BioGreenhouse

Sensible use of Primary Energy in Organic Greenhouse Production

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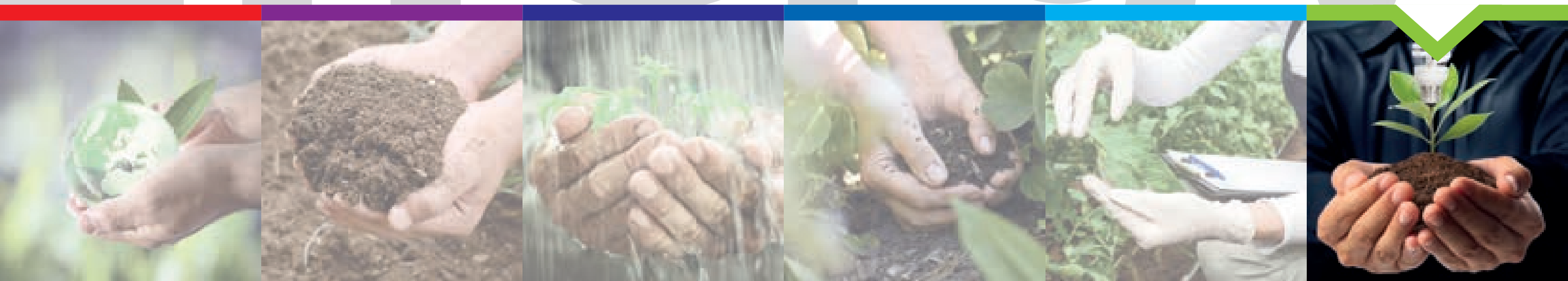

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Preface

In 2008, at the 16th IFOAM Organic World Congress in Modena (IT), about 25 participants expressed their interest in working together in the field of research and development for organic greenhouse or protected horticulture. A two-day workshop was organised in Cologne in 2009 to discuss the subject and further give body to the collaboration. 45 people from all Europe and from Canada attended this workshop. It was decided to join efforts in the field of organic protected horticulture, in particular with respect to planting material; soil fertility; water management; disease and pest management; climate management and energy conservation; and sustainability. The group also agreed to submit a COST (European Cooperation in Science and Technology) Action on the same subject. Mid 2011 the proposal „Towards a sustainable and productive EU organic greenhouse horticulture“, in short, BioGreenhouse, was submitted.

At the end of 2011 COST approved this proposal as COST Action FA1105 (see http://www.cost.eu/COST_Actions/fa/FA1105 and www.biogreenhouse.org), which builds a network of experts working in the field of organic protected horticulture and aims to develop and to disseminate through coordinated international efforts, knowledge for new and improved production strategies, methods and technologies to support sustainable and productive organic greenhouse/protected horticulture in the EU. In total 27 participating COST countries and two COST Neighbouring countries took part in the Action.

This Action offered the framework and funds for experts of the participating countries to meet and to work together in Working Groups concerning the objectives of the Action. The objectives related to climate and energy management where: an inventory of the use of fossil energy in the present organic greenhouse horticulture; to develop guidelines for the reduction of the use of primary energy in different regions; to join available information about reduction of energy use and improvement of productivity; and to evaluate the feasibility of substitutes of fossil energy.
Nine experts from different regions worked together on this topic. They have addressed their task with commitment, by reviewing the regulations as they exist on energy use for heating and humidity control in the different regions in Europe; presenting strategies for reduction of energy requirement and to increase the productivity of energy; by reviewing the indirect use of energy and the options for replacement of fossil energy by renewable energy.

Together they realised this booklet:
„Sensible use of primary energy in organic greenhouse production“
I believe this booklet will prove a unique source of information for all people and institutions involved in research in organic protected horticulture; for researchers, students, teachers, consultants and suppliers. This booklet could also serve also a starting point for developing strategies for a climate-neutral organic greenhouse horticulture. Much has to be developed in this respect.

On behalf of the COST Action Biogreenhouse I want to thank the team of the authors for the work they have done, their cooperative spirit and their perseverance. This work will for sure contribute to a more sensible use of primary energy in organic protected cropping and will be a basis for developing a new R & D agenda on Organic Greenhouse Horticulture.

Rob J.M.Meijer
Wageningen UR Greenhouse Horticulture
Chair, COST Action FA1105 Biogreenhouse

Executive summary

In this booklet we review the major sources for energy consumption in organic greenhouse horticulture and analyse the options available to reduce energy consumption or, at least, increase the energy use efficiency of organic production in greenhouses.

To start with, hardly any statistic is available about energy use in organic greenhouse production, and there is little consistency in public and private organic horticulture regulations with respect to this topic. This was confirmed once more by a survey we performed among the participants to the Action (Annex I).

With respect to energy use, organic greenhouse production faces challenges that are similar or worse than conventional production. Indeed, the limited choices for prophylactic crop protection (particularly against fungal diseases) demand a preventive climate management, aimed in particular at lowering humidity, often at the expense of additional energy. Hardly any research has been done up to now on energy saving in organic greenhouse production. Although much of the research done on energy saving in conventional greenhouses can be applied (and often is) in organic greenhouses as well, there is a need of research within the constrained conditions of organic greenhouse production.

A relatively high productivity is attained in heated greenhouses at the expense of much [fossil] energy. Indeed climatisation is by far the largest single user of energy in organic greenhouses, and in non-organic as well. We have reviewed recent knowledge about greenhouse insulation and climate management that can be implemented to reduce consumption of direct energy in such greenhouses. In fact there is strong potential for energy saving, particularly by improving greenhouse insulation.

Unheated greenhouses have obviously low energy requirement, however the energy use efficiency can be clearly improved by increasing on the relatively low productivity. Poor climate control is the main cause of low productivity in low-tech greenhouses. We have reviewed recent knowledge showing that better ventilation, greenhouse design, management and control could improve productivity up to a factor three.

Crop protection, steaming in particular, is a rather important contributor to (in)direct energy use, but also the energy needed for the production of crop protection means is far from negligible. The energy required for the production of the greenhouse itself (frame and cover material) is by far the largest contributor to indirect energy use. However, there seems to be little scope for improvement in the frame, in view of building norms. On the other hand, there is need for research on new cover materials to improve the solar collector function of the greenhouse and on additives to increase life of plastic films and the performance under condensation.

Better water management could reduce fertilisers use and lead to savings in the energy needed for their manufacture. It could also reduce the electricity use for pumping water, particularly in regions with deep wells.

The scope for application of renewable energy sources is not better nor worse than for conventional greenhouses. So, as for conventional greenhouses, the application of renewable energy is technically feasible but economically open to debate. This situation has not essentially changed for the last decades. Nevertheless one has to bear in mind that the cost of energy is related to an ever changing scenario where not only economic issues but environmental, social and political issues play a role.

At the moment, the best way to match demand and availability of electricity (solar and wind power) is through the grid, also in view of existing subsidies for electricity sale to the grid. There is some scope for local application of solar thermal energy for heating and/or humidity management, although this requires a large investment in thermal buffering.

In combined organic farms there is scope for biomass burning and/or biogas production. Technology developments ensure that currently there are commercial greenhouse operations that benefit from the use of biomass and, in some cases, biogas. Such alternative energy sources are progressively replacing traditional (and more pollutant) fuels .

In conclusion, the way to a higher energy efficiency in organic greenhouse production is:

- For heated greenhouses, to lower the need for heating, primarily through better insulation
- For unheated greenhouses, to increase crop productivity improving climate management, particularly through a better design and management of ventilation.

There are several options for the substitution of fossil with renewable energy sources. Although presently very few options are financially sound, their feasibility follows from price/subsidies policies that are variable among countries and that may be variable in time.

Introduction

This document addresses the direct and indirect use of energy in European organic greenhouse horticulture (OGH) with the aim of reviewing available means for making it more environmental friendly and identifying knowledge gaps that should be addressed to attain this aim.

The first observation is that there is no common regulation for energy use in OGH, which is not unexpected, since the need for climatisation is not uniformly distributed in the EU (and outside). Accordingly, the EU directive on organic agriculture does not set limitations on the use of energy, but rather promotes the responsible use of energy and of natural resources. The restrictions and rules of most private standards are slightly more stringent. Some standards have specific restrictions on the amount and sources of energy and/or on the seasonal use of energy for heating. Some standards also address processes that may affect (in)direct energy use, such as cultivation methods, mulching, lighting and growing media or substrates. However, most private standards have no or little restrictions or regulations on energy use. Accordingly, it should not surprise that very little quantitative information is available about energy use in OGH. In the present document we have filled the gaps with data with estimates drawn on energy use in conventional greenhouses.

With respect to ongoing research, whereas many of the present research results about energy use and saving in conventional greenhouses are relevant (and also applied) in OGH, little research is devoted to address the energy use that is peculiar to OGH, particularly energy use for humidity control. In short, there are still a lot of knowledge gaps to improve quality and to lower energy use in organic greenhouses.

The purpose of this document is a summary of present relevant knowledge about energy use and energy saving and of the perspective for improvement. In particular, the goal is to make an overview on the methods and technologies which can be used to reduce the energy use in OGH. We start from the assumption that methods and technologies that are used for reducing direct and indirect energy in conventional greenhouses can also be applied in organic greenhouses. Research on reducing energy use in conventional greenhouses is also more widely available because the area of conventional greenhouse horticulture is much larger than the area of OGH. When implementing these methods and techniques we should take into account the specific characteristics of organic agriculture like soil-based cultivation, use of organic fertilizers and the limited use of crop protection products.

This document is organised as follows: first we report the results of a survey about energy use and relevant standards in the countries participating to the COST action (chapter 1); then we review the energy use for climatisation: heating (chapter 2) and humidity (chapter 3). In chapter 4 we review the available design and management means that would either reduce energy use and/or increase energy use efficiency by increasing productivity of OGH. In chapter 5 we present a short summary of existing information on indirect energy use, that is the energy required to manufacture production means (greenhouse structure and cover, fertilisers, equipment etc.) and for crop protection, particularly steaming, and briefly discuss possible savings. Finally (chapter 6) we review briefly the potential for application of renewable energy sources in OGH.

1 A review of existing regulations regarding energy use in organic greenhouse production

At the start of the Action we realized that very little was known about data on energy in public and private organic horticulture regulations. In order to fill this gap, we prepared a questionnaire that was sent to at least one representative of each country participating in the COST action.

The questions are related to the energy economy and the use of fossil energy in OGH, in relation to region and growing system; national and private organic regulations and restrictions on energy use in OGH, research on energy use in OGH and possible knowledge gaps.

We had 26 respondents, from 19 participating countries to the COST action. An overview of the results of the survey can be found in Annex 1 and an overview of the respondents can be found in Annex 2. Although the results of the survey cannot be considered statistically relevant, they do give a general idea of the energy regulations, research and knowledge gaps on energy savings in the European OGH.

The most obvious conclusion is that there is no common regulation for energy use in OGH, which is not unexpected, since the need for climatisation is not uniformly distributed in the EU (and outside). As the climatic differences will prove extremely relevant in the following, in this document we identify:

North Western Europe:
- Relatively warm summer with high light levels and cold winter with low light levels.
- High intensive production in heated greenhouses with high energy input.
- Lots of innovation and technology is used.

Eastern Europe:
- Relative warm summer with high light levels and very cold winter with low light levels.
- Mostly extensive production (poly tunnels).
- Small fraction of the production is in heated greenhouses.
- Mostly not intensive use of technology.

Southern Europe:
- Warm summer with high light levels and mild winter with medium light levels.
- In some regions there is no production in summer because of too high temperatures.
- Mostly rather extensive seasonal production in low tech greenhouse (no climate control and heating).
- Mostly not intensive use of technology.

Probably in view of the climatic differences, the EU directive on organic agriculture does not set limitations on the use of energy, but rather promotes the responsible use of energy and of natural resources. The restrictions and rules of the most private standards are more specific. Standards in Sweden and Switzerland have specific restrictions on the amount of energy and on the energy sources. There are also restrictions on the seasonal use of energy for heating, cultivation methods, mulching and lighting. But still a lot of private standards have no or little restrictions or regulations on energy use.

With respect to ongoing research, the survey show that in countries where there is research on energy use and saving in greenhouse, results are relevant (and also applied) in OGH. Nevertheless, little research is devoted to address the energy use that is peculiar to OGH, particularly energy use for humidity control. In short, there are still a lot of knowledge gaps to improve quality and to lower energy use in organic greenhouses.

2 Energy use for heating

2.1 High-tech greenhouses (mainly North Western Europe)

In regions with such a climate that the temperature is for long periods below the desired level (set-point) for a crop, greenhouses are fitted with heating systems. The amount of energy required to maintain a given temperature difference between in and outside depends on the insulation of the greenhouse, which is quantified by the global heat transfer coefficient (U or K) of the greenhouse. Typical values of the U coefficient for various types of greenhouses (assumed to be 0.5 ha) are given in table 1.

Table 1
Compilation of global heat transfer coefficients for greenhouses, accounting for an estimate of infiltration and radiative losses.

Cladding material	U-value (W m^{-2} K^{-1})
Single glass	8.8
Double glass in sidewalls	7.9
Thermopane glass	3.0
All double glass	5.2
Double acrylic	5.0
Double polycarbonate	4.8
Single PE-film	8.0
Double PE-film	6.0

Obviously the values in the table are “mean” values, since the heat loss at a given moment will be affected by wind speed and conditions of the sky (cloudiness) and climate management.
The energy consumption for the heating period (Q_d, MJ m^{-2} soil) can be calculated by the temperature difference (ΔT) between in and outside and the U-value of the greenhouse:

The sum is calculated over all hours (or days or minutes) the greenhouse air temperature is lower than the set-point for heating +0.1 °C. As the U coefficient is just an estimate of the instantaneous energy loss of the greenhouse, this formula is more reliable for relatively long period such as the whole heating season.

$$Q_d = \sum_{t=0}^{t} \mathrm{U} \times \Delta\mathrm{T}$$

As the previous equation makes clear, two factors affect the energy consumption: the insulation of the greenhouse (more on this in chapter 4) and the difference between the desired temperature (which depends on the crop) and the external temperature.

With respect to the crops: crops like lettuce or radish have a low heat requirement, usually it is enough to keep the greenhouse a few degrees above zero. As table 2 shows, the temperature requirement of the crop affects energy requirements, somehow modulated by the crop cycle (e.g. strawberry).

Table 2

Present yearly energy use of the most important vegetable crops in The Netherlands.

Crop	Average temperature set-points (°C)	Yearly energy use ($m^3_{gas}\ m^{-2}_{soil}$)	Yearly energy use ($MJ\ m^{-2}_{soil}$)
Strawberry	17	19.9	631
Eggplant	19	35.7	1132
Zucchini	16	30.0	951
Cucumber	20	35.7	1132
Sweet pepper	20	36.4	1154
Radish	10	4.9	155
Lettuce	10	8.9	282
Tomato	18	36.2	1148

The table refers to crops grown conventionally. The conversion factor from cubic meter gas to MJ is 31.7. Energy use can be affected by varieties, for instance colour (sweet pepper) or size (tomato). (Source: Vermeulen, 2014).

Current Dutch greenhouses apply energy saving measures such as multiple screens and temperature management which lower much the apparent U value of the greenhouse with respect to values given in table 1.

2.2 Eastern Europe

In the countries of Central and Eastern Europe greenhouses and heated tunnels account for about 50-70% of all greenhouses. Most are fairly modern facilities, automated to varying degrees, but to provide close to optimal growing conditions, most use integrated methods of cultivation and plant protection. The remaining 30-50% are unheated tunnels led to the cultivation in soil during frostless period (March-November, e.g. radish, lettuce, cabbage, herbs, root early, early brassicas, cold-storage strawberry) and without ground-frost period (May-October, e.g. tomato, cucumber, pepper, eggplant, zucchini, green beans). However, growers often bear the risk of early start of crops already in April.

Countries of Eastern Europe have quite different climatic conditions despite the relatively close neighbourhood. Average temperatures throughout the year range from -3 °C to 28 °C in the Balkan countries and the Czech Republic, from -7 °C to +18 °C in Lithuania and Estonia. The largest temperature differences are in Latvia and Poland, even from -30 °C to +35 °C. The annual number of sunny hours ranges from 1560-1740 (Serbia, Lithuania, Estonia, Slovenia) to 1900 (Romania, Czech Republic) and 2200 (Poland, Bulgaria). The shortest vegetation period (180 days) is in Lithuania, the longest in Bulgaria (270 days).

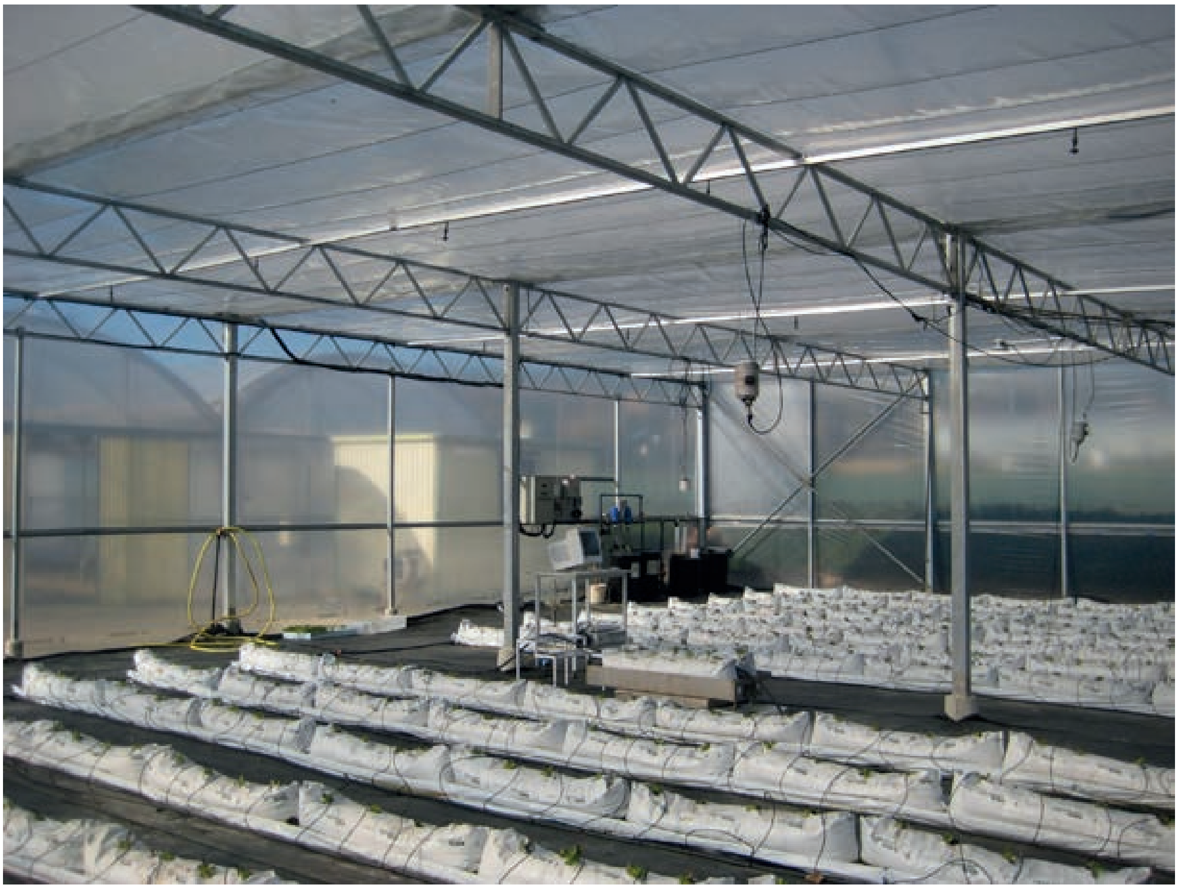
The share of energy in the production cost in heated greenhouses is 30-40%, although the use of renewable energy (which is often subsidised) is promoted. The average demand of energy for heating is approximately 400 kWh m^{-2} (1440 MJ m^{-2}) per year. In unheated tunnels the demand of energy is approximately 50 kWh m^{-2} (180 MJ m^{-2}).

2.3 Southern Europe

The vast majority of Southern European greenhouses is unheated. Nevertheless, during the coldest months growth is retarded, since average minimum temperatures in the warmest Mediterranean areas are between 7 and 9 °C (Montero *et al.* 1985). In an unheated greenhouse at night, indoor and open air temperatures run close together. Actually, greenhouse temperature can be lower than the air outside on clear nights, when most thermal radiation losses take place. Therefore heating is desirable in the winter, but in spite of the positive response of crops to heating (López, 2003) in most cases it has proved to be uneconomical.

In terms of energy requirements, the total energy consumption for the heating period can be predicted as described in paragraph 2.1. Since most Southern greenhouses use single layer polyethylene as covering material we have taken U = 8 W m^{-2} K^{-1}, as presented in Table 1.

Figure 1 shows the heating requirements for a multi tunnel greenhouse in Almería (Spain), Faro (Portugal) and Acate (Ragusa, Italy). Results are shown as a function of the night set point temperature. Heat requirements grow following a parabolic curve, as observed in the study presented by López *et al.* (2006). Almería is the Southern region with less heat requirement. Those greenhouses which try to keep a set point temperature of 16-18 °C usually have energy saving equipments, such as thermal curtains or double walls, so very unlikely a Southern European greenhouse would use more than 1000 MJ m^{-2}_{soil}.



Thermal PE screen in a high tech Southern European Greenhouse

It should be mentioned that in many Southern areas greenhouses are locally made, and so their infiltration loses are particularly high. The aforementioned study by López *et al.* (2006) showed an increase in heat requirement of 28% in local greenhouses compared to the multi tunnel industrial type, therefore figure 1 can underestimate heat requirements in local type greenhouses.

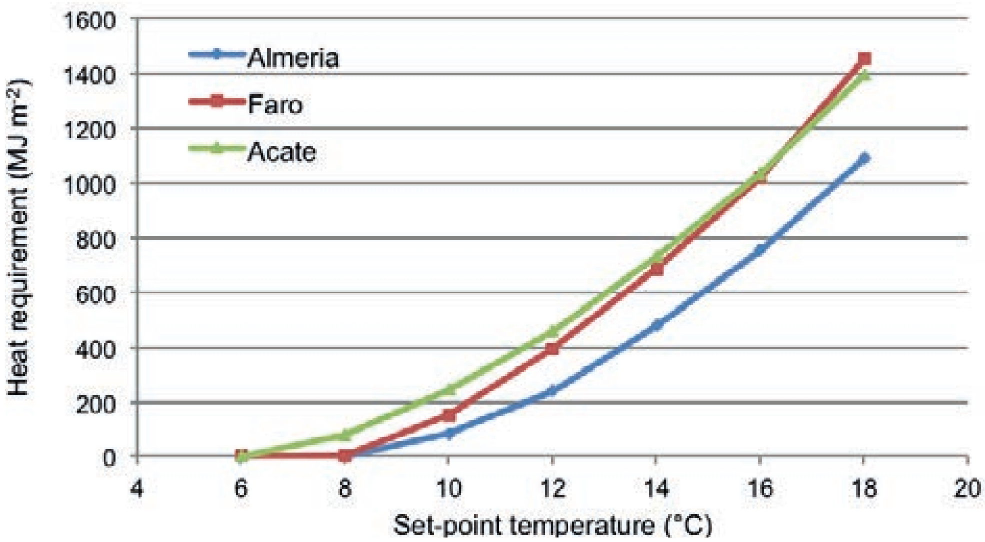
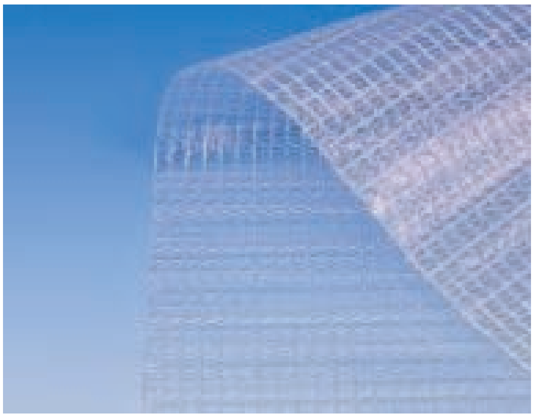


Figure 1. *Estimated yearly energy consumption (MJ $m^{-2}{}_{soil}$) as a function of the set-point temperature in a multi-tunnel greenhouse in Almería (Spain), Faro (Portugal) and Acate (Ragusa, Italy).*

More recently, some growers start thinking to improve the system production through a better greenhouse climate control, not only to extend the period of production for all year round but also to produce out of season with higher yields and better quality for a more demanding European market. In Portugal, Baptista *et al.* (2012a) estimated an average annual energy consumption approximately of 360 MJ m^{-2} for heating. Heating costs could vary between 2.5 € m^{-2} to more than 15 € m^{-2} depending on the heating system and on the temperature difference between inside and outside (Meneses and Baptista, 2011). Assuming the lowest value, energy costs can represent more than 45% of the variable production costs and more than 30% of the total production costs.

3 Energy use for humidity control

However, temperature is not the whole story: for instance, it is estimated that 20% of the energy consumption of Dutch greenhouses is not for heating, but for humidity management. In practice, this means that even when no heating would be required, [natural] ventilation and heating are used simultaneously to discharge the vapour released by the crop.
Among the many spurious reasons cited by growers to justify such a waste, there is one which is very sound, and it is the prevention of [parts of] the crop getting wet, either by direct condensation or by falling droplets of water condensed elsewhere. Wetness is well-known to favour the occurrence of fungal and bacterial diseases, increasing the need for chemical prevention and control, besides loss of yield and quality. The more limited means for crop protection available to organic growers cause them to be even more cautious with humidity management, which is the one reason energy consumption of organic growers in The Netherlands, 5-10% higher than the average consumption of traditional growers of the same crop.
An additional problem is that the need for humidity control very often interferes with (and frustrates) insulation of the greenhouse. It is a fact that a cold cover is a very effective remover (through condensation) of the vapour that is in the greenhouse air. Insulation (be it a screen or a double cover layer) creates a relatively warm boundary to the humid environment of a greenhouse, so that the equilibrium between the vapour that is produced and what is removed by condensation is reached at often unacceptable levels of humidity, and one has to rely on ventilation for discharging vapour. There is some (up to now limited) potential in screen materials porous to water vapour (Plaisier and Svensson, 2005).



LUXOUS 1347 FR: Example of screen material porous to water vapour.

In Southern areas no direct energy for dehumidification is used. Attempts to reduce excessive humidity are mostly based on natural ventilation, as discussed in paragraph 4.2.3.

4 Reduction of energy requirement for climatisation

To improve energy efficiency, there are two possibilities: reduction of the energy consumption with little effect on production or increase of the production with the same amount of energy.

Each measure which improves production also improve the energy efficiency. For example, better nutrition, good pest and disease control, improved irrigation, influence at the end the energy efficiency. In the following we will review several means available to organic greenhouse growers to increase energy efficiency. First we will review means by which more solar energy can be collected and kept into the greenhouse, to the benefit of the crop, and then we will review means to increase productivity, particularly through a sensible climate management.

4.1 Maximise the solar collector function of the greenhouse

The organic passive greenhouse must strongly benefit from a better use of the available natural resources, such as wind and solar radiation. This can be done by improving current structural designs, so that the greenhouse has better ventilation and better light transmission.

4.1.1 Radiative properties of the cover

An essential property of any greenhouse covering material is having high transmittance in the wavelength range that is useful for photosynthesis (PAR, Photosynthetically Active Radiation). Unfortunately, very often the requirements of a high PAR transmittance is in conflict with some other cover requirements, such as durability, spectral selectivity, high thermal insulation and so on. Studies on radiative properties of greenhouse covers are abundant, for instance Hemming *et al.* (2011, 2014). FAO has published a book on Good Agricultural Practices (FAO, 2013) for greenhouse vegetable crops where a discussion on greenhouse covering materials is presented (Montero *et al.* 2013).

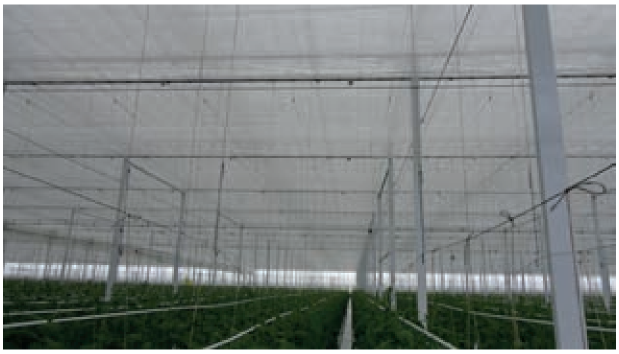
Diffuse coverings. Light diffusion has been proved to increase photosynthetic efficiency of crops. Dueck *et al.* (2009) have shown that the productivity of cucumber in The Netherlands could be increased by 9.2% by a highly diffusive cover (70% haze), in spite of an overall reduction in transmission of 3%. In Mediterranean climates traditionally growers prefer diffuse cladding materials to clear covering materials. In Almería (Spain) Magán *et al.* (2011) obtained a yield of 20.5 kg m^{-2} in a cucumber crop grown under a diffusive cover (53% haze) and 16.7 kg m^{-2} under a less diffusive cover (35% haze).

Anti-drip films. Drop-like condensation leads to light reflection; some studies on condensation have reported transmission losses up to 23% (Pollet and Pieters, 2000). Moreover, droplets can fall onto the plants fostering the development of fungal diseases. New formulations with improved anti-drip quality and duration are added in multilayer films that are preferred to monolayer films, since the central layers act as a reservoir of anti-drip additives continuously supplying replacement to the lost additives.

Blocking-NIR plastic materials. The potential of combinations of NIR-blocking (NearInfraRed) has been reviewed by Stanghellini and Montero (2012). Results are somehow disappointing: only NIR-filters with very high reflectance (at least 50%) will have some consequence. On the other hand, NIR-absorption will warm up the cover, so that a fraction of the withheld energy will end up in the greenhouse at longer wavelengths and through convection. In addition in some cases a significant reduction in PAR transmission under the NIR films have been observed, due to the additives used to filter NIR. As a consequence one has to be cautious with current blocking NIR covering materials.

4.1.2 Thermal properties of the cover (insulation)

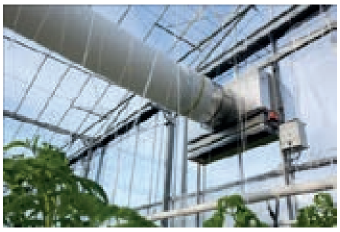
Insulation of the greenhouse can be achieved in two ways: insulation of the cover and use of (thermal) screens. Table 1 has already shown some examples of U-values of different covering materials. It has to be taken into account that these numbers are very general and in practice variable by the means of weather circumstances (mainly wind) and management of the greenhouse climate as for instance humidity control. Kempkes *et al.* (2014) showed that for Dutch climate it’s possible to reduce the heat consumption by more than 50% by exchange the single glass by insulating thermopane, without effect on crop production. Drawback of many insulating covering materials is the reduction of light transmission, which can run up to 20-30%. As light is in most countries in wintertime a limiting factor, this has to be taken into account in the greenhouse design.



A double luxous screen of LS in organic cucmber.

Cover with glass (outside) and film (inside) cover to create an insulating split.

The screens, especially when they are tight and aluminized, could in theory reach savings up to 70%. In practice, because of the opening constraints (light, humidity), the saving is in the order of 20% (Bakker *et al.* 2008). If additional dehumidification measures are taken (Vallières *et al.* 2014; Zwart De, 2014) screens can be applied for more hours and their effectivity is increased. In an experiment (Gelder De *et al.* 2012) the energy use was reduced by 40% by applying two movable screens and one fixed perforated film for a three months period in a tomato crop in the Netherlands. The humidity was controlled by a dehumidification system bringing in “dry” outside air.



Dehumidification units in organic tomato greenhouse in the Netherlands.

4.1.3 Ventilation

A greenhouse is a natural solar collector whose interior is warmed up by incoming solar radiation and excess of energy is removed by ventilation. Natural ventilation is usually the most effective tool for temperature control. Particularly in warm countries, one has to rely on whitewash to reduce incoming solar radiation whenever the ventilation capacity does not suffice for temperature control. This limits the potential for assimilation and production. Additional drawbacks of insufficient ventilation capacity are carbon dioxide depletion and high humidity.

Whitewashing greenhouse in Southern Europe.

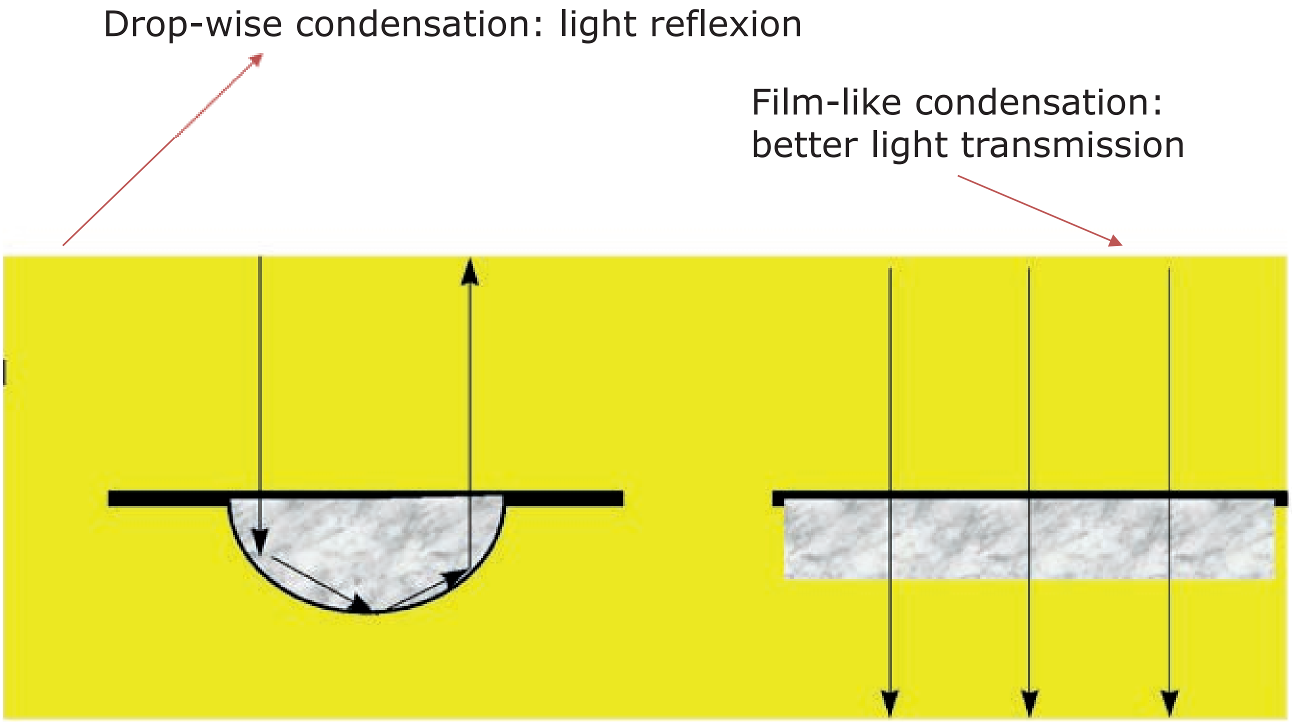
From the early work of Okushima *et al.* (1989) a number of studies on greenhouse ventilation have been published (for instance, Baeza, 2007). Based on the aforementioned Good Agricultural Practices, FAO (2013) major guidelines for better ventilation are as follows:

- New greenhouses are recommended to have clearly bigger ventilation area, minimum roof slope of 25° and limited width (no much more than 50 m) to avoid excessive temperature and humidity and lack of climate uniformity.
- Windward ventilation (roof ventilators open to the upcoming wind) produces higher air exchange than leeward ventilation. In windy areas there is a need to balance the need for good ventilation and the risk of mechanical damage.
- Under wind driven ventilation, first-span and last-span ventilators play a major role in the air exchange, while central-span ventilators have a secondary role. Nevertheless under low wind conditions (thermally driven ventilation) central span vents are also clearly needed.
- Flap roof ventilators are more efficient than rolling roof ventilators, particularly under moderate wind conditions (wind driven ventilation).
- The combination of side wall ventilation and roof ventilation strongly increases ventilation rate, even for greenhouses with a large span number.

Newly designed greenhouses with improved ventilation. Fundación Cajamar, Almería (Spain).

4.1.4 Greenhouse geometry

Greenhouse shape and orientation are important in terms of light transmission and ventilation. It is recommended avoiding low roof slopes (10° or so) in order to maximize solar radiation capture in the winter months. As ventilation is also increased when the roof slope increases, a roof slope close to 30° is a good compromise between greenhouse efficiency and construction cost (Castilla, 2012). An additional advantage of a high roof slope is the ability of the greenhouse roof to collect condensation, which is an effective way of reducing greenhouse air humidity. In order to avoid dripping it is important to maintain the plastic film well stretched to allow condensation running down.
In plastic covered greenhouses the drop-wise condensation on the interior of the covers is a problem. Undesirable effects are: the reduction of the light transmission due to total internal reflection of incident light, drops can act as lenses and burn the plant tissue by focusing the incident light, and the coalescence of small drops into larger ones will cause dripping and provide a high humidity atmosphere for a long period within the greenhouse, which favours the development of fungal diseases. The use of anti-drop films does not in fact prevent the formation of condensation but rather change its form into a film of water (Geoola *et al.* 1994).



In terms of orientation, simulation studies on light transmission show that for greenhouses with 30° roof slope the E-W greenhouse transmits approximately 13% more than the N-S greenhouse during the winter period. Therefore E-W orientation is preferred for winter production. Nevertheless light uniformity is better in N-S greenhouses since the gutter and ridge shadows change their position during the day as the sun moves. In practice there may be several reasons for growers to prefer other orientations.

4.2 Increasing productivity of energy

Greenhouses in areas with favourable climate (mild temperatures in winter and summer as well as high solar radiation) are generally simple structures with limited technology and climate control (Antón *et al.* 2012). There is a solid potential for improving yield without requiring expensive technologies. For instance, Raya Ramallo (2014) reported that the average yield of plastic-covered unheated greenhouses in the Canary Islands could be increased by a factor 3 provided they are properly designed (ventilation and light transmission) and managed. High-tech greenhouses are operated so that the desired (pre-set) climate is attained, and the associated large use of energy has been outlined above. The need is therefore to strike compromises in pre-setting climate set-points, so as to reduce energy requirement.

Environmental control in low-tech greenhouses is essentially achieved using various ventilation techniques to control temperature and humidity, which are in most cases far from ideal and strongly dependent of outside conditions. Low night temperatures and high relative humidity are the main environmental limiting factors, with cold weather. Low temperatures reduce plant growth and fruit yield and lead to serious problems of fruit-setting due to poor pollen quality (Abad and Monteiro, 1989). There is a need, therefore, to learn to manage better the limited means for climate control that one has.

4.2.1 Reduce energy consumption related to temperature control

Increasing insulation of the greenhouse (reduction of the U-value) is the most efficient way to reduce energy requirement. Beside double layer covers, thermal energy screen are very effective without the drawback reducing light transmission.

A double luxous screen in a cucumber crop.

In greenhouse crop production, maintaining set point temperatures accounts for most of the energy consumption (Dieleman *et al.* 2006). Lowered day and night set points by 2 °C in a tomato crop resulted in a 16% energy saving but reduced annual production by 3.3% (Elings *et al.* 2005).

Temperature integration (TI) is another way to save energy in greenhouses. This regime is based on the ability of plants to tolerate temperature fluctuations around an optimum, provided that the average temperature over a period of one to several days is respected (Körner and Challa, 2003). TI has been studied for decades in different conditions and on various crops. The energy savings depend on the crop and the magnitude of temperature fluctuations allowed. The range of energy savings with TI, according to experiments and simulations, is 5-15% (Buwalda *et al.* 1999; Körner and Challa, 2003; Elings *et al.* 2005), with few effects on production.

According to Bailey (1988), the best strategy for thermal screen management was temperature integration over 24 hours, lowering the day temperature set point and increasing the night temperature set point, when the screen is closed. According to Mercier *et al.* (1988), the opening at 30 W m^{-2} outside global radiation instead of 1 W m^{-2} saved 10% energy. Dieleman and Kempkes (2006) obtained an energy saving of 3.5% without effect on production with an opening of the thermal screen at 50 W m^{-2} instead of 5 W m^{-2} outside global radiation.

4.2.2 Reduce energy consumption in heated greenhouses related to humidity control

Humidity is an important factor in greenhouse climate. It is directly linked with the transpiration of the plants, which depends on solar radiation, air temperature and humidity in the greenhouse (Stanghellini and Van Meurs, 1989). To reduce energy consumption related to humidity control, different possibilities have been studied in conventional greenhouse: higher humidity set points, reducing crop transpiration or dehumidification with heat recovery. In a certain extent, they can also be applied to organic greenhouse.

Elings *et al.* (2005) studied by simulations the impact of an increase of the relative air humidity (RH) set point from 85% to 90%. An increase in the RH set point reduced by 5% the use of energy while production was maintained, but the risk of botrytis increased. With crop-based RH control energy use was reduced by 3% without impact on production.

Reduction of soil evaporation and crop transpiration has an indirect impact on energy efficiency (Marcelis *et al.* 2007). But if transpiration is too low, crop development may be reduced. De-leafing in peppers has been shown to save around 8% of weekly energy use towards the end of the season (approximately 18 MJ m^{-2} of gas annually) without any loss of yield or increase in disease (Adams *et al.* 2010). Simulations for tomato crops grown without humidity control showed that taking off additional six old leaves (to give a highly de-leafed crop with a leaf area reduced by an extra 35%) will reduce the energy use by 3.2%. When grown with a humidity control set-point of 90% RH, this saving rises to 5.8%. This degree of de-leafing didn’t have a significant effect on yield. But an increase in uneven fruit ripening was observed (Adams and Langton, 2009).

4.2.3 Temperature and humidity management in unheated greenhouses

Greenhouse microclimate parameters, such as air temperature and relative humidity and also leaf temperature and leaf wetness duration, influence the growth and development of crops and also the spread of certain diseases. According to Kittas *et al.* (2013) the majority of plants grown in greenhouses are adapted to average temperatures in the range 17–27 °C, with approximate lower and upper limits of 10 and 35 °C. If the average minimum outside temperature is < 10 °C, the greenhouse is likely to require heating. When the average maximum outside temperature is < 27 °C, ventilation will prevent excessive internal temperatures during the day. If the average maximum temperature is > 27–28 °C, artificial cooling may be necessary. The maximum greenhouse temperature should not exceed 30–35 °C for prolonged periods. Relative humidity within the range of 60–90% has little effect on plants. Values below 60%, especially when plants are young with small leaves, can cause water stress. On the other hand, serious problems can occur if relative humidity exceeds 85-90% for long periods, as this favours the rapid development of fungus diseases such as *Botrytis cinerea* which may be aggravated by water dripping on the plants (Fletcher, 1984).

Visible symptoms caused by B. cinerea on the tomato crop. a) infected flower, b) infected leaflet and a detail of an infected flower over the leaf, c) infected leaflet, d) several removed infected leaflets, e) infected leaf, f) infected stem and leaf, g) infected stem due to wound caused by the tutor, h) infected tomato fruit (soft rot), i) ghost spot on tomato fruit.

In Mediterranean regions, during spring/autumn periods, growers tend to close greenhouses late in the afternoon with the objective of reducing heat losses. However, air humidity can increase too much losing this advantage and promoting favourable conditions for condensation and diseases development. Nocturnal ventilation management in unheated greenhouses allows controlling air humidity avoiding saturation conditions (if outside air absolute humidity is lower than inside). Baptista *et al.* (2012b) reported a significant reduction on the relative humidity conditions in greenhouses ventilated at night. Also Piscia *et al.* (2015), using Computational Fluid Dynamics (CFD) simulation, showed that the relative humidity inside unheated greenhouses was always reduced by opening the ventilators; even with an external relative humidity of 85% there was a drop comparing with closed greenhouse. This ventilation management permits a better control of humidity and in consequence of diseases, reducing requirement for crop protection. Baptista (2007) reported a reduction of about 50% in *B. cinerea* severity on tomato leaves in greenhouses ventilated at night. This showed that ventilation management is an environmental control technique which can be used as a prophylactic measure, reducing the disease severity on tomato crops grown in unheated greenhouses. One could expect a significant reduction in air temperature which could affect negatively the crop development and production. However, it has been shown that nocturnal ventilation in unheated greenhouses did not significantly reduce air temperature.

Also, condensation on the cover was lower in the ventilated greenhouse by the decrease of the relative humidity and by the slow increase of internal air temperature during the first hours in the morning.

4.2.4 Mulching

Mulching is widely used in intensive agriculture because of soil moisture conservation, increase in soil temperature and nutrient availability, reduction of weed pressure and of certain insect pest (Cirujeda *et al.* 2012; Kasirajan and Ngouaijo, 2012; Haapala *et al.* 2013). These advantages are even more relevant for organic greenhouse productions.

Colour of mulch is important in terms of light and temperature conditions for plants. Commonly used colours of mulch films are black, white, black/white, brown, red, yellow, even transparent.

Dark mulches enhance soil warmth trough absorption of light radiation. In passive Mediterranean greenhouses, winter climate is usually suboptimal for crop production (Montero *et al.* 1985; López *et al.* 2008) when horticultural products usually reach the highest price (Bartzanas *et al.* 2005). In these greenhouses black mulching could be a simple passive system to increase solar heat storage in the soil and improve the air/soil thermal regime during the early stages of crop cycles starting in winter. Bonachela *et al.* (2012) observed a positive effect in soil heat flux, ground net radiation and air and root temperature with the use of black mulch compared to transparent mulch or bare soil.

Black mulch in cucumber.

Light mulch colours increase light reflection and thus the light available for the crop. For this purpose they are used in Northern countries. However light reflection also decreases the amount of energy stored in the soil, and has a negative effect on soil temperature. Indeed there are results showing negative effect of white mulch on winter cucumber production in Almería (Lorenzo *et al.* 1999) and on spring tomato crop in Portugal (Pereira, 2015).

Light mulch in tomato.

According to Ferus *et al.* (2011) red mulch serves to increase dry biomass production, leaf area and transpiration in warm temperature condition. In moderately low temperature (15-20 °C) also favours increasing the relative water content. Red PE mulch is especially recommended for Cucurbitaceae; it was found positive relationship between the root-zone, temperature, photosynthetic rate and fruit yield.

Gravel is also considered as a type of mulch particularly in Southern Spanish areas. Baille *et al.* (2006) observed that soil contributes about 20 Wm^{-2} of air heating during winter with a gravel mulched soil in a parral type greenhouse.

However, ventilation may have a negative effect on the benefits of mulching. For simple greenhouses in the Mediterranean area, ventilation should reflect a compromise between maximizing greenhouse heat storage and fulfilling ventilation requirements for suitable crop growth (Bonachela *et al.* 2012; Granados *et al.* 2015).

5 Indirect use of energy

A report on the environmental and economic profile of present greenhouse production systems was produced in the EUPHOROS project for heated (the Netherlands) and unheated (Southern Spain) tomato (Montero *et al.* 2012).

Such study showed the Cumulative Energy Demand (CED) that included direct energy for heating and indirect energy for manufacturing the greenhouse structure and covering material, as well as the energy required for fertilization (manufacturing and use), transport for waste management and others. Obviously, as the numbers given in chapter 2 will make clear, energy use for climatisation of heated greenhouse dwarfs all other uses.

Concerning the energy used for manufacture of the production means, the greenhouse structure (including cover) is the single largest item, ranging from some 20 MJ m^{-2} for plastic-covered multi-tunnels to 40 MJ m^{-2} for a Venlo greenhouse (steel frame covered with glass). In all cases, reducing the amount of steel in the construction may weaken the structure and also be in stride with local building norms. Anyhow, reducing these numbers would need a large re-investment in the greenhouse structure and is not the easiest approach to sensible energy use. On the other hand, there is some scope in increasing life-span of the plastic, which is usually renewed in three years and accounts for more than 50% of the CED of the multi-tunnel. Glass has a long life (15 years), but requires a heavier structure, as the numbers show. Obviously, increasing the productivity of a given surface is a way, as it has been shown in paragraph 4.2., and high-tech (glass) greenhouses are usually more productive than simple multi-tunnels.

The amount of energy required for pumping water for irrigation ranges from negligible to 6.6 MJ m^{-2} for the deep wells of Southern Spain, for instance.

A very recent study of tomato greenhouse organic production in Portugal (Baptista *et al.* 2016, in press) reported a total energy consumption of 29.17 MJ m^{-2} soil or 1.87 GJ t^{-1} referred to an annual production (for two crops per year) of 15.6 kg m^{-2}. Here, as well, structure materials contributed for more than 50% of indirect energy consumption and indirect energy represented approximately 74% of the total energy consumption. Irrigation and production of crop protection means (copper, sulfate and Bacillus thuringiensis) are the most representative inputs.

Steaming can indeed be a very important energy consumer. The amount of energy required depends obviously on the rooting depth (the depth of the soil layer one wishes to treat) and on soil texture and moisture content. Energy use ranges between 50 and 125 MJ m^{-2}. Also in view of the negative effect on soil life, steaming should be used as little as possible. As we have seen in survey, steaming is allowed in organic greenhouse production in most European countries. However, the EU document EGTOP (2013) recommend a very sparing application, if at all.

Soil steaming.

6 Replace fossil energy use by renewable energy

6.1 Solar Energy

Renewable energy resources (solar radiation and wind energy) show a certain similarity in their distribution. Obviously, there is much more energy during the day-time hours than during the night-time hours and in the months around the summer than during the winter. There is a concordance with the time of the year in which the conditions inside the greenhouse are such that the temperatures are above the optimum and limit temperatures, but not during the moments in which temperatures are below the limits (winter).

El Coronil Solar greenhouse.

The conclusion of a previous EU project on this topic (Baeza *et al.* 2012) clearly show that, at present, neither photovoltaic (PV) nor wind energy can be used economically to cover heating or cooling requirements of the greenhouses. The only possibility with some interest would be to use solar thermal energy and/or wind energy to produce heat (using a heat churn) and heat storage, but that would only meet part of the demand.

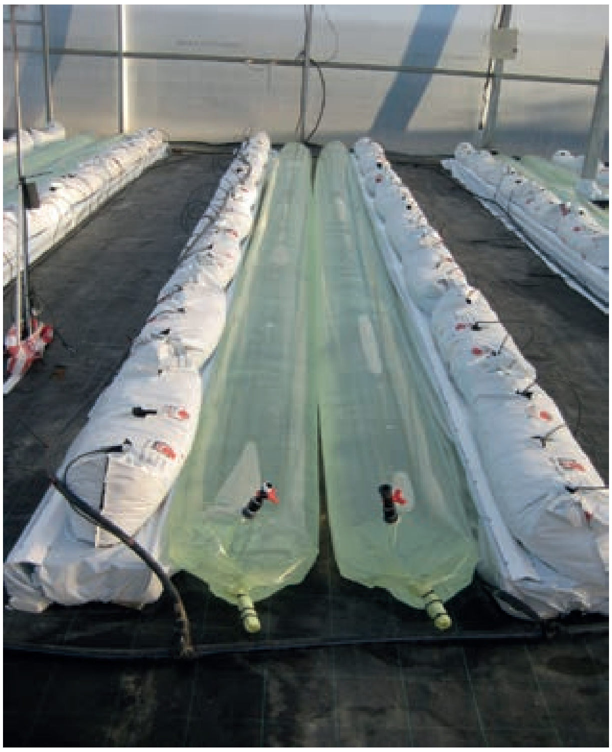
In any case, the growers which would decide to use PV or wind energy would normally sell the energy because in most countries, selling this energy is subsidized by the government, so the growers would rather sell it than use the electricity directly in the greenhouse, except for extremely isolated greenhouses. Recently there has been an enormous interest in some countries (mainly Mediterranean) in the installation of PV panels directly over the roof of the greenhouses. However, the ensuing decrease in transmissivity (even for semi-transparent PV panels that are still under development) will inevitably translate in a yield loss. Although this may be compensated by the income from electricity sale, one should considering installing PV panels on every other possible surface, before considering greenhouse roofs. There are very few [shade] crops for which yield reduction may be limited, and they are usually leafy ornamentals and not the food vegetables typically grown in organic greenhouses.

According to Campiotti *et al.* (2010) the PV capacity installed in the European Union during 2007 and 2008 reached up to 9533.3 MWp). Photovoltaics (preferably on service buildings) can power greenhouse electricity costs for actuators (opening and closing of windows, fertigation) and cooling operation in summer and supply water pumps, lights, electric fences. Since the associated goal is mainly to implementing solar PV systems into the greenhouse agriculture, the following criteria should be met: being simple, easy to manage and repair, and with the possibility of being manufactured locally.

Recently, on the market are being commercialized crystalline silicon modules coming from China, with relatively low price (between 1500 to 2000 € kWp^{-1}). The promotion of PV modules integration in greenhouse agriculture has also a significant importance for reducing the environmental impact associated with the fossil energy (for each kWhel - photovoltaic electricity generation - it is reported till to 700 g of CO_2 emissions) since the photovoltaic solar installations produce a corresponding GHG emissions between 21-45 g of CO_2-eq kWh^{-1} (Fthenakis and Alsema, 2006). Therefore we can conclude that for areas in which solar radiation is abundant (i.e. desert areas) in which greenhouses are built in remote locations, without access to the network, PV panel systems, if properly designed and provided that a good study of the electricity consumption patterns along the year is made, are a reliable source to cover small electricity consumptions of the greenhouse operation (motors opening and closing vents, pumps for irrigation or fogging, etc.).

In terms of thermal solar energy, considerable research and development efforts were made in the last century, mainly for heating purposes, as a consequence of the oil crisis in 1973. The FAO established a cooperative network to analyse different solar heated greenhouses around the world (Zabeltitz Von, 1988). Solar collectors outside the greenhouse proved to be technically feasible, but its economy is open to debate, mainly because of the large collector surface and energy storage volume required for heating. For instance, Montero and Short (1984) calculated that a ratio of collector area to greenhouse cover area of 0.5 is needed to satisfy 80% of the heating requirements in Southern Spain.

Those early studies showed that implementing energy saving equipments and strategies, improving the greenhouse efficiency as a solar collector and increasing the greenhouse thermal inertia were more solid applications of solar energy than the use of collectors outside the greenhouse. Such conclusion has proven to be true since over the years the greenhouse industry has implemented energy saving measures (as discussed earlier), has paid great attention to improving greenhouse light transmission, and has used mulching (paragraph 4.2.4.), double covers and, in some cases water sleeves inside the greenhouse, as a way of increasing the greenhouse thermal inertia. These are good examples of the application of passive solar energy for thermal purposes.



Water sleeves to increase greenhouse thermal inertia.

It is worthwhile mentioning that the most widely applied greenhouse structure in the world is the Chinese solar greenhouse (Yang, 2012). It is an E-W oriented single span greenhouse. The north wall is made of masonry or similar construction material, so that stores solar energy during the day and releases it at night. A rolling mechanism deploys a thermal blanket over the greenhouse roof providing heavy insulation (Figure 2).

Figure 2 *Outside and inside views of the Chinese solar greenhouse.*

6.2 Wind energy

The wind energy available for a wind turbine is related to the wind speed and to the area swept by the turbine blades. It can be demonstrated that the energy in the wind is proportional to the cube of the wind speed, therefore the suitability of a particular site for capturing wind energy is mainly related to the mean annual wind speed recorder in the site. A mean annual wind speed of about 5 m s^{-1} can be considered as a minimum to make wind energy use attractive in a given site. Local topography has also an effect of the efficiency of wind harnessing; flat areas are preferred over sharp discontinuities of the terrain since flat areas are less exposed to turbulence. The aforementioned factors make that many greenhouse locations are not attractive for the installation of wind turbines.

Windmill in Spain.

Baeza *et al.* (2012) evaluated the availability of wind energy in Almería (Southern Spain) and confronted such availability with the heating and cooling requirement of greenhouses in the same location. Calculations were based on meteorological data recorded during ten years. In terms of heating, it is required an area of approximately 10 m^2 swept by a wind turbine per each m^2 of greenhouse soil to cover peak heat requirements (January at sunrise), while at sunset 2.6 m^2 of wind catchment area may be sufficient. The study concluded that, at the moment, direct use of wind energy for heating or cooling greenhouses is not economically viable.

But even if it is not economic to install a wind turbine on a greenhouse as a source of energy for heating, it may be worthwhile to use it to produce electricity and feed it into the grid. This has the strong advantage of selling electricity when the greenhouse does not require energy for heating of for other purposes such as mechanical ventilation.

6.3 Biomass

Local burning of biomass is, in the short term, the most promising source of renewable energy, preferably in combined heat-power generation. In this way, electricity needs are covered and the waste heat can be used for heating.

In Central Europe, biomass is the most significant source of renewable energy. According to Bartoszewicz-Burczy (2012) biomass potential is estimated at 3900-4700 PJ $year^{-1}$. The most important are: wood waste from forests, orchards, green areas and roadside; waste from the wood industry (wood chips, shavings, sawdust), grains (rye, oat); waste from agricultural production (e.g. straw) and, as last, quick growing "energetic plants" as Miscanthus sinensis or Salix viminalis. Close to 0.3 million tons (oil equivalent) of straw are utilized for agricultural heat supply, mostly in Austria, Denmark, Germany. The average energy value from pelletized biomass is 16-18 MJ kg^{-1}, which corresponds to an average of 70% of the coal calorific value.


Biomass and combuster.

The technical potential of biomass varies depending on the region of Europe. Central Europe has large reserves: 20-200 PJ $year^{-1}$ Slovenia, Slovakia, Hungary; 300-900 PJ $year^{-1}$ Czech Republic, Austria, Poland and 1000-1700 PJ $year^{-1}$ Germany, Italy (Schilcher and Schmidl, 2009; Tempel, 2011). Pellets production in these countries is between 0.12 Mt (Slovakia) to 1.75 Mt (Germany). It is expected that in 2020 consumption of pellets will be at 60-100 Mt. According to Campiotti *et al.* (2010) thus corresponding to the 2005 European Plan of action's for biomass (149 Mt oil equivalent) of consumption at the end of 2010.

Research on the use of biomass as an energy source in greenhouses have been carried out since the eighties of the last century (Zabeltitz Von *et al.* 1994). Wood biomass is assessed as the source of the lowest amounts of GHG.

Chau *et al.* (2009) performed techno-economic analysis and determined that the installation of a wood pellet or a wood residue boiler can generate 40% of the greenhouse heat demand and it is more economical than using a natural gas boiler alone to generate all the heat for an average-sized greenhouse (7.5 ha) or a large one (15 ha). The results indicated that the attractiveness of using wood biomass would increase if the price of fossil fuels increased more than 3% per year or carbon taxes were applied. Increasing the biomass energy contribution to 20% (to provide 60% of the total heat demand) would still be economical.

A new idea is to use the greenhouse vegetal waste as biomass source. Great regions of protected horticulture produce large amounts of plant residues, e.g. the province of Almería, with a greenhouse area of 26000 ha, produces an estimation of 1.75 Mt of fresh biomass. The two main crops of the province (tomato and pepper) generate 60% of the total fresh weight of vegetal waste that includes near 40% of carbon and 5% of oxygen, sulphur and chloride. Chloride content should be low because a high content is harmful for the combustion process. Sulphur is environmentally harmful for obvious reasons (acid rain).
Searching results showed that the gross fraction has a good heating power, with a value of 9.9 MJ kg^{-1}. The thicker particles, which are the most ligneous ones reaches a value of 13.4 MJ kg^{-1}. The presence of smaller, more humid particles and with more ashes decreases the total heating power. However, the value is between impregnate sawdust (13.4 MJ kg^{-1}) or lignite (8.3-16.7 MJ kg^{-1}) but lower than soft coal (12.5-20.9 MJ kg^{-1}) or carbon coke (29.3 MJ kg^{-1}).

The annual biomass consumption as fuel for greenhouse heating, considering a thermal power of the greenhouse surface to be heated equivalent to 100 W m^{-2}, a conversion yield of 85% and a biomass producing 14.04 MJ kg^{-1}, is about 45 kg m^{-2} with 1.500 running.

If the grower is planning to use more than one type of biomass, it is important to choose a multi-residues boiler, although they are a bit more expensive, but provide flexibility. From an environmental and productive point of view, it would be advisable to adapt a system to the biomass heating system capable of adsorbing the CO_2 from the combustion gases, store it and use during the daytime for greenhouse CO_2 enrichment. Different materials, such as certain types of active carbon, are capable of doing almost infinite cycles of adsorption-desorption of CO_2. An example of such a system is being tested at the moment, linked to the biomass boiler at the Experimental Station of the Cajamar Foundation (Spain).

The wide-scale use of biomass in greenhouse horticulture depends on the national and European energy price policy and the introduction of subsidiary systems which are still necessary to make these technologies more attractive for the farmers.

6.4 Biogas

The European energy production from biogas reached 6 Mt of oil equivalent in 2007 (EurObserv'ER, 2008). The production of biogas through anaerobic digestion offers significant advantages over other forms of bioenergy production. It has been evaluated as one of the most energy-efficient and environmentally beneficial technology for bioenergy production (Weiland, 2010). Many conventional forage crops produce large amounts of easily degradable biomass which is necessary for high biogas yields (Braun, 2009). The highest gross energy potential has maize and forage beets but also different cereal crops and perennial grasses have potential as energy crops (Weiland, 2010). The residue after fermentation can be used as organic fertilizer due to the increased availability of nitrogen and the better short-term fertilization effect.

In combined heat and power agricultural biogas plants 15-20% of the power is used to maintain the methane fermentation, the rest to be used on the farm. One micro biogas plant can produce heat for facilities within 200 m, with no loss of investment for the construction of the pipeline.

Pig slurry biogas. From 1 m^3 of liquid dung one can get an average of 20 m^3 of biogas and 1 m^3 of manure gives 30 m^3 of biogas, with an energy value of about 23 MJ m^{-3}.

Plant and animal waste (maize silage + pig slurry) biogas. The necessary area of corn and pig livestock for 10 kW installation is 2 ha (20% maize silage + 80% pig slurry) or 7 ha (60% maize silage + 40% pigs slurry). For the installation of 40 kW, the necessary area is 7 ha (50% + 50%) or 26 ha (80% + 20%).
Biogas from sewage plants. Biological wastewater (municipal sewage plants and part of industrial ones) are the best for direct production of biogas. From 1 m^3 of sediment (4-5% dry matter) can be obtained 10-20 m^3 biogas containing approx. 60% methane. For economic reasons, the acquisition of biogas for energy purposes is justified only major wastewater treatment plants receiving sewage an average of over 8000-10000 m^3 day^{-1}.

6.5 Geothermal energy

Geothermal energy is potentially a very good and renewable energy source. However, in most cases, the costs associated to drilling wells several hundred meters deep, are daunting. Luckily, geothermal fields are near to the surface in several EU regions, making its use very attractive and economical.

Indeed, in Europe (and outside), greenhouses development have been built on locations where geothermal energy is available at the surface (e.g. Monte Amiata, Italy; Szeged, Hungary; Central Poland; Western Turkey; Southern Tunisia). At the other extreme, several greenhouses in The Netherlands are heated by geothermal wells exceeding a depth of 2 km, at the cost of high investment.

Closed-loop systems should be used to prevent the environmental damage caused by the discharge at the surface of geothermal water, and indeed, closed-loop is demanded in most EU countries.

Drilling a geothermal energy well in the Netherlands.

6.6 Other sources of renewable energy

Hydroelectric energy is obviously renewable and it will have an increasing role in the future continental “smart grids” for electricity distribution, thanks to the easiness of storing it. Obviously, the production of hydro-electric energy is not for the “average” grower, however, in several countries users can opt for “green” (renewable) electricity.

7 Conclusions

Very little is known about data on energy use in organic greenhouse production, and there is little consistency in public and private organic horticulture regulations. With respect to energy use, organic greenhouse production faces challenges that are similar or worse than conventional production. Indeed, the limited choices for prophylactic crop protection (particularly against fungal diseases) demand a preventive climate management, aimed in particular at lowering humidity, often at the expense of additional energy. Hardly any research has been done up to now on energy saving in organic greenhouse production. Although much of the research done on energy saving in conventional greenhouses could be applied in organic greenhouses as well, there is a need of research within the constrained conditions of organic greenhouse production.

A relatively high productivity is attained in heated greenhouses at the expense of much [fossil] energy. Indeed climatisation is by far the largest energy use in organic greenhouses. We have reviewed recent knowledge about greenhouse insulation and climate management that can be implemented to reduce consumption of direct energy in such greenhouses. In fact there is strong potential for energy saving particularly by improving greenhouse insulation.

Unheated greenhouses have obviously low energy requirement, however the energy use efficiency can be clearly improved by increasing productivity. Poor climate control is the main cause of low productivity in low-tech greenhouses. We have reviewed recent knowledge showing that better ventilation, greenhouse design, management and control could improve productivity up to a factor three.

Crop protection is a rather important contributor to (in)direct energy use, steaming in particular, but also the energy needed for the production of crop protection means. The energy required for the production of the greenhouse itself (frame and cover material) is by far the largest contributor to indirect energy use. However, there seems to be little scope for improvement in the frame, in view of building norms. On the other hand, there is need for research on new cover materials to improve the solar collector function of the greenhouse and on additives to increase life of plastic films and the performance under condensation.

Better water management could reduce fertilisers use and lead to savings in the energy needed for their manufacture. It could also reduce the electricity use for pumping water, particularly in regions with deep wells. The scope for application of renewable energy sources is not better nor worse than for conventional greenhouses. So, as for conventional greenhouses, the application of renewable energy is technically feasible but economically open to debate. This situation has not essentially changed for the last decades. Nevertheless one has to bear in mind that the cost of energy is related to an ever changing scenario where not only economic issues but environmental, social and political issues play a role.

At the moment, the best way to match demand and availability of electricity (solar and wind power) is through the grid, also in view of existing subsidies for electricity sale to the grid. There is some scope for application of solar thermal energy for heating and/or humidity management, although this requires a large investment in thermal buffering.

In combined organic farms there is scope for biomass burning and/or biogas production. Technology developments make that currently there are commercial greenhouse operations that benefit from the use of biomass and, in some cases, biogas. Such alternative energy sources are progressively replacing traditional more pollutant fuels .

In conclusion, the way to a higher energy efficiency in organic greenhouse production is:
- For heated greenhouses, to lower the need for heating, primarily through better insulation.
- For unheated greenhouses, to increase crop productivity improving climate management, particularly through a better design and management of ventilation.

There are several options for the substitution of fossil with renewable energy sources. Although presently very few options are financially sound, their feasibility follows from price/subsidies policies that are variable among countries and that may be variable in time.

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Annex 1 The survey

Question 1

National or regional regulations on energy use in OGH.

Answer	Number	Countries (info)
No	16	Belgium, Bulgaria, Cyprus, Denmark, Egypt, Estonia, France, Ireland, Italy, Netherlands, Poland, Portugal, Serbia, Spain, Sweden, Turkey.
Yes	4	Austria (Bio Austria), Germany, Switzerland (Bio Suisse), Greece (www.agrocert.gr and http://www.dionet.gr/).

Question 2

National organic legislation or private standards on the use of energy for climate control for crop protection.

Answer	Number	Countries
No	14	Denmark, Bulgaria, Cyprus, Egypt, Estonia, France, Greece, Ireland, Italy, Poland, Portugal, Serbia, Spain, Switzerland.
No info	1	Germany
Yes	5	Austria Belgium: General charter in Biogarantie that you must sign, engaging that you will measure the energy use and try to reduce it. Netherlands (soil steaming) Sweden: All KRAV greenhouses must do annually energy audits, have a plan for energy efficiency, minimum 80% of the energy for heating must be renewable, all KRAV greenhouses that are used during wintertime must be insulated. Turkey: There is a regulation on geothermal energy use (i.e. reinjection) in general. Also effects of energy resources on environment are considered in GAPs.

Question 3

Most important private standards.

Answer	Countries
No private standards, EU legislation	Austria, Cyprus
Biogarantie	Belgium
Danish red Ø (Government standard)	Denmark
No info	Germany, France, Turkey, Portugal
IOFGA LTD Standards	Ireland
EKO keurmerk (but not a standard yet)	Netherlands
KRAV	Sweden
Bio Suisse	Switzerland
Council Regulation (EC) No 834/2007 JAS Organic National Organic Program (NOP)	Bulgaria
No private standard, use EU directive 834/2007	Estonia
No info	Poland
Organic control system (http://www.organica.rs/index-en.html) Ecocert Balkan (http://www.organica.rs/index-en.html) Control Union Danube (http://www.cudanube.rs/istorijat.html) ETKO panonija (www.etkopanonija.org) Suolo e Salute Balkan d.o.o. (http://552233496691033095.weebly.com/) TMS CEE (http://www.tms.rs/sertifikacija-proizvoda/organska-proizvodnja)	Serbia
http://www.dionet.gr/	Greece
EU Standards USDA-NOP Standards	Egypt
EU Standards DEMETER Bio Suisse	Spain
ICEA DEMETER	Italy

Question 4

Restrictions for energy use in private standards.

Answer	Number	Countries
No rules about energy use	13	Belgium, Denmark, Ireland, Netherlands, Bulgaria, Estonia, Poland, Portugal, Serbia, Cyprus, France. Greece: In fact for this reason in the framework of a national project (regional innovation pole of Thessaly) we try to develop specialized certification protocols for greenhouse crops (tomato & cucumber) incorporating in the general national ones (www.agrocert.gr) issues for energy use, climate control, crop protection and greenhouse structures. Italy: The rules of ICEA private standards are the same of the REG. CE n. 834/2007.
Seasonal	5	Austria: during winter time only frost-free in greenhouses (December-February). Sweden: all KRAV greenhouses need insulation for winter production. Switzerland: for greenhouses with poor insulation: only heating frost free (5 °C) between November and April (from 1.1.2015 on); for greenhouses with double layer insulation:10 °C between 1 December and 28/29 February. Poland: no heating between May- October. Serbia France: Some private standards have regulations on energy use : "Seasonal heating": only for plants nursery and/or limited to frozen free (5°C max). See for example : http://www.biobreizh.org/page.php?rubrique=1-2 and http://www.biocoherence.fr/images/media/Telechargement/2cahier%20des%20charges-nov12-production.pdf
Amount of energy kWh m^{-2}	1	Sweden: energy audits in greenhouses; energy efficiency plan; at least 80% of the energy used for heating must be renewable. You must meet one of the two following standards: at least 80% of the total energy used for heating, lighting and cold storage rooms, as well as production of carbon dioxide must be from renewable energy sources or waste heat. Calculate this per calendar year; the amount of non-renewable energy used cannot exceed 2.5 kWh per square meter per cultivation week on average during the cultivation period.

Answer	Number	Countries
Cultivation methods	5	Austria: restrictions to the amount of fertilizers; peat content in substrate mixtures for young plants: < 70%; no peat as organic soil supplement; no steam treatment for soils. Switzerland Poland: soil cultivation with natural and organic fertilizers, biological pest control. Serbia France: Cultivation methods: limitation of steam disinfection and thermal weeding (1 year/2 max under greenhouse).
The use of growing media like substrate or soil	4	Austria Switzerland Bulgaria: no substrate allowed in organic cropping. Poland: no substrate allowed in organic cropping. Turkey: soilless culture is not allowed in OGH.
Use of supplementary lighting	1	Austria: Artificial lighting is forbidden (except young plants).
Mulching	3	Poland: mulching by PE and organic mulch (red clover and Lucerne); biodegradable fleece. Serbia Spain sand mulching (applied also in traditional growing in Almeria); organic mulching; double plastic tops in greenhouse; thermic plastic.

Question 5

Data available for high-energy consuming crops in OGH.

Answer	Number	Countries
No	16	Austria, Ireland, Sweden, Switzerland, Bulgaria, Estonia, Cyprus, France, Greece, Italy, Spain, Turkey, Egypt, Poland, Portugal, Serbia.
Yes	4	Belgium, Denmark, Germany, Netherlands.

Question 6

Research on energy use in OGH.

Answer	Number	Countries
No	12	Ireland, Switzerland, Bulgaria, Estonia, Poland, Portugal, Serbia, Egypt, Cyprus. Greece: To our knowledge there is no research for the energy use in organic greenhouse crops. There are several research works and publications in energy use in conventional or even integrated pest management greenhouses but not in organic. In fact I have carried out my bachelor thesis trying to collect information for the energy use in greenhouse and then (based on a specific software) to propose solutions for the reduction of the used energy. Spain Turkey: There is a publication for high-tech greenhouses (climate control, etc.): "Design of a sustainable innovation greenhouse system for Turkey" (by Hemming *et al.* 2010).
Yes	8	Austria: HBLFA für Gartenbau-Schönbrunn (www.gartenbau.at). Belgium: energy efficient organic greenhouse at Vegetable research center (www.pcgroenteteelt.be). Denmark: Very applied research on strawberries and apple. Nat. growers magazines. Germany: ZINEG project. Netherlands: WageningenUR Greenhouse Horticulture funded by Ministry of Economic Affairs. Sweden: some info are available in Swedish on the website of the Swedish board of agriculture (www.jordbruksverket.se). France Italy ORT.BIO project funded by the Ministry for Agricultural Food and Forestry Policies (MIPAAF). Migliorini, P., Chiorri, M., Paffarini, C., Galioto, F., 2012. Energy analysis of organic horticultural farms in Italy. Special Issue New Medit n. 4, 49-52.

Question 7

Possible knowledge gaps.

Answer	Countries
Transfer of existing knowledge from conventional greenhouses to organic for energy use, climate, control, with adaptation to specific organic conditions like soil production.	Denmark, Belgium, Netherlands.
Efficient humidity control (in insulated greenhouses).	Belgium, Germany, Switzerland.
Make organic fossil free; Low energy and climate neutral production; Renewable energy: suitable renewable energy sources, impact of use, only use renewable energy.	Germany, Belgium, Netherlands, Sweden.
Optimized control systems; Production process documentation and evaluation; Systems analysis.	Germany
More important than knowledge is room for investment in the right technology.	Netherlands
How to develop cost efficient sustainable energy systems.	Netherlands
Knowledge is at good level in general. No separation between organic and conventional.	Bulgaria
Few OGH growers heating greenhouses with wood or wood pellets (in spring and autumn). Most of the growers have no heating at all and they grow in polytunnels.	Estonia
Due to the lack of organic protected cultivation the energy-use in this kind of production is not taken into consideration.	Poland
Sufficiently of specialized research; Relatively small area under organic crops; Sufficiently state support in this area.	Serbia
I think there is a gap between the energy used in conventional, integrated pest management and organic greenhouse. The used systems and techniques are different in the 3 greenhouse systems and usually energy is not always spent for heating (for example in an integrated pest management greenhouse production, energy could be spent for dehumidification purposes). A survey for the used in the 3 different greenhouse systems together with a relative LCA and LCC analysis would be very interesting and useful.	Greece
Environment; Weed management; Long distance commercial fertilizers; Steam, solar disinfection.	France
Transfer of existing knowledge on organic greenhouse horticulture from research to growers.	Italy
Humidity control.	Italy
Economic analysis.	Turkey
Design of greenhouses to eliminate/decrease the cooling hours.	Egypt
Lack of information on the current consumption, in order to identify critical points and optimize energy consumption; The optimization of consumption depends greatly on the incorporation of knowledge in agricultural practices. For this we would need three things in my opinion: 1. To develop models to evaluate energy consumption taking in consideration management strategies; 2. Have technical staff in the companies with competences to incorporate these changes in the management; 3. Legislation and inspection that oblige to change.	Portugal
no	Cyprus, Spain

Annex 2 The respondents

	Sent to	Respondent 1	Respondent 2	Respondent 3
1	Austria	Wolfgang Palme		
2	Belgium	Justine Dewitte	Evert Eriksson	Esmeralda Borgo
3	Bulgaria	Veselin Penev	Dilyana Mitova	
4	Cyprus	George Kyrris		
5	Czech Republic			
6	Denmark	Carl-Otto Ottosen		
7	Estonia	Priit Põldma		
8	Finland			
9	France	Hélène Vedie		
10	Germany	Joachim Meyer		
11	Greece	Thomas Bartzanas		
12	Ireland	Owen Doyle		
13	Israel			
14	Italy	Francesco Giuffrida		
15	Malta			
16	Netherlands	Marjan Blom	Rob Meijer	Peter Vermeulen
17	Norway			
18	Poland	Agnieszka Stepowska		
19	Portugal	Ricardo Vicente	Fátima Baptista	
20	Romania			
21	Serbia	Djordje Moravčević		
23	Slovenia			
24	Spain	María del Carmen García García		
25	Sweden	Anders Carlborg		
26	Switzerland	Céline Gilli	Martin Koller	
27	Turkey	Yuksel Tuzel		
28	United Kingdom			
29	Egypt	Hamada Abdelrahman		
30	Jordan			

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Link to the Action:
http://www.cost.eu/COST_Actions/fa/FA1105
And:
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