Sustainable Horticultural Crop Production in Germany

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I. Introduction

When it comes to renewable energy technology, Germany is highly regarded as a trendsetter within the global scene. Does Germany's 'green' reputation hold true within the realm of horticultural crop production? In terms of sustainability, how do the practices of German horticulture rate? By providing current statistical data within an historical context, I hope to find answers to these questions. Furthermore, I will propose a development strategy that will build on the most sustainable practices and resources available. I will design a model greenhouse to be used for research, and look at an important German horticultural crop that could be used to test my proposed development strategy.

II. Overview

Germany is a large country in central Europe, with an estimated 82,369,552 people and a total land area of 357,021 km² (Central Intelligence Agency 2009). Its latitude ranges from approximately 60° N at its northernmost point where it borders Denmark, to approximately 47° N at its southern extreme where it borders Austria (Falling Rain 1996-2004). Along with the aforementioned countries, Germany shares borders with: Poland, the Czech Republic, Switzerland, France, Luxemburg, Belgium, and the Netherlands. Most of its northern perimeter is 2,389 km of coastline, with the North Sea to the northwest and Baltic see to the northeast ("Facts About Germany"). The Bavarian Alps stretch along the southern region of the country. A temperate climate and diverse landscape make it possible to grow many different economic crops throughout Germany, which will be discussed later.

III. Sustainability

Most of us have our own ideas of what 'sustainability' means, but the word is not entirely universal. Therefore, to objectively evaluate the sustainability of horticultural crop production in Germany, we must first know how the Germans themselves define the term. The Federal Ministry of Food, Agriculture and Consumer Protection uses the word 'sustainable' in a number of publications, referring to environmentally sound practices and the use of renewable energy as an alternative to fossil fuels. The main challenge that the horticulture industry faces in becoming more sustainable is to also maintain production and profit levels.

Germany has some of the most progressive programs designed for implementing renewable energy technologies and curbing greenhouse gas emissions. The Renewable Energy Sources Act, first implemented in 2000, offers subsidies to producers of renewable energy, thus encouraging its availability and use by consumers. In its 2004 revision, it states the goal of increasing renewable energy sources to at least 12.5% of the total power supply by 2010 and 20% by 2020 (EEG 2004). They are way ahead of schedule. By 2007 they had already surpassed 14%, and recently the government increased its 2020 target to 30% (Dan Rather Reports, 2009).

Simply by being on the power grid, and having to adapt to newer energy standards, one could say that horticulture in Germany will steadily become more energy sustainable by default. Moreover, the profitability of selling excess energy produced increases incentives for horticultural businesses to invest more in renewable energy, while remaining economically competitive.

IV. Historical Production Practices

The history of the cultivation of plants in Germany is confirmed as far back as the Neolithic period. Although most foodstuffs were primarily the result of hunting and gathering, archeological excavation in the region of Sachsen-Anhalt has unearthed evidence that cereals such as *Triticum dicoccum* (starch wheat) and *Hordeum vulgare* (barley) where grown by early Germanic people several thousand years ago (Hellmund 2008). Other archeobotanical records have revealed a much more diverse array of cultivated plants during the early medieval period. Between the third and sixth centuries A.D., the Alamanni tribes of southwestern Germanic lands grew a variety of cereals, oil seed, and fibrous crops as well as vegetables and spices such as *Apium graveolens* (celery), *Coriandrum sativum* (coriander), and *Melissa officinalis* (lemon balm) (Rosch 2008).

Between the years of 1949 and 1990, Germany was divided into two different countries: the Western-aligned Federal Republic of Germany and the German Democratic Republic, part of the Soviet Eastern Bloc. There were great differences in horticulture management between West and East Germany. While it was not required that land be collectively farmed in East Germany, it became the dominant form of agriculture under the Soviet influence. By 1984 over 85% of the total East German agriculture land was collectivized ("East Germany – Agriculture"). In West Germany land remained privately held. With the fall of Soviet Communism in the east came the reunification of the West and East, the latter state being merged into the Federal Republic of Germany. But reunification was not a quick or smooth transition for agriculture. The products of the former Eastern states did not meet quality and demands of the market, labor costs were high, and economic stress resulted in much the business being taken over by West German enterprise. Thus, horticulture production area decreased dramatically in the former East

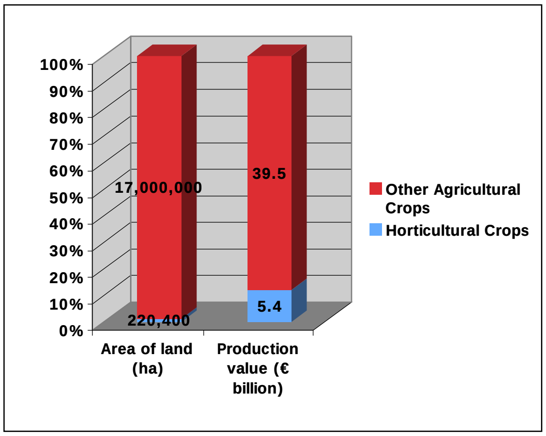
Germany states, with losses of approximately 65% in fruit production, 80% for field crops and 70% for greenhouse vegetables between 1990 and 1994 (Bokelmann and Lentze 2000).

During the 1970s energy crisis German horticulture started to seek more efficient operational methods. It was not only the economic situation, but also a gradually progressive environmental conscientiousness of society that has led to the technological and procedural changes in horticulture of the last three decades. I will look at some of these changes when discussing trends and evaluating sustainability.

V. Current Production Statistics

Germany is Europe's largest economy, with an estimated GDP of 2.278 trillion Euros ($2.863 trillion) in 2008 (Central Intelligence Agency 2009). The agricultural sector constitutes approximately 1% of that figure (Federal Ministry of Food, Agriculture and Consumer Protection 2006). Within that sector, only 220,400 of 17 million hectares of cultivated land in Germany are used for horticultural crops (Federal Ministry of Food, Agriculture and Consumer Protection 2008). Horticultural crop production is significantly more valuable than the other agriculture industries relative to the proportion of land usage (see Figure 1). In 2007, horticultural production was valued at 5.4 billion euros ($4.3 billion), approximately 12% of the agricultural sector (Federal Ministry of Food, Agriculture and Consumer Protection 2008).

Figure 1. A comparison of the value of horticultural land area compared to other agriculture in 2007 (Federal Ministry of Food, Agriculture and Consumer Protection 2008).



According to the 2007 main survey on land use in Germany, 54.5% was taken up by vegetable and berry crops, 29.5% orchards, 9.5% tree nurseries, 4.4% is used for flowers and ornamentals (Federal Ministry of Food, Agriculture and Consumer Protection 2008). Figure 2 shows the major horticultural food crops grown in Germany. The vast majority of these are grown outside with minimal or no protection from the elements. Tomatoes and salad vegetables are the primary food crops grown in greenhouses.

Figure 2. Production area of the major food crops produced in 2003 (Federal Ministry of Food, Agriculture and Consumer Protection 2006).

Field Grown – Area in ha				**Greenhouse – Area in ha**	
Malus domestica Borkh. - Apple	31,200	*Asparagus officinalis* L. - Asparagus	19,900	*Solanum lycopersicum* L. - Tomato	290
Fragaria x ananassa Duchesne - Strawberries	14,800	*Daucus carota* L. - Carrot	10,500	*Cucumis sativus* L. - Cucumber	265
Prunus (Subgenus Cerasus) - Cherry	9,600	*Brassica oleracea* L. (Capitata Group) - White Cabbage	7,000	*Valerianelia locusta* L. - Corn Salad	260
Prunus (subgenus Prunus) Plum	4,500	*Brassica oleracea* L. (Botrytis Group) - Cauliflower	5,700	*Lactuca sativa* - Head Lettuce	130

(Approximations based on 2004 census figures)

VI. Integration of Historical and Current Production Practices: Ranked Strategies

The future of horticultural production in Germany will be about improving on existing technologies while looking at sustainable practices from the past. The poor economy and rising gas prices of the 1970s pushed the industry to come up with new technology and systems that were more energy efficient and economical. This had both positive and negative implications on the sustainability of horticultural practices. On one hand, the greater urgency to increase energy efficiency led to a search for alternative energy sources that were more sustainable. Yet the use of plastics has risen in the last few decades. Curbing the use of finite resources like plastics is a major problem that the horticulture industry will need to solve sooner than later.

One of the biggest challenges in greenhouse engineering is finding alternative energy sources that are both economically viable and environmentally sustainable. Some of the technologies explored have been theoretically sound from a technical standpoint, but prove to be logistically impractical. One technology that was tested and thought to be a possible solution to the energy problem was piping in excess heat from power plants and other large industries- a very sustainable concept. While theoretically possible, waste heat was found to be impractical and often not feasible for most growers. The first problem in utilizing this technology was simply the lack of available land in close proximity to the waste heat source (von Elsner 1984). Even if this obstacle could be overcome, the investment costs of relocating an operation and setting up the proper system are much too high for most horticulture enterprises. Only major growers with large facilities would be able to save enough on energy costs to offset this initial investment (Bredenbeck 1992).

According to a 1999 study on greenhouse designs used in European Union countries, glass was by far the most used glazing material in Germany, at 80% over plastics. Of the glass-covered houses, the two most common styles were the Venlo-style and wide-span, the former becoming increasingly more favorable than the latter for primarily economic reasons (von Elsner, B. et al. 2000). Glass is the most sustainable glazing material. It is biodegradable and lasts potentially much longer than other coverings. While double-pane construction is more capable of retaining heat, it is not generally used for glass as light transmittance is significantly lowered. In contrast, using plastic glazing materials is an alternative that can offer good light transmittance and better insulation at lower initial investment costs than glass. While glass is still the most used covering, plastic-based glazing materials are on the rise in Europe due to advancements in the technology (Schories, Gerhard et. al. 2008). Newer plastics that last longer, transmit more light, and provide better heat retention are of course appealing to the horticulturist. However, when evaluating sustainability in horticulture for the long term, the rise in the usage of petroleum-based plastics is a regressive trend.

The use of chemical fertilizers and pesticides are components of horticulture that have created major detrimental effects on the environment. In recent decades, Germany has mandated legislation restricting the use of certain agricultural chemicals. The Plant Protection Act of 1986 and its subsequent revisions focus on integrated plant protection as a major factor of sustainable plant protection ("National Action Plan." Federal Ministry of Food, Agriculture and Consumer Protection 2008). The German government defines integrated plant protection as the control of pests in the most natural way possible. Fertilizers, under the system of controlled integrated cultivation, may only be applied when absolutely necessary. Soil protection is an important part of this system, and much focus is put on the nutrient reserves in the soil ("National Action Plan." Federal Ministry of Food, Agriculture and Consumer Protection 2008).

Future strategies for sustainability in horticulture will be a process of borrowing techniques from the past and present. I have created a ranking system of horticultural practices to rate the sustainability of the strategies used in the last century up to the present (see figure 3 below). The higher ranked strategies will serve as the primary components in which to build upon. My objective is to design a controlled environment system, using sustainable principles of the past and present that may serve in the research and development of better sustainable systems for widespread benefit.

Figure 3. Sustainability rankings by horticultural practice over the last century.

	Early-mid 20th c	1950s-60s	1970s-80s	1990s-current
Chemical Fertilizer/Pest control	Heavy use/low control. **Ranking: Low**	Heavy use/more control. **Ranking: Medium**	Introduction of integrated plant protection/more control. Increased interest in organic practices. **Ranking: Med-High**	Better plant protection and fertilization methods. Organic practices are increasingly used. **Ranking: High**
Energy Usage - Field	New mechanical technologies utilized. **Ranking: Medium-High**	Greater use of mechanization in fields. **Ranking: Medium**	**Ranking: Medium**	**Ranking: Medium**
Energy Usage – Controlled Environments	Controlled environment systems not common in commercial application. Small-scale passive greenhouses used. **Ranking: High**	Greenhouse technology less systems and materials less efficient. Energy usage high. **Ranking: Low**	Better heat retention with newer designs/materials. Important research and development of more efficient practices. Energy consumption still high and very reliant on fossil fuels. **Ranking: Medium-Low**	Despite major advances in efficiency and design, greenhouses require an incredible amount of energy consumption. However, the increase in renewable energy use has potential to greatly reduce dependence on fossil fuels. **Ranking: Medium**
The use of petroleum based materials	Little to no use of plastics in horticulture. **Ranking: High**	Plastics become incorporated into commercial horticulture. Usage on the rise. Much of the early plastic was poor quality and didn't last as long. **Ranking: Low**	Plastics used on a massive scale. **Ranking: Low**	Improvement in plastic materials, but usage continues to rise. Industry still overly dependent on finite resources. **Ranking: Medium-Low**

I will focus on *Valerianella locusta* (corn salad) as the test crop to be used in exploring sustainable horticulture strategies. This is a cold tolerant winter salad, native to the Mediterranean and Atlantic coastal areas of Europe, though it has been naturalized in many other parts of the world. Its biggest region of cultivation is in Nantes, France, where 75% of world production is grown (Peron and Rees 1998). There the warmer climate allows it to be grown even in the winter months with low tunnels (Peron and Rees 1998). While corn salad is not commonly cultivated in the United States, it is one of the top food crops grown under glass in Germany. Approximately 240 hectares were devoted to corn salad production in greenhouses in 2003 (Federal Ministry of Food, Agriculture and Consumer Protection 2006). Corn salad is an important economic crop in many parts of Europe, and has major economic potential on a widespread level.

Valerianella locusta. Photograph courtesy of Ewa in the Garden (ewainthegarden.blogspot.com).

VII. Sustainable Development Strategy

The implementation of sustainable strategies brings unique challenges to the horticulture business. For example, photovoltaic cell technology has been a highly successful part of the fast growing alternative energy movement in Germany. In some communities you would be hard pressed to find a building in sight without a rooftop covered in photovoltaic cells. However, this technology is not yet possible for most greenhouse applications because of the shading created by the cells. In the future, I believe it will be possible and cost-effective to implement active solar energy in greenhouses, at least as a supplemental power source. Achieving this will require innovations in greenhouse design, as well as advancements in solar technology.

Another major challenge is curbing the use of plastics. Plastic glazing materials and containers revolutionized horticulture in the 1960s and 70s. Plastic is often cheaper, offering better initial returns on investments than other alternatives. Finding applicable, cost effective ways to utilize sustainable materials is a challenge that has not been overcome. Glass glazing material is more expensive than most plastic-based materials and, while it lasts longer and has a higher light transmittance (but less diffusion), double layer plastics have much better insulating properties. Because of the greater heat loss through glass, much research and design should go into making the other parts of the greenhouse more energy efficient.

My sustainable development strategy involves the amalgamation of highly ranked sustainable production techniques of the past and present. Specifically, I want to move away from plastics, utilize as much passive energy as possible, and integrate wind and solar power. There are gaps in our understanding of the feasibility of wind and solar energy in controlled production environments and how to integrate that into a design that seeks to maximize passive solar energy. The country of Germany is the ideal setting for finding solutions to these unknowns. Besides being highly capable of providing the technical resources needed (wind and solar technology), it also features the proper climatic conditions for testing winter heating and summer cooling capabilities.

Before commencing with my proposal, some research questions must be posed.

Will enough solar power be produced, considering the limited space available so as not to overshadow greenhouse crops? How effective will passive solar heating and heat storage be with a design using glass glazing? Will the benefits outweigh the costs? The cost of materializing such an endeavor will be high. My proposal will most certainly have some flaws, but the trial and error process shall be justified for advancing research in sustainable greenhouse technology.

VIII. Proposal for a New Sustainable Greenhouse Test Facility

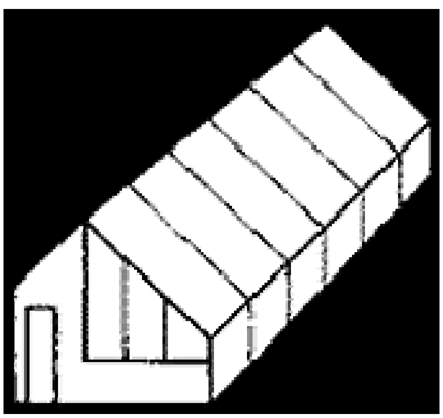
Future sustainable greenhouse design in Germany will need to make better use of the wind and solar technologies that are already so prevalent in German society. However, to maximize sustainability and minimize energy costs future greenhouses need to also better utilize passive heating and cooling. My design integrates active wind and solar technology with existing passive solar greenhouse designs. This greenhouse will serve as a research facility, aimed at finding better, sustainable greenhouse techniques that may be implemented in future commercial production environments.

I have chosen Freiburg, Germany to locate the facility. Freiburg is in the southwestern corner of the country, at latitude 47°59' N, and has an altitude of 280m/919ft (Commission Internationale de l'Eclairage, 1997). The climate is temperate, warm and dry with temperature averages of 1.5°C/34.7°F in January, and 19.5°C/67.1°F in July (Commission Internationale de l'Eclairage, 1997). This temperature range is ideal for testing seasonal heating and cooling requirements. Located along the western edge of the mountain ranges making up the Black Forest, the wind velocity in the area averages 7kts/8mph (“Wind Statistic: Freiburg”). This will power a wind turbine located on-site near the greenhouse.

Freiburg is well known for its alternative energy. It is home to the largest solar power research facility in Europe, the Fraunhofer Institute for Solar Energy Systems – ISE. Also in Freiburg is Projects in Solar Energy - PSE AG, a company specializing in solar energy technology and consulting. It would be a mutually advantageous partnership to work with the ISE and PSE AG in testing out active solar technologies for use in greenhouse systems.

The structural design of my greenhouse is largely based on that of the 'shed-type' passive solar greenhouse (Figure 4). These structures are long and narrow with glazing along the south-facing wall angled so as to collect the greatest light exposure. While these greenhouses are typically used in rather small-scale production of cool weather crops, I believe that certain modifications can be made to it which will allow it to function in larger commercial applications with versatile heating and cooling requirements.

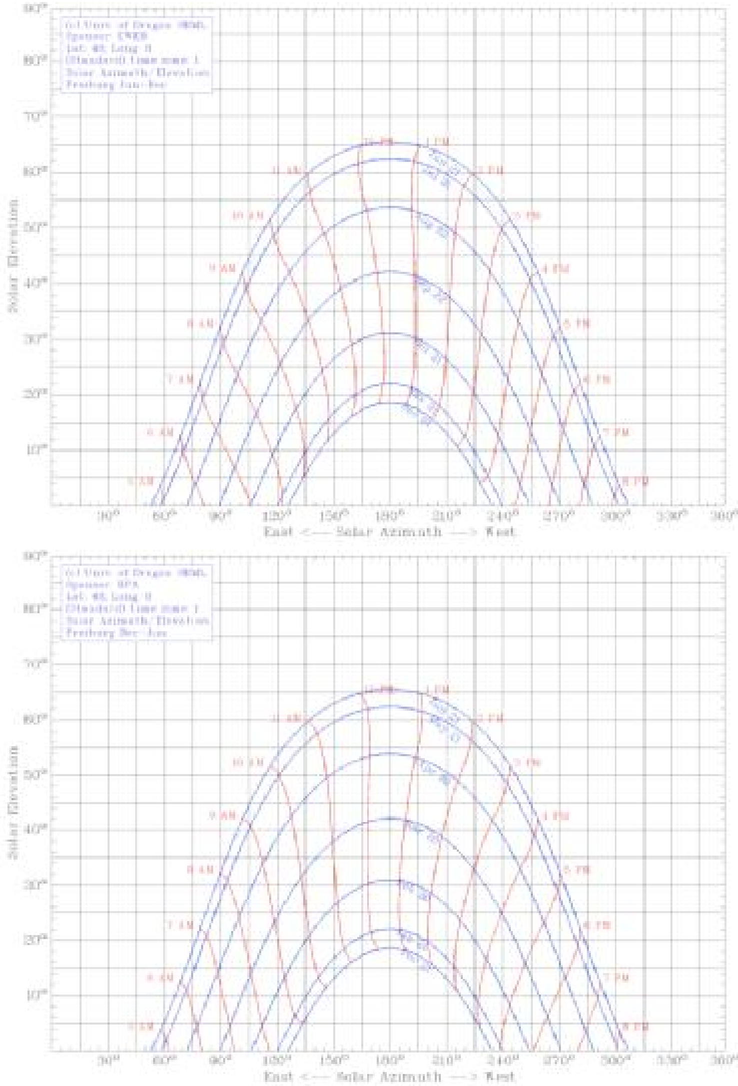
Figure 4. A basic 'shed-type' passive solar greenhouse. (National Sustainable Agriculture Information Service).



In order to maximize the duration and even transmittance of solar exposure, a calendar of solar elevation and azimuth can be used to help calculate the proper house position and angle of the south wall. I input the latitude, longitude, and time zone of Freiburg into the sun path chart program developed by the University of Oregon Solar Radiation Monitoring Laboratory, (available online at http://solardat.uoregon.edu/SunChartProgram.php), as shown in figure 5. If this greenhouse were to be specialized for growing crops during a particular season, this chart can be used to orient the structure slightly east or west to maximize sun exposure for that season

(Bellows, 2008). This design, however, is designed for year round application so will be faced true south. The angle of the south glazing will be 65°.

Figure 5. Solar azimuth/elevation for Freiburg December-June, then June-December (University of Oregon Solar Radiation Monitoring Laboratory).



The dimensions of my proposed design are as followed:

Length (north and south wall): 70 m	Width (east and west wall): 22.5 m
Total perimeter: 185 m	Perimeter under glass: 170 m
Total floor area: 1575 m^2	Floor area under glass: 1050 m^2
Height at rear wall: 12.5m	Non-glass roof area: 7.5 m * 70 m = 525 m^2

The use of photovoltaic cells on existing greenhouse facilities is not common because the cells themselves create major shading over the growing area, severely limiting the type of crop that can be grown. My greenhouse facility will be designed to test the application of photovoltaic cells and other new solar technologies. The design of the greenhouse is modified from the existing 'shed-type' design to have a level (180°) top, 525 m^2 of which is solid rooftop (no glazing material). Most of the solar transmittance will come through the sloped glazing on the south end, so the placement of these cells atop the rooftop portion of the north end of greenhouse should absorb enough light to provide supplemental energy with minimal shading. The cells would be in angled stands, two rows that would run along the entire length of the greenhouse (Figure 6).

Figure 6. Photograph courtesy of Conergy AG/ESTIF (European Solar Thermal Industry Federation).

For wind power, a WES18 Mk1 turbine will be erected on site (technical specifications on these can be found on the web at http://www.windenergysolutions.nl/products/wes18/) (Figure 7). Along with the solar energy, this should be capable of generating more than enough supplemental power for heating, cooling, lighting or other energy needs.

Figure 7. Photograph of a WES18 Mk1 (Wind Energy Solutions BV).

With such a large area of glazing material, finding ways to store passive energy is very important. Instead of using rock beds or water commonly used in solar greenhouses, my design will utilize phase-changing materials, which can be used for both retaining heat and reducing greenhouse temperatures during the summer months.

IX. Experimentation

One of the main reasons for choosing *Valerianella locusta* as the initial crop grown to test the sustainable components of this greenhouse is that it is a cool weather crop. This makes it ideal for this facility, which will rely more on passive heating and cooling principles. However, year round production will require additional heating, cooling, and lighting at times. Through experimentation, it is my intention to find the proper balance of passive and active power usage to provide the controlled environment necessary for top quality production. The amount of excess energy produced by the wind turbine and solar panels will be tested, giving insight into other possible crop applications.

X. Conclusion

Germany provides the necessary infrastructure and resources for developing innovative strategies to make controlled environments in horticulture more sustainable. The history of environmentalism in society, as well as the current innovations and implementations of green technology make the country a choice research location. The future of sustainable horticulture contains many unknowns. My proposed model is just one idea for approaching the endeavor to find answers to these questions.

XI. Literature Cited

"Amending the Renewable Energy Sources Act (EEG): Key Provisions of the New EEG as amended on 21 July 2004." Available from: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Accessed 2009. <http://www.bmu.de/files/pdfs/allgemein/application/pdf/eeg_begruendung_en.pdf>.

Bokelman, W. and W. Lentz. "The Development of the Horticultural Sector in Eastern Germany Since 1990." Acta Hort. 524 (2000): 157-168. Accessed March 2009. University of Minnesota Libraries, Twin Cities. <http://www.actahort.org>.

Bredenbeck, Henning. “The Use of Waste Heat from a Power Plant for Greenhouse Heating in Commercial Application in Germany.” Acta Hort. 312 (1992): 29-36. Accessed March 2009. University of Minnesota Libraries, Twin Cities. <http://www.actahort.org>.

Directory of Cities, Towns, and Regions in Germany. Falling Rain Genomics, Inc. 1996-2004. Accessed February 2009. < http://www.fallingrain.com/world/GM/>.

"East Germany – Agriculture." Country Data. Accessed February 2009. < http://www.country-data.com/cgi-bin/query/r-5100.html>.

"Facts about Germany - Geography." Facts about Germany. Accessed February 2009 < http://www.tatsachen-ueber-deutschland.de/en/content-home/facts-and-figures>.

Federal Ministry of Food, Agriculture and Consumer Protection. Horticulture in Germany (2006). Accessed February 2009 <http://www.bmelv.de/nn_757134/SharedDocs/downloads/__EN/01-Brochures/HorticultureGermany__Broschure,templateId=raw,property=publicationFile.pdf/HorticultureGermany_Broschure.pdf>.

Federal Ministry of Food, Agriculture and Consumer Protection. Horticulture in Germany – Facts and Figures (2008). Accessed February 2009 < http://www.bmelv-statistik.de/fileadmin/sites/070_Gartenb/Horticulture_2008_Internet.pdf>.

Federal Ministry of Food, Agriculture and Consumer Protection. National Action Plan on Sustainable Use of Plant Protection Products (2008). Accessed May 2009 < http://www.bmelv.de/cln_044/nn_757134/SharedDocs/downloads/__EN/05-Agriculture/NationalActionPlanonSustainableUseofPlantProtectionProducts,templateId=raw,property=publicationFile.pdf/NationalActionPlanonSustainableUseofPlantProtectionProducts.pdf>.

The Fraunhofer Institute for Solar Energy Systems. Accessed May 2009. < http://www.ise.fraunhofer.de/welcome-to-the-web-pages-of-the-fraunhofer-institute-for-solar-energy-systems?set_language=en&cl=en>.

"Freiburg, Germany." International Daylight Measurement Programme. Commission Internationale de l'Eclairage. 1997. Accessed May 2009. <http://idmp.entpe.fr/stations/deu02/deu02.html>.

Hellmund, Monika. "The Neolithic records of *Onopordum acanthium*, *Agrostemma githago*, *Adonis* cf. *aestivalis* and *Claviceps purpurea* in Sachsen-Anhalt, Germany." Vegetation History and Arcaeobotany. 17 (2008): 123-130. Accessed March 2009. <www.springerlink.com>.

Kurklu, Ahmet and Aziz Ozmerzi. "Use of a Phase Change Material (PCM) for the Reduction of Peak Temperatures in a Model Greenhouse." Acta Hort. 443 (2007): 105-110. Accessed May 2009. University of Minnesota Libraries, Twin Cities. <http://www.actahort.org>.

"Leading the Way With Strategies for More Sustainability." German Missions in the United States. Accessed March 2009. <http://www.germany.info/Vertretung/usa/en/07__Economy/03__Gov__Environment/Sustainability__Strategies__DM.html>

"Our Company." PSE AG – Projects in Solar Energy. Accessed May 2009. < http://www.pse.de/typo3/t3site/index.php?id=85&L=1>.

"Pictures of Different Applications" European Solar Thermal Industry Federation (ESTIF). 2009. Accessed May 2009. <http://www.estif.org/pictures/gallery/>.

"Power from the People." Dan Rather Reports (Television Program). Episode 417(5/12/2009). Transcript online accessed May 2009. <http://www.hd.net/transcript_list.php?pd=danrather>.

Rosch, Manfred. “New Aspects of Agriculture and Diet of the Early Medieval Period in Central Europe: Waterlogged Plant Material from Sites in South-Western Germany.” Vegetation History and Arcaeobotany. 17 (2008): 225-238. Accessed March 2009. University of Minnesota Libraries, Twin Cities. <www.springerlink.com>.

Schories, G., von Marees, H., Sadowski, M. Lopez, L., Paetz, H., Ionel, I. and D. Cebrucean. “Investigation on Energy Savings Potential in Pot Plant Greenhouses.” Scientific Bulletin of the Politehnica University of Timisoara Transactions on Mechanics, Special Issue. 53 (2008):545-549. Accessed March 2009. <http://www.mec.upt.ro/~hme2008/lucrari/L_84.pdf>

Storck, H. “Structural Changes in German Horticulture During the Last Decade.” Acta Hort. 155 (1984): 335-341. Accessed February 2009. <http://www.actahort.org>.

von Elsner, B. “The Feasibility of Greenhouse Heating with Reject Heat in West Germany.” Acta Hort. 148 (1984): 199-207. Accessed March 2009. <http://www.actahort.org>.

von Elsner, B., Briassoulis, D., Waajenberg, D., Mistriotis, A., von Zabeltitz, Chr., Gratraud, J., Russo, G., and R. Suay-Cortes. “Review of Structural and Functional Characteristics of Greenhouses in European Union Countries, Part II: Typical Designs.” Journal of Agricultural Engineering Research. 75 (2000): 111-126. Accessed February 2009. <http://www.sciencedirect.com>.

The University of Oregon Solar Radiation Monitoring Laboratory. Accessed May 2009. <http://solardat.uoregon.edu/index.html>.

“Wind Statistic: Freiburg.” Windfinder. Accessed May 2009. <http://www.windfinder.com/windstats/windstatistic_freiburg.htm>.

"The World Factbook – Germany." The World Factbook. Central Intelligence Agency. Accessed February 2009. <https://www.cia.gov/library/publications/the-world-factbook/geos/gm.html>.