FLINT

TRADEOFFS BETWEEN ECONOMIC, ENVIRONMENTAL AND SOCIAL SUSTAINABILITY: THE CASE OF A SELECTION OF EUROPEAN FARMS

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ABOUT THE FLINT PROJECT

FLINT will provide an updated data-infrastructure needed by the agro-food sector and policy makers to provide up to date information on farm level indicators on sustainability and other new relevant issues. Better decision making will be facilitated by taking into account the sustainability performance of farms on a wide range of relevant topics, such as (1) market stabilization; (2) income support; (3) environmental sustainability; (4) climate change adaptation and mitigation; (5) innovation; and (6) resource efficiency. The approach will explicitly consider the heterogeneity of the farming sector in the EU and its member states. Together with the farming and agro-food sector the feasibility of these indicators will be determined.

FLINT will take into account the increasing needs for sustainability information by national and international retail and agro-food sectors. The FLINT approach is supported by the Sustainable Agriculture Initiative Platform and the Sustainability Consortium in which the agro-food sector actively participates. FLINT will establish a pilot network of at least 1000 farms (representative of farm diversity at EU level, including the different administrative environments in the different MS) that is well suited for the gathering of these data.

The lessons learned and recommendations from the empirical research conducted in 9 purposefully chosen MS will be used for estimating and discussing effects in all 28 MS. This will be very useful if the European Commission should decide to upgrade the pilot network to an operational EU-wide system.

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TABLE OF CONTENTS

List of tables 5

List of acronyms 6

Executive summary 7

1 Introduction 8

2 Methodology and data 10

2.1 Methodology 10

2.2 Data 14

3 Results 18

3.1 Tradeoffs between economic, environmental and social sustainability 18

3.2 Structural characteristics of the most sustainable farm cluster in each farm type 28

4 Conclusions 34

4.1 Main outcomes 34

4.1.1 No consistent relationship between economic and environmental indicators 34

4.1.2 High social sustainability was associated with high economic performance 35

4.1.3 Farm size was not consistently related to performance 35

4.1.4 Farm subsidies were not consistently related to either economic and/or environmental performance 35

4.2 Methodological recommendations 35

4.3 Limitations to interpretation 36

5 References 38

LIST OF TABLES

Table 1: Definition of the indicators of economic sustainability used from the FADN data 11

Table 2: Definition of the indicators of environmental sustainability used from the FLINT data 12

Table 3: Definition of the indicators of social sustainability used from the FLINT data 13

Table 4: Number of farms per type of farming (TF) 14

Table 5: Average structural characteristics of the farms for the whole sample per type of farming (TF) . 15

Table 6: Average indicators of economic, environmental and social sustainability for the whole sample per type of farming (TF) 16

Table 7: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 1 - Field crops 20

Table 8: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 2 – Horticulture 21

Table 9: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 3 - Permanent crops 22

Table 10: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 4 - Grazing livestock 23

Table 11: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 5 – Granivores 24

Table 12: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 6 - Mixed cropping 25

Table 13: Average indicators of economic and environmental sustainability of the clusters of type of farming 7 - Mixed livestock 26

Table 14: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 8 - Mixed crops-livestock 27

Table 15: Average structural characteristics of the clusters of type of farming 1 - Field crops 29

Table 16: Average structural characteristics of the clusters of type of farming 2 – Horticulture 30

Table 17: Average structural characteristics of the clusters of type of farming 3 - Permanent crops 30

Table 18: Average structural characteristics of the clusters of type of farming 4 - Grazing livestock 31

Table 19: Average structural characteristics of the clusters of type of farming 5 – Granivores 31

Table 20: Average structural characteristics of the clusters of type of farming 6 - Mixed cropping 32

Table 21: Average structural characteristics for the clusters of type of farming 7 - Mixed livestock 32

Table 22: Average structural characteristics for the clusters of type of farming 8 - Mixed crops-livestock 33

LIST OF ACRONYMS

AWU	Annual Working Unit
CAP	Common Agricultural Policy
EFA	Ecological Focus Areas
EU	European Union
FADN	Farm Accountancy Data Network
FWU	Family Working Unit
GHG	GreenHouse Gases
LFA	Less Favoured Areas
LU	Livestock Unit
NVA	Net Value Added
TF	Type of Farming
UAA	Utilised Agricultural Area

EXECUTIVE SUMMARY

For a selection of farms in the Farm Accountancy Data Network (FADN) of the European Union, the economic, environmental and social performance of farms is measured using farm level sustainability indicators based on FADN data and additiona data collected through the FLINT project. For each type of farming (TF), that is to say each main production specialisation, farms are then clustered on the basis of their economic performance and following this their environmental and social performances are assessed. The analysis addresses the question of whether top performing farms from an economic perspective can also be high-performing farms from an environmental and social perspective. The characteristics of the top performers are also investigated.

Results suggest that economic sustainability and environmental sustainability are positively correlated for some farm types but not others, and this depends on the type of environmental indicator. By contrast, there are no tradeoffs between economic performance and (private) social performance. From a methodological perspective, the choice of the indicator, in particular the choice of the functional unit is crucial and may influence conclusions. In addition, some indicators never or almost never discriminate between clusters.

1 INTRODUCTION

An increasing number of so-called "Grand Challenges" for food and agriculture have emerged in the first decade of the 21st century. These include population growth, climate change, energy, water supply and re-emerging diseases, all of which affect the potential of agriculture to provide a secure supply of safe and nutritious food for a rapidly growing population. Hence, the sustainable intensification of agricultural production is emerging as a major priority for policymakers and international development agencies. Sustainable intensification has been defined as producing more from the same area of land while reducing negative environmental impacts and increasing contributions to natural capital and the flow of environmental services.

Godfray et al. (2010) argue that a threefold challenge now faces the world: to match the rapidly changing demand for food from a larger and more affluent population to its supply; to do so in ways that are environmentally and socially sustainable; and to ensure that the world's poorest people are no longer without basic food supplies. Bos et al. (2007) state that agricultural sustainability should be viewed from three alternative perspectives: people, planet and profit or social, environmental and economic.

A key question facing modern society is whether the agricultural sector can develop in a manner that is sustainable from an economic, environmental and social perspective. Sustainable intensification is at the heart of the new Common Agricultural Policy (CAP) of the European Union (EU) and the Greening of the CAP was a major theme of the last reform. But this prompts the question: does the drive for a greener agriculture impact on the CAP's original objective as laid out in the Treaty of Rome "to provide a fair standard of living for farmers"? The purpose of this paper is to use farm level indicators of sustainability to examine the relationship between the different measures of sustainability and to address the specific question: can farms be economically and environmentally sustainable, as well as socially sustainable?

Sustainability indicators can help to monitor the economic, environmental and social consequences of structural changes in farming and to design policy packages to boost sustainable rural development (Reig-Martinez et al. 2011). A number of studies have developed farm level indicators measuring sustainability from this multidimensional perspective but at an individual Member States level; see Dillon et al. (2015) for a review. To date, there has been relatively little research conducted across EU Member States on the multidimensional nature of sustainability, mostly due to the lack of a representative dataset that is sufficiently broad to facilitate the application of economic, environmental and social indicators. The analysis here relies on the data collected via the FLINT project. These are farm level data for a sample of farms of the Farm Accountancy Data Network (FADN) in several EU countries (The Netherlands, Hungary, Finland, Poland, Spain, Ireland, Greece, France and Germany). The data include accountancy data from FADN (hereafter, 'FADN data'), as well as additional data on the economic, environmental and social sustainability of farms (hereafter, 'FLINT data'). These additional FLINT data were collected via face-to-face survey or merging of existing data, depending on the country. The FADN and FLINT data relate to the accountancy year 2015, except for France and Germany for which it is 2014. It should be made clear here that the sample used is not representative.

Here, the economic, environmental and social performance of farms is measured using farm level sustainability indicators. Farms are then clustered on the basis of their economic performance and following this their environmental and social performances are assessed. The analysis explores the correlation between economic, environmental and social performance and addresses the question of

whether top performing farms from an economic perspective can also be high-performing farms from an environmental and social perspective.

The remainder of the report is structured as follows. In the second section the methodology and data are presented. In the third section results are presented, in two parts. The first part explains the tradeoffs between the three sustainability dimensions within each main production specialisation considered, and the second part presents the characteristics of the top performers in each production specialisation (TF). The conclusion in section four comprises a discussion of the main findings, methodological recommandations, and limits of the analysis.

2 METHODOLOGY AND DATA

This section firstly explains the methodology used and then describes the data used.

2.1 Methodology

Economic sustainability is quantified using FADN data. These data consist of accountancy data, and are therefore particularly well suited to assessing farm profitability as well as productivity. The indicators of economic sustainability used here are defined in

Table 1.

Environmental sustainability data are provided from the FLINT dataset. The following themes of environmental sustainability are considered here: greenhouse gas (GHG) emissions, nitrogen (N) balance, water consumption, ecological focus areas (EFA), grass-based rotation area, extensive grassland, UAA with nitrate risk, and UAA with erosion mitigation. The environmental indicators are further defined in

Table 2. Social sustainability data are also provided from the FLINT dataset. The social indicators selected here relate to farmers' perceived quality of life, degree of stress, and social engagement. These indicators are further defined in Table 3.

The analysis is performed separately for specific farm systems as given by the FADN farm types, called the types of farming (TF): TF1-Farms specialised in field crops; TF2-Farms specialised in horticulture; TF3-Farms specialised in permanent crops; TF4-Farms specialised in grazing livestock; TF5-Farms specialised in granivores; TF6-Farms with mixed cropping; TF7-Farms with mixed livestock; TF8-Farms with mixed crops-livestock.

For each TF, farms are classified into clusters based on all of the economic sustainability indicators listed in

Table 1. Clusters are created with hierarchical ascendant classification, where, in each TF, farms are partitioned in homogenous groups (the clusters). Farms in a cluster are close to each other in terms of the economic sustainability indicators, that is to say the Euclidian distance between the value of a farm and the value of another farm is minimised. By contrast, the distance between clusters, measured by Ward's distance between clusters' gravity centers, is maximised, that is to say clusters are as heterogenous as possible.

The optimal number of clusters could be obtained by statistical methods but we decided to cut off manually the number of clusters to three. This number facilitates variability between clusters more than if only two clusters were created, and at the same time enables an easy interpretation of the clusters which would be more difficult with a higher number of clusters; the small sample size of some TF also limits the number of clusters. However, in the case of TF3, 6 and 7, one of the three clusters contained only one or two farms. As it is not meaningful to have less than three farms in a cluster and because it is not possible to show the statistics for this cluster due to statistical confidentiality, the number of clusters was set to two. But again, in the case of TF7, the two-farm cluster appeared as a separate cluster. For this reason, we removed these two farms and performed the statistical analyses on the two remaining clusters. In summary, the number of clusters for the analysis is three for TF1 (field crops), TF4 (grazing livestock), TF5 (granivores) and TF8 (mixed crops-livestock); and the number of clusters is two for TF2 (horticulture), TF3 (permanent crops), TF6 (mixed cropping) and TF7 (mixed livestock).

Following the creation of clusters, environmental and social sustainability are compared across clusters in each TF, based on the indicators of

Table 2 and Table 3. Tests of equality of means of proportions are performed. Finally, the structural characteristics of each cluster are investigated (size, use of external production factors, etc) also with tests of equality of means or proportions.

Table 1: Definition of the indicators of economic sustainability used from the FADN data

Indicator	Definition	Unit	Used in cluster creation for:	FADN code
Output per ha	Total farm output in value related to utilised agricultural area (UAA)	Euros per hectare (ha)	Crop TF only	SE131 / SE025
Output per LU	Total farm output in value related to the number of livestock units (LU)	Euros per LU	Livestock TF only	SE131 / SE080
Output per capital	Total farm output in value related to total assets in value	None	All TF	SE131 / SE436
Output per AWU	Total farm output in value related to total farm labour	Euros per annual working unit (AWU)	All TF	SE131 / SE010
Operational costs per output	Operational costs on the farm related to total farm output	None	All TF	SE281 / SE131
Farm NVA per ha	Farm net value added (NVA) related to UAA	Euros per hectare (ha)	Crop TF only	SE415 / SE025
Farm NVA per LU	Farm net value added related to the number of LU	Euros per LU	Livestock TF only	SE415 / SE080
Farm NVA per capital	Farm net value added related to total assets in value	None	All TF	SE415 / SE436
Farm NVA per AWU	Farm net value added related to total farm labour	Euros per annual working unit (AWU)	All TF	SE415 / SE010
Family farm income per FWU	Farm income related to family labour	Euros per family working unit (FWU)	All TF	SE430

Note: Crop TF are TF1 (field crops), TF2 (horticulture), TF3 (permanent crops), TF6 (mixed cropping) and TF8 (mixed crops-livestock). Livestock TF are TF4 (grazing livestock), TF5 (granivores) and TF7 (mixed livestock).

Source: the authors, based on FADN data

Table 2: Definition of the indicators of environmental sustainability used from the FLINT data

Indicator	Definition	Unit	FLINT code
GHG emissions per ha	Quantity of greenhouse gases (GHG) emitted by farms measured at farm level per hectare (ha) of utilised agricultural area (UAA)	tonnes CO_2 equivalent (t eq CO_2) per ha	E_14_1 / SE025
GHG emissions per LU	Quantity of GHG emitted by farms measured at farm level per livestock unit (LU)	t eq CO_2 per LU	E_14_1 / SE080
GHG emissions per Euro of output	Quantity of GHG emitted by farms measured at farm level per Euro of output	t eq CO_2 per Euro	E_14_1 / SE131
N balance per ha	Farm gate nitrogen (N) balance (= N imported on the farm – N exported from the farm) per ha of UAA	kg of N per ha	E_5_1 / SE025
N balance per LU	Farm gate N balance per LU	kg of N per LU	E_5_1 / SE080
N balance per Euro of output	Farm gate N balance per Euro of output	kg of N per Euro	E_5_1 / SE131
Water consumption per ha	Water consumption on the farm, estimated or measured by a water meter, per ha of UAA	cubic meter per ha	water / SE025
Water consumption per LU	Water consumption on the farm, estimated or measured by a water meter, per LU	cubic meter per LU	water / SE080
Water consumption per Euro of output	Water consumption on the farm, estimated or measured by a water meter, per Euro of output	cubic meter per Euro	water / SE131
Share of EFA	Share of ecological focus areas (EFA), related to total farm area. EFA include fallow land, terraces, landscape features, buffer strips, area of agro-forestry, strips of eligible area along forest, area with short rotation coppices, afforested areas, areas with catch crops or green cover, areas with nitrogen-fixing crops.	%	EFA * 100 / (SE025 + SE074 + SE075)
Share of grass-based rotation area	Area for use of a grass-based crop as part of the arable system/crop rotation, related to UAA	%	Z5_SO_5020_A_7 / SE025
Share of extensive grassland	Permanent grassland that is extensively managed (> 50 kg N fertiliser per ha per annum), related to total permanent grassland	%	E_1_2
Share of UAA with nitrate risk	Area with nitrate risk, related to UAA	%	E_10_4
Share of UAA with erosion mitigation	Area with erosion mitigation, related to UAA	%	E_11_8

Note: ¤ EFA = (Z5_GR_1030_A + Z5_GR_1040_A + Z5_GR_1050_A + Z5_GR_1060_A + Z5_GR_1070_A + Z5_GR_1080_A + Z5_GR_1090_A + Z5_GR_1100_A + Z5_GR_1110_A + Z5_GR_1120_A) / 100
¤ arable area = (I_A_10110_TA + I_A_10120_TA + I_A_10130_TA + I_A_10140_TA + I_A_10150_TA + I_A_10160_TA + I_A_10170_TA + I_A_10190_TA + I_A_10210_TA + I_A_10220_TA + I_A_10290_TA + I_a_10300_TA + I_A_10400_TA + I_A_10500_TA + I_A_10601_TA + I_A_10602_TA + I_A_10603_TA + I_A_10604_TA + I_A_10605_TA + I_A_10606_TA + I_A_10607_TA + I_A_10608_TA + I_A_10609_TA + I_A_10610_TA + I_A_10611_TA + I_A_10612_TA + I_A_10613_TA + I_A_10690_TA + I_A_10731_TA + I_A_10732_TA + I_A_10733_TA + I_A_10734_TA + I_A_10735_TA + I_A_10736_TA + I_A_10737_TA + I_A_10738_TA + I_A_10739_TA + I_A_10790_TA + I_A_10810_TA + I_A_10910_TA + I_A_10921_TA + I_A_10922_TA + I_A_10923_TA + I_A_11000_TA + I_A_11100_TA + fallow)*100 where fallow = SE074 - I_A_30300_TA*100
¤ water = Z10_WU_2000_WM_1 + Z10_WU_2000_CE_1 + Z10_WU_2000_WM_2 + Z10_WU_2000_CE_2 + Z10_WU_2000_WM_3 + Z10_WU_2000_CE_3

Source: the authors, based on FADN and FLINT data

Table 3: Definition of the indicators of social sustainability used from the FLINT data

Indicator	Definition	Unit	FLINT code
Quality of life	Farmer perceived satisfaction of their quality of life	Scale from 0 (very unsatisfied) to 10 (very satisfied)	S_6_4
Stress	Farmer perceived stress in their job on a typical day	Scale from 0 (free of stress) to 10 (very stressful)	S_6_6
Social engagement	The farmer is involved in at least one association (e.g. farmer's union, professional organisation, other farmers group, environmental association, civil association, local government)	Yes=1 No=0	S_4_1

Source: the authors, based on FADN and FLINT data

2.2 Data

After cleaning the database for aberrant and outlier data, the total sample used here contains 1,090 farms. Table 4 lists the TF considered and the number of farms in each TF. Grazing livestock farms were the most numerous, followed by field crop farms and permanent crop farms. The smallest sub-samples were for horticultural farms, mixed cropping farms and mixed livestock farms.

Table 4: Number of farms per type of farming (TF)

	TF1 – Field crops	TF2 – Horti-culture	TF3 – Permanent crops	TF4 – Grazing livestock	TF5 – Grani-vores	TF6 – Mixed cropping	TF7 – Mixed livestock	TF8 – Mixed crops-livestock
Total	255	35	165	409	82	21	15	108

Source: the authors, based on FADN and FLINT data

The description of the sample in terms of structure is provided in

Table 5. On average, horticulture farms are among the smallest farms in terms of UAA but they use the most labour and capital, although the highest average value of capital is found for field crop farms when it is related to labour. A farm is considered to be producing under label if it produces under an organic certified label, or under an EU public quality label or under another collective quality label. The highest share of farms producing under label is found in the permanent crop sample.

Table 6 shows the descriptive statistics of the sample regarding the sustainability indicators. In terms of economic sustainability, in general farms specialised in horticulture perform better than other farms, while mixed livestock farms and mixed crops-livestock farms are the worst performers. As regards the environmental indicators, horticulture farms have the lowest GHG emitted per Euro of output, while livestock farms have the highest. Horticulture farms also perform best in terms of N balance per Euro of output, and the poorest performers are mixed crops-livestock farms. Field crop farming performs best with respect to the share of EFA in total farm area, but do worst with respect to water consumption.

Table 5: Average structural characteristics of the farms for the whole sample per type of farming (TF)

	TF1 – Field crops	**TF2 – Horti-culture**	**TF3 – Permanent crops**	**TF4 – Grazing livestock**	**TF5 – Grani-vores**	**TF6 – Mixed cropping**	**TF7 – Mixed livestock**	**TF8 – Mixed crops-livestock**
UAA (ha) (SE025)	160(255)	24(35)	21(165)	74(409)	28(82)	123(21)	71(15)	173(108)
Number of LU (SE080)	NC	NC	NC	100(409)	464(82)	NC	126(15)	115(108)
Labour (AWU) (SE010)	3.13(255)	8.43(35)	2.71(165)	1.95(408)	2.42(81)	3.64(21)	2.35(15)	3.76(108)
Capital (Euros) (SE436)	1111268 (255)	2011834 (35)	466851 (165)	1025139 (409)	1175509 (82)	1075608 (21)	484072 (15)	817110 (108)
Capital to labour (Euros per AWU) (SE436 / SE010)	683771 (255)	487751 (35)	205785 (165)	556531 (408)	545093 (81)	451000 (21)	210271 (15)	264991 (108)
Share of rented land in UAA (%) (SE030*100/SE025)	19(255)	58(35)	30(165)	11(408)	19(81)	42(21)	6(15)	16(108)
Share of hired labour in total labour (%) (SE020*100/SE010)	60(255)	28(35)	36(165)	49(409)	38(65)	61(21)	50(15)	51(108)
Share of crop output in total output (%) (SE135*100/SE131)	90(255)	92(35)	94(165)	12(409)	15(80)	90(21)	18(15)	50(108)
Share of livestock output in total output (%) (SE206*100/SE131)	3(255)	0(35)	3(165)	85(409)	81(80)	3(21)	75(15)	46(108)
Total subsidies – excluding investments (Euros) (SE605)	22208(255)	2748(35)	3714(165)	25580(409)	16811(82)	20754(21)	8059(15)	46002(108)
Produces under label (dummy EI_2_1 = 1 if yes)	0.91(81)	1(8)	1(95)	.98(189)	1(23)	1(9)	1(5)	1(26)
Is non-organic (dummy A_CL_140_C = 1 if yes)	0.95(255)	0.89(35)	0.81(165)	0.9(409)	0.96(82)	0.81(21)	.93(15)	0.94(108)
Not in LFA (dummy A_CL_160_C = 1)	0.4(255)	0.94(35)	0.49(165)	0.19(409)	0.6(82)	0.43(21)	0.07(15)	0.23(108)

Note: The number of observations is given between brackets. 'NC' indicates not computed.

Source: the authors, based on FADN and FLINT data

Table 6: Average indicators of economic, environmental and social sustainability for the whole sample per type of farming (TF)

	TF1 – Field crops	TF2 – Horti-culture	TF3 – Permanent crops	TF4 – Grazing livestock	TF5 – Grani-vores	TF6 – Mixed cropping	TF7 – Mixed livestock	TF8 – Mixed crops-livestock
Economic indicators								
Output per ha (Euros)	1859(255)	284304(35)	8007(165)	4023(409)	NC	3121(21)	2075(15)	1420(108)
Output per LU (Euros)	NC	NC	NC	1887(409)	1066(80)	NC	1352(15)	2027(107)
Output per capital	0.37(255)	0.88(35)	0.4(165)	0.27(409)	0.44(80)	0.27(21)	0.26(15)	0.29(108)
Output per AWU (Euros)	98281(255)	157296(35)	43092(165)	94693(408)	192213(79)	92656(21)	53318(15)	60906(108)
Operational costs to output	0.38(254)	0.26(35)	0.12(165)	0.48(409)	0.67(80)	0.27(21)	0.47(15)	0.51(108)
Farm NVA per ha (Euros)	468(255)	122478(35)	4447(165)	1102(409)	NC	-1754(21)	349(15)	238(108)
Farm NVA per LU (Euros)	NC	NC	NC	529(409)	165(82)	NC	239(15)	376(107)
Farm NVA per capital (Euros)	0.07(255)	0.37(35)	0.24(165)	0.07(409)	0.06(82)	0.05(21)	0.03(15)	0.04(108)
Farm NVA per AWU (Euros)	24173(255)	67167(35)	23819(165)	24125(408)	16392(81)	33641(21)	5214(15)	8905(108)
Family farm income per FWU (Euros)	12306(255)	163797(35)	35783(165)	17134(409)	7479(82)	14051(21)	1423(15)	4178(108)
Environmental indicators								
GHG emissions per ha (t eq CO2)	0.098(153)	0.051(33)	0.121(101)	8.364(267)	NC	0.077(15)	4.607(9)	2.123(70)
GHG emissions per LU (t eq CO2)	NC	NC	NC	4.518(267)	2.13(49)	NC	3.02(9)	2.815(69)
GHG emissions per Euro of output (t eq CO2)	0.11(153)	0.001(33)	0.049(101)	2.99(267)	2.268(49)	0.101(15)	2.357(9)	1.554(70)
N balance per ha (kg N)	5.3(151)	332.7(33)	10.9(101)	8.4(266)	NC	6.3(14)	6.5(9)	9.9(71)
N balance per LU (kg N)	NC	NC	NC	4(266)	4(49)	NC	6.5(9)	8.70(70)
N balance per Euro of output (kg N)	3.2(151)	1.5(33)	3.0(101)	2.8(266)	4.0(49)	2.0(14)	3.9(9)	6.10(71)
Water consumption per ha (cubic meters)	954(212)	3712(33)	894(104)	69(258)	NC	595(18)	39(13)	45(92)
Water consumption per LU (cubic meters)	NC	NC	NC	36(258)	11(75)	NC	39(13)	38(92)
Water consumption per	656(212)	13(33)	206(104)	20(258)	20(73)	333(18)	30(13)	28.94(92)

Euro of output (cubic meters)								
Share of EFA (%)	12(255)	3(35)	6(165)	5(409)	NC	4(21)	8(15)	8(108)
Share of grass-based rotation area (%)	17(32)	35(4)	25(8)	38(151)	NC	Insuff. obs.	12(8)	19(27)
Share of extensive grassland (%)	25(219)	40(10)	7(105)	49(361)	NC	28(15)	33(15)	49(95)
Share of UAA with nitrate risk (%)	38(255)	33(35)	38(165)	25(409)	NC	35(21)	28(15)	31(108)
Share of UAA with erosion mitigation (%)	53(48)	Insuff. obs.	67(51)	52(61)	NC	100(2)	83(3)	67(26)
Social indicators								
Quality of life (scale 0-10)	7.38(248)	8.16(25)	6.98(165)	6.79(398)	6.81(80)	7.52(21)	5.60(15)	6.58(107)
Stress (scale 0-10)	5.86(253)	4.41(34)	6.33(164)	5.71(398)	6.14(81)	5.5(20)	5.60(15)	6.19(107)
Social engagement (0 or 1)	0.75(255)	0.74(35)	0.70(165)	0.78(409)	0.70(82)	0.71(21)	0.53(15)	0.64(108)

Note: The number of observations is given between brackets. 'NC' indicates not computed as it would not be meaningful. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. The economic performance indicators related to UAA in ha have not been used to create the clusters in TF4, TF5 and TF6, but these indicators are nonetheless indicated in the table for information for TF4 (grazing livestock farms) and TF6 (mixed livestock farms), as these farms also rely on UAA (contrary to granivores farms-TF5). Similarly, the economic performance indicators related to the number of LU have not been used to create the clusters in TF8 (mixed crops-livestock farms), but they are nonetheless indicated in the table for information, as these farms have a non-negligible number of LU.

Source: the authors, based on FADN and FLINT data.

3 RESULTS

3.1 Tradeoffs between economic, environmental and social sustainability

As explained above, for each TF, clusters have been created on the basis of all the economic indicators listed in

Table 1, and then environental and social sustainability is compared across clusters. For each TF, Tables 7 to 14 display the profiles of the clusters as regard the economic indicators. The economic indicators are shown in the first part of the tables. For all TF, when looking at the indicators which are significantly different between clusters, in general average economic performance increases from cluster 1 to cluster 3 (on average, cluster 1 has the lowest economic performance, while cluster 3 the highest) or from cluster 1 to cluster 2 in cases where there are only two clusters (although it is less clear for the granivores sub-sample TF5 and the mixed livestock sub-sample TF7).

The second part of Tables 7 to 14 shows the environmental sustainability of each cluster.

Table 7 shows for field crop farms (TF1) that the best-performing cluster in terms of economic performance (cluster 3) is also the best-performing one (or second-best performing one in one case) as regards all environmental indicators for which the test of equality is significant: GHG per Euro of output, N balance per Euro of output, water consumption per Euro of output, share of area with nitrate risk. However, this cluster has the lowest portion of total farm area under EFA, suggesting that biodiversity is neglected. There is no significant difference between the other indicators across clusters. Table 8 shows that for horticulture farms (TF2), the economically better performing cluster (cluster 2, except for operational costs per output) has lower environmental performance for all indicators for which there is a significant difference in means, namely: GHG per ha, N balance per ha, water consumption per ha and share of EFA. For permanent crop farms (TF3) (Table 9), cluster 2 which has the highest economic performance on average, has the highest environmental performance for all indicators for which the test is significant: GHG per ha and Euro of output, N balance per ha, water consumption per ha and Euro of output, and share of EFA. Mixed cropping farms (TF6) (Table 12) that are highly performing in economic terms (cluster 2), are better performing only in terms of N balance per Euro of output; the other environmental indicators are not significantly different between the two clusters. It should be noted that in this sub-sample, one cluster has only a few number of farms (4) which could explain the lack of statistical differences.

In summary, regarding crop TFs, the cluster that is best performing in economic terms is better or equally performing in environmental terms, except for horticulture TF for which the reverse is true.

As for the livestock TF, as shown by Table 10 for grazing livestock (TF4), cluster 3 is the best performing cluster economically along all indicators, except for operational costs to output, farm NVA per LU and family farm income per FWU for which the performance of this cluster is close to the highest one (in cluster 2), and except for farm NVA per capital for which it has the lowest performance. As regards the environmental indicators that are significantly different across clusters, cluster 3 is the worst (or second worst) environmental performer in terms of GHG emissions per ha and LU, water consumption per ha, share of EFA, share of extensive grassland, and share of UAA with nitrate risk. By contrast, cluster 3 performs the best in terms of N balance (related to any size unit) and share of grass-based rotation area. Table 11 for granivores (TF5) is not clear-cut in terms of economic performance. Cluster 3 has the highest average economic performance per AWU and FWU, as well as in terms of output per ha, but the worst in terms of operational costs to output and NVA per LU. Regarding environmental performance, cluster 3 performs best in terms of water consumption per LU and Euro of output, share of UAA with nitrate risk; it performs worst in terms of GHG per ha, water per ha and share of EFA; the other indicators are not significantly different. In the mixed livestock sub-sample (TF7) (Table 13), cluster 2 is better performing only in terms of output per capital and AWU (the other economic indicators are not significantly different between the two clusters). No environmental indicator is significantly different across clusters, again maybe due to the small number of farms within clusters.

The results for the mixed crops-livestock farms (TF8) (Table 14) are very clear: the increase in economic performance (from cluster 1 to cluster 3) goes in parallel with an increase in environmental performance in terms of GHG per Euro of output, N balance per Euro of output, water per Euro of output and share of UAA with nitrate risk. The rest of the indicators are not significantly different across clusters.

The last part of Tables 7 to 14 show the social performance of farms. For field crop farms (TF1) (Table 7), an increase in economic performance (from cluster 1 to cluster 3) goes hand in hand with an increase in social performance (i.e. increase in average quality of life perception, decrease in average stress perception, and more farmers socially engaged). The same conclusion can be drawn for grazing livestock farms (TF4) except that the most performing cluster (cluster 3) is in second position as regard quality of life. Simularly, for mixed crops-livestock farms (TF8) the best performing cluster in terms of economic performance is also the best performing in terms of quality of life perception and social engagement (no statistical difference in terms of stress). For two TF, one social indicator is highest for the best economically performing cluster (highest quality of life for TF5-granivores; more socially engaged farmers for TF7-mixed livestock), the other indicators being not significantly different. Finally, for three TF (TF2-horticulture, TF3-permanent farms, TF6 mixed cropping), there is no difference in any of the three social indicators.

Table 7: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 1 - Field crops

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	129	115	10	
Economic indicators				
Output per ha (Euros)	1238(129)	2290(115)	5004(10)	31.46***
Output per LU (Euros)	NC	NC	NC	NC
Output per capital	0.33(129)	0.43(115)	0.15(10)	20.75***
Output per AWU (Euros)	35380(129)	129060(115)	561337(10)	162.64***
Operational costs to output	0.40(129)	0.38(115)	0.23(10)	22.22***
Farm NVA per ha (Euros)	256(129)	556(115)	2206(10)	20.67***
Farm NVA per LU (Euros)	NC	NC	NC	NC
Farm NVA per capital (Euros)	0.06(129)	0.07(115)	0.07(10)	0.39
Farm NVA per AWU (Euros)	7523(129)	22488(115)	259513(10)	26.49***
Family farm income per FWU (Euros)	3601(129)	3786(115)	223794(10)	14.07***
Environmental indicators				
GHG emissions per ha (t eq CO2)	0.129(86)	0.058(56)	0.066(10)	2.98
GHG emissions per LU (t eq CO2)	NC	NC	NC	NC
GHG emissions per 1000 Euros of output (t eq CO2)	0.164(86)	0.045(56)	0.014(10)	13.35***
N balance per ha (kg N)	5.5(86)	4.9(54)	6.1(10)	0.49
N balance per LU (kg N)	NC	NC	NC	NC
N balance per 1000 Euros of output (kg N)	4.4(86)	1.6(54)	1.8(10)	16.21***
Water consumption per ha (cubic meters)	1354(113)	541(90)	73(8)	35.06***
Water consumption per LU (cubic meters)	NC	NC	NC	NC
Water consumption per 1000 Euros of output (cubic meters)	833(113)	499(90)	14(8)	35.68***
Share of EFA (%)	10(129)	15(115)	5(10)	11.11***
Share of grass-based rotation area (%)	24(12)	13(19)	Insuff. obs.	1.18
Share of extensive grassland (%)	30(104)	20(105)	22(9)	3.25
Share of UAA with nitrate risk (%)	42(129)	35(115)	32(10)	10.22***
Share of UAA with erosion mitigation (%)	49(26)	58(22)	Insuff. obs.	0.48
Social indicators				
Quality of life (scale 0-10)	6.99(129)	7.79(108)	8.00(10)	12.14***
Stress (scale 0-10)	6.37(128)	5.36(114)	4.80(10)	12.59***
Social engagement (0 or 1)	0.60(129)	0.89(115)	0.90(10)	26.78***

Note: The number of observations is given between brackets. 'NC' indicates not computed as it would not be meaningful. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. The test of equality of means is computed to compare all three clusters together, except when there are insufficient observations in one cluster; in this case the test is computed to compare the two remaining clusters.

Source: the authors, based on FADN and FLINT data.

Table 8: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 2 – Horticulture

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	13	22		
Economic indicators				
Output per ha (Euros)	17947(13)	441696(22)		53.80***
Output per LU (Euros)	NC	NC		NC
Output per capital	0.30(13)	1.23(22)		3.91**
Output per AWU (Euros)	175013(13)	146827(22)		0.48
Operational costs to output	0.22(13)	0.28(22)		6.27**
Farm NVA per ha (Euros)	7204(13)	190594(22)		43.16***
Farm NVA per LU (Euros)	NC	NC		NC
Farm NVA per capital (Euros)	0.12(13)	0.51(22)		4.46**
Farm NVA per AWU (Euros)	76557(13)	61618(22)		0.62
Family farm income per FWU (Euros)	106418(13)	197703(22)		2.49
Environmental indicators				
GHG emissions per ha (t eq CO2)	0.019(12)	0.069(21)		9.98***
GHG emissions per LU (t eq CO2)	NC	NC		NC
GHG emissions per 1000 Euros of output (t eq CO2)	0.002(12)	0.00015(21)		1.98
N balance per ha (kg N)	25.8(12)	508.0(21)		9.19***
N balance per LU (kg N)	NC	NC		NC
N balance per 1000 Euros of output (kg N)	2.1(12)	1.1(21)		1.46
Water consumption per ha (cubic meters)	316(11)	5410(22)		19.52***
Water consumption per LU (cubic meters)	NC	NC		NC
Water consumption per 1000 Euros of output (cubic meters)	14(11)	12(22)		0.20
Share of EFA (%)	8(13)	0(22)		3.63*
Share of grass-based rotation area (%)	35(4)	Insuff. obs.		
Share of extensive grassland (%)	25(8)	100(2)		
Share of UAA with nitrate risk (%)	42(13)	28(22)		1.47
Share of UAA with erosion mitigation (%)	Insuff. obs.	Insuff. obs.		
Social indicators				
Quality of life (scale 0-10)	8.10(10)	8.20(15)		0.07
Stress (scale 0-10)	4.62(13)	4.29(21)		0.19
Social engagement (0 or 1)	0.77(13)	0.73(22)		0.08

Note: The number of observations is given between brackets. 'NC' indicates not computed as it would not be meaningful. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. When there are insufficient observations in one cluster, the test is not computed.

Source: the authors, based on FADN and FLINT data.

Table 9: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 3 - Permanent crops

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	145	20		
Economic indicators				
Output per ha (Euros)	6206(145)	21067(20)		7.36***
Output per LU (Euros)	NC	NC		NC
Output per capital	0.39(145)	0.44(20)		0.34
Output per AWU (Euros)	32401(145)	120605(20)		48.3***
Operational costs to output	0.13(145)	0.08(20)		13.87***
Farm NVA per ha (Euros)	3307(145)	12709(20)		6.09**
Farm NVA per LU (Euros)	NC	NC		NC
Farm NVA per capital (Euros)	0.24(145)	0.26(20)		0.09
Farm NVA per AWU (Euros)	17398(145)	70366(20)		46.08***
Family farm income per FWU (Euros)	18355(145)	162141(20)		5.54**
Environmental indicators				
GHG emissions per ha (t eq CO2)	0.125(98)	0.001(3)		19.22***
GHG emissions per LU (t eq CO2)	NC	NC		NC
GHG emissions per 1000 Euros of output (t eq CO2)	0.050(98)	0.001(3)		14.90***
N balance per ha (kg N)	11.2(98)	2.1(3)		5.38**
N balance per LU (kg N)	NC	NC		NC
N balance per 1000 Euros of output (kg N)	3.1(98)	1.1(3)		2.43
Water consumption per ha (cubic meters)	1024(89)	125(15)		7.91***
Water consumption per LU (cubic meters)	NC	NC		NC
Water consumption per 1000 Euros of output (cubic meters)	239(89)	10(15)		11.67***
Share of EFA (%)	5(145)	12(20)		6.14**
Share of grass-based rotation area (%)	27(7)	Insuff. obs.		
Share of extensive grassland (%)	7(86)	5(19)		0.23
Share of UAA with nitrate risk (%)	38(145)	40(20)		0.45
Share of UAA with erosion mitigation (%)	65(45)	85(6)		1.72
Social indicators				
Quality of life (scale 0-10)	6.96(145)	7.15(20)		0.22
Stress (scale 0-10)	6.38(144)	5.95(20)		0.9
Social engagement (0 or 1)	0.69(145)	0.75(20)		0.3

The number of observations is given between brackets. 'NC' indicates not computed as it would not be meaningful. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. Chi-sqwuare and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. The test of equality of means is computed to compare all three clusters together, except when there are insufficient observations in one cluster, the test is not computed.

Source: the authors, based on FADN and FLINT data.

Table 10: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 4 - Grazing livestock

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	249	122	37	
Economic indicators				
Output per ha (Euros)	2569(249)	5746(122)	8185(37)	22.83***
Output per LU (Euros)	1527(249)	2369(122)	2708(37)	75.82***
Output per capital	0.27(249)	0.28(122)	0.23(37)	2.15
Output per AWU (Euros)	46261(249)	136429(122)	283013(37)	331.29***
Operational costs to output	0.50(249)	0.45(122)	0.47(37)	4.99*
Farm NVA per ha (Euros)	789(249)	1542(122)	1768(37)	9.54***
Farm NVA per LU (Euros)	402(249)	760(122)	614(37)	31.75***
Farm NVA per capital (Euros)	0.06(249)	0.09(122)	0.05(37)	12.01***
Farm NVA per AWU (Euros)	9507(249)	41187(122)	66244(37)	148.32***
Family farm income per FWU (Euros)	5286(249)	35866(122)	35567(37)	63.17***
Environmental indicators				
GHG emissions per ha (t eq CO2)	5.309(139)	10.295(94)	15.835(33)	62.46***
GHG emissions per LU (t eq CO2)	4.152(139)	4.914(94)	4.896(33)	49.63***
GHG emissions per 1000 Euros of output (t eq CO2)	3.479(139)	2.619(94)	1.993(33)	44.78***
N balance per ha (kg N)	7.3(138)	8.9(94)	11.5(33)	1.24
N balance per LU (kg N)	4.8(138)	3.4(94)	2.7(33)	8.92**
N balance per 1000 Euros of output (kg N)	4.1(138)	1.7(94)	1.0(33)	17.10***
Water consumption per ha (cubic meters)	39(160)	95(67)	172(30)	8.66**
Water consumption per LU (cubic meters)	32(160)	43(67)	46(30)	1.19
Water consumption per 1000 Euros of output (cubic meters)	21(160)	19(67)	18(30)	0.39
Share of EFA (%)	6(249)	2(122)	3(37)	17.83***
Share of grass-based rotation area (%)	32(98)	50(41)	51(11)	11.17***
Share of extensive grassland (%)	57(231)	38(100)	18(29)	29.23***
Share of UAA with nitrate risk (%)	21(249)	32(122)	29(37)	24.26***
Share of UAA with erosion mitigation (%)	47(40)	59(20)	Insuff. obs.	0.98
Social indicators				
Quality of life (scale 0-10)	6.56(246)	7.23(118)	6.97(33)	9.46***
Stress (scale 0-10)	5.95(247)	5.29(117)	5.27(33)	9.37***
Social engagement (0 or 1)	0.69(249)	0.91(122)	0.95(37)	30.22***

Note: The number of observations is given between brackets. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. The test of equality of means is computed to compare all three clusters together, except when there are insufficient observations in one cluster; in this case the test is computed to compare the two remaining clusters. The economic performance indicators related to UAA in ha have not been used to create the clusters for this type of farming, but they are nonetheless indicated in the table for information, as these farms also rely on UAA (contrary to granivores farms for example).

Source: the authors, based on FADN and FLINT data.

Table 11: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 5 – Granivores

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	55	15	9	
Economic indicators				
Output per ha (Euros)	11611(44)	47322(12)	518923(6)	7.16**
Output per LU (Euros)	979(55)	1443(15)	1004(9)	6.58**
Output per capital	0.45(55)	0.39(15)	0.46(9)	2.77
Output per AWU (Euros)	69758(55)	310981(15)	742602(9)	58.9***
Operational costs to output	0.63(55)	0.75(15)	0.78(9)	23.00***
Farm NVA per ha (Euros)	3221(44)	472(12)	52867(6)	3.57
Farm NVA per LU (Euros)	195(55)	111(15)	59(9)	10.92***
Farm NVA per capital (Euros)	0.07(55)	0.02(15)	0.03(9)	7.45**
Farm NVA per AWU (Euros)	7748(55)	14808(15)	54240(9)	6.88**
Family farm income per FWU (Euros)	3243(55)	-4128(15)	17766(9)	1.67
Environmental indicators				
GHG emissions per ha (t eq CO2)	9.935(36)	64.595(8)	451.379(4)	8.44**
GHG emissions per LU (t eq CO2)	1.752(36)	3.523(8)	2.768(4)	4.66*
GHG emissions per 1000 Euros of output (t eq CO2)	2.157(36)	2.604(8)	2.491(4)	0.61
N balance per ha (kg N)	13.6(36)	517.8(9)	612.5(3)	4.32
N balance per LU (kg N)	3.1(36)	7(9)	6.3(3)	2.34
N balance per 1000 Euros of output (kg N)	2.9 (36)	7.9(9)	5.4(3)	2.91
Water consumption per ha (cubic meters)	142(40)	484(10)	1646(6)	8.14**
Water consumption per LU (cubic meters)	13(50)	9(13)	4(9)	12.41***
Water consumption per 1000 Euros of output (cubic meters)	26(50)	8(13)	4(9)	8.21**
Share of EFA (%)	6(44)	2(12)	0(6)	3.50**
Share of grass-based rotation area (%)	8(5)	Insuff. obs.	Insuff. obs.	
Share of extensive grassland (%)	42(34)	50(9)	20(5)	1.57
Share of UAA with nitrate risk (%)	40(44)	19(12)	19(6)	13.15***
Share of UAA with erosion mitigation (%)	63(5)	Insuff. Obs.	Insuff. obs.	
Social indicators				
Quality of life (scale 0-10)	6.43(54)	7.36(14)	7.89(9)	12.98***
Stress (scale 0-10)	6.46(54)	5.67(15)	5.22(9)	3.14
Social engagement (0 or 1)	0.65(55)	0.80(15)	0.78(9)	1.50

Note: The number of observations is given between brackets. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. The test of equality of means is computed to compare all three clusters together. When there are insufficient observations in two clusters, the test is not computed.

Source: the authors, based on FADN and FLINT data.

Table 12: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 6 - Mixed cropping

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	17	4		
Economic indicators				
Output per ha (Euros)	2758(17)	4664(4)		2.22
Output per LU (Euros)	NC	NC		NC
Output per capital	0.28(17)	0.23(4)		0.63
Output per AWU (Euros)	45875(17)	291476(4)		8.62***
Operational costs to output	0.27(17)	0.29(4)		0.27
Farm NVA per ha (Euros)	-2631(17)	1974(4)		1.74
Farm NVA per LU (Euros)	NC	NC		NC
Farm NVA per capital (Euros)	0.04(17)	0.08(4)		0.17
Farm NVA per AWU (Euros)	14983(17)	112937(4)		7.81***
Family farm income per FWU (Euros)	-1422(17)	79813(4)		8.76***
Environmental indicators				
GHG emissions per ha (t eq CO2)	0.099(11)	0.018(4)		1.59
GHG emissions per LU (t eq CO2)	NC	NC		NC
GHG emissions per 1000 Euros of output (t eq CO2)	0.136(11)	0.004(4)		2.04
N balance per ha (kg N)	8(10)	2(4)		1.57
N balance per LU (kg N)	NC	NC		NC
N balance per 1000 Euros of output (kg N)	3(10)	0.4(4)		3.91**
Water consumption per ha (cubic meters)	648(15)	328(3)		0.32
Water consumption per LU (cubic meters)	NC	NC		NC
Water consumption per 1000 Euros of output (cubic meters)	387(15)	57(3)		1.03
Share of EFA (%)	4(17)	6(4)		0.29
Share of grass-based rotation area (%)	Insuff. obs.	Insuff. obs.		
Share of extensive grassland (%)	24(11)	40(4)		0.44
Share of UAA with nitrate risk (%)	36(17)	31(4)		0.29
Share of UAA with erosion mitigation (%)	Insuff. obs.	Insuff. obs.		
Social indicators				
Quality of life (scale 0-10)	7.41(17)	8.00(4)		0.50
Stress (scale 0-10)	5.81(16)	4.25(4)		1.83
Social engagement (0 or 1)	0.65(17)	1.00(4)		1.98

Note: The number of observations is given between brackets. 'NC' indicates not computed as it would not be meaningful. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. When there are insufficient observations in one cluster, the test is not computed.

Source: the authors, based on FADN and FLINT data.

Table 13: Average indicators of economic and environmental sustainability of the clusters of type of farming 7 - Mixed livestock

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	7	6		
Economic indicators				
Output per ha (Euros)	1690(7)	2395(6)		0.84
Output per LU (Euros)	1464(7)	1272(6)		0.16
Output per capital	0.16(7)	0.39(6)		7.90***
Output per AWU (Euros)	17386(7)	59554(6)		15.62***
Operational costs to output	0.52(7)	0.38(6)		2.53
Farm NVA per ha (Euros)	274(7)	348(6)		0.09
Farm NVA per LU (Euros)	296(7)	178(6)		0.32
Farm NVA per capital (Euros)	0.02(7)	0.05(6)		0.77
Farm NVA per AWU (Euros)	2104(7)	5776(6)		0.98
Family farm income per FWU (Euros)	1578(7)	105(6)		0.12
Environmental indicators				
GHG emissions per ha (t eq CO2)	3.687(7)	Insuff. obs.		
GHG emissions per LU (t eq CO2)	2.672(7)	Insuff. obs.		
GHG emissions per 1000 Euros of output (t eq CO2)	2.322(7)	Insuff. obs.		
N balance per ha (kg N)	7.5(7)	Insuff. obs.		
N balance per LU (kg N)	7.5(7)	Insuff. obs.		
N balance per 1000 Euros of output (kg N)	4.55(7)	Insuff. obs.		
Water consumption per ha (cubic meters)	40(7)	39(5)		0.00
Water consumption per LU (cubic meters)	57(7)	19(5)		0.82
Water consumption per 1000 Euros of output (cubic meters)	22.84(7)	17.31(5)		0.24
Share of EFA (%)	5(7)	14(6)		1.23
Share of grass-based rotation area (%)	10(4)	14(4)		0.19
Share of extensive grassland (%)	22(7)	42(6)		0.75
Share of UAA with nitrate risk (%)	33(7)	20(6)		2.2
Share of UAA with erosion mitigation (%)	Insuff. obs.	Insuff. obs.		
Social indicators				
Quality of life (scale 0-10)	4.86(7)	5.50(6)		0.22
Stress (scale 0-10)	5.29(7)	6.17(6)		0.57
Social engagement (0 or 1)	0.14(7)	0.83(6)		8.21**

Note: The number of observations is given between brackets. 'NC' indicates not computed as it would not be meaningful. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. When there are insufficient observations in one cluster, the test is not computed. The economic performance indicators related to UAA in ha have not been used to create the clusters for this type of farming, but they are nonetheless indicated in the table for information, as these farms also rely on UAA (contrary to granivores farms for example).

Source: the authors, based on FADN and FLINT data.

Table 14: Average indicators of economic, environmental and social sustainability of the clusters of type of farming 8 - Mixed crops-livestock

	Cluster 1	Cluster 3	Cluster 3	test of equality of means
Number of farms	46	52	10	
Economic indicators				
Output per ha (Euros)	1133(46)	1368(52)	3006(10)	8.70**
Output per LU (Euros)	NC	NC	NC	NC
Output per capital	0.22(46)	0.32(52)	0.43(10)	12.49***
Output per AWU (Euros)	19897(46)	79993(52)	150291(10)	99.53***
Operational costs to output	0.56(46)	0.48(52)	0.39(10)	12.16***
Farm NVA per ha (Euros)	169(46)	144(52)	1048(10)	11.41***
Farm NVA per LU (Euros)	NC	NC	NC	NC
Farm NVA per capital (Euros)	0.03(46)	0.02(52)	0.16(10)	7.72**
Farm NVA per AWU (Euros)	3458(46)	5413(52)	52112(10)	20.24***
Family farm income per FWU (Euros)	2299(46)	-8309(52)	77753(10)	15.13***
Environmental indicators				
GHG emissions per ha (t eq CO2)	2.007(38)	1.861(25)	3.688(7)	1.99
GHG emissions per LU (t eq CO2)	NC	NC	NC	NC
GHG emissions per 1000 Euros of output (t eq CO2)	1.788(38)	1.285(25)	1.241(7)	8.24**
N balance per ha (kg N)	16.3(38)	2.2(26)	3.2(7)	3.04
N balance per LU (kg N)	NC	NC	NC	NC
N balance per 1000 Euros of output (kg N)	10(38)	2(26)	1(7)	8.05**
Water consumption per ha (cubic meters)	61(44)	31(41)	21(7)	0.86
Water consumption per LU (cubic meters)	NC	NC	NC	NC
Water consumption per 1000 Euros of output (cubic meters)	32(44)	29(41)	5(7)	6.56**
Share of EFA (%)	8(46)	9(52)	4(10)	2.57
Share of grass-based rotation area (%)	7(6)	23(18)	12(3)	4.42
Share of extensive grassland (%)	56(35)	47(50)	36(10)	2.12
Share of UAA with nitrate risk (%)	36(46)	28(52)	24(10)	6.30**
Share of UAA with erosion mitigation (%)	100(3)	64(21)	Insuff. obs.	1.94
Social indicators				
Quality of life (scale 0-10)	5.78(46)	7.06(52)	7.89(9)	26.33***
Stress (scale 0-10)	5.83(46)	6.54(52)	6(9)	1.96
Social engagement (0 or 1)	0.46(46)	0.73(52)	1.00(10)	14.19***

Note: The number of observations is given between brackets. 'NC' indicates not computed as it would not be meaningful. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. The test of equality of means is computed to compare all three clusters together, except when there are insufficient observations in one cluster; in this case the test is computed to compare the two remaining clusters. The economic performance indicators related to the number of LU have not been used to create the clusters in this TF, but they are nonetheless indicated in the table for information, as these farms have a non-negligible number of LU.

Source: the authors, based on FADN and FLINT data.

3.2 Structural characteristics of the most sustainable farm cluster in each farm type

Tables 15 to 22 display for each TF the structural characteristics of the clusters. For field crop farms (TF1), cluster 3 was shown above to be the top performer in terms of economic, environmental and social performance (except as regard the share of EFA). Table 15 shows that this cluster has on average a medium UAA but the lowest labour and the highest capital. Farms in this cluster use on average the least external labour and land, and have the lowest share of total output stemming from crops. Farms in this cluster also receive the least subsidies per farm on average. More farms are far less likely to be in Less Favoured Areas (LFA) compared to the other two clusters.

For horticulture farms (TF2) (

Table 16) cluster 2 was generally better performing in economic terms (except for operational costs to output) but lower performing in terms of GHG per ha, N balance per ha, water consumption per ha and share of EFA. This cluster has on average the smallest UAA (with highest rented land share), the highest labour use (but with lowest hired labour share) and the lowest capital to labour. This cluster contains more non-organic farms.

For permanent crop farms (TF3) (Table 17), cluster 2 is the cluster with the highest economic and environmental performance (in terms of GHG per Euro of output, N balance per ha, water consumption per ha and Euro of output) and share of EFA. This cluster is clearly the one with the largest size (in terms of UAA, labour and capital) and the highest reliance on external factors on average; it receives the most subsidies on average.

Regarding grazing livestock farms (TF4) (Table 18), cluster 3 has the highest economic performance; the highest environmental performance in terms of GHG per Euro of output, N per LU and Euro of output and share of grass-based rotation area; the lowest environmental performance in terms of GHG per ha and LU, water consumption per ha, share of EFA and share of extensive grassland; and the highest social performance in terms of social engagement. Table 18 shows that this cluster is the largest on average in terms of UAA, LU and capital. It has a medium reliance on rented land, has the strongest livestock orientation, and receives a medium level of subsidies compared to the other two clusters on average. More farms are located in non-LFA.

For granivores farms (TF5) (Table 19), cluster 3 was identified as the best performing cluster in terms of economic indicators per AWU and FWU, and of output per ha. It was also the best performer in terms of water consumption per LU and Euro of output and share of UAA with nitrate risk, but the worst performer in terms of HGH per LU, water consumption per LU and share of EFA. As for social performance, it has the highest quality of life in indicator. This cluster has the smallest UAA and labour use, but the highest number of LU and capital, on average. It has the strongest livestock specialisation and receives the least subsidies on average. In contrast with cluster 3, cluster 1 (which had the highest farm NVA per LU and capital, and the lowest GHG emissions per LU), has the largest farms in terms of UAA and labour use but smallest farms in terms of LU and capital; it has the highest crop character, which may explain why it receives the most subsidies.

Cluster 2 in the mixed cropping sub-sample (TF6) has the highest economic performance related to AWU and FWU, and is better performing only in terms of N balance per output than the other clusters (the rest of the environmental and social indicators being non significant). Table 20 shows that this cluster is larger in terms of capital but smaller in terms of labour, and receives less subsidies on average.

As for mixed livestock farms (TF7), cluster 2 which is better performing in terms of output per capital and AWU and in terms of social engagement (no environmental indicators significantly different between clusters), is shown as the cluster with the largest farms (UAA, LU, labour, capital) and with the highest reliance on external factors on average (Table 21).

Finally, Table 22 shows that for mixed crops-livestock farms (TF8), the best performing cluster in economic terms and in terms of GHG, N and water indicators related to output, as well as in terms of quality of life and social engagement (cluster 3), contains farms with medium UAA, highest capital, and receiving a medium amount of subsidies on average. It has the highest rented land share and a high hired labour share (close to the highest, on average).

Table 15: Average structural characteristics of the clusters of type of farming 1 - Field crops

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	129	115	10	
UAA (ha)	114(129)	192(115)	130(10)	5.73*
Number of LU	NC	NC	NC	NC
Labour (AWU)	3.34(129)	2.47(115)	1.43(10)	8.07**
Capital (Euros)	374176(129)	1316744(115)	7992521(10)	26.51***

Capital to labour (Euros per AWU)	160585(129)	756079(115)	6664259(10)	32.34***
Share of rented land in UAA (%)	18(129)	20(115)	8(10)	8.61*
Share of hired labour in total labour (%)	54(129)	70(115)	26(10)	22.99***
Share of crop output in total output (%)	92(129)	89(115)	81(10)	7.86**
Share of livestock output in total output (%)	3(129)	2(115)	2(10)	3.23
Total subsidies – excluding investments (Euros)	22617(129)	16969(115)	6273(10)	8.10**
Produces under label	0.86(28)	0.94(47)	1.00(6)	2.00
Is non-organic	0.94(129)	0.96(115)	1.00(10)	0.99
Not in LFA	0.32(129)	0.46(115)	0.80(10)	12.05***

Note: The number of observations is given between brackets. 'NC' indicates not computed as it would not be meaningful. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. The test of equality of means is computed to compare all three clusters together.

Source: the authors, based on FADN and FLINT data.

Table 16: Average structural characteristics of the clusters of type of farming 2 – Horticulture

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	13	22		
UAA (ha)	58(13)	3(22)		6.42**
Number of LU	NC	NC		NC
Labour (AWU)	4.84(13)	10.56(22)		4.08**
Capital (Euros)	2447273(13)	1754529(22)		0.85
Capital to labour (Euros per AWU)	971280(13)	202029(22)		4.48**
Share of rented land in UAA (%)	42(13)	67(22)		4.30**
Share of hired labour in total labour (%)	48(13)	16(22)		5.08**
Share of crop output in total output (%)	93(13)	91(22)		0.44
Share of livestock output in total output (%)	0(13)	0(22)		2.22
Total subsidies – excluding investments (Euros)	2956(13)	2625(22)		0.02
Produces under label	1.00(4)	1.00(4)		0.00
Is non-organic	0.69(13)	1.00(22)		7.64***
Not in LFA	0.92(13)	0.95(22)		0.15

Note: The number of observations is given between brackets. 'NC' indicates not computed as it would not be meaningful. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively.

Source: the authors, based on FADN and FLINT data.

Table 17: Average structural characteristics of the clusters of type of farming 3 - Permanent crops

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	145	20		
UAA (ha)	17(145)	48(20)		7.06***
Number of LU	NC	NC		NC
Labour (AWU)	2.43(145)	4.71(20)		8.02***
Capital (Euros)	343723(145)	1359529(20)		12.81***
Capital to labour (Euros per AWU)	187686(145)	337000(20)		5.75**
Share of rented land in UAA (%)	28(145)	48(20)		6.58**
Share of hired labour in total labour (%)	32(145)	67(20)		10.49***
Share of crop output in total output (%)	93(145)	97(20)		11.42***
Share of livestock output in total output (%)	4(145)	0(20)		3.17*
Total subsidies – excluding investments (Euros)	2792(145)	10404(20)		5.61**
Produces under label	1.00(77)	1.00(18)		0.00
Is non-organic	0.79(145)	0.90(20)		1.28
Not in LFA	0.48(145)	0.600(20)		1.08

Note: The number of observations is given between brackets. 'NC' indicates not computed as it would not be meaningful. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively.

Source: the authors, based on FADN and FLINT data.

Table 18: Average structural characteristics of the clusters of type of farming 4 - Grazing livestock

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	249	122	37	
UAA (ha)	66(249)	79(122)	87(37)	6.98**
Number of LU	67(249)	126(122)	222(37)	78.21***
Labour (AWU)	1.88(249)	2.09(122)	2.03(37)	2.98
Capital (Euros)	413963(249)	1469631(122)	3630532(37)	76.47***
Capital to labour (Euros per AWU)	257912(249)	793009(122)	1786415(37)	105.16***
Share of rented land in UAA (%)	8(249)	16(122)	14(37)	17.78***
Share of hired labour in total labour (%)	52(249)	45(122)	46(37)	3.11
Share of crop output in total output (%)	14(249)	10(122)	8(37)	15.31***
Share of livestock output in total output (%)	84(249)	88(122)	89(37)	7.35**
Total subsidies – excluding investments (Euros)	17500(249)	39442(122)	23130(37)	13.29***
Produces under label	0.98(101)	0.97(70)	1.00(18)	0.58
Is non-organic	0.92(249)	0.88(122)	0.86(37)	2.80
Not in LFA	0.09(249)	0.25(122)	0.68(37)	74.25***

Note: The number of observations is given between brackets. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. The test of equality of means is computed to compare all three clusters together.

Source: the authors, based on FADN and FLINT data.

Table 19: Average structural characteristics of the clusters of type of farming 5 – Granivores

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	55	15	9	
UAA (ha)	35(55)	23(15)	5(9)	25.95***
Number of LU	230(55)	412(15)	1277(9)	24.27***
Labour (AWU)	2.54(55)	1.93(15)	1.72(9)	4.84*
Capital (Euros)	417707(55)	1623880(15)	2686521(9)	38.42***
Capital to labour (Euros per AWU)	226229(55)	875101(15)	1629347(9)	42.95***
Share of rented land in UAA (%)	21(55)	8(15)	14(9)	5.04*
Share of hired labour in total labour (%)	37(44)	43(12)	36(6)	0.36
Share of crop output in total output (%)	20(55)	7(15)	1(9)	45.60***
Share of livestock output in total output (%)	77(55)	87(15)	98(9)	48.63***
Total subsidies – excluding investments (Euros)	12769(55)	8933(15)	1855(9)	10.98***
Produces under label	1.00(10)	1.00(8)	1.00(4)	0.00
Is non-organic	0.95(55)	1.00(15)	1.00(9)	1.36
Not in LFA	0.45(55)	0.87(15)	1.00(9)	15.22***

Note: The number of observations is given between brackets. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. The test of equality of means is computed to compare all three clusters together.

Source: the authors, based on FADN and FLINT data.

Table 20: Average structural characteristics of the clusters of type of farming 6 - Mixed cropping

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	17	4		
UAA (ha)	119(17)	139(4)		0.21
Number of LU	NC	NC		NC
Labour (AWU)	4.03(17)	2(4)		2.93*
Capital (Euros)	641880(17)	2918954(4)		6.91***
Capital to labour (Euros per AWU)	211299(17)	1469731(4)		7.56***
Share of rented land in UAA (%)	45(17)	28(4)		2.28
Share of hired labour in total labour (%)	60(17)	64(4)		0.14
Share of crop output in total output (%)	89(17)	97(4)		2.41
Share of livestock output in total output (%)	4(17)	0(4)		1.72
Total subsidies – excluding investments (Euros)	25163(17)	2015(4)		3.12*
Produces under label	1(7)	Insuff. obs		
Is non-organic	0.82(17)	0.75(4)		0.11
Not in LFA	0.35(17)	0.75(4)		2.08

Note: The number of observations is given between brackets. 'NC' indicates not computed as it would not be meaningful. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. When there are insufficient observations in one cluster, the test is not computed.

Source: the authors, based on FADN and FLINT data.

Table 21: Average structural characteristics for the clusters of type of farming 7 - Mixed livestock

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	7	6		
UAA (ha)	22(7)	84(6)		15.44***
Number of LU	34(7)	168(6)		9.36***
Labour (AWU)	1.88(7)	2.96(6)		4.66**
Capital (Euros)	243614(7)	479464(6)		5.59**
Capital to labour (Euros per AWU)	127036(7)	164885(6)		2.05
Share of rented land in UAA (%)	0(7)	12(6)		5.29**
Share of hired labour in total labour (%)	22(7)	81(6)		15.68***
Share of crop output in total output (%)	23(7)	13(6)		2.37
Share of livestock output in total output (%)	66(7)	82(6)		2.65
Total subsidies – excluding investments (Euros)	4942(7)	8136(6)		1.73
Produces under label	Insuff. obs.	1(4)		
Is non-organic	1.00(7)	0.83(6)		1.61
Not in LFA	0.14(7)	0.00(6)		1.22

Note: The number of observations is given between brackets. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. When there are insufficient observations in one cluster, the test is not computed.

Source: the authors, based on FADN and FLINT data.

Table 22: Average structural characteristics for the clusters of type of farming 8 - Mixed crops-livestock

	Cluster 1	Cluster 2	Cluster 3	test of equality of means
Number of farms	46	52	10	
UAA (ha)	55(46)	274(52)	186(10)	13.46***
Number of LU	NC	NC	NC	NC
Labour (AWU)	2.59(46)	4.91(52)	3.16(10)	1.67
Capital (Euros)	230429(46)	1226803(52)	1385436(10)	17.22***
Capital to labour (Euros per AWU)	117240(46)	304926(52)	736980(10)	41.85***
Share of rented land in UAA (%)	4(46)	22(52)	32(10)	15.92***
Share of hired labour in total labour (%)	32(46)	66(52)	60(10)	22.93***
Share of crop output in total output (%)	55(46)	46(52)	45(10)	6.85**
Share of livestock output in total output (%)	43(46)	49(52)	48(10)	3.04
Total subsidies – excluding investments (Euros)	14945(46)	72585(52)	50634(10)	6.06**
Produces under label	1.00(4)	1.00(21)	Insuff. obs.	0.00
Is non-organic	0.93(46)	0.94(52)	1.00(10)	0.67
Not in LFA	0.28(46)	0.17(52)	0.30(10)	1.94

Note: The number of observations is given between brackets. 'Insuff. obs.' indicates insufficient observations for statistical confidentiality reasons, that is to say less than three valid observations. Chi-square and significance are reported in the last column. *, **, *** indicate significance at 10, 5, 1% level respectively. The test of equality of means is computed to compare all three clusters together, except when there are insufficient observations in one cluster; in this case the test is computed to compare the two remaining clusters.

Source: the authors, based on FADN and FLINT data.

4 CONCLUSIONS

The sustainability of food production is an important societal issue and one that must be addressed by policy makers. Future policy will need to ensure food security while maintaining environmental protection. In order to develop such policy, a deep understanding of the complex relationship that exists between economic, environmental and social performance and how policy affects this relationship is required. The objective of this paper is to explore the relationship between these three factors using farm-level indicators. Specifically, this paper explores the links between economic, environmental and social sustainability for a sample of European farms in 2014-2015. Sustainability was assessed through various indicators of economic, environmental and social performance. We used farm-level data from EU FADN to compute economic performance, and additional data collected through the FLINT project. The latter data provide information that facilitated the calculation of various environmental and social performance indicators. For each TF, that is to say each main production specialisation, we constructed clusters based on farms' economic performance. Then we compared the environmental and social performance across clusters. Economic indicators included output and farm NVA related to size (UAA in ha, labour in AWU, capital in Euros), operational costs related to the value of output, and farm NVA per FWU. Environmental indicators included GHG emissions, N balance and water consumption related to size (UAA in ha, number of LU, output in Euros), the share of total farm area that is EFA, the share of grass-based rotation area in UAA, the share of extensive grassland in total permanent grassland, and the share of UAA with nitrate risk and the share of UAA with erosion mitigation. Social indicators included the farmers' perceived quality of life, stress levels, and degree of social engagement.

4.1 Main outcomes

4.1.1 No consistent relationship between economic and environmental indicators

The first finding from our analyses is that economic sustainability and environmental sustainability are positively correlated for some farm types but not others, and this depends on the type of environmental indicator. Within crop farms, with the exception of horticulture farms, (i.e. for field crop farms, permanent crop farms, mixed cropping farms and mixed crops-livestock), farms that perform well in economic terms are also the ones that perform well in environmental terms: they perform the same or better than the other farms in environmental terms. By constrast, grazing livestock farms that are best performing in economic terms are not always best performing in environmental terms: for instance, they are highly performing for GHG and N related to output value, but are low performing in terms of GHG per ha, water per ha and share of EFA. Results are equally constrasted for granivores farms. Finally, very few indicators are significantly different between clusters in the sub-sample of mixed livestock farms, which suggests a more homogenous sub-sample and may be due to the small size of this sub-sample. In summary, some of the environmental indicators may correlate with economic indicators, and others do not. This is important because assessments of sustainability that do not take into account the indicators that are not correlated with economic performance will give an incorrent assessment of 'true' sustainability, and lead to poorer decision-making (Teillard et al., 2016). While ecologists expect that GHG efficiency per kg product is negatively related to area of habitat, we find here similarly that farms with the highest economic performance have the lowest GHG emissions per Euro of output and the lowest share of EFA in total farm area for TF1 (field crops farms) and TF4 (grazing livestock farms). By contrast, in TF3 (permanent crop farms), farms with the highest economic performance also have lowest GHG emission per Euro of output but highest share of EFA.

4.1.2 High social sustainability was associated with high economic performance

High social sustainability was clearly linked to high economic performance for field crop farms (TF1), grazing livestock farms (TF4) and mixed crops-livestock farms (TF8), and to a lesser extent (it depends on the social indicator considered) for granivores farms (TF5) and mixed livestock farms (TF7). By contrast, social sustainability does not significantly vary with economic sustainability for farms in TF2 (horticulture), TF3 (permanent crops) and TF6 (mixed cropping). In other words, there are no tradeoffs between economic performance and (private) social performance; both performances may even be complementary.

4.1.3 Farm size was not consistently related to performance

The third finding is that farm size is linked to various types of performance in different ways. The link is clear for permanent crop farms, where larger farms are better performers both economically and environmentally, and for grazing livestock farms, where larger farms are the better performers economically and socially, but better or poorer environmentally (depending on the indicator). By contrast, better economically performing farms in horticulture and granivores production (but not clear in terms of environmental performance) are smaller.

4.1.4 Farm subsidies were not consistently related to either economic and/or environmental performance

The fourth finding is that subsidies are not always significantly related to either economic and/or environmental performance of farming systems. For field crop farms and for mixed cropping farms, the best performing cluster in terms of economic and environmental performance receives the lowest subsidies, whereas the reverse is true for permanent crop farms. Regarding the grazing livestock farms, the best performing cluster in economic terms but not clear-cut in environmental terms receives a medium amount of subsidies compared to the other two clusters. This finding is of particular interest for our policy recommendations.

In terms of policy recommendations, our analysis provides some insights into how a policy supporting economic performance, as is the case for Pillar 1 of the CAP, may force farms to make some tradeoffs in terms of environmental performance, as regard the indicators considered here, but possibly support the social sustainability of farms regardless of farm type. Our analysis shows that field horticulture farms in particular, as well as grazing livestock farms and granivores face tradeoffs. By contrast, field crop farms, permanent farms, mixed cropping farms and mixed crops-livestock farms do not make tradeoffs, as economic performance and environmental performance go hand in hand, or environmental performance is not affected by economic performance (in the cases of no significant differences across clusters in terms of environmental indicators). Hence, depending on the policy objective, policy support instruments should be designed so as to account for the complexity of the economic and environmental tradeoffs on different farm types.

4.2 Methodological recommendations

Several methodological recommendations can be drawn for further research. Firstly, it is important to compare the sustainability of farms within a specific TF and not for all TF together. One reason is that the size of a farm has a different meaning depending on the TF (e.g. size in ha is fully meaningful for field crop farms but not at all for granivore farms), and therefore the performance indicators cannot be related to the same size proxy across TF. Another reason is that, since technologies are obviously different between TF, they do not have the same margins of manoeuvre for increasing specific environmental indicators: for example, GHG emissions are inherently much higher for grazing livestock

farms than for field crop farms; thus, if clusters were created over both TF taken together, then field crop farms would always appear in the best performing cluster.

Secondly, from a methodological perspective, the choice of the indicator is crucial and may influence conclusions. We have for example shown that within grazing livestock farms, one cluster was best performing in terms of GHG if the latter is considered per output; however this same cluster is the worst performer if GHG is related to area or livestock units. The functional unit used is crucial, as discussed in Salou et al. (2017). GHG per output may be viewed as an efficiency indicator rather than an indicator of environmental impact, and could be thus be linked positively to economic performance. Furthermore, arguments in support for food security put more influence on GHG per output rather than per hectare. Although GHG reduction commitments are set at a country or Member State level, it could also be argued that GHG per ha should not be displayed nor commented, as the problem of GHG emission is not linked to area. Rather, it is linked to output since the global stake is to continue to produce sufficiently to match society's food demand while reducing the GHG emissions. Still regarding the choice of indicator, one can also note that within the mixed farming sample (TF8-mixed crops-livestock farms), clusters are significantly different from each other only when the indicators (GHG, N balance, water consumption) are related to Euros of output. There is not significant difference when these indicators are related to land and to the number of livestock units. For this mixed sample it may therefore not be appropriate to use environmental indicators related to physical size (ha or number of livestock units).

Thirdly, some indicators never (or almost never) discriminate between clusters. This is the case of UAA with erosion mitigation, and, to a lesser extent, of the share of grass-based rotation area and share of extensive grassland. One reason is the very low number of observations that are valid for these indicators. This suggests that surveyed farmers may not have been able to answer questions relating to these indicators, and further research should thus investgate how best to collect such information. One explanation may be that soil erosion concerns some specific regions, which were not covered by the FLINT sample, and hence farmers were not very aware of these issues for their farm.

Fourthly, while we have not made cross-country comparisons here due to limited sample size, one could do it in further research. Indeed, some clusters appear to be constituted mainly by farms in a single country, perhaps revealing differences in technology availability and environmental conditions and legislation that constrain economic performance. For example, the best performing cluster in the field crop farms sub-sample comprises only farms in the Netherlands (mostly) and in Hungary, while the best performing cluster in the permanent farms sub-sample mostly comprises French farms. A striking example is also given for the sub-sample of granivore farms where the cluster performing best in terms of economic indicators of AWU and in terms of water use (and including smallest farms in terms of UAA), contains only Dutch farms, while the cluster performing best in terms of LU, particularly GHG emissions (and including largest farms in terms of UAA), contains mostly Hungarian and Polish farms. The country differences should be kept in mind in terms of policy recommandations, as the delivery of direct subsidies may not be enough to enhance farm performance: measures to help spread technological innovations or to lift barriers on factor markets may be necessary and may need to be targeted.

Finally, collecting such information over several years may help address the temporal variability, in terms of year-to-year variation arising from temporal sampling error, year-to-year variation due to variation in stochastic factors (market volatility, weather) and changes over time such as temporal trends in response to e.g. technology adoption, policy implementation. We have provided here a picture of the situation in 2014/2015, which may be a specific economic or climatic context for some TFs. In addition, analysing the sustainability tradeoffs over several years can help capture the influence of price variability on economic performance (revenue), environmental performance (adoption of mitigation options or not), and social performance (quality of life).

4.3 Limitations to interpretation

Our analyses suffer from various limitations. Firstly, it should be noted that our sample is not representative of EU agriculture. Although the FADN database is representative of the EU agriculture in

terms of main productions and farm size, the sample considered for the FLINT project is not. The farms in the sample may not have been chosen for their representativeness but for other various reasons such as the willingness by an individual farmer to provide the additional sustainability information. In addition, while the FADN database is representative in terms of agricultural production, it is not representative of environmentally important farmland areas e.g. high nature value farmland.

Secondly, the numbers of farms in some TF are low (e.g. mixed livestock farms), as well as the number of farms having valid information for specific indicators (e.g. share of UAA with erosion mitigation), limiting the meanfulness of the conclusions.

Thirdly, the link between sustainability and CAP subsidies would need to be further explored with the help of a longer time-series of data. Indeed, we have provided here simple correlations but they do not indicate causal effects. It may be that subsidies influence sustainability, but it also may be the other way round: highly performing farmers are more able to obtain more subsidies than poorly performing farmers. This would need more specific investigation beyond the current methodology, by controlling for endogeneity. There may also be delayed effect of subsidies on performance, particularly on environmental performance as the generation of environmental outputs may be over a longer time period than for food.

Fourthly, this analysis assumes that our selection of a limited set of environmental (and social) indicators are sufficient to reflect the environmental (and social) performance of these farming systems. This is unlikely, but the data collection exercise in FLINT and this analysis indicate the insight and analyses that are possible to achieve, and this can be improved over time. For example, the environmental indicators related to soil management (grass-based rotation area, extensive grassland, nitrate risk area and area with erosion mitigation) contain a lot of missing data (due to farmers being unaware, unable or unwilling to answer), and thus the findings regarding these indicators should be considered with caution. More generally, the FLINT data set allowed us to calculate more environmental indicators in comparison to the FADN data set. However, in general, the FLINT environmental indicators are only based on management data and not on soil and climate date, so that their predictive quality remains very limited. Further research should focus on how best information needed for computing environmental indicators and their predictors can be collected, e.g. by providing clearer definition to farmers or by relying on soil experts. More generally, further research is needed to define the minimum set of environmental data that is required, and the most cost-effective means of collecting these data.

Finally, we have not weighted the economic performance indicators when constructing the clusters, and we have considered all environmental performance indicators separately with the same attention. However, depending on the policy focus or on the stakeholders' interests, some indicators may be given higher weight than others.

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5 REFERENCES

Bos, M.G., Bosch, H.D., Diemont, H., Keulen, H.V., Lahr, J., Meijerink, G. and Verhagen, A. (2007) Quantifying the sustainability of agriculture. *Irrigation Drainage System*, 21(1): 1-15.

Dillon, E, Hennessy, T., Buckley, C., Donnellan, T., Hanrahan, K. and Moran, B. (2016). Measuring progress in agricultural sustainability to support policy making. *International Journal of Agricultural Sustainability*, 14(1): 31-44.

Godfray, C.J., Beddington, J.R., Crute, I.R., Hadad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. and Toulmin, C. (2010). Food Security: The challenge of feeding 9 billion people. *Science*, 327(5967): 812-818.

Reig-Martinez, E., Gomez-Limon, J. and Picazo-Tadeo, A.J. (2011). Ranking farms with a composite indicator of sustainability. *Agricultural Economics*, 42(5): 561-575.

Salou, T., Le Mouël, C., van der Werf, H.M.G. (2017). Environmental impacts of dairy system intensification: the functional unit matters! *Journal of Cleaner Production*, 140(2): 445-454.

Teillard, F., Maia de Souza, M., Thoma, G., Gerber, P. and Finn, J.A. 2016. What does Life-Cycle Assessment of agricultural products need for more meaningful inclusion of biodiversity? *Journal of Applied Ecology*, 53(5): 1422–1429.