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Energy-oriented analysis in grain production

For the last years the agriculture industry's development and production of farm machinery have been subject to existing EU emissions legislation. In addition to that the demand for more powerful and efficient machines in Germany, but also abroad is high and will continue to rise. The search for potential reduction of greenhouse gases may thereby not only focus on the engine and the exhaust aftertreatment, but shall also include the individual work processes and all production chains in agriculture. In the course of this research, a practical, holistic and process-oriented analysis of agriculture machine data was accomplished, so system-wide savings, such as machine overpowering up to 119 kW as well as high non-active/waiting-times in the harvest logistics have been identified. Furthermore the entire process chain of tillage, seedbed preparation and drilling have been analyzed, so the fuel-optimized process for the research farm could be worked out.

Keywords
Grain value chain, work processes, CO_2-reduction, documentation, energy flows, CAN-Bus

Abstract
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The present research was part of the project AgroMICoS with the TU-Berlin's institute of construction of machine systems as a leading project partner. Aim of the project is the development and realization of an integral, process-oriented information management solution system with suitable and cheap equipment engineering as well as an intelligent software solution. The author's key part of the project has been the joint research with the TU Berlin's "LaSeKo-Box" system (the previous system of AgroMICoS) to determine energy flows in agricultural machines and their working processes. To illustrate these flows, 1.5 years worth of working data were collected from machines used for cereal production on a German farm. These data were then processed, visualized and analyzed, providing insights into CO_2 emissions for the production of a tonne of wheat.

As a first step, a database model has been developed in order to cluster different energy flows in the grain production (**Figure 1**).

The energy-flows have been subdivided into three levels including their subgroups: the machine level, the working processes level and the production processes level.

Then it had to be identified how much energy is used at different fieldworks like soil cultivation, drilling, manuring and harvesting. Furthermore it had to be worked out, which consumption share single components of a machine like engine, transmissions and ancillary components show. For a meaningful assessment, a summarizing system consideration should have been carried out because a sinking use of energy in one area can lead to an increasing energy requirement in other areas. CO_2 reduction potentials at agricultural machinery finally can then be derived and quantified.

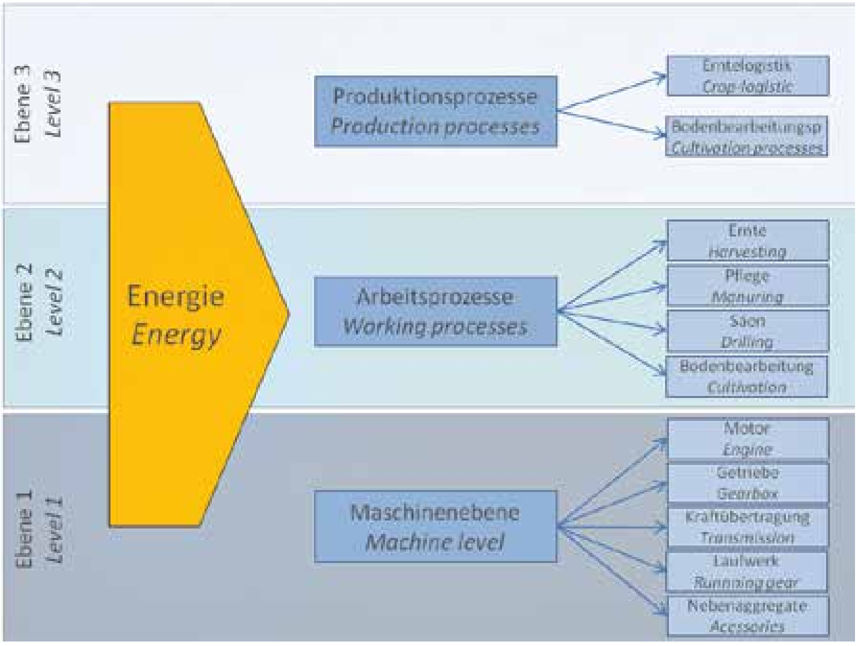
Research execution

To evaluate the relevant agricultural machinery data, the LaSeKo-Box was used at a research farm (**Table 1**) [1]. The box was developed at the TU-Berlin, institute of construction of machine systems and the company LogicWay.

In the course of this, two harvesters and five tractors from the latest model series were connected to the research LaSeKo-Box. The box was linked to the machine's internal CAN-bus network and connected to the power supply (**Figure 2**).

As soon as the machine was started, the research box logged the engine data on a SD-card, which were relevant for the energy analysis such as fuel consumption, engine speed, engine torque mode, engine load and GPS-data. The agricultural machinery was equipped with the research boxes over a period of one and a half years so that data could be evaluated by two harvests and a complete soil cultivation, drilling and manuring cycle. For processing, filtering and transforming the data, a CAN-csv editor based on Linux was programmed, and

Fig. 1



Levels of energy consumption

several scripts in the scientific software Diadem and Matlab have been written. The program and the scripts allowed an automated data handling with little human intervention.

Four different fields from 2 to 40 hectares with similar external conditions were determined as research-fields and analyzed. For this, various diagrams have been developed which then illustrated an evaluation of fuel consumption and machine utilization for different work processes and field sizes. It was then possible to identify the amount of energy used in the different field works and the total consumption of different process chains. From this information, CO_2 savings could be derived and quantified according to feasibility and savings amount.

Table 1

Information about research farm (January 2013)

Betriebsgröße *Farm size*	1400 ha
Ø Schlaggröße *Ø Field size*	24.66 ha
Höhe über N. N. *Height above N. N.*	30–68 m
Ø Jahrestemperatur[1)] *Ø annual temperature*[1)]	7.7 °C
Niederschlag p.a.[1)] *Rainfall p. a.*[1)]	797.4 mm
Bodenpunkte *Ground points*	30–70
Bodenklasse *Ground class*	Sand, Stark lehmiger Sand, Lehm, Ton *Sand, heavy loamy sand, loam, clay*

[1)] Deutscher Wetterdienst (DWD), Abteilung Agrarmeteorologie, Zentrum für Agrarmeteorologische Forschung Braunschweig (ZAMF), www.dwd.de/mittelwerte.

Research results

Table 2 summarizes the specific savings for tractors in terms of the different working processes on the research farm. Based on the previous analysis, in particular power charts and load bars (**Figure 3** and **4**) as well as power comparisons - at some work-

Fig. 2

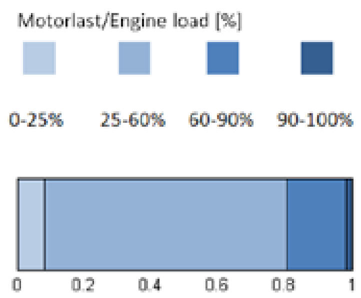
Installed LaSeKo-Box on tractor with plugs (Photo: C. v. Toll)

Table 2

Savings in machine- and farming unit design

Prozess ***Process***	**Leistung Traktor** ***Power tractor***	**Bewertung** ***Result***	**Einsparung/Zusatzleistung** ***Reduction/additional power***	**Quelle** ***Source***
Kreiselegge, 6 m Arbeitsbreite *Harrow, 6 m working width*	239 kW	Übermotorisiert *Overpowered*	-59 kW	Leistungsdiagramm *Power chart*
Kreiselegge, 4 m Arbeitsbreite *Harrow, 4 m working width*	239 kW	Übermotorisiert *Overpowered*	-89 kW	Lastbalken, Leistungsvergleich *Load bar, power comparison*
Drillmaschine, 6 m Arbeitsbreite *Seed drill, 6 m working width*	224 kW	Untermotorisiert *Underpowered*	+45 kW	Lastbalken, Leistungsvergleich *Load bar, power comparison*
Düngerstreuer AGT, 36 m Arbeitsbreite *Fertilizer spreader, 36 m working width*	269 kW	Übermotorisiert *Overpowered*	-119 kW	Lastbalken, Leistungsdiagramm *Load bar, power chart*
Korntransport 2 x 18 t *Grain transportation, 2 x 18 t*	141 kW	Untermotorisiert *Underpowered*	+39 kW	Lastbalken, Leistungsdiagramm *Load bar, power chart*
Überladewagen 22 t *Field trans trailer 22 t*	239 kW	Übermotorisiert *Overpowered*	-39 kW	Lastbalken, Leistungsdiagramm *Load bar, power chart*
Pflug, 2 m Arbeitsbreite *Plow, 2 m working width*	239 kW	Übermotorisiert *Overpowered*	-89 kW	Lastbalken, Leistungsdiagramm *Load bar, power chart*

Fig. 3

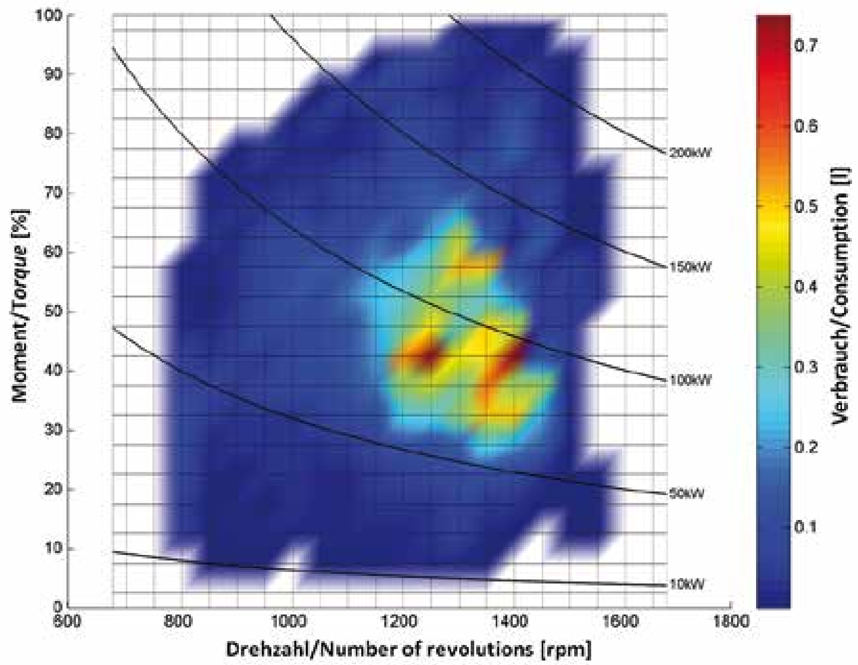


Engine load bar for fertilizer spreading on 10 ha field, tractor power: 261 kW

ing processes two machines with different power were tested and the engine data were compared – were used to identify fuel reduction potentials. This table focuses on over- or undersized tractor engines in the different working processes, so the result is either “overpowered” or “underpowered”. In addition to that, a concrete number on how much power is redundant or missing is given.

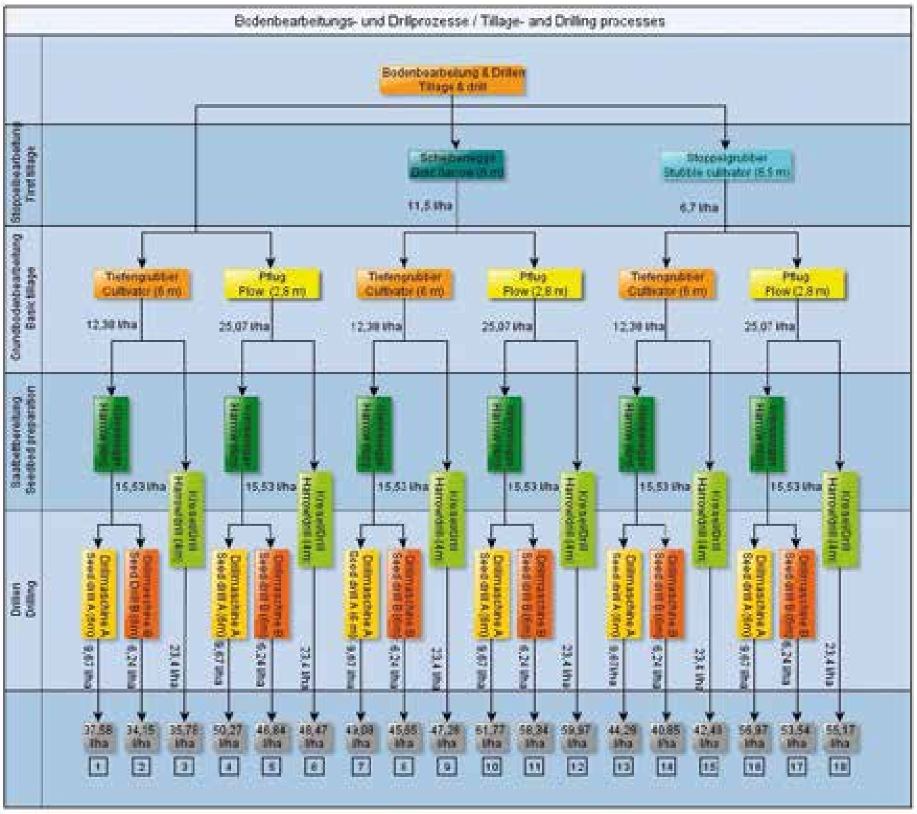
On the level of work processes at seven machines of the research farm CO_2 savings could be worked out. At five processes, overpowered machines could be identified so that 39 to 119 kW of power could be reduced, which would have a positive effect on the CO_2-emission. Two other processes have shown

Fig. 4



Power chart for fertilizer spreading on 10 ha field, tractor power: 261 kW

Fig. 5



Process chains tillage and drilling

underpowered tractors with a lack of 39 to 45 kW. In this case a power adjustment would also reduce CO_2-emissions [2].

Figure 3 and **4** illustrate exemplarily the machine data of a tractor fertilizing with an AGT-spreader (manufacturer: Rauch). The figure reveals, that the tractor almost exclusively uses a power less than 150 kW and 80 % of the complete working time in neutral (0–25 %) or part load (25–60 %). The maximum power of 269 kW was not used at all, a power more than 150 kW was seldom used. The tractor was therefore overpowered for this operation because a machine with 150 kW of maximum power could have managed the fertilizing-process with the same result. Therefore in the future 44.2 % or 119 kW less power can be used at fertilizing which would cause a lower fuel consumption and CO_2 emission.

On the production process level, all possible process chains and their associated consumptions from primary tillage over seed bed preparation to drilling of the research farm were recorded (**Figure 5**). Thus from the collected consumption data, the most fuel-efficient process chain for tillage and drill could be calculated (**Figure 5**, scenario 2).

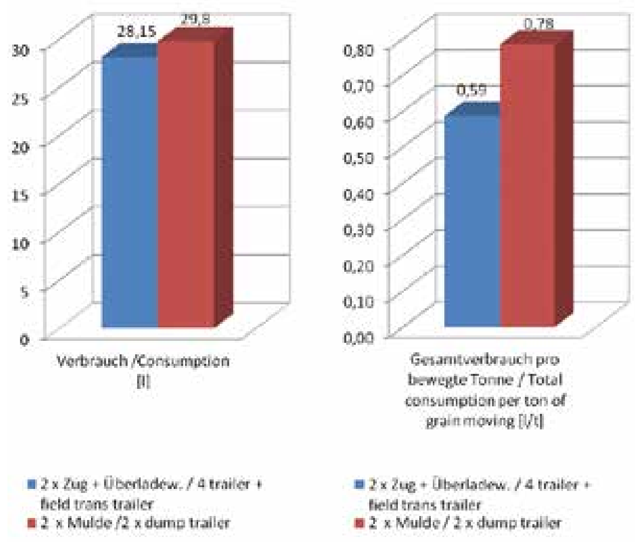
At the same time, an alternative process chain was determined which gains high soil loosening combined with lowest possible fuel consumption (**Figure 5**, scenario 14).

Furthermore, the entire harvest logistics of the research farm have been analyzed and thereby additional savings have been identified. Using the data of speed and GPS, the non-active/waiting-times of the various machines involved in the harvesting process (two harvesters [9 m and 11.5 m cutting], field trans trailer [18 t], two grain transportation tractors each two trailer [2 x 18 t]) have been detected. Especially the field trans trailer as well as the two grain transportation tractors have revealed big non-active/waiting-time. If these times can be eliminated at the research farm, e.g. by a different logistic chain or an additional harvester, fuel-reduction of up to 6.65 liter (field trans trailer on a 40 hectares field) and 8.83 liter (crop transportation tractor on a 40 hectares field) can be reached. A reasonable alternative would also be a start-stop system for agricultural machinery.

Additionally, alternative grain transportation with two dump trailer was analyzed. It turned out that the two dump trailer had an additional consumption of 1.65 liter per cycle compared to the usual transportation system (field trans trailer [18 t] plus two grain transportation tractors each two trailer [2 x 18 t] (**Figure 6**).

This difference increased even more when considering the tones transported (**Figure 6**, right diagram). The additional consumption per ton of grain moving is 32 % (base value: consumption 4 trailer + field trans trailer). At the analyzed farm it is therefore useful to favor the transport chain with a trans trailer and two crop tractors (with two trailers per tractor) for

Fig. 6



Comparison grain transportation

far distance fields. For fields with short distances to the silo the holding times of the crop tractors with two trailers increase sharply. In this case the use of dump trailers is advantageous and generates fuel savings [2].

At the machine level a simplified calculation model based on literature data was developed. With this model the consumption shares of the different machine components were calculated [3; 4]. The model revealed that in future especially the losses by waste heat as well as by running gear must be minimized.

Finally the average value of the consumption and the CO_2 emission per ton of grain at the research farm could be derived from the data. In the grain production cycle in 2011 and 2012, 14.79 liters were consumed and 39.2 kg of CO_2 were ejected per ton of grain.

Conclusion

In the future, it is critical for farmers to analyze the power requirement of new tractors. To design and interpret the machine on their most power-intensive work process can be very expensive because the high initial cost and the additional fuel consumption are not to be underestimated. The present analysis has shown how far away demand and reality of the power requirements of various work processes can be. At the same time, this analysis can be a useful tool to help farmers to identify the actual power requirement of their work processes and derive a purchase decision. In addition, it is conceivable that a sophisticated model of the present research system – including the knowledge gained from the research – can be used in the future for the optimization of process chains in grain production.

These collected data and the derived results can thus be reference-value as well as food for thought for future savings analysis and optimization strategies. In the course of this, the research box LaSeKo with the developed algorithms can be used as monitoring tool as the identification of CO_2 savings potential in agricultural machinery and the concrete measures for implementation will become even more relevant in the future.

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