Energy efficiency improvement in farming equipment, for agricultural holdings

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Abstract. The use of depreciated and outdated agricultural equipment reflects both, on the increased cost of production (due to the higher energy component), and the greater amount of emissions produced during the operation of that equipment. The presented paper deals with energy and emission analysis of the replacement of existing farming equipment in a holding, with a new one. The analysis considers the baseline tractor and harvester and their specific agricultural operations, related to the processing of the soil and the harvesting of the production. The analysis is based on the existing energy consumption of the old machines and accounting information on the operation of the new equipment, one year after its commissioning. The study shows that the estimated energy savings from the measures of 17.2%, with a similar carbon footprint reduction. Based on the technical characteristics, CO, HC, HC + NOx and NOx emissions were also analyzed. The percentage of estimated carbon emission savings is higher than 43.5%.

1. Introduction
Large portion of the existing agricultural equipment in Bulgaria is heavily depreciated and energy consuming, which is responsible for both, the high cost of production of the farm and the significant emissions produced by the machinery. In [1], an analysis of the energy consumption of the agricultural sector in Iraq was carried out, according to which, from 1994 to 2006, energy consumption increased from 29 to about 42%, while the introduction of energy efficiency measures led to savings in the range of 16 to 20%. This shows that the growth in energy efficiency gains is much smaller than in European countries.

When assessing energy consumption in the agricultural sector, the state of the agricultural equipment used must be taken into account, including the attached inventory, the type of soil processing operations, and the conditions under which the activities are carried out. The studies in [2, 12] present an analysis of the fuel consumption of the same soil activities during different seasons. On this basis, with a view to improving energy efficiency, a recommendation is made as to the type and timing of soil cultivation activities. This achieves energy savings of up to 14.24% in winter and up to 14.10% in summer.

In studies [3-5] are shown the influence of different systems (wireless sensors, energy management systems, mobile Sinks collectors etc.) on fuel consumption when using agricultural equipment. These
systems not only provide real-time energy consumption monitoring, but also provide optimization recommendations for machine operation. Another way to reduce energy consumption in the agricultural sector is by the use of hybrid electric agricultural tractors [6, 7]. In this way, energy savings of up to 5% are achieved, when performing operations.

In the recent decades, with the increase of the Earth's population, there has been a significant increase in the cultivation of agricultural land. The operation of machines that largely use liquid fuels is associated with the generation of significant carbon emissions that have a negative impact on the environment. In studies [8-10], a critical analysis is made, regarding the percentage of increase in emissions resulting from increased plowing, as well as the type of additional activities carried out.

2. Aim of the presented study
The aim of the presented study is to analyze the energy consumption of different agricultural equipment, depending on the type of activities performed. For this purpose, two farming vehicle machines have been selected - a wheeled tractor and a harvester in an agricultural holding. The main activity of the farm is the cultivation of cereals: wheat, barley, rapeseed, sunflower and corn.

3. Efficiency assessment of the implementation of energy efficient farming equipment
The cultivation of the land is carried out by means of an existing wheeled driven tractor and attached implements, and the harvesting of the finished products is carried out by the harvester available on the holding. In addition, logistic operations within the farm (relocation, loading and unloading activities) are carried out by a front loader.

3.1. Analysis of the energy consumption, when using a wheeled driven tractor

3.1.1. Current status (baseline)
The activities related to the cultivation of the land are carried out by the tractor “UMZ 6L” and the equipment attached to it. The tractor is produced 1990. The power of the machine is 45.6kW (61.9 hp).

The equipment carries out the following agricultural activities: plowing, cultivation, diskling, sowing. The average diesel fuel consumption of the tractors provided is approximately as follows: plowing - 3.00 l/da, cultivation - 1.50 l/da, diskling - 1.20 l/da and sowing - 1.25 l/da.

The fuel consumption of the individual treatments is high, leading to high fuel consumption compared to modern machines. With current machine use, according to the farm accounting information, the annual fuel consumption is 14 790 l/year diesel, which energy equivalent is 137 355.32 kWh/year (188 123 kWh/year - related to primary energy). Detailed information on the amount of workable land and the type of activities carried out is presented below, in Table. 1.

| ACTIVITIES       | WORKED AREA | SPECIFIC | CONSUMPTION | TOTAL       |
|------------------|-------------|----------|-------------|-------------|
|                  | da/year     | l/da     | l/year      | kWh/year    |
| Deep plowing     | 2 900       | 3.00     | 8 700.00    | 80 797.25   |
| Disking          | 1 450       | 1.20     | 1 740.00    | 16 159.45   |
| Cultivation      | 2 900       | 1.50     | 4 350.00    | 40 398.62   |
| **TOTAL**        | **14 790.00**|          | **137 355.32**|             |

From the table it is seen that, the highest consumption is for deep plowing (8 700 liters), accounting for 58.82% of the total fuel consumed by the tractor. Second in fuel consumption is cultivation (1 740 liters) with a share of 29.41%. The lowest amount of diesel fuel is spent on diskling. This expenditure accounts for about 11.7% of total consumption.

3.1.2. Suggested measure
In order to increase the energy efficiency in soil tillage, it is foreseen to purchase a new energy efficient John Deere 8370R tractor. Information on the consumption of the new tractor by type of
activity, based on accounting data provided by the farm for the purposes of the assessment, is presented in Table 2. The tractor is high-performance and energy-efficient. The engine power is 275.9 kW (370 hp). Engine emission level is Tier 4.

| ACTIVITIES     | WORKED AREA | CONSUMPTION | TOTAL      |
|----------------|-------------|-------------|------------|
|                | da/year     | l/da        | l/year     | kWh/year   |
| Deep plowing   | 2 900       | 2.998       | 8 693.10   | 80 733.12  |
| Disking        | 1 450       | 0.787       | 1 141.73   | 10 603.28  |
| Cultivation    | 2 900       | 0.770       | 2 233.00   | 20 737.96  |
| TOTAL          | 12 067.82   | 112 074.36  |            |            |

Table 3 shows a reduced consumption of diesel fuel, compared to that before the measure was introduced, with more significant reduction in disking and cultivation activities. The total consumption is 12 067.82 liters, respectively 112 074.36 kWh, while the plowing activity within its limits retains its maximum share.

### 3.1.3. Energy saving after the introduction of an energy efficient tractor

The diesel savings, achieved with the introduction of Measure 1, are calculated as the difference between the consumption of the tractor used (from Table 1) and that of the new John Deere 8370R tractor (from Table 2). The total amount of diesel savings achieved from Measure 1 is 2 722 l/year. This amount of saved diesel fuel is equivalent to 25 280 kWh/year saved final energy. Converted to primary energy, these savings are 27 809 kWh/year. Conversions are made by adjusting the value of the saved final energy by coefficient, regarding the losses in extraction, production and transportation, according to Appendix №2 to Regulation №E-RD-04-2/22.01.2016. For the diesel fuel, this ratio is 1.1. Based on the final energy saved in kWh, the CO₂ savings are calculated. For all farm activities, the estimated CO₂ savings for the measure are 6.75 t/year. The ecological equivalent coefficients have been used for the calculations, according to Appendix No. 3 to Regulation No.Е-RD-04-2/22.01.2016. For diesel fuel this coefficient is 267 gCO₂/kWh.

The energy saving factor of Measure 1 is estimated at 18.41%. The results of the calculations by types of activities performed are presented in Table 3.

### 3.2. Analysis of the energy consumption, when using a harvester

#### 3.2.1. Current status (baseline)

For harvesting of the agricultural production, mainly wheat and sunflower seeds, the farm uses a grain harvester. The main activities, carried out with this type of agricultural machinery, are classified by previous survey as:

- Harvest of spring cultures (1 400 da);
- Harvest of autumn cultures (1 500 da).

The annual diesel fuel consumption within the scope of the measure (consumption of the farm's own grain harvester used) is 4 630 liters, equivalent to 42 999 kWh. Information on this consumption by type of harvested cultures, based on a previous survey (baseline), is presented in Table 4.
Table 4. Consumption by types of harvested cultures (before the measure)

| ACTIVITIES               | WORKED AREA | CONSUMPTION |            |            |
|--------------------------|-------------|-------------|------------|------------|
|                          | da/year     | l/da        | l/year     | kWh/year   |
| Harvest of spring cultures| 1 400       | 1.70        | 2 380.00   | 22 103.16  |
| Harvest of autumn cultures| 1 500       | 1.50        | 2 250.00   | 20 895.84  |
| TOTAL                    | 4 630.00    |             | 42 999.00  |            |

Table 4 shows that both activities are characterized by close annual consumption of diesel fuel. This is explained by the almost identical areas for the two harvested cultures and the small difference in the values of specific consumption for the two activities.

3.2.2. Suggested measure

As an energy efficient measure, it is recommended to replace the existing combine harvester with a new energy efficient John Deere S660. Engine volume is 9l, and the engine power is 239kW (320 hp).

Information on the consumption of the new grain harvester by type of activity, based on accounting data and related to the cultivation area from the baseline, is presented in Table 5.

Table 5. Consumption by types of harvested cultures (after the measure)

| ACTIVITIES               | WORKED AREA | CONSUMPTION |            |            |
|--------------------------|-------------|-------------|------------|------------|
|                          | da/year     | l/da        | l/year     | kWh/year   |
| Harvest of spring cultures| 1 400       | 1.280       | 1 792.00   | 16 642.38  |
| Harvest of autumn cultures| 1 500       | 1.480       | 2 220.00   | 20 617.23  |
| TOTAL                    | 4 012.00    |             | 37 259.60  |            |

3.2.3. Energy saving after the introduction of an energy efficient harvester combiner

The savings on diesel fuel, achieved with the commissioning of the new harvester, are calculated as the difference between the consumption of the existing combiner and that of the new energy efficient John Deere S660 combiner.

The total amount of diesel savings achieved from is 618 l/year. This amount of saved diesel fuel is equivalent to 5 739.39 kWh/year saved final energy. Converted to primary energy, these savings are 6 313.33 kWh/year (same conversion methodology presented in 3.1.3).

Based on the final energy saved in kWh, the CO2 savings are calculated. For all farm activities, the estimated CO2 savings for the measure are 1.53 t/year.

The energy saving factor of Measure 2 is estimated at 13.35% (here accepted 267 gCO2/kWh).

The results of the calculations by types of activities performed are presented in Table 6.

Table 6. Savings, achieved by the introduction of the measure

| ACTIVITIES               | SAVED ENERGY | PRIMARY | SAVED CO2 |
|--------------------------|--------------|---------|-----------|
|                          | l/year       | MWh/year| MWh/year  | t/year    |
| Harvest of spring cultures| 588          | 5.46    | 6.01      | 1.46      |
| Harvest of autumn cultures| 30           | 0.28    | 0.31      | 0.07      |
| 618                      | 5.74         | 6.31    | 1.53      |

3.3. Analysis of the energy consumption after implementing the measures

The total energy savings from the implemented measures for one full year operation are estimated at 31 020 kWh. The total energy consumption for all activities of the existing tractor and harvester is 180 354 kWh/year. Thus, the energy saving factor from the introduction of the measures is 17.2%. The annual savings are 8.28 t/year (Table 7).
Table 7. Savings, achieved by the introduction of the package of measures

| ACTIVITIES                        | FINAL l/year | MWh/year  | PRIMARY MWh/year | SAVED CO₂ EMISSIONS t/year |
|-----------------------------------|--------------|-----------|------------------|----------------------------|
| Wheeled tractor introduction      | 2340.18      | 31.02     | 34.12            | 8.28                       |
| Harvester combine introduction    | 618          | 5.74      | 6.31             | 1.53                       |
|                                   | **3 340.18** | **31.02** | **34.12**        | **8.28**                   |

4. Analysis of the emissions, after implementing the package of measures

The measures implemented lead in carbon savings of 8.28 t/year.

Stage III/IV emission standards for non-road engines were adopted by the European Parliament in April 2004 (Directive 2004/26/EC), and for agricultural and forestry tractors. Stage III standards, which are further divided into Stages IIIA and IIIB, are phased-in between 2006 and 2013, while Stage IV enters into force in 2014. In addition to the engine categories regulated at Stage I/II, Stage III A standards also cover engines used in inland waterway vessels [11].

The type and amount of emissions released from Stage I, II and IV off-road diesel engines shall not exceed the amount presented in Table 8.

Table 8. Types of emissions, by power and engine category of agricultural equipment

| Category | Net installed capacity kW | CO g/kWh | HC | NOx | PM g/kWh |
|----------|---------------------------|----------|----|-----|---------|
| Stage I  |                           |          |    |     |         |
| C        | 37 ≤ P < 75               | 6.5      | 1.3| 9.2 | 0.85    |
| Stage II |                           |          |    |     |         |
| E        | 130 ≤ P ≤ 560             | 3.5      | 1.0| 6.0 | 0.2     |
| Stage IV |                           |          |    |     |         |
| Q        | 130 ≤ P ≤ 560             | 3.5      | 0.19| 0.4 | 0.025   |

The engine of the suggested John Deere 8370R tractor put into service, complies with the Stage IV exhaust emission standard. The engine of the harvester intended for commissioning meets the Stage II exhaust emission standard. In table 8 are presented the emission limit values for the respective diesel engine expressed in grams per kWh of fuel consumed. Based on the amount of fuel consumed before and after implementation of measures are estimated the limit values of emissions released from old and new agricultural equipment, and the estimated savings achieved. The table shows that the percentage of carbon emissions reduced in terms of replacement of equipment is extremely high - over 43%. This is noticeable when the engines are Stage III standard and higher.

Table 9. Achieved emissions savings, by the replacement of the agricultural equipment

| Type of carbon emissions | CO  | HC  | NOx |
|-------------------------|-----|-----|-----|
| Annual emissions released from the UMZ 6L tractor, t/yr | 0.893 | 0.179 | 0.117 |
| Annual emissions released from the new tractor John Deere 8370R, t/yr | 0.392 | 0.007 | 0.015 |
| Annual emissions released from existing harvester, t/yr | 0.279 | 0.056 | 0.037 |
| Annual emissions released from the new tractor John Deere 8370R, t/yr | 0.130 | 0.037 | 0.007 |
| Annual emission savings after the introduction of EEM 1 and 2, t/yr | 0.650 | 0.190 | 0.131 |
| Percentage of the emission savings, % | 55.4% | 81.1% | 85.4% |

5. Conclusion

The use of outdated and depreciated agricultural equipment leads to an increase in the energy component in the cost of agricultural production. In addition, the amount of emissions released is also significant. Depreciation costs are very high and repairs are often required with old farm equipment.
The equipment suggested in the study is high performant and energy efficient. The percentage of energy savings depends on the type of activities performed and the rate of utilization of the equipment.

With the introduction of new wheeled equipment, the percentage of savings for the volume of activities is over 18%, and the replacement of an existing harvester with a new one, results in energy savings of 13.35%. Thus, with the introduction of the selected set of measures, the annual energy savings are 17.2%.

The reduced energy consumption leads to significant carbon savings. For the measures selected, the estimated annual savings are 8.28 t/year. In addition, the use of engines with higher class, results in savings of CO, HC, HC + NOx and NOx emissions. The estimated savings rate is greater than 50%.

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