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Energy poverty: SOS

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Energy Poverty: SOS

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Purpose and Objectives

My honors thesis is a part of a larger project. I am currently conducting my Integrated Science And Technology (ISAT) Senior Capstone project with my partner Rachel Stukenborg. The purpose of our collaborative ISAT Capstone Project is to develop a set of lesson packages for faculty teaching about energy poverty in an interdisciplinary context. The overall goal is to research and conduct data analysis of global energy poverty and to educate college students on the findings, the direct implications that come along with energy poverty for those individuals experiencing it, and the indirect consequences the rest of the world encounters as a result.

This creative project is unique in that the lessons use a spherical display system, Science on a Sphere (SOS), as a pedagogical tool for formal education in a university setting. The title of the project, Energy Poverty: SOS, is a play on words with "SOS" being the abbreviation for the display system and a call for help. The project entails conducting literature searches, identifying indicators of energy poverty, gathering data for the indicators, developing lesson plans, and creating visualizations on Science on a Sphere. The final project will include four lesson packages that contain the following:

- a full lesson plan
- the written analytical background that supports the lesson
- supporting teaching and learning resources, such as readings, worksheets, and/or assignments with answer keys
- digital files for the spherical display system

My honors thesis work within the context of this larger project represents three extensive literature reviews, the methodology write up, and two full lesson plan packages that I complete by myself. The collaborative work that I conduct with my partner will account for the rest of our ISAT Capstone Project.
This value of this thesis is that it will do three things for Science on a Sphere and formal higher education:

1. There is not a large amount of formal higher education material for Science on a Sphere. This thesis will help fill in that gap by developing material on energy poverty, a topic not yet addressed for the SOS, for collegiate courses.
2. Many classes that use Science on a Sphere have a limited amount of time with the sphere and that allotted time differs from class to class. This thesis designs multiple flexible lessons specifically for standard increments of university class time so that they are manageable and adaptable.
3. The thesis work, as represented by the lesson plans, enables future formal learning assessments of the use of Science on a Sphere for college students.

The topic of energy poverty is not addressed in the existing National Oceanic and Atmospheric Administration (NOAA) database for the SOS. This thesis will significantly add to the growing field of spherical use for teaching scientific topics by bringing energy poverty in a formal realm in the form of upper education in researched best practices which will be discussed in further detail later. The NOAA database currently contains different layers, not always accompanied by a script, and a few movies for the sphere. This project will produce a scholarly contribution bringing a key teaching aspect to the sphere: full lesson plans with accompanying layers for the sphere.

Although this thesis is created for formal education, it will fill the gaps in these studies of informal education in a few ways. The limitation of Hsi's study was that the audience did not have enough time to match the expectations of the study. This thesis is designed to adapt to different time constraints an audience may have that ranges from a fifty-minute presentation, to a seventy-five-minute lecture by producing a multi-layered bundle of four individual lesson plans that can be added onto each other or presented individually.

Although this thesis will not have the time necessary to conduct an evaluation of the success of the lesson plan packets, due to the formal instructional design of the lesson plans future parties will be able to assess learning impacts of the final products. Currently there are no formal higher education materials on the NOAA database available for assessment which creates a gap that collegiate courses would benefit from greatly. This thesis will fill that gap by producing an adaptable product on an unaddressed topic ready for evaluation.

This project is rooted in the ISAT habits of mind because the team started the project as their ISAT Capstone. The ISAT habits of mind consist of: understanding the bigger system within which the problem exists; engaging diverse stakeholders; explicitly addressing the political and cultural contexts; taking a long-term perspective on how the problem came to exist and what that means for the future; employing sound science; considering scientific, technological, economic, social, and political merits of possible solutions; recognizing how the work of this project fits in with the bigger picture; identifying where outside experts need to assist this project; and evaluating the system-wide impacts of possible solutions. Each step of this project will consider these principles and use them to achieve the end goal.

I am proposing that my well-defined portion of the ISAT Capstone be used as my Honors Capstone Project. In addition to a written report that contains the lesson packets, my final deliverables in April 2017 will include an oral presentation at the ISAT Capstone Symposium with my partner and an individual poster presentation at the JMU Honors Symposium.

Methodology

Data Analysis

To plan the focus and goal of the project, the team began by developing a Big Goals table that included what they felt were the main points and goals of the project along with each goal's respective energy poverty indicators, bloom's taxonomy tag, action verbs, individual concepts, and sphere data and links. These goals eventually developed into the final four lesson topics that make up this Capstone Project.

Parsing the big goals versus the big idea was a challenge due to the complexity of this topic. At first, the team developed five ideas and concepts of energy poverty. Those ideas and concepts were then turned into action verb goals. For example, the original first goal was, "To understand that the overarching problem of energy poverty is that it is closed intertwined with global poverty in a positive feedback loop". Each goal was then paired with a bloom's taxonomy tag, an appealing action, sphere data set names and links, indicator data and sources, and Department of Energy Literacy Goals. These five goals were later mended into four with more concise language. The final four goals kept getting confused with the energy poverty/global poverty feedback, so the team developed the Big Idea: Energy poverty and global poverty are caught in a reinforcing feedback loop. The final four goals then became the four lesson goals that all fall under the big idea.

The next step was to then research each indicator of energy poverty identified for each goal, as well as others from multiple sources. Both members collectively created a data catalog where they input country data by hand from three main sources: World Bank, Central Intelligence Agency World Factbook (CIA), and International Energy Agency (IEA). After much deliberation, the team was advised to use only World Bank data as to create consistency. It was not discovered until later that the World Bank had full downloadable excel spreadsheets. Determining the final indicators for each lesson was a combination of analyzing excel spreadsheets for each indicator with available data and researching indicators of energy poverty in library databases. Any indicator that related to each goal was analyzed and discussed in the analytical backgrounds, but indicators for the ArcGIS (Geographic Information System) files were chosen more carefully.

To decide which indicators to create ArcGIS images for the sphere, the team used two primary methods. The first was to look at the raw data numbers and determine if there was a wide enough spread numerically to show a difference between countries for each indicator. The second was to throw the raw data into ArcGIS and look at the maps of data and use the maps that best show energy poverty links.

Analysis and Literature Review Writing

Once the team developed a list of indicators for each big goal, or lesson, they began researching each indicator. To do this, the team combed through the James Madison University Library

Database as well as Scopus Database for studies, periodicals, and books that discuss each indicator in detail. Once they compiled a list of over 90 sources, they then began writing their literature reviews. Notes would be taken on each source and similar concepts and conclusions found between multiple sources were discussed in the literature reviews. These analyses then influenced what indicators were chosen for further data analysis and eventually for ArcGIS image creation. Literature reviews were sent to advisors for revision and feedback. Once literature reviews were finalized, the writing of each lesson plan respectively could begin.

Lesson Planning

Before any lesson planning could begin, research on what a lesson plan entails and how to write one first had to be conducted. The team read a handful of books from the James Madison University library as well as multiple digital articles. They also found multiple lesson plan templates and finally decided on the Paul D. Camp Community College lesson plan template (with permission granted by the school) as their first guide (Walker, S. Clark, L). They used this template to write up each lesson plan packet, but used the JMU SOS Middle School Lessons template for the final format (Mangan, J., 2016).

The team also conducted a variety of other lesson planning research tasks before beginning any lesson plan writing. They watched a video by Dr. St. John to create a list of best practices when teaching on Science on a Sphere, learned about storyboarding, and self-taught bloom's taxonomy so they could decide what levels they wanted students to learn in for each lesson. Once these basic concepts were grasped by the team, they moved onto their first draft of the first lesson plan.

Lesson planning for each lesson could not begin until their respective literature review was completed. Once the literature review was completed, the team wrote up their lesson plan using the Paul D Camp Community lesson plan template which they later modified to adapt to the deliverables they wanted to give to professors. How the team created each section within the lesson plans are discussed next in the order that they were developed.

ArcGIS images were created after literature reviews were written because the entire lesson plan focuses on the images. Nothing can be written up without knowing what images will be discussed and analyzed so these had to be created and then chosen for the lesson plan before the actual writeup could begin. The creation of ArcGIS images for the sphere is discussed in the following section, "Learning and Using ArcGIS".

Objectives were created by deciphering what the main takeaways of the literature review were and using action verbs to describe how students would show understanding of these concepts or facts.

The Lesson Sequence was typically written next because all other sections of the lesson plans rely on the specific content of each lesson. Using the decided images from ArcGIS, the lesson sequence structure was formed. The team determined the best flow of image content, and used that as the structure of the entire lesson. Then they described each image and its main points to help determine question topics. To review material from post-lesson assignments, analytical clicker questions were used. For example, the first clicker question in lesson 1 is:

Clicker Question 1: Drawing on your understanding of energy poverty, which person is living in energy poverty?

a) Jalal who must do his homework by kerosene lamp light.

b) Ali who cooks with manure as fuel.

c) Jenny who cooks with fuelwood and has no electricity.

d) Mack who cooks with fuelwood and has no water purification system.

In-class worksheet questions were created based on what the team wanted the students to observe on their own. For example, the first in-class worksheet question from lesson 1 is:

In-Class Worksheet Question 1: Record your observations of what areas or countries have the most lights and which have few or none.

This question guides the students to focus on the difference in lighting between countries, without being specific enough to influence what differences they see. Questions like these were then expanded on in the clicker questions. Clicker questions were created to help students draw key analytic conclusions about each image. For example, the clicker question following the first in-class worksheet question from lesson 1 is:

Clicker Question 3: Why does Sub-Saharan Africa have the least amount of lights on the Night-time Lights map?

a) They suffer from both energy and global poverty.

b) They have the lowest population.

c) They have the lowest population.

d) Their cultural views prevent them from adapting modern fuel sources.

This question uses student's observations from the previous in-class worksheet questions but then asks them to use those observations to draw conclusions from a specific scenario. Once the lesson sequence was completed, the pre-lesson and post-lesson assignments were created.

Building the pre-lessons and post-lessons for each lesson plan needed the most revision and teaching. For the pre-lessons, the team drew on personal experiences from previous classes. They began with looking for readings or videos that related to or introduced the topic of each lesson specifically. Once the team has compiled a list of readings and videos they would read through and watch them more carefully, looking for the materials with the most relevant content. The team was advised to rely more on scholarly readings and use videos as supplements rather than use primarily videos. Once the materials were selected, the assignments themselves differed greatly depending on the lesson. For lesson 1, the team wanted students to feel comfortable with the general geography of African countries so they decided that having students follow two specific countries, a developed country and an African country, through their assignments and the lesson would help them get a grasp on the continent and its differences from developed countries. For the other three lessons, the pre-lesson assignments focused on either introducing students to new concepts through textbook and scholarly readings or through questions and analyzing, depending on the depth of the lesson. Post-lesson assignments were geared more towards individual analytical thinking. All four lessons' post-lesson assignments were prompted essays on the main takeaway from the lesson. The team felt this was more substantial and required more analytical thinking on the students' end than questions would be, and would help the material reside with them.

Deciding the materials list for the first three lessons also continually changed over time as the team debated over the best combination of pre-lessons and post-lesson assignments, in-class worksheets, and clicker questions. With explanation of how questions are typically used in teaching from the advisors, the team decided that providing an in-class worksheet to guide student's observations and supplementing that with analytical clicker questions would help achieve the lesson goals the strongest. This way students would write their observations down to start their own analysis and thinking. Then they would be asked analytical questions in multiple choice form and answers could be discussed by the instructor. Having the students start their own thinking process before analytical questions are asked helps put them in the right mindset.

The bloom's taxonomy description was a rather straightforward section for the team because it depended on the objectives created. The team used their knowledge of the bloom's taxonomy levels and categorized the lessons accordingly.

Learning and Using ArcGIS

To illustrate the identified indicators of energy poverty, original images needed to be created. Science on a Sphere uses specifically designed images generated in a software program called ArcGIS. The team self-taught their way through ArcGIS functionality and had no prior knowledge or exposure to the software. To do this, they used the Science on a Sphere manual and received guidance from one of the James Madison University GIS Teaching Assistants, Elise Mazur. There were several challenges presented with learning ArcGIS. The main issue was that the manual had many conflicting directions with what is available in ArcGIS, such as the projection type. The team had to troubleshoot on multiple occasions to determine the basic settings for the Sphere. One major problem that occurred was the labeling of countries in the program. To correct it, cross referencing was required and for that reason only data from the World Bank was used (excluding the population density map that required Center for International Earth Science Information Network data (CIESIN)). The correct steps to create a Science on a Sphere image through ArcGIS that the team used are described below.

Creating the initial image, GDP_PPP_Per_Capita, required partly different steps than the rest of the images because a base map that contains the country borders needed to be established. The first set of steps are for the initial image, and the second set of steps are for any image that has a pre-established base map.

To create the first image, the GDP_PPP_Per_Capita data from the World Bank had to be downloaded as an excel file to receive the meta data. That excel file was then converted into CSV files to condense them to one sheet for image creation. The version ArcMap 10.4.1 was used in this capstone project. Once the software was opened, the pulldown arrow of the yellow load data button was selected, and the option to "add base map" was chosen. This was modified to become the base map for all other images, and was labeled Correct World Country Map. The Correct World Country Map was then changed into a correct projection in ArcGIS that works with Science on a Sphere, "World equidistant cylindrical (Sphere) (GRS80 authalic) (std parallel = 0)". The manual dictated to use "Equatorial Cylindrical Equidistant (ECE) projection", however that projection type did not appear in ArcGIS. The base map then needed to be resized for the correct dimension of the sphere. Images need to be twice as long as they are wide, and the largest size that could be created by the team was 4080x2040. To do this, the team resized the page in the ArcGIS window in the printer settings and fitting the map to the new page dimensions. To account for countries that would have no data available within the data files, the team then created two layers of the base map. The first, called "in order" meaning that showed up on top, is where the data was filled in so that where countries with no data showed no color which is called "hollow" spots. The second layer was grey and filled in the hollow spots so the countries where no data was available showed up grey uniformly. To achieve this, the first map was simply copied and pasted in the layer tab. The next step was to join the data desired to be mapped to the base map. Since the World Bank data list of country names differed from the base map list, cross referencing was required to create one uniform list of country names. This meant that the team had to go through each country in the base map attributes table and type the World Bank's country names in the World Bank's order. To do this the team opened the editor tool bar and selected start editing. Once editing was enabled, the attribute table was opened. In the "CNTRY_NAME" tab on the Correct Country Map is where the names were reentered. This ensured that the World Bank data files would not have to be changed individually to match the base map list, only the base map attribute table had to be changed once. Therefore, allowing the base map to be used with all World Bank data without any country pairing issues. Next the map needed to be rescaled and color adjusted. The software automatically splits the data into sections based on number of data points, or natural breaks. However, this does not represent all data well so data breaks were determined on the raw data in Properties. Also in Properties was the color scheme and scale set by selecting the Color Bar tab. For the entire project, all images were designed so that the bad or detrimental values of each indicator were assigned the darkest shade in the color scheme. For example, in the GDP_PPP_Per_Capita map, low GDP_PPP_Per_Capita values were assigned the darkest shade of Red. As GDP values increase, the color lightens signifying a better economy. The final step in creating the first image was to insert a legend. Before a legend was inserted, the classes were labeled with correct titles, units, and numbers because once a legend is created these cannot be altered. To insert a legend, the team selected the Insert tab and the legend option. Then they right clicked on the legend to open properties. The font was set to Arial size 20. The legend was then aligned with Jarvis Island so that all legends appear in the same place in every image. This consistency will make analysis of multiple images easier for the audience. The team then right clicked on the legend. and selected convert to graphics and set the title to size 22. The title was then moved up one space. Finally, all parts of the legend were selected, grouped, and the final legend was realigned with Jarvis Island. To then export the image as a Jpeg, the team selected file type to be Jpeg and the dimensions to be 4080 x 2040. Items such as legends and citations were dragged in and out of the page which determined what was exported in the image. Items off the page were excluded from the exported file. By selecting file and then export, the GDP_PPP_Per Capita image was finally complete and exported.

For the remaining images, a few of the steps changed. Instead of creating a base map, the GDP_PPP_Per_Capita map was selected under the file tab. Then the GDP_PPP_Per_Capita data had to be unjoined in order for the remaining images' data to be mapped one at a time. This was done by right clicking on the Correct World Map Country Map layer and selecting remove all joins. This did not happen in real time but appeared when edits were finished. The GDP_PPP_Per_Capita legend then had to be deleted so a legend for the new data could be later added. The next step was to insert the remaining images' data. The team right clicked on the Correct World Country Map and selected the joins/relates tab. In Text box 1 they selected CNTRY NAME. In Text box 2 they selected the csv file desired to be mapped. In Text box 3 they selected the column that the country names were in which was the first column in this case and it is typically labeled Data Source. To then select the corresponding data, the team clicked on the Correct World Country Map properties where they entered the Symbology tab. Under Quantities, in the value textbox the team chose the column in which the data resided. This column was always titled Field (#), which is the column that the data in the correct year was. The Field number varied based on the data. All the aesthetics programming and exporting steps remined the same for all images.

Troubleshooting was required in small amounts for most images but the most prevalent was the Population Density image. Data for population density was acquired from CIESIN instead of the World Bank which created a multitude of challenges. The team spoke with CIESIN representatives, multiple James Madison University professors, and Teaching Assistant Elise Mazur over the course of six weeks.

Sphere Literature Review

This thesis explores the effectiveness of a spherical display system and its ability to educate college students on the topic of energy poverty. Spherical displays systems are a relatively new technology primarily used for informal science education, especially public literacy in Earth Science (Beaulieu, 2015). Studies have found that the major problem with educating individuals on scientific topics is that most scientists communicate solely with one another in forms only experts can follow (Schollaert Uz, 2014); (Vega, 2015); (Beaulieu, 2015). Luckily there are multiple different spherical display systems that all attempt to achieve the goal of educating the public on related earth sciences and global trends (Schollaert Uz, 2014); (Beaulieu, 2015); (Riedl, 2013). Projections on these display systems can be applied in formal settings such as scientific conferences and collegiate courses, as well as informal settings such as museums and movie screens (Schollaert Uz, 2014); (Vega, 2015); (Beaulieu, 2015); (Riedl, 2013). Unfortunately, the field of teaching with spherical displays is small and unexplored to a great degree, especially for scientific topics (Schollaert Uz, 2014); (Beaulieu, 2015); (Vega, 2014). There have been a handful of studies conducted to investigate informal and formal teaching with spherical displays. Although not much information has been concluded on teaching with spheres, the studies conducted have all generally found this pedagogical tool to be beneficial and productive (Schollaert Uz, 2014); (Vega, 2015); (Beaulieu, 2015); (Riedl, 2013).

Since there are multiple different spherical display systems it is important to investigate the differences between them. One key variable is that the operations differ from system to system. Projections can be internal (projected from within the sphere) or external (projected onto the screen from the outside) (Vega, 2014). The following table compares the major spherical display systems currently in use.

Table 1

Spherical Display Systems

SPHERICAL DISPLAY	MANUFACTURER	PROJECTION TYPE	SIZE(S)	PORTABILITY	MARKET	REFERENCE
PufferSphere M	Pufferfish	Internal	600mm, 760mm, 900mm	Seems portable	Interactive exhibits, user-led presentations	Pufferfish Ltd. (2002-2015) (a)
PufferSphere 1200	Pufferfish	Internal	N/A	Permanent installation		Pufferfish Ltd. (2002-2015) (b)
PufferSphere Pro	Pufferfish	Internal	1200mm-3000mm	Permanent installation	AV	Pufferfish Ltd. (2002-2015) (c)
Science on a Sphere	NOAA	External	68in diameter	Permanent installation	Education and outreach	National Oceanic and Atmospheric Administration (a&b)
HyperGlobe	iGlobe	Internal	Rigid: 18in-5ft Inflatable:2-15 ft.	Rigid: permanent Inflatable: portable	Museums, businesses, trade shows	Lalley, M., iGlobe Inc. (2012).
OmniGlobe	ARC	Internal	32", 48", 60"	32" is portable, 48" and 60" look permanent	Classrooms, museums	ARC Science Simulations (2015).

The spherical display that will be used in this study is Science on a Sphere. Science on a Sphere is a turnkey system that serves as a pedagogical tool (Beaulieu, 2015); (Vega, 2015); (Schollaert Uz, 2014); (Riedl, 2013). Currently it has been implemented in science museums, visitor centers, zoos, aquariums, laboratories, universities, and schools worldwide. National Oceanic and Atmospheric Administration (NOAA) developed Science on a Sphere in order to visualize Earth System sciences to audiences of all ages and backgrounds. NOAA has many educational program goals and Science on a Sphere works to extend them. One of NOAA's major efforts is to increase environmental literacy which the sphere plays a significant role in. There are 136 SOS locations, with the majority stationed in the United States, which bring in 33 million visitors a year (Schollaert Uz, 2014).

The SOS Users Collaborative Network, comprised of institutions who use Science on a Sphere, is supported by NOAA's Office of Education. The Network shares information with all members concerning creation of new content, improvements, and any evaluations conducted, and it has established guidelines for creating effective content. The Network heavily focuses on improving content and usage of the sphere as an educational tool, and it meets in person roughly every 18 months.

The sphere is 6ft in diameter but the collective system fills up a room, comprised of a computer and four external projectors all controllable by an iPad remote. (National Oceanic and Atmospheric Administration). It projects datasets from the Science on a Sphere Data Catalog that was created and updated mostly by NOAA and NASA, with smaller contributions from universities, science centers, and other organizations (National Oceanic and Atmospheric Administration). The catalog is broken down into six categories: Atmosphere, Ocean, Land, Astronomy, Models and Simulations, and Extras (National Oceanic and Atmospheric Administration). The top three datasets played are Blue Marble, Air Traffic, and Clouds-Real-time (National Oceanic and Atmospheric Administration).

The topic of energy poverty is not addressed in the existing NOAA database (National Oceanic and Atmospheric Administration). This thesis will significantly add to the growing field of spherical use for teaching scientific topics by bringing energy poverty in a formal realm in the form of upper education in researched best practices which will be discussed in further detail later. The NOAA database currently contains different layers, not always accompanied by a script, and a few movies for the sphere. This project will produce a scholarly contribution bringing a key teaching aspect to the sphere: full lesson plans with accompanying layers for the sphere.

Although this thesis is focusing on formal education it is important to understand the progress made in both the formal and informal education realms using the sphere. There have been a few studies of applications of Science on a Sphere in informal education that all contribute to the growth and success of Science on a Sphere as a public pedagogical tool. Stace E. Beaulieu and other contributors conducted a study that investigated using digital globes to explore the deep sea and advance public literacy in earth system science. In order to conduct their study, they first needed to develop new content for digital globes about biological and geophysical processes and exploration in the deep ocean. They created two narratives titled: Life Without Sunlight and Smoke, and Fire Underwater. They then evaluated perceived learning outcomes for the narratives as both movies and live docent-led presentations using Science on a Sphere through a posttest. The posttest, or survey, was refined by staff at the Ocean Explorium. The posttest comprised of seven questions that took less than five minutes to fill out. Questions in the posttest were reworded literacy principles and asked respondents to indicate if the presentation increased their knowledge on the subject or not on a Likert scale. Results indicated that perceived learning outcomes were greatest for adult lifelong learners, followed by students under 18. There were also no significant differences in effectiveness of the literacy principles, and all presentations led to "Quite a bit" of excitement for all viewers. Therefore, the study could conclude that digital globes can be effective in teaching scientific literacy principles. A major limitation of this posttest-only experimental design is that it only measured *perceived* learning outcomes. Self-reporting of knowledge gained and level of engagement is not always accurate. However, it is positive that the study found that digital globes *can* be effective in teaching scientific and literacy principles. (Beaulieu, 2015).

Another study conducted in informal education through Science on a Sphere that focused on audiences of varied ages was The Effectiveness of Science on a Sphere Stories to Improve Climate Literacy Among the General Public by Stephanie Schollaert Uz and others in 2014. The goal of this study was to determine what method, auto run, docent, or activity, is the most effective in engaging the general public on climate science issues as well as further an audience's understanding of earth science core discoveries and how they are relevant to them. Researches designed the study to test key concepts included in the EarthNow visualization about El Niño's effect on phytoplankton and chose a relevant marine food web activity to compare the three methods in one museum: the Maryland Science Center. The survey was comprised of eight multiple choice questions to quantify results and two open-ended questions to capture qualitative data. After conducting the survey with multiple groups and one control, the results showed that groups who saw a Science on a Sphere show gained knowledge of some concepts better than groups who heard information while doing an activity. Live show audiences also resulted in slightly higher but not significant gains in understanding than audiences who attended auto run shows. Researches were also able to conclude that visitors are drawn to interactive shows more so than auto run shows. A major limitation of this study is that researchers did not quantify background knowledge or demographics which are important components of evaluating effectiveness of informal learning. This study included a wide variety of ages which allows for a comprehensive analysis of the public's learning abilities with Science on a Sphere. Other studies, however, focus on smaller age ranges to draw conclusions based on more specific audiences. (Schollaert Uz, 2014).

One example of studying a more specific audience is Math on a Sphere: Using Public Displays to Support Children's Creativity and Computational Thinking on 3D Surfaces conducted by Sheri Hsi and Michael Eisenberg. This study explored the effectiveness of tools Science on a Sphere and Math on a Sphere to enhance students' mathematics and computational knowledge. In order to do this, they set up two versions of a two-day workshop at Lawrence Hall of Science in California that twenty-five children ages 8-13 participated in to create art on the sphere and engaged in hands-on crafts and inquiry-based math activities. On the first day of the workshop, children received an overview and orientation in the Sphere exhibit and were shown sample designs on the sphere to give them context and motivation. They then took a pretest which determined their level of prior mathematics knowledge, use of computers, and interest in math, geometry, and computers. After the pretest, all participants partook in a group discussion about circles, lines, angles, and spheres. The students were then given a design task to make a sphere with craft materials. This concluded the first day of the workshop. On the second day, students worked as a large group to construct small, medium, and large triangles with masking tape and put them on inflatable globes and made observations of how the triangles acted on a spherical plane. They then role-played to learn the Logo language and spent 1-1.5 hours programming on computers using paper instructions and tutorials. Students presented their final products and took a post survey. The post survey consisted of drawing tasks, feedback about content, and multiple choice questions about their interest in math, geometry, and computers again. Results of the post survey found no change in children's interest in math or geometry but a significant increase in their interest in computer programming. Almost all (94%) students liked seeing their designs on the big sphere, but only 77% liked showing them to other students. This alerted the researchers to the fact that public presentations require more preparation in managing learner expectations since there was such a wide range of ages and abilities. Researchers also found children had an increased understanding of planar geometry but not spherical. They expect that more time would enable children to gain further understanding of spherical geometry, but two half-days of workshop was not enough time to grasp the different components of spherical geometry. (Hsi, 2012).

Although this thesis is created for formal education it will fill the gaps in these studies of informal education in a few ways. The limitation of Hsi's study (2012) was that the audience did not have enough time to match the expectations of the study. This thesis is designed to adapt to different time constraints an audience may have that ranges from a fifty-minute presentation, to a seventy-five-minute lecture with take home worksheets. This work aims to fill the gap between both previous studies of informal language and higher education in Science on a Sphere.

Another important contribution of this work is that few studies have been conducted of spherical displays in higher education. Evaluations of spherical displays have found that the method of presentation is crucial (Schollaert Uz, 2014); (Vega, 2014); (Riedl, 2013); (Beaulieu, 2015). Storytelling and aesthetics contribute to the success of a presentation and SOS provokes the interest of viewers while still providing important and accurate information to the audience (Riedl, 2013); (Vega, 2014); (Schollaert Uz, 2014). Evaluations have also found that visitors stay at live Science on a Sphere projections longer than they would at similar exhibits (Vega, 2014); (Schollaert Uz, 2014). This has led to a handful of studies that focus on assessing the success of Science on a Sphere as a new pedagogical tool in higher level education.

One example of sphere use in higher level education is a study performed in 2014 titled, Visualization on Spherical Displays: Challenges and Opportunities by Karla Vega et al. This study identified and assessed the challenges and opportunities that spherical display formatting has for public and educational sites (Vega, 2014). The major challenges that this study found are, a viewer will not be able to see half of the information at any given time due to the 3D spherical projection, and the projection itself presents layout and geometric obstacles (Vega, 2014). The positives found are that the use of four projectors offer the advantage of seamlessness and mobility, as well as giving viewers a completely new perspective of their earth (Vega, 2014). Viewers feel a sense of sublime realization as they take an external look on their planet and changes happening on and to it (Vega, 2014). Vega and authors reached a few conclusions. First that spherical displays are still new technologies which contributes to their highly compelling, versatile, and effective nature as a technology for presenting scientific and informative visualizations as well as creative works in the public eye (Vega, 2014); (Schollaert Uz, 2014); (Beaulieu, 2015); (Riedl, 2013). They also concluded that spherical displays have a unique characteristic that they can enhance perception for aiding audiences in visualizing information (Vega, 2014). Closer to home is a brief evaluation that James Madison University has performed on classes that visit Science on a Sphere located in Memorial Hall. (Vega, 2014).

The National Center for Science Education has an online survey that James Madison University has used to evaluate student perceptions on climate through education on the sphere. The evaluation is directed at six courses: GISAT 100, GISAT 112, GGEOL 115, GEOL 406, GSCI 166, and IDLS 395 but can be applied to others. It is comprised of 13 questions which contain a combination of self-perceived and information dependent multiple choice and open ended questions. It explores students' examinations, general understanding of climate change, and potential changes in opinions concerning climate change before and after viewing the sphere presentation. Unfortunately, there are no published findings from this evaluation.

This thesis will produce a multi-layered bundle of four individual lesson plans for the sphere based on researched best practices for developing lesson plans and instructional design. It will consider current spherical teaching use as well as what is missing from the NOAA database as it aims to fill in those gaps.

Lesson Planning and Instructional Design Literature Review

Role and Purpose of a Lesson Plan

There are three commonly recognized views on the role and purpose of a lesson plan, and this project draws on all three of these. Mary Renck Jalongo explains that there is one traditional view of what the role and purpose of a lesson plan is and should be but there are three major viewpoints on lesson plan validity (2007). The first is that it should be created by an individual teacher and contain an introduction, objectives either behavioral or not, materials, procedures, and evaluation (Jalongo, 2007). It should present linear events linked to predefined learning objectives (Jalongo, 2007). Individuals that support this type of lesson plan, "lesson-plan purists", believe that clear defined guidelines ensure effective instruction (Jalongo, 2007). These lessons draw on this view by utilizing a linear lesson sequence that includes learning objectives, an introduction, materials, and clicker questions and worksheets to evaluate.

The next viewpoint of lesson plans is that lesson plans approaches myth (Jalongo, 2007). This is the belief that teachers must constantly adapt, change, alter, and even abandon lesson plans depending on various variables of the classroom. Using a lesson plan and transforming it into effective instruction is considered by many "moderate" teachers to be an impressive task that requires creativity and deserves much credit (Jalongo, 2007). Here lesson planning is considered cyclic, audience dependent, and improvisational (Jalongo, 2007). However, this view does acknowledge that a lesson plan is one way of achieving effective instruction (Jalongo, 2007). These lessons draw on this view by building in time and room for adaption. The lessons can work for classes anywhere between 50-75 minutes and include time and space for teachers to go off script and answer audience questions.

The third viewpoint of a traditional lesson plan is quite opposite of the first. This view point considers lesson plans to be a roadblock to teachers' thinking and suppresses the ability to take a behavioral approach (Zeegers, 2000). This view takes the approach of critical pedagogy. Critical pedagogy is the perspective that planning a lesson should be a tool to challenge learners, not script the instruction to a tee, and that engaging the students is the main priority for effective learning (Jalongo, 2007). Regardless of how opposite these three viewpoints are, they can combine their goals to reach their common vested interest through collaborative planning (Jalongo, 2007). This allows teachers to pull the benefits of research and practice in order to encourage learning (Jalongo, 2007). These lessons draw on this view by giving teachers a general guideline with extensive background notes but no word-for-word script.

Instructional Design

Before instructional design can be discussed, a few key definitions must be laid out. The implementation of these lessons builds on the following definitions, terms, and design principles from the field of instructional design. Robert Gagne defines instruction as "a set of events embedded in purposeful activities that facilitate learning" These events can include printed pages, lecture, group activities, directing attention, rehearsing, reflecting, and monitoring progress (Gagne, 2005, p.1). This is important to note because instruction as defined by Gagne does not only include the speaking portion of a lesson. Instruction can be given in a multitude of ways, all of which must be chosen with careful consideration when designing instruction. But what is the difference between instruction and a lesson? Patricia Smith helps to clarify here. She defines instruction as, the "delivery of these focused educational experiences" (Smith, 2005, p.5). Her term educational experiences is the same as events as earlier defined. Therefore, instruction events (as those examples listed above) are used within and make up a lesson plan.

Learning and teaching are also two different concepts that work synergistically. Smith explains her definition of teaching as learning experiences that are facilitated by a human being-not a DVD, textbook, or educational Website, but by a live teacher (2005, p. 6). Gagne then defines learning as "a process that leads to a change in a learner's disposition and capabilities that can be reflected in behavior" (2005, p. 3). Learning is the consequence of effective teaching based on solid instruction. Without effective teaching, learning does not happen to the maximum potential degree in students, and without maximum learning the teaching is therefore deemed ineffective. Learning, however, goes one step further. Since it is a change in behavior that foreshadows that students will take what they interpret from instruction given and decide to either change their actions and thoughts or not. Effective teaching is teaching that makes students think and act, not just listen. To teach is to inspire and to learn is to react.

A key aspect of instructional design is that it “is aimed at “intentional” learning not “incidental” (Gagne, 2005, p. 2). The difference is that intentional learning are concepts and points that a teacher wants students to take away from the lesson whereas incidental learning would be students pulling their own conclusions by chance. Effective design is oriented around goals and desired learning outcomes. Prespecified learning outcomes are pertinent to achieving intentional learning because they lay out goals and keep instruction focused.

As seen so far in this research, not all learning is the same for every student. The Carroll Model 1963 explains the causes for the variation in student academic achievement (Carroll, 1989). This model specifies that students need to know what they are expected to learn, have access to adequate materials, and steps must be well planned. It discusses five classes of variables to explain variation:

1. Aptitude: a student’s ability to learn quickly (Carroll, 1989). People are born with certain abilities, and one of those is the speed at which they are able to learn new concepts or tasks. This speed can affect how a student accepts new information taught to them. A higher aptitude means that a student can learn quickly and a lower aptitude means that a student learns new things slower.

2. Opportunity to learn: amount of time that a student is given to learn. This is, unfortunately, often less than the student’s aptitude requires (Carroll, 1989). For effective learning to take place it is important that opportunity to learn and aptitude are considered together. Since aptitude defines the amount of time a student requires to learn effectively, the time they are given (opportunity to learn) should meet that requirement in order to achieve maximum learning.

3. Perseverance: the amount of time that a student is willing to spend learning (Carroll, 1989). Perseverance is less adaptable by the teacher than the first two variables. This is an internal variable that teachers can attempt to raise by sparking interest, motivation, and encouragement but cannot alter directly.

4. Quality of instruction: when this is less, time needed increases (Carroll, 1989). Quality of instruction should influence opportunity to learn as well. If quality is lower, students will require more time to understand the material. However, if it is higher, they may be able to move on faster, or at their individually set opportunity to learn.

5. Ability to understand instruction: if this is lower, time needed also increases (Carroll, 1989). Ability to understand instruction is more specific to the instruction than aptitude. Ability to understand instruction focuses on the effectiveness of the instruction given rather their personal ability to learn in general.

With these five classes of variables the influence student success in mind, the basic principles of instructional design can now be discussed.

Basic Principles of Instructional Design

Instructional designers apply instructional design principles (rules) when designing the external events (instruction) (Gagne, 2005, p. 3). Gagne discusses four major principles of instructional design, each equally pertinent to accounting for in effective design (2005). The first of these is Contiguity: the object of instruction should be closely followed by the desired response (Gagne, 2005, p.4). More simply put, when a student correctly applies knowledge gained they should see positive feedback shortly after to reinforce learning. Seeing direct connections between performing well and understanding correctly with positive feedback help students retain the information and gain confidence.

The second principle is Repetition: the principle of repetition states that a situation and its response need to be repeated or practiced for learning to improve and for retention (Gagne, 2005). This is not true for all learning, but some situations such as remembering a new word or pronunciation fall under this principle while other research argues that making connections and learning ideas do not fall under this category as strictly (Gagne, 2005). When information is repeated multiple times, students have a higher change of recalling it. According to other research this is geared more towards pronunciation and facts not as much for connections and large concepts. Those most likely require practice and application.

The third principle is Reinforcement: the principle of reinforcement states that learning a new act or idea is better solidified by following the information with internal or external reward (Thorndike, 1913). Internal reward is more common than external, which can be classified as a student being "self-motivated" (Gagne, 2005). This is when a student answers, understand a concept, or completes work correctly and feels pride or satisfaction (Gagne, 2005). Gagne explains that there are societal expectations to perform well and achievement is often recognized by others which brings internal reinforcement (2005). Therefore, when good performance is paired with positivity and reward (internal or external), information is better solidified in students' memories.

The last principle, Social-Cultural Principles of Learning, is more complex than the first three because it has its own sub-principles. Gagne explains that the social-cultural environment of which a student is exposed to during learning is an important factor of learning (2005). Social-cultural environment is a large topic on its own and there are three major principles that stem from this concept, negotiated meaning, situated cognition, and activity theory (Gagne, 2005). Negotiated meaning is when students collaborate to determine the meaning of information (Gagne, 2005). Principles of practice, feedback, and reinforcement are applied here in this social-cultural environment which enhances their learning (Gagne, 2005). Situated cognition is learning that happens at maximum potential and is better remembered when introduced in situations where it can be realistically applied (Gagne, 2005). Activity theory can also be classified as active learning. The principle of active learning states that learning occurs as a result of participating in an activity. Engaging in activities enhances the concepts or information (Gagne, 2005).

This thesis will use these principles of instructional design and the basics of lesson planning to create collegiate focused lesson plans that incorporate original data sets for Science on a Sphere. This information will help support the creation and development of the overall lesson plan as well as the individual instruction events. This background can be referred to when determining how to present the lesson plans and data sets as well as when ad4aptations are necessary for different audiences.

ENERGY POVERTY: SOS
HUMAN WELLBEING CONSEQUENCES OF ENERGY POVERTY

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TABLE OF CONTENTS

OVERVIEW OF THE LESSON

The purpose of this project was to develop a set of college-level teaching and learning resources about energy poverty that incorporate the spherical display system Science On a Sphere (SOS). This manual consists of the second of four full lesson “packages” regarding energy poverty that make up the authors’ larger Senior Capstone Project in the Department of Integrated Science and Technology at James Madison University in Harrisonburg, Virginia.

This manual contains the Lesson 2 package about the consequences to human wellbeing associated with energy poverty. It includes a background analysis, a comprehensive lesson plan, an instructor script, images, and descriptions.

The manual includes:

- Learning Objectives[1]
- VA SOL Correlations
- Next Generation Science Standards
- Dataset Descriptions
- Student Handouts & Worksheets
- Presentation Tips
- Instructor Script
- Audience Frequently Asked Questions (FAQs)
- Pre & Post Lesson Assessment

The manual also includes instructions to access to a supplemental video that illustrates an interactive lesson with Science On a Sphere. The video is interspersed with commentary regarding pedagogy with SOS.

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[1] All icons used in this manual are Creative Commons images and selected from the Noun Project
https://thenounproject.com. Individual designer attribution for each icon is below: Learning Objectives: Pete Fecteau, VA SOL Correlations: Jan Christoph Borchardt, Next Generation Science Standards: Adrian Rguez Perez, Dataset Descriptions: Creative Stall, Student Handouts and Worksheets: Jaclyn Ooi, Presentation Tip: mh, Instructor Script: TukTuk Design, Audience FAQs: Anas Ramadan, and Pre & Post Visit Assessment: Berkay Sargin.

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Background Analysis

Feedback Loop in Complex Systems

Feedback loops are an important concept in understanding the complexities of energy poverty. There are two major categories that make up complex dynamic systems, stocks and flows (Fischer, H., 2016; Meadows, D. H., 2008). A stock does not have to be a tangible item such as money or trees. A stock can be an accumulation of material or information over time, such as good will, energy poverty, and global poverty (Meadows, D. H., 2008). These stocks change over time through verbal flows in and out of each stock such as births and deaths, purchases and sales, withdraws and deposits, etc. (Fischer, H, 2016; Meadows, D. H., 2008). Flows, therefore, are the actions that cause change in stocks. In systems, such as an ecosystem, there are multiple stock and flows that all affect one another and overlap, creating a complex system (Fischer, H, 2016; Meadows, D. H., 2008). Feedback loops are the mechanism through which all flows and stocks interact.

In general, a feedback loop is a mechanism or state in which the increase or decrease of a stock affects the flows in and out of that same stock or a different stock (Meadows, D.H., 2008; Bajzelj, B., Richards, K. S., 2014; Carbo-Valverde, S., Linares-Zegarra, J. M., Rodriguez-Fernandez, F., 2012). Feedback loops can be simple and direct or they can be complicated with multiple stocks and flows impacting one another simultaneously (Meadows, D.H., 2008). There are two major types of feedback loops balancing (better known as negative feedback loops) and reinforcing (better known as positive feedback loops).

Negative feedback loops, are stabilizing, goal seeking, and regulating feedback loops (Meadows, D. H., 2008, p. 187). They reverse the direction of change of a stock rather than enforcing it in the same direction (Meadows, D. H., 2008). An example of this would be an average person's consumption of coffee (Meadows, D. H., 2008). As someone loses energy they will often consume coffee as a source of caffeine to raise that level of energy back to the desired amount. Once they feel that the appropriate level of energy has been restored, they will stop the consumption of coffee. They are able to correct both an overabundance of energy and underabundance. Coffee can therefore be used to reverse the change in energy level in both directions in a negative feedback loop.

Positive feedback loops, however, only work in one direction. Rather than correcting an incorrect level of stock, they enhance the direction of change that happens to it (Meadows, D. H., 2008; Bajzelj, B., Richards, K. S., 2014; Carbo-Valverde, S., Linares-Zegarra, J. M., Rodriguez-Fernandez, F., 2012). Because they amplify change, they can often lead to exponential growth if uninhibited and create a "viscous cycle and virtuous circle" (Meadows, D. H., 2008, p. 187). A continuous positive feedback loop is what energy poverty and global poverty exist in without outside intervention (Meadows, D.H., 2008). Rabbit reproduction is a clear example of positive feedback loops.

The more adult rabbits there are increases the volume of baby rabbits that will be born. The more baby rabbits there are will grow up to create a higher population of adult rabbits. The more adult rabbits will birth even more baby rabbits after that. With energy poverty, individuals require money to purchase both clean and dirty energy producing resources such as propane and fuelwood respectively. Without energy resources, they lose the ability to perform daily tasks such as cooking, cleaning, studying, and business management or production. Without those daily tasks, individuals cannot earn enough money to purchase energy resources. Thus, exists the simplified positive feedback loop between energy poverty and global poverty.

Energy poverty and global poverty are each considered their own stock, therefore they exist in a two-stock positive feedback loop. There are two types of two-stock feedback loop systems, a renewable stock constrained by a nonrenewable stock, and a renewable stock constrained by a renewable stock (Meadows, D. H., 2008). Since both energy poverty and global poverty can both be renewed by human action, they exist in a renewable stock constrained by a renewable stock feedback loop. Many factors or resources affect changes in each stock and each stock affects the other stock which makes for a complex feedback loop system. Renewable resources that affect each stock are flow-limited meaning they can be indefinitely harvested at a sustainable replenishing or regeneration rate (Meadows, D. H., 2008).

Two other concepts are pertinent to feedback loop behavior, shifting dominance and resilience. It is rare that two feedback loops will exist in perfect balance always, therefore one of them typically has slight dominance over another (Meadows, D. H., 2008). The constant changing of dominance is referred to as shifting dominance (Meadows, D. H., 2008). Feedback loops also constantly experience many variables and impacts due to their complex nature. Their ability to recover back to their equilibrium state is referred to as resilience (Meadows, D. H., 2008, p. 76). Feedback loops can work together to achieve resilience, unfortunately, energy poverty and global poverty produce negative effects when they work together.

Human Wellbeing Consequences of Energy Poverty

Having low to no energy access results in dire physical health and wellbeing consequences for many people. Examples of physical health and wellbeing effects include, the volume of able people to perform labor, business growth, quality of health, comfort, life expectancy, and education quality and access (El-Katiri, L., 2014; Silwal, 2015; Global Alliance for Clean Cookstoves, 2016; Practical Action, 2012, 49; Schilmann, 2015; Weldu, 2017; Sambandam, 2015; Sanchez, 2010, p.9). Energy is necessary for many daily activities such as cooking, but households with energy poverty do not have conventional and clean cooking methods available (Sanchez, 2010, p. 2; Practical Action, 2010, p. 7; Global Alliance for Clean Cookstoves, 2010). They instead rely on solid biomass fuels which are a major fuel source for countries with energy poverty (Silwal, 2015; Thorsson, 2014; Sambandam, 2015; Schilmann, 2015; Poddar, 2016). Those fuels consist of firewood, charcoal, crop waste, dung, and coal (Poddar, 2016; Weldu, 2017; Silwal, 2015; Sambandam, 2015). Common inefficient stoves that utilize these dangerous fuels are three-stone fires, traditional mud stoves, and metal, cement, pottery or brick stoves with no chimneys or hoods (IEA, 2010, p. 13). Unfortunately, burning these results in human and ecological health degradation as well as high indoor air pollution (IAP indoor air pollution can also be referred to as household air pollution (HAP) in the context of this thesis) (Poddar, 2016; Weldu, 2017).

The indoor air pollution created from inefficient combustion of biomass through open fires and inefficient stoves in these homes causes a variety of harmful emissions (Poddar, 2016; Weldu, 2017; Halff, 2014; Thorsson, 2014; Schilmann, 2015; Global Alliance for Clean Cookstoves, 2016). Some of which are above the current World Health Organization (WHO) air quality guide values and some particulate matter have been found in concentrations over 100 times the World Health Organization recommended levels (Sambandam—WHO 2006; Global Alliance for Clean Cookstoves, 2016). These emissions include: particulate matter, carbon monoxide, and polycyclic aromatic hydrocarbons, and more (Schilmann, 2015; Sambandam, 2015; Thorsson, 2014). When these are inhaled over a certain period of time, it leads to a myriad of health effects including pneumonia, lung cancer, chronic obstructive pulmonary disease, heart disease, cataracts, low birthweight in babies, acute and chronic irritation of the respiratory tract and interference in inflammatory response (Schilmann, 2015; Sambandam, 2015; Thorsson, 2014; Global Alliance for Clean Cookstoves, 2016). Air pollution from biomass fuels also increases the risk of pneumonia and respiratory disease in children, and lung cancer and COPD in adults because of particulate matter (Thorsson, 2014). An estimated 1.45 million people die prematurely each year from indoor air pollution, which is greater than the number of deaths caused by malaria or tuberculosis (IEA, 2012, p. 13). Therefore, identifying indoor and household air pollution as leading suppressors of health and societal, growth.

Cooking with firewood is the primary cause behind household air pollution, which is a major cause of poor respiratory health. Poor respiratory health has been shown to shorten lives, therefore, cooking with firewood is likely to decrease life expectancy (Silwal, 2015). Lifetime expectancy is an indicator of energy poverty because those with a shorter life expectancy are most likely those using cheap, dirty fuels such as firewood.

Indoor air pollution is especially a health detriment for women and children under the age of five because young children spend most of their time with their mothers who cook inside with open fires using unhealthy cooking fuels that produce harmful emissions (Schilmann, 2015; Thorsson, 2014; Silwal, 2015; Halff, 2014; Global Alliance for Clean Cookstoves, 2016). These women and children are spending disproportionate amounts of time indoors where this air pollution is created (Schilmann, 2015; Thorsson, 2014; Silwal, 2015; Halff, 2014; Global Alliance for Clean Cookstoves, 2016). With extended exposure comes increased risk of health complications. These dangerous open flames in close proximity to the living area can also cause burning which may result in scars or even death (Global Alliance for Clean Cookstoves, 2016). Therefore, “babies are born into a world of smoke” (Halff, 2014, p.152) and women and children are dying at higher rates because of their environment.

Not only do women and children disproportionately attend to cooking, they also complete the house chores and studying for school. Children that are enrolled in school often use cookstoves as their light source for studying and homework which is strenuous on the eyes and increases their exposure to the burning of unclean cooking fuels (Global Alliance for Clean Cookstoves, 2016). Lighting is also necessary for working or maintaining a business after sunlight hours which is commonly necessary for many businesses (Practical Action, 2012, 49). People living in energy poverty have no access to electricity for lighting and therefore rely on inefficient forms of lighting, such as kerosene lamps, candles, and cookstoves (Practical Action, 2012, 49; Global Alliance for Clean Cookstoves, 2016). Even with those technologies, only low levels of light are possible which makes it difficult for children to study and perform well in school (Practical Action, 2012, 49). Switching from open fire cooking methods to efficient biomass cook stoves such as the Patsari cook stove improve children's health, decrease the time children are sick, improve lung capacity, decrease respiratory consequences, and improve business and educational success (Schilmann, 2015; (Halff cited Barnes et al 1994); Weldu, 2017; Sambandam, 2015; Sanchez, 2010, p.9). This would help society improve and grow as a whole as overall health would increase, children would perform better in school, and businesses (upon which societies are based) could grow, flourish, and provide more jobs and incomes. Those incomes could then go towards more efficient cooking technologies, cleaner fuels, and eventually gain the ability to gain access to the cleanest fuel source: electricity.

Low or no access to energy also results in inadequate and unreliable household space heating in the winters and cooling in the summers, which can prove to be fatal if weather is severe (Practical Action, 2012, p. 55). Space heating is especially important in temperate regions, where heating is a necessity for survival in cold seasons (Practical Action, 2012, p. 55). However, roughly half of a billion people in South Asia rely primarily on cookstoves for heating (Practical Action, 2012, p. 55). Unfortunately, prolonged expose to cold temperatures leads to the same respiratory diseases that indoor air pollution does (Practical Action, 2012, p.55). This puts many people living in those climates in a situation where they must decide between enduring the cold weather health consequences without heating but breathing in no pollution, or being comfortable with heating but enduring the health consequences of indoor air pollution. Like cold climates, indoor space cooling is necessary for hot and humid areas, but people living in energy poverty often do not have the means to access this service. Prolonged exposure to very hot temperatures also causes negative health effects and reduces productivity and comfort (Practical Action, 2012, p.57). For example, cooling is very necessary for preserving food for prolonged periods and preventing contamination (Practical Action, 2012, p.57). Lack of cooling also prevents hospitals from achieving reliable storage temperatures of vaccines and medicines which can further impact people that are getting sick from having no energy access to begin with (Sanchez, 2010, p. 9). This can have many societal consequences if medical care severely decreases from already poor standards.

Not only does low to no energy access negatively impact comfort and safety within residential buildings, but no energy access within hospitals and health care buildings can have fatal implications. Hospitals and health care buildings are the most energy intensive of all commercial buildings (Wang, T., 2016). Because hospitals and health care are essential to quality of health, this makes them a key element when studying energy impoverished countries. Due to hospital variations and high levels of uncertainty, it is extremely difficult to estimate how much energy is consumed by hospitals but it is agreed upon that energy is a key element to hospital success (Christiansen, N., 2015; Christiansen, N., 2016). Electricity specifically is an important part of the energy flows in hospitals and health care buildings because of their direct connections to diagnostics and medical care (Christiansen, N., 2016). Hospital energy, like all commercial and residential building energy, is devoted to heating, cooling (refrigerators), lighting, electrical equipment, medical appliances (Christiansen, N., 2015). However, their vast variety of medical equipment is what separated hospitals from all other buildings in the context of energy evaluation (Christiansen, N., 2016). The major energy consuming appliances and devices include: operating rooms, intensive care units, examination and treatment rooms, and large scale equipment such as linear accelerators, MRI scanners, computer tomographs, angiographs, x-ray generators, and mammographs, sterilization (Wang, T. 2016; Christiansen, N., 2016). What is clear from this list is that the most essential devices dealing with emergency care require the most energy. If a country is without energy access, their hospitals will lack basic emergency procedures. Without these procedures and clean spaces, the overall quality of health care greatly decreases which will then degrade quality of life for the citizens over time. Energy access is strongly connected with quality of health care and quality of life.

In addition, obtaining enough biomass to fuel inefficient cookstoves often requires time-consuming and strenuous labor (Practical Action, 2012, p.51; IEA, 2010, p.14, Global Alliance for Clean Cookstoves, 2016). Women are often the ones to carry heavy loads of firewood and other fuels for long distances rather than the men (Practical Action, 2012, p.51, IEA, 2010, p.14). For example, in some areas of Tanzania, women walk 5 to 10 kilometers a day, carrying between 20 and 38 kilograms of fuel (Practical Action, 2012, p.51). This hard, manual labor leads to risk of head and spinal injuries, gender-based violence, dehydration, animal attacks, and skin disorders (IEA, 2010, p. 14, Global Alliance for Clean Cookstoves, 2016). The time demand of fuel retrieval also creates gender inequalities as women are unable to find time to generate income or complete education (Practical Action, 2012, p. 51).

In all areas of the world there is a strong relationship between education and health. If a person is in good health they are able to focus on more education but if they are in poor health, education often becomes a lesser priority and less achievable. Increasing education will increase knowledge of negative health impacts from indoor air pollution, therefore influencing individuals' fuel choice to switch to cleaner fuels which will reduce indoor air pollution (Poddar, 2016). Using better fuels are therefore directly influenced by higher level of education (Poddar, 2016). Education duration and literacy rates of countries can therefore be used as indicators of energy poverty. Higher levels of energy correlate to cleaner energy which allow for longer education duration which then leads to higher literacy rates. With greater education and literacy will come a desire for healthy fuels which will improve overall health.

Unfortunately, education and knowledge of negative health impacts from indoor air pollution are not the only factor in fuel choice. There are two major factors in fuel choice: money and availability of resources. Money is a leading factor because fuel constitutes a large portion of household spending. As a household's finances change over time they are more likely to upgrade to clean cooking fuels or downgrade to dirtier cheaper ones depending on if income rises or falls (Silwal, 2015). Households with more money are more likely to use cleaner cooking fuels than less fortunate houses. Availability also plays a major role in fuel choice (Poddar, 2016). People can only burn what is physically available to them in their surroundings. If there is a supply of fuelwood and no electricity within reach of a household, they must choose to use that fuelwood due to no other options. Regardless of how much money a household has to spend, they cannot buy something that is not there. Therefore, heat production sources used are another indicator of energy poverty. If those households are able to make the switch from hazardous solid cooking fuels to electricity, they reap many benefits.

When a household switches from solid fuels to electricity, they are exposed to fewer combustion emissions resulting in lower indoor air pollution and less incidence of disease (Silwal, 2015; Poddar, 2016). As households acquire more income they are able to gain more resources, often leading to the addition of electricity in their lives. Because the switch from solid cooking fuels to electricity results in much lower health risk, and electricity is obtained by monetary gain, this shows a direct causation correlation between wealth and health. Unfortunately, many countries are struggling to obtain energy, making it a modern fuel (Poddar). Those living in energy poverty are unable to access electricity by definition, and therefore electricity rates are another indicator of energy poverty.

All of these indicators have concluded that degraded health is the major immediate consequence of living in energy poverty. However, with degraded health comes many more negative consequences that build on each other creating a lower quality of life and a difficult situation to escape from. These include discomfort, shortened life expectancy, learning impairments, work limitations, and less time to be productive. According to Maslow's Hierarchy of Needs, physical and mental health of an individual are basic needs that must be met before any other needs can be fulfilled (Kermally, 2004; Taormina, 2013). Therefore, low health leads to a society's inability to advance because it is a basic need that must be met before economic or societal growth can be considered. Energy poverty has many negative wellbeing consequences at both the individual and societal scale that can make it near impossible to escape from.

Human Wellbeing Consequences of Energy Poverty

Run time: 50 – 75 minutes

This lesson plan is the second section of a larger modifiable Science on a Sphere module on Energy Poverty designed for college-level courses. This second lesson can range from 50-75 minutes. A 50-minute class would assign the post-class worksheet as homework, and a 75-minute class would complete the worksheet at the end of class.

Learning Objectives

Big Idea: Energy poverty and global poverty are caught in a reinforcing feedback loop.

Lesson Goal: for students to develop a factual understanding of the consequences to human wellbeing from energy poverty.

Student Learning Goals and Objectives:

1. Students will demonstrate and understanding of the concept of feedback loops.
2. Students will explain how no energy access degrades human health and wellbeing as well as demonstrate examples of this.
3. Students will analyze relationships between different Science on a Sphere datasets in order to draw conclusions on how global poverty and energy poverty affect each other.

Datasets

Primary Education Completion

Primary Education Completion shows the percentage of the population that has completed primary education. The data were obtained from the World Bank's Sustainable Energy for all (SE4ALL) database from the WHO Global Household Energy database, as well as the Population Refence Bureau DataFinder database, and compiled on a world dataset using ArcGIS for the purposes of this project. Values were parsed together between the years 2005-2014. The image is included in the 'Datasets (Images)' section of this manual.

World Bank, Sustainable Energy for All (SE4ALL) database from World Bank, Global Electrification database. (2014). *Primary completion rate, total (% of relevant age group)*. Retrieved from http://data.worldbank.org/indicator/SE.PRM.CMPT.ZS

PRB The World's Women and Girls 2011 Data Sheet. (2011). *Primary School Completion Rate, by Gender*. Retrieved from http://www.prb.org/DataFinder/Topic/Rankings.aspx?ind=242

Infant Mortality Rate
Infant Mortality Rate shows number of infants that died per every 1,000 live births in 2015. The data were obtained from the World Bank's Sustainable Energy for all (SE4ALL) database from the WHO Global Household Energy database, and compiled on a world dataset using ArcGIS for the purposes of this project. The image is included in the 'Datasets (Images)' section of this manual.

World Bank, Sustainable Energy for All (SE4ALL) database from World Bank, Global Electrification database. (2015). *Mortality rate, infant (per 1,000 live births)*. [Data file]. Retrieved from http://data.worldbank.org/indicator/SP.DYN.IMRT.IN

Labor Force in Agriculture
Labor Force in Agriculture shows the percentage of people in the labor force that work in agriculture. The data were obtained from the World Factbook library, and compiled on a world dataset using ArcGIS for the purposes of this project. The image is included in the 'Datasets (Images)' section of this manual.

The World Factbook. (2015). *Field Listing: Labor Force – By Occupation*. [Data file]. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/fields/2048.html

PM 2.5 Exposure
Particulate Matter 2.5 Exposure shows the percentage of population that is exposed to particulate matter 2.5 air pollution at levels that exceed the WHO guideline values in 2015. The data were obtained from the World Bank's Sustainable Energy for all (SE4ALL) database from the WHO Global Household Energy database, and compiled on a world dataset using ArcGIS for the purposes of this project. The image is included in the 'Datasets (Images)' section of this manual.

World Bank, Brauer, M. et al. 2016, for the Global Burden of Disease Study 2015. PM 2.5 air pollution, population exposed to levels exceeding WHO guidelines (% of total). [Data file]. Retrieved from: http://data.worldbank.org/indicator/EN.ATM.PM25.MC.ZS

Instructor Script

Pre-lesson Preparation (1 hour, before presentation)
Before taking part in the lesson, students will be asked to complete an assignment in order to familiarize themselves with systems, feedback loops, and human wellbeing consequences of energy poverty. This will ensure that all students who complete the assignment are coming to the lesson with the same foundational knowledge of what systems and feedback loops are and start thinking about how energy poverty and global poverty interact. By beginning the thinking process beforehand, students will be able to develop a deeper understanding of these concepts during the lesson. The pre-lesson preparation assignment is found at the end of this lesson plan.

Procedures/Lesson Sequence

This portion of the class is instructor led. Students will watch the Science on a Sphere presentation and discuss the information presented as a large group. The lesson will open in a transition from the first portion: Overarching Problem of Energy Poverty. It will then close in a transition into considering the environmental impacts of energy poverty.

Before any projections are displayed on the sphere, it is important for the instructor to reiterate to the class that the shading scale for all of the projections is uniform: dark coloring indicates the "bad" level of the indicator. For example, in the map showing access to non-solid fuels, low percentages of total access are dark orange and high percentages of total access are light orange. The projections are intentionally designed this way in order to draw viewers' attention to the energy impoverished countries rather than the developed countries. All projections created for this lesson are intentionally not adjusted to mimic the Earth's natural tilt of 23 degrees in order to allow for better critical thinking and analysis. The instructor should feel free to tilt the projections at any time in order to show a country higher up on the globe to make important points to the class.

For classes of 20 or less, students should be encouraged to walk around the sphere as projections are displayed. This will allow for more individual analysis and will help with answering worksheet and clicker questions. For classes larger than 20, students should remain in their seats for the lesson or they can be paired into groups of 2 and take turns walking around the sphere.

Lesson Opening (12 minutes): The instructor should review the pre-assignment to ensure that the students understand the concepts of systems and feedback loops and are in the right mindset for this presentation.

- **Clicker Question 1**: Drawing on your understanding of feedback loops and systems, which of these individuals is experiencing the energy poverty/global poverty feedback loop?
    a) Jane who is unable to hire a new employee for her paper business because her town members can't afford to print personal documents.
    b) Leon who has to decide between getting an MRI scan and fixing his car's engine problem.
    c) Delilah who spends 5 hours a day collecting fuelwood which is suppressing her hand-woven blanket business.
    d) Marcel who cannot get his gas station business off the ground because his town has greatly adopted electric cars.
    Students should select "c".

Dataset 1 (5 minutes): The first indicator of human wellbeing that will be presented on the Sphere is Educational Attainment. This dataset shows the percentage of women in the 25 years and older population that have completed upper secondary education.

- **In Class Worksheet Question 1:** Looking at the Educational Attainment dataset, record your observations.

- **Clicker Question 2**: Jelani is a 20-year-old woman lives in the Central African Republic. What does her country's level of educational attainment of 25+ years-old women imply?

    e) Jelani's town does not prioritize education because they do not find it necessary in their culture.
    f) Jelani has most likely only received schooling up to grade 6 and does not have the skills to get a job which will prevent her from gaining economic growth.
    g) Jelani has completed upper secondary school but there is no infrastructure that will allow her to gain economic growth.
    h) Jelani most likely just has poor studying skills and dropped out of school by choice. Thus, prohibiting her from getting a steady job.
    Students should select "b".

Dataset 2 (5 minutes): Students will next look at the second human wellbeing indicator on the Sphere, Infant Mortality. This indicator is essential to this lesson because it holds a great deal of information within it. Infant mortality encompasses air quality, cooking fuel cleanliness, health care availability and quality, sanitation, indoor comfort, and maternal health because they act as an indicator species.

- **In Class Worksheet Question 2**: What percent of infants die in the United States annually? What percent of infants die annually in Angola? Note that the legend is in number of deaths per 1,000 not 1 per 100.

- **Clicker Question 3**: What does infant mortality also tell us about indirectly?

i) Human tolerance of current pollution levels
j) Quality of and available hospital and health care
k) Sanitation processes
l) Maternal health
m) All the above
Students should select “e”.

Dataset 3 (5 minutes): Students will then look at the third human wellbeing indicator on the Sphere, Labor Force in Agriculture.

- **In Class Worksheet Question 3**: Why doesn’t the United States have a higher percentage of people in agriculture? Why are African and Asian countries living with such high populations working in agriculture?

- **Clicker Question 4**: Why are African and Asian countries living with such high populations working in agriculture?

  n) The United States eats a lot of processed foods and therefore needs less farms.
  o) People living in African and Asian countries have lower incomes and must grow their own food per household.
  p) The United States only supports industrial business growth and does not offer any farming subsidies which makes it harder for farmers to excel.
  q) African and Asian countries have agriculture ingrained in their culture and do not want to progress out of individual farms.
  Students should select “b”.

Dataset 4 (5 minutes): Students will end by looking at the fourth human wellbeing indicator on the Sphere, PM 2.5 Exposure.

- **Clicker Question 5**: Jeremiah lives in the Democratic Republic of the Congo. What is a likely reason that he lives with a much higher exposure to PM 2.5 air pollution exposure than Alia who lives in Florida, US?
  r) Jeremiah does not have any air conditioning and hot air sits around longer.
  s) Alia is fortunate enough to live in a drier climate which naturally has less air pollution.
  t) Jeremiah has no central air system and uses natural gas to cook.
  u) Jeremiah burns switchgrass to cook and has no ventilation system.
  Students should select “d”.

Wrap-Up (10 minutes): The instructor will summarize the following conclusions that this lesson has reached:

- Feedback loops can be very complex. Energy poverty and global poverty exist in a complex feedback loop because a negative consequence in one of them causes negative consequences in the other. For example, an income below the poverty line inhibits one from affording quality health care which long-term could lead to a pregnant woman not receive health care during labor resulting in either maternal or infant death.

- There are many wellbeing consequences for humans living in energy poverty including poor health and health care availability, high infant mortality rates, inability to advance economically, and poor air quality.

Pre & Post Assessment

The following sections include a pre-lesson preparation assignment, in-class "clicker"-style multiple choice questions and answers, an in-class worksheet and corresponding answers, and a post-lesson assignment. These resources will be used to assess the students' learning and comprehension of the concepts presented before, during, and after observing the presentation.

Human Wellbeing Consequences of Energy Poverty: Pre-Lesson Preparation Assignment

Part A: Read Meadows' Thinking In Systems: A Primer Part 1: Systems Structure and Behavior (Pages 11-34).

Meadows, D. H. (2008). *Thinking In Systems: A Primer*. London, UK: Earthscan.

Part B: Using your assigned country from lesson 1, go back to the World Bank database and research your country's infant mortality rate. Infant mortality rate is the number of infants dying before 1 year of age per every 1,000 births in a year. In the indicator description, the World Bank states that malnutrition and medical intervention are large contributors to neonatal deaths. What other factors do you think contribute to infant mortality? Consider where they spend the majority of their time.

- World Bank infant mortality indicator link: http://data.worldbank.org/indicator/SP.DYN.IMRT.IN?view=chart

Human Wellbeing Consequences of Energy Poverty: In-Class Clicker Questions and Answers

- Clicker Question 1: Drawing on your understanding of feedback loops and systems, which of these individuals is experiencing the energy poverty/global poverty feedback loop?
    - v) Jane who is unable to hire a new employee for her paper business because her town members can't afford to print personal documents.
    - w) Leon who has to decide between getting an MRI scan and fixing his car's engine problem.
    - x) Delilah who spends 5 hours a day collecting fuelwood which is suppressing her hand-woven blanket business.
    - y) Marcel who cannot get his gas station business off the ground because his town has greatly adopted electric cars.

    Students should select "c".

- Clicker Question 2: Jelani is a 20-year-old woman lives in the Central African Republic. What does her country's level of educational attainment of 25+ years-old women imply?
    - z) Jelani's town does not prioritize education because they do not find it necessary in their culture.
    - aa) Jelani has most likely only received schooling up to grade 6 and does not have the skills to get a job which will prevent her from gaining economic growth.
    - bb) Jelani has completed upper secondary school but there is no infrastructure that will allow her to gain economic growth.
    - cc) Jelani most likely just has poor studying skills and dropped out of school by choice. Thus, prohibiting her from getting a steady job.

    Students should select "b".

- Clicker Question 3: What does infant mortality also tell us about indirectly?
    - dd) Human tolerance of current pollution levels
    - ee) Quality of and available hospital and health care
    - ff) Sanitation processes
    - gg) Maternal health
    - hh) All the above

    Students should select "e".

- Clicker Question 4: Why are African and Asian countries living with such high populations working in agriculture?

  ii) The United States eats a lot of processed foods and therefore needs less farms.
  jj) People living in African and Asian countries have lower incomes and must grow their own food per household.
  kk) The United States only supports industrial business growth and does not offer any farming subsidies which makes it harder for farmers to excel.
  ll) African and Asian countries have agriculture ingrained in their culture and do not want to progress out of individual farms.
  Students should select "b".

- **Clicker Question 5**: Jeremiah lives in the Democratic Republic of the Congo. What is a likely reason that he lives with a much higher exposure to PM 2.5 air pollution exposure than Alia who lives in Florida, US?
  mm) Jeremiah does not have any air conditioning and hot air sits around longer.
  nn) Alia is fortunate enough to live in a drier climate which naturally has less air pollution.
  oo) Jeremiah has no central air system and uses natural gas to cook.
  pp) Jeremiah burns switchgrass to cook and has no ventilation system.
  Students should select "d".

Human Wellbeing Consequences of Energy Poverty: In-Class Worksheet

Question 1: Looking at the Educational Attainment dataset, record your observations.

Question 2: What percent of infants die in the United States annually? What percent of infants die annually in Angola? Note that the legend is in number of deaths per 1,000 not 1 per 100.

Question 3: Why doesn't the United States have a higher percentage of people in agriculture? Why are African and Asian countries living with such high populations working in agriculture?

Human Wellbeing Consequences of Energy Poverty: In-Class Worksheet Answers

Question 1: Compare the GDP PPP Per Capita values of Central African Republic and the United States.

Students should note that the Central African Republic is in the lowest possible GDP PPP Per Capita bracket whereas the United States is in the highest possible bracket. They should also observe that the maximum of the low bracket is $33,000 dollars below the minimum of the highest bracket. It is also important to observe that there is also a significant difference in the two brackets' ranges. The low bracket spans $2,200 whereas the high bracket spans $110,000. Students can also make general observations that are consistent with lesson 1 conclusions. African countries are in the lowest two brackets whereas the North America and Europe are in the highest two brackets. This is consistent with lesson 1 because with all of the energy poverty and global poverty indicators, developed countries will be much more successful than underdeveloped countries.

Question 2: What percent of infants die in the United States annually? What percent of infants die annually in Angola? Note that the legend is in number of deaths per 1,000 not 1 per 100.

Students will look at the legend ranges and divide those number by 10 to get the number of deaths per 100 deaths, which is percentage. The percentage of infants under a year old that die in Angola every year is somewhere between, 7.6-9.0%. The percentage of infants under a year old that die in the United States every year is somewhere between 0.2-1.5%

Question 3: Why doesn't the United States have a higher percentage of people in agriculture? Why are African and Asian countries living with such high populations working in agriculture?

Income is closely tied to people's ability to purchase food rather than provide it for themselves. People that live with low incomes are more likely to provider their own basic food needs such as grains and produce. Gardens and farms are typically cheaper and more reliable than regular grocery shopping, so it is quite common for lower income households to maintain small scale agriculture. When entire countries are living in poverty on a large scale, it is less likely that strong grocery infrastructure will exist because individual households are more likely to try to support themselves. Working on a household farm is considered a person's job, so when large portions of a country support themselves on individual farms most the labor force is made up of agriculture. This is the case for African and Asian countries. The United States on the other hand is a very wealthy country and the majority of the population is able to focus their efforts on other types of work rather than supporting their basic daily needs. Therefore, wealthy countries' labor force has a small percentage of agriculture representatives.

Human Wellbeing Consequences of Energy Poverty: Post-Lesson Assignment

There are many types of complex and dynamic feedback loops in nature and our lives. What is another example of a feedback loop (can be positive or negative)? Explain. (200-300 words). Drawing yourself a diagram may prove helpful.

You also learned a multitude of health consequences of energy poverty. Which one stood out the most to you? What other branching effects would this consequence or indicator have on your life, those around you, or the environment? Explain. (200-300 words).

Human Wellbeing Consequences of Energy Poverty: Post-Lesson Assignment Rubric

Students should start by identifying a natural feedback loop and explaining the relationship based on how feedback loops were explained and discussed in the lesson. A positive feedback loop is a relationship in which as one thing increases, the other amplifies as well. A good example of a positive feedback loop is high birth rates. If birth rates increase, populations will increase, and as population increases, more relationships can form and create more babies, who will then grow up to form more relationships and so on. Students can also discuss negative feedback loops which are relationships balance or reinforce one another. A good example of a negative feedback loop is a predator prey relationship between sheep and wolves. Imagine there is an environment of only sheep and wolves. If the sheep fall ill and their population decreases, there is less food for wolves and their population will decrease as well. A decreased wolf population allows for the sheep population to grow again (after illness) to greater numbers because there are less wolves eating them. An increased sheep population, however, allows for the wolf population to grow again. This cycle continues constantly balancing and reinforcing.

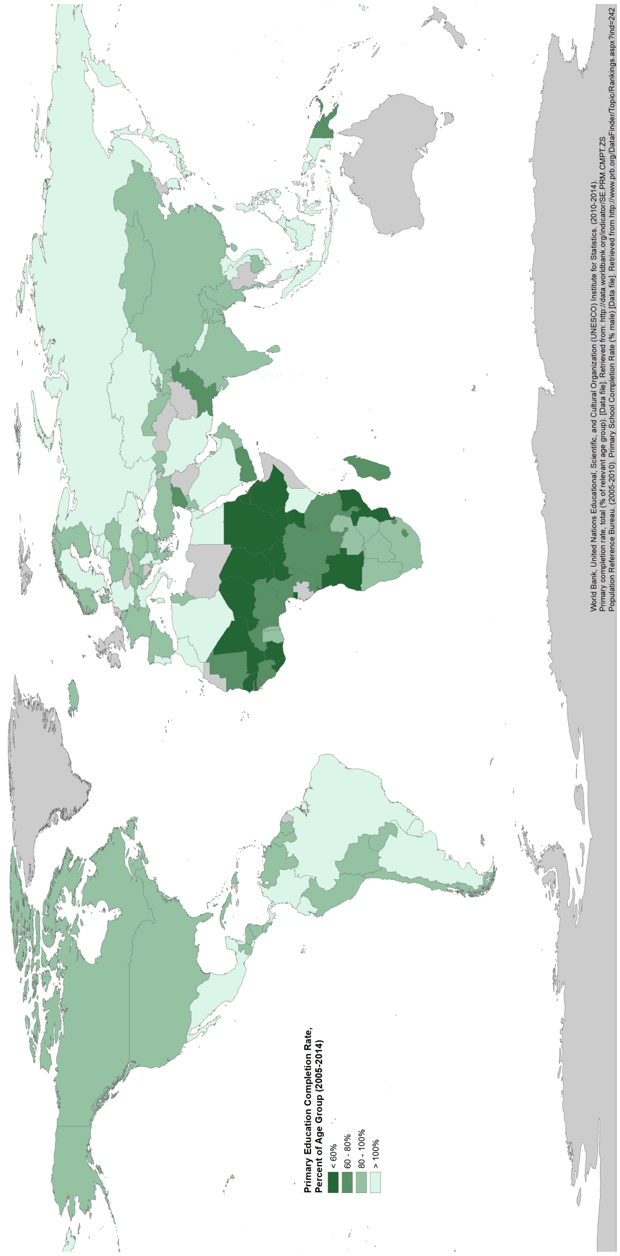
For the second portion, students should recognize that the indicators of human wellbeing consequences (Infant Mortality, Primary Education Completion, and Labor Force in Agriculture) also support that the country is living in energy poverty. They should then point out and focus on one of those three in particular that had the biggest impact on them. Although these indicators alert us of countries living in energy poverty, they also have a domino effect on other things such as, but not limited to, other health complications, economics, and cultural limitations. Students should consider what else their chosen indicator impacts and implies. For example, infant mortality is an indicator that has multiple indicators wrapped inside. High infant mortality rates may indicate unsafe air and/or water, quality, poor nutrition, sick or overworked mothers, dangerous temperatures, and low levels of or lack of sanitation. A student could then go into detail on how those would impact their lives even further, or how high infant mortality rates would impact a village or society short and long term.

Students are welcome to use reliable resources to get an idea of how their indicator interacts with other aspects of health, environment, social, cultural, political, and economic aspects of life. They can even use a specific country to illustrate their points.

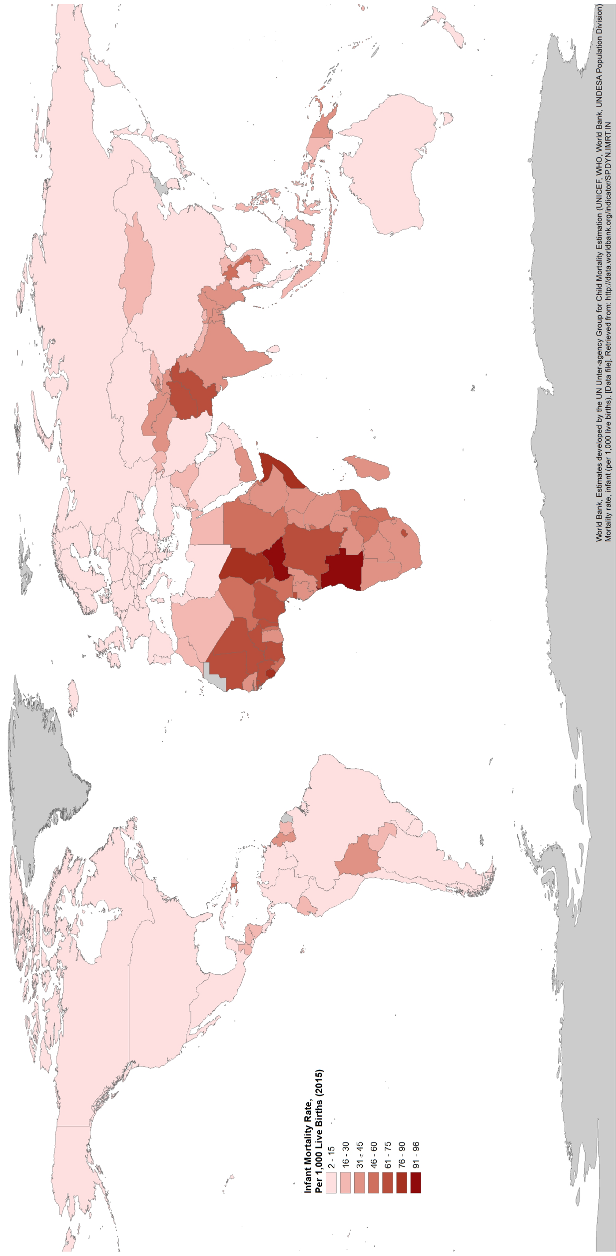
Datasets (Images)

This section contains the original images created by the authors. Using data from the World Bank, The World Factbook, and the Population Refence Bureau, maps were created in ArcGIS and saved as JPEG files. These include Primary Education Completion, Infant Mortality, Labor Force in Agriculture, and PM 2.5 Exposure.

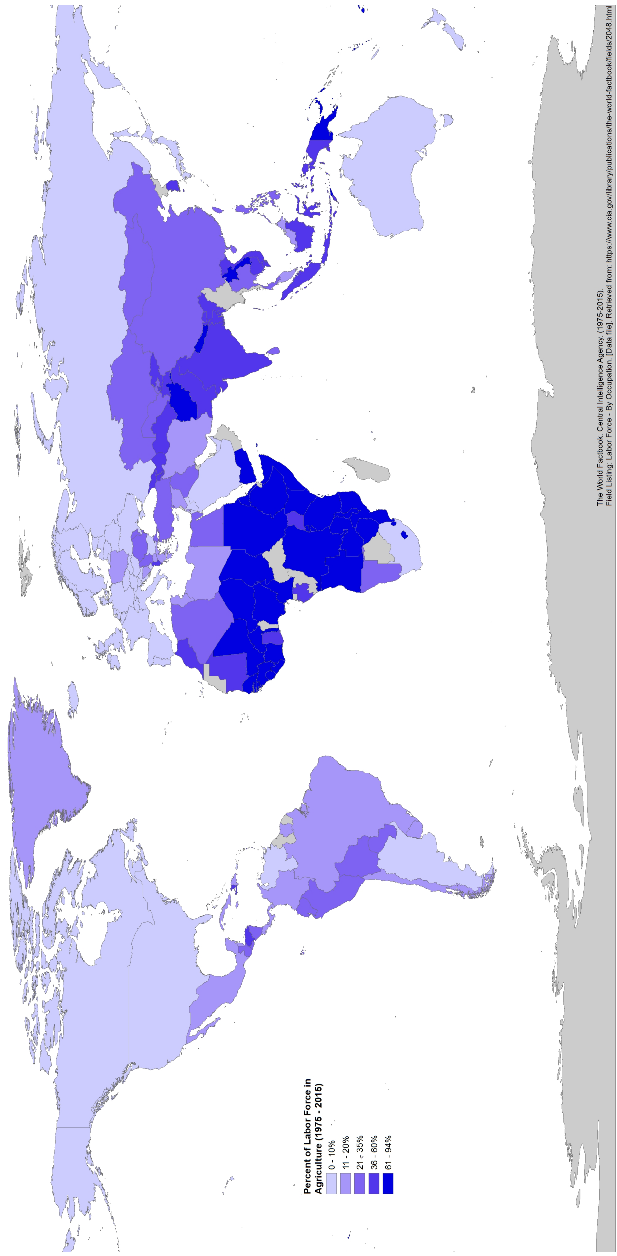
DATASET 1. PRIMARY EDUCATION COMPLETION



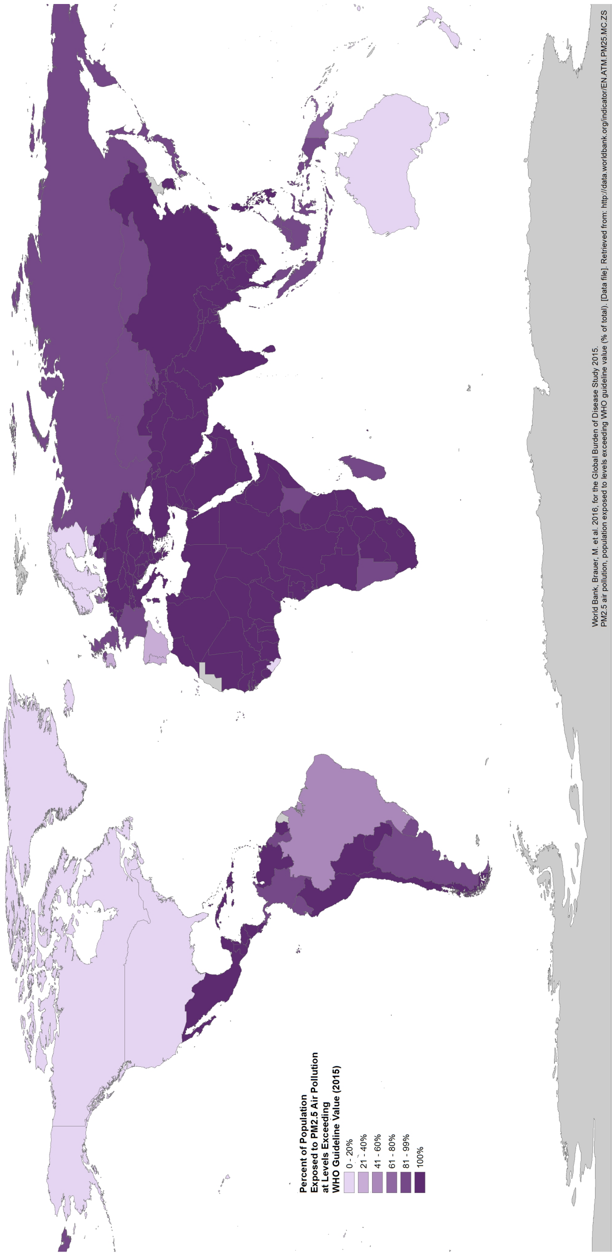
DATASET 2. INFANT MORTALITY



DATASET 3. LABOR FORCE IN AGRICULTURE



Dataset 4. PM 2.5 Exposure



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Energy Poverty: SOS Environmental Wellbeing Consequences of Energy Poverty

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*Rachel aided with dataset creation but none of the literature review nor lesson planning for this lesson.

Table of Contents

Overview of the Lesson

The purpose of this project was to develop a set of college-level teaching and learning resources about energy poverty that incorporate the spherical display system Science On a Sphere (SOS). This manual consists of the third of four full lesson “packages” regarding energy poverty that make up the authors’ larger Senior Capstone Project in the Department of Integrated Science and Technology at James Madison University in Harrisonburg, Virginia.

This manual contains the Lesson 3 package about the consequences to environmental wellbeing associated with energy poverty. It includes a background analysis, a comprehensive lesson plan, an instructor script, images, and descriptions.

The manual includes:

- Learning Objectives[2]
- VA SOL Correlations
- Next Generation Science Standards
- Dataset Descriptions
- Student Handouts & Worksheets
- Presentation Tips
- Instructor Script
- Audience Frequently Asked Questions (FAQs)
- Pre & Post Lesson Assessment

The manual also includes instructions to access to a supplemental video that illustrates an interactive lesson with Science On a Sphere. The video is interspersed with commentary regarding pedagogy with SOS.

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2 All icons used in this manual are Creative Commons images and selected from the Noun Project
https://thenounproject.com. Individual designer attribution for each icon is below: Learning Objectives: Pete Fecteau, VA SOL Correlations: Jan Christoph Borchardt, Next Generation Science Standards: Adrian Rguez Perez, Dataset Descriptions: Creative Stall, Student Handouts and Worksheets: Jaclyn Ooi, Presentation Tip: mh, Instructor Script: TukTuk Design, Audience FAQs: Anas Ramadan, and Pre & Post Visit Assessment: Berkay Sargin.

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Background Analysis

Introduction

Environmental consequences of energy poverty are a complex topic because of the relationships between fuel sources, burning processes, and ecosystems. When comparing developed countries to underdeveloped countries it is easy to blame developed countries for high greenhouse gas emissions and the encouragement of climate change. What is not obvious, is that modern energy sources are not the only problem. In fact, traditional fuels and cooking such as burning fuelwood in an open fire have more detrimental environment consequences than modern energy sources (Ogwumike. F.O., 2015; Sovacool, B.K., et al., 2014; Goldemberg, J., p.102, 2010). Modern energy sources, such as natural gas, produce lower levels of environmental pollution than traditional sources (Ogwumike. F.O., 2015). Goldemberg explains this anti-intuitive conclusion as traditional fuel sources are the cause of respiratory diseases on a micro scale, but on a macro scale, energy consumption is the major source of greenhouse gases (Goldemberg, J., p.102, 2010). Since energy sources are used for essential daily tasks such as to heat homes and cooking, fuel emissions are key to evaluating environmental impacts. This puts modern fuels in a star position in addressing climate change (Ogwumike. F.O., 2015). Therefore, traditional fuels and cooking methods are more detrimental to the environment than modern energy sources (Ogwumike. F.O., 2015; Sovacool, B.K., et al., 2014; Goldemberg, J., p.102, 2010).

In developing countries, more fuel is required for food cooking because of the low efficiencies of traditional cooking stoves (Cartledge, B. et al., 1993). This means that these households will burn higher volumes of traditional fuels than would be required of modern fuels to perform the same tasks, therefore increasing environmental impacts. Unfortunately, many underdeveloped and developing countries show a trend of relying heavily on traditional fuels. For example, Sub-Saharan Africa relies roughly 80% on wood fuels for cooking (Mazimpaka, E., 2014). As discussed in Lesson 2, there are many harmful consequences to human health that come from burning traditional fuels in traditional methods. There are three major categories of environmental consequences that traditional sources produce, deforestation, declining air quality through air pollution, and degrading ecosystems.

Deforestation

Deforestation is the elimination of forests, commonly by human activity (Spray, S., et al, 2006; Asante, M., 2005). Fuelwood is a heavily relied on fuel in most underdeveloped and developing countries which means that trees are cut down constantly to fuel this demand. As populations in these countries grow, there is an increase strain on the environment to provide for the increasing needs which has led to high deforestation (Ogwumike. F.O., 2015; Asante, M., 2005). To exemplify this, Sambo explains that in Nigeria 350,000 hectares of natural vegetation and forests are destroyed annually and that rate is expected to increase due to an increasing demand for traditional, environmentally harmful fuel sources (Sambo, 2009). If these levels are higher than the replenishing rates, as is true for firewood consumption and regeneration in Nigeria, deforestation results (Sambo, 2009).

The major causes of deforestation include logging, spread of agriculture, and collection of firewood (Eckholm, 1979). Agriculture is the major cause of forest loss because of the amount of land required (Eckholm, 1979; FAO, 2012). The second major cause of deforestation is firewood collection (Eckholm, 1979). Half of all wood cut in the world is burned for fuel by the one-third of people who still rely on firewood for cooking and heating (Eckholm, 1979). This indicates that depletion of forestry is also a result of daily foraging for fuelwood (Eckholm, 1979) in underdeveloped countries.

Although deforestation is an ecological consequence of improper land management, it has many ecological consequences of its own including soil degradation, erosion, loss of biodiversity, decreased volume of vegetation and wildlife, and impacts on climate and water resources (Asante, M., 2005; Spray, S., et al., 2006' Sponsel, L., et al., 1996; Sovacool, B.K., et al., 2014). The National Energy Policy and Energy Strategy blame woodfuel for environment implications and explain that the collection of those materials need to be properly managed in order to avoid unsafe deforestation rates (EUEI, 2009). As of 2014 there are permits in place for removal of forest material but there are no permit procedures for individual consumption (Mazimpka, E., 2014), which is the main problem in underdeveloped and developing countries.

Loss of biodiversity is caused by deforestation because of the sudden removal of large pieces of habitat. For example, each hectare may potentially contain millions of organisms that represent thousands of different species (Uhl, C., et. al, 1986) and as a result, 10,000 species may become extinct each year due to habitat destruction (Raup, D.M., 1988; Simberloff, D., 1986; Whitemore, T.C., et al. 1992; Wilson, 1992). Biodiversity also ranges by the vertical gradient from forest floor to canopy (Sponsel et. al, 1996). Older trees grow taller so as deforestation rates increase above regeneration rates, forests become more scarce and younger. Less vertical gradient then leads to a decrease in species biodiversity and volume. Decreasing biodiversity and volume also inhibits future evolution (Mannion, 1992) which can pose threats to species' resiliency to disease and further habitat change.

Deforestation also poses a serious problem with soil degradation and erosion. The rough surfaces that forest canopies create also protect the bottom layers of forests from strong winds which would contribute to more soil erosion (Sponsel, L., 1996). Removal of large canopy trees would then expose the forest floor to stronger wind and increase erosion. Not only does deforestation cause soil degradation and erosion through wind exposure, but also from increased precipitation exposure. Forestry protects soils from rainfall, erosion, and siltation of rivers, therefore, deforestation leads to increased erosion rates (Sponsel, L., 1996; Andersen, L.E., et al., 2002; Eckholm, 1979). Erosion and siltation of rivers then leads to damage of downstream activities such as fisheries and dams (Anderssen, L.E., et al., 2002). Rain runs off of compacted pasture soils more quickly than forested soils because there is no vegetation to absorb or slow it down. Precipitation is then unavailable for transpiration through vegetation back into the atmosphere (Fearnside, 1995, p.53). A decrease in transpiration causes naturally occurring dry seasons to lengthen and become more severe which has detrimental effects of its own (Anderson, L.E., et al., 2002). There is still some uncertainty about the long-term, overall effects of deforestation on the hydrological cycle. In some cases, deforestation reduces ground water and raises the water table which can increase dry season flow (Anderson, L.E., et al., 2002) however, this can be dependent on volume of deforestation. It is, however, agreed upon that forests play a major role in the cycling of water (Eckholm, 1979; Anderson, L.E., et al., 2002; Aiken and Moss 1975; Ekachai, 1990; Myers, 1992; Pushparajah, 1985). According to Andersen, deforestation on the scale of hundreds of square kilometers results in increased rainfall, whereas deforestation on the scale of millions of square kilometers results in reduced rainfall (2002). However, according to other studies deforestation is believed to lead to soil erosion and decreased rainfall (Aiken and Moss 1975; Ekachai, 1990; Myers, 1992; Pushparajah, 1985). Deforestation can also lead to severe flooding, as seen in Bangladesh and Thailand (Myers, 1986; Lohmann, 1989, 1993; Project for Ecological Recovery, 1992; Eckholm, 1979), which can cause severe damage and long-term effects.

The real question then becomes, who is causing all of this widespread deforestation? Developing countries contain roughly three-fourths of the world's population, and yet they only account for 13 percent of globally consumed 'industrial wood' (Eckholm, 1979). Industrial wood includes marketed logs, sawn wood, panel products such as plywood and fiber board, paper, and other manufactured products (Eckholm, 1979). To compare their wood consumption to other countries, volume of paper products can be used. The annual per capita paper use in developing countries is six kilograms whereas it is 257 kilograms in North America (Eckholm, 1979). This indicates that developing countries are consuming much less paper products and therefore wood. It is also important to note that 80% of wood use in the Third World is burned for fuel (Eckholm, 1979). These countries do not have the resource volume required to spend wood on many other activities other than fuel for cooking and heating. Many poor tropical countries even export the timber they cut down. For example, southeast Asia exports to Japan, and African tropical logs go to western Europe (Brown, L.R, 1976). This poses a problem for underdeveloped countries because they already require large volumes of wood for daily needs so when they start exporting their resources, the pool of resources available to them dwindles even more.

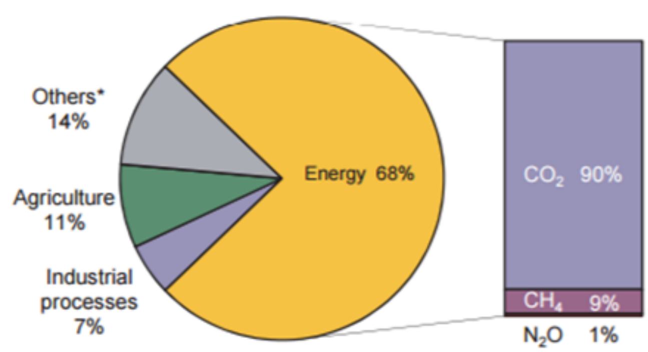
In order to combat the ecological impacts cutting forests down for fuel has, countries in Africa, Asia, and Latin America use shifting cultivation to restore soil fertility and allow for tree regrowth on the land the cultivate (Eckholm, 1979). However, many migrants of people moving from country to country have become new shifting cultivators who will permanently reduce timber and wildlife resources (Eckholm, 1979, p.19). Many people in Africa, Asia, and Latin America are being pushed into plains due to lack of land and jobs, clearing forests as they go because it is unfamiliar ecological conditions (Eckholm, 1979). For example, people moving from the crowded country Java to the outer islands in Indonesia are migrants that don't have experience with

Indonesia's ecology and can cause serious damage through land mismanagement (Eckholm, 1979). Because forests are a source of raw material for buildings, transportation, communication, food, and fuel, when they are cleared they become a new source for farms and cities (FAO, 2012; Cramer, V.A., 2012). However, this change comes at a cost. This creates challenges between putting a halt to deforestation and its consequences, and meeting elementary fuel and wood needs in developing countries (Eckholm, 1979).

Air Pollution

The traditional method of burning biomass in an open fire produces a great amount of air pollution which decreases air quality (Ogwumike. F.O., 2015). Biomass fuel burning in traditional ways, such as open fires and inefficient cookstoves, results in a buildup of greenhouse gases and carbon in the atmosphere (Venkataraman, C., et al., 2010). Black carbon is a climate risk forcer (Ramanathan, V., Carmichael, G., 2008; World Bank, 2011) meaning that it contributes to global warming (US Environmental Protection Agency). The National Energy Policy and Energy Strategy (EUEI, 2009) blames woodfuel for environment implications and claim that woodfuel collecting needs to be properly managed to combat this.

However, it has also been found that fossil fuels are the main contributor to air pollution and climate change impacts, especially carbon dioxide (Perera, F.P., 2017). Fossil fuels emit toxic gases, particles, and CO2, particulate matter, black carbon, polycyclic aromatic hydrocarbons, mercury, nitrogen dioxide, sulfur dioxide, carbon monoxide (Perera, F.P., 2017). Carbon dioxide makes up 90 percent of all energy emissions, which contribute to 68% of global greenhouse gases, shown in Figure 1:



* Others include large-scale biomass burning, post-burn decay, peat decay, indirect N_2O emissions from non-agricultural emissions of NO_x and NH_3, Waste, and Solvent Use.

Source: based on IEA estimates for CO_2 from fuel combustion and EDGAR 4.3.0 and 4.3.2 for non-fuel combustion CO_2 and 4.2 FT2010 for all other sources; for 2010; based on 100-year Global Warming Potential (GWP).

Figure 1: This infographic illustrates the breakdown of estimated shares of global anthropogenic greenhouse gases by energy, industrial processes, agriculture, and others in 2010. It then breaks down the energy sector into its emissions. Carbon dioxide makes up 90 percent of total energy use emissions, followed by methane and a small amount of nitrous oxide. (International Energy Agency, 2016).

It is then important to look at what in the energy sector is causing these massive emissions of greenhouse gases. As of 2014, coal has accounted for 46% of global carbon dioxide emissions, oil accounted for 34%, natural gas accounted for 19%, and the category 'other' accounted for only 1% (International Energy Agency, 2016). The category 'other' includes nuclear power, hydropower, geothermal, solar, tide, wind, biofuels, and waste (International Energy Agency, 2016). Therefore, showing that biomass emissions from open fires contribute less than 1% of total global carbon dioxide emissions. That same data shows that the 'other' category contributes 19% of total primary energy supply (TPES) (International Energy Agency, 2016). These breakdowns are illustrated in Figure 2:

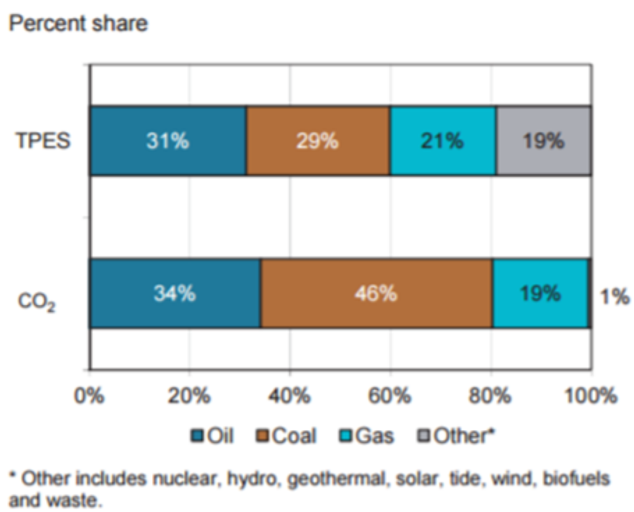


Figure 2: This figure shows the world primary energy supply and carbon dioxide emissions breakdowns by energy sources oil, coal, natural gas, and 'other' in 2014. Coal contributes to roughly one third of the world energy supply, and almost half of global carbon dioxide emissions. In contrast, biomass sources contribute roughly one fifth of the world energy supply, but only a fraction of one percent of global carbon dioxide emissions (International Energy Agency, 2016).

Biomass fuels are relied on in many underdeveloped and developing countries, but their contribution to total energy and emissions is quite low compared to the major fossil fuel sources heavily depended on in developed countries. This is analyzed even more in Figure 3:

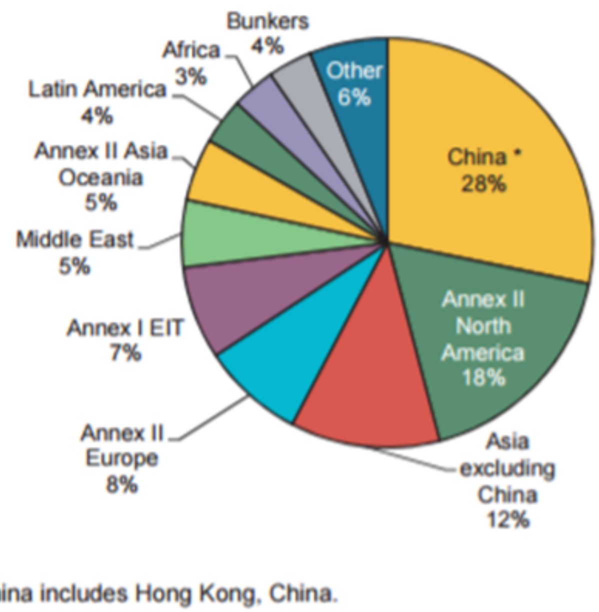


Figure 3: This figure displays the breakup of global carbon dioxide emissions by regions set by the UN Convention on Climate Change. Annex I countries are: Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, European Economic Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Monaco, the Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom and United States. Annex I EIT consists of those members of Annex I that are Economies in Transition (EIT). Annex II consists of the remaining members of Annex I except Cyprus, Malta and Turkey. (International Energy Agency, 2016).

Underdeveloped countries contribute much smaller portions of the global carbon dioxide emissions than developing and developed countries. For example, African countries, and Middle Eastern countries only contribute three and five percent of the global carbon dioxide emissions respectively, whereas China contributes 28 percent of the global carbon dioxide emissions. This indicates that fossil fuel usage contributes to carbon dioxide emissions, which are a main contributor to greenhouse gases. Developing countries usually rely on fossil fuels more than biomass and renewables, and therefore may explain why China is the largest contributor to global carbon dioxide emissions.

Figure 4 expands on this wide range of carbon dioxide contributions across the globe. The top ten emitting countries as of 2014 are China, the Unite States, India, the Russian Federation, Japan, Germany, Korea, Islamic Republic of Iran, Canada, and Arabia (International Energy Agency, 2016). It is important to note that all those countries are either developed or developing.

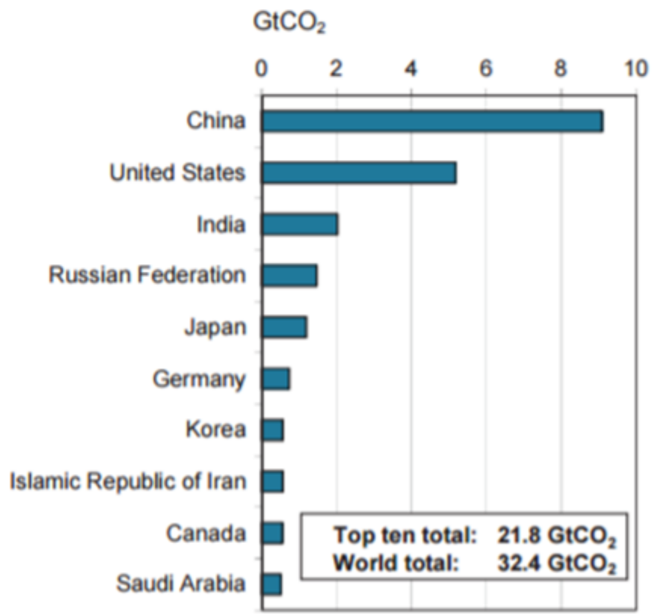


Figure 4: This figure shows the top ten carbon dioxide emitting countries and their emissions in gigatonnes in 2014.

It is also important to note that the total global carbon dioxide emissions for 2014 were 32.4 Gt and the top ten countries combined produced 21.8 Gt. This means that the top ten carbon dioxide producers contribute over two-thirds of the world carbon dioxide emissions (International Energy Agency, 2016), and underdeveloped countries are not even on the list of major contributors. Therefore, developed and developing countries seem to be the problem concerning air pollution, not underdeveloped countries.

Although biomass fuels are extremely dangerous to burn, fossil fuels are the bigger problem currently. The current growing global energy demand of fossil fuels plays a large role in the upward trend of carbon dioxide emissions (International Energy Agency, 2016). If populations in countries currently using biomass fuels continue to grow and begin switching over to fossil fuels, the world will encounter a devastating emissions volume problem.

Declining Ecosystems and Livelihoods

It is clear that traditional fuels degrade ecosystem health. This degradation of ecosystem health hurts the livelihood of surrounding communities because of their high dependency on the surrounding environment. Development in poorer regions along with increasing populations leads to an increase demand in energy demand (Peter, F. et al, 1992, p. 13-14). An increased energy demand increases a demand on non-renewable resources which result in inevitable waste and pollution (Peter, F. et al, 1992, p. 13-14). This puts pressures on arable land, forestry, and fishery resources (Peter, F. et al, 1992, p. 13-14). Many poor countries depend on ecosystem services for livelihood such as agriculture so declining their own environment health feeds into their poverty (Watmough, G.R., 2015).

This creates a feedback loop between populations and environment. As populations of communities that rely on biomass and agriculture increase, their use of biomass fuel also increases. This high demand degrades ecosystem health which agriculture relies on. Unhealthy agriculture produces a lower volume and quality crop yield. Lower yield means less food and less income. Farmers have less crop to sell which lowers their income even more, therefore keeping them in poverty. Populations have less available food, prices rise, and the feedback between population size and environment health continues. To make problems worse, petroleum fuels and electricity are unaffordable for underdeveloped or developing households which forces their dependence on biomass fuels for essential activities such as cooking (Mazimpaka, E., 2014). Without any alternative sources of energy, energy impoverished countries continue to degrade the surrounding environment for necessities, therefore hurting their own food and income source: agriculture.

Biodiversity is an incredibly important trait for an ecosystem to have because it creates resilience and allows for natural selection. Greater the biodiversity creates a greater genetic pool. The greater variety a genetic pool has, the larger pool of immunology a species of ecosystem has. Therefore, allowing a species or ecosystem to withstand a wide variety of diseases and natural events. Forests house millions of plant and animal species that will disappear without them (Eckholm, 1979). If multiple species all exist with great biodiversity, forests become stronger genetically and will withstand more natural events and invasive diseases. Deforestation in both developed and underdeveloped countries is lowering biodiversity. This is mostly due to deforestation for energy resources and development in developed countries as seen in the lesson 3 maps. The Swindon Climate Change Action Plan recognizes relationship between energy use and biodiversity (Eaton, R.L., 2007). As a country gains energy service access the decrease biodiversity as a side effect, therefore creating a link between energy use and biodiversity.

As mentioned earlier, The National Energy Policy and Energy Strategy (EUEI, 2009) blames woodfuel collection and use for environment implications, which attributes to a country's ecological footprint. Ecological footprint analysis is a method that determines a simple measurement of how much human activity impacts the environment (Eaton, R.L., 2007). These analyses have been widely used as indicators of resource consumption and waste absorption on biological productive land (Eaton, R.L., 2007). These analyses are shown numerically. According to Goldemberg, North America's footprint is 9.2 and Europe's is 4.8 compared to Africa's footprint of 1.8 and Asia-Pacific countries' footprint of 2 (Goldemberg, J., 2010). Although these numbers have no units, it is clear that developed countries such as North America and Europe are causing more damage due to human activity than underdeveloped countries like African countries and Asia-Pacific countries. Once again, underdeveloped countries prove to be leaving less of a mark on the environment compared to developed countries. Sources of human activity that cause a larger ecological footprint can include power production, water, transportation, materials and waste, industry, building, and deforestation (Goldemberg, J., 2010; Eaton, R.L., 2007).

Sustainable Development Goals

The United Nations originally developed the Millennium Development Goals in order to push the world into a better future by 2015. In 2016, those were developed into the Sustainable Development Goals with a deadline of 2030. Sustainable Development is defined as “development that caters for the welfare of future generations” (Ogwumike. F.O., 2015). Brundtland report also discusses the concept of sustainable development. It says that sustainable development implies meeting the needs of the present generation without compromising the ability of future generations (UN, 1987). This can then be taken a step further and applied directly to humans by titling the concepts sustainable human development (Watmough, G.R., 2015). The two goals in the United Nations’ Sustainable Development Goals that relate to environmental consequences of energy poverty are goal 1 and goal 7. Goal 1 is to end poverty in all its forms everywhere (UN, 2015). Goal 7 is to ensure access to affordable, reliable, sustainable, and modern energy for all (UN, 2015). There are a handful of other environment goals ,12, 13, 14, and 15, (UN, 2015) that are unrelated to energy, but still imperative to reach for long-term environment health. Access to modern sources of energy is very important for the provision of clean water, efficient sanitation and healthcare (OECD/IEA, 2010) which would help meet the Sustainable Development Goals. Therefore, energy poverty is a prominent issue that needs to be addressed to solve other branching problems.

Environmental Wellbeing Consequences of Energy Poverty

Run time: 50 – 75 minutes

This lesson plan is the third section of a larger modifiable Science on a Sphere module on Energy Poverty designed for college-level courses. This third lesson can range from 50-75 minutes. A 50-minute class would assign the post-class worksheet as homework, and a 75-minute class would complete the worksheet at the end of class.

Learning Objectives

Big Idea: Energy poverty and global poverty are caught in a reinforcing feedback loop.

Lesson Goal: for students to develop a factual understanding of environmental consequences from energy poverty.

Student Learning Goals and Objectives:

4. Students will explain how no energy access degrades environmental health through human action as well as demonstrate examples of this.
5. Students will analyze relationships between different Science on a Sphere datasets in order to draw conclusions on how global poverty and energy poverty affect each other.

Datasets

Greenhouse Gas Emissions

This dataset shows the total greenhouse gas emissions in kt of carbon dioxide equivalent which scales the greenhouse gases and makes them relatable. The data were obtained from the World Bank's Sustainable Energy for all (SE4ALL) database from the WHO Global Household Energy database, and compiled on a world dataset using ArcGIS for the purposes of this project. The image is included in the 'Datasets (Images)' section of this manual.

World Bank, Sustainable Energy for All (SE4ALL) database from World Bank, Global Electrification database. (2012). *Total greenhouse gas emissions (kt of CO2 equivalent).* [Data file]. Retrieved from http://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE

Deforestation Series
These two datasets are in a series to show the change in percent of land area that is forest area from 1990 to 2015 which illustrates deforestation. The data were obtained from the World Bank's Sustainable Energy for all (SE4ALL) database from the WHO Global Household Energy database, and compiled on a world dataset using ArcGIS for the purposes of this project. The image is included in the 'Datasets (Images)' section of this manual.

World Bank, Sustainable Energy for All (SE4ALL) database from World Bank, Global Electrification database. (2015). *Forest area (% of land area).* [Data file]. Retrieved from http://data.worldbank.org/indicator/AG.LND.FRST.ZS?view=chart

Plant Species Threatened
This dataset shows number of plant species threatened in each country. The data were obtained from the World Bank's Sustainable Energy for all (SE4ALL) database from the WHO Global Household Energy database, and compiled on a world dataset using ArcGIS for the purposes of this project. The image is included in the 'Datasets (Images)' section of this manual.

World Bank, Sustainable Energy for All (SE4ALL) database from World Bank, Global Electrification database. (2016). *Plant species (higher), threatened.* [Data file]. Retrieved from http://data.worldbank.org/indicator/EN.HPT.THRD.NO?view=chart

INSTRUCTOR SCRIPT

Pre-lesson Preparation (1 hour, before presentation)
Before taking part in the lesson, students will be asked to complete an assignment in order to familiarize themselves with environmental wellbeing consequences of energy poverty. This will ensure that all students who complete the assignment are coming to the lesson with the same foundational knowledge of what systems and feedback loops are and start thinking about how energy poverty and global poverty interact. By beginning the thinking process beforehand, students will be able to develop a deeper understanding of these concepts during the lesson. The pre-lesson preparation assignment is found at the end of this lesson plan.

Procedures/Lesson Sequence

This portion of the class is instructor led. Students will watch the Science on a Sphere presentation and discuss the information presented as a large group.

Before any projections are displayed on the sphere, it is important for the instructor to reiterate to the class that the shading scale for all of the projections is uniform: dark coloring indicates the “bad” level of the indicator. For example, in the map showing access to non-solid fuels, low percentages of total access are dark orange and high percentages of total access are light orange. The projections are intentionally designed this way in order to draw viewers’ attention to the energy impoverished countries rather than the developed countries. All projections created for this lesson are intentionally not adjusted to mimic the Earth’s natural tilt of 23 degrees in order to allow for better critical thinking and analysis. The instructor should feel free to tilt the projections at any time in order to show a country higher up on the globe to make important points to the class.

For classes of 20 or less, students should be encouraged to walk around the sphere as projections are displayed. This will allow for more individual analysis and will help with answering worksheet and clicker questions. For classes larger than 20, students should remain in their seats for the lesson or they can be paired into groups of 2 and take turns walking around the sphere.

Lesson Opening (10 minutes): The instructor should review the pre-assignment to ensure that the students understand the concepts of ecological footprint, environmental consequences of fossil fuels, and are in the right mindset for this presentation.

- **Clicker Question 1**: How many planets would it take to sustain your lifestyle if every person on earth lived the way you do?

    a. 1-3
    b. 4-6
    c. 7-9
    d. 10+

- **Clicker Question 2**: Imagine there are two coal power plants of the same size, one in China and one in Egypt. Based on your reading from the IEA, why would it make a larger impact on the globe's carbon dioxide emissions if the plant in China was shut down instead of the plant in Egypt?

    e. There is a higher population in China so less coal would be burned.
    f. China accounts for 28% of the globe's carbon dioxide emissions whereas Egypt accounts for a fraction of 5%.
    g. China accounts for 50% of the globe's carbon dioxide emissions whereas Egypt accounts for 20%.
    h. Egypt does not need heating which is the largest sector of carbon dioxide emissions.

The instructor should open this to a class discussion of what actions or behaviors played the largest role in their footprint and why. The instructor should also ask if anyone would be willing to take away some of these services or change their behaviors.

Dataset 1 Reflection (10 minutes): The first indicator of environmental consequences that will be presented on the Sphere is Total Greenhouse Gas Emissions. The instructor should review that greenhouse gas emissions in this data include carbon dioxide, methane, nitrous oxide, and multiple F-gases.

- **In Class Worksheet Question 1**: Record your observations of what areas have the highest greenhouse gas emissions.

- **Clicker Question 3**: Why do developed countries such as the United States have almost 80 times the volume of greenhouse gas emissions as underdeveloped countries such as Niger and Angola?

    i. The United States have a larger population and therefore create more greenhouse gas emissions.

j. Underdeveloped countries aren't burning anything because they can't afford any type of energy fuel.
k. Fossil fuels are less restricted in the United States as to encourage small business growth.
l. Fossil fuels in the United States are burned at higher volumes due to industrialization and are the primary contributor to global emissions.

- **Clicker Question 4**: Why do developing countries such as China have higher emission levels that developed countries such as the United States?

m. China hasn't embraced any renewable energy yet and has a much larger population.
n. The United States doesn't use high levels of fossil fuels anymore and has switched to a large portion of renewables.
o. Developing countries rely on cheaper fossil fuels such as coal which produce high levels of greenhouse gases.
p. This can't be explained by experts.

Dataset 2 Reflection (10 minutes): Students will next look at the second environmental consequences indicator on the Sphere, Plant Species Threatened. The instructor should point out the countries with the highest rates of threatened plant species such as China, Brazil, and Tanzania.

- **In Class Worksheet Question 2**: Why do you think China and Brazil fall into the highest bracket of plant species threatened?

- **Clicker Question 5**: Lucas lives in a small town in Brazil close to the Amazon Rainforest. His town is experiencing severe plant biodiversity which is impacting their crop's ability to withstand diseases. What is a possible reason for this?

q. The town needs wood for building, fuel, and export business so they are cutting down high quantities of trees faster than the natural replenishment rate.
r. Lucas's town wants to focus on a handful of types of crop to increase productivity and therefore are not encouraging biodiversity.
s. The town does not understand the benefits of biodiversity and is oblivious to the effects.
t. The Amazon Rainforest does not have a naturally high biodiversity value, and development is not helping this value grow.

Dataset 3 and 4 Progression (10 minutes): Students will then end environmental consequences with the Deforestation series.

- **In Class Worksheet Question 3**: What rainforests show deforestation?

- **Clicker Question 6**: The main rainforests suffering from deforestation include the Amazon Rainforest, Congo River Basin Rainforest, and the Rainforests of South-East Asia. If these rainforests reside within countries living in energy poverty, why are they suffering from high deforestation rates?

  u. Countries such as Brazil, Nigeria, and Myanmar don't value wood so they cut it down for business.
  v. Underdeveloped and developing countries are cutting down forests for development and export business to developed countries.
  w. Developed countries don't have any forest land to cut down so their data is invalid.
  x. There isn't very much deforestation happening, none of the above.

- **Clicker Question 7:** Based on your knowledge of other energy poverty indicators and the deforestation leading countries, what is the main causes of deforestation?

  y. Logging
  z. Agriculture
  aa. Firewood collection
  bb. Paper product creation

Pre & Post Assessment

The following sections include a pre-lesson preparation assignment, in-class "clicker"-style multiple choice questions and answers, an in-class worksheet and corresponding answers, and a post-lesson assignment. These resources will be used to assess the students' learning and comprehension of the concepts presented before, during, and after observing the presentation.

Environmental Consequences of Energy Poverty: Pre-Lesson Preparation Assignment

Part A: Take the Ecological Footprint Quiz and see how many planet Earth's it would take to sustain your lifestyle if every person on earth lived the way you do. Here is the link: http://www.footprintnetwork.org/resources/footprint-calculator/

Take a screenshot of your results or take notes and bring these to class.

Part B: Read chapter 1 of the International Energy Agency's CO2 Emissions From Fuel Combustion Highlights (2016 ed.) report. This pdf can be found at: https://www.iea.org/publications/freepublications/publication/CO2EmissionsfromFuelCombustion_Highlights_2016.pdf

International Energy Agency. (2016). *CO_2 Emissions From Fuel Combustion Highlights* (2016 ed.) France: International Energy Agency.

Environmental Consequences of Energy Poverty: In-Class Clicker Questions and Answers

- **Clicker Question 1**: How many planets would it take to sustain your lifestyle if every person on earth lived the way you do?

  cc. 1-3
  dd. 4-6
  ee. 7-9
  ff. 10+
  Answers will vary based on student lifestyles.

- **Clicker Question 2**: Imagine there are two coal power plants of the same size, one in China and one in Egypt. Based on your reading from the IEA, why would it make a larger impact on the globe's carbon dioxide emissions if the plant in China was shut down instead of the plant in Egypt?

  gg. There is a higher population in China so less coal would be burned.
  hh. China accounts for 28% of the globe's carbon dioxide emissions whereas Egypt accounts for a fraction of 5%.
  ii. China accounts for 50% of the globe's carbon dioxide emissions whereas Egypt accounts for 20%.
  jj. Egypt does not need heating which is the largest sector of carbon dioxide emissions.
  Students should select 'b'.

- **Clicker Question 3**: Why do developed countries such as the United States have almost 80 times the volume of greenhouse gas emissions as underdeveloped countries such as Niger and Angola?

  kk. The United States have a larger population and therefore create more greenhouse gas emissions.
  ll. Underdeveloped countries aren't burning anything because they can't afford any type of energy fuel.
  mm. Fossil fuels are less restricted in the United States as to encourage small business growth.
  nn. Fossil fuels in the United States are burned at higher volumes due to industrialization and are the primary contributor to global emissions.
  Students should select 'd'.

- **Clicker Question 4**: Why do developing countries such as China have higher emission levels that developed countries such as the United States?

  oo. China hasn't embraced any renewable energy yet and has a much larger population.
  pp. The United States doesn't use high levels of fossil fuels anymore and has switched to a large portion of renewables.
  qq. Developing countries rely on cheaper fossil fuels such as coal which produce high levels of greenhouse gases.
  rr. This can't be explained by experts.
  Students should select 'c'.

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- **Clicker Question 5:** Lucas lives in a small town in Brazil close to the Amazon Rainforest. His town is experiencing severe plant biodiversity which is impacting their crop's ability to withstand diseases. What is a possible reason for this?

  ss. The town needs wood for building, fuel, and export business so they are cutting down high quantities of trees faster than the natural replenishment rate.
  tt. Lucas's town wants to focus on a handful of types of crop to increase productivity and therefore are not encouraging biodiversity.
  uu. The town does not understand the benefits of biodiversity and is oblivious to the effects.
  vv. The Amazon Rainforest does not have a naturally high biodiversity value, and development is not helping this value grow.
  Students should select 'a'.

- **Clicker Question 6**: The main rainforests suffering from deforestation include the Amazon Rainforest, Congo River Basin Rainforest, and the Rainforests of South-East Asia. If these rainforests reside within countries living in energy poverty, why are they suffering from high deforestation rates?

  ww. Countries such as Brazil, Nigeria, and Myanmar don't value wood so they cut it down for business.
  xx. Underdeveloped and developing countries are cutting down forests for development and export business to developed countries.
  yy. Developed countries don't have any forest land to cut down so their data is invalid.
  zz. There isn't very much deforestation happening, none of the above.
  Students should select 'b'.

- **Clicker Question 7:** Based on your knowledge of other energy poverty indicators and the deforestation leading countries, what is the main causes of deforestation?

    aaa.Logging
    bbb.Agriculture
    ccc.Firewood collection
    ddd.Paper product creation
    Students should select 'b'.

Environmental Consequences of Energy Poverty: In-Class Worksheet

Question 1: Record your observations of what areas have the highest greenhouse gas emissions.

Question 2: Why do you think China and Brazil fall into the highest bracket of plant species threatened?

Question 3: What rainforests show deforestation?

Environmental Consequences of Energy Poverty: In-Class Worksheet Answers

Question 1: Record your observations of what areas have the highest greenhouse gas emissions (GHG).

Students should conclude that countries such as the United States, China, Russia, some of South America, and Canada have relatively high greenhouse gas emissions. From this they may attempt to guess why these countries have such high GHG emissions. Conclusions may include, but are not limited to, developed countries such as the United States have high quantities of industrial processes and therefore produce high volumes of GHG, and developing countries have just recently gained industrial processes and therefore are expanding rapidly without any standards and regulations as it is a new system for the country.

Question 2: Why do you think China and Brazil fall into the highest bracket of plant species threatened?

Students should note that China and Brazil are both developing countries, and therefore are industrializing rapidly without enforced regulations. This leads to quick development and land use without concerning the environment. High volumes of development lead to clearing land for buildings and therefore destroying habitat. Plants will die and animals will lose their homes which leads to a decrease in plant variety and therefore higher volumes of plant species are in danger and threatened.

Question 3: What rainforests show deforestation?

The main rainforests suffering from deforestation include the Amazon Rainforest, Congo River Basin Rainforest, and the Rainforests of South-East Asia. Student may not know rainforest geography this specifically (however these are listed in a clicker question), so they may also list areas in detail.

Environmental Consequences of Energy Poverty: Post-Lesson Assignment

This lesson discussed three major environmental consequences indicators of energy poverty. Choose one environment consequence indicator of energy poverty and research ways to solve this problem without inhibiting progress in underdeveloped countries. How does this consequence and solution contribute to human wellbeing? For reference, the indicators discussed in class include: total greenhouse gas emissions, plant species threatened, and deforestation. Include citations of sources. (400-500 words).

Environmental Wellbeing Consequences of Energy Poverty: Post-Lesson Assignment Rubric

Students should identify which indicator they are going to be researching: greenhouse gases, deforestation, or plant species threatened. They should find credible sources such as, but not limited to, the World Bank, The World Factbook, the CIA, UNESCO, OECD.org, and WHO.org. They should provide any new statistics that they can and conclusions that incorporate both their new findings and what was discussed in class on the Sphere.

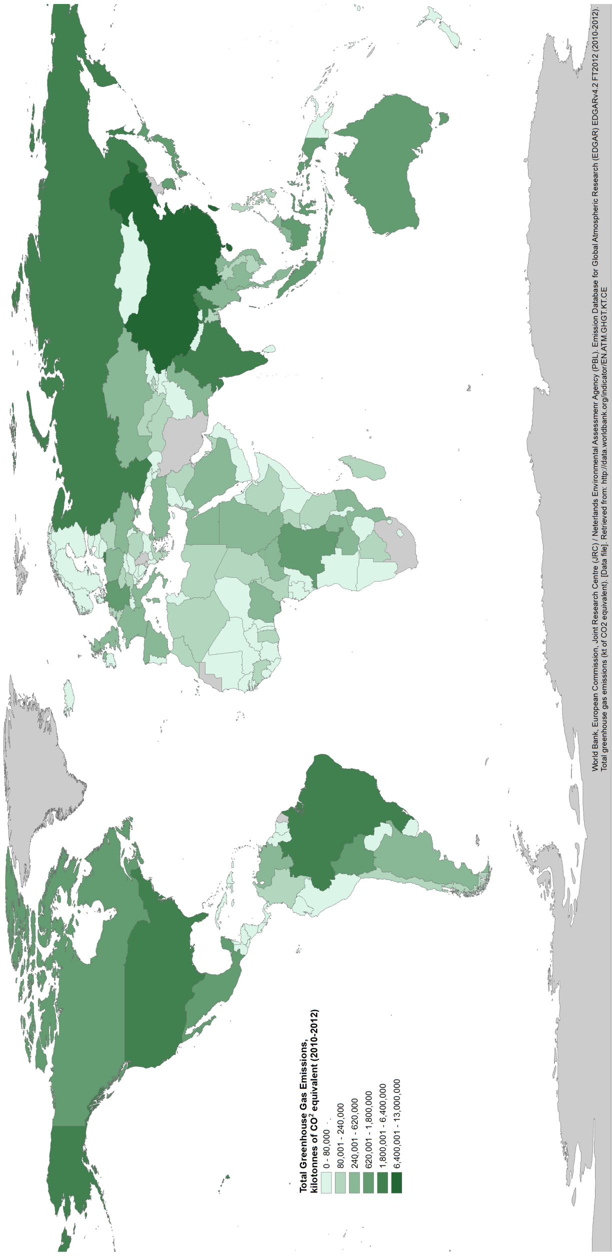
They should also discuss in detail one solution they either find or develop themselves. Solutions can be large or small scale, global or country specific, or short-term or long-term. These solutions should include a plan that will reduce greenhouse gas emissions, how to conserve or replenish forest area, and/or how to save threatened plant species. These solutions can be community wide or per household daily behaviors.

Students should also discuss in their solutions that it is not just consequences of energy poverty, but alleviating energy poverty can be damaging to the environment. For example, there are higher greenhouse gases associated with developed and developing countries which the lesson discusses as an outcome of gaining energy access and industrializing. Discussions and solutions should include analysis of this problem that alleviating energy poverty will bring negative consequences but not alleviating it already has negatively impacts millions of people.

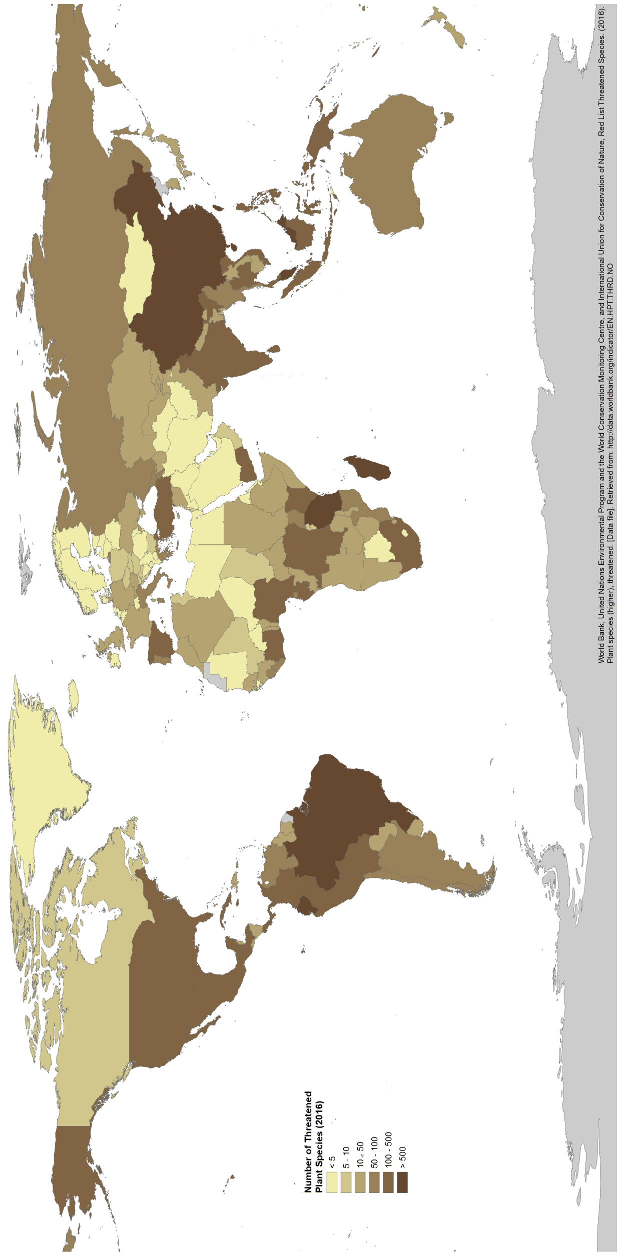
DATASETS (IMAGES)

This section contains the original images created by the authors. Using data from the World Bank, maps were created in ArcGIS and saved as JPEG files. These include Greenhouse Gas Emissions, Deforestation, and Plant Species Threatened.

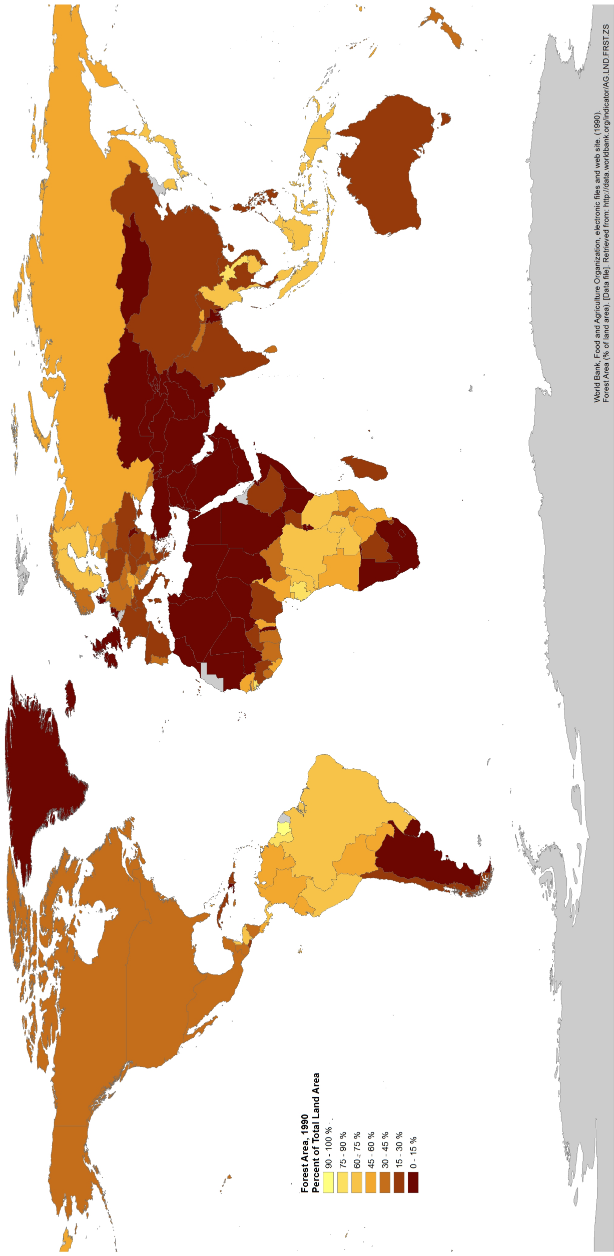
Dataset 1. Greenhouse Gas Emissions



Dataset 2. Plant Species Threatened

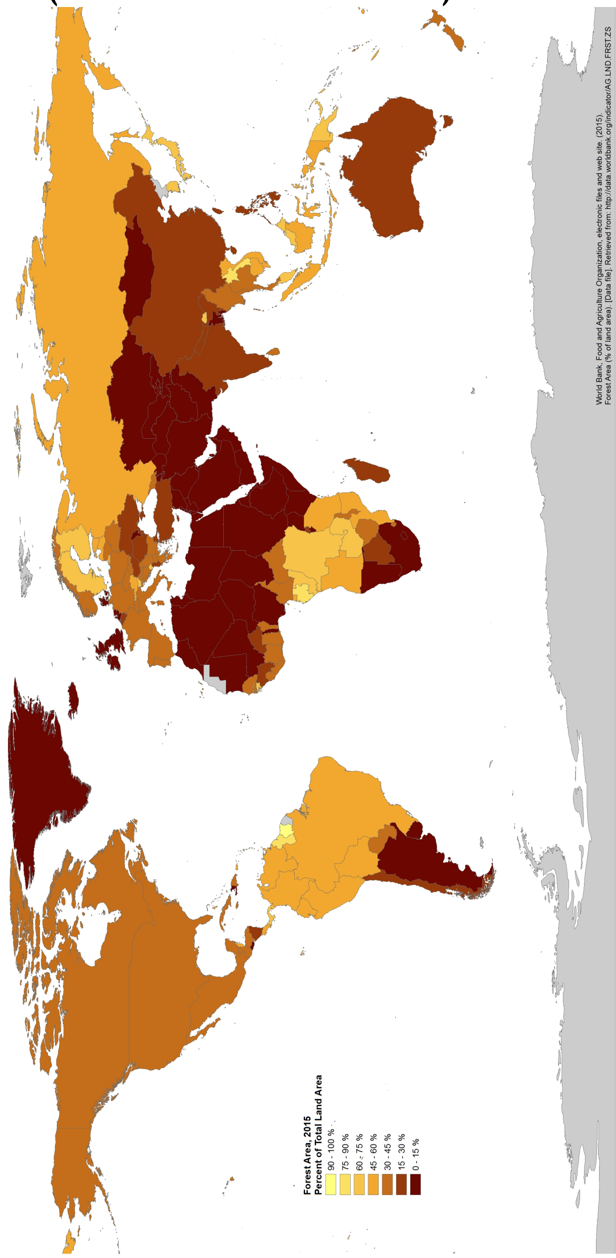


Dataset 3. Deforestation (Forest % Land Cover 1990)



Forest Area, 1990
Percent of Total Land Area
90 - 100 %
75 - 90 %
60 - 75 %
45 - 60 %
30 - 45 %
15 - 30 %
0 - 15 %
World Bank, Food and Agriculture Organization, electronic files and web site. (1990).
Forest Area (% of land area). [Data file]. Retrieved from: http://data.worldbank.org/indicator/AG.LND.FRST.ZS

DATASET 4. DEFORESTATION (FOREST % LAND COVER 2015)



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