Errata for A Combined Energy and Geoengineering Optimization Model (CEAGOM) for Climate Policy Analysis

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An error in a small portion of the CEAGOM code was discovered. The error was in the ToyOptCl.m, ToyOptCMEM.m, ToyOptEM.m, ToyOptNL.m, and ToyOptTL.m files. This coding error allowed a higher quantity of tree planting to be deployed than what was specified by the user. Specifically, it allowed too large an upper bound to be passed to the fmincon subroutine. The original incorrect code was:

```
if t <= lt
        capt = tzero(15);
    else
        capt = qt(t-1) + Lta;
        if capt > Lt
            capt = Lt;
        end
end
```

The corrected code is the following:

```
if t <= lt
        capt = tzero(15);
    else
        capt = Lta;
end
```

This error has been corrected in all of the above files.

The only results in the original dissertation that were impacted by this coding error were those associated with the Ch-Trees case in the China emissions analysis. In all other cases where tree planting was employed, the amount of tree planting deployed was either well below the specified limit or the amounts were hard coded in order to obtain a desired level of tree planting as specific times in the simulation.

In addition to this coding error, more recent data indicated that the amount of land that was assumed available for tree planting, biomass, and biofuel production in the China emissions analysis was too high. Based on current references for China's actual land area, available arable land, and forested area, it was determined that a more reasonable estimate for the total amount of land available for tree planting, biofuel, and biomass would be 10% of the China's land area which comes to 93 million hectares (Central Intelligence Agency, 2018; World Bank, 2018).

As a result of both the coding error and the high assumption of available land, the China analysis was completely rerun. In addition to correcting the available land assumption, the allowable annual increase in wind (parameter Lwa) was increased from 4 GW per year to 30 GW per year and the allowable annual increase in solar-PV (parameter Lspa) was increased from 4 GW per year to 50 GW per year based on recent industry data (Clean Technica, 2018; Froese, 2017).

Even with the changes outlined above, the no emissions limit case Ch-NoLim remained essentially unchanged. Hence, the China emissions target of 13.87 Gt CO_2-eq starting in 2030 remained unchanged. The revised results for the base emissions limit case Ch-BaseEM showed some differences from the prior results due to the reduced land area for biofuel production. The revised Ch-BaseEm case had one-third the biofuel usage and a 1 billion barrel increase in oil usage. In order to meet the emissions limit, the revised Ch-BaseEM showed significantly lower usage of coal (dropping from over 4000 million metric tons per year to 2700 million metric tons per year in 2035), and a large increase in the use of natural gas, wind and solar-PV. A significant deployment of biofuels was also needed. Figures 1 and 2 below show the resource mixes for the no limit and base emissions limit cases.

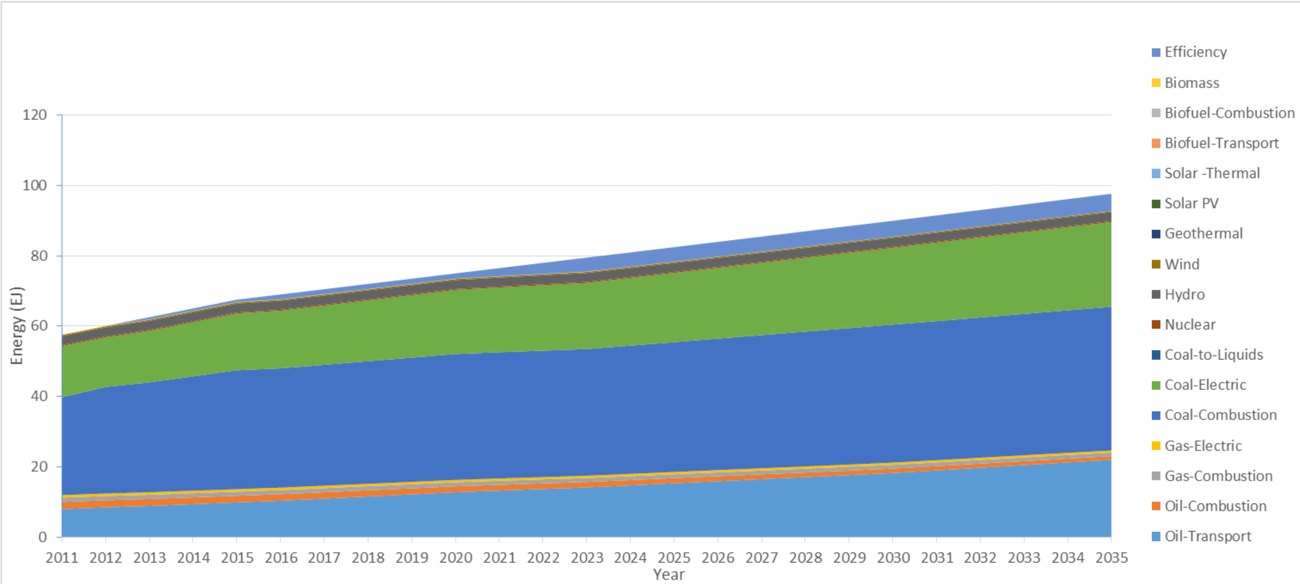

Figure 1. China Resource Mix with No Emissions Limit (Ch-NoLim Case).

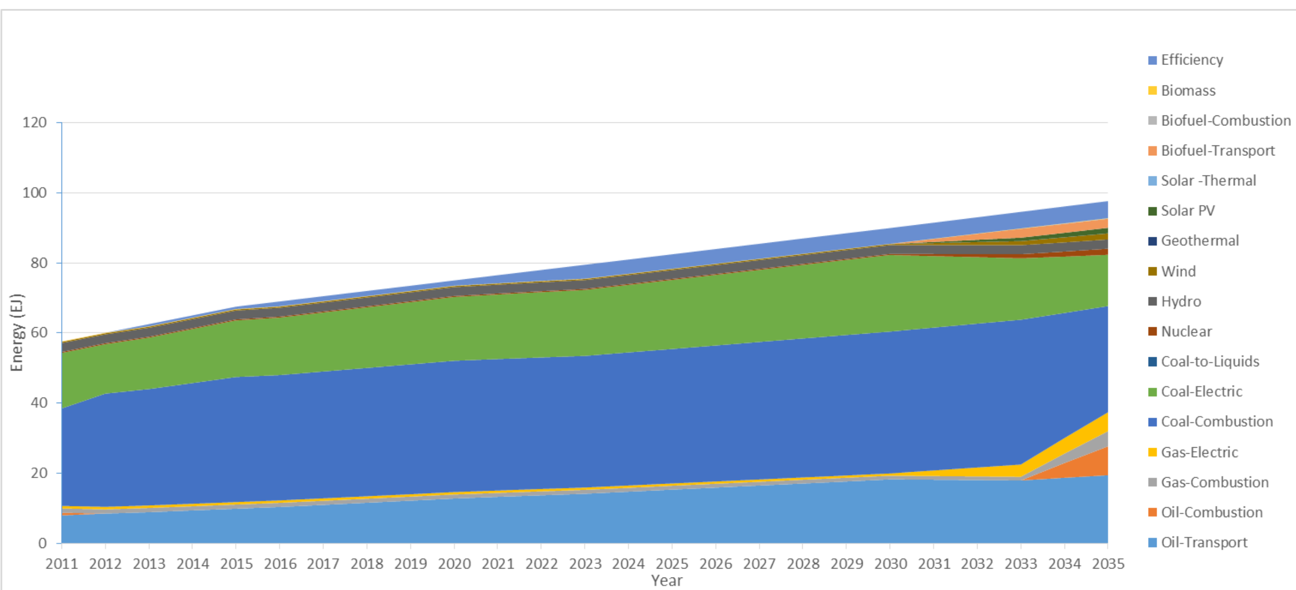

Figure 2. China Resource Mix with Emissions Limit (Ch-BaseEM Case).

The effects of the code and data changes were more pronounced in the sensitivity cases. The case with energy efficiency potential increased up to 10% of energy demand, Ch-10%Eff, demonstrated results similar to what had been seen previously. The increased energy efficiency allowed coal use of over 3550 million metric tons per year by 2035 with a sharp drop in natural gas, oil, and solar-PV usage. The increased coal usage and energy efficiency offset these other energy resources for electricity, transportation, and industrial combustion purposes as illustrated in Figure 3. The increased energy efficiency, in turn, offset the coal emissions.

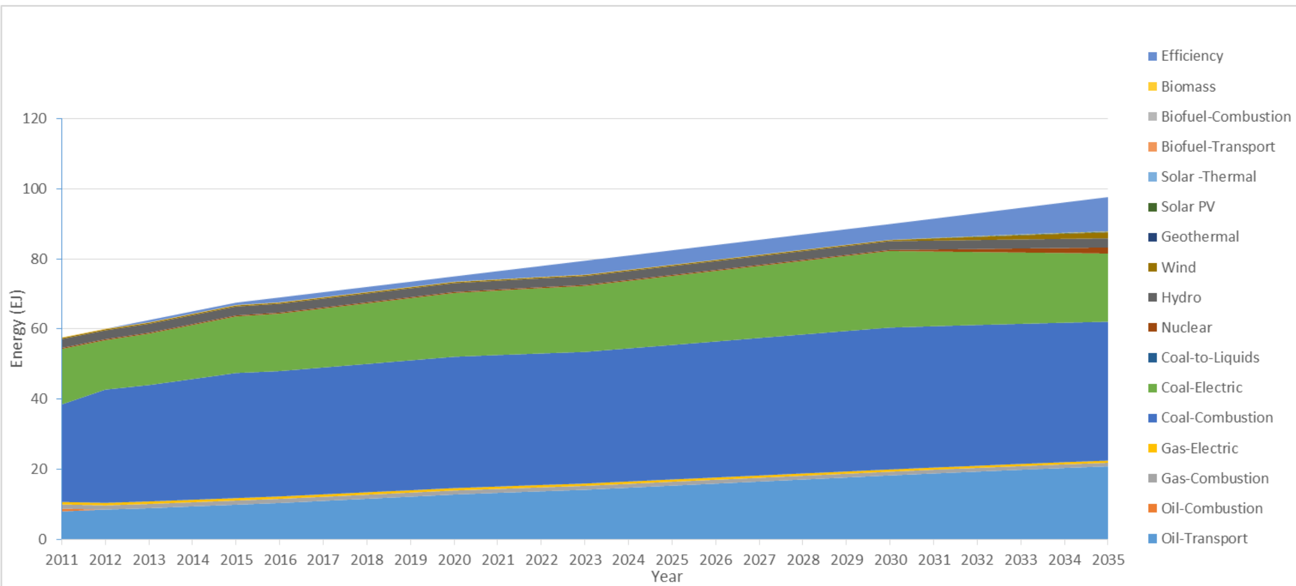

Figure 3. China Resource Mix with 10% Energy Efficiency Potential (Ch-10%Eff Case).

The case with no new nuclear plants assumed, Ch-NoNuke, required a 10% energy efficiency potential as previously estimated. This case also had annual coal usage over 3500 million metric tons by 2035, so the same interaction between coal use and energy efficiency appeared in this case. In addition, Ch-NoNuke required additional natural gas, solar-PV, and hydroelectric resources in order to take the place of the nuclear resources (see Figure 4).

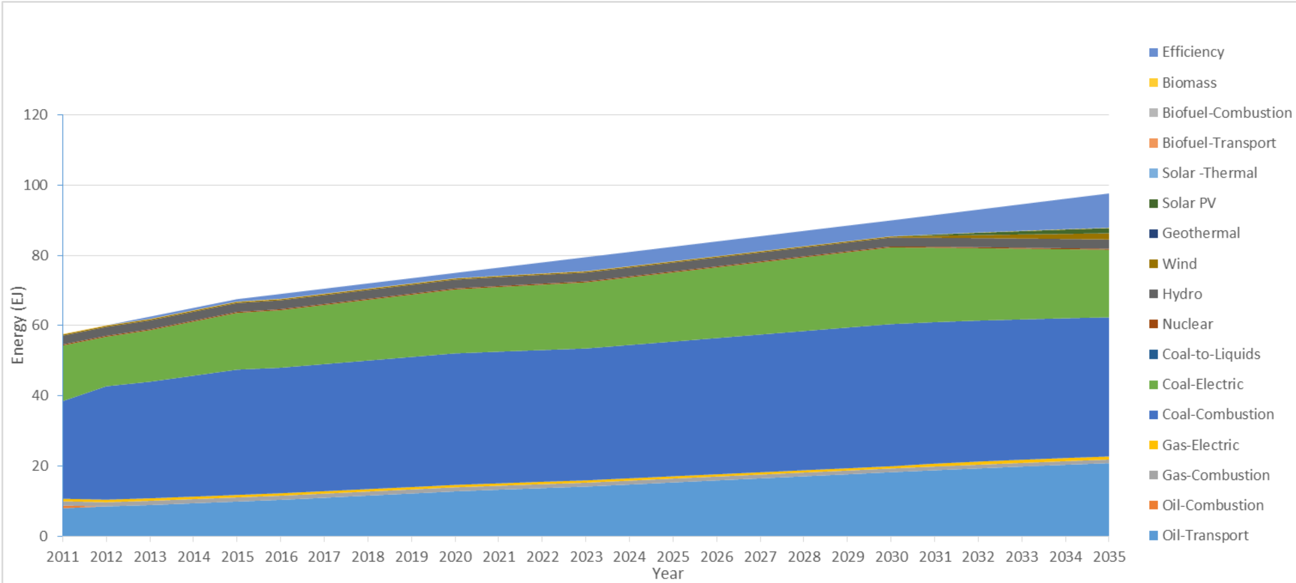

Figure 4. China Resource Mix with No New Nuclear Plants (Ch-NoNuke Case).

The case with electric vehicle usage increased to 10% by 2035, Ch-ElecCar, showed results that were similar to the base emissions case Ch-BaseEm. This case had coal usage up to 3200 million metric tons per year by 2035; however, these emissions were offset by a drop in oil use of nearly 3 billion barrels per year (see Figure 5).

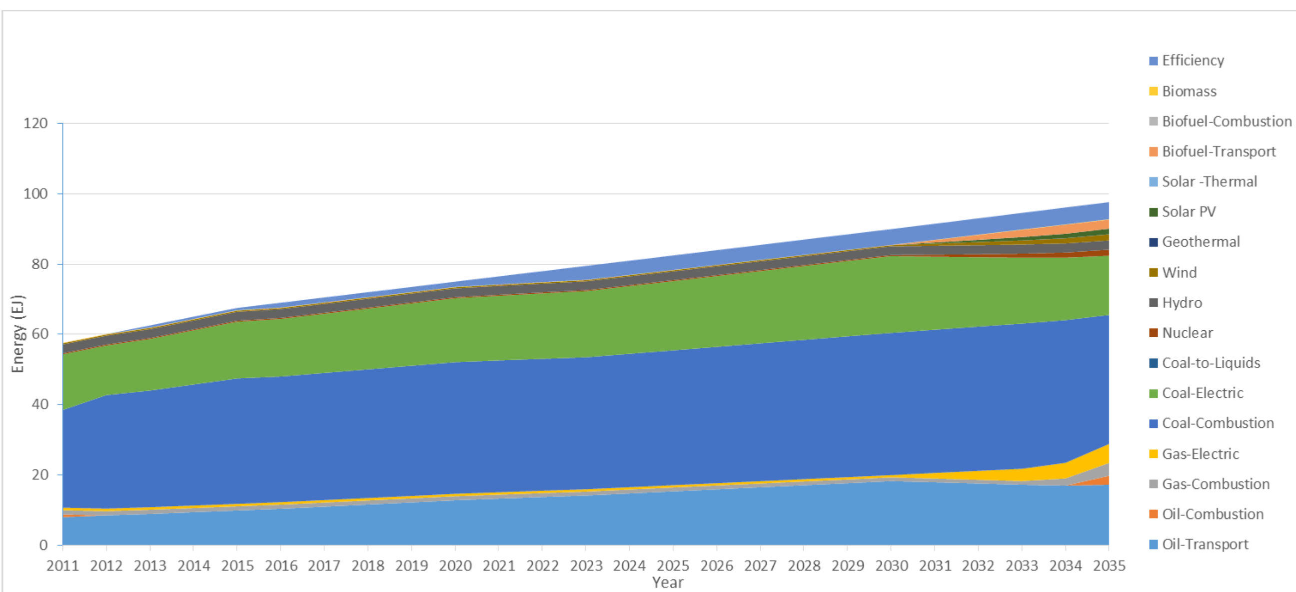

Figure 5. China Resource Mix with Increased Electric Car Deployment (Ch-ElecCar Case).

The largest change in results compared to the original analysis was in the case of tree planting sensitivity case, Ch-Trees. The original analysis deployed far more tree planting than the allowed 20 million hectares per year. That, coupled with the over-estimate of available land which provided high biofuel availability, yielded unrealistically optimistic results. The revised analysis showed that 20 million hectares of trees could be planted each year in 2031 through 2033 and another 11 million hectares in 2034. The tree planting had to be reduced starting in 2034 because the available land was needed for biofuel production. Oil use in the case was the highest of all the cases reaching 16 billion barrels per year in 2035 since biofuel production was significantly reduced as a result of the tree planting. Coal usage had to be decreased to 2600 million metric tons annually by 2035, 100 million tons lower than the base emissions case. The decrease in coal usage coupled with the tree planting offset the increased emissions resulting from the higher oil usage. Figure 6 shows the resulting resource mix.

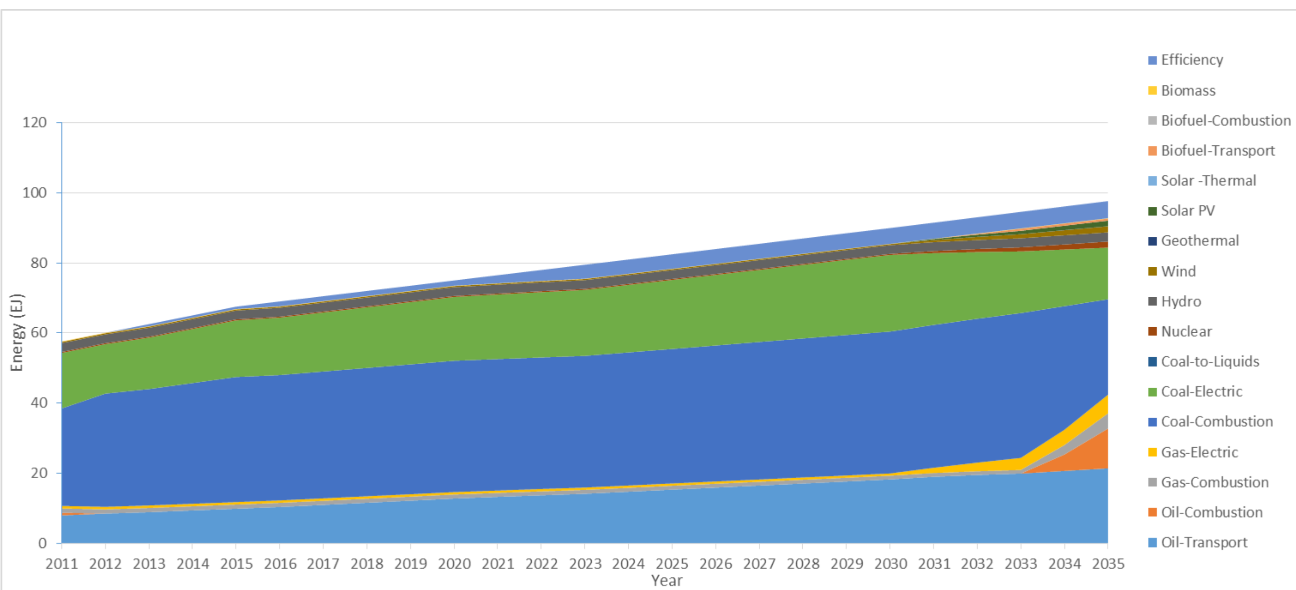

Figure 6. China Resource Mix with Tree Planting (Ch-Trees Case).

The cost results for this revised analysis for China are summarized in Table 1 below.

Table 1. China Emissions Analysis – NPV and Total Nominal Costs.

Case	NPV of Total Energy Costs ($trillion)	Nominal Total Energy Costs ($trillion)
Ch-NoLim	15.0	26.4
Ch-BaseEM	15.4	27.8
Ch-10%Eff	14.6	25.7
Ch-ElecCar	15.1	27.1
Ch-NoNuke	14.8	26.4
Ch-Trees	15.3	27.7

These results clearly demonstrate that increasing energy efficiency would be the most cost-effective way for China to meet its emissions pledge. It would even allow China to use more of its coal resources than some of the other alternative strategies. It also avoids the need for the development of biofuels and the accompanying need for land. In addition, coupling increased energy efficiency with increased deployment of natural gas, wind, hydroelectric, and solar-PV would even enable China to avoid having to build new nuclear plants.

Increasing the use of electric vehicles would be another promising strategy for China. The cost of this approach is only slightly above the no emissions limit case and also allows for the use of a substantial level of China's abundant and inexpensive coal reserves.

Finally, the use of tree planting appears to have only a marginal benefit. The cost is only slightly below that of the base emissions case. This strategy would require a substantial reduction in coal usage and a large increase in oil use. Also, this case highlights the competition for available land that would arise between tree planting efforts and biofuel production.

References

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