# FARM-LEVEL INPUT INTENSITY, EFFICIENCY AND SUSTAINABILITY: A CASE STUDY BASED ON FADN FARMS

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**Summary**

There is a growing demand in the last years for farm-level sustainability data reflected in various initiatives from farmers, science and food or related industries. The broad aim to develop viable food production systems, through supporting the sustainable management of natural resources and climate action and to strive for more balanced territorial development are core values within the EU and are reflected in the changing Common Agricultural Policy (CAP). The CAP is one of the key drives of agricultural practice across the EU, it has become more oriented towards the concepts of sustainability reflecting these higher order objectives. The EU operates a farm-level monitoring system, the Farm Accountancy Data Network (FADN), which acts as a check to establish if such successful change is being achieved, currently the primary focus is on the economic dimension of sustainability.

This article uses an FADN farm sample for which both FADN and additional sustainability data were available form a data collection carried out by the EU-project FLINT. In particular, we compare the relationship between input intensity, efficiency and sustainability. Sustainability performance of the farms is compared by applying sustainability thresholds as identified in a literature survey. The farms were grouped according to their degree of efficiency and sustainability and possible relationships with farm characteristics are analysed.

Based on farm benchmarking, around one half of the farms was observed to be neither efficient nor sustainable, while 15% met our criteria for being classified as efficient and sustainable. The results of our study are not representative but illustrative and can be a starting point for further analyses in this field.

**Keywords**: sustainable intensification, farm-level sustainability, FADN

# 1 Introduction

Farm intensification is seen as driver for economic development of rural areas but also as one of the main reason for environmental deployment. Acknowledging the limited availability of land and other natural resources, "*sustainable intensification*" is seen as a necessary path to close yield gaps and achieve food, fibre and fuel production goals at less environmental costs (WELTIN et al., 2018). The term "*sustainable intensification*" refers to the need to simultaneously increase agricultural productivity to face the greater demand for food while further reducing negative environmental aspects ( GARNETT et al., 2013; MAHON et al., 2017) or even progressing on environmental and social outcomes ( PRETTY et al., 2018).

While the overall concept has been accepted as a strategy for sustainable development, there is lack of clarity as to how exactly define and measure intensification and its association with sustainability (MAHON et al., 2018; RASMUSSEN et al. 2018). The connection between intensification, productivity/efficiency and environmental outputs has been explored at greater detail at national aggregated level (FUGLIE et al., 2016) whereas an argued lack of comparable information at the farm-level (BALDONI et al., 2017).

Nonetheless, there is a growing demand in the last years for farm-level sustainability data reflected in various initiatives from farmers, science and food or related industries (LATRUFFE et al., 2016). A large number of indicator or check-list based assessment systems have been developed (HÄNI et al., 2003; VAN CAUWENBERGH et al., 2007; MEUL et al., 2008; ZAHM et al., 2008; BOCKSTALLER et al., 2009; SATTLER et al., 2010; ELSAESSER et al., 2013; FAO, 2013; HENNESSY et al., 2013; TERRIER et al., 2013; WRZASZCZ and ZEGAR, 2014). Another option to developing new tools is to further develop existing farm monitoring systems, such as the EU-wide Farm Accountancy Data Network (FADN), which is in place for more than 50 years, and to test collecting sustainability data from the farms in this network (VROLIJK et al., 2016; KELLY et al., 2018). Such an approach has been undertaken by the EU-project FLINT (POPPE et al., 2016; POPPE AND VROLIJK, 2017). In addition to already existing FADN data and computed indicators, additional data for economic, environmental and social topics were collected from FADN farms in different EU countries.

The objective of the paper is to use FADN and complementary sustainability data to analyse the relationship between agricultural intensification and sustainability at farm level by comparing metrics of intensification, efficiency and sustainability and determining which managerial factors and farm characteristics are associated with the observed patterns.

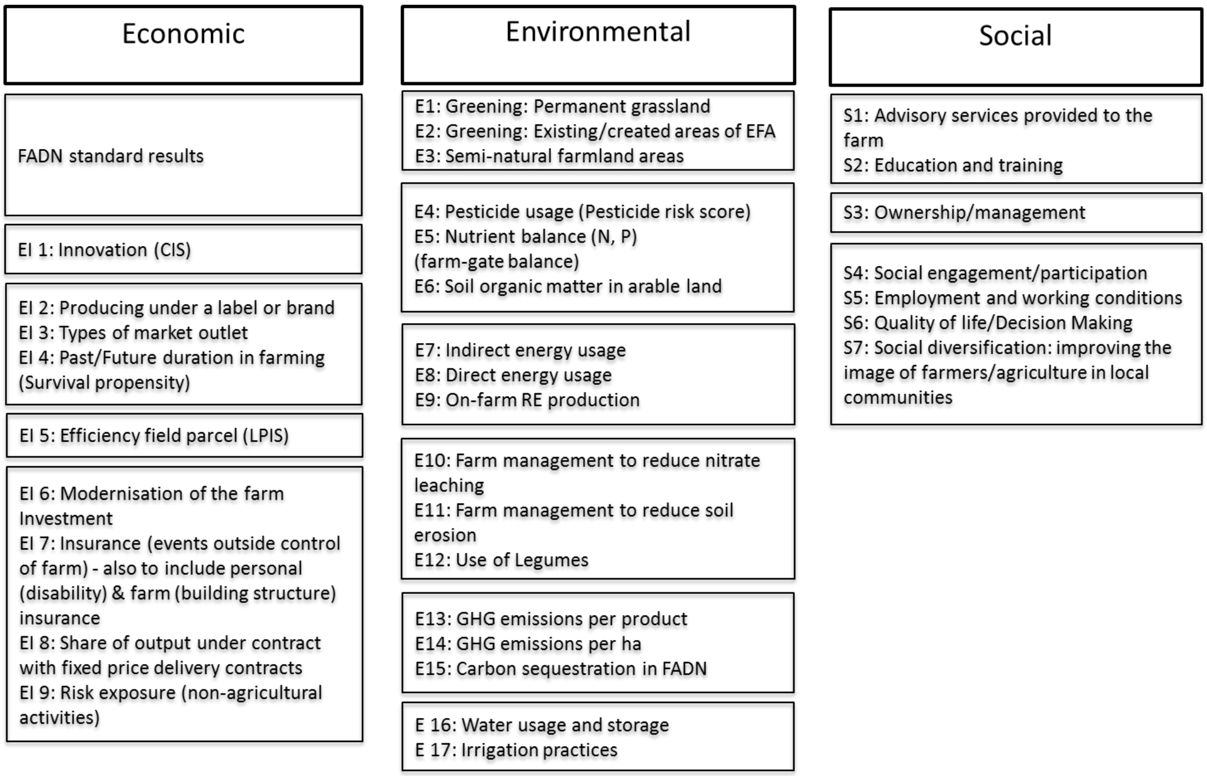
# 2 Methods

## 2.1 Data

Our analysis is based on a sample of 59 arable farms which were part of a farm survey carried out by the EU-project FLINT in the year 2014/15. The FLINT-project carried out a pilot study collecting sustainability data from FADN farms in nine European countries (POPPE and VROLIJK, 2017). The overall objective was to explore whether the FADN can be further developed to meet increased data demands associated with a changing CAP that today pursues a broader range of objectives apart from farm income stabilisation such as sustainability topics (POPPE et al., 2016).

The sustainability indicators considered in FLINT were derived in a multi-level approach, starting with an initial indicator list based on literature research and expert surveys, which was further reduced through expert assessment to a list of 33 sustainability topics (Figure 1), each underpinned with sub-indicators.

**Figure 1: FLINT sustainability topics**




Source: FLINT Project

Although the FLINT survey involved the most relevant FADN types of farming, we limit our analysis in this article to arable farms (FADN classification: specialist field crops) to enable a comprehensible result presentation and to be able to use a single set of indicators. For example, for grassland-based farms, several typical crop-related indicators are inappropriate; making different indicator sets necessary which would complicate the result analysis and presentation. For all 59 farms both FADN and additional sustainability data collected in FLINT were available. FADN data consisted of the FADN farm return data tables A-M[1] and standard results[2]. Additional data collected in FLINT consisted of 10 newly defined data tables related to specific sustainability topics as well as a result table with sustainability indicator results.

## 2.2 Analysis

Our intention in this article is to compare farms along their degree of intensification, their efficiency and their sustainability. All three concept are interpreted differently in the literature, therefore in the following we provide an overview, how we derived the respective definitions presented in Table 1.

### Agricultural intensification, productivity and efficiency

[1] Regulation (EU) 2015/220: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R0220&from=EN (Access : 2019/3/7)

[2] Definitions of Variables used in FADN standard results (European Commission RI/CC 1750) https://circabc.europa.eu/ui/group/880bbb5b-abc9-4c4c-9259-5c58867c27f5/library/f0115388-31be-4e5e-8771-33a8f77d1057/details (Access: 2019/3/7)

The concept of agricultural intensification varies from the physical quantity of inputs such as nitrogen (VAN ASSELEN and VERBURG 2013), energy (ALLUVIONE et al., 2011), calorie gains (SCHERER et al., 2018), technology use (MA et al., 2018) or monetary values of inputs (FADN). Additionally, also differences in the functional unit such as land (FADN), output (MUTYASIRA et al., 2018) or farm can be found. For this study, we use the EUROSTAT description of input intensity of a farm which is "*the level of inputs used by the farm per unit of factor of production, in general, land"*[3]. Two indicators reflect this definition: total external input costs per ha and total intermediate consumption per ha (Table 1). Productivity, on the other hand, is defined as the return from each unit of resource invested in the farm, which indicates an output over input ratio. Generally, productivity is measured by comparing total agricultural output to the amount of land, labour and capital employed in production (DGAGRI 2016). Measures of environmental partial productivity and environmental efficiency are defined as the ratio of the agricultural output to an environmental indicator (OECD 2014). The inverse of productivity ratios are used as efficiency metric (JAN et al., 2012, LYNCH et al., 2018) or as a measure of environmental cost (BALMFORD et al., 2018). We use as indicators Total output/total input (SE132) and External inputs/total output (Table 1).

**Table 1: Calculation of indicators for agricultural intensification, efficiency and sustainability and data sources**

| Classification indicators | Unit | Source | Calculation | Mean | St dev | Min | Max | 1st tertile boundary | 2nd tertile boundary |
|---|---|---|---|---|---|---|---|---|---|
| **Agricultural intensification** | | | | | | | | | |
| External input costs_ha | Euro/ha | FADN | (SE295+SE300+SE310+SE320)/SE025 | 280.1 | 129.1 | 51.7 | 638.4 | 205.7 | 331.5 |
| Total intermediate consumption_ha | Euro/ha | FADN | SE275/SE025 | 640.7 | 230.1 | 224.8 | 1387.9 | 526.8 | 699.3 |
| **Efficiency/ productivity** | | | | | | | | | |
| Total output/total input | index | FADN | External input costs_ha/SE131 | 1.05 | 0.31 | 0.38 | 1.78 | 0.91 | 1.17 |
| External inputs/total output | index | FADN | SE132 | 0.31 | 0.10 | 0.05 | 0.53 | 0.26 | 0.35 |
| **Sustainability** | | | | | | | | | |
| SustIndex | index | FLINT, FADN | equations 1-4, sub-components and assessment rules shown in Table 2 | 0.44 | 0.15 | 0.11 | 0.82 | 0.40 | 0.51 |

Source: the authors

## Sustainability assessment

Sustainability is the least clearly defined concept. Although environmental costs are somehow associated with sustainability measurement, there is the argument that environmental efficiency ratios are an insufficient measure of sustainability as they insufficiently capture the total consumption of environmental services used by the agricultural sector and therefore they do not measure those modifications in the biophysical system capacities to recover and continue providing ecosystems services in the future (FUGLIE et al., 2016). Moreover, the sustainability development concept involves changes in economic, environmental and social aspects which societal value is higher than the value to the individual farmer such as soil quality (BRAUSMANN and BRETSCHGER 2018), biodiversity conservation (EGLI et al., 2018),

[3]https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_intensification_-_extensification

pesticide use (LECHENET et al., 2014) or quality of life making them difficult to be measured through a farm resource or farm output -based metric.

At farm-level, often an operational triple-bottom-line approach based on indicators is chosen to represent economic, environmental and social aspects of sustainability (HÄNI et al., 2003; BREITSCHUH, 2008; EHRMANN and KLEINHANß, 2008; MEUL et al., 2008; ZAHM et al., 2008; ELSAESSER et al., 2013; FAO, 2013; HENNESSY et al., 2013; TERRIER et al., 2013; SAI, 2014; WRZASZCZ and ZEGAR, 2014), and was also used for this article. From the complete list of FLINT indicators a final set of indicators was selected for this study (Table 2). A correlation analysis was done to further reduce the number of indicators, given preference to less correlated indicators. In addition, consideration was given to include the most relevant indicators for each dimension, while keeping the total number of indicator manageable.

Our intention for the economic dimension was that the three widely used categories profitability, liquidity and stability are adequately covered. The indicators selected are taken from BREITSCHUH (2008). The social dimension was intended to cover both farm-internal and external aspects. For the environment dimension a combination of resource-related (NBal_ha, GHG_Euro) and biodiversity-related (Shannon index, Ecological Focus Area, PestLD50) indicators was aimed at. All environmental indicators are primarily based on farm data collected with the FLINT farm return.

**Table 2: Overview of the sustainability indicators used this study study, descriptives and assessment rules**

| Sustainability indicators | Indicator Name Short | Unit | Data source | Sustainability assessment | Mean | Stdev |
|---|---|---|---|---|---|---|
| **Index Economic** | IndexEco | index | Own calculation | n.i. | 0.3 | 0.2 |
| Farm net value added [SE425] | FNVA_AWU | Euro/AWU | FADN | >=25,000[a] Euro/AWU | 21,754.4 | 31,173.4 |
| CashFlow II [SE530]/[SE025] | CashFlowII_ha | Euro/ha | FADN | >=500 Euro/ha[a] | 54.0 | 458.2 |
| Change in net worth [SE506]/[SE025] | ChangeNetWorth_ha | Euro/ha | FADN | >=160 Euro/ha[a] | 131.2 | 435.7 |
| **Index Social** | IndexSocial | index | Own calculation | n.i. | 0.6 | 0.3 |
| Working hours | WorkingH | hours per weeks | FLINT | <=40 hours[b] | 35.55 | 39.50 |
| Quality of life | QualLife | Likert scale 1-10 | FLINT | >=5[c] | 6.9 | 1.7 |
| Social diversification | SocDivInd | index | FLINT | upper tertile | 2.0 | 1.8 |
| **Index Environment** | IndexEnv | index | Own calculation | n.i. | 0.5 | 0.2 |
| Pesticide toxicity index (LD50rats) | PestLD50 | kg rats killed per ha | FLINT | upper tertile | 1,933.4 | 1,592.4 |
| Crop variety (Shannon index) | Shannon | index | FLINT | >=1.25[a] | 1.5 | 0.3 |
| Nitrogen balance | NBal_ha | kg/ha | FLINT | -50 kg/ha to 50 kg/ha [a] | 131.8 | 81.9 |
| Ecological focus area | EFAShare | % in UAA | FLINT | >=5%[a] | 8.6% | 12.3% |
| GHG-emissions | GHG_Euro | Tonnes $CO_2$ Equivalents per Euro output | FLINT, FADN | upper tertile | $2.51*10^{-4}$ | $4.37*10^{-4}$ |

[a] Source: BREITSCHUH (2008); [b] Source: OECD (2017); [c] Source: EUROPEAN UNION (2015)

To calculate indexes for the economic, social and environmental dimensions of sustainability the indicator values were transformed into assessment categories by applying the assessment rules specified in Table 2. For example, if a farm has a net value added above 25,000

Euro/AWU it is assigned to category 1, while with a lower net value added is assigned to category 0.

For indicators without thresholds reported in the literature, a tertile-based assessment was conducted. For example, if a farm is in the upper tertile with regard to a particular indicator, we consider it being in the "sustainable" range (assessment category =1).

The thereby created assessment values are aggregated according to:

$$(1)\ IndexEco = \frac{\sum_i^k Indicator_i}{k} \qquad \text{Equation 1}$$

With k: 0/1 assessment categories for indicators FNVA_AWU, CashFlowII_ha and ChangeNetWorth_ha in

$$(2)\ IndexSoc = \frac{\sum_i^l Indicator_i}{l} \qquad \text{Equation 2}$$

With l: 0/1 assessment categories for indicators WorkingH, QualLife, SocDivInd

$$(3)\ IndexEnv = \frac{\sum_i^m Indicator_i}{m} \qquad \text{Equation 3}$$

With m: 0/1 assessment categories for indicators PestLD50, Shannon, NBal_ha, EFAShare, GHG_Euro included

All three indexes were combined into a single sustainability index (Equation 4). We used the simplest option (equal weighting) to achieve a high level of transparency being aware of the compensation effects that occur as a result of this procedure. Given that the sub-components and their relationship to the intensification, efficiency and other farm classification indicators are also shown, this approach seems tolerable.

$$(4)\ SustIndex = \frac{IndexEco + IndexSoc + IndexEnv}{3} \qquad \text{Equation 4}$$

The farms were grouped into tertiles using the boundaries shown in Table 1. Kendall's tau was used to analyse correlations among the variables. A non-parametric Kruskal-Wallis test was used to test for differences in group means.

## 3 Results

Table 3 shows all significant relationships between agricultural intensification, efficiency and farm sustainability. External inputs per ha were positively correlated with field size, pesticide toxicity, N-balance, advisory contacts and the number of insurance categories. A negative correlation was found for the economic index, the environmental index, the Shannon index, ecological focus area, and the overall sustainability index. This result is in line with expectations, since a pure input increase per ha without necessarily increasing output is usually associated with lower economic and environmental outcomes.

If total intermediate consumption is used, the negative environmental correlation is reduced, with some indicators as well as the environmental index itself no longer being significantly correlated. The direction of the correlation for those indicators that remain significant, however, is similar. As for the two efficiency/productivity-related indicators, more efficient farms produce more output with less input, therefore a positive correlation with the economic index could be found. More efficient farms tended to have a higher farm net value added per ha (FNVA_AWU) and a higher cash flow II per ha. No significant relationship with the environmental and social indicators could be found. Farms with a high dependence on external inputs, however, showed both a negative correlation with the economic environmental index. Regarding the single indicators, a negative relationship with the N-balance, ecological focus area and GHG emissions could be identified.

**Table 3: Correlation between metrics for farm-level intensification and efficiency and farm sustainability indicators**

| | **Agricultural Intensification** | | **Efficiency** | | **Output per ha** | **Total farm area** | **Labour per Output** |
|---|---|---|---|---|---|---|---|
| | External input costs_ha | Total intermediate consumption_ha | Total output/total input | External inputs/total output | SE131/ SE025 | SE025 | SE010/ SE131 |
| IndexEco | -.212$^{*}$ | -.215$^{*}$ | .328$^{**}$ | -.378$^{**}$ | | .282$^{**}$ | -.272$^{**}$ |
| FNVA_AWU | | | .296$^{**}$ | -.287$^{**}$ | | .453$^{**}$ | -.479$^{**}$ |
| CashFlowII_ha | | | .389$^{**}$ | | .218$^{*}$ | | |
| ChangeNetWorth_ha | | -.178$^{*}$ | | | | | |
| IndexSoc | | | | | | .207$^{*}$ | -.200$^{*}$ |
| WorkingH | | | | | | | |
| QualLife | | | | | | .333$^{**}$ | -.362$^{**}$ |
| SocDivInd | | | | | | .277$^{**}$ | -.258$^{**}$ |
| IndexEnv | -.239$^{*}$ | | | -.335$^{**}$ | | | |
| PestLD50 | .301$^{**}$ | .202$^{*}$ | | | .258$^{**}$ | | |
| Shannon | -.192$^{*}$ | -.186$^{*}$ | | | | .192$^{*}$ | |
| NBal | .494$^{**}$ | .335$^{**}$ | | .232$^{*}$ | .393$^{**}$ | | -.177$^{*}$ |
| LFShare | -.253$^{*}$ | | | -.314$^{**}$ | | .235$^{*}$ | |
| GHGEuro | | | | .262$^{**}$ | -.194$^{*}$ | | |
| SustIndex | -.208$^{*}$ | | | -.320$^{**}$ | | .277$^{**}$ | -.265$^{**}$ |

Source: the authors

In addition, also correlation with other typical farm indicators (output per ha, total farm area, labour input per output) was analysed (also Table 3). Total output per ha was positively correlated with the cash flow II per ha, the toxicity index, the N-balance, while a slight negative relationship with the GHG-emissions was found. Farm size had a positive correlation with the economic index, the social index and selected environmental indicators, while a labour input was associated with a negative correlation with the economic and social index, while it the N-balance of labour-intensive farms tended to be lower (small negative correlation). Table 4 shows how the metrics for agricultural intensification, productivity/efficiency and sustainability are related to each other (only significant).

**Table 4: Relationship between metrics for farm-level intensification, efficiency and sustainability**

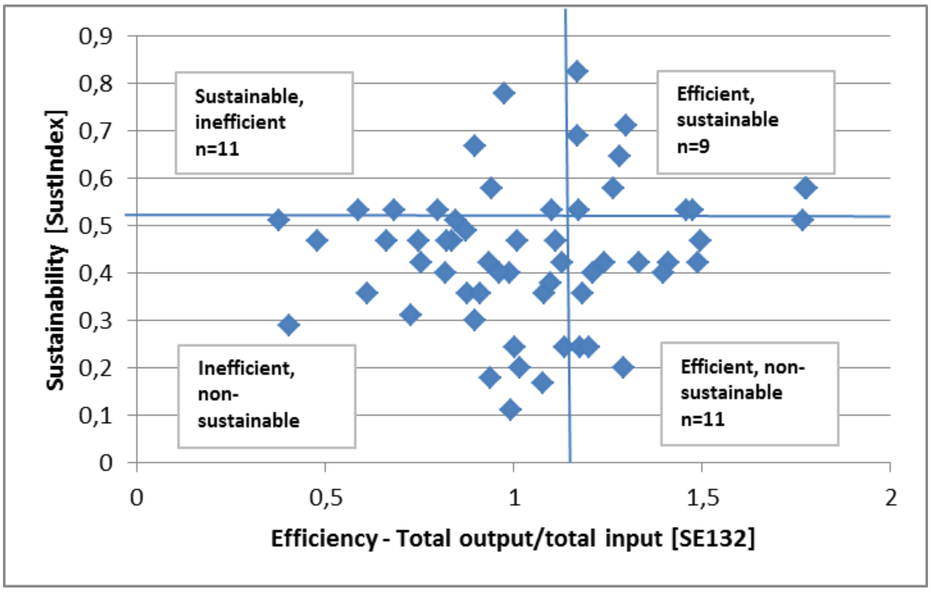
| | External input costs_ha | Total intermediate consumption_ha | Total output/total input | External inputs/total output | IndexEco | IndexSoc | IndexEnv | SustIndex |
|---|---|---|---|---|---|---|---|---|
| External input costs_ha | 1.000 | .625$^{**}$ | | .425$^{**}$ | -.212$^{*}$ | | -.239$^{*}$ | -.208$^{*}$ |
| Total intermediate consumption_ha | | 1.000 | -.183$^{*}$ | .253$^{**}$ | -.215$^{*}$ | | | |
| Total output/total input | | | 1.000 | -.327$^{**}$ | .328$^{**}$ | | | |
| External inputs/total output | | | | 1.000 | -.378$^{**}$ | | -.335$^{**}$ | -.320$^{**}$ |
| IndexEco | | | | | 1.000 | | | .503$^{**}$ |
| IndexSocial | | | | | | 1.000 | | .581$^{**}$ |
| IndexEnv | | | | | | | 1.000 | .316$^{**}$ |
| SustIndex | | | | | | | | 1.000 |

Source: the authors

In our sample, efficiency (total output/total input) was negatively correlated with t external inputs/total output and positively correlated with economic index, while no correlation was found with regard to the other sustainability indices.

Using the tertile boundaries in Table 2 (SE132: 1.17; SustIndex: 0.51), four different areas can be identified, as shown in Figure 2. 9 farms are in the upper tertile for both efficiency and sustainability (Figure 2). Around one half of the farms (n=28) was neither efficient nor sustainable, while 22 farms were in the upper tertile for at least one criterion.

**Figure 2: Comparison of farm-level efficiency and sustainability**




Source: the authors

A closer look at the individual indicators of the four farm groups (Table 5) reveals that farm in the EffS – efficient and sustainable - group were characterised by a good to excellent performance for all three economic indicators. Regarding the social indicators, a medium-level performance could be observed.

For the environmental dimension, the EffS-group had on average a good performance with regard to crop diversity (Shannon index), ecological focus area and GHG emissions. The latter observation was also found in a study by RYAN et al. (2015). However, the environmental index was at the lower tertile boundary on average, revealing that the performance for other environmental indicators, N-balance and pesticides, was not optimal.

**Table 5: Relationship between intensification, efficiency and sustainability**

| | Efficient and sustainable (EffS) | Inefficient but sustainable (IneffS) | Efficient but non-sustainable (EffNonSus) | Inefficient and non-sustainable (IneffNonS) |
|---|---|---|---|---|
| Total output/total input | 1.48 | 0.87 | 1.31 | 0.89 |
| External input costs_ha | 291.65 | 189.03 | 285.42 | 310.16 |
| Total intermediate consumption_ha | 680.06 | 578.21 | 555.95 | 685.83 |
| External inputs/total output | 0.22 | 0.28 | 0.29 | 0.36 |
| Total output_ha | 1279.17 | 737.86 | 992.13 | 844.95 |
| Farm area (UAA) | 128.35 | 233.87 | 48.51 | 212.69 |
| Labour input per ha | 0.02 | 0.01 | 0.05 | 0.04 |
| Labour input per total output | 0.02 | 0.09 | 0.08 | 0.08 |
| FNVA_AWU | 56,005.00 | 39,312.50 | 9,984.67 | 8,471.19 |
| CashFlowIIHa | 328.30 | -128.22 | 235.89 | -34.01 |
| ChangeNetWorth | 231.98 | 248.89 | 256.00 | 3.46 |
| WorkingH | 33.67 | 29.09 | 41.36 | 36.52 |
| QualLife | 7.78 | 7.82 | 6.18 | 6.57 |
| SocDivInd | 3.00 | 3.18 | 1.00 | 1.68 |
| PestLD50Index | 2883.33 | 953.31 | 1816.63 | 2058.98 |
| Shannon | 1.60 | 1.53 | 1.51 | 1.50 |
| NBal | 145.32 | 83.85 | 127.26 | 146.36 |
| EFAShare | 0.10 | 0.12 | 0.06 | 0.07 |
| E_14_Euro | 2.81E-05 | 4.84E-04 | 3.40E-04 | 2.05E-04 |
| IndexEco | 0.48 | 0.42 | 0.27 | 0.14 |
| IndexSocial | 0.74 | 0.82 | 0.36 | 0.54 |
| IndexÖko | 0.51 | 0.58 | 0.45 | 0.40 |
| SustIndex | 0.58 | 0.61 | 0.36 | 0.36 |
| Age buildings | 22.58 | 30.88 | 22.62 | 29.47 |
| Age machinery | 10.53 | 13.85 | 12.73 | 14.54 |
| Favorability of field pattern | 2.67 | 2.55 | 2.73 | 2.82 |
| Field size | 9.31 | 6.55 | 4.50 | 7.34 |
| Experience as decision maker | 19.67 | 11.64 | 21.55 | 18.75 |
| Advisory contacts | 31.88 | 14.67 | 21.27 | 32.52 |
| Technology use | 1.22 | 1.45 | 0.73 | 0.93 |
| Farm diversification | 0.67 | 0.55 | 0.73 | 0.57 |
| Innovation | 0.67 | 0.64 | 0.45 | 0.50 |
| Insurance categories | 2.11 | 2.18 | 2.18 | 2.64 |
| Income sources | 0.44 | 0.36 | 0.09 | 0.25 |
| Other gainful activities | 0.33 | 0.27 | 0.09 | 0.21 |

Source: the authors

This is a result of the sample inherent benchmarking: the environmental index is on average comparatively low, reflecting that only few farms are "sustainable" for all five environmental indicators (n=2 in the entire sample), while the majority of the farms had a mixed performance, with only some indicators achieving the sustainability threshold. With a greater sample and normative instead of tertile-based thresholds this pattern could possibly be avoided. As for other farm characteristics, EffS-group farms were of medium farm size and their farm equipment (buildings, machinery) was comparatively modern. Their self-assessed favourability of the field pattern (FavField) was below the sample average, while the average field size was larger. EffS-group farms were more likely to be innovative, have multiple income sources and other gainful activities.

In contrast, inefficient and non-sustainable farms (IneffNonS-group), had the highest external inputs costs ha, the lowest economic outcome, a lower quality of life and were characterized by a lower social diversification index (SocDivInd). Their pesticide toxicity (PestLD50Index) and N-balance were comparable to the SI-Group, while their output per ha was considerably lower. They were less likely to be innovative (Innovation) or use modern technology (Technology use)

## 4. Conclusions

Our study contributes to the discussion on the metrics of sustainable intensification. We have shown how an FADN extended towards sustainability data can be used to carry out analyses in this context to identify farms with a varying efficiency/sustainability patterns and possible farm characteristics that are associated with these patterns.

A focus on external input use per ha appeared to be inappropriate for a sustainable intensification assessment, while efficiency metrics, such as total output per input were more appropriate. The relationship between efficiency and sustainability was not straightforward in our farm sample. Around one half of the farms were neither efficient nor sustainable, these farms are potential candidates for specially designed policy and extension measures to achieve a sector-level move towards sustainable intensification. 15% of the farms were classified as efficient and sustainable however, given that the classification was based on farm benchmarking within our sample, the overall environmental performance was only relatively (within the sample) high, while selected environmental indicators still had a below sample average performance (toxicity, N-balance).

Overall, our study remains therefore illustrative, as the sample size is small. The chosen sustainability metrics influence the results, they are not universally applicable but driven by farm-level other studies and the available data from the FLINT-project. Therefore similar studies should be carried out at larger scale to confirm or reject our observations and to further enhance farm-level sustainability assessments.

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