus in this article, is the most disputed one at the science-policy interface. Key normative assumptions are often made transparent in applied economic studies. Yet, the framework and typology of normative assumptions, outlined in the following, may make researchers, policymakers and stakeholders more aware of other implied normative assumptions; they often fail to notice them, as this requires some interpretation. The normative bias in model-based studies is therefore mostly unintended.

We regard philosophical pragmatism in the tradition of John Dewey (Dewey 1986, 1988, Putnam 2004) as a particularly convincing methodological starting point for such a framework. Pragmatism is basically a theory of valuation; it is increasingly accepted among scholars (Khalil 2004).

Dewey's variant of pragmatism particularly offers two provoking hypotheses that are relevant to the framework aspired to in this paper: (1) Scientific findings are always and inevitably value-laden, and they very often include normative assumptions as defined above (Putnam 2004). (2) It is nonetheless possible to come to highly plausible or even objective, though always fallible statements—even on controversial, value-laden issues (Putnam 2004), such as competing water policy objectives. For Dewey, assessing disputed and value-laden policy objectives, and the means to achieve them, requires scrutinizing the whole range of relevant practical consequences of the means. With a focus on policy analysis, the following figure interprets and depicts this "ends-means rationality," as discussed in detail by Dewey (1986, 1988). This rationality has many implications for the identification of normative assumptions in applied economic studies.

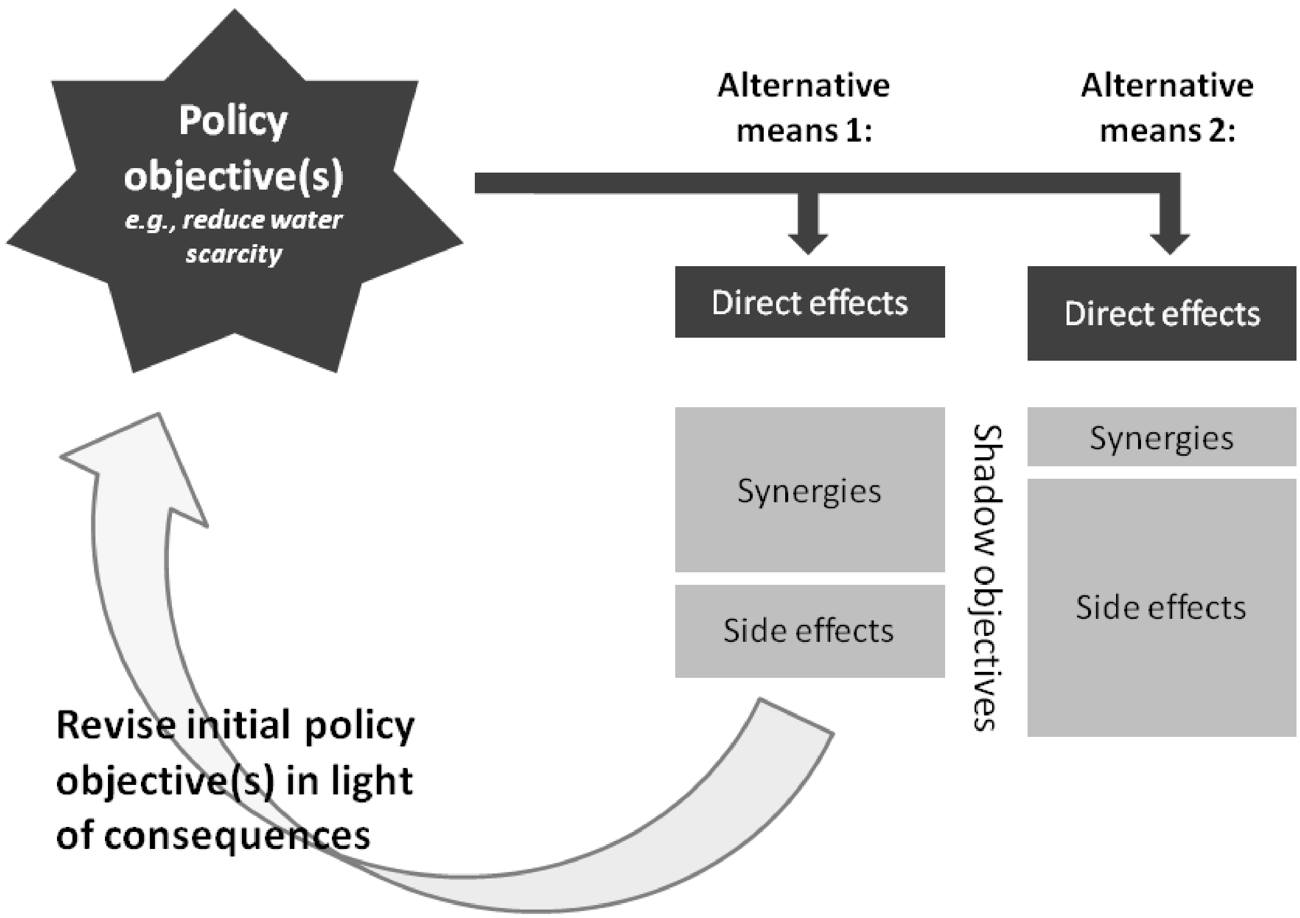


*Figure 1: Simplified scheme of evaluating policy means or policy objectives in light of the practical means-consequences. The star represents the initially given policy objectives (all related elements in dark gray). The dark gray arrows represent two different possible means that are supposed to achieve these objectives. The rectangles represent the various kinds of quantitative and qualitative practical consequences of the means (respectively) that are to be identified once possible means have been proposed. The rectangles' thickness indicate their weights; those in light gray are related to additional objectives, i.e. the shadow objectives. If it turns out that even the best available means (here: "alternative means 1") have severe side effects, the initial policy objectives have to be revised or abandoned.*

Think, for example, of reducing water scarcity in a particular region as a policy objective. Alternative means (i.e., policy instruments and measures) to this policy objective include trade liberalization, changing consumption patterns, etc. These alternative means have different kinds of practical consequences: First, there are the direct effects of the means, as determined by the policy objective (i.e., reducing or even increasing water scarcity). Second, there are (a) unwanted side effects (including risks and economic costs) and (b) desirable synergies. Both side effects and synergies are determined by "shadow objectives". In contrast to "policy objective(s)," we define "shadow objectives," which can also include general ethical values, as objectives that are relevant for society, but that are not being taken into account initially and explicitly in a particular model-based study (see Section 4 for examples). Third, there may be further practical consequences of the means, which are irrelevant, because they affect neither the given policy objective nor the existing shadow objectives.

The different practical consequences of the means obviously vary in their strengths and ethical weights (i.e., welfare units), which are hypothetically indicated in a highly simplified manner by the thickness of the rectangles that represent the consequences in Figure 1. Comparing the total outcomes, the “alternative means 1” seem more appropriate in this example, although the “direct effects” are stronger (i.e., thicker rectangle) with “alternative means 2,” because of the higher synergies and lower side effects.

Yet, the crucial point is that if the best available means to given policy objectives have severe side effects, then the initial policy objectives would have to be revised and completed with the identified shadow objectives. In extreme cases, they may even have to be abandoned. Hence, this ends-means rationality implies that policy objectives cannot be evaluated a priori, but only by assessing the expected or actual practical consequences of their means. In contrast to most types of cost-benefit analysis, the objectives and related evaluative criteria are not to be regarded as fixed (instead, they need to be revised if there are severe side effects) and the full range of practical consequences is to be assessed, including the non-quantifiable consequences. This interdependency between objectives, means and their various consequences is the main characteristic of the pragmatist ends-means rationality and is highly relevant for the analysis of normative assumptions.

This general ends-means rationality reflects widespread common sense rationality that is often employed in daily life (Dewey 1988). It should sensitize us to the fact that not only assumed (policy) objectives, constraints and the related, explicit evaluative criteria could render scientific studies policy-prescriptive. Rather, analyses of policy means and their practical consequences could also easily result in policy-prescription, given the ends-means rationality. A rough typology of normative assumptions can be developed based on the pragmatist ends-means rationality; it will become clearer through the examples in Section 4. Thus, the typical kinds of normative assumptions directly given or implied in ecological-economic studies and particularly in the underlying models are:

1. Directly (explicitly or implicitly) suggested policy objectives, or more general ethical values and goals;

2. Normative assumptions about policy means and policy objectives through the (sometimes implicit) evaluation of means and their consequences;

3. Implied normative assumptions through the treatment of model simplifications, uncertainties and ambiguities regarding hypotheses on policy objectives, means or consequences.

The first type includes most of the examples presented in the literature on normative assumptions in economics. This type mainly refers to normative assumptions (a) given in the objective function of an economic model and its basic constraints or (b) in particular policy objectives or constraints assumed by scenarios. Even if a study does not value policy objectives explicitly, the sheer “descriptive” scientific analysis of a particular policy objective can give this objective some political weight (Schattschneider, 1960), if at the same time being tacit about alternative policy objectives. Furthermore, as often missed in the literature, problem definitions (e.g., “water scarcity”) and other guiding concepts used in the study (e.g., “efficiency”) can also have (intended or unintended) normative implications of this first kind.

The second type includes normative assumptions in scientific studies related to statements on policy means and their consequences. Such statements are often regarded as value-neutral. However, if a study finds that certain means are appropriate (or inappropriate) for a given policy objective, then it may indirectly suggest that the related policy objective is desirable (or undesirable) as well, according to the ends-means rationality explained above. This could become policy-prescriptive, particularly when promising alternative means are tacitly omitted, or when the study fails to evaluate adequately the full range of practical consequences of the given means, including all relevant effects regarding the many shadow objectives in a given society. Moreover, the policy-relevant description of practical means-consequences (i.e., costs, risks, benefits, etc.) always requires value-laden concepts (Putnam 2004; Douglas 2009). Furthermore, similar to the argument made for the first type, merely mentioning certain means and the omission of relevant alternatives may, as such, create bias towards certain policy means.

While for the two previous types of normative assumptions the scope of the addressed policy objectives, means and their consequences is decisive, the third type is about the scientific quality of the hypotheses of applied economic studies regarding the policy objectives, means or practical consequences. Thus, this type is about (a) model simplifications, (b) uncertainty (in both the results and the choice of methods, data or theoretical assumptions) and (c) ambiguities in the interpretation of the results. Much has been written about scientific uncertainties (e.g., van der Sluijs 2010). The point here is not that uncertainties, model limitations and ambiguities are normative assumptions as such, but rather that their treatment in scientific studies often requires value-laden choices that can have a considerable impact on the evaluation of policy objectives or means. If these crosscutting issues are concealed and only one possible interpretation is presented, a study's conclusions regarding policy objectives, means and consequences may become policy-prescriptive.

### 3.2 The constructive treatment of normative assumptions in applied economic studies

For model-based applied economic studies, the above framework and typology will help increase transparency of the - virtually unavoidable - normative assumptions. Yet, transparency alone, although crucial and indispensable from a democratic perspective, cannot avoid the possible policy-prescription of such studies; transparency can only reveal and defang policy-prescription while the normative assumptions are still there. The question remains how researchers—beyond transparency—can constructively deal with normative assumptions, i.e. how they can reduce policy-prescription in such studies, while effectively informing water policy-making, without cuts in scientific credibility (see Cash et al. 2003 for a justification of these criteria). Our response to this question builds on an approach that further elaborates the pragmatist ends-means rationality outlined above and that was developed by Edenhofer and Kowarsch (submitted); we will only point out the basic idea here and apply it to model-based ecological-economic studies on water management.

This approach claims that the exploration and presentation of several *alternative* policy objectives or other normative assumptions reduces policy-prescription in scientific studies, although still normative assumptions are involved. Moreover, if also the various practical consequences of these alternative normative assumptions are explored in an interdisciplinary manner, high policy-relevance can be achieved and social learning about these disputed issues can be facilitated (Edenhofer and Kowarsch, submitted). Although, according to pragmatism (Dewey 1986, 1988), the best policy objectives and means could theoretically be determined through comparing the practical consequences of alternative ends-means combinations, high uncertainty and complexity exist in practice and make objective scientific statements on these policy issues frequently impossible. This is why policy alternatives and their practical consequences should be explored and presented, also in order to let policymakers - rather than scientific experts - make the political decisions. Obviously, however, not every normative assumption in an applied economic study and not all possible policy objectives or means can be subject to a full analysis of practical consequences - reasonable choices have to be made. A single study can only explore a very small part of the full political solution space. Policy-prescription can, thus, be further reduced and policy-relevance can be increased through a dialogue with stakeholders and the public on which relevant alternative policy objectives, values, etc. to select for the analyses, particularly in scientific assessments (for a discussion of stakeholder engagement see Callon, 1999; Durant, 1999; Scoones, 2009; Renn, 2009).

Figure 2 expands on Figure 1, which only assumed one initial set of policy objectives. In a simplified manner, it depicts the idea of exploring the full political solution space by critically comparing the practical consequences of the means to achieve alternative sets of policy objectives (and other normative assumptions) - allowing for a rational discourse about normative assumptions:

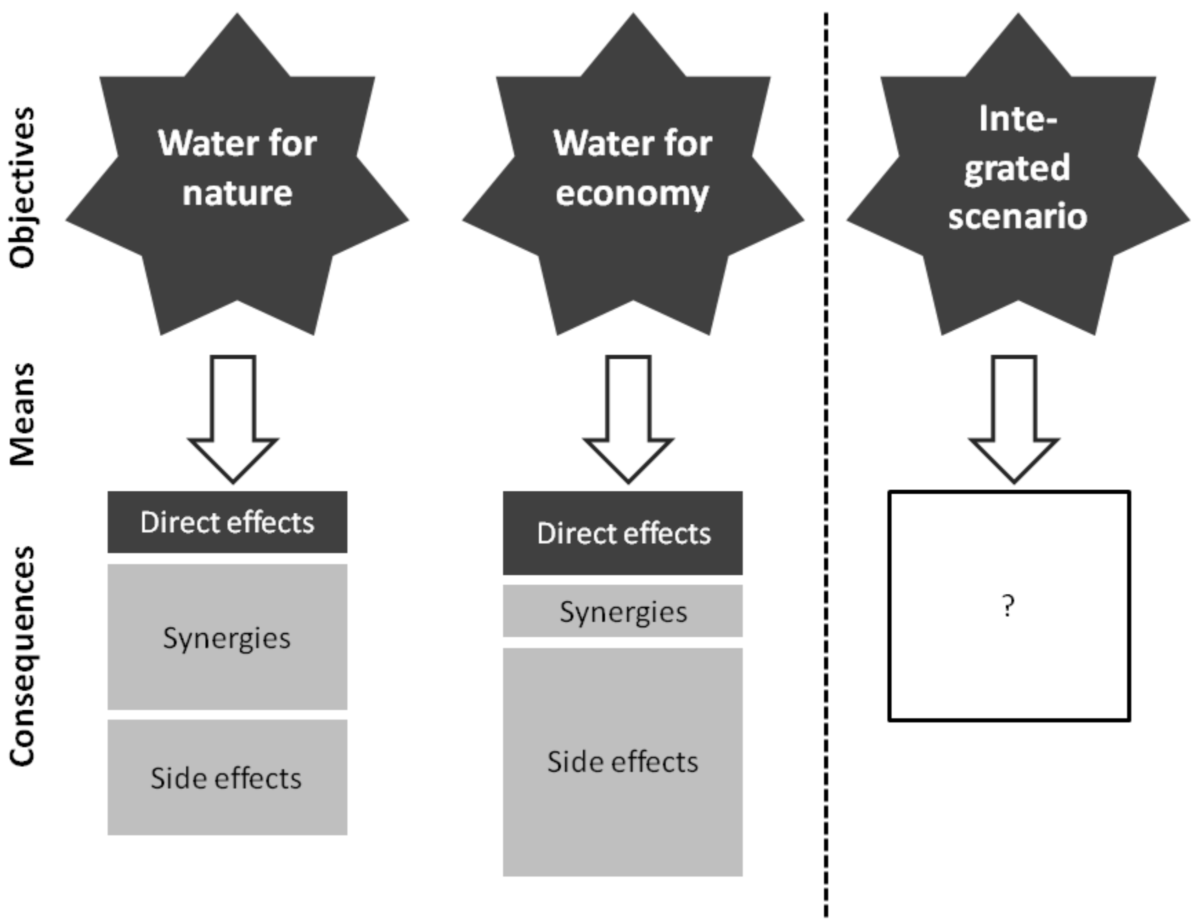


*Figure 2: Scheme for a fruitful and constructive treatment of normative assumptions in terms of comparing alternative policy objectives (as an example for normative assumptions) via the various consequences of the best available means. The figure indicates the analysis and comparison of two competing water policy objectives ("water for nature" and "water for economy") in terms of their practical means-consequences, also to better understand where trade-offs occur more precisely. Beyond that, the challenge is to develop a scenario (i.e., the "integrated scenario") for a policy pathway that takes several policy objectives and shadow objectives into account, while creating strong overlap (i.e., no-regret options) between the competing policy pathways through multi-functional, well-*

*designed means.*

Instead of denying normative assumptions in science or endless disputes about abstract values, the here proposed approach allows for a more constructive treatment of controversial normative assumptions in applied economic studies. Scientifically exploring and comparing the practical consequences of disputed normative assumptions, such as policy objectives, can enlighten and inform public discourses; it may result in a revision and enhancement of the normative assumptions. As an example, think of the competing water policy objectives: (1) maximum water usage for economic growth ("water for economy") and (2) very strict protection of water resources for ecological reasons ("water for nature"). The trade-offs may become clearer and solutions can be identified more easily if the practical consequences of these normative assumptions are explored thoroughly. Yet, if possible, it would be most useful if researchers could also develop scenarios for a policy pathway that includes several objectives and creates strong overlap between the competing policy pathways through multi-functional, well-designed means.

This exercise of comparing and evaluating the practical consequences of alternative policy objectives or more general social values will be called an "ethical sensitivity analysis" in this paper. Transforming shadow objectives into thoroughly analyzed, alternative policy objectives is one possibility (among others) for how a scientific comparison of value-laden issues can provide valuable information to policymakers. The public would then be considerably more enlightened about future policy paths and their various practical consequences.

# 4 Results: Normative assumptions in MAgPIE and the exploration of policy alternatives

We are now prepared to demonstrate the identification (Sections 4.1 - 4.3) and the more constructive treatment (Section 4.4) of normative assumptions in model-based applied economic studies, using MAgPIE.

## 4.1 The Normative assumptions in terms of policy objectives

Many normative assumptions of the first type explained above (Section 3.1) are often made transparent in model-based applied economic studies because they are relatively obvious. Yet, to clarify the meaning and the broad scope of this first type, we will provide some examples to increase transparency even more.

At the core of MAgPIE lies an objective function that minimizes the costs of producing agricultural goods and is subject to many constraints. The goal function, together with the minimum constraint of global agricultural production, is responsible for fulfilling the two central policy objectives implied in the model: (1) producing a pre-defined global demand for agricultural goods and (2) doing this at minimum costs. Even if one argues that MAgPIE's objective function merely attempts to describe the actual behavior of players in the real world, this can be misinterpreted by policymakers in normative terms.

The model treats the value of feeding the world as even more important than minimizing production costs, which implies the ethical judgment that food security should have the highest political priority. Put differently, providing every person with food now and in the future is formulated as an a priori goal to be fulfilled at any cost and for every scenario. However, the amount of food provided differs, as the model's exogenously given calorie demand is different for each of the ten world regions and at various points in time. Calorie demand increases over time depending on the specific regional developments of diets in the past and on projections for regional income in the future (Bodirsky et. al, submitted). This assumption leads to the continued unequal global distribution of calorie consumption in the future. Although this assumption can be justified by the assertion that global distribution patterns will likely remain as they are now, it implies that the world's calorie distribution is not regarded as ethically problematic.

The general assumptions about population and income (measured as GDP) predetermine the global food demand in the model. Although relatively realistic, these status quo-related assumptions have normative implications that are similar to the assumption of unequal future calorie distribution, in the sense that they suggest there will not be any ambitious population policy nor any economic de-growth policies.

Minimizing global production costs is a second policy end implied in the model. An important ethical aspect of this is the value to be optimized. In economic models, this value is often monetary costs (as in MAgPIE) or utility (as in welfare-maximizing models). Yet, one could theoretically also optimize all the other variables considered in the model - e.g., water scarcity (interpreted as the relation between water withdrawal and water availability), the water shadow price or the use of additional land for agriculture in MAgPIE.

Indirectly suggesting that everyone follows the same rationality (such as cost minimization) is a very strong and controversial assumption (e.g., Beckerman 2011, Rodriguez-Sickert et al. 2009, Hands 2001). This is especially true for reflecting on a mainly local problem such as water scarcity, because its solution often also depends on specific socio-cultural conditions which differ a lot between regions. The ethical relevance of this assumption is not only that it suggests that players *actually* behave according to this rationality, but there is also a (often unintended) normative implication that people *should* strive for the particular rationality (Hands 2001).

Moreover, cost minimization implies that the *aggregated* costs for all producers are decisive ethically, instead of, for instance, trying to minimize costs for a particular (e.g., very poor) group of producers. This ethical judgment seems to stem from classical utilitarianism, where aggregated utility counts more than, e.g., the equal distribution of utility among individuals (e.g., Bentham 1907).

Besides the core policy objectives in MAgPIE's goal function, also envisaging certain model outputs can imply normative policy ends. For example, the calculation of local water shadow prices with MAgPIE implies that water scarcity is regarded as ethically problematic, because irrigation water for agricultural production is assumed to be limited in the model and its usage can lead to water scarcity at the local level.

In addition to the policy ends implied in the model *structure*, model-based studies often add further normative assumptions. An example is Schmitz et al. (2013) where the policy end of reducing water scarcity is *explicitly* analyzed. However, there are different possible definitions of water scarcity which should be made transparent. Schmitz et al. (2013) identified water scarcity using the water shadow price. Falkenmark (1989) investigated water scarcity using per capita water availability. Smathkin et al. (2004) examined the water requirements for sustaining a certain ecological system. The normative character of defining a problem such as water scarcity is obvious, as any definition values (explicitly or implicitly) different possible uses of water (see the ethical discussions in Brown and Smith 2010).

### 4.2 Normative assumptions implied in the evaluation of policy means

International trade of agricultural goods with differing degrees of trade liberalization is one of the two means examined by Schmitz et al. (2013) to achieve the policy end of alleviating global water scarcity. However, besides the analyzed direct effects, these means can also have unwanted side effects which were not analyzed by Schmitz et al. because they had to focus. However, these side effects could have a significant influence on the appraisal of the means and the ends in question. Therefore, Schmitz et al. provide a good example for how such studies can imply normative assumptions of the second type, which are typically less obvious and not always made transparent.

Potential side effects of liberalized agricultural trade could include an undesired change in land-use patterns and an increase in greenhouse gas emissions. Van Meijl (2006), Eickhout (2009) and Schmitz (2012) show that trade liberalization without special forest protection leads to additional deforestation in developing countries, especially in the ecologically sensitive tropical rainforest, which again has strong implications for the concentration of greenhouse gases in the atmosphere. In addition to the environment, global and national economies are also affected by trade liberalization. While the literature seems to confirm that more liberalized trade has synergies for the global economy (Hertel et al. 2007) and that the pressure on global food prices will decrease (Schmitz 2012 , Federico 2005), the impact on developing countries is unclear. Some authors argue that trade liberalization will worsen the economic situation in poor countries without additional adjustments (e.g., Bouët 2004, Panagariya 2005), while others say, freer trade may improve economic prosperity in poor regions (Anderson 1993, Martin and Winters 1996).

The second means considered in the study by Schmitz et al. (2013) is the change in global livestock consumption. Since this assumption implies that most people will eat less meat, the synergies of this means include health benefits for people (Pimentel and Pimentel 2003). These and many other possible side effects and synergies are related to shadow ends, which were not analyzed by Schmitz et al. (2013). A full evaluation of the assumed policy objectives, however, would require taking the full range of relevant means-consequences into account. This needs to be made transparent.

In addition to making the unintended side effects and the synergies of policy means transparent, it is also crucial that scientific studies highlight the existence of alternative means to achieve policy objective(s). Alternative means to reduce water scarcity in the context of the study by Schmitz et al. (2013) can include investments in water-related technologies, efficiency improvements in agricultural production and irrigation, and education on water use (WWAP 2009). Comparing these alternative means in terms of their practical consequences with the practical consequences of trade liberalization and changing consumption patterns (i.e., the two means analyzed in Schmitz et al. 2013) may change one's opinion about the adequacy and ranking of the means in question.

### 4.3 The treatment of model simplifications and uncertainties

The sections above suggested that it is clear what the practical consequences of means could be and only discussed whether they were made transparent or not. However, scientific models and their results are prone to: (1) simplifications due to the complexity of real world processes; (2) uncertainties due to our limited knowledge of the world; and (3) ambiguous interpretations of the results.

The third type of normative assumptions is difficult to analyze because there is a high number of such simplified, uncertain or ambiguous assumptions in the models and virtually *every* assumption influences the results. Thus, we will limit ourselves to (1) model simplifications and (2) some uncertainties in the model structure. We will examine these in terms of water scarcity.

The economic units in MAgPIE are reduced to ten world regions due to data limitations and to make the model computationally feasible. One consequence is that there are no trade barriers within regions. Therefore, trade volumes are overestimated as long as national trade barriers exist. Since trade barriers influence local water scarcity (as shown in Schmitz et al. 2013), this simplification influences the model results regarding water scarcity.

Aggregating all countries into ten economic world regions also implies that all country-based economic input information, such as factor costs, GDP and population scenarios, have to be aggregated at the regional level. Consequently, the economic differences between the countries in each region are averaged out. This affects the model results regarding local water scarcity because water-related technological developments such as drip water irrigation, dams, rainwater harvesting and desalinization, which reduce water scarcity, depend on a country's economic development. For example, while Israel uses advanced irrigation techniques and reuses a large part of its wastewater, neighboring countries in the same region are still behind on implementing such water-saving techniques (Bakir 2001, Friedler 2001).

The examples above show how simplifications can distort model output; we will now discuss the consequences of some uncertainties in the model assumptions.

Agricultural yield is one of the determinants of water consumption and, hence, water scarcity. Since the limits of plant growth is a controversial issue and is highly uncertain (Dietrich et al. 2012, van Ittersum 1997), the indirect limit to yield growth—implemented through a factor in the yield growth function, which leads to exponentially rising production costs—may result in an inaccurate estimation of production, thus influencing the level of water scarcity.

The actual prices for irrigation water are similarly problematic. Since there is hardly any valid data on observed prices (Berbel 2007) and since they certainly vary among countries, they are provisionally set to zero in the model (while shadow prices are computed). Prices are an important factor for water consumption in the real world; therefore, the lack of costs can lead to an over-simulation of water use and, thus, an overestimation of local water scarcity.

Global data sets are always afflicted with uncertainty. As an example, data on the water productivity of crops are provided for each crop on a 0.5 grid basis. These data are model outputs from the biophysical model, LPJmL, where the specific water productivity is calculated for each crop and grid based on climatic conditions (precipitation, radiation and temperature) and soil (Bondeau 2007). Uncertainties in these data affect model outputs, such as water consumption and water scarcity, but cannot be avoided.

All of these examples might distort policymakers' opinions about the suitability of certain water policy ends or means.

### 4.4 Dealing with normative assumptions: The example of future food distribution

This section provides an example of how to deal with *other* conflicting value-laden issues - besides the initial water-related objectives in a model-based study. The example is the comparison between two different assumptions about future global food distribution and their practical implications. This example illustrates (1) that normative assumptions can have a high impact on model results and (2) what a single paper's contribution to an exploration of the full political solution space of water policy (see Section 3.2) could look like more specifically. It is important to note that the ethical sensitivity analysis introduced here lacks a comprehensive analysis of the implied normative assumptions (e.g., side effects of the assumed policy means) because its only purpose here is to sketch how a full-fledged ethical sensitivity analysis could be conducted.

What and how much people eat influences their environments and societies because the extent of agricultural production is closely related to the usage of land, water and food prices. This is why exogenous model assumptions about the amount and composition of human food intake matters. The future demands for food and livestock in each of MAgPIE’s ten world regions are developed according to a historical functional relationship between GDP and demand (Bodirsky et al. submitted, Valin et al. 2014, see section. 2.1). For our ethical sensitivity analysis, we construct a scenario where political actions regarding food waste management and health education in developed countries, as well as political decisions taken to provide a sufficient amount of food in developing countries, will lead to a globally equal diet of 2600 kcal per day and person in 2045. Approximately 2200 kcal per day satisfies the metabolistic energy requirements of an average person (Smil 2000, Bodirsky et al. 2014) and the remaining 400 kcal are considered unavoidable waste. Additionally, we assume that the share of animal based calories in the globally equal diet will converge to 10% by 2045. We call this the “Equal diet scenario,” and the model default scenario with the calorie and livestock share development determined by the regional GDP growth is called the “Reference scenario.” As already argued above (Section 4.1), even this reference scenario can have normative implications.

The model results show that in the equal diet scenario in 2045, global crop production is about 40% lower than in the reference scenario, and global crop land decreases by approximately 10%. The release of pressure on agricultural systems through a global common diet also reduces global water scarcity (the average water shadow price decreases by almost 30%) and food prices (food price index is reduced by 15%) (see Table 1). This effect can be derived from the reduction in the direct demand for crops, as well as from the lower demand for crops as livestock feed.

*Table 1: Comparing the global impact of a globally equal diet scenario to a regionally differentiated reference diet in the year 2045 (WSP=Water shadow price, FPI=Food price index).*

| Scenario | Crop production (Exa Joule) | Crop area (mio ha) | WSP (US$/$m^3$) | FPI (1995=100) |
|---|---|---|---|---|
| Reference | 139 | 1768 | 0,0162 | 143 |
| Equal diet | 101 | 1604 | 0,0117 | 121 |

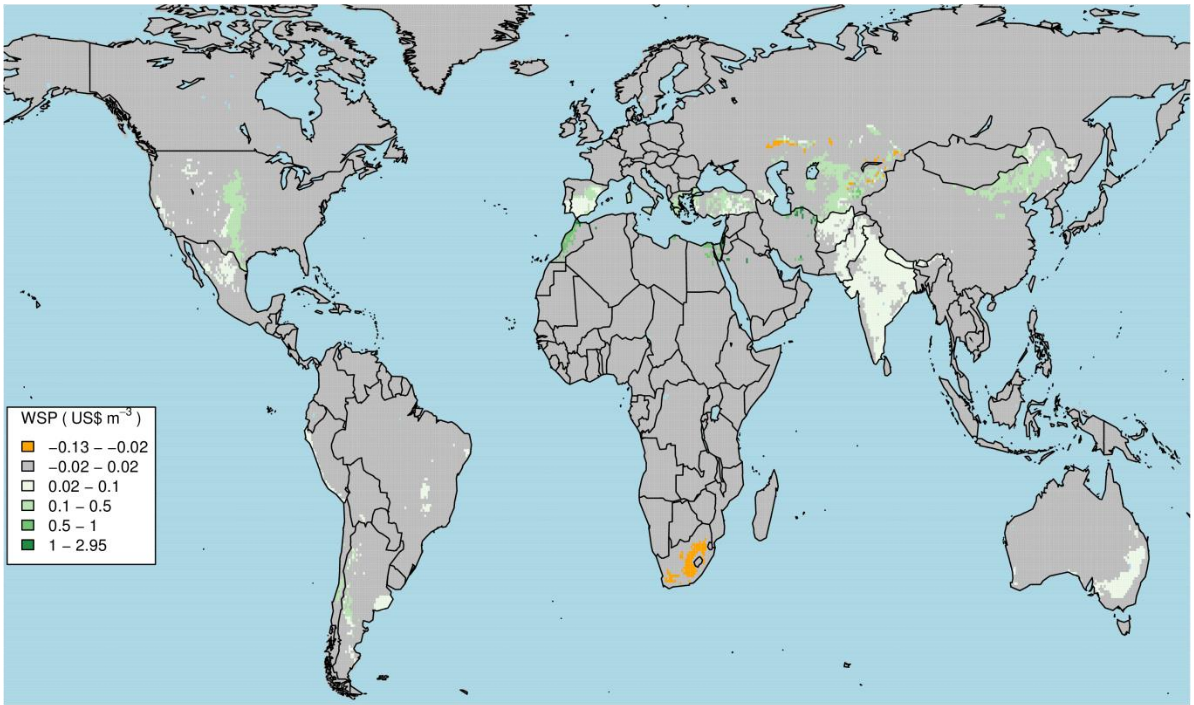


*Figure 1: Magpie-simulated difference between the water shadow price for the reference scenario and the equal diet scenario in 2045 (US$ $m^{-3}$) on a 0.5 grid basis.*

Looking at the locally specific impacts of the two different food demand scenarios on water scarcity (figure 1), we see that in many of the world's water scarce regions, water shadow prices decrease when comparing a global equal diet to a regionally differentiated diet. In Spain and Portugal, water shadow prices decrease because the export of irrigated cereals decreases due to a reduction in global demand. In North America, the reduction of cereal exports leads to less water consumption in the area of the Ogallala Aquifer where groundwater is already over-exploited (Custodio 2002). In India, the reduced demand for food alleviates the massive exploitation of groundwater (Tiwari 2009).

While water scarcity in most parts of the world decreases, it increases in South Africa because Sub-Sahara Africa is the only region where food demand increases compared to the reference scenario. However, the additional food required cannot be imported due to model-based trade restrictions and, therefore, has to be produced locally.

This section shows that different normative assumptions about future global food distribution and consumption patterns can lead to different practical consequences—and their exploration makes model-based studies relevant to policy making.

# 5 Discussion

## 5.1 The appropriate role of normative assumptions

Normative assumptions seem to be ubiquitous in scientific assessments, even in seemingly innocent “descriptive” studies, such as “business as usual” future projections. Normative assumptions, like those in MAgPIE, can be found in other applied economic models. Economic models that are based on aggregated or individual welfare maximization usually make more obvious normative assumptions than cost-minimizing and partial equilibrium models, such as MAgPIE (Robinson 2006, Beckerman 2011). We argue, however, that it is particularly important to analyze normative assumptions in models like MAgPIE where normative assumptions are not so obvious and often missed.

The existence of normative assumptions in model-based studies is not a failure of scientists, nor is it a bad thing per se. In fact, it is hardly possible to refrain from normative assumptions in scientific studies (Putnam 2004, Douglas 2009). This contradicts the still prevailing view that scientific studies must be value-free. Moreover, uncertainties are unavoidable in policy-relevant economic modeling, and knowledgeable simplifications are precisely what the art of modeling is about.

However, many normative assumptions are rather controversial; therefore, transparency is required to avoid undemocratic policy-prescriptions, which can occur unintentionally. A lack of transparency of assumptions can also (indirectly) limit scientific quality (Kloprogge et al. 2011).

The most politically important and disputed normative assumptions should be made transparent. Although most studies make their core model assumptions and analyzed policy objectives transparent, there is still considerable room for improvement along the lines discussed above. On the other hand, some of the normative assumptions identified above are subject to interpretation and policy-prescription is often only indirectly implied in model-based studies.

Normative assumptions should not be disparagingly regarded as inevitable evils that can at best be made transparent. Rather, applied economic studies should make use of normative assumptions in the politically fruitful and legitimate manner outlined above (Section 3.2). This presupposes, but goes beyond making normative assumptions transparent, in the sense that alternative normative assumptions should be deliberately selected to represent a broad range of societal viewpoints and that their practical consequences should be thoroughly explored to facilitate social learning in a pragmatist sense.

The mere existence of normative assumptions does not automatically make scientific studies policy-prescriptive. The example in Section 4.4 showed that model-based studies can use normative assumptions (i.e., different policy objectives) constructively without being policy-prescriptive. This way of dealing with normative assumptions is not only democratically tolerable and legitimate, but also reasonably informs water policy debates. Ethical sensitivity analyses like the one indicated in Section 4.4 are multi-scenario analyses that explicitly explore the practical implications of the alternative normative assumptions that are relevant to political debates.

## 5.2 An outlook on possible model enhancements

Based on the ethical discussions in the literature (e.g., Kowarsch and Gösele 2012, or Armstrong 2006 and Groenfeldt 2013 for a more specific discussion on water ethics), modelers could include a broader range of normative assumptions and explore their practical consequences. However, there is a trade-off in covering a wider range of issues on the one hand, and accounting for their increasing complexity (possibly leading to more errors in the model results), low transparency and the difficulty of understanding them on the other hand.. Although a relatively small number of issues can be explored in model-based studies, we argue that they should attempt to better address the most heated and fundamental normative issues in water management debates. Among these are conflicts between economic, ecological and social arguments. For instance, think again of the conflict between “water for economy,” which ensures water availability for agriculture etc., and “water for nature,” which ensures environmental water flows in rivers (Aiken and LaFollete 1995). In general, distributional aspects are hard to address with models like MAgPIE, but these issues are usually most relevant for political debates on sustainability governance.

So far, MAgPIE has not been able to analyze intra-generational distributional effects. Malnourishment and starvation cannot be simulated because the exogenously given demand in the model means that there is sufficient food for all. In order to tackle this problem, it would be necessary to introduce flexible demand functions that react to changes in food prices and depict the fact that people with different living standards react to changes in their incomes differently (see Engel curve in Lewbel 2007, Deaton and Muellbauer 1980). Such an implementation would help identify an income threshold below which it is not possible to purchase all necessary calories, thus simulating starvation. Price-induced changes in demand lead to a different production pattern for food, which affects local water scarcity.

Another important topic to be explored in the scenarios is inter-generational justice. To simulate accurately, for instance, the sustainable use of a slowly renewable resource, such as fossil groundwater resources, over time, it is necessary to use an inter-temporal optimizer that simulates the optimal path for resource use and preserves resources for future generations without constraining current generations too much. Limited computational resources are the main impediment to implementing inter-temporal optimization in spatially explicit models like MAgPIE.

The importance of being informed about the full range of means-consequences has already been highlighted several times. Therefore, in order to enhance the policy-relevance of model-based studies, it is necessary to enlarge the scope of the study to include more shadow ends and related means-consequences. The more policy ends are analyzed (i.e., former shadow ends), the more practical means-consequences can be identified, and the better linkages between different policy fields can be analyzed. The aspects discussed in Section 3.2 (i.e. the specific shadow ends, related means-consequences, and omission of means) provide further ideas for enhancing the scope of MAgPIE-based analyses in order to make them more policy-relevant.

Assuring policy-relevance in a substantial sense requires model-based studies on water management to incorporate (in a transparent manner) disputed normative assumptions and explore their respective implications. The point is not to create huge, complex models that can answer any question, but to identify the issues that are most relevant. Different models could potentially focus on different aspects to make this task more feasible, and the comparability between the model results would be decisive.

# 6 Conclusion

We have shown that there are many explicit and implied normative assumptions in ecological-economic studies, such as those based on the MAgPIE model. This could lead to policy-prescription in a complex field where so much is at stake ethically. Avoiding concealed policy-prescription requires the transparency of relevant and not-so-obvious normative assumptions that are often missed, such as those related to policy means and their various practical consequences. Normative assumptions are frequently unintended by scientists and can hardly be avoided. Yet, there is no need to shy away from value-laden issues in scientific studies. Referring to the pragmatist ends-means rationality, we argue that contributing to the scientific exploration of the full political solution space, including alternative policy objectives and means, allows researchers to make constructive use of normative assumptions in their model-based studies. This would inform policy-making processes in a socially valuable, scientifically reliable and politically relevant manner without being policy-prescriptive. The role of researchers should not be to make decisions about policies, but to explore alternative viable policy paths jointly with policymakers and the public. Some modifications and enhancements of applied economic models might be helpful in this regard.

Going beyond the existing literature, this article offers: (1) the theoretical tools and concrete examples to identify the normative assumptions in model-based applied economic studies and (2) a promising strategy to constructively deal with them. Both scientists and practitioners at the science-policy interface could benefit from that the result of this article.

However, two remarks regarding the science-policy interface are required here. First, the impact of scientific studies on policy should neither be overestimated nor misinterpreted (Shulock 1999). Policymakers rarely make decisions based on scientific results. Yet, it is also absurd to argue that research does not have an impact on the political realm. Instead, policy-prescriptive scientific papers and assessments can have undesirable implications for political debates (Pielke 2007; Sarewitz 2004). Second, individual applied economic studies cannot explore the whole political solution space and, therefore, should not be overstated. Large-scale scientific assessments are required for an integrated and comprehensive policy appraisal, e.g., regarding water management. However, these assessments only work if there is a high quality of scientific material; therefore, individual applied economic publications should address at least some aspects related to the political solution space. In other words, assessments are dependent on the appropriate scientific material.

# Appendix

## Appendix A: Graphical representation of MAgPIE

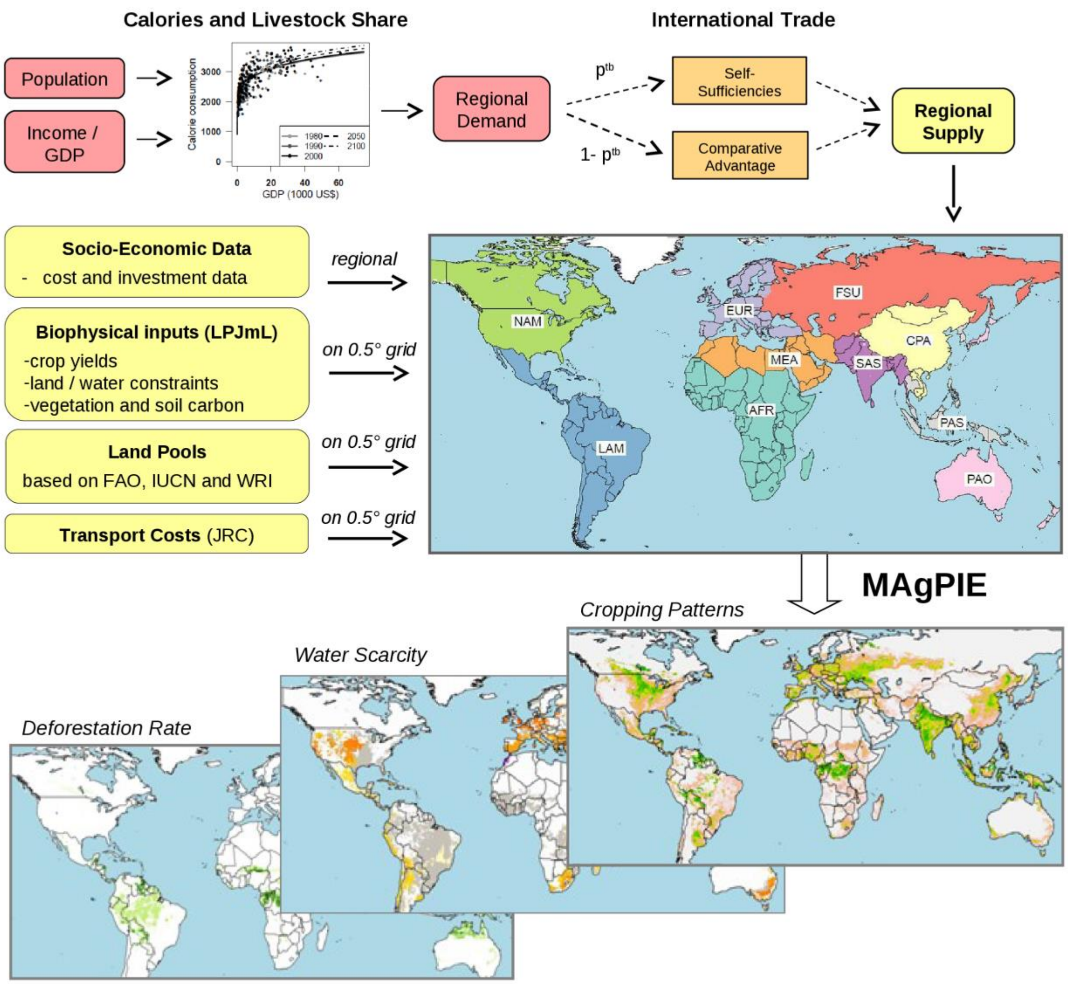


*Figure 2: Simplified MAgPIE flow chart of key processes. Economic regions in MAgPIE: AFR=Sub-Saharan Africa, CPA=Centrally Planned China, EUR= Europe (incl. Turkey), FSU=FormerSoviet Union, LAM = Latin America, MEA=Middle East and NorthAfrica, NAM=North America, PAO=Pacific OECD(Australia, Japan and New Zealand), PAS=Pacific Asia, SAS=South (incl. India).*

**Appendix B: Scenario assumption in the ethical sensitivity analysis**

*Table 2: Regional daily calorie intake per capita, 1995 and for both scenarios in 2045.*

| Scenario | Year | AFR | CPA | EUR | FSU | LAM | MEA | NAM | PAO | PAS | SAS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1995 | 1998 | 27275 | 3216 | 2769 | 2606 | 2945 | 3458 | 2602 | 2291 | 2259 |
| Reference | 2045 | 2439 | 3441 | 3537 | 3296 | 3123 | 3170 | 3756 | 3050 | 2874 | 2859 |
| Equal diet | 2045 | 2600 | 2600 | 2600 | 2600 | 2600 | 2600 | 2600 | 2600 | 2600 | 2600 |

*Table 3: Regional livestock share in the total diet, 1995 and for both scenarios in 2045.*

| Scenario | Year | AFR | CPA | EUR | FSU | LAM | MEA | NAM | PAO | PAS | SAS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1995 | 0,06 | 0,15 | 0,27 | 0,23 | 0,19 | 0,09 | 0,27 | 0,18 | 0,07 | 0,07 |
| Reference | 2045 | 0,12 | 0,40 | 0,21 | 0,32 | 0,26 | 0,15 | 0,18 | 0,15 | 0,18 | 0,18 |
| Equal diet | 2045 | 0,10 | 0,10 | 0,10 | 0,10 | 0,10 | 0,10 | 0,10 | 0,10 | 0,10 | 0,10 |

*Table 4: Regional food demand in Exajoule, 1995 and for both scenarios in 2045.*

| Scenario | Year | AFR | CPA | EUR | FSU | LAM | MEA | NAM | PAO | PAS | SAS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1995 | 1,7 | 5,3 | 2,7 | 1,7 | 1,9 | 1,3 | 1,6 | 0,55 | 1,4 | 4,4 |
| Reference | 2045 | 6,3 | 8,8 | 2,9 | 1,4 | 3,7 | 3,2 | 2,2 | 0,63 | 2,8 | 9,9 |
| Equal diet | 2045 | 6,7 | 6,7 | 2,2 | 1,1 | 3,1 | 2,6 | 1,5 | 0,53 | 2,6 | 9,0 |

## Appendix C: Regional changes in crop production, area, technical change and food prices in the scenarios in the ethical sensitivity analysis

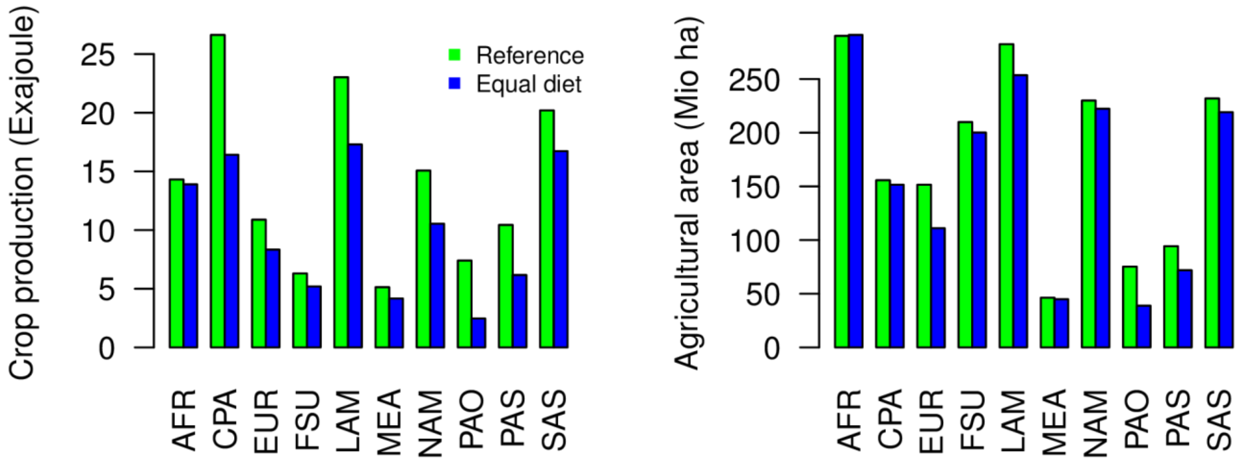


*Figure 3: Comparison of agricultural production and crop area for the reference and the equal diet scenario in 2045.*

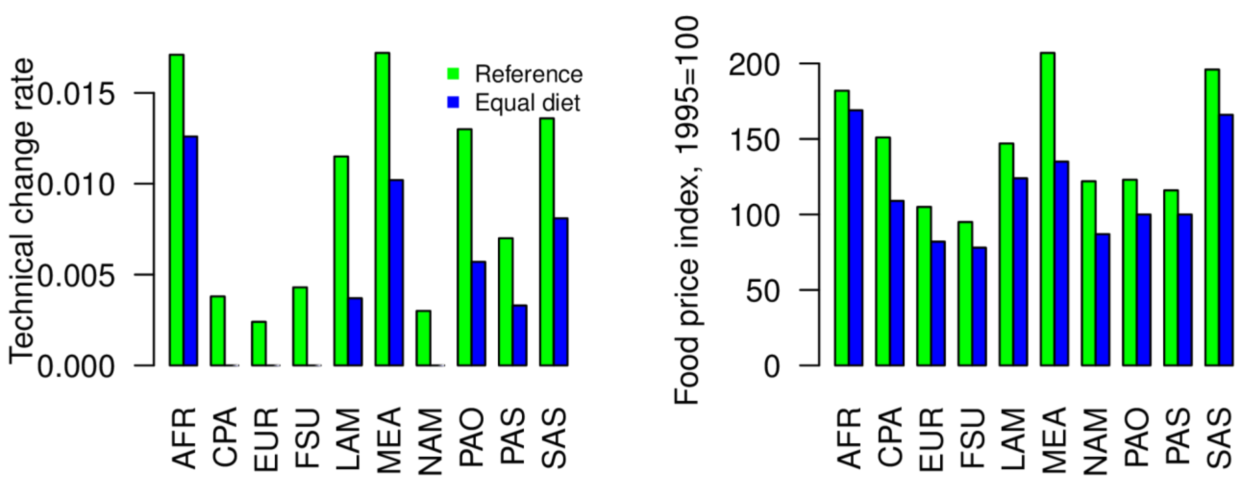


*Figure 4: Comparison of the technical change rate and the food price indices of the reference and the equal diet scenario in 2045.*

## References

Ackerman, F., Decanio, S., Howarth, R., Sheeran, K., 2009. Limitations of integrated assessment models of climate change. Climatic Change 95, 297–315.
Aiken, W., Hugh LaFollette, H. (eds.), World Hunger and Morality 1995. Prentice-Hall.
Anderson, K., Tyers, R., 1993. More on welfare gains to developing countries from liberalizing world food trade. Journal of Agricultural Economics 44, 189–204.
Armstrong, A., 2006. Ethical issues in water use and sustainability. Area 38, 9–15.
Bakir, H.A., 2001. Sustainable waste water management for small communities in the Middle East and North Africa. Journal of Environmental Management 61, 319–328.
Beckerman, W., 2011. Economics as applied ethics. Value judgements in welfare economics. In Palgrave Macmillan, Houndmills, Basingstoke.
Bentham, J., 1907. An introduction to the principles of morals and legislation. Clarendon Press, Oxford.
Berbel, J., Calatrava, J., Garrido, A., 2007. Water pricing and irrigation: A review of the European Experience. In: Irrigation Water Pricing : The Gap between Theory and Practice. - Wallingford, UK: CABI Publishing, 2007, 360 pp.
Bodirsky, B., Rolinski, S., Biewald, A., Weindl, I., Popp, A., Lotze-Campen, H. (submitted). Global food demand scenarios for the 21st century.
Bondeau, A., Smith, P.C., Zaehle, S., Schaphoff, S., Lucht, W., Cramer, W., Gerten, D., Lotze-Campen, H., Müller, C., Reichstein, M., Smith, B., 2007. Modelling the role of agriculture for the 20th century global terrestrial carbon balance. Global Change Biology 13, 679–706.
Bouët, A., Bureau, J.-C., Decreux, Y., Jean, S., 2005. Multilateral agricultural trade liberalisation: The contrasting fortunes of developing countries in the Doha round. The World Economy 28, 1329–1354.
Brown, P., Schmidt, J. (eds.), 2010. Water ethics: Foundational readings for students and professionals. Island Press, Washington.
Callon, M., 1999. The role of lay people in the production and dissemination of scientific knowledge. Science Technology Society 4, 81–94.
Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003: Knowledge systems for sustainable development. PNAS 100(14): 8086-8091.
Custodio, E. 2002. Aquifer overexploitation: what does it mean? Hydrogeology Journal 10 (2), 254–277.
Deaton, A., Muellbauer, J., 1980. Economics and consumer behavior. Cambridge University Press, Cambridge.
Dewey, J., 1986. Logic: The theory of inquiry. In John Dewey. The Later Works, 1925–1953, Volume 12: 1938, ed. Jo A. Boydston, pp. 1–527. Carbondale and Edwardsville: Southern Illinois University Press.
Dewey, J., 1988. Theory of valuation. In John Dewey. The Later Works, 1925–1953, Volume 13: 1938–1939, ed. Jo A. Boydston, pp. 189–251. Carbondale and Edwardsville: Southern Illinois University Press.
Dietrich, J.P., Schmitz, C., Müller, C., Fader, M., Lotze-Campen, H., Popp, A., 2012. Measuring agricultural land-use intensity – A global analysis using a model-assisted approach. Ecological Modelling 232, 109–118.
Douglas, H., 2009. Science, Policy, and the Value-free ideal. University of Pittsburgh Press, Pittsburgh.
Durant, J., 1999. Participatory technology assessment and the democratic model of the public

understanding of science. Science and Public Policy 26(5), 313–319.

Edenhofer, O., Kowarsch, M. (submitted): Cartography of policy paths: A model for solution-oriented environmental assessments. Working Paper. available at http://www.mcc-berlin.net/fileadmin/data/pdf/Publikationen/Edenhofer-Kowarsch_PEM_article.pdf

Eickhout, B., Meijl, H. van, Tabeau, A., Stehfest, E., 2008. The impact of environmental and climate constraints on global food supply. GTAP Working Paper No. 47.

Fader, M., Gerten, D., Krause, M., Lucht, W., Cramer, W. Spatial decoupling of agricultural production and consumption: Quantifying dependence of countries on food imports due to domestic land and water constraints, 2013. Environmental Research Letters 8 014046.

Falkenmark, M., Lundqvist, J., Widstrand, C., 1989. Macro-scale water scarcity requires micro-scale approaches. Aspects of vulnerability in semi-arid development. Natural Resources Forum 13(4), 258–267.

Federico, G., 2005. Feeding the world: An economic history of agriculture, 1800-2000. Princeton University Press.

Friedler, E., 2001. Water reuse - an integral part of water resources management: Israel as a case study. Water Policy 3, 29–39.

Gerten, D., Heinke, J., Hoff, H., Biemans, H., Fader, M., Waha, K., 2011. Global water availability and requirements for future food production. Journal of Hydrometeorology 12, 885–899.

David Groenfeldt, 2013: Water Ethics: A values approach to solving the water crisis. Routledge, New York.

Hall, S., 2011. Scientists on trial: At fault? News Feature. Nature 477, 264–269.

Hands, W., 2001. Reflection without rules. Economic methodology and contemporary science theory. Cambridge University Press.

Hausman, D.M., McPherson, M.S. 2006. Economic analysis, moral philosophy and public policy, 2nd ed. Cambridge University Press, Cambridge.

Havlík, P., Schneider, U.A., Schmid, E., Böttcher, H., Fritz, S., Skalský, R., Aoki, K., Cara, S.D., Kindermann, G., Kraxner, F., Leduc, S., McCallum, I., Mosnier, A., Sauer, T., Obersteiner, M., 2011. Global land-use implications of first and second generation biofuel targets. Energy Policy 39, 5690–5702.

Hertel, T.W., 1998. Global trade analysis: modeling and applications. Cambridge University Press.

Hertel, T.W., Keeney, R., Ivanic, M., Winters, L.A., 2007. Why Isn’t the Doha development agenda more poverty friendly?. GTAP Working Paper No. 35.

Hof, A., den Elzen, M., van Vuuren, D., 2008. Analysing the costs and benefits of climate policy: Value judgements and scientific uncertainties. Global Environmental Change 18, 412–424.

IPCC, 2007. Climate Change 2007. Mitigation of climate change. Contribution of working group III to the fourth assessment report of the Intergovernkhalmental Panel on Climate Change. Cambridge University Press, Cambridge.

Jasanoff, S., 1989. The Fifth Branch: Science advisers as policymakers. Harvard University Press.

Khalil, E., 2004. Introduction. John Dewey, the transactional view, and the behavioral sciences. In Dewey, pragmatism, and economic methodology. Routledge, London.

Kloprogge, P., Sluijs, J.P. van der, Petersen, A., 2011. A method for the analysis of assumptions in model-based environmental assessments. Environmental Modelling & Software 26, 289–301.

Kowarsch, M., Gösele, A., 2012. Triangle of justice, In Climate Change, Justice and Sustainability: Linking Climate and Development Policy. Springer, Dordrecht.

Krause, M., Lotze-Campen, H., Popp, A., Dietrich, J.-P., Bonsch, M. 2012: Conservation of undisturbed natural forests and economic impacts on agriculture, Land Use Policy 30: 344-354.

Lewbel, Arthur. Engel curve. In The new palgrave dictionary of economics, 2008. 2nd Edition. Steven

N. Durlauf and Lawrence E. Blume. (Eds.). Palgrave Macmillan,

Lotze-Campen, H., Müller, C., Bondeau, A., Rost, S., Popp, A., Lucht, W., 2008. Global food demand, productivity growth, and the scarcity of land and water resources: a spatially explicit mathematical programming approach. Agricultural Economics 39, 325–338.

Maasen, S., Weingart, P. (eds.), 2005. Democratization of Expertise? Exploring Novel Forms of Scientific Advice in Political Decision-Making. Sociology of the sciences Yearbook, Vol.24, Springer, Dordrecht.

Martin, W., Winters, L.A., 1996. The Uruguay Round and the Developing Countries. Cambridge University Press, Cambridge.

M'barek, R., Britz, W., Burrell, A., Delince, J. (eds.), 2012. An integrated modelling platform for agro-economic commodity and policy analysis (iMAP). JRC Scientific and Policy Reports 25267.

Molden, D., 2007. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. Earthscan, London.

Narayanan, B., Walmsley, T.L., 2008. Global Trade, Assistance, and Production: The GTAP 7 Data Base. Center for Global Trade Analysis, Purdue University.

Panagariya, A., 2005. Agricultural Liberalisation and the Least Developed Countries: Six Fallacies. World Economy 28, 1277–1299.

Peil, J., Staveren, I. v. (eds.), 2009. Handbook of Economics and Ethics. Edward Elgar, Cheltenham, UK.

Pielke Jr., R., 2007. The honest broker: Making sense of science in policy and politics. Cambridge University Press, Cambridge.

Pimentel, D., Pimentel, M., 2003. Sustainability of meat-based and plant-based diets and the environment. American Journal of Clinical Nutrition 78, 660–663.

Pingali, P., 2007. Westernization of Asian diets and the transformation of food systems: Implications for research and policy. Food Policy 32, 281–298.

Putnam, H., 2002. The Collapse of the Fact/Value Dichotomy And Other Essays. Harvard University Press, Cambridge.

Putnam, H., 2004. The collapse of the fact/value dichotomy and other essays. Cambridge, Mass.: Harvard University Press, Cambridge.

Putnam, H., Walsh, V.C. (eds.), 2012. The End of Value-Free Economics. Routledge, London, New York.

Renn, O., 2009. Inclusive Risk Governance: Concepts and Application to Environmental Policy Making. Environmental Policy and Government 19, 174–185.

Robert, C., Zeckhauser, R., 2011. The methodology of normative policy analysis. Journal of Policy Analysis and Management 30(3), 613–643.

Robinson, J., 2006. Economic Philosophy. Transaction Publishers.

Rodriguez-Sickert, C. (2009): Homo economicus. In: Peil, J., van Staveren, I. (eds.).

Rosegrant, M., Sombilla, M., 1997. Critical issues suggested by trends in food, population, and the environment to the year 2020. American Journal Agricultural Economics 79, 1467–1470.

Rosegrant, M.W., Paisner, M.S., Meijer, S., Witcove, J., 2001. Global food projections to 2020: Emerging trends and alternative futures, International Food Policy Research Institute. Washington, D.C.

Sarewitz, D., 2004. How science makes environmental controversies worse. Environmental Science & Policy 7, 385–403.

Schattschneider, E., 1960. The semisovereign people: A realist′s view of democracy in America. Holt, Rinehart & Winston, New York.

Schmitz, C., Biewald, A., Lotze-Campen, H., Popp, A., Dietrich, J.P., Bodirsky, B., Krause, M., Weindl,

I. 2012: Trading more food - Implications for land use, greenhouse gas emissions, and the food system. Global Environmental Change 22(1): 189–209.

Schmitz, C., Lotze-Campen, H., Gerten, D., Dietrich, J.P., Bodirsky, B., Biewald, A., Popp, A., 2013. Blue water scarcity and the economic impacts of future agricultural trade and demand. Water Resources Research 49, 3601–3617.

Schneider, S., 1997. Integrated assessment modeling of global climate change: transparent rational tool for policy making or opaque screen hiding value-laden assumptions? Environmental Modeling and Assessment 2, 229–248.

Scoones, I., 2009: The politics of global assessments: the case of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). The Journal of Peasant Studies 36(3), 547–571.

Sen, A., 1988. On ethics and economics. Malden, Blackwell, MA.

Shulock, N., 1999. The paradox of policy analysis: If it is not used, why do we produce so much of it? Journal of Policy Analysis and Management 18, 226–244.

Smakhtin, V., Revenga, C., Döll, P., 2004. A pilot global assessment of environmental water requirements and scarcity. Water International 29, 307–317.

Smil, V. (2000). Feeding the world: A challenge for the 21st century . The MIT Press

Sohngen, B., Tennity, C., Hnytka, M., 2009. Global forestry data for the economic modeling of land use. In: Hertel, T.W., Rose, S., Tol, R.S.J. (Eds.), Economic Analysis and Use in Global Climate Change Policy. Routledge, New York, 49–71.

Streeten, P., 1950. Economics and value judgments. The Quarterly Journal of Economics 64, 583–595.

Tiwari, V. M., Wahr, J., Swenson, S., 2009. Dwindling groundwater resources in northern India, from satellite gravity observations. Geophysical Research Letters 36.

United Nations Environment Programme (UNEP) 2012. GEO-5. Global Environment Outlook. Environment for the future we want.

Valin, H., Sands, R.D., van der Mensbrugghe, D., Nelson, G.C., Ahammad, H., Blanc, E., Bodirsky, B., Fujimori, S., Hasegawa, T., Havlik, P., Heyhoe, E., Kyle, P., Mason-D’Croz, D., Paltsev, S., Rolinski, S., Tabeau, A., van Meijl, H., von Lampe, M., Willenbockel, D., 2014. The future of food demand: understanding differences in global economic models. Agricultural Economics 45, 51–67.

Van der Sluijs, J., 2002. A way out of the credibility crisis around model-use in integrated environmental assessment. Futures 24, 133–146.

Van der Sluijs, J., Rinie van Est, M.R., 2010. Beyond consensus: Reflections from a democratic perspective on the interaction between climate politics and science. Current Opinion in Environmental Sustainability 2, 409–415.

Van Ittersum, M.K., Rabbinge, R., 1997. Concepts in production ecology for analysis and quantification of agricultural input-output combinations. Field Crops Research 52, 197–208.

Van Meijl, H., van Rheenen, T., Tabeau, A., Eickhout, B., 2006. The impact of different policy environments on agricultural land use in Europe. Agriculture, Ecosystems & Environment 114, 21–38.

Van Vuuren, D.P., Isaac, M., Kundzewicz, Z.W., Arnell, N., Barker, T., Criqui, P., Bauer, N.,Berkhout, F., Hilderink, H., Hinkel, J., Hochrainer, S., Hof, A., Kitous, A., Kram, T., Mechler, R., Scrieciu, S., 2009. Scenarios as the basis for assessment of mitigation and adaptation. In: Hulme, M., Neufeldt, H. (Eds.), Making climate change work for us–ADAM synthesis book. Cambridge University Press, Cambridge.

Vorösmarty, C., Green, P., Salisbury, J., Lammers, R., 2000. Global water resources: Vulnerability from climate change and population growth. Science 289, 284–288.

White, D.D., Wutich, A., Larson, K.L., Gober,P., Lant, T., Senneville, C., 2010. Credibility, salience, and legitimacy of boundary objects: water managers' assessment of a simulation model in an immersive decision theater. Science and Public Policy 37, 219–232.

World Water Assessment Programme (WWAP), 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. UNESCO, Paris.