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Measuring the Effects of a Food Carbon Footprint Training and Tool on Consumer Knowledge, Transfer Intentions, and Environmental Self-Efficacy

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Abstract

The supply chains through which foods are produced, processed, and transported can have a significant impact on the environment in terms of the carbon dioxide (CO_2) that is emitted during each of these phases; however, little research has incorporated information about environmental impact into supply chain scenarios. Moreover, many consumers are unaware of how their food choices may impact the environment in this way. To fill these gaps, distribution networks were modeled and analyzed to determine CO_2 footprints for a variety of foods, and a tool called CarbonScope was developed to give consumers a way to find out the CO_2 emissions for different types of foods that are provided either locally or transported over long distances. A short training was designed that walks participants through various food scenarios using CarbonScope. Participants from a major urban university were given pre- and post-training surveys to capture a) user reactions in order to improve the training, b) learning gains, c) intentions to transfer training (use or apply the knowledge gained from the game) and d) changes in environmental self-efficacy (the extent to which people believe that their individual behaviors can impact the environment). We confirmed our hypotheses that the training process and tool significantly increases participants' post-training knowledge and environmental self-efficacy, and that participants would intend to use the knowledge they gained from the training and tool. Contributions include (a) application of supply chain sustainability analysis methods to food to create the CarbonScope tool, (b) information about the CO_2 footprints of specific combinations of foods and supply chains, (c) the food carbon footprint training, and (d) explicitly measured knowledge gains, behavior intentions, and change in user beliefs as a result of exposure to the training and tool.

INTRODUCTION

The underlying purpose and motivation for this study was to educate consumers about the CO_2 impact of particular foods, which would tend to increase their sense of environmental self-efficacy and encourage them to more carefully consider their food selection decisions and, possibly, to share the knowledge gained with others.

Tools to assess environmental impact (carbon footprint) of different foods are scarce and cumbersome to use. Furthermore, research is lacking that measures the degree to which using such tools impacts consumer knowledge, beliefs, and intentions. To address this gap, we developed a web-based tool called CarbonScope that teaches consumers about the CO_2 footprint of different foods, depending on where they are grown or produced and how they are shipped. We also designed a web-based training built around the tool, and developed a survey-based method to evaluate the effectiveness of the training and tool.

The study was an interdisciplinary effort that employed engineering analysis to develop the content data, computer science to embed the data into a web-based analysis tool, and psychological expertise to develop the training and examine the effectiveness of the tool and training process. The experimental procedure was designed to: a) gauge user reactions in order to improve the training, b) measure learning gains, c) capture intentions to transfer/use training, and d) measure changes in environmental self-efficacy (beliefs regarding the extent to which individual choices impact the environment via the contribution of CO_2 to global warming).

Background information is provided to indicate the significance of the study and to review the relevant literature regarding food supply chains, computer-based training, and recent theoretical and empirical work in psychology regarding strategies for training evaluation. The background section concludes with research questions and hypotheses. The methods section begins with a description of the CarbonScope analysis tool, including details regarding the data sources used to develop the underlying database. Next, the training process is described. The survey methods are then discussed, including descriptions of the participants, the experimental protocol, and the measures employed. The fourth section of the paper provides the results, largely portrayed in graphical form. The paper concludes with a discussion that interprets the results, points out limitations, and highlights opportunities for improvement.

BACKGROUND

Consumers are likely not to be aware of how their food choices impact the environment, which is often measured by the amount of carbon dioxide (CO_2) emitted or released during the production and transportation of the food. The environmental impact of food production varies considerably by food type, and supply chain considerations are also very important--how far the food travels from producer to consumer, what transport methods are utilized, and how food is packaged and stored.

Food Supply Chain Literature

Food is provided to consumers via a supply chain. With the rapid increase of long-distance trade in recent decades, supply chains are also becoming increasingly longer, consuming significantly more fossil-fuel energy for transportation and emitting much more carbon dioxide than a few decades ago. For example, fruits and vegetables travel over 1500 miles on average within the U.S. (which has been widely quoted as an indicator of high “food miles”), and, overall, approximately half of the energy usage associated with food production and delivery is related to transportation (Pirog et al., 2001). A basic diet with imported ingredients can consume four times the fossil-fuel energy and emit four times the carbon dioxide compared to domestically produced ingredients (Halweil 2002). Particularly problematic is the growing use of trucks and airplanes at the expense of slower and more efficient trains and ships. The transportation sector already produces a quarter of all energy-related carbon dioxide emissions and these emissions are increasing rapidly (Venkat 2003). In the U.K., road transport has been identified as the largest source of carbon dioxide emissions (Mason & Lalwani, 2003). Transportation is the fastest growing energy consumer in the European Union with a 47 percent increase since 1985 compared with 4.2 percent for other sectors (Lalwani & Mason, 2004).

The more frequent deliveries required to preserve food freshness in food supply chains puts considerable stress on the environment (Simons & Mason, 2002). Simons and Mason suggest that producing food closer to the point of consumption and being more responsive to the consumer will help lead to a win-win situation where time compression and emissions minimization can occur synergistically. Typical metrics for measuring environmental performance include scrap or non-product output, materials use, hazardous materials use, energy use, water use, air emissions, hazardous waste, and water pollution (EPA, 2005). The metric used by Simons and Mason (2002) divides the supply chain carbon dioxide emissions by the market weight of product.

Overall, the food production system accounted for 17% of all fossil fuel usage in the US in 2002 (Eshel & Martin, 2005) and food consumption accounts for nearly a third of our individual carbon footprints (EPA, 2007). These factors make it clear that sustainability of food supply chains will be a critical component of any effort to build a sustainable economy. Moreover, individual consumers may well have a significant role to play in this effort through their food choices.

Web-Based Training Literature

Computer-based training has been described as the "future of training" (Brown & Ford, 2002, p.192). This training represents a shift away from passive, lecture-style learning in the classroom toward a more learner-centered, learner-controlled training environment that is flexible and efficient. Research shows that computer-based training is highly effective provided that it is well-designed and encourages active learning in participants (Kraiger, 2003). Developers can encourage active learning by designing a meaningful and easy-to-use organization of information, balancing program guidance with learner control, and providing opportunities for practice and feedback (Brown & Ford, 2002).

Scenario analysis is one type of training that promotes active learning. Web-based analysis tools allow learners to acquire knowledge via their interactions with a virtual environment. This type of learning, termed *experiential learning*, comes about because learners are placed in an environment or situation that requires them to be personally involved in some way, causing them to experience real feelings of accomplishment and failure as the simulation provides feedback (Keys & Wolfe, 1990; Walter & Marks, 1981). In a review of experiential learning theory, Bowen (1987) recommended that learning is more likely to lead to behavioral change when the training encourages emotional arousal, operates within a "safe environment", and offers a cognitive map of information to guide the learner.

With regard to research design, web-based studies allow researchers to control extraneous variables in the environment to maximize the validity of their causal conclusions and minimize the impact of potential confounding variables. Further, these tools allow for practice as well as rapid, consistent feedback on performance to a greater extent than instructor-led learning techniques (Keys & Wolfe, 1990). These features have been linked to better training outcomes with regards to learning and post-training behavior change (Chhokar & Wallin, 1984; Machin, 2002; Stajkovic & Luthans, 2003).

Training Evaluation

It is important to measure the effectiveness of the CarbonScope tool and the food carbon footprint training in terms of quantifying their impact on consumers' knowledge and behavioral intentions, and also to evaluate user reactions in order to facilitate development of the tools themselves. To guide this process, we drew from the psychological literature on training evaluation, which emphasizes that training should be evaluated using multiple criteria to provide a comprehensive understanding of its contributions (Campbell et al., 1970). Kirkpatrick (1959) proposed a framework for evaluating training which included four components: reactions, learning, behavior, and results. Of particular relevance to this work is the measurement of *learning* (specific knowledge gains after the training) and *behavior* (the extent to which the knowledge gained in the training is transferred or used). A significant *result* would be for the training to impact the participants' sense of *environmental self-efficacy*, which represents one's beliefs that he/she has the ability to impact the environment (Denious, 2003).

In evaluating a training system, user *reactions* are also important to measure for two primary reasons: a) they tend to influence other training outcomes and, b) they can be used to improve the training. Reactions are highly related to learning and training transfer, or the extent to which the knowledge gained during training will be used (Alliger et al 1997). There are two general categories of reactions: *affective reactions*, which are emotional reactions to the training, and *utility reactions*, which are subjective evaluations on the usefulness and effectiveness of the training. Utility reactions have a stronger relationship to learning and training transfer than affective reactions; however, affective reactions have a strong impact on these utility reactions (Alliger et al., 1997). For instance, people who like the training will also tend to evaluate the training as being useful. Those who rate training as useful also tend to gain more knowledge and are more likely to use the knowledge than people who don't find it useful.

<u>Research Questions and Hypotheses</u>

Because our training and tool are prototypes, it is important to gauge trainee reactions so that the training simulation game can be improved. Therefore, we will ask participants to rate their affective and utility reactions, as well as a number of other targeted reactions about the extent to which the training is liked, useful, informative, clear, fun, and functional.

Research Question A: How likeable/ useful/ informative/ clear/ fun/ functional is the training?

To maximize feedback on the quality of the training in this preliminary phase, participants will be asked open-ended questions in order to help us to capture relevant information about the most-liked aspects of the program and ideas for improvement.

Research Question B: What features of the training are well-liked by participants?

Research Question C: What features of the training need improvement?

While reactions are important in understanding how the simulation is perceived, the primary goal of this training is to increase participants' knowledge about ecologically-friendly foods. To the greatest extent possible given the web-based format, training design elements proven to enhance learning were incorporated into the infrastructure. Therefore, we propose the following:

Hypothesis 1: Using the training process and tool will significantly increase participants' post-training knowledge.

One of the aims of this research was that the participants would actually use the knowledge gained in training when making food selection decisions. It is impractical, however, to measure this explicit behavior directly after the simulation training, and so we predict that the training will impact participants' intentions to apply the information they learned in training, whether it be in their own food selection decisions or in educating others.

Hypothesis 2: Participants will intend to use the knowledge they gained from the training and tool.

It is also the aim of this project to teach people that their individual impact has an effect on the environment, empowering individuals to make behavioral changes. Educating the public about existing problems in our environment can sometimes backfire, increasing feelings of frustration, confusion, and powerlessness. Research suggests that the public is more concerned about our ability to solve these problems (Immerwahr, 1999). These attitudes might characterize an individual with low environmental self-efficacy as one who doesn't believe that individual people have the power to change the environment. By teaching people about how the individual's food choices result in high/low levels of carbon emissions, the training game offers actual knowledge about a) the individual impact of one's food choices on the environment, and b) how to select foods that are low carbon impact, thus demonstrating that it is possible for an individual to make a difference. We would therefore expect to see levels of environmental self-efficacy increase after the training, because participants learn that they have the power to change the environment.

Hypothesis 3: Participation in the training will increase participants' environmental self-efficacy.

METHODS

The methods section covers three main topics: the CarbonScope tool, the food carbon footprint training, and the survey methods used to assess effectiveness.

<u>CarbonScope</u>

CarbonScope (Venkat 2007) in an interactive web-based software tool that allows users to assess the energy and environmental impact of their food choices (types of foods chosen and how far the food travels). Users choose their location in the US, and then add food products from various US and overseas locations. The results screen shows estimated energy consumption and carbon emissions associated with each item in the list of products, as well as some nutritional information. Carbon-dioxide emissions are provided as the primary sustainability metric, as it is often used to serve as a proxy for general environmental impact. The advantage of this metric is that it efficiently captures various aspects of food production and distribution systems in a single number – including fossil fuel use, adoption of renewable energy sources, energy efficiency in production and distribution, transport modes, and distances.

Data to calibrate the tool was gleaned from the literature, various encyclopedias, and other sources. Data sources for energy use in food production include work by leading researchers such as David Pimentel (Cornell University), Annika Carlsson-Kanyama (Royal Institute of Technology, Sweden), and Peter Tyedmers (Dalhousie University). Additional data sources include Elsevier's Energy in World Agriculture Series (Fluck 1992, Singh 1987) and Encyclopedia of Energy Series (Cleveland 2004).

Potentially, thousands of foods could be incorporated, that are delivered over a wide variety of distribution networks ranging from local farmer's markets to exotic foods air freighted across the globe. The current prototype version includes 114 food items, including meats, seafood, grains, vegetables, fruits, some processed foods; and three food distribution networks: regional, national, and global. Transportation options include truck, ocean, and air. Packaging and storage are also incorporated into the analysis.

Figure 1 is a screen shot from the Food Carbon Footprint Training that shows the CarbonScope user interface for adding items. The user specifies his/her location, and then adds as many food items as desired, specifying the amount of each food and where it is produced and how it is shipped.

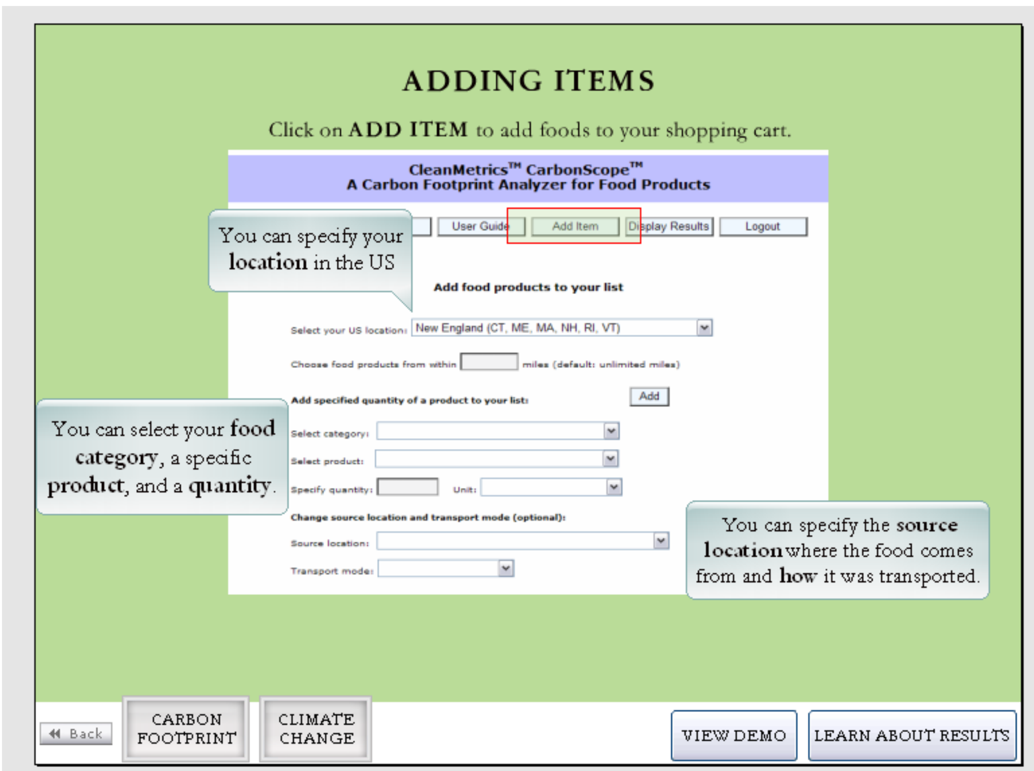

Figure 1. CarbonScope User Interface (screen shot from food carbon footprint training)

The CarbonScope results screen shows the carbon footprint for each food item, making it easy for the user to compare different choices. The results screen also shows the energy consumed, and some nutritional information (protein content). Figure 2 is a screenshot of the CarbonScope results screen (also from the training).

Food Carbon Footprint Training

A short food carbon footprint training program was developed that employs CarbonScope. Figures 1 and 2 were taken from the training. Adobe Captivate© was used to deliver the training via the web. The training walks the participant through various food scenarios using CarbonScope. Figure 3 shows four example sea foods that were compared during the training process. The training emphasized several best practices used to achieve learning goals in this type of training: repetition, hands-on activities, "what to notice," pop-up windows, and frequent summaries.

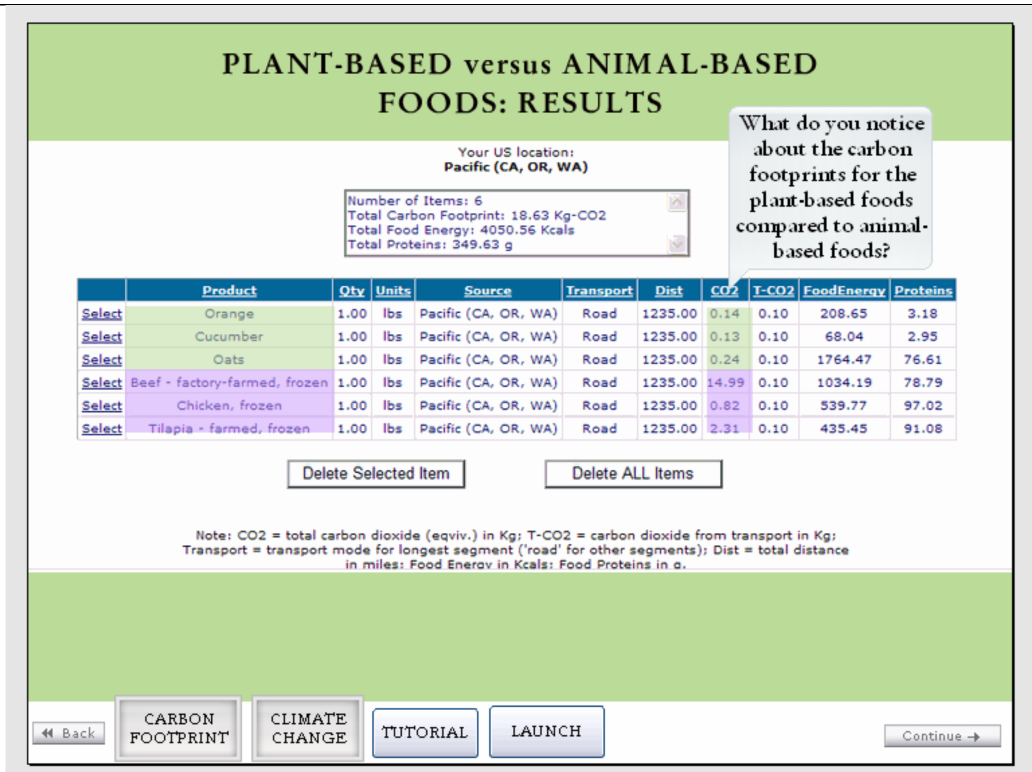

Figure 2: CarbonScope results screen (screen shot from the food carbon footprint training)

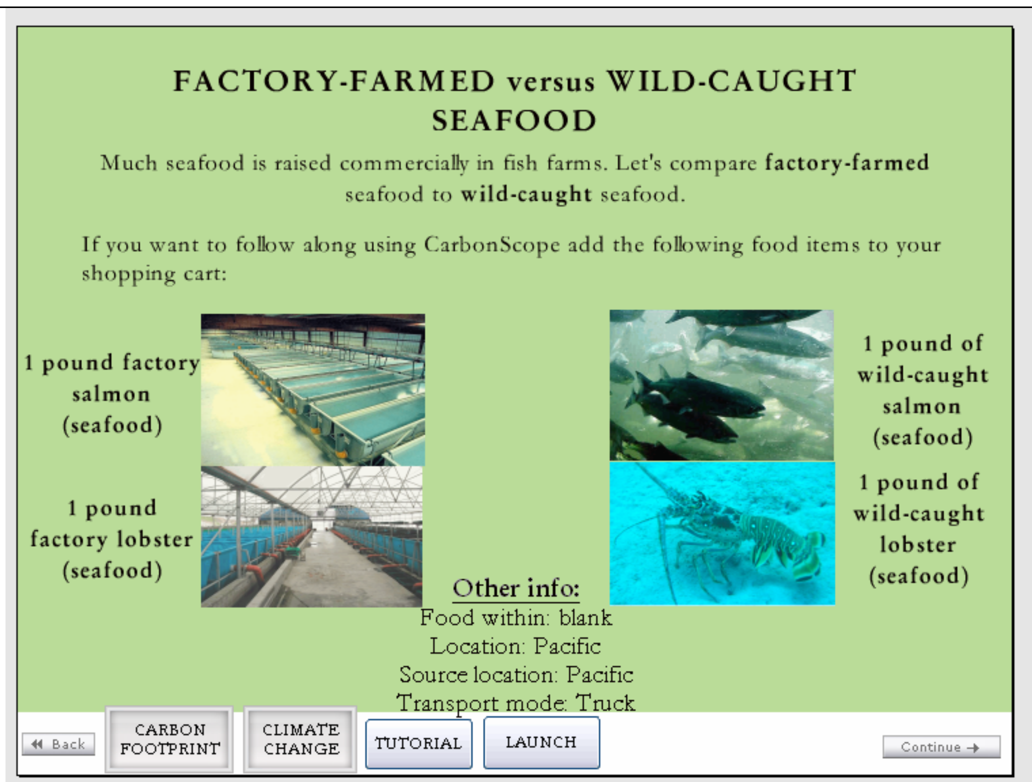

Figure 3. Screenshot describing four of the seafood alternatives foods analyzed

Survey Methods

This subsection describes the participants in the study, the study design, the study protocol, and the measures used in the surveys.

Participants

Graduate and undergraduate students from Portland State University (PSU) were recruited from a dozen classes in business, psychology, urban studies, and the physical science to pilot test the tool and training process. The goal was to recruit at least 100 students, but in fact over 250 students participated, as discussed later. Because PSU has a high number of non-traditional students (approximately 60%), a sample of PSU students can be considered representative of general population of consumers, therefore it was well suited to the purposes of this pilot study.

Study Design

The study was a standard pre-test, treatment, post-test design, as summarized below:

- Pre-training Survey
  - Demographics
  - Knowledge
  - Environmental Self-efficacy
    - The extent to which people believe that their individual behaviors can impact the environment
- Treatment
  - Food carbon footprint training (using CarbonScope to compare food scenarios)
- Post-training Survey
  - Reactions (to improve the tool and training)
  - Knowledge (to measure learning gains)
  - Intentions to transfer training (to use or apply the knowledge gained)
  - Environmental Self-efficacy (to measure the degree of change)

Study Protocol

Faculty members at Portland State University who taught courses Fall Term, 2007 related to supply chain management, sustainability, psychology, and the physical science were asked if the researchers could announce the survey in their classes. Some faculty offered to give extra credit to the students who participated in the study. All participants were entered in a drawing to win one of six $25 gift cards. At the beginning of class, the researchers described the research and invited students to participate. Students were given a slip of paper with web link. The link took them to an informed consent page that allowed them to choose an alternative assignment. If they choose to participate in the study, the student was directed to an online pre-training questionnaire. In this questionnaire, they were asked questions about their basic demographics, pre-training knowledge about the carbon footprint of particular foods, and their environmental self efficacy. This was anticipated to take 5-10 minutes.

Participants were then directed to the web-based training where they were shown how to use CarbonScope to enter food choices. The tool/training then showed how CarbonScope presents the carbon footprint of each food choice. Participants were encouraged to experiment with alternative food scenarios. The tool and training also highlighted whether the carbon resulted largely from the production of the food, processing of the food, or the distribution of the food from the producer to the consumer. The training concluded with a summary of the key learning goals. The training was designed to take approximately 15-20 minutes.

After the participant completed the training, they were directed to an online post-training survey where they were asked about their reactions and suggestions regarding the tool and training. The knowledge and environmental self-efficacy question were then repeated, and the participants were also asked about their intentions to transfer knowledge gleaned from the training.

Study Measures

Demographics. Age, gender, ethnicity, dietary constraints.

Reactions. A 5-point agreement scale was used to evaluate participants' reactions to both the tool and the training on 6 dimensions.. The item is "In my opinion, the [tool -or- training] was…", and participants rated their degree of agreement regarding whether the [tool -or- training] was likable, useful, informative, clear, fun, and functional. The following open-ended items were used to capture the features of the [tool –or- training] that participants liked: "Please explain what you liked about the [tool -or- training] and why you liked it, being as specific as possible." The following open-ended items were used to capture recommendations for improvement; "Please describe in detail what you think should be changed in the [tool -or- the training you just took], being as specific as possible."

Knowledge. Eight true/false and multiple choice items that reflect the training content were used to evaluate student knowledge about the carbon impact of particular foods.

Training Transfer Intention. A 5-point agreement scale was used to evaluate the extent to which participants intend to transfer or use the knowledge gained in training. Participants also rated their agreement with 3 intention items. A sample item is, "I will use the knowledge learned in this training when I make food selection decisions".

Environmental Self-Efficacy. A 5-point agreement scale was used to evaluate 5-items that capture environmental self-efficacy. A sample item is, "Alone, I can't make a significant difference on environmental problems".

RESULTS

The results include a summary of the sample characteristics, the results regarding the hypotheses presented graphically, and results regarding the research questions, also presented graphically.

<u>Sample Characteristics</u>

The sample characteristics were as follows:

- *268 respondents (mostly students and a few faculty) from public university in the Pacific Northwest region of the U.S.*
- *Ages: 16-50 years old (Mean=24.75, S.D.=6.81)*

- *71.7% female*
- *76.9% Caucasian, 11.9% Asian, 1.5% African American, 3.4% Other, 3% Hispanic, 2.6% Multi-racial/ethnic, .7% Native American/Pacific Islander*
- *10.5% vegetarian, .8% vegan*

Results regarding Hypotheses

Figure 4 shows the percentage correct on the three knowledge subscales related to the carbon footprint of plant vs. animal foods, wild vs. farmed foods, and processed vs. raw foods. The effect size for the knowledge gain was large, a 30% increase on all three measures, and these gains were statistically significant ($p < .001$).

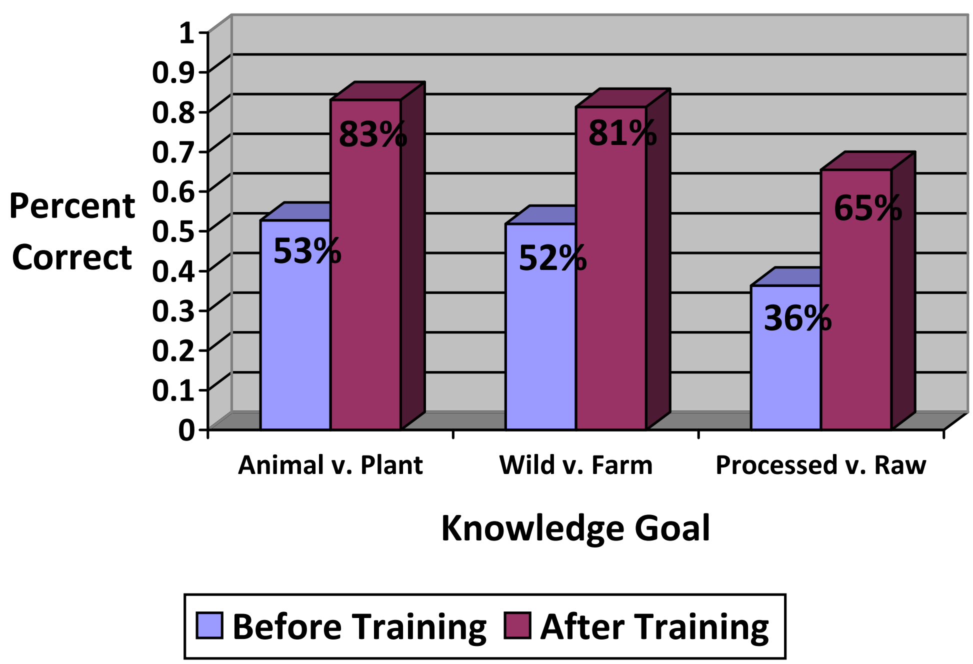

Figure 4: Knowledge Gains

Figure 5 shows the respondents behavioral intentions score for the three items: 3.72/5 for using the training, 3.83/5 for applying the training to their food purchases, and 4.00/5 for sharing the knowledge acquired.

Figure 6 shows that user self-efficacy, which was already quite high to begin with at 4.08, increased by approximately .2 through the use of the tool/training. Although this is small effect size, the increase was statistically significant at the $p<.001$ level.

Results regarding Research Questions

Figure 7 shows the overall participant reactions to the training. Five of the six items were scored as "Agree" and one item (the training was fun) was scored as neutral. Answers to

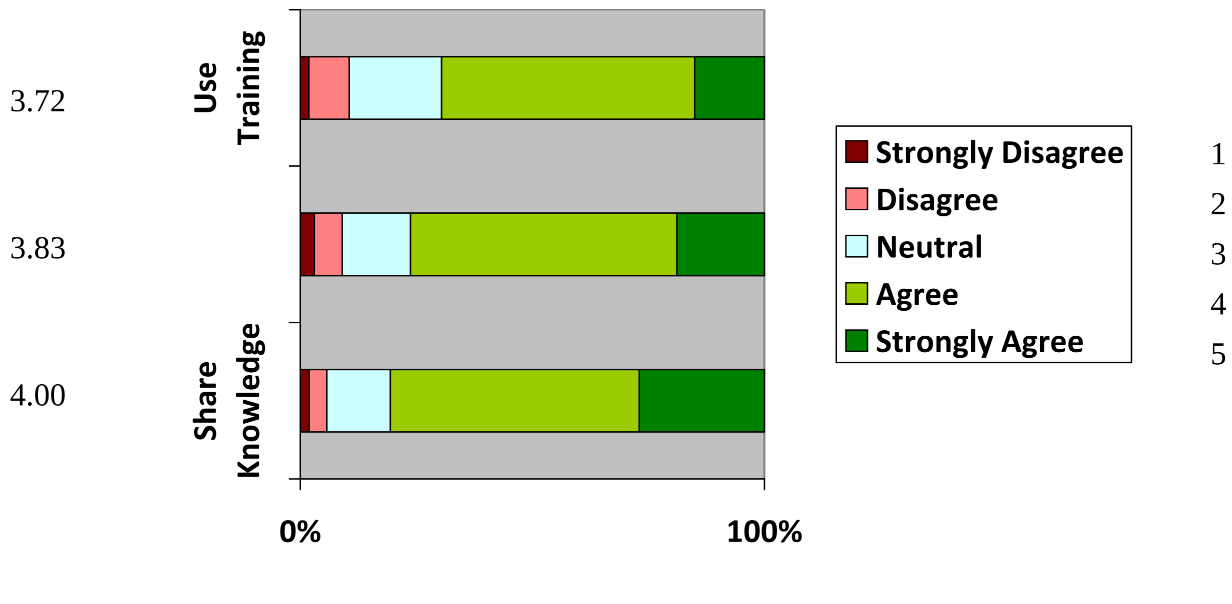

Figure 5: Behavioral Intentions

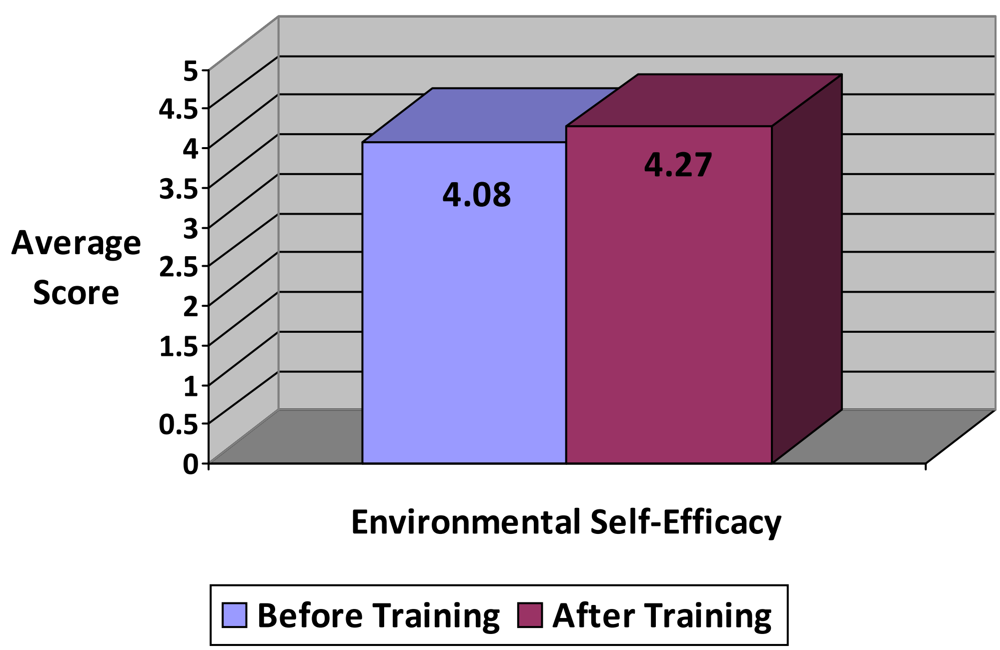

Figure 6: Impact of Training on Environmental Self Efficacy

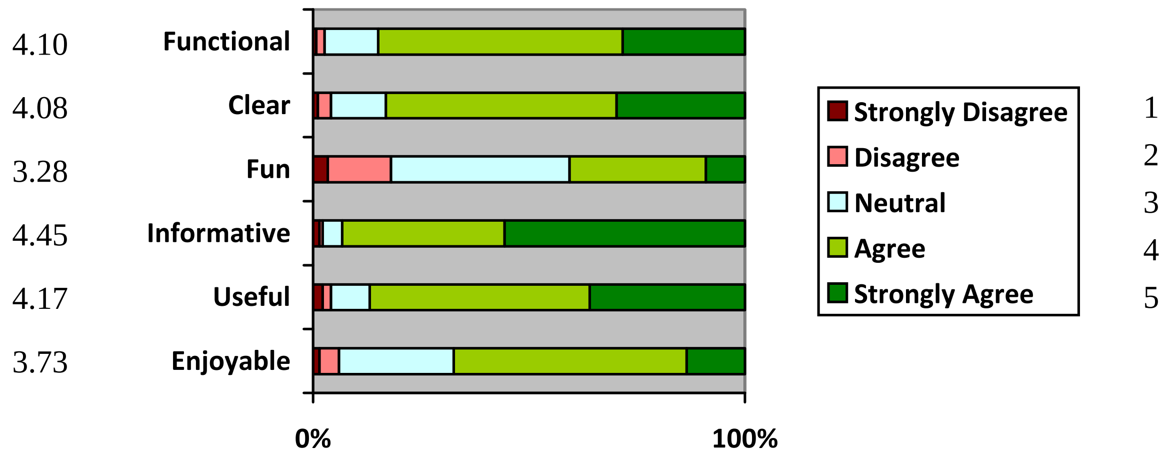

Figure 7: Overall User Reactions to the Questions, "The Training was..."

questions about the tool were similar (not shown). Figure 8 summarizes the qualitative results from the four open-ended questions that asked what participants liked and their suggestions for improvement for both the tool and the training. Figure 8 indicates that the vast majority of the participants enjoyed the tool and training, liked many of the features, and had many helpful suggestions for improving both the tool and the training.

DISCUSSION

The discussion begins with a brief summary, and then describes the contributions of the research, limitations of the present design, and future plans.

Summary

Results from the CarbonScope tool indicate that food choices have a significant impact on the environment. The results also suggest that there may be interesting and practical tradeoffs

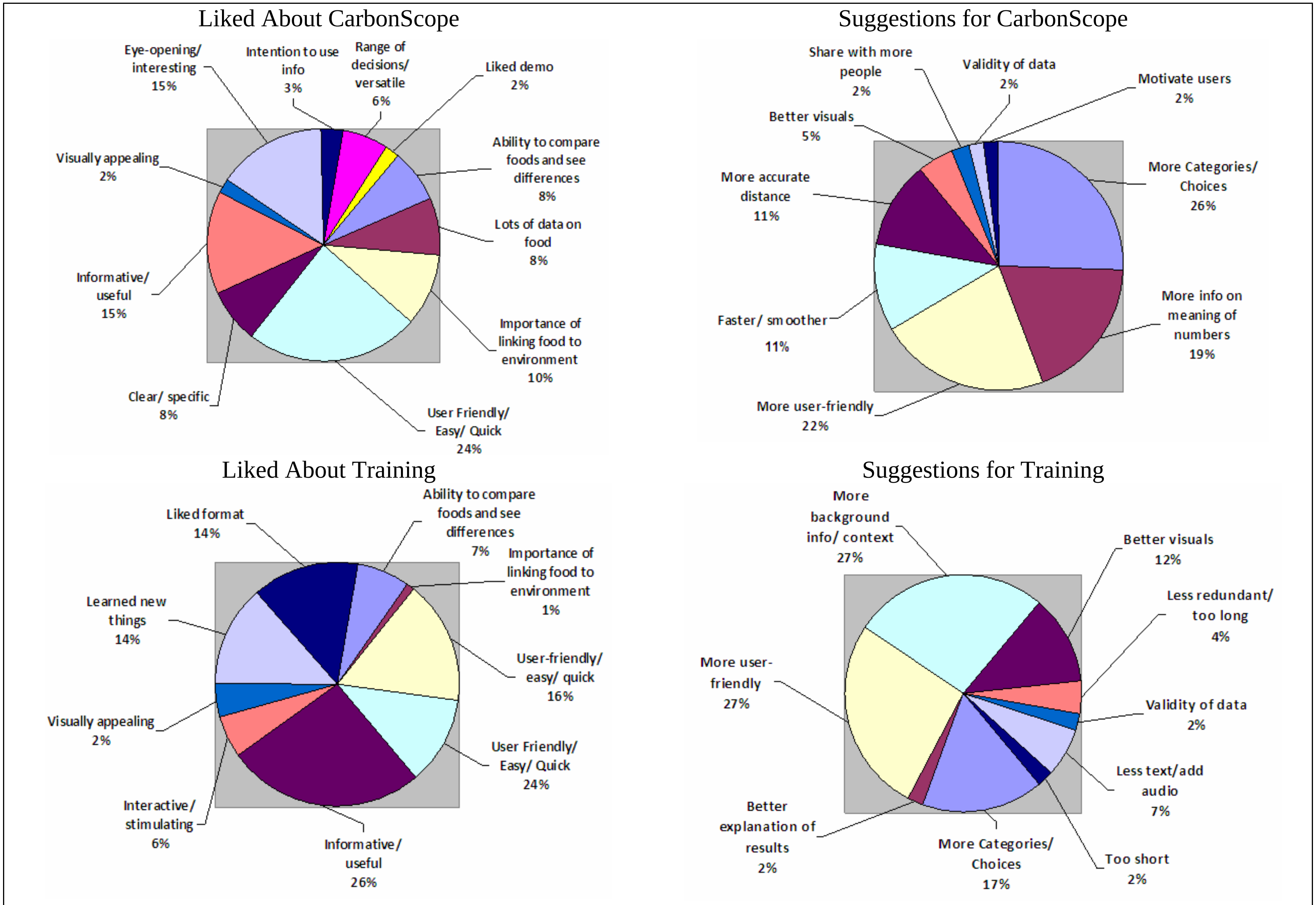

Figure 8: User likes and suggestions

based on food types (between plant and animal foods, for example), production processes, transport methods, and distances.

Participants reacted well to the tool and training, and offered many constructive suggestions. Their knowledge increased significantly, and their sense of environmental efficacy also increased, that is, participants left the training session with stronger beliefs that their actions impact the environment. Most of the participants stated that they intended to use the knowledge gained in the training, indicated that the tool and training process represent a promising new way to teach and motivate people to consider environmental impact when selecting foods.

Innovative aspects of this research include: (a) the use of supply chain sustainability models to analyze food carbon footprint, (b) development of a training vehicle for educating consumers about their food choice impact the environment, and (c) explicit measurement of behavior intentions and change in user beliefs as a result of the training.

Contributions

One contribution is the CarbonScope tool itself, a web-based tool that allows consumers to analyze the carbon footprint of alternative food choices, including both the impacts of farming and/or production processes and the impacts of the supply chain. Energy requirements and nutritional information are also provided.

Other contributions include: a) specific content information about the carbon footprints of a variety of foods and different supply chains for those foods, b) a training process that teaches consumers about the carbon footprint of different food, and c) the explicit measurement of the impact of the training and tool in terms of knowledge gains, behavior intentions, and outcomes (change in beliefs).

Limitations

The results may not generalize to a larger population because the sample for the present study was 72% female and 77% Caucasian.

Potential biases include: a) sample bias, since this was a university sample drawn from a highly “environmentally conscious” student body, b) response bias, since environmentally concerned people are more likely to participate, c) acquiescence bias, since people tend to agree with survey items rather than carefully consider each item, and d) access to information, since the survey and training process requires some degree of computer literacy and proficiency in English.

Another possible limitation stems from the fact that the post-training questionnaire was given directly after training. How long will the knowledge acquired be retained? The study did not assess the persistence of the learning and change in beliefs.

Finally, although the study measured behavioral *intentions*, there is no way to know in the present design whether or not the participants actually changed their behaviors.

Future Plans

Future plans for CarbonScope include expanding the list of food commodities (possibly to include beverages and highly processed foods), finer-grained distance calculations, more accurate farm production figures, and possibly adding recipes. Future plans for the food carbon footprint training include addressing nutritional and cost considerations, increasing the “fun” factor, and making the training process a richer experience overall. We also plan to expand the study to address a broader, larger, and more diverse study population; and to follow up with participants at a later point in time to see if the changes in knowledge, behaviors, and self-efficacy persist over time.

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Figure A.1 shows the configuration for the two illustrative generic distribution networks similar to those used to ship food commodities. To provide information for the Food Carbon Game, food commodities are analyzed in terms of their total environmental impact. The Appendix details the key data and assumptions used in the modeling and analysis of the distribution networks.

The carbon impact of food is also included in popular carbon calculators, such the one provided by the Nature Conservancy (2007). The food and diet tab for their calculator asks how often meat is eaten and how often organic food is eaten. "More info" links are also provided.

Table A.I summarizes the energy used in producing one kg of several different food commodities, excluding transportation of final product (Pimentel & Pimentel, 1996), as well as an approximate density for each commodity during storage and transit (estimated using USDA, 2007).

We used a software tool called SEAT (SEAT 2007) – which uses a simulation model to analyze energy use and carbon dioxide emissions in supply chains – to analyze the production and movement of each food commodity through different supply chains. SEAT considers all the energy consumed in the supply chain, from the production of the food commodities through final delivery at a store or restaurant, taking into account all the transport links and storage facilities along the supply chain. SEAT calculates energy consumed at each step and then converts the energy to corresponding carbon dioxide emissions based on the actual fuel or energy source used at that step.

Since SEAT is a specialized desktop software tool, it was not presented directly to users during the training. Instead, SEAT was used to perform all the detailed environmental analyses

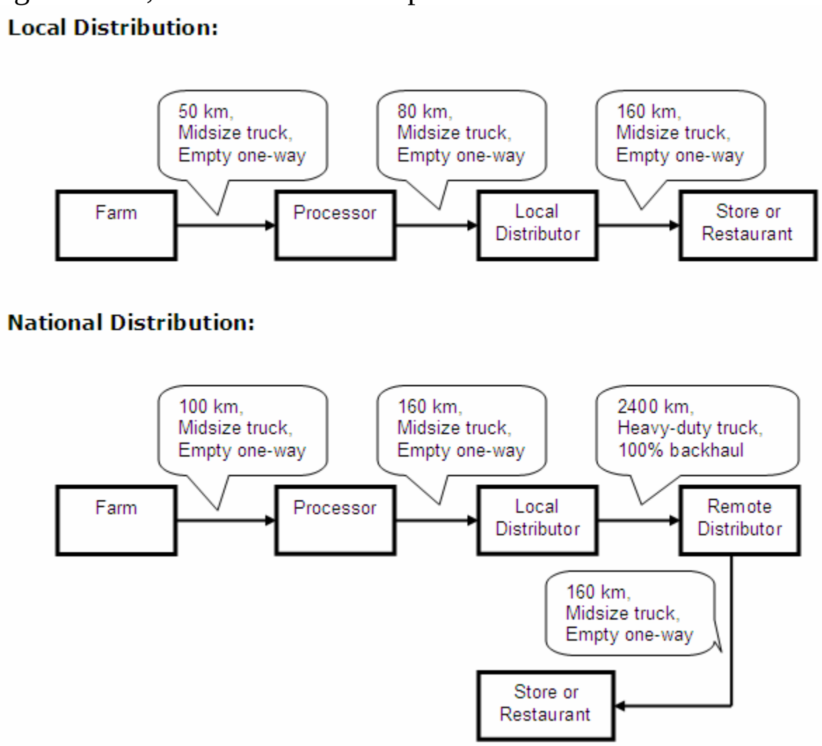

Figure A.1. Food Supply Chain Configurations, Local Distribution and National Distribution.

Table A.I. Input Data and Sources for the Food Carbon Game

	Food Commodity	Unit Prod'n Energy (excl. transport) GJ/kg	Temperature Control	Avg. Estimated Product Density (incl. packaging) kg/cu-m
Vegetables	Potato	0.00188	Refrigerated	600
	Spinach	0.00474	Refrigerated	600
	Tomato	0.00138	Refrigerated	600
	Brussels	0.00272	Refrigerated	600
Fruits	Orange	0.00122	Refrigerated	600
	Apples	0.00216	Refrigerated	600
Grains/ Legumes	Corn	0.00583	Cool	550
	Wheat	0.00615	Cool	550
	Soybeans	0.00401	Cool	550
Animal Products	Milk	0.04773	Refrigerated	825
	Eggs	0.15358	Refrigerated	450
	Chicken	0.11522	Frozen	750
	Beef	0.25205	Frozen	750
	Pork	0.40713	Frozen	750

Sources: Pimentel and Pimentel (1996); USDA (2007).

of food commodities in order to generate a database of all the relevant results in the form of carbon dioxide emissions. The different web-based tool called CarbonScope was used to deliver the results from this database to endusers so that they can learn the impacts of their food choices.

We show for reference results from SEAT for the 14 food commodities listed in Table I. Figure A.2 illustrates the carbon-dioxide emissions intensity (measured in kg of CO2 per kg of product delivered) for all commodities using both the local and national distribution networks. It is clear that emissions are the highest for animal products – typically one to two orders of magnitude higher than non-meat products – and most of it comes from production. Transport is a negligible contributor, since the differences between local and national distribution are not significant for animal products. Figure A.3 illustrates carbon intensities for plant-based commodities, which highlights the sensitivity of these products to transport distance.

These results show that CO2 emissions generated in transport and storage are significant only for commodities that require relatively low energy to produce and process: fruits, vegetables, grains, and legumes. For these products, there is significant difference in total energy and emissions between national and local sourcing. Thus, "food miles" are an important consideration in the overall environmental impact of these plant-based products. For animal products, "food miles" add only a small amount to the total emissions, and therefore may not be an important consideration when assessing their overall environmental impact.

These results are consistent with information in the popular press, such as a recent article in the Guardian (2007) encouraging readers to "eat their greens." One message in this article, for example, was that, as we also state above, food miles do not represent the total environmental impact of foods.

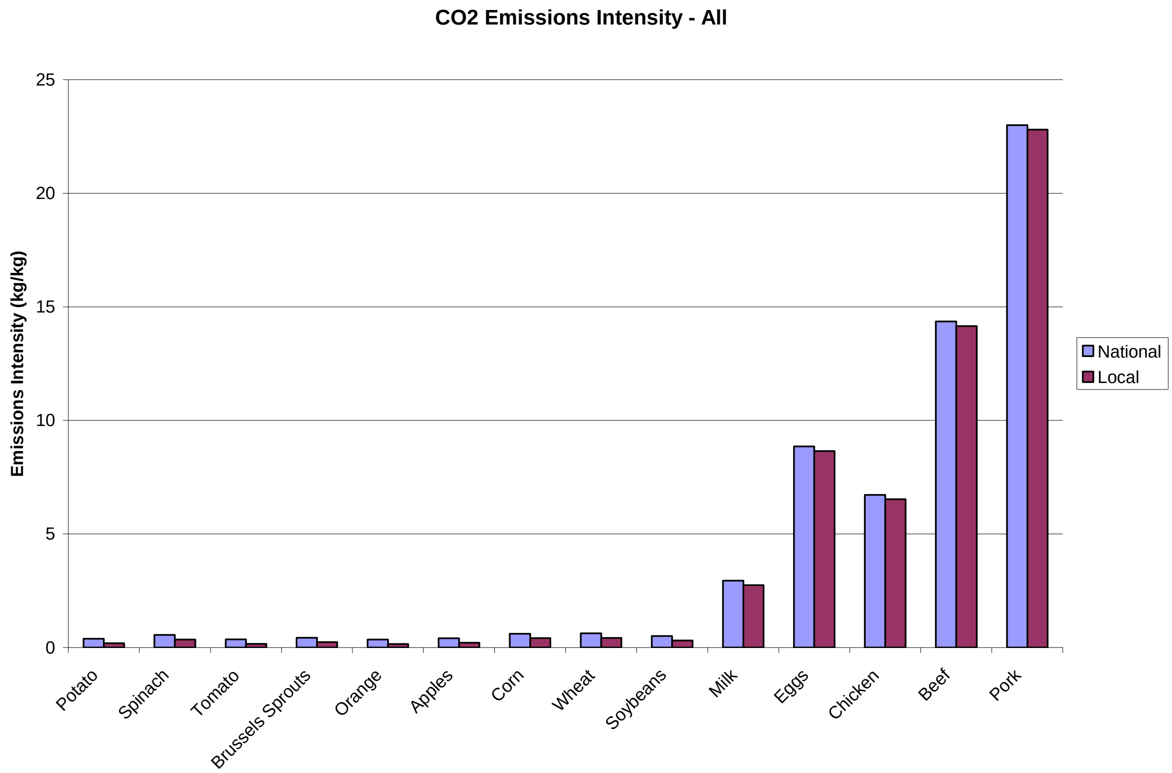

Figure A.2. CO2 Emissions Intensity for Vegetables, Fruits, Grains & Animal Products.

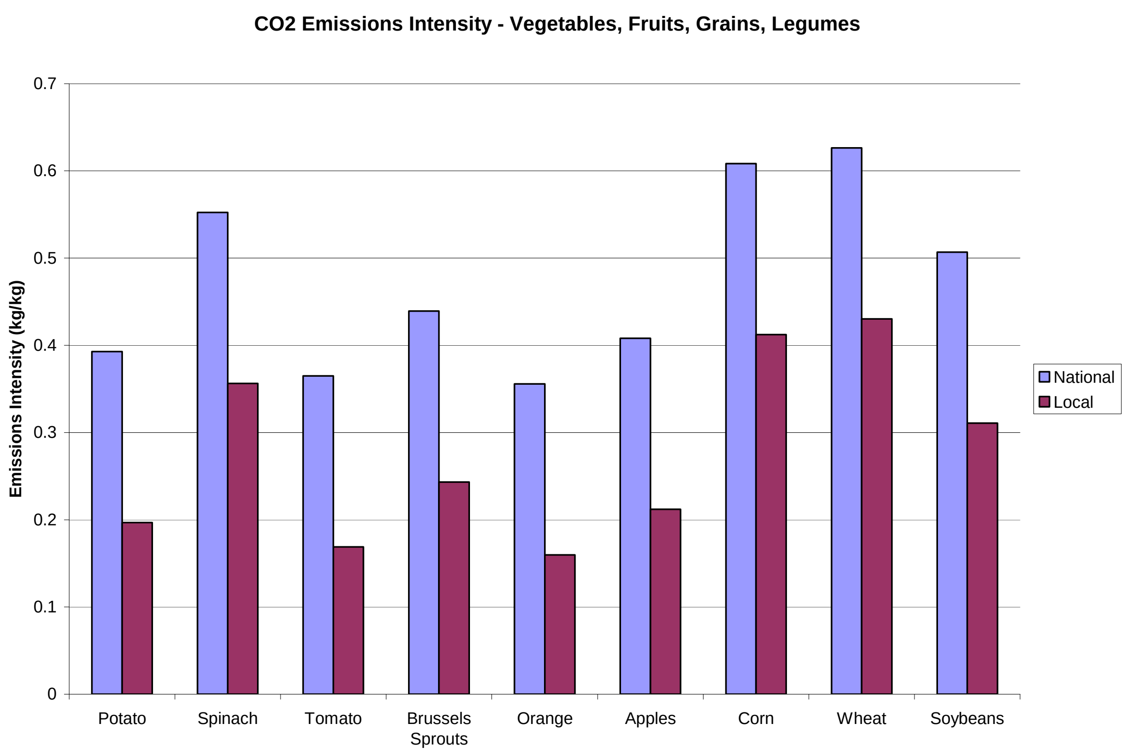

Figure A.3. CO2 Emissions Intensity for Vegetables, Fruits, Grain, re-scaled.

Additional data and assumptions used to analyze the different configurations of the supply chain,include:

- **Fuel/Energy characteristics:**
  - Diesel: 0.0371 GJ/Liter ; 2745.77 g CO_2/Liter (GHG Protocol 2007)
  - Electricity (US ave.): 0.0036 GJ/kWH ; 606 g CO_2/kWH (Energy Information Administration 2007b)
  - General Mix (US ave.): 55746.6 g CO_2/GJ (Energy Information Admin. 2007a)
- **Transportation characteristics:**
  - Midsize truck, Class 6, diesel (GVW: 19501-26000 lbs):
    - 7 mpg = 0.3359 L/km (Dept of Energy 2007)
    - Typical capacity: 6250 kg ; 39.02 cu-m (Pirog et al 2001)
  - Heavy-duty truck, Class 8, diesel (GVW: > 33000 lbs):
    - 5.7 mpg = 0.4125 L/km (Dept. of Energy 2007)
    - Typical capacity: 17240 kg; 107.62 cu-m (Pirog et al 2001)
  - Key Assumptions:
    - Midsize trucks used for distances of < 500 km one-way, with trucks typically running empty in one direction
    - Heavy-duty trucks used for distances > 500 km, with trucks typically used productively in both directions
    - Refrigeration typically reduces truck fuel economy by 2-5 % and is variable. Since we are using conservative mpg numbers for each truck class, we are not explicitly reducing the mpg numbers for refrigeration – this is consistent with similar work done by others (Pirog et al 2001, and Talberth and Sweitzer 2006)
    - Product is transported from farm to processor twice a week and from processor to local distributor's warehouse twice a week. From there, further shipments occur once a week. This assumption tries to capture reality and creates some non-zero inventory at the local distributor's warehouse – which adds some refrigeration energy to the total energy consumption.
    - Trucks are assumed to be filled by weight – ignoring product density and assuming that full weight capacity of trucks can be utilized for each product type or mix of products transported by a truck on any route. This assumption applies to both less-than-truckload (LTL) and full-truckload (FTL) shipments.
- **Refrigerated warehousing characteristics:**
  - Energy Star formulas for maximum (average) energy use in commercial refrigerators: (Energy Star 2007)
    - Refrigerators (for fruits, vegetables and dairy products)
      - $(0.1 * V + 2.04)$ kWH/day = 44.22 kW, where V = internal volume in cu-ft
    - Freezers (for meat products):
      - $(0.4 * V + 1.38)$ kWH/day = 176.61 kW
  - Key assumptions:
    - All warehouse energy use assumed to be electricity.
    - Warehouse space assumed to be fully utilized.

- Product density, including allowance for packaging and empty space determines storage cost per unit of food.
- For products requiring only “cool temperatures” (dry goods such as cereals, pasta, rice, bread), power consumption is assumed to be 25% of full refrigeration, or 11.06 kW.

The characteristics of specific commodities, such as product density, which are needed to calculate storage and transit costs, are extrapolated from data provided by the USDA (2007). This data is dependent largely on water content, with 25% added for packaging materials and air.