Project Update:Visualizing A Connection Between Electrical Generation and Surface Temperatures and CO_2 Emissions CSE6242 - Team 52

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1 DEFINING OUR PROBLEM SPACE:

We will use the following datasets to develop analytical tools for presenting geographic and time-based visualizations:

(1) Berkely Earth - temperature data [Rohde et al. 2013] [link]
(2) CDIAC - CO_2 emissions [Andres et al. 1997] [link]
(3) EIA-923 - US Power Generation Statistics [link]

2 HEILMEIER'S QUESTIONS

2.1 What we are trying to do:

We will construct a visualization toolkit to aid in analysis of long-term trends in surface temperature, CO_2 emissions, and energy mix in the United States. We aim to offer a presentation of these diverse datasets that is easy to digest.

2.2 How it is done today:

Most current visualizations on these subjects are static and siloed, i.e. they do not allow for interactivity or correlated between linked data.

One example is available from the Energy Information Administration (EIA) website [link].

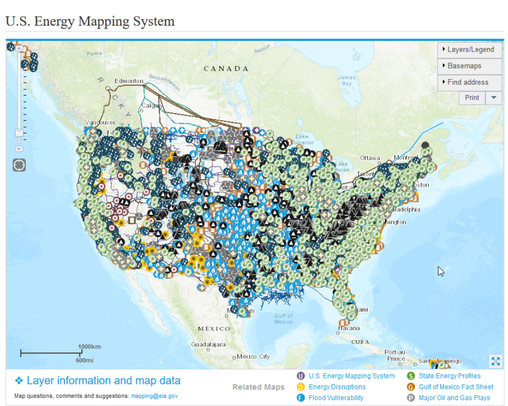


Figure 1: EIA Mapping System Example

2.2.1 *Shortcomings:*

- Poor interactivity and responsiveness
- Inability to display graphical data versus time
- Minimal and confusing data filtering options
- Low data-to-ink ratio

2.3 How this is a new approach:

We propose a set of interactive visualizations which will allow users to explore data from multiple sources on common media.

The success of our approach will require clear visuals which allow users to develop their own conclusions on climate impact, instead of being presented with a tailored narrative.

2.4 Who should care:

Climate change is a concern of individuals and organizations worldwide. More effective visualizations can reduce the awareness gap between scientific experts and the public.

2.5 Measuring Success and Expected Impact:

Success is measured by the effectiveness of our visualizations at conveying similar data as others while adding interactivity and blending of data sources. Impact is measured through user engagement and interaction.

2.6 Risks

- Resource needs to process, clean, and present three large datasets
- Responsive performance for multiple visualizations on one page
- Geographic data granularity is insufficient to provide insights

2.7 Payoffs

- Visualization provides real-world data for independent conclusions
- Climate insights from coal reduction and renewable expansion
- Sparks conversation and challenge around tailored climate data

2.8 Costs

- Team time investment for data processing and visualizations
- Computational resources for large data set use
- Minimal monetary costs may be required for hosted solution

2.9 Measuring Progress:

In the Project Proposal an action plan and due dates was provided. In **Table 1** the **Task**, **Initial Due Date** and **Owner** are copied from the Proposal. The **Current** column provides the status as of this Update with deltas included.

Table 1: Team 52 Actions

Task	Initial Due Date	Current	Owner
Submit Progress Report	3/29	Completed (3/31)	All
Begin Final Poster	3/29	Not Started Due: 4/5	All
Complete Final Poster	4/12	No Change	All
Tue and Thur Status Meetings	4/19	On-Going	All
The Data			
Download and clean CO_2 Dataset	3/14	Completed (3/14)	Carvallo
Download and clean Berekley weather dataset	3/14	Completed (3/14)	Smith
Using EIA API pull power plant information	3/14	Completed (3/28)	Comfort Bonifield
Combine datasets into a single database	3/19	On-Going New Due: 4/5	All
Visualizations			
Determine Visualization Platform (D3/Python/Tableau, etc)	3/14	Completed (3/30) Python-Plotly	All
Base (non-dynamic) visualization working (either energy or climate only)	3/26	Completed (3/25) CO_2 & Temp	All
Time Dependent visualization working	4/2	On-Going (temp works)	All
Full Visualization Working	4/9	No Change	All
Milestones			
Locate 2 possible datasets	N/A	Complete	All
Locate 3 survey sources each	N/A	Complete	All
Submit Project Proposal	N/A	Complete	All

2.10 Checking Progress:

The final exam will be a user test of the finalized visualization. The midterm check will be a cleaned, organized, and combined dataset organized geographically and a basic functioning visualization.

3 INNOVATIONS

The following list of innovations stand out in our team's work:

- **Interactivity** – ability for the user to see impacts and results through interacting with visualization
- **Combination of multiple datasets** – combining different sources into a single view
- **Multi-year time series** – displaying data over time versus statically; allows for exploration and comparison
- **Map overlays** – including geographic information provides context to data

4 METHODS

4.1 Platforms and Frameworks

The code for this project is based mainly in Python 3. We use Pandas for data processing and Plotly for plotting. Plotly uses Python code to generate graphs built on D3, which allows for rapid prototyping and experimentation without sacrificing quality or portability. Plotly also provides automatic hosting and interactivity features.

4.2 Visualization Methodology

The centerpiece of the visualization we are building is an interactive US map capable of displaying power plants and generation statistics, CO2 emissions, and temperature data. Auxiliary charts, e.g. line, bar, may be overlain or displayed alongside the map. Interactivity will be provided in the form of data selection (by year, statistic, etc.), mouse hovers, and clickable data points.

The challenges of this approach will include deciding which data to display in each format. For instance, CO2 and temperature data cannot both be used to color in the map.

4.3 Visualizing Temperature Data

US temperature data in the Berkeley Earth dataset is available by state and nationally. The plot below is one early prototype of how this data can be displayed. The goal is to allow users to explore the long-term trends in temperature change.

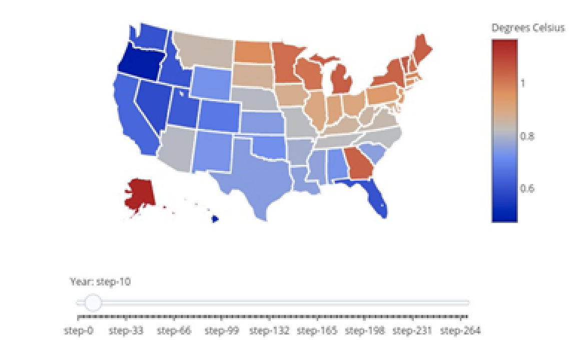


Figure 2: Single-year temperature anomaly for US states relative to a per-state absolute value

The slider at the bottom controls the year being displayed, and the states are colored individually by their 10-year average temperature relative to an absolute. The absolute temperature used is a per-state average between the years 1951-1980.

4.4 Visualizing CO_2 Data

One example visualization of CO2 data as dynamically sized circles based on emission amount is shown below (**Figure 3**). One of the challenges, however, is that the CO2 data is only available in single degrees of latitude and longitude which means that there is approximately 60 nautical miles of distance between points, as shown below (**Figure 4**).

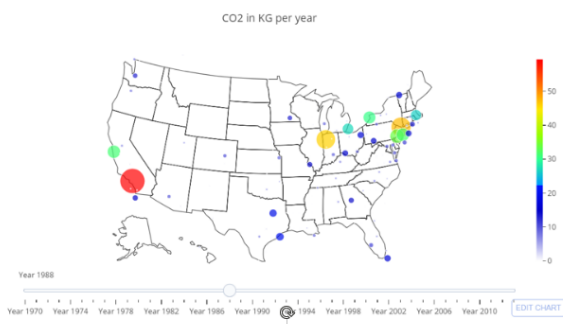


Figure 3: US CO_2 by Circle Size Example

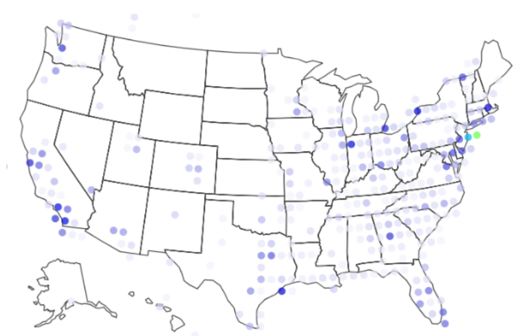


Figure 4: CO_2 Lat Long Distribution

4.5 Process Power Plant data

The power plant data, unlike both the Surface Temperature and CO2 datasets, was not available in a well-developed dataset. The power plant generation data was represented in three different formats for different cohorts between 1970-2018, all of which were missing latitude/longitude attributes requiring a fourth dataset. This required a large amount of data scraping from the EIA web site, data cleaning and manipulation to combine the data into a single dataset that included plant location, emission and generation information.

As of this update, the power plant data has successfully been combined into a single dataset and testing of Plotly is on-going to align with the other datasets mentioned previously.

Under Construction: Working to develop visualization and slider with appropriate hovering information.

5 EXPERIMENTS

A chief focus of future work will be combining the separate visualizations into one. We will experiment with different visualization formats and interactivity.

Further work includes visualization CO2 data as a cloud/contour plot, rather than a scatterplot. Temperature data will be displayed on an absolute color scale to improve visual clarity. Power plant will be represented as circles that are identified by plant emission and annual generation to show possible impacts to CO2 and surface temperature. A tooltip and/or mouse click will show detailed plant information.

The results we will obtain include a unified visualization displaying data from all sources. We will gauge our success by visual clarity and ease of use.

Under Construction

6 LITERATURE SURVEY

6.1 CO_2 Emission Projections from Electrical Generation [Bruninx et al. 2013, Page Count: 11] and [Hammons 2006, Page Count: 17]

Main Ideas: Consisted of two papers which utilized climate modeling to predict CO_2 emissions based on energy production changes in Germany and Russia, Greece and Italy respectively.

Table 1
Prognos (2011a) concludes that, in the case of a nuclear phase-out, nuclear generation is replaced by gas, coal and lignite based generation. As a result, electricity prices and CO_2-emissions rise considerably. All results are presented relative to the earlier proposed lifetime extension of 20 years.

	2015	2020	2023
Electricity prices (%)	+12	+13	+17
CO_2-emissions (%)	+8	+30	+60
Generation mix			
Nuclear (%)	−43	−62	−100
Lignite (%)	+5	+15	+48
Coal (%)	+14	+28	+77
Gas (%)	+17	+42	+68
RES (%)	0	0	0

Figure 5: CO_2 Emission Impact Table [Bruninx et al. 2013]

Uses: There is an overall correlation between CO_2 emissions and energy production. The larger the percentage of low (or zero) CO_2 plants the lower overall CO_2 concentrations were predicted.

Shortcoming: CO_2 concentration results were projected to show a future state while our proposal focuses on measured data.

6.2 Contemporary Climatic Analogs for 540 North American urban areas in the late 21st century [Fitzpatrick and Dunn 2019, Page Count: 7]

Main Idea: This survey developed analysis and visualization techniques that link current contemporary urban area climate-analogs to predict how future conditions in other urban areas may be similar.

Uses: It provides an interesting visualization approach through connecting similar climate areas in an effort to provide context to future climate change.
Shortcomings: In some cases (**Table 6**) the visualization becomes very busy connecting urban areas.

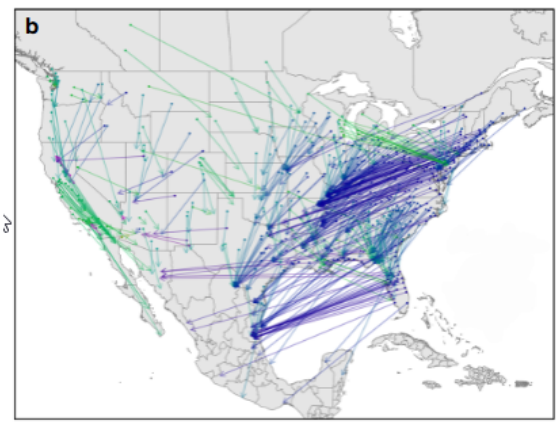


Figure 6: Urban Area Connected Analog [Fitzpatrick and Dunn 2019]

6.3 Prospective Analysis of Life-Cycle Indicators through Endogenous Integration into a National Power Generation Model [García-Gusano et al. 2016, Page Count: 17]

Main Idea: Due to the lack of integration between Energy systems modeling and life cycle modeling, the authors of the report combined the two into one model to be utilized for forecasting. Their final proved to be useful in energy forecasting decision making.

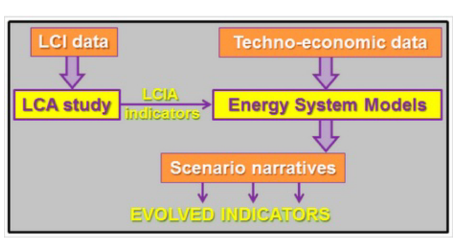


Figure 7: Merging LCA and ESM Approach [García-Gusano et al. 2016]

Uses: Proves the need to integrate energy data with climate data. Further, it provides an example of an existing model that combined both for forecasting reasons.

Shortcomings: Their model is specific to the Spanish energy market end focuses solely on one major climate indicator and simplifies energy production into three main sources (nuclear, renewable and fossil).

6.4 The global climate change and its effect on power generation in Bangladesh [Khan et al. 2013, Page Count: 10]

Main Idea: Energy sources in developing countries are more susceptible to different climate effects. Unless stopped, current trends estimate the effects of climate change to exponentially increase with time.

Uses: Provides examples of major climate factors that affect power generation and describes a need to reduce the effects of climate change.

Shortcomings: Data is specific to Bangladesh and smaller countries. Model presented extrapolates climate change effects which may be unrealistic.

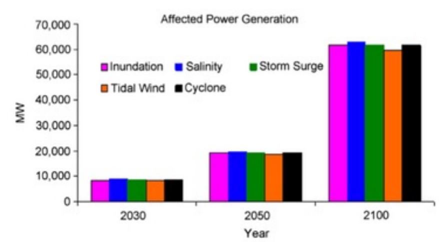


Figure 8: Affected power generation by climate change till 2100 [Golombek et al. 2012]

6.5 Climate Change: Impacts on Electricity Markets in Western Europe [Golombek et al. 2012, Page Count: 14]

Main Idea: Quantifies the effects of temperature and precipitation for electricity markets in Western Europe.

Uses: Paper provides quantifiable values which can be compared to values in our visualization to determine world-wide differences.

Shortcomings: Large model variability in countries depending on generation production split.

6.6 Reflections—What Would It Take to Reduce U.S. Greenhouse Gas Emissions 80 Percent by 2050? [Heal 2017, Page Count: 16]

Main Idea: Details the path to reducing CO2 emissions by 80% by 2050. The greatest potential improvement being by replacement coal and gas with wind and solar.

Uses: The analysis and projections of the author can inform our visualizations of trends in recent capacity across differing electricity production sectors.

Shortcomings: Ignores the emission-reducing effects of other generation methods such as nuclear.

6.7 Visualization of Climate and Climate Change Data: An Overview [Nocke et al. 2008, Page Count: 6]

Main Idea: The effective visualization of Climate Change is essential. Surveys climate scientists and researchers on most used visualization strategies and software, and seeks to bridge the gap between cutting-edge climate and visualization research.

Uses: The results and analysis of this usage research can help the team craft a more effective visualization.

Shortcomings: Places insufficient emphasis on interactivity.

6.8 Visualizing Climate change Risk and Adaptation Options for California [Koy 2014, Page Count: 24]

Main Idea: California is particularly sensitive to climate disruption. Visualization tools are critical to communicating the risks to local communities.

Uses: The results and analysis of this usage research can help the team craft a more effective visualization.

Shortcomings: California specific focus limits general applicability.

6.9 Visualising the potential impacts of climate change on rural landscapes [Dockerty et al. 2005, Page Count: 23]

Main Idea: Broad visualizations of climate change are often not as effective at communicating a message as specifically tailored local approaches. By using a GIS database combined with photorealistic software and scenarios powered by decision rules specific the impact on specific communities

Uses: The results and analysis of this usage research can help the team craft a more effective visualization with respect to scenario modeling.

Shortcomings: Difficult to scale local approaches to all communities due to high variance in geographic/climate factors.

6.10 CO_2 Emission Trends for the US and Electric Power Sector [Klein 2016, Page Count: 14]

Main Idea: The US has made remarkable progress recently in reducing CO2 emissions. From 2005-2012, more CO2 reduction occurred in the US than in all other countries combined. Electric power generation was the greatest contributor to this decline.

Uses: Contains very relevant data for our research detailing the effects of power generation mix on CO2 emissions.

Shortcomings: Many visualizations are used which suffer from the same problems discussed elsewhere. We aim to bring this same data to life by adding interactivity.

6.11 Climate Change 2013: The Physical Science Basis, Chapter 2 [Stocker 2014, Page Count: 90]

Main Idea: Provides a complete survey of recent results in climate science across a broad range of sources with a wealth of visual content. A central finding since previous reports is that there is widespread agreement in temperature increase estimates among the various temperature datasets.

Uses: Inform our understanding of state-of-the-art techniques in climatology on a global scale, specifically with respect to atmosphere and surface.

Shortcomings: Visualizations lack interactivity and are often jargon-heavy, failing to highlight recent findings adequately for observers with little domain knowledge.

7 TEAM MEMBER EFFORT:

All team members have contributed equally to the project.

8 WORD COUNT - SEE APPENDIX

REFERENCES

Robert J Andres, Gregg Marland, Inez Fung, Elaine Matthews, and Antoinette L Brenkert. 1997. *Geographic Patterns of Carbon Dioxide Emissions from Fossil-Fuel Burning\, Hydraulic Cement Production\, and Gas Flaring on a One Degree by One Degree Grid Cell Basis: 1950 to 1990 (NDP: 058)(Issued March, 1997).* Technical Report. Carbon Dioxide Information Analysis Center (CDIAC); Oak Ridge National Lab ....

Kenneth Bruninx, Darin Madzharov, Erik Delarue, and William D'haeseleer. 2013. Impact of the German nuclear phase-out on Europe's electricity generation—A comprehensive study. *Energy Policy* 60 (2013), 251 – 261. https://doi.org/10.1016/j.enpol.2013.05.026

Trudie Dockerty, Andrew Lovett, Gilla Sünnenberg, Katy Appleton, and Martin Parry. 2005. Visualising the potential impacts of climate change on rural landscapes. *Computers, Environment and Urban Systems* 29, 3 (2005), 297–320.

Matthew Fitzpatrick and Robert Dunn. 2019. Contemporary climatic analogs for 540 North American urban areas in the late 21st century. *Nature Communications* 10, 1 (2019), 1–7. http://search.proquest.com/docview/2178969657/

Diego García-Gusano, Mario Martín-Gamboa, Diego Iribarren, and Javier Dufour. 2016. Prospective Analysis of Life-Cycle Indicators through Endogenous Integration into a National Power Generation Model. *Resources* 5, 4 (2016). https://doi.org/10.3390/resources5040039

Rolf Golombek, Sverre Kittelsen, and Ingjerd Haddeland. 2012. Climate change: impacts on electricity markets in Western Europe. *Climatic Change* 113, 2 (2012), 357–370.

T Hammons. 2006. Impact of Electric Power Generation on Green House Gas Emissions in Europe: Russia, Greece, Italy and Views of the EU Power Plant Supply Industry - A Critical Analysis. *International Journal of Electrical Power & Energy Systems* 28, 8 (2006), 548–564. http://search.proquest.com/docview/14790114/

Geoffrey Heal. 2017. Reflections—What Would It Take to Reduce U.S. Greenhouse Gas Emissions 80 Percent by 2050? *Review of Environmental Economics and Policy* 11, 2 (07 2017), 319–335. https://doi.org/10.1093/reep/rex014 arXiv:http://oup.prod.sis.lan/reep/article-pdf/11/2/319/19530563/rex014.pdf

Iftekhar Khan, Firoz Alam, and Quamrul Alam. 2013. The global climate change and its effect on power generation in Bangladesh. *Energy Policy* 61 (2013), 1460 – 1470. https://doi.org/10.1016/j.enpol.2013.05.005

Daniel E. Klein. 2016. CO2 emission trends for the US and electric power sector. *The Electricity Journal* 29, 8 (2016), 33 – 47. https://doi.org/10.1016/j.tej.2016.09.008

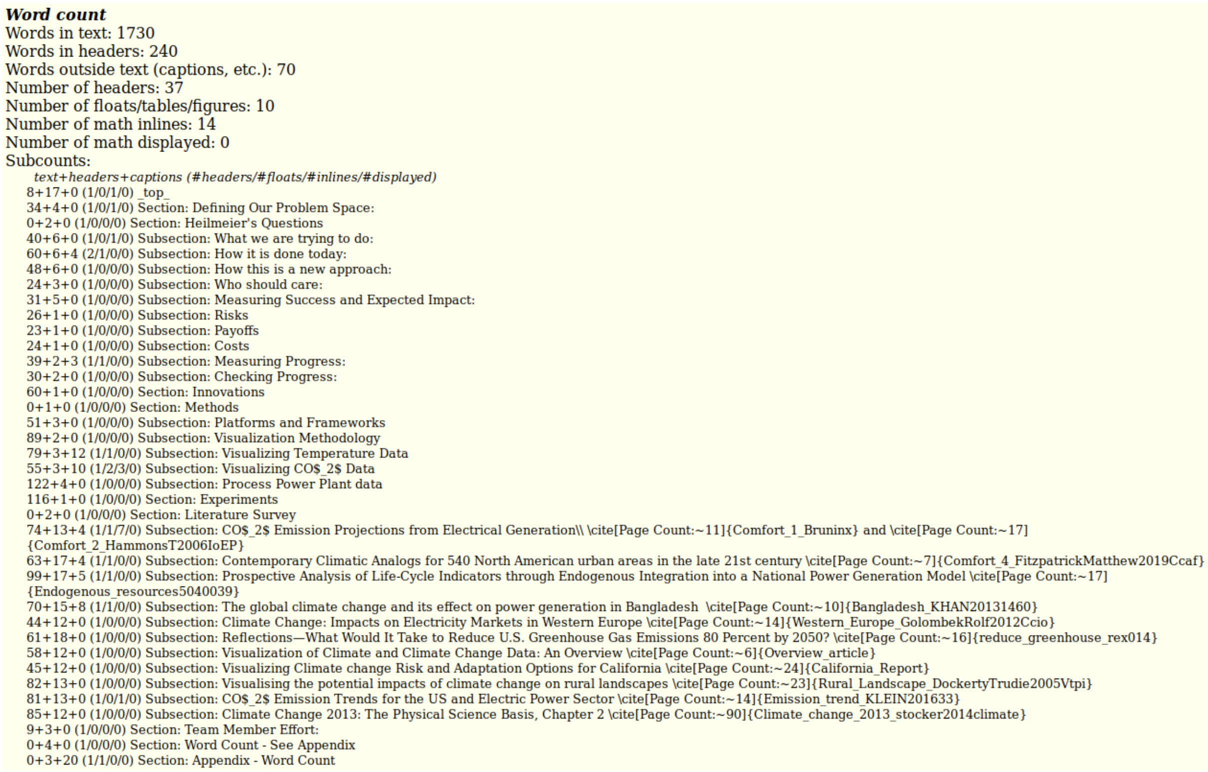
Kevin; Maggi Kelly; Brian Galey Koy. 2014. Cal-Adapt: Visualizing Climate Change Risk and Adaptation Options for California. (2014).

Thomas Nocke, Till STERZEL, Michael Böttinger, and Markus Wrobel. 2008. Visualization of Climate and Climate Change Data: An Overview. *in Ehlers et al. (Eds.) Digital Earth Summit on Geoinformatics 2008: Tools for Global Change Research (ISDE'08), Wichmann, Heidelberg, pp. 226-232, 2008* (01 2008).

Robert Rohde, Richard Muller, Robert Jacobsen, Saul Perlmutter, Arthur Rosenfeld, Jonathan Wurtele, Judith Curry, Charlotte Wickham, and Steven Mosher. 2013. Berkeley earth temperature averaging process. *Geoinfor. Geostat.: An Overview* 1, 2 (2013), 1–13.

Thomas Stocker. 2014. *Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change.* Cambridge University Press.

APPENDIX - WORD COUNT



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Words in headers: 240
Words outside text (captions, etc.): 70
Number of headers: 37
Number of floats/tables/figures: 10
Number of math inlines: 14
Number of math displayed: 0
Subcounts:
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  45+12+0 (1/0/0/0) Subsection: Visualizing Climate change Risk and Adaptation Options for California \cite[Page Count:~24]{California_Report}
  82+13+0 (1/0/0/0) Subsection: Visualising the potential impacts of climate change on rural landscapes \cite[Page Count:~23]{Rural_Landscape_DockertyTrudie2005Vtpi}
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Figure 9: The word count for this document, excluding this section is: 1730 using TeXCount Web Service.