D3.3 Model interactions capabilities for the ABM

agricore

Deliverable Number	D3.3
Lead Beneficiary	IDE, AKD, AUTH, IAPAS, UNIPR
Work package	WP3
Delivery Date	September 2022 (M37)
Dissemination Level	Public

www.agricore-project.eu

The Agricore project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No. 816078

Document Information

Project title	Agent-based support tool for the development of agriculture policies
Project acronym	AGRICORE
Project call	H2020-RUR-04-2018-2019
Grant number	816078
Project duration	1.09.2019-31.8.2023 (48 months)

Version History

Version	Description	Organisation	Date
0.1	Deliverable template proposal	IDE	20 Jul 2022
0.2	Modifications to ToC and template approval	UNIPR	31 Jul 2022
0.3	First (incomplete) draft	IDE	10 Sep 2022
0.4	First round of revision and comments	UNIPR	17 Sep 2022
0.5	Second (complete) draft ready to be checked	IDE	15 Oct 2022
0.6	Revisions and comments	UNIPR, IAPAS, AKD, PBS	10 Nov 2022
0.7	Implementation of changes and corrections	IDE	24 Nov 2022
0.8	Final exportation and formatting procedures	IDE	12 Jan 2023
1.0	Final Version complete	IDE	13 Jan 2023

Executive Summary

AGRICORE is a research project funded by the European Commission under the RUR-04-2018 call, part of the H2020 programme, which proposes an innovative way to apply agent-based modelling to improve the capacity of policymakers to evaluate the impact of agricultural-related measurements under and outside the framework of the Common Agricultural Policy (CAP).

This deliverable (D3.3) presents the results of Task 3.3 - Model interactions, led by IDE and supported by AUTH, AKD, IAPAS and UNIPR. The activities performed within the task aim to establish the interconnecting variables for the non-linear dynamic model developed within T3.1. and presented in D3.1, that account for the bidirectional interconnection with agricultural structures: other agents, land and products market, and production factors. The activities performed are strongly related to the activities performed within T3.1. and T3.2. In the first place, it is detailed the interaction between the agents. The interaction is defined by answering three questions in regard to how the interaction is performed and incorporated; based on a literature review of similar studies. In this sense, how the agent and especially their behaviours are modelled is key. In the second place, the interconnection with the land market detailed in D5.2, which resolution is determined by each agent's decisions and expectations. For last, the interconnection with the production market and the production factors. All in all, D3.3. presents the description of the extended ABM, obtained from the extension of the model provided in D3.1 and the agent's behaviour foundation in the decision-making with model interaction capabilities.

Abbreviations

Abbreviation	Full name
ABM	Agent-based model
FADN	Farm Accountancy Data Network
LMM	Land Market Module
PMP	Positive mathematical programming
LT	Long-term
ST	Short-term
SPEI	Standardised Precipitation-Evapotranspiration Index
PMM	Product Market Module

Table of Contents

1 Introduction

In this deliverable are presented the results of T3.3, which aimed to interconnect ABM's models. The objective is to reinforce the ABMs' models' capabilities by simulating part of the environment with which the agents interact, such as the land market. Moreover, the interaction between the own agents. All of those, and more, are external factors that affect the dynamics of the farm and the agricultural holding owner's decision-making. Within the ABM's framework and from a control theory point of view, all these interconnections could be seen as disturbances as they are variables that are not controlled by the agent but that do influence its optimisation. Their integration is not an easy task. However, their incorporation would improve the reliability of AGRICORE's tool. In conclusion, this deliverable presents how the agent interconnects with each other and the interconnections of the agents with other modules. Nevertheless, this deliverable is just presented on how the interconnection is done (i.e. variables implemented) and not how the modules work, which is the subject of their corresponding deliverables.

2 Interconnection with other Agents

Interconnection of an agent with other agents refers to the interaction between neighbouring farmers and how their agroeconomic strategies influence each other (i.e. selection of a determined technology or crop). In order to properly replicate this interaction, a few questions arise:

1. How to determine who each agent's neighbours are?
2. Which behaviours influence the neighbour's decision-making?
3. How to incorporate the influence of the neighbours in the decision-making?

In order to find the best method to approach the problem, there have been performed a literature review to answer the question previously stated. Bellow, there is presented a brief description of the similar studies found and their approach to solving the questions stated above, in order to settle the baseline for further conclusions.

- **An Integrated Economic, Environmental and Social Approach to Agricultural Land-Use Planning (2021) [1]. This investigation examines** how the development and uptake of irrigation infrastructures across a regional landscape were affected by the cumulative impacts of farmers' decisions. Modelling the influence of such decision factors provides an opportunity to explore multiple scenarios and gain insight into the influence of, and feedback between, spatial, social, economic and environmental decisions. In this study, an ABM is used to show the results of the actions and interactions between farmers. This model is based on the data provided by GIS platforms, concretely the data of the Dorset region of Tasmania. The motivation of this study was to develop a framework that allows the exploration of alternative scenarios of future agricultural land-use development by accounting for social, societal, and political needs within existing specific biophysical constraints of climate and soil type. Answers, in order, to the questions raised:
    a. The region of Dorset has the same extension as the region of Sierra Norte of Seville or half of the province of Cádiz. In this region, neighbours have at least one adjacent border with a target parcel, sharing edges and vertices.
    b. Neighbour farmers' cultivated crops.
    c. The neighbours' proximity effect is modelled with the Queen Contiguity Method. There is a neighbour proximity effects threshold parameter ($NG_{effects}$) used to model the influence of social interaction and neighbours' decision effects.
- **Neighbourhood influence and technological change (1992) [2].** This paper presents the development of a model to test the interdependence of farmers' attitudes toward the adoption of new technologies, such as the sickle, in wet rice farming in Indonesia. Answers, in order, to the questions raised:
    a. In this study, 1664 farms are considered, which belong to four rural provinces of Java composed of 84 districts. In this case, the neighbourhood of a farmer includes all the farmers of the same district. Thus, only geographical proximity determines the neighbours, although the paper leaves the way open for other criteria more appropriate according to the context. Districts are the third level of the Indonesian territory organisation, and they have several municipalities. However, it must be taken into account that the population density in Indonesia is much higher than in Spain and any other developed country. For instance, in the province of Central Java, more than 30 million people live, and its area is about 32 thousand square kilometres.

   b. All the neighbours have the same weight, so their influence is expressed with a matrix of mean characteristics. These characteristics are features of the farm that are relevant to take the decision.

   c. The decision is based on the estimated profit derived from taking the decision positively. In other words, the farmer estimates if he/she would earn more if he/she adopts the new technology.

- **Agent-based modelling to simulate farmers' sustainable decisions: Farmers' interaction and resulting green consciousness evolution (2022) [3].** This paper develops a modelling approach that integrates ABM and LCA (Life Cycle Assessment) to evaluate the implications of different farmers' behaviours concerning environmental awareness and their mutual interactions. The modelling framework developed in this work has the potential to simulate the interactions among different actors in the agriculture sector and can be used to incorporate temporal dynamics into sustainability assessment. The ABM considers farmers' proneness to risk, which was assessed via a Naïve Bayesian model trained with the data collected throughout a survey campaign. The parametrisation of the approach is based on the results of the Bayesian network, GIS information and national statistics. Answers, in order, to the questions raised:

   a. This study has been done in Luxemburg, where there are almost 1900 farms, according to the GIS information. However, the location of the parcels is not public, and an artificial map of them was generated based on the number of the parcel and their size. In this case, the neighbouring farms were those inside a distance threshold.

   b. Each agent has a risk aversion level and a green consciousness, which models the farmer's behaviour in terms of the importance that she/he decides to assign to the environmental sustainability of the farming strategy undertaken. The former is modified with the time steps (older, more risk-averse), and the green consciousness of the neighbours influences the latter.

   c. The decision depends on the green consciousness because if it is higher than a certain threshold, the farmer takes action with less impact on the environment.

- **Agent-based modelling of bioenergy crop adoption and farmer decision-making (2016) [4].** This study develops an agent-based simulation model to analyse farmers' decision-making in bioenergy crop adoption and predict related farmers' group behaviour. Agents include farmers and biofuel producers, and each is represented with its own decision-making mechanism. We quantitatively model the decision-making of farmers in Iowa, USA as an optimisation model based on values derived from published literature and social survey data; results were further validated with social survey data. The economic and environmental impacts of growing conventional row crops versus dedicated energy crops are considered and evaluated under a series of operational constraints, including neighbourhood influence. Answers, in order, to the questions raised:

   a. In this paper, the farmers of the same country are considered neighbours. These counties have approximately the same area as regions of Andalusia (~1.5 km2).

   b. Several parameters are calculated based on the area of the neighbours' crops:

      - The land area is dedicated to bioenergy crops of previous contracts.
      - The average bioenergy crop percentage of farmer i's neighbours in year t.
      - The upper and lower bounds for the difference between a farmer's bioenergy crop area percentage and the neighbours' average level. A farmer with a large u1 and small u2 hold more positive attitudes about bioenergy crops than one with a small u1 and large u2.

c. The influence of the neighbourhood is included in the constraints to solve the optimisation problem. Basically, the farmer's decision must meet the thresholds of her/his neighbourhood.

2.1 How to determine who each agent's neighbours are?

In order to correctly define which agents are neighbours, all the above-mentioned publications concur in that it is necessary to first define the geographical region to work with (e.g. NUTS3) and, secondly, to define the location of the agents. Once defined, it can be stated that agents between the same region are neighbours.

- **Geographical region.** Based on the literature, two points must be taken into account: population density and available data. Usually, those two are related, and a higher population density will traduce in higher precision in the exploitation's localisation. Considering those points, each use case will require a different grid. Therefore, there a grid is proposed adaptable to the features of the zone. For example, it could be done at the municipality level or NUTS3. The first option will provide a higher resolution; nevertheless, its applicability depends on the available data.
- **Agent's locations.** The definition of the agent's location depends on the available data. The best options would be to estimate the location of the agricultural holding based on the coordinates of the headquarters or determine the percentual distribution of the agricultural holding within a region. However, those options require the coordinates of the agricultural holding, which are unavailable due to privacy policies. Therefore, based on the available data, the agent's location is defined as belonging to a region, such as NUTS3.

2.2 Which behaviours influence the neighbour's decision-making?

First, it is necessary to identify the influencing attributes that can influence an agent's behaviour. Once done, the next step is to average the neighbours' values. In this sense, a first approach concerning influencing attribute selections could be the technologies implemented by the neighbours, which could involve decisions such as passing to ecological farming. Another common attribute considered is crop selection. For last, it is important to keep in mind if the attributes selected can and how they will be incorporated into the agent's decision-making procedure defined. Therefore, the implementation acts as a limitation for the behaviours selection. All in all, given the high dependency on the implementation, in the next subsection where the incorporation is boarded, the neighbours' behaviours are taken into account in the decision-making and how.

2.3 How to incorporate the influence of my neighbours into decisions?

The main feature of the PMP model used in AGRICORE is to allow interactions between agents. These interactions can be of two types:

1. **Exchange of the land factor.** Land can be purchased or sold in the long term period or rented (or rent out) in the short term. These types of interconnections are described in D5.2 AGRICORE Land Market Module and are common to many mathematical programming models through the definition of constraints that allow the exchange of the land factor between agents.
2. **Exchange of information regarding technologies** used by the agents for production processes already in use in the AH and for processes not implemented in the agent's

production plan. This type of interconnection is specific to the AGRICORE ABM model and has been developed in previous research, the results of which are described in the literature. Information exchange between agents is achieved by means of the self-selection rule. The "self-selection" approach tackles the issue of why in a homogeneous territory, agents with the same information behave differently from one another, producing various combinations of crops present in the region. Self-selection can be achieved through two different approaches depending on the information available. If the variable production cost is available, a primal problem can be defined with a frontier farm, and a maximum entropy approach can be used. If the variable cost per activity is not available, likewise, in FADN, the maximum entropy approach cannot be used, and a dual approach is needed to retrieve the missing costs. The Least Square (LQS) approach can be used in this scenario.

Using the maximum entropy approach, the frontier farm is defined as an additional "hypothetical farm" that includes all the activities implemented by all agents in a specific and predefined production area. The land availability of all farms is summed in the vector $\bar{b}$, the output of the production activities are summed in the vector $\bar{X}$, prices and costs are averaged related to those farms producing the specific crop, while the matrix of technical coefficients for the entire sample is defined by the ratio: total hectares allocated of each production process versus the total amount of outputs for each crop. The frontier farm contains all the production activities of the agents included in the sample and the related technical and economic information. Each agent knows the information related to technologies associated with production processes not implemented on its own land. The availability of this information allows an agent to potentially change production allocation over time.

Since the cost function is a frontier function of the sample of farms as a whole, each individual farm's cost function is expressed as a deviation from the frontier cost function (defined through the cost matrix $\frac{1}{2}xQx'$). Thus, the marginal cost function of the nth farm is represented as:

$$mc(x_n) \equiv \lambda_{LPn} + c_n = Qx_{Rn} + u_n \tag{1}$$

Where the vectoru_n *index is the sample cost function with respect to the specific characteristics of the nth farm.*

In order to take into account the agents' willingness to follow their strategy based on knowledge, perceived risks, and business costs (explicit and implicit), and thus their own selection of production processes, the marginal costs of each farm need to be further defined in order to distinguish between activities carried out by the farm and activities in a latent state (not activated but that could be potentially chosen at some point in time). This distinction can be made by formulating two sets of constraints for the nth farm.

The first group of constraints concerns the activities carried out (crops actually cultivated) for which the relation of the marginal cost can be described as follows:

$$c\,\mathrm{m}_{nk} \mid x_{Rk} > 0 \colon \lambda_{nk} + c_{nk} = Q_k x_{Rn} + u_{nk}, \tag{2}$$

The second group of constraints concerns the latent activities (not carried out by the nth farm). In this case, the relation of marginal cost is a weak inequality compared to the sample marginal cost function for that specific crop:

$$c\,\mathrm{m}_{nk} \mid x_{Rk} = 0 \colon \bar{\lambda}_k + \bar{c}_k \leq Q_k x_{Rn} + u_{nk}, \tag{3}$$

To summarise, if market prices, due to new market or policy conditions, are exogenous, hence common to all agents, and allow profit margin, then the agent will be able to activate new processes (or technologies) and incorporate them into its own production plan.

If the variable cost per crop is not available, a dual approach to the farm problem using the Least Squares approach can be used. This approach, described in detail in the section "***ST PMP approach: cost estimation and calibration phase***" of D3.1 has important implications with regard to the application of self-selection. In fact, in the minimisation model, the frontier farm is not present as the model simultaneously estimates: the matrix of total variable cost (½xQx') and the variables α and λ, which correspond respectively to the 'accounting' and 'transaction' costs of the processes in the sample. The structure of the self-selection constraints is thus represented in the following formulation:

$$\begin{aligned} \boldsymbol{\alpha} + \boldsymbol{\lambda} &= \mathbf{R}'\mathbf{R}\bar{\mathbf{x}} + \mathbf{u} \text{ if } \bar{x} > 0 \\ \boldsymbol{\alpha} + \boldsymbol{\lambda} &\leq \mathbf{R}'\mathbf{R}\bar{\mathbf{x}} + \mathbf{u} \text{ if } \bar{x} = 0 \end{aligned} \qquad (4)$$

The expression indicates that if in the nth farm the culture is present α and λ will assume the costs estimated by the cost matrix. Conversely, if in the nth farm, the culture is not present α and λ will assume a value between zero and the cost set in the cost matrix ½xQx'. Again, in the simulation model, when the market prices of the goods not present are higher than the marginal costs, the farmer will include this activity in the production plan.

3 Interconnections with Land Market Module

Within the agent's decision, options are increasing or decreasing the amount of available land for agricultural activities. The amount of available land of each agricultural holding can be modified through buying/selling and/or renting, although renting would not modify the owned land. Therefore, the approach for implementing each action will be different. Nevertheless, for both actions, the interaction concerning land interchange can be done only within a delimited zone, which is the NUTS3 region. Figure 1 presents, through a diagram, an overview of the interconnections between the ABM and the LMM.

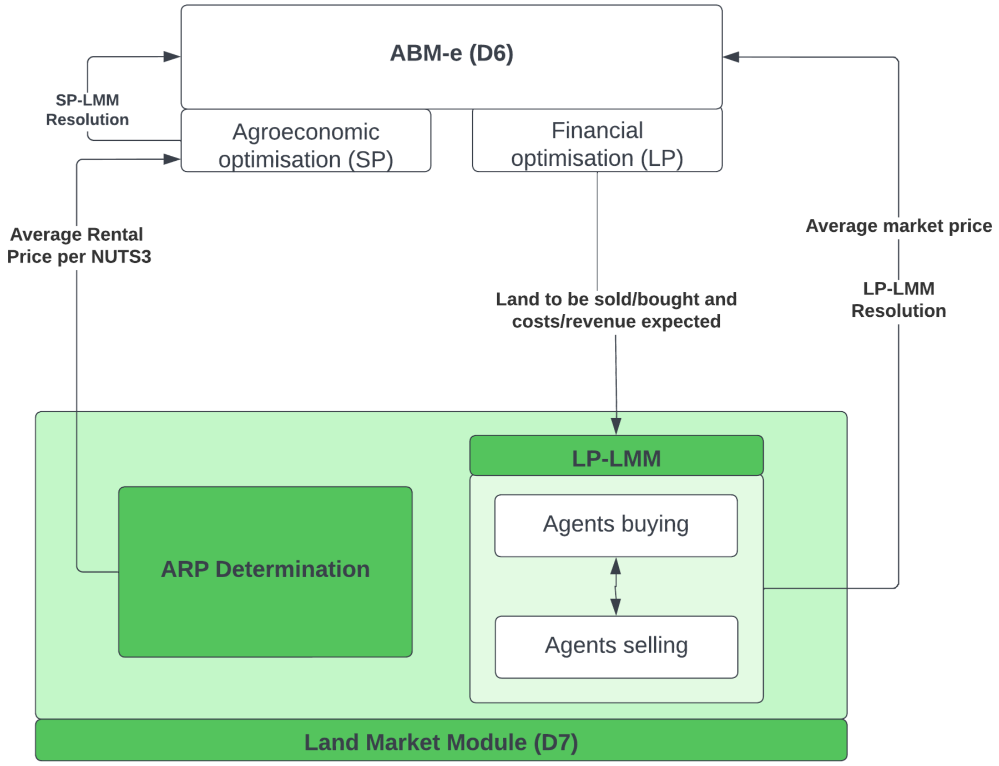

Figure 1 ABM interconnections with the land market module

On the one hand, the land interchange through buying or selling actions is managed through the Land Market Module (LMM). The decision to enter the LMM is taken within the financial optimisation as detailed in D3.1 and D3.2. Within the LMM, an auction system is used to interchange land between agents. The procedure goes as follows: 1) each agent, based on its financial status, decides if it is beneficial to expand its available land due to high production expectations or otherwise decrease the available in order to pay existing loans; 2) in both situations the agent determines the increment or decrement of land intended, and the willingness to accept and pay for the land - *those variables are computed within the financial optimisation and are inputs of the LMM*; 3) The LMM receives as inputs the variables and through an auction system the buying and selling of land are executed. It is important to clarify that the agents might not achieve buying/selling the expected land; 4) Therefore, as the last step, the financial optimisation is updated based on the LMM results. The whole process taking place in the LMM, plus a literature review on it, is detailed in D5.2. Moreover, the whole workflow is detailed in D3.1.

On the other hand, the decision to rent in or rent out land is taken within the Agroeconomic optimisation. The reason for this is that renting is a decision that is part of the short-period optimisation since usually, the rental contracts are done just for the upcoming agricultural campaign. Further on, depending on the results obtained, the agricultural holder decides to rent in or out the land again or not. For last, concerning the renting procedure, there is defined an average renting price for the land available within the region (NUTS3). Secondly, each agent, based on its financial and agroeconomical parameters, decides whether it is worth renting in or out of the land. Once the agricultural campaign finishes and the rental contract ends, the costs and revenues for the decision are computed.

4 Interconnections with Production Factors and Product Markets Modules

One of the most important factors in the agents' decision-making process is the revenue of the actions selected. Based on the revenue obtained minus the overall costs of the agricultural holding, the agent will modify its behaviour/actions accordingly. It is, therefore, essential to correctly calculate the crop production and the revenue from the products generated, i.e. the crop yield (€/tons). Both crop production and product prices are computed through external modules. Moreover, this section will briefly present how those modules work and detail how the agents interconnect with them.

In the first place, **crop production** is influenced by several factors, some of them upcoming from the agent's strategy and others from external sources. Based on those, the agricultural holding will get a production or another. On the one hand, the agent's strategy determines the crop selection, land allocation and technologies implemented. Each agent decides, based on their financial and agroeconomical situation and the estimation of the average price for each product, the crop, and the hectares to be planted. Further on, each agent decides the technology alternative be followed during its simulation based on its estimated yield depending on the crop and the region conditions (e.g. weather). The technology alternative settled determines factors such as fertilization or irrigation. Moreover, it can be conditioned by policies such as promoting organic farming. For last, It is important to remark that crops and available areas for cultivation may change during the simulation period of the agents; however, the technology alternative is selected during the agents' initialisation and remains constant throughout the whole simulation. On the other hand, external factors refer to meteorological and biophysical conditions of the parcels' region. The agent does not control those factors; however, as mentioned before, each agent gets an estimation of these factors for its decision-making. Within the agent's optimisation process (detailed in D3.2), those factors are considered perturbations in the MPC methodology. Concerning the meteorological conditions, those are estimated for each region and categorised in different types of years with respect to the standard conditions in the region (e.g. dry, standard or "wet" year). The estimation is done based on the Standardised Precipitation-Evapotranspiration Index (SPEI), and how it is done is detailed in D3.4. Further on, regarding the biophysical factors, those are determined within the biophysical module, which also computes the production of each crop. The biophysical factors reflect the impact of the land condition and the crop itself on the crop's growth and overall production. Moreover, those factors are highly influenced by the technology alternative selected by the agent. All in all, summing all those factors and through the biophysical model, the production of each crop within the agricultural holding is computed.

In the second place, the **prices of the products** are determined by the Product Market Module (PMM). The objective of this module is to determine the average price of each product, so afterwards, calculate the revenue of the agricultural holding based on its production. In addition, as previously mentioned, the average price of the products is also in the crop selection and the land allocation. However, the estimation may diverge from the final price of the products and thus change the expected revenue. How the PMM works and how the average product prices are computed are detailed in D5.3. For last, based on the final product's prices, each agent will get revenue, which, added to the final resolution of the financial sheet of the agricultural holding, will result in a positive or negative balance. Consequently, in the next year of the simulation, the agent will modify the strategy accordingly in order to maximise the benefits.

5 Conclusions

In this deliverable have been detailed ABM's interconnections with other modules simulate different aspects of the agent's environment. All in all, increasing the complexity of the model while improving its overall performance by replicating agricultural exploitation. Along the deliverable, the main interconnections required by the ABM have been presented and how the interconnection has been implemented within the model and agent's decision-making. Moreover, those "external" modules have been previously detailed in preceding deliverables. Firstly, there have been boarded the interaction between the own agents. This interconnection cover aspects such as that a farmer can be influenced in his decision-making by the decisions made by his neighbours and the visible results of these decisions. By adding this interconnectedness, the agent's decision-making better reflects reality, even if the neighbour's influence may not be great. Secondly, the interconnection with the land market module. This interconnection is key since the land exchange comes as an agent's decision. Moreover, the land market module resolution directly impacts the agricultural holding financial and agroeconomical optimisation. Thirdly, the interconnection with the production factors and product market module. Through this interconnection is determined the revenues for the agent's production. To conclude, thanks to the modularity of AGRICORE's tool, in the future, the interconnection of the ABM can be easily expanded by adding new modules or substituting existing modules in order to improve reliability and overall performance.

6 References

1. S. Shahpari, J. Allison, M. T. Harrison, and R. Stanley, "An integrated economic, environmental and social approach to agricultural land-use planning," Land, vol. 10, no. 4, 2021, doi: 10.3390/land10040364.

   Referenced at: *1*

2. A. Case, "Neighborhood influence and technological change," Regional Science and Urban Economics, vol. 22, no. 3, 1992, doi: 10.1016/0166-0462(92)90041-X.

   Referenced at: *1*

3. A. Marvuglia, A. Bayram, P. Baustert, T. N. Gutiérrez, and E. Igos, "Agent-based modelling to simulate farmers' sustainable decisions: Farmers' interaction and resulting green consciousness evolution," Journal of Cleaner Production, vol. 332, 2022, doi: 10.1016/j.jclepro.2021.129847.

   Referenced at: *1*

4. S. Huang et al., "Agent-based modeling of bioenergy crop adoption and farmer decision-making," Energy, vol. 115, 2016, doi: 10.1016/j.energy.2016.09.084.

   Referenced at: *1*

For preparing this report, the following deliverables have been taken into consideration:

Deliverable Number	**Deliverable Title**	**Lead beneficiary**	**Type**	**Dissemination Level**	**Due date**
D3.1.	Non-linear dynamic model of the farm agents	IDE	Report	Public	M37
D3.2.	AI-based farmer's behavioural foundation	IDE	Report	Public	M37
D5.3	AGRICORE land module	AKD	Other	Public	M34
D5.4	AGRICORE market module	AKD	Other	Public	M36