Calculating energy efficiency and carbon tax for greenhouses

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Industry and traffic world-wide produce a lot of carbon dioxide gas (CO2) and this may have adverse effects on the global weather situation ('global warming'). The Kyoto protocol was set up to address this problem. Greenhouse growers, like all energy users, need to be aware of the amount of energy they use and amount of CO2 they discharge. This article shows how the carbon tax can be calculated from the type of fuel and the amount of fuel used. This article also discusses the concept of energy efficiency, which is the ratio between energy use and yield. It shows that the energy consumption (or the CO2 production) can be regarded in relation to the growing area (m^2), or in relation to the yield (kg).

Data on energy in greenhouses
Most of the energy used for greenhouse cultivation is for climate control, including heating, humidity control and CO2 enrichment. The most used fuels in greenhouses in NZ are natural gas, coal and various sorts of oil, while less important fuels are electricity, wood and geothermal energy. It is hard to find figures about energy use in greenhouses in NZ. New data will become available in the near future, but for the moment we use data from a small survey we conducted some years ago. Ten 'small' tomato growers in Auckland and Christchurch using coal, natural gas, oil or electricity provided data on energy use and production. The average energy usage and the average yield are higher at present than some years ago when the survey was done. Nevertheless, we use these figures, just as examples for calculating energy efficiency.

Energy usage
The data on energy usage were expressed in tons of coal, litres of oil, etc., and were converted to MegaJoules (MJ). The survey showed that the energy usage ranged from 524 to 1772 MJ per m^2 per year, with an average of 1228 MJ/m^2/y. To give an idea of how much this is: 1228 MJ/m^2/y equals 341 kWh/m^2/y and is also equal to 32 m^3 natural gas, 54-58 kg sub-bituminous coal, 31 litre oil, 32 litre diesel, or 25 kg propane, butane or LPG per m^2 per year. Obviously per ha greenhouse area the figures are 10,000 times higher, and per acre the figures are 4,000 times higher. For example the average energy use per acre per year was equivalent to 128,000 m^3 natural gas; 216-232 ton coal; 124 m^3 oil; 128 m^3 diesel; or 100 tons of propane, butane or LPG.

Energy efficiency
Energy efficiency is the ratio between energy usage (MJ) and yield (kg). Some people use energy input divided by yield (MJ/kg) and call this efficiency, whereas others divide the yield by the energy input (kg/MJ). The first one (MJ/kg) gives more handy figures, but the second one (kg/MJ) fits the definition of efficiency. A higher figure (more kg per MJ) means a better efficiency. Because of this confusion, it is important to properly specify the units when quoting energy efficiency figures.
In the survey, the yield varied from 15 to 44 kg/m^2 with an average of 34 kg/m^2, and the energy usage varied from 524 to 1772 MJ/m^2 with an average of 1228 MJ/m^2. The energy input per kg tomatoes was 17 to 82 with an average of 41 MJ/kg. The energy efficiency varied from 0.012 kg/MJ to 0.060 kg/MJ, with an average of 0.032 kg/MJ.

Difference explained
The differences between growers in energy usage and also in energy efficiency are partly due to different climatic conditions and length of growing season: growing in winter and/or growing in a cold climate requires more energy. Other factors are the type of greenhouse cladding, leakiness, burner efficiency, energy saving facilities, temperature regime, weather variations, etc. Also the price of the fuel may play a role, i.e. an expensive fuel like electricity is used more sparingly. The other very important factor is the yield. The grower in the survey with the nearly-lowest efficiency had a normal energy input but a very low yield, perhaps due to diseases. The energy efficiency can be improved by reducing the energy input, or by increasing the yield, or both.

Energy efficiency as a policy tool
Energy efficiency data enable comparisons. Growers can estimate their energy efficiency and compare that with benchmarks. The factors affecting the energy efficiency (see above) can be analysed. Energy efficiency can be very helpful for internal comparison, e.g. between years, for instance to assess the effect of energy-saving measures or new growing practices that are put in place.
The most important use of energy efficiency is perhaps as a policy tool. In the Netherlands the energy efficiency is a key parameter in energy saving policies of the agricultural organisations and the government. The target for the greenhouse industry in terms of the Kyoto protocol is to achieve 65% improvement in energy efficiency in 2010 compared to 1980. A considerable part of the improved energy efficiency comes from increased yield due to a wide range of actions.

CO2 tax
When a carbon tax will be added to the fuel price it can be as high as 2.5 cent per 1 kg CO2 emitted. If CO2 uptake by the plants is ignored, the amount of CO2 emitted depends in the type and amount of fuel burned. This amount can be related to the greenhouse area (m^2), or to the yield (kg). The ten growers in the survey emitted between 11 and 158 kg of CO2 per m^2 greenhouse area per year, with an average of 86 kg/m^2/y. Hence the costs of the carbon tax would be between $0.28 and $3.94 per m^2 per year, with an average of $2.13/$m^2$/y. This adds up to $8520 per acre per year, and $21,300 per ha per year.
Related to the yield, the CO2 emission was between 0.3 and 7.3 kg CO2 per kg tomatoes, with an average of 3 kg CO2 per kg tomatoes. The costs of the carbon tax would be between $0.01 and $0.18 per kg tomatoes, with an average of $0.08 per kg tomatoes. Once again, the data are based on an old survey, and the average energy usage and yields are higher today. It will be interesting to see figures on current energy usage and energy efficiency.

Table. *Data from an energy survey with ten tomato growers, to show energy efficiency and possible carbon tax (based on 2.5 cent per 1 kg CO2 produced). See explanation in text.*

	min	max	average
Tomato yield (kg/m^2/y)	15	44	34
Energy usage (MJ/m^2/y)	524	1772	1228
Energy input (MJ/kg)	17	82	41
Energy efficiency (kg/MJ)	0.012	0.060	0.032
CO2 production (kg/m^2/y)	11	158	86
CO2 production (kg/kg)	0.3	7.3	3.0
Carbon tax ($/$m^2$/y, max)	0.28	3.94	2.13
Carbon tax ($/kg, max)	0.01	0.18	0.08