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Farm System Management and Governance for Good Water Quality and Drinking Water Supplies

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Assessment of costs and benefits for farmers, water companies and society from using Decision Support Tools

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SUMMARY

Decision support tools Tools (DSTs) are tools used to assist decision making at farm level or by water companies or decision makers, and there are costs and benefits of using such DSTs for both farmers, water companies, administration and society as a whole. These costs and benefits vary with the DSTs as do the problems they are designed to adress.

The aims of Task 5.3 are to assess the costs and benefits for farmers and society of using DSTs that directly or indirectly improve or affect water quality. Societal costs and benefits include the costs and benefits for water utilities/water works. These aims were divided into subquestions and assessments for farmers, water companies, administration (governmental decision makers) at national and catchment level.

Criteria, such as time consumption, savings, costs of using the DSTs as well as potential gains, were established and assessed for six chosen Farm Level DST's. These DSTs have been analysed in former deliverables in FAIRWAY. Two Catchment level DSTs were also analysed for their options to calculate cost-effective solutions and to explore and reduce risks related to the assumptions that the regulation and modelling builds on.

It is concluded that the evaluated farm level DST's all have in common that total costs of using the tools are kept at a low level and that this is essential for a tool to be effective. It was also concluded that this type of tools can save money for the farmers if inputs are reduced, but also that DST's are important to fulfill the the cross compliance requirements, that are compulsory in all countries in EU.

The evaluation of the catchment level tools indicate that significant resources can be saved by using such tools to reveal cost-effective solutions and management practices. The catchment level models are also capable for assessment of the effects of assumptions on the cost-effective solutions, and can therefore be used to assess the risk of wrong or limited information.

In addition to cost-oriented DSTs, ecosystem service approaches and meta-analysis of valuation projects are methods that can be used for decision support. These type of tools can be used for general and more spatially specific assessments and measurements of the value of protection, including spatial analyses of synergies and trade-offs between services to support multi-objective land use planning, such as water quality regulation, climate regulation, recreation, food provision, timber production and biodiversity. The benefits measured by these tools can be used to make cost-benefit analyses of protection or other policy scenarios and decisions.

1. INTRODUCTION

Decision support tools Tools (DSTs) are tools used to assist decision making at farm level or by water companies or decision makers, and there are costs and benefits of using such DSTs for both farmers, water companies, administration and society as a whole. These costs and benefits vary with the DSTs as do the problems they are designed to adress.

1.1 AIMS AND OBJECTIVES

The aims of Task 5.3. are to assess the costs and benefits for farmers and society of using DSTs that directly or indirectly improve or affect water quality. Societal costs and benefits include the costs and benefits for water utilities/water works.

These aims were divided into the following subquestions and assessments for farmers, water companies and administration (governmental decision makers) at national and catchment level:

Farmers/farm level:

1. Evaluation and assessment of the **costs** for farmers, from the use of DSTs relating to nitrogen and pesticide use and management. These costs include:

   - Direct costs for the farmers.
   - User costs and fees related to the use of the DST.
   - Payment to advisors, including the time used by the advisors.
   - Time used by farmers.
   - The direct effects on profits. These costs include, for example, lost/increased yields as well as changes in inputs and the time spent, and the increased or decreased uncertainty over the outcomes. Changes in work hours used and changes in the risk of obtaining the target yield are also of importance.
   - Indirect costs for the farmers, e.g. costs related to using and learning to understand and use the tools.

2. Evaluation and assessment of the **benefits** of using DST's at the farm level, including:

   - The benefits of using the tools in terms of saved costs for the farmer,
   - Information on whether use of the DST reduces or increases risk.
   - Benefits from advice for implementation of abatement measure to ensure cross-compliance, according to the CAP and national regulations.

Water companies, administration, society/catchment level:

3. The **cost** for water companies, administration and society as a whole is adressed in two ways:

   - Assessment of catchment tools that model and estimate costs.
   - Assessment of the cost-effectiveness of implementing measures to reduce nitrogen and pesticide losses to surface water and/or groundwater.

4. Assessment of **benefit** valuation studies and approaches that provide knowledge of the value of using these catchment tools and from implementing measures to achieve clean

drinking water and good ecological status of surface water. Ecosystem services approaches are prove to be valuable for such assessments.

1.2 Previous evaluations of decision support tools

There is an extensive literature evaluating DSTs and systems. Examples are provided here to draw on previous experiences of the importance of DSTs and to elicit criteria for the evaluation made in this report.

Maynard *et al.* (2001) evaluated an extensive number of decision support systems used for different purposes. They attempted to develop generic critera for evaluation of DSTs, emphasising that different stakeholders and decison makers apply different sets of criteria. Four broad types of criteria were identified, all having effects on the costs and benefits of using DSTs:

- Effectiveness - refers to the level of the fulfillment of the goals of the DST. Flexibility to adjust to end-users requirement is part of this criterion, being important to save time using DSTs.
- Efficiency - refers to the degree of performance of the DST; one example of a sub-criterion that falls under this domain is whether the use of the DST reduces costs or increases the profitability for those who use the tool.
- Satisfaction - refers to end-users perception of the tool.
- Use - refers to the ease of use and the extent of DST use among relevant end-users.

Ease of use, which is important for the perceived costs of using the DSTs, was also of concern in an evaluation of DSTs by Inman *et al.* (2011). Based on a literature review, these authors defined “ease of use” as the ability of DSTs to present information to the user in a clear and familiar way, with rapid comprehension. They also identified that difficulties using a DST might negatively affect the overall satisfaction with the tool, referring to Sanders and Courtney (1985). A study by Srinivasan (1985), referenced in Inman *et al.* (2011), showed that the greater the time spent using a DST the lower the perceived effectiveness became. Inman *et al.* (2011) suggested that the actual time used for operating the system can be used as an indicator of the effectiveness as it is related to the ease of use of the DST. Technical suitability and transparency can also be indicators for effectiveness.

The summary from an EIP-AGRI workshop on “Tools for Environmental Farm Performance” (EIP-AGRI 2017) also points out that ease of use is important. It was concluded that reasons for poor uptake of DSTs among farmers are:

- the tool is not found to be useful by the farmer,
- the tool might be difficult to understand,
- the DST may require the farmer to spend a lot of time setting it up or learning how to use it,
- the costs outweigh its perceived benefits.

These findings are in line with our findings in FAIRWAY D5.1. report, Chapter 4.8. “Barriers to uptake” (Nicholson *et al.,* 2018).

The summary of EIP AGRI also mentioned lack of trust, for example the concern that using the DST may lead to new regulations being imposed on the farmers. Another conclusion from the wokshop was that the DST should be affordable in the context in which it is expected to be used. This means that for marginal producers the costs of using the DST should be very low, while “high-value agro-industrial production systems might be willing and also able to invest more, in order to gain more” (EIP AGRI 2017, page 18).

Related to the efficiency criterion, many studies have revealed that economic outcome and minimization of risks are important. In a study of Danish farmers, Pedersen *et al.* (2011) found that 92% of the farmers who responded to the survey preferred it when advice improved economic outcome and reduced risks (related to pesticide application to reduce diseases and weed). Farmers’ considerations about the economic outcome are a trade-off between the cost of pesticides or other treatment, and the marginal benefit from this use. The advice provided by DSTs and/or advisors should therefore be able to provide information about this trade-off. Rose *et al.* (2016) conducted a survey among farmers in the UK and pointed out the importance of the cost of using a DST and its influence on uptake by end-users. They concluded that DSTs that are free of costs or provided by a grant are more likely to be used, and they also highlighted that usability and relevance are important criteria for the success.

In the FAIRWAY report D5.1 (Nicholson *et al.*, 2018) we referred to a farmer survey made by Defra (2015) where economic gain from using tools was found to be important. Drawing on information from in-depth interviews and focus groups Defra (2015) found that, amongst other things, farmers wanted tools to be more user friendly and more flexible (ease of use was important) and also that the potential economic gain should be explicitly demonstrated (efficiency matters).

Axelsen *et al.* (2012) evaluated the Danish Plant Protection Online, and they also concluded that the large amount of time required and level of complexity have had led to a low uptake of this tool among farmers.

For catchment and national assessments of costs and benefits other methods and tools exists.

Ward (2007) reviewed studies on the use of economic concepts and tools for the analysis of management of water resources, and summarized economic analyses to support policy decisions. It was found that there are many methods and approaches, including valuation of water, valuation of water quality management, optimization models and integrated model approaches. Cost-benefit analysis is one approach that attempt to give advice on both benefits and costs, Similarly, there are also a number of tools which have been developed to advise on both how the costs can be minimized and the benefits maximized.

The DSTs for advising how to minimize costs include cost-effectivess approaches. Balana *et al.* (2011) have reviewed a large number of assessments that have been made to estimate cost-effective combinations of measures to reduce nutrient losses to the aquatic environment. Balana *et al.* (2011) concluded that many studies performed before 2011 were based on models of ‘representative’ farms without capturing the variability among real-world farms. In addition, they concluded that many studies were based on a few examples of effects and did not include uncertainties in cost and effectiveness estimates. The review indicated that examples of DSTs that capture spatial modelling beyond farm level and which can be used to assess the effects of uncertainty and heterogeneity on the cost-effectiveness results should be favored.

For valuation of benefits for society, different approaches can be used for decision support. A number of authors have developed criteria for, and recommendations for, how valuation of benefits of water quality improvements as well as other environmental improvements can be measured and used for policy advice. Meta-analysis is such an approach, also called the "study of studies" (Bergstrom and Taylor, 2006). Meta analysis and regression analysis represent attempts to statistically measure systematic relationships between data from valuation studies, as well as data for human population, environmental characteristics of the place where the regression results should be used. Following Bergstrom and Taylor (2006), meta-analysis is a useful tool for advising on the benefits of water quality improvements that build on extensive experiences from many studies. The strength of meta regressions as a DST is the ability of this approach to combine and summarize large amounts of information from previous studies, and build on these experiences for policy advice.

The weakness of meta analysis might be that spatial differences are neglected when using data from a number of studies to create a generic function to measure the value of an improvement. The spatial differences between locations can be huge, and several studies highlights this by using ecosystem services assessment tools to address how ecosystems services and goods vary spatially. This type of information can be very important in order to enable social planners and decision makers to target the efforts to where the benefits are the largest and outweigh the costs.

Bateman *et al.* (2013) demonstrated the development of such a spatial assessment framework applied in the UK, using land-use as example to provide information on the benefits of ecosystem services from land use- and climate changes, on water quality services, biodiversity and other services. This type of assessment method has also been applied as DST in Denmark, and the DST's include the creation of scenarios for how ecosystem services such as recreation, biodiversity, water quality regulation and climate regulation, are influenced by set aside of land at different locations. Spatial maps were used in both Bateman *et al.* (2013) and Termansen (2018) to illustrate the distribution of the value stemming from the ecosystem services and their spatial, locations.

1.3 THE DECISION SUPPORT TOOLS CHOSEN

The tools chosen selected for evaluation in this FAIRWAY deliverable report were the tools reviewed and chosen as part of FAIRWAY deliverable 5.1. (Nicholson *et al.*, 2018) and tested in FAIRWAY deliverable 5.2 (Laursen *et al.*, 2019). These DSTs were:

Farm level decision support tools:

- Mark Online, Denmark
- Plant Protection Online, Denmark
- Düngeplanung, Germany (Lower Saxony)
- Environmental Yardstick, Netherlands
- Phytopixal, France *
- MANNER-NPK, UK
- ANCA, Netherlands*
- Farmscoper, UK

Catchment level decision support tools:

- TargetEconN, Denmark

- Farmscoper, UK
- Siris, France *

The tools with an * (SIRIS, Phytopixal and ANCA) were omitted from the list due to their lack of focus on economic information or lack of related information relevant for the assessment in FAIRWAY deliverable 5.3. Note also that farmscoper is included in both categories as it can be used at both the farm and catchment/national level.

In addition to these farm and catchment levels DSTs, tools for ecosystem services assessments to value the benefits of water quality improvements were chosen from the literature and following application in the FAIRWAY case-study area in Denmark. These are presented as examples of applications of benefit and ecosystem services assessments for decision support. The examples chosen were:

- MAES: Mapping and Assessments of Ecosystem Services. This is an European level decision support system (DSS) developed by the EU Commission, JRC (Maes et al 2012). Examples from implementation of a similar ecosystem services assessment tool in the Danish case study area in FAIRWAY, called MAES-DK, are used for illustration, as well as a similar example from the UK (The UK National Ecosystem Assessment, UK NEA (Bateman *et al.*, 2011)).
- Meta analyses (benefit transfer) of valuation studies of water quality improvements: Two examples were chosen for illustration, namely:
    - An international groundwater valuation study applying meta-analysis (Brouwer and Neverre, 2018).
    - A Danish meta-analysis based on valuation studies from the Nordic countries, valuing water quality improvements using the Water Framework Directive classification of ecological status. Structure of the deliverable

1.4 THE DECISION SUPPORT TOOLS CHOSEN

The report is divided into 6 chapters, where the following parts are introduced here and in the method section (Chapter 2). In chapter 3 the farm level tools are examined and presented, and in chapter 4 the catchment level tools. Chapter 5 summarizes the findings, and they are discussed and concluded upon in chapter 6.

2. METHOD AND DATA

2.1 CRITERIA FOR ASSESEMENTS OF DSTS AT FARM LEVEL

1. Assessment of **direct costs** for the farmers

- These costs include user costs and fees related to the use of the DST.
  Question: Is there a price on purchasing the DST, annual fee or other type of payment, or is it free? How do we evaluate the effect of the price/no-price on the uptake/use of the DST?
- Payment for advise by advisory services:
  Question: Is advice necessary and is there a fee/payment?

- Time and costs of time.
  Question: How much time is used by advisors and farmers when using the DST?
- The direct effects on profits.
  Question: Is it possible to estimate the effects on the economic outputs in terms of decreases or increases in yields, changes in inputs, time spent and the increased or decreased uncertainty of the outcomes? Are there any data from DSTs on changes in inputs (fertilisers, pesticides) – can examples from the DST's be included as an example?
- Changes in the risk of obtaining the target yield are also of importance.

2. Assessment of **indirect costs** for the farmers:

- The indirect costs for the farmers include transaction costs, e.g. costs of using and learning to understand and use the tools, costs of reporting, if such information is available. *Question: Short assessment of the costs of learning and practising this type of DST, if no information exist, then this point is described qualitatively based on expert judgement.*

3. Evaluate and assess the **benefits** of using DSTs at farm level

- The benefits of using the tools for the farmers is evaluated in terms of saved costs, including information on whether use of the DST reduces or increases risk.
  Question: Are there any data/information on saved fertiliser or pesticide use that can be used to calculate reduced nutrients and pesticides? Cf. earlier question under 1.
- Benefits from advice for implementation of abatement measure to ensure cross-compliance, according to the CAP and national regulations.
  Question: Does the DST include advice on how to fulfill cross compliance or other requirements due to the CAP? Even though this benefit varies greatly between farms and might be difficult to assess at general level, there is no doubt that advice on how to secure cross compliance, which is compulsory in EU, has been and is important.

4. Evaluation of the DSTs ability to assess costs and benefits

In this section we sum up the evaluation points in 1, 2 and 3. We also add information on the use and uptake of the DST among farmers in the respective countries, and discuss the causes for uptake, as well as potential obstacles for the uptake. For this assessment we look at whether the functions described and identified in deliverable 5.2 for the likelihood for a DST to be succesful have been fulfilled, cf. Figure 1 (Laursen *et al.*, 2019). The criteria in Figure 1 used for the evaluation are marked with a red cross.

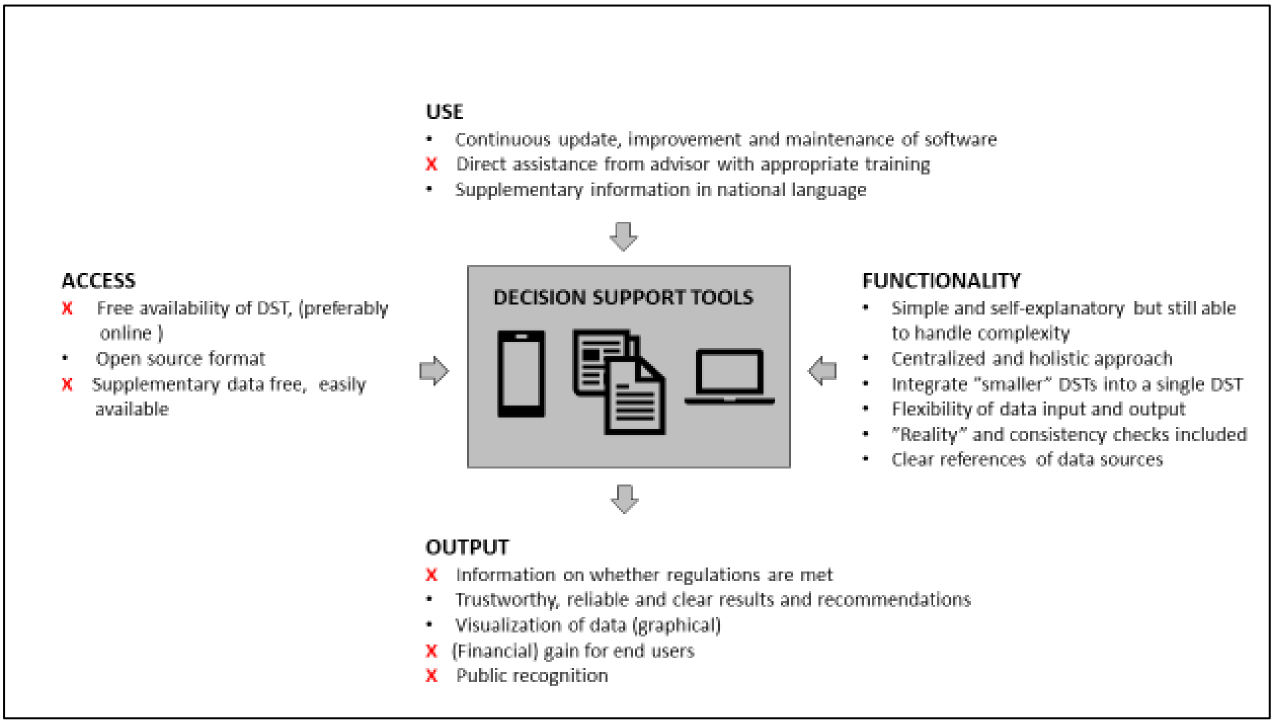

Figure 1. Requirements for decisions support tools to be successful (modified from Laursen *et al.*, 2019). Red crosses indicate the criteria used for the evaluation.

2.2 CRITERIA FOR ASSESSMENTS OF DSTS FOR COSTS AND BENEFITS FOR WATER COMPANIES, ADMINISTRATION AND SOCIETY AS A WHOLE

1. Costs

In this part of the evaluation of DSTs, two catchment DSTs were chosen as good examples for assessment of costs and cost-effectiveness for water companies, adminstration and society as a whole. Important criteria for this assessment are the ability for of the DST to model:

- cost-effective solutions;
- how measures and spatial scale are taken into account;
- distribution between farms/farm types/regions
- ability to model and to assess risk and uncertainty.

This part of the assessment includes two examples of catchment tools that model and estimates costs and cost-effectiveness of implementing measures to reduce nutrients and pesticides to surface water and/or groundwater, and a description on what information these catchment tools provide for adminstration at various levels, decision makers and water companies/water works. The examples include illustrations on how costs and cost-effectiveness are displayed for end-users, and short descriptions on how the results are used by managers/end-users.

2. Benefits of water quality improvements

DSTs that address benefits can be assessed using the following criteria:

The benefits should represent the populations' willingness to pay for water quality protection or improvements to be comparable to the costs and to enable cost/benefit analyses. The benefits should be estimated for

- a defined level of change; e.g. quality change from a baseline to a policy target (e.g. a limit value for groundwater pollution or a defined level of ecological or chemical status such as in the Water Framework Directive).
- the population affected.

For this type of valuation both cost-based and utility-based approaches exist. A direct way to value the benefits of water quality improvements is by use of stated or revealed valuation approaches, where the value of groundwater or surface water quality improvement is valued, and where the benefits of these improvements are measured for the population affected. There are a large number of such studies available, and these studies are used to apply benefit transfer and meta regression analyses, i.e. value estimates are either transferred to use at another place, or by meta regressions where data from a large number of original studies on specific problems and areas are used. The meta regression analyses and functions are established in order to make models for decision support, by using primary and original studies and data to provide more generic information of the value on an environmental improvement.

Ecosystem services mapping and valuation approaches are also examples of approaches for assessments of the benefits of water quality improvements, as this type of approach can be used to value a large range of benefits from the improvements in water quality. The ecosystem services mapping approaches are spatial, and can include information from the above mentioned meta regression analyses.

If the tools for assessments of costs and benefits address coherent implementation of nutrient and pesticide emissions and pollution, this will also be described, as tools that integrate assessment of more than one pollutant can prevent unintended effects on the other pollutants.

3. DECISION SUPPORT TOOLS AT FARM LEVEL

In this chapter, each of the farm level DSTs is presented and evaluated based on the criteria and questions outlined in the method section.

The farm level decision support tools are:

- Mark Online, Denmark (section 3.1)
- Plant Protection Online, Denmark (section 3.2)
- Düngeplanung, Germany (Lower Saxony) (section 3.3)
- Environmental Yardstick, Netherlands (section 3.4)
- MANNER-NPK, UK (section 3.5)
- Farmscoper, UK (section 3.6.)

3.1 MARK ONLINE, DENMARK

Mark Online is the most widely used farm information management system in Denmark and covers all aspects of crop management including soil tillage and crop protection (Bligaard, 2014). The decision support tool is actively used by approximately 350 advisers and 2,500 farmers on 85% of all land in DK (2.2 million ha distributed on 25,000 farms). The first version of Mark Online was developed in ca.1991 by SEGES, Denmark. The current latest version was released in January 2017.

Mark Online is used by the farmers and advisors for fertilizer planning, optimization and documentation in Danish crop production. Mitigation is included by economic assessments of how to comply to national rules and regulations. In this way, Mark Online ensures that pesticides and nutrients are used according to legislation. Key data is obtained via field trials (Nicholson *et al.*, 2018).

Assessment of direct costs for the farmers

User costs and fees related to the use of Mark Online: The purchase price for Mark Online is 1,350 Danish Kroner (DKK), which is approximately 181 EUR per year. The annual subscription fee differs depending on farm size, see Table 3.1. Software support is included in the annual subscription fee.

Table 1. Annual subscription fee for Mark Online differs with farm size.

Farm size (ha)	0 - 49	50 - 199	200 - 499	+ 500
Annual subscription fee (DKK.) (EUR in parenthesis)	1,650 (221)	2,650 (356)	3,675 (493)	950 (128)

Payment for advisory services: Mark Online is a complex all-inclusive decision support system, which means that advisory assistance is necessary for use in most cases. Therefore most farmers also seek advice from advisory services for fertilizer planning etc. The advisory work is usually paid for to the local advisors as an advisors package. The package price varies depending on farm size etc.

Time and costs of time: It is extremly individual how much time a farmer uses in Mark Online. Some farmers use the DST several hours a day, whereas others use it once a year. It depends on how much the farmer does and how much is left for the advisor to do. Additionally, it depends on the hectares, number of fields, number of crops etc. A large fertilizer plan may take days to a week to complete, whereas a small fertilizer plan may take only a few hours.

The direct effects on profits. Mark Online shows information on saved inputs (fertiliser and pesticides) with links to the pesticide database, if applicable.

3.2 PLANT PROTECTION ONLINE, DENMARK

Plant Protection Online was jointly developed by Aarhus University and SEGES. The development of Plant Protection Online was initiated after the launch of the first Danish Pesticide Action Plan in 1986, which required significant reductions in the application of pesticides. The first version was released in 1991 as PC-Plant Protection. In 2006 the latest version of Plant Protection Online was published.

Plant Protection Online is an online system applied by skilled farmers and advisors in Denmark, the Baltic countries and Poland for reduction of use of pesticides and ensuring that only legal pesticides are used. Plant Protection Online gives recommendations on whether to spray or not, dosage and spraying time in individual fields based on the result of field trials, individual field data and features of the active ingredients (insecticides, herbicides and fungicides) (Nicholson *et al.*, 2018).

Assessment of direct costs for the farmers

User costs and fees related to the use of the DST: The purchase price for Plant Protection Online is 1,350 Danish Kroner (DKK), which is approximately 181 EUR per year. The annual subscription fee is 1,250 DKK (168 EUR) per user per year. Software support is included in the annual subscription fee.

Payment for advice by advisory services: Often farmers do not use Plant Protection Online themselves. They pay an advisor for the information from Plant Protection Online. This advisory service is usually a part of a package price that varies depending on farm size etc.

Time and costs of time: Often the advisory companies use Plant Protection Online once a week. Based on the information from the DST a combined advice strategy is made and agreed on between the advisors. The advisors then communicate that information to the farmers.

The direct effects on profits. Plant Protection Online shows information on saved inputs by showing a percentage reduction compared to the maximum dose.

Benefits of using DSTs at farm level

Plant Protection Online reduces the use of pesticides and ensures that only legal pesticides are used. Information on measures to implement is not included in Plant Protection Online.

3.3 DÜNGEPLANUNG, LOWER SAXONY, GERMANY

Düngeplanung is part of a software package of tools dealing with efficient nutrient management in Lower Saxony. The particular tool Düngeplanung was developed in 2014 for water protected areas in order to optimize allocation of nutrients on field-scale. It combines data on soil measures, crop rotation and fertilization. The tool’s output is a detailed fertilization plan which combines agronomically optimum amounts of fertilizers with environmental legislation.

Assessment of direct costs for the farmers

The whole software package can be purchased by farmers and advisors. The software provides several IT-interfaces in a way that data from one application can by transferred and used in other applications, too. **Direct costs for farmers** are an onetime fee for buying the software package of 77 EUR and an annual maintenance fee of 10 EUR. Prior to buying the software, farmers usually want to gather experience with the software in order to find out whether they consider it to be useful. Often, the license stays with the advisor (so there is no software purchasing cost for the farmer) and the farmers pay the hours of advisory service, instead.

In addition, **paying an advisor** is indispensable especially in the learning phace of the application of Düngeplanung. Most farmers do not use the software themselves but make use of their advisors. The advisor's hourly wage (e.g. for LWK (Chamber of Agriculture Lower Saxony, Germany) is 74 EUR. However, in the past years this fee has been subsidized by a programme called "Promoted advisory service", financed by both EU and the agricultural ministry of the federal state of Lower Saxony. This subsidy covers 80% of the time spent by the advisor (hence the farmer has to pay about 15 EUR/hour). However, the total budget for this subsidy is limited and long-term funding is not secured.

Time spent (both by the advisor or the farmer) differs tremendously from farm to farm, depending on the number of fields, diversity in cropping and fertilizer use. Also management changes during the crop season which consequently require an updated fertilization plan take a lot of time. Furthermore, the quality of data delivered by the farmer is of crucial importance in respect to time consumption (e.g. some farmers just fill the data template while others report a lot of single information and estimates which have to be corrected retrospectively). Generally, time expenditure is highest in the first years, since soil data and additional information has to be entered. Average time spent to plan and to maintain Düngeplanung for a farm is about 8 hours for a year, however, depending on the individual farm and the intensity of advisory service, there is a huge variation (3-20 hours per farm per year).

Düngeplanung does not cause an increased risk of obtaining the target yield. However, since the fertilizer plan is usually designed in winter, prior to the vegetation period, it is of cause necessary to update it on a regular basis.

Assessment of indirect costs for the farmers

Indirect costs for the farmer refer to time spent to learn and manage the tool. Since many farmers do not apply the software themselves, costs are direct (payment of the advisor) rather than indirect. Time for learning to understand and use the tool cannot be quantified and depends very much on the individual user. Usually, a beginner starts with the basic features and step by step discovers additional functions of the tool. The Düngeplanung manual can help to some extent but in most cases it might be more effective to ask a trained user of Düngeplanung directly if problems occur.

The benefits of using DSTs at farm level

Düngeplanung acts on the maxim that yields should be kept stable while reducing nutrient inputs as much as possible. It is impossible to report definite numbers on saved inputs since it can be very different from farm to farm. Generally, we estimate a reduction of 5-10% of nitrogen inputs due to field-specific planning of fertilization. However, reduced inputs bear the risk of an unsufficient availibility of nutrients during plant growth. (In particular, nutrient in organic fertilizers are sometimes not directly plant available since mineralization is crucially dependent on weather conditions). Hence Düngeplanung has to be updated several times during the growing period to account for this effect. In Düngeplanung it is also possible to compare different fertilizer scenarios with each other. Depending on the recent price of mineral and organic fertilizers it can help the farmer to identify the best choice of fertilizer from an economic point of view.

A **direct economic effect of the use of Düngeplanung** for the farmer cannot be generalized since it depends very much on individual farm management. In some cases there can be benefits in respect to saved costs for fertilizers (see above). In most cases farmers appreciate the fact that by following the instructions of Düngeplanung requirements of cross compliance are met. In Germany cross compliance requirements are implemented by different national laws (fertilisation law (DüG), fertilizing ordinance (DüV), fertilizing ordinance of the federal states and Act on Plants handling with Substances Hazardous to Waters (AwSV)). The ammendment of DüV in 2017 obliges farmers to document plant requirement of nutrients prior to fertilization. These plant nutrient requirements are based on legally defined values in DüV which are implemented in Düngeplanung. Furthermore it checks that the benchmark of 170 kg organic N/ha (in farm's average) is not exceeded. Hence, Düngeplanung both helps farmers to fulfil requirement of documentation and makes sure fertilization legislation is met. Still, it has to be highlighted that Düngeplanung goes beyond cross compliance requirements since it not only document plants nutrient requirements but also plans how this requirement will be fulfilled (type of fertilizer, time of application, etc.).

Evaluation of the DST's ability to assess costs and benefits

The fact that many farmers make use of Düngeplanung already shows that farmer's overall benefits by using the tool outweigh the costs. Due to the fact that fertilization legislation in Germany has been tightened recently, most farmer's make use of the tool in order to make sure they meet current obligations. Also saved inputs are of clear benefit since they directly reflect on marginal return. Indirectly, reduced inputs also negatively affect emissions to the environment which is, however, not of direct economic benefit to the farmer. However, the overall uptake of the tool significantly depends on the subsidy payments (for respective advisory service) which keep direct costs for the farmer comparatively low.

3.4 ENVIRONMENTAL YARDSTICK, NETHERLANDS

The Environmental Yardstick was developed in 1991 by the Centre for Agriculture and Environment (Reus, 1991; Reus,1992; Reus and Pak, 1993). The Yardstick enables farmers to choose pesticides with the least harmful effect on the environment, and aims to quantify the impact of the use of pesticides crops grown at arable land and horticulture as well as from greenhouses. The Yardstick is used to assign environmental impact points for risk to aquatic organisms, risk of leaching to groundwater, and risk to soil organisms. The risk for natural enemies and pollinators is indicated on the Yardstick with an A, B or C. An A means that the pesticide fits within integrated cropping systems. B means that it doesnot always fit and C means that is not compatible with integrated crop protection. The tool therefore serves to monitor environmental performance of farming activities, but is also used to set standards for ecolabels and for information about sustainable agricultural products. The tool works at field level but results can be scaled up to regional or national levels. The tool is used as a policy tool to inform policy makers on the effect of collective changes in farmers' pesticide use over years, based on information on pesticide used – and therefore information can be provided before changes are observable in the water bodies, including groundwater.

Assessment of direct costs for the farmers

User costs and fees related to the use of the Environmental Yardstick: The Environmental Yardstick is free for farmers in the form of a limited edition, using 3 pesticides at a time. Commercial (advisor) companies or projects use the full list of pesticides for a price of €2.250/year (excl. VAT). There are 15.000 agricultural users in farming, about a third of the total farmer population (Nicholsson et al, 2018. 5.1. Deliverable). Most users use the Environmental Yardstick indirectly, through pesticide registration programs or demands from their clients or environmental label.

Payment for advisory services: As the tool and information sheets are readily available, most farmers can use it without additional advice. When in doubt which alternative to choose, they may consult their farm advisors. Within projects, the farmers receive free advice on their environmental impact and the possible alternatives.

Time and costs of time: Advisors make use of the environmental impact sheets available in the tool, which are relatively quick to make and consult, i.e. the use is not time demanding for advisors. For farmers the free tool allows for the comparison of 3 pesticides at a time. This would take about 5-10 minutes per 3 pesticides, so total time depends on the number of pesticides in use. The information sheets (mostly available in Dutch) give direct overview of the scores per pesticide. We conclude that the use of the tool is not time-demanding for farmers.

The direct effects on profits. There is no direct information on saved inputs to the farmers from using the online tool, as their input is not saved. CLM has access to historical data of the farmers involved in projects where the tool is used.

Through use in the project ‘Clean Water for Brabant’, environmental impact has been monitored since 2001. The farmers use the environmental impact sheets and get their individual scores after each growing season. Between 2011 and 2018, the difference between the 25% of farmers with lowest impact and 25% of farmers with highest impact has been recorded (Table 2). While not a direct consequence of using the environmental yardstick, it serves to show that lower environmental impact does not result in higher costs for the farmers.

Table 2 Environmental impat points (EIP) and pesticide costs (€) of potato farmers with 25% highest and 25% lowest impact points on groundwater and surface water. Averages between 2011 and 2018.

Environmental impact	**Environmental impact (EIP)**	**Costs of pesticides (€)**
25% lowest groundwater	317	603
25% highest groundwater	1799	843
25% lowest surfacewater	345	599
25% highest surfacewater	1283	823

A group of students compared three different spraying schemes against weeds in potato, sugar beet and maize, namely the ‘Clean Water scheme’, the scheme advised by independent advisers, and the sceme as advised by salespersons from de pesticide companies. The clean water approach did not only have the lowest environmental impact, it also had a lower cost compared to the other schemes. For the duration of the trial, there were no significant differences in weed presence in the plots.

The two examples above show that reducing environmental impact through the Environmental Yardstick can result in pesticide cost reduction for the farmer. Also, in practice there are no yield losses, as farmers and their advisors base their choice of pesticides on effectiveness on the target organism.

Assessment of indirect costs for the farmers

The indirect costs for the farmers include transaction costs, e.g. costs of using and learning to understand and use the Yardstick.

Evaluate and assess the benefits of using DSTs at farm level

The benefits of using the tools for the farmers is the ability to evaluate the environmental effects. We conclude that the farmer is not able to evaluate if changes in pesticide use have any effects on the costs, and not either whether the changes in pesticide use affects the risks. But Yardstick provides information to assess the environmental risk, which is the purpose of the tool.

From a test of Environmental Yardstick (done by reserachers from University of Lincoln as part of Fairway, task 5.1) on farmers and agronomists in UK, it was concluded that 70% of the farmers participating in the survey would consider using this tool. Among the reasons for their appreciation of the tool was that it was considered that the tool was easily accessible and easy to use, in an app for smart phone or iPad, meaning that it is not time consuming to use. Concrete information about time was not provided, however.

Benefits from advice for implementation of abatement measure to ensure cross-compliance, according to the CAP and national regulations. The Yardstick only provide information on the environmental impact of the pesticide, and no advice is given on the choices.

4. Evaluation of the DST's ability to assess costs and benefits

The Yardstick is free for farmers as long as they test only 3 pesticides at a time, and about 15.000 farmers use the tool. This is 36% of the farm population. The tool is developed to enable assessment of environmental effects and not economic. It provides information to farmes so that they are able to choose consciously and measure the progress they make towards a more environmentally sound crop protection. We conclude that the tool is not able to give advise on costs and benefits.

3.5 MANNER-NPK, UK

MANNER (MANure Nutrient Evaluation Routine) was developed by ADAS with funding from the UK government Department for Environment, Food and Rural Affairs (Defra) and was first launched in August 2000. It was originally developed to predict crop available nitrogen (N) supply following farm manure (and other organic material) applications to land, taking into account manure N analysis, ammonia volatilization and nitrate leaching losses, and the mineralization of organic N. A new version of the software (MANNER-NPK) was developed to enhance the N loss and crop available N supply predictions by utilizing more recent scientific information. In response to user and stakeholder feedback, the software functionality was also extended to include predictions of phosphorus (P), potassium (K), sulphur (S) and magnesium (Mg) supply to crops, and to enable users to view the results in terms of both the fertilizer replacement value (kg/ha) and the economic value (£/ha) of manure applications.

The tool operates at the individual field level and is **used by farmers and advisors**, often as part of a nutrient/manure management advice package. The MANNER-NPK software is also incorporated within PLANET (Planning Land Applications of Nutrients for Efficiency and the environmenT), which is a nutrient management DST used by farmers and advisers for field level nutrient planning, and for assessing and demonstrating compliance with Nitrate Vulnerable Zone (NVZ) rules.

MANNER-NPK can also be used as a policy tool to demonstrate the effect of different manure application timings and methods on losses of nitrate, ammonia and nitrous oxide. For example, it has been used to model the impacts on N loss of introducing the closed period for spreading high N available manure (cattle slurry, pig slurry, broiler litter and layer litter) in England and Wales.

Assessment of direct costs for the farmers

User costs and fees related to the use of MANNER-NPK: MANNER-NPK and PLANET are free for both farmers and advisors to use; the software is also freely available to other software developers.

Payment for advisory services: MANNER-NPK is often used as part of a nutrient/manure management advisory package.

Time and costs of time. The typical time to create a nutrient management plan is 40 hours (for a farm of 24-40 ESU (European Size Unit), although this can range from 6 hours for small farms up to 70 hours for the largest farms. It is difficult to estimate how much of this time is required for use of the DST per se, however it would probably take an experienced used about 10 minutes per field to run MANNER-NPK, assuming all the required input data was to hand. If a farmers' time is costed at £20 per hour, then the cost of using MANNER-NPK would be about £3.30 (€2.80) per field.

The direct effects on profits. Information on the fertiliser value (N, P and K) of each manure application is shown in kg/ha and £ sterling. This tells the farmer the potential savings in the amount of mineral fertiliser that would need to be used depending on the manure application timing and method. If this information is correctly acted on, then a farmer (who is not already accounting for the nutrients in manure applications) could expect to benefit from reduced spending on mineral fertilizer without experiencing any loss of yield i.e. increased profitability.

Assessment of indirect costs for the farmers

The indirect costs for the farmers include the costs of learning to understand and use MANNER-NPK. The DST was specifically designed to be easy to understand and use, and comprehensive user information and help is available. It is therefore expected that no more than 1-2 hours would be required before a farmer could start to use it effectively. Other indirect costs could include the cost of the laboratory analysis of manure samples for their dry matter and nutrient content (typically about £100/€85), if this is not already being done. However, in the absence of farm-specific manure analyses, the farmer can use the default values provided as part of the DST.

One consequence of using the DST could be that a farmer is advised to apply high readily-available N manures (i.e. slurry and poultry manure) in spring rather than autumn, to reduce the risk of overwinter nitrate leaching losses and comply with NVZ rules. This may mean that more slurry storage is required which would obviously result in a large cost to the farmer that could not be recovered in other ways e.g. increased yields or savings in mineral fertilizer use. The benefits of DST use in this case are at the societal level rather than for the individual farmer who will experience it as a cost.

The benefits of using DSTs at farm level

The benefits of using the tools for the farmers include the ability to evaluate the environmental effects of manure application timings and methods. Mitigation measures are not directly represented by MANNER-NPK, but N losses via leaching are shown. This information can be used to demonstrate to a farmer how changing the timing or method of manure application could affect N losses to water (and hence water quality). If farmers have a better understanding of the factors affecting N losses to water (and air), then any subsequent changes they make to the timing and method of manure application could help reduce the environmental risk.

MANNER-NPK was tested at Case Study no. 11 in Baixo Mondego (PT). It was concluded that a DST with similar functionality would be of benefit to farmers in the case study area, where no equivalent software is available at present for producing nutrient management plans. Because it was developed for use in the UK, country-specific data and calibration would be required before MANNER-NPK could be used in other countries (Laursen *et al.*, 2019). Nevertheless, clear benefits to users were identified by stakeholders who supported the provision of a similar DST in the case study area.

Benefits from advice for implementation of abatement measure to ensure cross-compliance, according to the CAP and national regulations. MANNER-NPK includes a facility whereby it shows a 'warning message' in situations where a planned manure application will not comply with NVZ Action Programme rules. The DST also provides more information about which rule(s) would be broken, thereby allowing the farmer to adjust the quantity of manure to be applied and/or the application timing in order to ensure compliance.

Evaluation of the DST's ability to assess costs and benefits

MANNNER-NPK (and PLANET) are provided free for farmers to use. There are currently over 18,000 registered users of PLANET and 4,600 registered users of MANNER-NPK. The main benefit is that MANNNER-NPK allows the farmer to account for the nutrient content of their manures (and their economic value) and to make savings in mineral fertilizer use. It also promotes a better understanding of how the timing and method of a manure application can influence N losses to the environment (including via nitrate leaching to watercourses), reducing the risk of pollution incidents and aiding compliance with NVZ regulations.

3.6 FARMSCOPER, UK

The Farmscoper DST can be used to assess diffuse agricultural pollutant loads at farm, catchment and national scale and quantify the impacts of farm mitigation methods on these pollutants. It was developed by ADAS for England and Wales with funding from the Department of Environment, Farming and Rural Affairs (DEFRA) and subsequently from the national Environment Agency.

The Farmscoper DST is a series of Microsoft Excel spreadsheets with macro-driven databases that has been designed to allow the generation and customisation of individual farm systems, based on on-farm data or using available census data on livestock, cropping and manure management.

Outputs to water and air are modelled for a range of atmospheric and waterborne contaminants including nutrients, pesticides and sediments. Predictions are based on well-established models which have been used in the UK, including NEAP-N for nitrate (Anthony *et al.*, 1996) and PSYCHIC Davison *et al.*, 2008; Strömqvist *et al.*, 2008) for phosphorus and sediment; MACRO Tool (Jarvis, 1995) and SWAT for pesticides. Contaminant losses are apportioned across source (e.g. dairy, beef, arable products, grass products), pathway (e.g.

runoff, preferential flow, leaching) and timescale (short to long term) within the model. Soil types in the model are represented based on soil permeability and classified based on the requirement for artificial sub-surface drainage (e.g. pipe drains). Three drainage classes are available and used as the basis for generating contaminant export coefficients for farming systems on different soils. Three workbooks in the model (Evaluate, Prioritise and Cost) are used to estimate the environmental impact and cost-effectiveness of one or more mitigation methods, from a library of over 100 options, including those in the DEFRA Mitigation Method Guide which farmers have access to. Model evaluation can be undertaken at farm level, or upscaled to catchment or national level. Whilst it is generally used as a tool to inform water quality management strategies and other policy issues (see Section 4.2), it can also be used by individual farmer (providing they have appropriate training, and advice and guidance). Here we consider Farmscoper use at the farm level.

Assessment of direct costs for the farmers

Farmscoper is free to users and can be downloaded from the ADAS website (https://www.adas.uk/Service/farmscoper). There are a range of video tutorials to guide users through setting up a farm model and baseline pollutant losses, using it to identify and assess mitigation measures and work out the cost of the selected mitigation measures on-farm.

Farmscoper can be used both by planners and farmers. When used by farmers the user can set up a “Farm sheet” which allows customisation of farm, crop, livestock and nutrient management; this is straightforward for anyone who has previously done a farm nutrient plan. Most farmers would be capable of this within an hour providing data on crops, land area and management are available. This would provide them with a baseline model covering the expected losses of pollutants to water and air for their farm. For evaluation of mitigation options and running different scenarios the time taken would depend on the options and scenarios being assessed. It is not possible to estimate this.

Assessment of indirect costs

For farmers the tool can be time-consuming to use, but it is feasible. We estimate that it would take 3-4 days of familiarisation for a user with average skills to be adept in using Farmscoper. If an advisor was to produce a model for a farmer then, providing they were trained, it might take 5-6 hours to produce the results for a single farm. It is very user-friendly and the online advice and help is good. A basic user could set up their farm as a baseline in approximately 1-2 hours.

The assessment of the economic costs and the cost-effectiveness of mitigation measures

It is possible to estimate the effects on the economic outputs in terms of a decrease or increase in yields, changes in inputs, time spent and the increased or decreased uncertainty on the outcomes. All the costs of activities (e.g. for dairy the value of milk produced for a herd of a set size) and mitigation measures (e.g. the price of a buffer strip) are included in the model (updated to 2015 but allowing the user to alter if needed). The baseline can be set up at the farm level or catchment level.

Farmscoper allows the user to set a prior implementation level for mitigation measures for the farm against which the impact of the planned measures can be evaluated. It provides both the environmental impacts and the cost implications for the farms of single and sets of mitigation measures. It is possible to select measures based on their effect on particular pollutants (e.g. pesticides or nitrate) and optimise these automatically within the tool. The output from such an optimisation process is a graph of the costs plotted against the % reduction in a specific pollutant, allowing the user to identify the point at which cost-benefits are maximised for their farm. Reporting features provide tabulated and graphical outputs to facilitate comparison of options. An example of how Farmscoper can be used to assess the costs and benefits of implementing mitigation measures for a typical UK lowland grazing farm demonstrates the evaluation of mitigation options within Farmscoper an example of a 101 hectare Lowland Grazing farm type is provided. This livestock farm (beef and sheep, Table 3) is based on the average crop types and areas for that farm type in the 2015 June Agricultural Survey for England and Wales. A free draining soil type and rainfall range of 900-1200 mm per annum was selected. The farm has a stocking density of 89 kg N/ha with 40% of fields next to watercourses and 10% of the area classed as organic soils. In the initial model cattle have access to watercourses during grazing and when moving between fields and the year. Details of land use, nutrient and pesticide use are provided in Table 4. Unit cost data for the model were set at the average for the 2011-15 period, based on a broad range of sources including dairy and meat processors, fertiliser companies, contractors, power, machinery and water companies. For each mitigation method the total upfront capital and annual variable, fixed, output and capital costs for 100% implementation were given alongside the environmental losses to air and water.

Table 3: Livestock numbers on the exemplar Lowland Grazing farm**.**

Bulls (2 years +)	1
Beef Cows and Heifers	27
Beef Heifers in Calf (2 years +)	2
Beef Heifers in Calf (< 2 years)	1
Other Cattle (2 years +)	14
Other Cattle (1 - 2 years)	37
Other Cattle (< 1 year) & Calves	39
Sheep	184
Lambs (< 1 year)	170

Table 4: Farm cropping, nutrient management and plant protection products (PPP) use on the exemplar Lowland Grazing farm**.**

Crop-ping	**Area** (ha)	**Fertiliser applied**				**Manure**		**Pesticides/Plant Protection Products**				
		N (kg/ha)	**P_2O_5** (kg/ha)	**FYM (%)**	**Dirty Water** (%)	**Manure Total N** (kg/ha)	**Manure Total P** (kg/ha)	**Fungicide** (%PPP)	**Herbicide** (%PPP)	**Insecticide** (%PPP)	**Growth Regulator** (%PPP)	**Molluscicide** (%PPP)
Permanent Pasture	75.0	47	14	41	100	12.7	2.8	0	100	0	0	0
Rotational grazing	16.0	90	25	32	0.0	44.5	10.0	0	100	0	0	0
Rough Grazing	4.0							0	100	0	0	0
Winter Barley	4.0	116	48	18	0.0	100.1	22.5	35	35	15	15	1
Spring Barley	1.0	95	37	0.0	0.0	0.0	0.0	40	54	3	3	0

Maize	1.0	20	19	9	0.0	200.3	45.1	0	100	0	0	0

The benefits of using Farmscoper at farm level

The power to evaluate single and multiple mitigation measures and get a direct tabulated and graphical output showing the financial cost/gains and the environmental costs/gains is the main benefit of the DST and something farmers would appreciate. Some indicators as to compliance are also provided in the model. For example, if stocking rates exceed the limit for N based on land area farmed then the exceedance is flagged with a warning to the user.

Evaluation of Farmscopers ability to assess costs and benefits

Farmscoper provides an assessment of diffuse agricultural pollutant loads at farm-scale and allows the impacts of farm mitigation methods on these pollutants to be quantified. Over 100 mitigation options, typical for English and Welsh farms, are available for selection and their performance can be assessed based on the specifications of the farm and farm management input as a baseline. Both economic and environmental costs/benefits are assessed simultaneously and outputs are provided in tabular and graphical formats. The cost/benefits of different scenarios can be assessed by a user and optimised to their specific requirements in terms of the pollutant of interest. It provides a strong basis for on-farm decision making. Although the exact number of users is not known, the Farmscoper webpage on the ADAS website from which the tool can be downloaded has had over 3,000 unique page views since it was created in 2012.

3.7 SUMMARY AND DISCUSSION ON FARM LEVEL DSTS

A summary of the evaluation of the different farm level DSTs is shown in Table 5, based on a qualitative assessment of their relative costs and benefits, drawing on the expertise of the project team and experience from the FAIRWAY case studies. The criteria used for the comparison were based on those identified in earlier Work Packages (c.f. Figure 1) and elaborated in the Methods section.

Table 5. Synopsis of costs and benefits of farm level DSTs

		DK		GE	NL	UK	UK
		Mark Online	**Plant Protection Online**	**Dünge-planung**	**Environ-mental Yardstick**	**Manner NPK**	**Farm-scoper**
Direct costs	Purchasing fee	181 EUR	181 EUR	74 EUR	0 EUR	0 EUR	0 EUR
	Maintenance fee	220-500 EUR	168 EUR	10 EUR	0 EUR	0 EUR	0 EUR
	Advisory service	-	-	++	-	-	++
	Time spent	-/++	-	-/++	-	-	++
Benefits	Saved inputs	+/++	+/++	+/++	-/+	++	+

	Cross compliance fulfilment	++	++	++	-/+	+	++
	Environmental awareness	++	++	-/+	++	+	++
	Public recognition			-/+		?	?
"+" means high, "-" means low							

Table 5 shows that there are significant differences between the farm level DSTs we have assessed. None of the tools have a positive score on all criteria.

The experiences from the assessment of the farm level DST's can be summarized in these points: All of the investigated DSTs have a significant relevance in practice.

1. They all have in common that **total costs are kept on a low level**. This is realized in two ways:
   Option 1: Tools are free and very easy to handle (Environmental Yardstick or Manner-NPK) which encourages farmers to use the tool themselves.
   Option 2: The tools are quite complex and require the assistance of an advisor (Mark Online, Plant Protection Online, Düngeplanung). The advisory time is either paid for as part of the general advice from the advisory company (Mark Online, Plant Protection Online) or the advisory time is subsidized (Düngeplanung).
2. Tools have to be in line with agricultural and environmental legislation (e.g. cross compliance (CC) and legislation on national or regional level.). The most important **benefit** for farmers is the security that by following the tool's instructions they **fulfill CC**. The second ranked economic benefit is savings on inputs, reducing waste and the potential for losses to air or water, which closely correspond to environmental awareness. Environmental awareness is, however, of no direct economic return to the farmer.
3. Generally: Variation is substantial and individual costs and benefits always depend on farm scale, mangement practice, user habits, etc.
4. Public recognition cannot be achieved by any of the DST.

4. DECISION SUPPORT TOOLS AT CATCHMENT AND NATIONAL LEVELS

4.1 FARMSCOPER, UK

The Farmscoper DST and its use at the farm scale have been described in Section 3.6 above. In addition, the DST can also be used at a catchment or national level using the Upscale tool. The Upscale tool is prepopulated with catchment level census data for Water Framework Directive waterbodies up to river basin scales (in England only). This has been used to inform water quality management strategies and has been applied as a policy tool in a number of studies to date (e.g. Micha *et al.*, 2018; Collins *et al.*, 2016; Gooday *et al.*, 2014; Zhang *et al.*, 2012).

Modelling Cost-Effective Measures using Farmscoper

The current version of Farmscoper contains over 100 mitigation measures that can be applied to a given farm or farm type. The options are based primarily on the Defra Mitigation Method Guide and includes those relating to Cross Compliance, Catchment Sensitive Farming and the Countryside Stewardship Schemes in England and Wales. Each option has a full cost and contaminant loss estimate associated with it, and they are classified depending on whether their impacts relate to nutrients, livestock, soil, delivery or pesticides either singly or in combination. Measures applicable to arable crops, for example, include cultivation of compacted soils, establishing buffer strips, management of field corners, wild bird cover, uncropped margins and leaving residual levels of non-aggressive weeds in crops. For dairy farms, measures include increased scraping frequency in dairy cow cubicle housing and washing down of dairy cow collecting yards.

Inclusion of Measures in the Farmscoper DST

Measures for implementation are selected from lists in the Farmscoper Evaluate tool. For selected measures it is possible to estimate, both individually and in combination, the effects on losses to the environment and alterations in economic outputs in terms of increased/decreased yields, changes in inputs, time spent and increased/decreased uncertainty of the outcomes. It provides both the environmental impacts and the cost implications of single and sets of mitigation measures. It is possible to select measures based on their effect on particular pollutants (e.g. pesticides or nitrate) and optimise these automatically within the tool. The output from such an optimisation process is a graph of cost plotted against the % reduction in a specific pollutant allowing the user to identify the point at which cost-benefits are maximised. Reporting features provide tabulated and graphical outputs to facilitate comparison of options.

The initial scenario evaluated considers the impact of introducing mitigation methods that correspond to Cross Compliance Good Agricultural and Environmental Conditions, namely:

- 1 (Establishment of Buffer Strips along Water Courses),
- 4 (Providing Minimum Soil Cover) and
- 5 (Minimising Soil Erosion).

These methods ("X-C GAEC" in the model) are given in Table 6 below. In a second scenario, 4 additional measures were added covering potential sources and pathways of sediment and nutrients to water courses (Table 7). A 100% implementation of each measure on the farm was assumed, but it is possible to also consider a partial implementation (such as where a crop rotation is implemented and a measure is only active on a sub-set of fields in each year). A comparison of the outputs from the model is given in Table 8. The baseline scenario refers to no implementation of measures on the farm.

Farm total production changes little from £81,212 (€95,455) (£44,949 (€52,832) gross margin after costs of £36,263 (€42,623)) for no measures to £81,173 (€95,410) for all measures (both scenarios) as little land is removed from production and stocking rates would not alter. The costs of implementing the measures however need to be included; as fixed costs covering the capital investment, labour and machinery associated with the measure and variable costs covering the change in gross margin for stock or cropping based on implementation of the measure. This is an estimated total of £8,618 (€10,129) for Scenario 1 or £10,211 (€12,002) for Scenario 2.

The environmental benefit value (£912 (€1,072) for Scenario 1; £1972 (€2,318) for scenario 2) is an estimate of the monetary value of the pollutant emission reductions, converting reductions in methane and nitrous oxide to CO_2 equivalents, reductions in ammonia to a value representing the damage costs to society and reductions in nitrate, phosphorus and sediment to values representative of the impacts of water pollution on water quality. Given that the mitigation measures selected for this example target overland pathways for contaminant losses to waterbodies, the greatest improvements in pollutant outputs are in sediment, with a reduction in load of 17.4% for Scenario 1 and 30.2% for scenario 2, and phosphorus, with a reduction in load of 16.1% (1,404kg) for Scenario 1 and 21.7% (2,441kg) for Scenario 2. To maximise cost-benefits Farmscoper allows model optimisations to be run for single or multiple parameters, identifying the investment which maximises the reduction of phosphorus and sediment losses.

Table 6: Mitigation measures relating to Cross Compliance Good Agricultural and Environmental Conditions ("X-C GAEC" in the model).

Method IDs: Set 1	**Description**
5	Early harvesting and establishment of crops in the autumn
8	Cultivate compacted tillage soils
9	Cultivate and drill across the slope
10	Leave autumn seedbeds rough
11	Manage over-winter tramlines
14	Establish riparian buffer strips
37	Reduce field stocking rates when soils are wet
76	Fence off rivers and streams from livestock
115	Leave over winter stubbles

Table 7*:* Mitigation measures relating to Cross Compliance Good Agricultural and Environmental Conditions with 4 additional mitigation measures (marked with bold text).

Method IDs: Set 1	**Description**
5	Early harvesting and establishment of crops in the autumn
8	Cultivate compacted tillage soils
9	Cultivate and drill across the slope
10	Leave autumn seedbeds rough
11	Manage over-winter tramlines
14	Establish riparian buffer strips
37	Reduce field stocking rates when soils are wet
38	**Move feeders at regular intervals**

39	**Construct troughs with concrete base**
60	**Site solid manure heaps away from watercourses/field drains**
76	Fence off rivers and streams from livestock
79	**Farm track management**
115	Leave over winter stubbles

Table 8: Comparison of output costs (£) and benefits for implementation of 2 mitigation option sets on the Lowland Grazing Farm.

	Fixed Cost	Variable Cost	Total Cost	Environmental Benefit	Nitrate	Phosphorus	Sediment	Ammonia	Methane	Nitrous Oxide	Pesticides	FIOs	Soil Carbon	Energy Use	Production	Biodiversity	Water Use	Soil Quality
Values	£	£	£	£	kg	kg	kg	kg	kg	kg	Units	10^9 cfu	t	kg	£	-	-	-
Baseline	0	0	0	-	2,295	23	8,090	1,287	7,254	887	0.5	8,764	14,316	73,331	81,212	-	-	-
Cross Compliance GAEC	4,093	4,525	8,618	912	2,230	19	6,686	1,370	7,252	865	0.5	7,175	14,260	73,665	81,173	7.7	0.0	13.5
Cross Compliance GAEC with Extra Measures	4,510	5,701	10,211	1,972	2,209	18	5,649	1,370	7,252	836	0.5	5,903	14,254	73,705	81,173	7.9	0.0	15.5
Impacts (Change relative to Prior)	**£**	**£**	**£**	**£**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**-**	**-**	**-**
Cross Compliance GAEC	4,093	4,525	8,618	912	2.8	16.1	17.4	-6.5	0.0	2.4	7.3	18.1	0.4	-0.5	0.0	7.7	0.0	13.5
Cross Compliance GAEC with Extra Measures	4,510	5,701	10,211	1,972	3.7	21.7	30.2	-6.5	0.0	5.7	7.3	32.6	0.4	-0.5	0.0	7.9	0.0	15.5

Spatial scale – Upscaling to Catchment or National Scales

The Farmscoper Upscale tool allows pollutant losses to air and water to be made at catchment up to national scales for England (data flows and relationships among the tools are summarised in Figure 2). For each catchment multiple farm models are generated representing those typical within the catchment and calculating losses from those catchments under the different climatic and soil characteristics present in the catchment. Up to ten farm types covering the main categories present in England can be represented in the upscaling model; each customised according to the likely number, size and stocking rates and land use within a particular catchment. For small catchments with records for individual farms can be used or for larger catchments the farms can be generated using Census data (from Defra's 2015 June Agricultural Survey for England) included in the tool covering 4091 WFD waterbodies, 336 Operational Catchments,90 water management catchments and 10 river basin districts in England. The spatial definition of farms has been improved within the 2015 database used in the current DST. Instead of a single geographical location for a farm to which a climate and soil type was defined, the current database uses field boundary data and extracts the proportions of each farm within each WFD waterbody, their individual climate and soil types and represents them within the model.

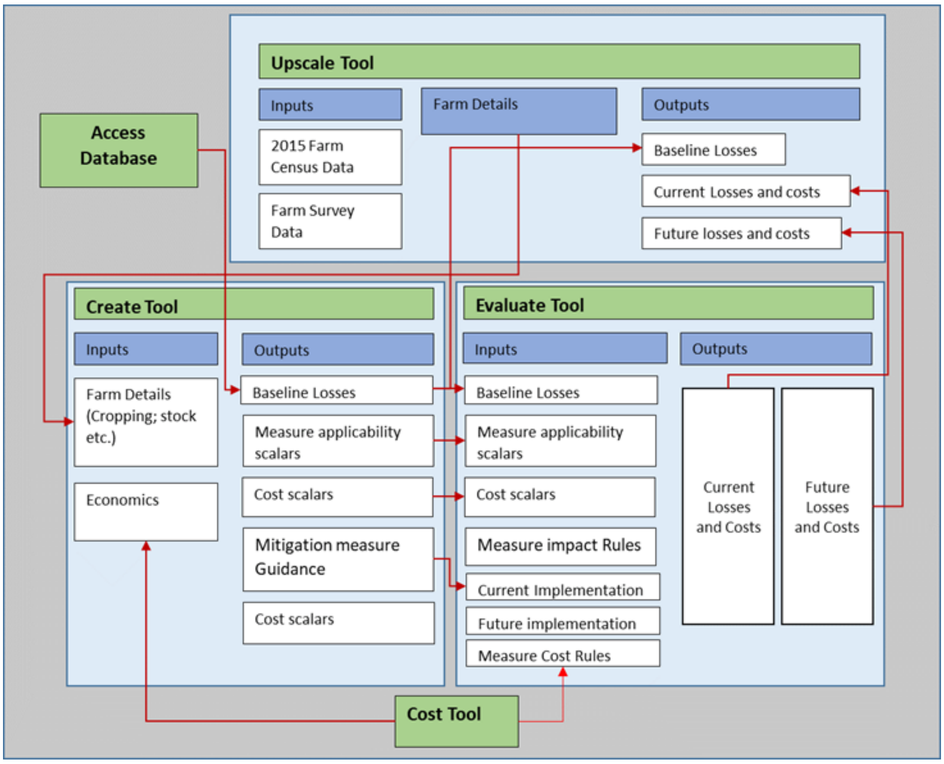

Figure 2: Relationships between the Farmscoper tools and data flows in a catchment scale model (modified after Figure 4 in Gooday, 2017).

Ability to model risk and uncertainty

Uncertainties in the model both at single farm and small to large catchment scales have been considered by the developer and are included with the DST documentation.

The model is based on a database of pre-calculated contaminant export coefficients to generate a baseline contaminant load. These calculations are based on a set of assumptions from national level practices (such as the standard times at which fertiliser or slurry is applied) and what is typical across a farm type rather than data from an individual farm. Climate and soil data were aggregated to 3 soil types and 6 climatic zones. In each application of the model these assumptions need to be considered and baseline outputs validated against available monitoring data for the catchments where possible.

There is considerable flexibility within the model for customisation and adaptation. Baseline pollutant estimates and reductions associated with each mitigation measure can be assigned uncertainty bounds within the tool. A set of sensitivity controls within the Evaluate Tool allows a range of variation to be set for each contaminant, with a default value of 25%, within a Confidence Ranges worksheet (Table 9). Evaluation of measures with sensitivity included provides outputs which are robust within the defined uncertainty limits in the relative contributions of different contaminant source and pathway.

Table 9: Tabulated display of confidence limit settings (set to 25% default) for Nitrate, Phosphorus and Sediment within Farmscoper

Pollutant	Source	Area	Pathway	Type	Timescale	Form	Max Variation (+/- %)
Nitrate	All	All	All	AllPollutant	All	Dissolved	25
Phosphorus	All	All	All	AllPollutant	Short	Dissolved|Particulate	25
Sediment	Land	All	All	Soil	Short	Particulate	25

Use of the model by decision makers

Several published studies have used the Farmscoper DST at catchment scales to estimate the impact of a range of mitigation measures. Collins *et al.* (2016), for example, surveyed farmers across England to identify the mitigation measures more likely to be adopted by farmers and then applied the model to identify the potential reductions in emissions to air and water relative to business as usual. Business as usual emissions and uncertainties were based on comparisons with available monitoring data for England and Wales but acknowledging the limitations of available data in terms of low sampling frequencies and difficulties in disaggregating non agricultural sources. Across a range of farm types they identified 29 measures which, due primarily to low cost of implementation, were appealing to farmers and likely to be adopted. They then evaluated these measures for the major farm types in 99 water management catchments across England and Wales and, assuming a 95% uptake level, established what the technically feasible impact on agricultural emissions to air and water would be. Projected emission reductions across the catchments were estimated to range between 8-37% for sediment, 12-24% for ammonia, 6-29% for Total Phosphorus, 4-16% for nitrate/methane and 5-10% for nitrous oxide. This information provides guidance and evidence for policy makers in the development of agri-environmental schemes, the likely costs and their efficacy across a range of catchment typologies and farm types.

4.2 TargetEconN, Denmark

The Target Econ N model for decision support

The TargetEconN model is an integrated economic and biophysical social planner DST, set up for Danish catchments/watersheds. The model minimizes the costs for society, of meeting a nutrient load reduction target in a specific water body, from the catchment loading to this water body.

The DST was designed for the assessment of cost-effective implementation of nutrient load reductions, as required in the Water Framework Directive to achieve good ecological status. The model is now calibrated for the whole of Denmark and is set up for modelling reductions to coastal water and lakes. The model will be set up to include groundwater as soon as the data sources for this modelling are available. The first version of the model was designed for the Limfjorden catchment, where Aalborg, one of the Danish case studies in FAIRWAY, is situated (Konrad *et al.*, 2017; Hasler *et al.*, 2019). A fact sheet describing the model concept can be found at http://dnmark.org/wp-content/uploads/2017/03/Fact-sheet-TargetEconN-modelling-framework_Final.pdf.

The model has been developed by Aarhus University as part of several research projects and by funding from the Danish Economic Councils and by the Ministry of Environment and Food. The model has been used for advising the Danish Ministry of Environment and Food, as well as the Danish Economic Councils.

Method to elicit cost-effective solutions

The method used in TargetEconN is to minimise the costs for reaching the N reduction target by implementing abatement measures in the fields of the catchment. Only one measure can be implemented for each field in order to avoid infeasible solutions, such as implementation of reduced nitrogen application and wetland at the same time. The costs and effects of the measures are modelled using information on the crops grown at field scale in the catchments. The effects of the measures are measured as the leaching in kg per ha from the root zone, using empirical leaching functions. The transport from the root zone to the coast is, being modelled by retention coefficients and the transport includes retention in soil, surface and groundwater. The retention reduces the nitrogen load to coastal areas between 0 and 90% of the initial leaching. The capacity for implementing each of the N abatement measures in the catchment is an assessment of the hydrological and land use specific potential, subtracting the area where measures have been implemented before.

The optimization routine enables calculation of the optimal spatial location of nutrient abatement measures, taking into account the spatial differences in costs, the potential of implementing the different measures at field level as well as the nitrogen leaching reduction effects. The model is developed for both nitrogen and phosphorus, but because of poor data the model is not calibrated for phosphorus yet.

Data overview

The modelling at field scale level is enabled by detailed data at field level from the General Agricultural Register and the Danish Husbandry register, collected by the Ministry of Environment and Food, and used for establishing the dataset Basemap (Levin *et al,* 2017). These registers include information on crops grown at each field, and time series data are used. The data set also includes information at crop- and field level on manure and fertiliser application. Prices for the crops included in the model were averages from 2011-2013 in the former Limfjord application (Hasler *et al.*, 2019), and for the most recent version of the model these costs are updated to an average for the period 2013-2018. Cost data are collated from Farmtal Online, administered by the Danish Agricultural Advisory service, SEGES (2018).

Abatement measures

The model includes in total 24 different N abatement measures for sand and clay soils. The abatement measures include technological, land management and set aside options, and all measures are implemented on agricultural land, except for constructed wetland. This measure is expected to be implemented in areas close to the fields, and the wetlands reduce the nitrogen loads from the fields to the coast.

The DST's ability to model the spatial distribution between farms or locations

TargetEconN is not set up to model farms, but is configured to model the cost-effective allocation of measures at agricultural field scale. The map in Figure 3 shows the spatial allocation of measures in the Limfjord catchment from implementing nitrogen load reductions of 4165 tons N. The map shows the distribution of the measures implemented to achieve the cost-effectve solution (Hasler *et al.*, 2019, page 915).

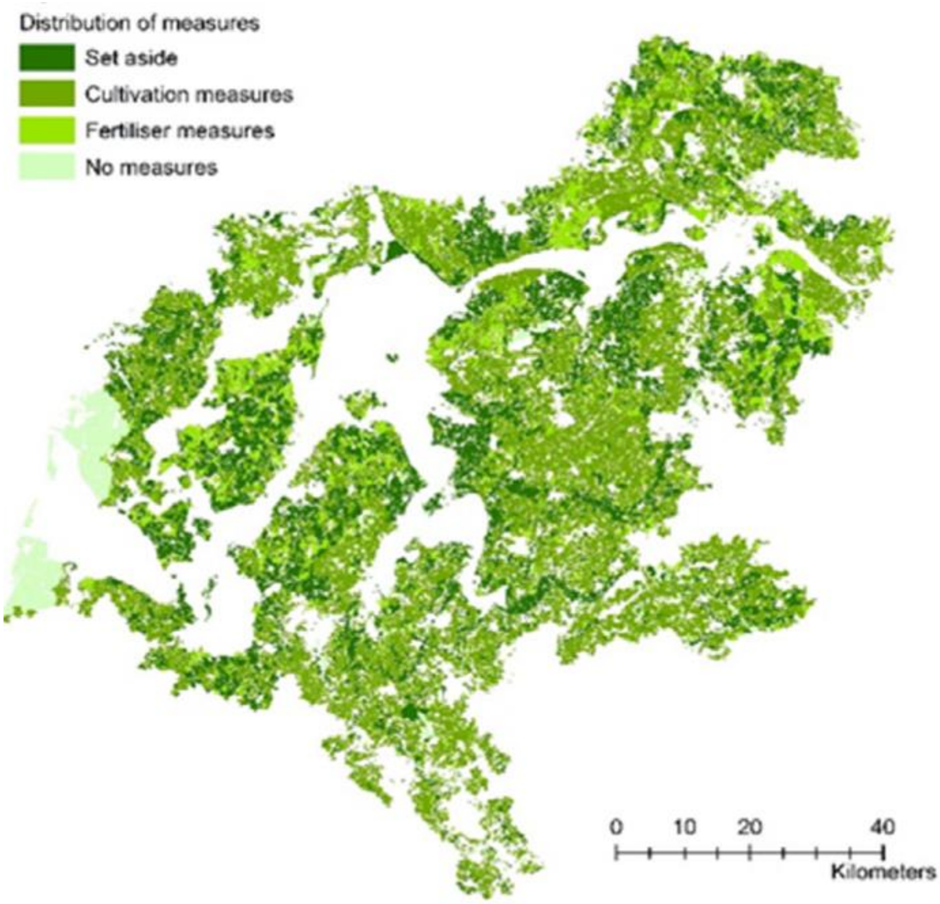

Figure 3. The spatial configuration of the cost-effective solution to achieve the WFD target in Limfjorden, Denmark (*Source*: Hasler *et al.,* 2019).

TargetEconN has also been used to compare a general regulation with more targeted regulations, which is more cost-effective as the targetting included optimisation of the spatial localisation of the measures to both costs and nitrogen load reductions. This comparison showed that the savings for society and agriculture can be substantial: While the general, non-targeted regulation could achieve the load reduction target of the fjord at a cost of 58 DKK/kg N (approx. 7.76 €/kg N), the targeted and cost-effective solution fulfilled the same load reduction target at a cost of just 13 DKK/kg N (approx. 1.74 €/kg N) (Hasler *et al.*, 2015). This assessment was done for a rather low load reduction target which was the maximum achievable load reduction when using genereal load reductions of the nitrogen appliation to crops in the catchment. The results are not comparable to results from Hasler *et al.* (2019), illustrated in the maps, as different load reduction targets are achieved, i.e. the costs per kg N are necessarily higher to achieve the high load reduction.

The ability to model risk and uncertainty in TargetEconN

TargetEconN is suitable for sensitivity analyses of the assumptions and data inputs to the model, and the uncertainty inherited in such assumptions. Examples are the assumptions made on effects of measures to reduce the nitrogen leaching and load, the abatement costs or the retention of nitrogen in soil and water before it reaches the target water body.

Hasler *et al.* (2019) tested the effects on the cost-effective solutions from uncertainty on the retention in the catchment. They investigated both the level of retention and the distribution of the retention within the field blocks in the catchment.

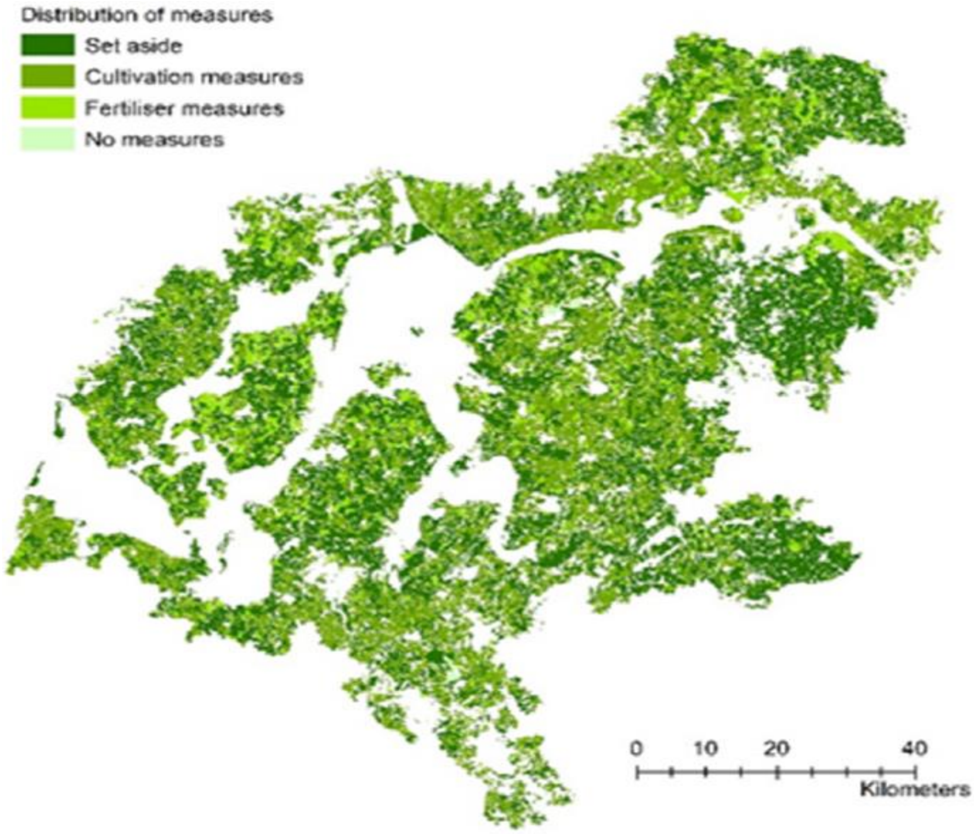

Figure 4. The average retention scenario.

The map in Figure 4 shows the spatial distribution of the cost-effective mix of measures, when differences in retention are not taken into acount, but modelled as an average retention in the whole catchment. This application of constant retention on 69% in the whole catchment can be compared to the solution shown in Figure 3, which is built on variations in the retention, ranging from 0 to 90% retention. It can be observed that the measures are more uniformly distributed in Figure 4, compared to Figure 3. Furthermore the costs of achievning the load reductions are 218 Million DKK/year (approx. 29.8 million. €/year) when variation in the retention is assumed, while the costs increase to 273 DKK/year (36.5 €/year) when the retention is averaged thorougout the catchment. The cost-effectiveness of the achievement in the solution with variation in retention is 52 DKK/kg N (6.96 €/kg N) and with constant retention the cost-effectiveness is 66 DKK/kg N (8.83 €/kg N); i.e. taking retention into account reduces the cost signifiantly. Since retention is modelled with uncertainty this assessment is an example of how uncertain assumptions can be modelled and measured (Hasler *et al.*, 2019).

Use of the model by decision makers

The results from the model have been used by different decision makers, such as the Ministry of Environment and Food as well as the Danish Economic Councils. In 2019 the model is being used to advise the Ministry of Environment and Food on cost-effective implementation of the Water Framework Directive, and different sentitivity analyses are being made in order to explore the effect of e.g. capacity of the implementation of measures in the catchments on the cost-effective solution. In the mentioned study the model results are being compared to the results from other models.

The usefulness for cost-assessments for waterworks has been discussed with Aalborg Water, who found the facilities of this model attractive because of the detailed data sources and the field scale model results. Because of the field scale data inputs the model can be run at other spatial scales than the predefined catchments used now – the model can e.g. be calibrated to a drinking water protection area.

The costs of using the model correspond to the costs of the time researchers use for modelling, and these costs have been covered by the users. The development costs of the model have been covered by research grants.

4.3 SUMMARY AND DISCUSSION ON CATCHMENT SCALE DST'S

Both Farmscoper and TargetEconN are examples of catchment scale tools that model cost-effective solutions, that can be used for policy advicse.

The TargetEconN model is a model tool which is designed to model cost-effective solutions to nutrient policies, and the model has been used to advise decision makers in Denmark. The model is complicated to run, and requires specific software, so the model is only run by researchers. The spatial distribution of the results is considered valuable for decision support, and this is also being commentedsupported by feedback from the Aalborg Water's point of view. The Ministry of Environment and Food in Denmark have also indicated that the model results provide good information on the allocation of the measures and their distribution. In Hasler et al. (2019) it was concluded that the model is well suited for policy advice, and for assessment of the sensitivity of the assumptions used. TargetEconN has been used to compare a general regulation compared to a more targeted regulation, which is more cost-effective as the targetting included optimisation of the spatial localisation of the measures to both costs and nitrogen load reductions. This comparison showed that the savings for society and agriculture can be substantial. The scenario assessment illustrates that using a DST with detailed hydrologial parameters, as well as cost information, is important for assessment of cost-effectiveness and uncertainty on data inputs and assumptions. This is an important feature of integrated economic and ecological DSTs. The model TargetEconN is well suited to do theise types of sensitivity analyses, and to indicate what the effects are for both resulting load reductions and costs.

Farmscoper has been used as a policy tool in a number of studies to estimate the impact of mitigation measures on water quality. It allows a policy user to test the potential reduction in pollutant loads (includinge nitrate and pesticides) loads that could be achieved by implementing one or more diffuse or point pollution mitigation measures; it also quantifies the costs of such measures and the potential benefits for biodiversity. This approach was designed to allow a more holistic assessment of the mitigation of diffuse agricultural pollution given the different policy targets (e.g. Water Framework Directive, Climate Change Act, and the Gothenburg Protocol) and to identify the mitigation methods that provide multiple benefits. The explicit calculation of agricultural production allows for the identification of mitigation methods that can help to achieve target pollutant reductions whilst not reducing food production or adversely affecting farm profitability.

The Farmscoper tool has been used by a variety of government organisations, research institutes, consultancies, levy bodies and other agricultural organisations for more complex assessments of the impacts of policy scenarios and agri-environment schemes, through to prioritising catchment management plans, and assessing pollutant footprints and mitigation potential of individual farms or groups of farms.

5. DECISION SUPPORT TOOLS FOR ASSESSMENTS OF BENEFITS

As described in the introduction to this report, DSTs that measure benefits of water quality improvements for decision makers were chosen as examples of applications of benefit and ecosystem services assessments for decision support. The benefits are measured as the populations' (in catchments or country level) willingness to pay for water quality protection or improvements, and should be measured so that they can be compared to the costs to enable cost benefit analyses. DSTs were chosen that could measure a defined level of change; e.g. a water quality change from a baseline to a policy target (e.g. a limit value for groundwater pollution or a defined level of ecological or chemical status such as in the Water Framework Directive). For this type of valuation both cost-based and utility-based approaches exist.

One valuation approach which can be used as a DST is meta regression analysis which uses data from a large number of original studies on water quality valuation. Meta regression is an example of benefit transfer, i. e. use of original study results for transfer to other sites, where the results can be used for decision support. Meta regression analyses and functions have been established in order to create models for decision support, by using primary and original studies and data to perform more general and generic information on the value of an environmental improvement, and two examples are given to illustrate the use of this type of DST:

- One international groundwater valuation study applying metaanalysis (Brouwer and Neverre, 2018).
- One Danish metaanalysis based on valuation studies from the Nordic countries, valuing water quality improvements using the Water Framework Directive classification of ecological status.

These examples are presented in section 5.1.

Ecosystem services mapping using valuation study results is another example of an decision support approach for assessments of the benefits of water quality improvements. This type of approach can be used to value a large range of benefits from the improvement of water quality. The ecosystem services mapping approaches are spatial, and can include information from the above mentioned meta regression analyses (Bateman *et al.*, 2011). This type of approach also has the possibility of assessing coherence and conflicts between different policy objectives and related ecosystem services, such as the different services resulting from implementation of pesticide and nutrient policies.

Examples of mapping and asessments of ecosystem services as decision support are provided in section 5.2.

5.1 EXAMPLES OF DECISION SUPPORT TOOL USING BENEFIT TRANSFER AND META REGRESSION ANALYSIS ASSESSMENT OF BENEFITS

Meta regression analyses represent a robust type of benefit transfer method which can be used to estimate individuals' or households' willingness to pay (WTP) for environmental changes, e.g. in water quality, effects of groundwater protection etc. The modelling is built on data from existing studies that are already published, and by using regression the large variety of results and explanatory factors from the literature are combined to create a robust function that can be used for decision support. Metaregression models are typically estimated as log-linear models (log (WTP) which include constants and the explanatory variable. When used for decision support, this function is then populated with data from the policy area being considered.

The way it works is that a WTP function is estimated using data from the identified literature, and this function can then be applied to so-called policy sites by including important local values into the function, e.g. regarding demographic factors, average income level and natural conditions in the area. One of the inputs to the model is the change in environmental status of the water, e.g. from moderate to good, and the output of the model is the value of improving water quality from moderate to good condition.

Brouwer and Neverre (2018) made a global meta-analysis consisting of almost three decades of groundwater quality valuation studies, including uncertainty assessment in terms of the uncertainties linked to groundwater quality levels and groundwater contaminants. The functions they have developed are interesting as they have estimated separate meta-regression models for

USA, Europe and the rest of the world. In a FAIRWAY context, the European metaregression model is most interesting, as this type of model is robust .The number of groundwater valuation studies has increaed a lot after the Groundwater Directive was agreed on in 2006, meaning that there exist good datasources to populate the regression model. The tests of the developed function indicate that it was very robust, and the model can therefore be used for decision support in European catchments, groundwater protection zones, by water works professionals and other decision makers.

Olsen *et al.* (2019) conducted a meta-regression analysis based on the primary valuation studies undertaken for water quality improvement in the Nordic countries. The main purpose of this study was to develop a meta-regression function that could be used for benefit transfer for decision support when assessing new policies and projects having impacts on water quality. The development of this model built on a review of the literature to identify all primary valuation studies that were relevant for water quality in the Nordic countries. A list of 50 potentially relevant studies was identified, and from this 34 studies were selected for further study. The criterion for choosing a study was that it should provide estimates of WTP for changes in water quality, but also include sufficient information on sociodemongraphic and environmental characteristics of the population studied in the primary study. Identification of about 100 variables from this literature study provided data for the meta regression; using these regressions a function describing a households' WTP was derived.,. Using this meta regression therefore enables estimation WTP for water quality improvements at both household andcatchment level. It was found that improvement from 'moderate' to 'good' ecological status was more valuable than an improvement from 'good' to 'high' ecological status. In addition, a range of biophysical, sociodemographic as well as other study-specific variables significantly influenced WTP.

The metaregresion model developed by Olsen et al (2019) will be used for advising decision makers on the value of improving water quality, and the function is an input to the Ministry of Environment and Foods assessments of the economic effects of the Water Framework Directive.

5.2 EXAMPLES OF DECISION SUPPORT TOOLS USING SPATIAL MAPPING OF ECOSYSTEM SERVICES AS DECISION SUPPORT

Termansen *et al.* (2017) developed a tool for analysing changes in the provision of a range of different ecosystem services resulting from setting aside land in agricultural or forestry production. Water quality regulation is one of the services included in the tool, which is used for decision support by the Danish Ministry of Environment and Food. The focus of the development of the tool has been on the spatial analysis of synergies and trade-offs between services, such as water quality regulation, climate regulation, recreation, food provision, timber production and biodiversity. By focusing on synergies and potential conflicts the tool aims to support multi-objective land use planning. The tool is currently set up for the Limfjord Catchment, where the Aalborg case study in FAIRWAY is situated.

When modelling the ecosystem service water quality regulation (which is a regulating service) attention is paid to how the variation of hydrology and nitrogen retention in the catchment affects the nitrogen loads to Limfjorden. Three different land use change scenarios are modeled in the analysis reported in Termansen *et al.* (2017):

1. Conversion of agricultural land to semi-natural areas;

2. Conversion of agricultural land to forest land;

3. Conversion of productive forest land to semi-natural un-managed forest land.

The results are illustrated in maps. An example illustrates this in Figure 5, which specifies the location of the areas selected for conversion.

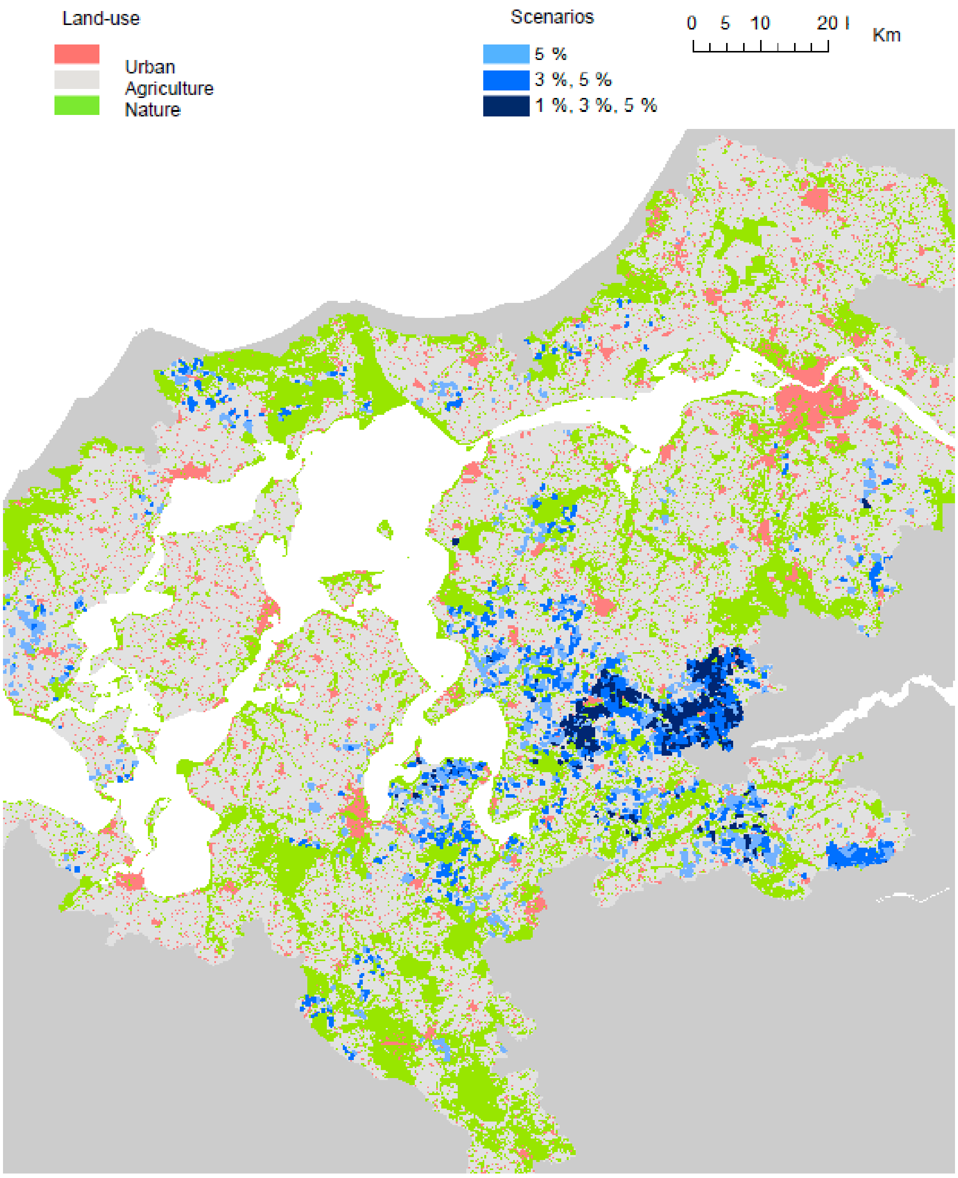

Figure 5: Location of set aside to maximise water regulation services.

The scenarios for agriculture are modelled for setting aside 1%, 3% and 5% of the agricultural land. The effect on water quality regulation is modelled as an effect of optimizing the land set aside with respect to achieving nitrogen load reductions. In addition, the effect on water quality is modelled when achievement of the other ecosystem services are optimized, one by one. Finally, a scenario was set up to maximise several services at a time. For this purpose the ecosystem services were measured in monetary terms. Maps are then used for illustration of each of the identified scenarios, as well as scenario-effect matrices in tables. The results of the assessment include the expected changes in ecosystem services and their values.

Water quality targets in the sub-sea regions, soil types in the area and crop composition were shown to be important determinants of which areas should be set aside, and the analysis also showed that synergies with other ecosystem services were limited.

The chosen method is static, and further work could focus on developing more dynamic approaches as the delivery of ecosystem services often will develop over time. An example is water quality regulation, including protection of groundwater and drinking water, where changes in nitrogen leaching will have an effect over time and not immediately as assumed in this model tool.

The tool will be set up for th whole ounry in 2020, and used for decision support with respect to decision on land-use and protection of land and water-bodies.

A similarision support system; UK NEA, (National Ecosystem Assessment)was developed in UK; supported by Defra. The UK NEA aimed at providing better understanding and improved quantification of the value of the natural environment at large. As part hereof the aim was to develop decision support tools that could be used by governmental agencies as well as other stakeholders from local to national level.

5.3 Summary and discussion of benefit related DST's

Decision support tools for assessments of benefits related to water quality protection include, amongts others, valuation approaches such as meta-regression analyses and more spatialy explicit ecosystem services value assessment tools. The examples given in this chapter show that

- There are good data to use for development of generic value functions. Two examples of a national and a global approach shows that this can be done at many spatial levels.
- There are also rich experiences on assessment tools that value the ecosystem services linked to water quaility improvements. The apporaches are developed in Denmark, but also other countries have developed more or less similar DST's. In UK the National Eosystem Assessment (NEA) was constructed by a large number of researcher, and used for a large number of assessments of conflicts and synergies between the production of different types of ecosystem services.

6. DISCUSSION AND CONCLUSIONS

Many DSTs exist, that can support water management and related decisions at farm and catchment levels by farmers, policy makers, waterworks and other stakeholders. The DSTs can inform policy-making and implementation at many scales; from farm level up to local, national, regional and international levels. The different types of DSTs belong to different "families", e.g. the farm level tools that are developed to support farmers in production decisions, and catchment level tools that are developed to assist and inform policymakers at different levels on the likely outcomes of projects and policy actions to protect water. In this deliverable a summary of important findings from the literature was used to define criteria for what makes a DST within these different domains effective and of economic relevance.

Using these criteria it was concluded that the evaluated farm level DSTs, which have been analysed in earlier deliverables in FAIRWAY, all have in common that total costs of using the tools are kept low and that this is essential for a tool to be effective. The individual cost related to the use of a DST cannot be quantified as it vary substantial depending on farm scale, management practice, user habits, etc. However it was concluded that the farm level tool can save money for farmers if inputs are reduced, but also that they are important in meeting the cross compliance requirements that are compulsory in all EU countries. The farm level DSTs are not designed to rise environmental awareness as it is of no direct economic return to the farmer

The Catchment level DSTs, Farmscoper and TargetEconN, were chosen as examples of catchment scale tools that model cost-effective solutions, that can be used for policy advice and management decisions. The evaluation indicates that significant resources can be saved by using such tools to reveal cost-effective solutions and management practices. The explicit modelling and inclusion of spatial data on agricultural production in both models allows for the identification of mitigation methods that can help to target pollutant reductions whilst not reducing food production. The catchment level models are also capable of assessing the effects of assumptions on the cost-effective solutions, and can therefore be used to assess the uncertainties associated with wrong or limited information.

Finally, there are DSTs to assess the benefits of water quality protection. Two different approaches are presented, and they can be used for general and more spatially specific assessments and measurements of the value of protection. The benefits measured by these methods can be used to make cost-benefit analyses of protection or other policy scenarios and decisions.

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8. APPENDIX

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8.1 INTRODUCTION TO THE APPENDIX - DECISION SUPPORT TOOLS AT FARM LEVEL IN NORWAY

This appendix presents a flyer with an overview of decision support tools avalialbe for farmers in Norway. The flyer is NIVAs contribution to the deliverable, and will be disseminated in Norway and as part of this deliverable. NIVA is part of task 5.3. , but was not part of 5.1. and 5.2. and Norwegian decision support tools were therefore not part of the testing in these task. It was therefore decided to include an overview of the Norwegian decision support tools as an appendix to this deliverable report.

Introduction

Decision support tools (DST) are tools used to assist decision making by application of specialized and evidence based knowledge. There are at least two strands of DST's being relevant to achieve cost-effective drinking water protection: farm level DST's and catchment based DST's. This flyer focuses on DST, and planning tools relevant for application of fertilizers and pesticides available for Norwegian farmers – i.e. at farm level.

8.2 A FLYER ON DECISION SUPPORT TOOLS AVAILABLE FOR FARMERS IN NORWAY

Norwegian legal reference

The regulation on Fertilizer planning (FOR 2014-09-03-1144) states that farmers receiving production subsidy must develop a fertilizer plan, and log a pesticide journal. A farmer will not receive production subsidy if the fertilizer plan and the pesticide journal are not available.

The regulation specifies, that the farmer is responsible for providing a fertilizer plan. The plan must include a chart, with a stated scale, which clearly shows the division of the crop (skifteinndelingen). The fertilizer plan must be specified for each field patch, and based on representative soil samples (every 4 to 8 years) being analyzed for ph, phosphorus, potassium, glow loss or an assessment of mold content. This year's crop yield; expected yield per acre; and last year's fertilizer usage. A plan must be prepared before each growing season for all agricultural land. Only fields of active agricultural operation can be approved for application of fertilizers. Buffer zones cannot be approved for application of fertilizers, nor areas with catch crops. If the fertilizer plan is not prepared according the regulation, reduced production subsidy may result.

A table overview of DSTs

Different tools and approaches are available to support farmer decision making in identifying what are optimal fertilizer rates and what are optimal spraying of herbicides and pesticides based on economic and environmental criteria. The table aims to present an overview of the variation of the different decision making support tools (DST) available in Norway. Decision making tools are defined here as programmes and technical applications which may assist farmer decision making. Farmers use different applications and programmes to assist their farm decision making. Different farmers have different needs, as crops, farm size, competence and interest differs. Some prefer a comprehensive tool including a range of different functionalities and services. Others prefer a simple system to support personal knowledge based experience and decision making process. It is also possible for a farmer to buy the service to prepare the fertilizer plan.

Identification of the DSTs listed in this flyer is based on interviews of farmers, and advisors in Morsa sub-basin, and including also short interviews with regional and national agricultural advisors. The overview of DSTs is presented in the below table, includes information on such as main functionalities of the tool, costs and cost benefit perspectives. The information provided in below table has been collected from the different home pages in November 2019 as part of the Fairway project.

Overview of various tools to assist farmers in their fertilizer planning (data downloaded and available December 1st, 2019)

Name of DST /logo	Producer	User interface; available since and updates	Tool	Functionalities	Costs	Benefits and user considerations
Skifteplan	Agromatic AS, the tools aredeveloped in collaboration with Norsk landbruksrådgiving (The Norwegian Agricultural Advisors) Partners: Yara, John Deere, Gartnerhallen, Agco, Foran Norge. The company is responsible for devlopment of the product. Dealers sell the product and dealers provide user support.	Since 1988 as DOS version Windows since 1996 Since 2018 as web version https://www.skifteplan.no/	Farm planning tool - calculates optimal fertilization rates (N, P, K) for all crops for every point of analysis (soil sample point)	Map feature; import GiS data from public GIS sources. Farm planning tool. utveksler data med GH Doc Includes form for integrated pesticide planning	Subscription: 500 NOK; new customers 700 NOK per holding /yr. + 0,75 NOK /daa above 400 daa	Comprehensive – includes several different functions. Used by both farmers and agricultural advisors. Some farmers need user support. Courses and webinars are available.
		Mobil app available since 2012 – with continuous updates. License must be ordered.		Offline modus A license by one person for 3 units. Automatic updates between web installation and app.	First license 400 NOK /yr.; second yr - 200 NOK yr.	
Agrilogg	Produced by Agrilogg AS	Web portal, and Mobile App – available 2016. https://vest.nlr.no/media/2993675/noteringsverktoey-paa-mobil.pdf	Web based program / farm planning tool.	Several persons can use same login information. Facilitates for logging of mowing, threshing, fertilizing, spraying, tillage.	Subscription 79 NOK / month; NOK 948 yr. Price per extra user account is 16 NOK / month; 190 NOK yr).	Simple and easy to use. Does not calculate fertilizer need; own competence, an advisory or additional tool is needed.
CropPlan	Felleskjøpet AS	Web based portal available since August 2019 https://www.felleskjopet.		Planning tool for farm production		Does not calculate fertilizer needs. CropPlan subscription

MyFarm		no/medlem/tjenester-og-verktoy/cropplan/ MyFarm is the CropPlan app	Web based program / farm planning tool.		 Free	is needed to use MyFarm; same login. Up to six persons can use the app.
Yara N-Sensor or ALS_2	Yara Norge	GPS based instrument 2006 Yara N-Sensor® ALS https://www.yara.no/gjoedsel/hjelpemidler-og-service/n-sensor/	Calculates N needs for cereals - wheat, oilseed, barley, maize	Measure crop nitrogen requirement directly while spreading fertilizer passes across the field.		Yields increased 3.5%; Nitrogen savings of up to 14%; carbon footprint reduced 10-30%; 80% reduction in lodging rates supports application of fertilizers for 4000 dekar
Yara N-Tester Yara N App	Yara AS	An app and a hand held instrument https://www.yara.no/contentassets/a7bcc9bf7f69453b9ab6d49f1602af98/beskrivelse-av-yara-n-app_tcm420-256345.pdf/	A hand held leaf nitrogen measurement tool to measure nitrogen status in a growing crop.	Determines the nutritional status of the plants to assist decision making on the timing and amount of fertilizer during crop growth: Winter wheat spring wheat, grass field timotei	The Yara N-App is free. The Yaran N-tester 11500 DKK	Yara agronomist to support you with calibration and to provide you the fertilizer recommendations based on the N-Tester measurement.
YaraIrix-app	Yara AS	An app and a hand held instrument https://www.yara.no/gjoedsel/hjelpemidler-og-service/yarairix/	By combining the app with either the N-test meter N-Tester Clip or N-Tester BT, you get a recommendation of N-quantity needed in the app.	The image analysis in Irix assesses the amount of leaf mass in digital images, and gives an estimate of the amount of nitrogen taken up in the foliage. - applies to autumn wheat in early stages of development.	App is free. N tester BT subscription from 19 Eur per month	No user stories were available in case area.

CropSAT	Yara AS and Dataväxt .	https://cropsat.com/no/nn-no	Show biomass variation in the field calculated from satellite images.	N fertilizer maps and allocation files for site-specific fertilizers available. An assignment file can be prepared for a GPS in the tractor.	Free	Assisted by satellite images from CropSAT the farmer makes the agro-scientific assessments – to decide fertilizer needs.
Jordplan	Jordplan AS Agricultural cooperative. Partners are: Eurofins, Miljøkalk, Gartnerhallen, Norsk Landbruksrådgivning .	https://jordplan.no/ Early version available 2011 – continuous updates. Web portal Mobile app.	Jordplan.no is a website where data about the farm with maps as background can be stored.	Access to data sources as orthophotos, soil maps, drainage needs and water sources. 3 modules: “Free” contains soil analyzes located on map; “Basis” also records shifts and production; “Sludge” is a map for application to spread sludge, registration of time and quantity for spreading.	Access to all modules annual subscription NOK 490 (from 2012). If NLR Viken member discount of NOK 100.	Allows for personal judgement. A tool for collaboration between different types of users, including a super user, the municipal advisor – different levels of access can be specified.
Norsk landbruks-rådgivning (NLR)	NLR is an umbrella and service organization for ten regional advisories and a member organization. NLR represents a link between research and agriculture.	https://www.nlr.no/	**Advisory** – the fertilizer plan is prepared by the organization.	A variety of different advisory services are available: cereals, oilseeds, grass and forage, oilseeds, potatoes and vegetables, and on organic production.	Minimum costs for fertilizer plan 0,5 hour NOK 363; 725 NOK /hour. With farm visit 800 NOK. Additional advice: 100 NOK / month. For non-members 60% added cost.	The fertilizer plan is prepared for the farmer.

Overview of different Tools to assist farmers in their pesticide application planning

Name of DST /logo	Producer	User interface; available since and updates	Main tool	Functionalities	Costs	Cost benefit assessments
VIPS VIPS Varsling Inn... PlanteSkade...	VIPS is an automatic forecasting system for agricultural pests and diseases, developed by NIBIO and The Norwegian Agricultural Extension Service	https://www.vips-landbruk.no/; Since 2001; update 2016. Mobil app available from 2016	Pest and disease warnings based on data from about 80 weather stations. The warnings are based on weather data, observations and thresholds, and the biology of the pests.	Risk models for 16 pests and diseases, damage thresholds for pests, information and reports on observations of pests and diseases; based on the Danish Plant Protection Online, and RimPRO.	It is a free service.	The services presents a warning system and information that are important for the farmer.
DAT-sensor (Dimensions Agri Technologies DAT	Dimensions Agri Technologies (DAT) AS Initiated by Norwegian farmers, then also NIBIO, SINTEF and ADIGO .	https://www.dimensionsagri.no/	A high-precision spraying system that allows farmers to more precisely spray the weeds in their fields	Takes photographs of speeds 25 km/h. The onboard computer analyzes the photographs and calculates if spraying the current field patch. Includes an option to Calculate costs savings with a prepared spreadsheet.		Herbicided can be reduced by 40 – 50 % . Assuming herbicide costs NOK 25 / USD 3 / EUR 2.6 per 1000 m², this saves NOK 30 000 / USD 3 600 / EUR 3 150 per year, on a km² farm. Reduces trips back to herbicide reservoir saves time and money. From : https://www.dimensionsagri.no/benefits/