LCA Methodology to incorporate new technologies in USEEIO

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Disclaimer: This methodology is not generalizable to the addition of any new technology since it was thought to add a biofuels sector that includes 3 new technologies (here industries) and 1 new commodity. Other new technologies may have a different combination of number of new industries per number of new commodities or vice versa.[1]

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[1] However, it is generalizable to the addition of any new commodity that can be produced with three different technologies.

Objective

Incorporate new technologies in USEEIO to evaluate potential future Bio-economy scenarios in which 2nd generation biofuels are part of the economy. To represent the new technology/bio-product/bio-service, a similar existing technology/product/service will be disaggregated into the existing (traditional) and a bio-based version. This correspond to the Type 2[2] of disaggregation applied to 2nd generation biofuels in the context of Bio-economy.

USEEIO assumptions

Base IO level: Detailed model (Commodity)
IO year: 2012
Model type: US[3]/GA
Base price type: Producer's prices
Elementary flows:

- Data is gathered for V1.1.
- Data is organized for V2.0-GHG in useeior

Industries and commodities included

Considering the vision of a future Bio-economy in GA, 2nd generation biofuels technologies are selected to be included in USEEIO. In general, when referred to 2nd generation biofuels,

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[2] This correspond to the addition of a new industry and/or commodity that do not exist in current economy. Therefore, it does not exist in current BEA tables or current satellite data. In contrast, Type 1 disaggregation takes an existing sector of the economy and disaggregate it into the sub-industries contained in it.

[3] Since we are incorporating a nth representative plant and we are not using domestic matrices. Therefore, it is the same if we add it to the state level. It's a future development to obtain the import matrices required to create domestic matrices. At that point it will be different to include the industries at a national level or at a state level.

it means the processes by which fuels (ethanol, gasoline, diesel, jet fuel and more) are produced using lignocellulosic materials (wood waste, forest residues, saw mill dust, municipal solid waste (MSW), corn stover, and more) as biomass, instead of high-sugar alternatives as corn and sugarcane.

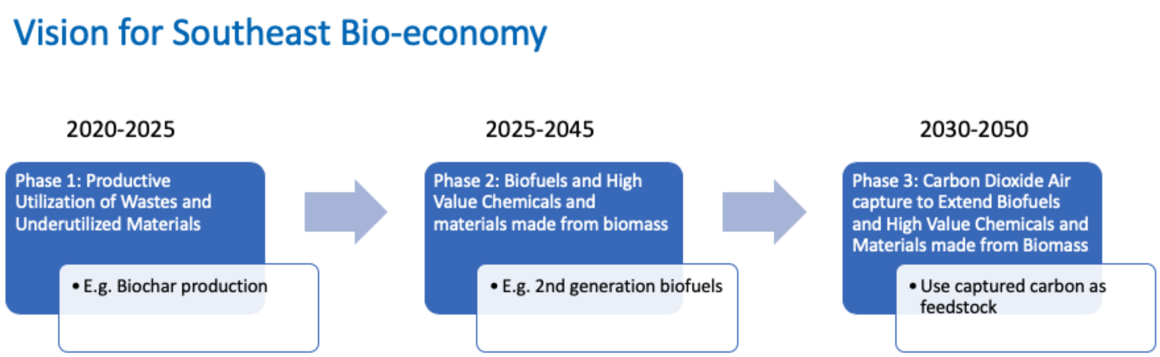


Figure 1- Vision for a future bio-economy in Southeast GA

Table 1 shows the specific technologies included, its feedstock and products.

Table 1- Technologies included

Technology	**Feedstock**	**Product**
Syngas fermentation to ethanol to isobutene to higher olefins to fuels	Blended biomass contains 45% pulpwood, 32% wood residues, 3% switchgrass, and 20% construction and demolition waste	Naphta, Jet fuel and Diesel Fuel
Syngas to liquid fuels via Fischer-Tropsch	Blended biomass contains 45% pulpwood, 32% wood residues, 3% switchgrass, and 20% construction and demolition waste	Naphta, Jet fuel and Diesel Fuel
Syngas to molybdenum disulfide-catalyzed alcohols followed by fuel production via Guerbet reaction	Blended biomass contains 45% pulpwood, 32% wood residues, 3% switchgrass, and 20% construction and demolition waste	Jet fuel and Diesel Fuel

With this in mind, in USEEIO 3 new industries are added: Gas fermentation, Thermochemical and Guerbet. Each of the technologies is added as a different industry to allow for comparison when using USEEIO.
Similarly, 1 new commodity is created: Biofuel. This commodity corresponds to a single fuel product that is a combination of all fuel products: gasoline, jet fuel and diesel blendstocks. This is for simplicity and following (Eric C.D. Tan et al., 2016) .

When including these industries in USEEIO, we are considering that the three new industries have as primary product the Biofuel commodity and no other industry produce biofuels.

Methodology: LCA EEIO modifications

Here we describe the changes required in terms of EEIO models and considering nomenclature used in USEEIO model to add the 3 new sectors and 1 new commodity. This methodology was design considering (Matthews, Hendrickson, & Matthews, 2014), (Horowitz & Planting, 2009),(Young, Vendries, & Cashman, 2019), (Yang, Ingwersen, Hawkins, Srocka, & Meyer, 2017) and (Joshi, 1999).

What needs to be changed

Make and Use tables, A and B matrices, Y vector

Information required

- About the new commodity:
    - Name: A descriptive name for the commodity.
    - Code: An identification code for the new commodity. The suggestion is to use "B" after the similar commodity code.
    - Primary producer: this methodology assumes the 3 new industries are the primary producers of the new commodity and there are no secondary producers.

- A similar commodity in the current economy for which the new bio-product will be a perfect substitute[4].We are going to manage the new commodity and similar commodity in the same units[5]. About this similar commodity you need:
    - Name: The descriptive name for the commodity based on BEA information.
    - Code: BEA identifier code.
    - Price of commodity: An estimated price for the commodity in current economy ($/unit of new commodity).
    - Primary producer name: The name of the primary producer industry according to BEA information.
    - Primary producer code: The identifier code of the primary producer industry according to BEA information.

- How much % of the current production of the similar commodity, produced by its primary producer, will be replaced with the new commodity?
  For example, for biofuels: How much % of the current production of fuels, produced by Petroleum refineries, will be replaced with biofuel?

[4] See Ripple effect in the economy and other economic assumptions to see the implications of this.

[5] For example, when used to include the biofuels sector, both fuels (similar commodity) and biofuels (new commodity) are managed in GGE units.

The percentage use will be an initial suggestion. However, this is the main variable to evaluate different bio-economy future scenarios.

- About new industries:

For each of the 3 new industries:

  - Name: A descriptive name for the new industry.
  - Code: An identification code for the new industry. The suggestion is to use the code for the similar industry and add a "B" after. Since this methodology is for 3 new industries use "B1", "B2", "B3". See the Data section to see an example with the biofuels sector.
  - Primary product: it is assumed that the primary product of the three technologies is the new commodity.
  - Secondary product: Not currently included in the model, but important to consider for future development.
  - Price of new commodity: What is the price at which each of the new industries sell the new commodity? ($/ unit of commodity).

Note: The production price for each of the technologies will be used, but for model purposes, by default, the price used for each industry will be the same to the price of the similar commodity being replaced. See assumption ii in Ripple effect in the economy and other economic assumptions section for more details.

- Since we have more than one primary producer of the new commodity, we need: How much of the new commodity will be produced by each of the technologies?

  This is another variable that could be changed for future bio-economy scenarios.
- Input purchases and value added for new industries:
  - We need the input purchases of each of the commodities (including the new one) in producer's prices, from each of the new industries, required to produce 1 unit of the new commodity. This means we need a matrix with:
    - Number of rows: Number of current commodities + Number of new commodities= 405 + 1=406
    - Number of columns: Number of new industries= 3
  - We need the elements of the value added, for each of the new industries, required to produce 1 unit of the new commodity.
    - Compensation of employees
    - Taxes on production and imports, less subsidies
    - Gross operating surplus (Optional- this element will be used to balance the Make and Use tables so the data will be useful for validation, but will not be explicitly included)

- Environmental data. In specific a matrix that includes all the environmental flows in unit of environmental flow per dollar produced of the new commodity for each of the three new industries.
    - Number of rows: 1903 (Total based on USEEIO V1.1), 15 (only GHG environmental flows currently included in useeior).
    - Number of columns: Number of new industries=3.

Modeling steps

These do not include software or management specificities, only include steps in a IO-LCA or Extended Environmental Input Output (EEIO) modelling considering some information about how it is implemented in useeior. We're applying the modeling steps in the modeleearth useeior fork: https://github.com/modelearth/useeior/tree/Bio-Modeling

Click "Clone or download" to begin. The methodology is coded in BioeconomyFunctions.R and a practical example to add biofuels sector is in USEEIO20-GHG-Biofuels.R.
Let $n_I = 405$ be the number of current Industries, $n_c = 401$ be the number of current commodities, $n_o = 4$ be other commodities used for adjustment (Scrap, Used and second hand goods, Noncomparable imports and Rest of the world adjustment). Let $n_{c1} = n_c + n_o$

To convert from $million USD to GGE: $GGE = \$\,million\ USD\ \times \frac{GGE}{\$USD} \times \frac{1{,}000{,}000\ \$USD}{1\ \$million\ USD}$
To convert from GGE to $million USD: $\$million\ USD = GGE\ \times \frac{\$USD}{GGE} \times \frac{1\ \$million\ USD}{1{,}000{,}000\ \$USD}$

I'll use a C before some variables to indicate if it is from current economy or F to indicate it comes from future economy.

1. Initial calculations

Determine:

Current	How much does the similar industry produce of the similar commodity in $ million USD? (CX_{s_1,s_2})	Current production in Make Table
	How much does the similar industry produce of the similar commodity in GGE? (CGP_{s_1,s_2})	Transformation of CX_{s_1,s_2} to GGE
	% of total produced of the similar commodity produced by its primary producer?$(\%_p)$	$CX_{s_1,s_2}/CTotalCommodityOutput_{s_2}$
Future	How much will the bio-product replace in GGE? (FBP)	$\% \cdot CGP_{s_1,s_2}$
	How much will the similar industry produce of the similar commodity in GGE? (FGP_{s_1,s_2})	$(1-\%) \cdot CGP_{s_1,s_2}$
	How much will the similar industry produce of the similar commodity in $million USD? ($FX_{s_1,s_2}$)	Transformation of FGP_{s_1,s_2}
	How much will the technology 1 industry produce of bio-product in GGE? $(FGP_{n_I+1,n_{c1}+1})$	$FBP \cdot \%_{Tech1}$
	How much will the technology 2 industry produce of bio-product in GGE? $(FGP_{n_I+2,n_{c1}+1})$	$FBP \cdot \%_{Tech2}$
	How much will the technology 3 industry produce of bio-product in GGE? $(FGP_{n_I+3,n_{c1}+1})$	$FBP \cdot \%_{Tech3}$

2. Modify Use Table

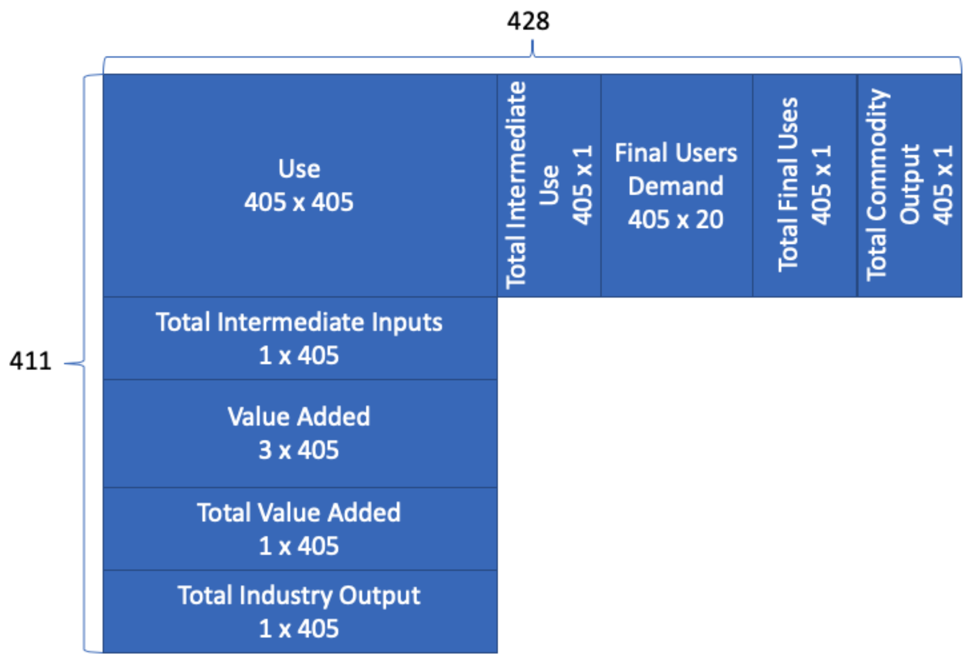


Figure 2- Dimensions of Use table in current useeior. Rows 1 to 405 correspond to Commodities and Columns 1 to 405 correspond to Industries.

Let $n_1 = n_c + n_o = 405$ be the number of rows and $n_2 = n_I = 405$ be the number of columns in the transactions section of the Use table.

Let s_1 be the index to indicate the row and s_2 be the index to indicate the column of the similar sector in the Use table.

Let $Y_{i,j}$ be the use value from industry j of commodity i in $million USD.

a. Modify dimensions (add additional row and three additional columns).
b. Fill new row and columns with data:

Row (i)	Data description	Data added
$n_1 + 1$ (Industry users/intermediate inputs)	How much each of the industries use the new commodity to produce (in producer's prices- $million USD)?	For columns $j \in \{1, \dots, n_2\} \backslash \{s_2\}$, Let CGU_j be the amount currently[6] used of fuels from industry j in GGE.[7] Let FBU_j be the future amount used of biofuels from industry j in GGE. Let FGU_j be the future amount used of fuels from industry j in GGE. $FBU_j = CGU_j \cdot \%_{\boldsymbol{p}} \cdot \%$ $FGU_j = CGU_j - FBU_j$ Then $Y_{s_1,j}$ and $Y_{n_1+1,j}$ are the respective transformations to $million USD of FGU_j and FBU_j[8].
$n_1 + 1$ (Final users)	How much final users/customers demand of the new commodity (in producer's prices- $million USD)?	Same process as for Industry users. For columns j= $n_2 + 3 + 2, \dots, n_2 + 3 + 21$ Let CFU_j be the amount currently used of fuels from user j in GGE. Let FFB_j be the future amount used of biofuels from user j in GGE. Let FFU_j be the future amount used of fuels from user j in GGE. $FFB_j = CFU_j \cdot \%_{\boldsymbol{p}} \cdot \%$ $FFU_j = CFU_j - FFB_j$ Then $Y_{s_1,j}$ and $Y_{n_1+1,j}$ are the respective transformations to $million USD of FFU_j and FFB_j.

c. Recalculate totals:
- (Row $n_1 + 1 + 1$): Total Intermediate Inputs= $\sum_{i=1}^{n_1+1} Y_{i,j}$ for all $j = 1, \dots, n_2 + 3$
- (Column $n_2 + 3 + 1$): Total Intermediate Use = $\sum_{j=1}^{n_2+3} Y_{i,j}$ for all $i = 1, \dots, n_1 + 1$
- (Column $n_2 + 3 + 2 + 20$): Total Final Uses = $\sum_{j=n_2+3+2}^{n_2+3+21} Y_{i,j}$ for all $i = 1, \dots, n_1 + 1$
- (Column $n_2 + 3 + 2 + 21$): Total Commodity Output= Total Intermediate Use + Total Final Uses for all $i = 1, \dots, n_1 + 1$.

d. Fill value added rows with data:

[6] In current economy, i.e, without the new industries or commodities.
[7] Obtained transforming the current use of fuels in $million USD to GGE using formula … and fuels price.
[8] The price to transform the biofuel use in GGE to $Million USD correspond to a weighted average of the selling prices for biofuel for each of the technologies using the percentages of production.

<table>
<tr><td>Row (i)</td><td>Data description</td><td>Data added</td></tr>
<tr><td rowspan="3">Value added
(3 components of value added)
Rows: $i = n_1 + 3, n_1 + 4, n_1 + 5$</td><td>Which is the compensation of employees (returns to labor)?
(Row $i = n_1 + 3$)</td><td>Let $CVA_{i,j}$ be the current value added value for the row i and the column j and let $FVA_{i,j}$ be the future value added value for row i and column j.

For column $j = n_2 + 1, n_2 + 2, n_2 + 3$

Compensation of employees required to produce 1 unit of the new commodity using each of the three technologies. From process data. When added in the model:
$FVA_{i,j} = FGP_{j,n_{c_1}+1} \cdot VAfromProcessData_{i,j} \cdot \frac{1}{1{,}000{,}000}$

For column $j = s_2$

$$FVA_{i,j} = CVA_{i,j} \cdot (1 - \%)$$
For columns $j \in \{1, \ldots, n_2\} \backslash \{s_2\}$,
Remains the same</td></tr>
<tr><td>Which are the taxes on production and imports less subsidies (returns to government)?
(Row $i = n_1 + 4$)</td><td>Let $CVA_{i,j}$ be the current value added value for the row i and the column j and let $FVA_{i,j}$ be the future value added value for row i and column j.

For column $j = n_2 + 1, n_2 + 2, n_2 + 3$

Taxes on production and imports less subsidies required to produce to produce 1 unit of the new commodity using each of the three technologies. From process data. When added in the model:
$FVA_{i,j} = FGP_{j,n_{c_1}+1} \cdot VAfromProcessData_{i,j} \cdot \frac{1}{1{,}000{,}000}$

For column $j = s_2$

$$FVA_{i,j} = CVA_{i,j} \cdot (1 - \%)$$
For columns $j \in \{1, \ldots, n_2\} \backslash \{s_2\}$,
Remains the same</td></tr>
<tr><td>Which is the gross operating surplus (returns to capital)?
(Row $i = n_1 + 5$)</td><td><u>(Optional – for validation)/ For new industries</u>
Gross operating surplus obtained when producing $FGP_{n_I+1,n_{c1}+1}, FGP_{n_I+2,n_{c1}+1}, FGP_{n_I+3,n_{c1}+1}$ GGE of new commodity for technology 1, technology 2 and technology 3, respectively. From process data.
<u>In model</u>
For all existing industries,
Gross operating surplus = Total Industry Output (From Make table)- Total intermediate inputs-Compensation of employees- Taxes on production and imports less subsidies

For new industries $j = n_2 + 1, n_2 + 2, n_2 + 3$,
Gross operating surplus = Total Industry Output ($FGP_{j,n_{c_1}+1}$ transformed to $million USD)- Total intermediate inputs-Compensation of employees- Taxes on production and imports less subsidies</td></tr>
</table>

Column (j)	Data description	Data added
n_2+1, n_2+2, n_2+3	How much the new industry uses of each commodity to produce its primary product (in producer's prices- $million USD)?	The amount spent in each of the n_1+1 commodities to produce 1 unit of the new commodity using each of the three technologies. From process data. Correspond to the input purchases. When adding it to the model: For rows $i \in \{1, \dots, n_1+1\}$ $FY_{i,j} = FGP_{j,n_{c_1}+1} \cdot InputPurchasesfromProcessData_{i,j} \cdot \frac{1}{1{,}000{,}000}$
s_2	The uses of the similar industry must be reduced because it is now producing less.	For rows $i \in \{1, \dots, n_1\} \backslash \{s_1\}$, $FY_{i,j} = CY_{i,j} \cdot (1 - \%)$ Let $\%_j^u = \frac{FGU_j}{CGU_j}$ For row $i = s_1$ $FY_{s_1,s_2} = CY_{s_1,s_2} \cdot (1 - \%) \cdot \%_{s_2}^u$ For row $i = n_1+1$ $FY_{n_1+1,s_2} = FBU_{s_2} \cdot (1 - \%) \cdot \$_{NewCommodity} \cdot \frac{1}{1{,}000{,}000}$

e. Recalculate totals:
   - (Row n_1+1+5): Total Value Added= Compensation of employees + Taxes on production and imports, less subsidies+ Gross operating surplus
   - (Row n_1+1+6): Total Industry Output= Total Intermediate Inputs + Total Value Added

Assumptions for Use Table:

- *All previous industries and final users consume the same amount in units of the commodity (for example: in GGE for biofuels sector). But distributed using % between the traditional commodity and the new bio-commodity.*
- *The input purchases to produce in the new industries comes from user data.*
- *To obtain the use in $million USD first I transform the use of the similar commodity to units, then using the price for the new commodity I retransform it in $million USD. This applies for both industry intermediate use and user final use.*
- *When another industry uses the bio-product, it buys to each of the industries that produces it according to $\%_{Tech1}, \%_{Tech2}, \%_{Tech3}$. So, the price used to transform from units to $million USD will be a weighted average between the three technologies.*
- *The Uses and the Value Added of the similar industry have to be reduced accordingly to the reduction in production. Here we assume the "recipe[9]" correspond to the primary product.*
- *For the Total Industry Output and the Total Commodity Output to match between the new commodity and the 3 added industries, Gross operating surplus will be used to adjust (it will ensure that the amount produced by the industries in Use table*

[9] In terms of input purchases.

correspond to $FGP_{n_I+1,n_{c1}+1}$, $FGP_{n_I+2,n_{c1}+1}$, $FGP_{n_I+3,n_{c1}+1}$ *units of the new commodity for Technology 1, Technology 2 and Technology 3, respectively.)*

- *Economically, because the new sectors create new/additional demand of some commodities (as input purchases), and since this demand has to be produced, then the uses of all the other industries producing this additional inputs have to increase accordingly. However, this increase in the demand of commodities to produce the inputs of the new technologies is not included in this methodology.*[10]
- *Since the other industries will produce the same, but now one of its inputs cost differently, then its Gross operating surplus will change. Here I calculate it to balance the tables.*
- *The values of the Use table that are not explicitly changed, remain unchanged.*

3. Modify Make Table

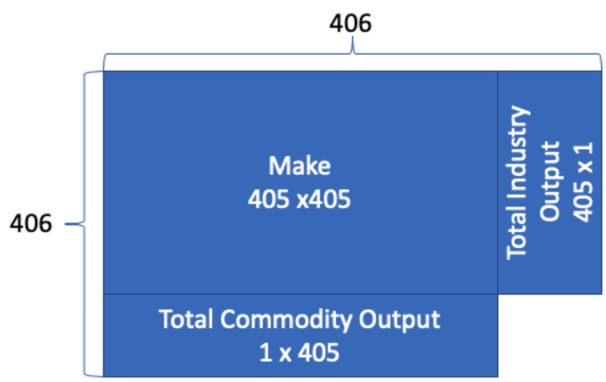


Figure 3- Dimensions of current Make table in useeior. Rows 1 to 405 correspond to Industries and Columns 1 to 405 correspond to Commodities.

Let $n_1 = n_I = 405$ be the number of rows and $n_2 = n_c + n_o = 405$ be the number of columns in the Make table, this excludes the column for Total Industry Output and the row for Total Commodity Output.

Let s_1 be the index to indicate the row and s_2 be the index to indicate the column of the similar sector in the Make table.

Let $X_{i,j}$ be the make value of industry i of commodity j in $million USD.

a. Modify dimensions (add 3 additional rows and 1 column).
b. Fill new rows and column with data:

[10] This is in fact a ripple effect. See section *Ripple effect in the economy and other economic assumptions* for more information.

Row (i)	Data description	Data added
n_1+1, n_1+2, n_1+3	How much the new industry produces of each commodity (in $million USD)?	For $j = 1, \dots, n_2$, $$X_{i,j} = 0$$ For $j = n_2+1$, X_{i,n_2+1} $= Total\ Industry\ Output_i (From\ Use\ Table)$
s_1	How much the similar sector produces of each commodity (in $million USD)?	For its primary product, $$FX_{s_1,s_2} + Y_{s_1,n_I+1} + Y_{s_1,n_I+2} + Y_{s_1,n_I+3}$$ For all other existing commodities: remain the same For new commodity: 0
$i \in \{1, \dots, n_1\} \backslash \{s_1\}$	How much each of the existing industries produce of each commodity (in $million USD)?	For its primary product (usually on diagonal cell), $$X_{i,i^{11}} = CX_{i,i} + Y_{i,n_I+1^{12}} + Y_{i,n_I+2} + Y_{i,n_I+3} - (CY_{s_1,i} - Y_{s_1,i})$$ For all other commodities: remain the same. For new commodity: 0

c. Recalculate totals:
   - (Row $n_1 + 3 + 1$): Total Commodity Output= $\sum_{i=1}^{n_1+3} X_{i,j}$ for all $j = 1, \dots, n_2 + 1$
   - (Row $n_2 + 1 + 1$): Total Industry Output= $\sum_{j=1}^{n_2+1} X_{i,j}$ for all $i = 1, \dots, n_1 + 3$

Assumptions:

- *The new industries are not producing secondary products.*
- *Only the three new industries produce the new commodity.*
- *We'll substitute the % of the similar commodity (e.g: fuels) produced by its primary producer (e.g: Petroleum refineries), but we will not substitute the production of the similar commodity produced by other industries.*
- *If the similar sector produces more than one commodity, the substitution will only be for its primary product (the similar commodity, e.g:fuels).*
- *Ignoring the fact that probably if it produces less of its primary product, it will produce less of its secondary products.*
- *Someone must produce the additional demand generated by the input purchases of the new industries. Here I assume that additional demand is produced by its primary producers.*
- *All industries primary product production has to change according to the changes in the economy (the decrease in demand for inputs from Similar Industry and the increase of demand given the inputs required to produce in the new industries).*

[11] Here I indicate indices (i,i) but in fact, the column index should correspond to the column index where the commodity produced by sector in row i is located.
[12] Careful with indices, this for example refers to the Use value, of commodity produced by industry in row i of Make table, by new industries ($n_I + 1, n_I + 2, n_I + 3$).

- *There will be an excess production of the similar commodity produced by the similar industry and for the new commodity if the similar industry uses the similar commodity as an input.*

4. Model recalculations

a. Recalculate normalized Make/ Market Shares matrix:
Recalculate V_n= each number in make table ($X_{i,j}$)/ Total commodity output.

b. Recalculate normalized Use/ Direct Coefficients table:
Recalculate U_n= each number in use table ($Y_{i,j}$)/Total industry output

c. Update A matrix:
Recalculate square direct requirement matrix A.

Commodity x Commodity type:
A= U_n * V_n

Industry x Industry type:
A= V_n * U_n

d. Modify B matrix:
   i. Modify dimensions (add 3 additional columns) to matrix B. (We have now 3 more industries).
   ii. Fill data for new columns ($n_I + 1, n_I + 2, n_I + 3$) using process data for each of the environmental flows per dollar of output of new industries.

e. Transform B matrix to flow x commodity matrix.

$$B^C = B \cdot V_n$$

f. Recalculate L matrix
Recalculate Total requirements matrix $L = (I - A)^{-1}$

f. Recalculate matrix D
Recalculate Direct Impact Matrix $D = C \cdot B^C$.

g. Recalculate matrix M
Recalculate Total environmental flows use per dollar $M = B^C \cdot L$.

h. Recalculate matrix U
Recalculate Total impacts per dollar matrix $U = C \cdot M = C \cdot B^C \cdot (I - A)^{-1}$.

i. Update final demand vector
   a. Add 3 rows to final demand vector.

b. Fill the 3 new rows with the demand for each new industry extracting it from the updated Use Table.

j. Recalculate USEEIO model results
Re-run calculateEEIOModel().

Ripple effect in the economy and other economic assumptions

In this section a give a brief description of the ripple effects in the economy when a new commodity and/or industry is introduced and some economic assumptions that have been made under this methodology. In Figure 4 I show an example of the ripple effect when adding biofuel commodity to replace part of the supply and demand of fuel commodity produced by Petroleum refineries. Here I'll refer to the specific case of adding the new biofuel sector, but these considerations remain if this methodology is used for any new commodity produced by three new industries.

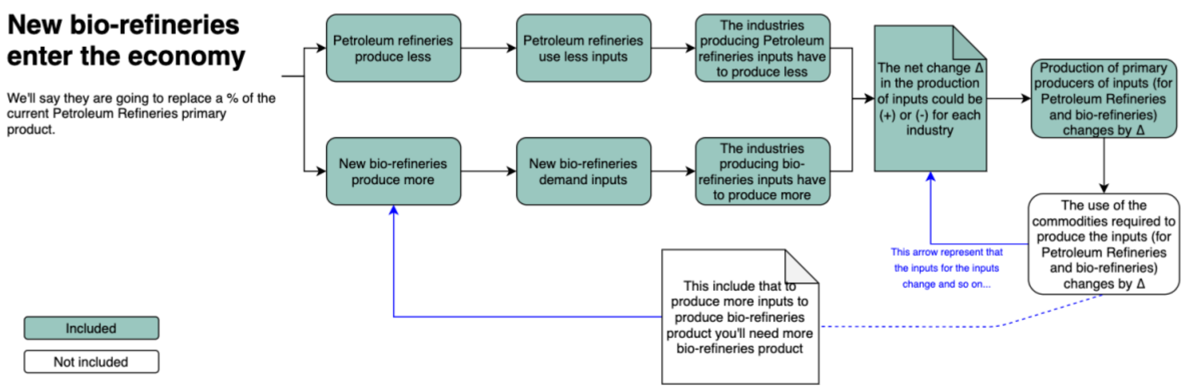


Figure 4- Ripple effect when biofuels and biorefineries enter the economy

Additional economic assumptions:

i. Note that with every increase in demand of any commodity, there is an increase in production and demand for the commodities used to produce this initial commodity. Also, there is an increase in demand/supply for the commodities used to produce the commodities needed to produce the commodities that are used to produce the initial commodity, and so on with all the providers of the providers.

Here, I include the change Δ in demand (Use) of commodities that are inputs for both the Petroleum refineries and the 3 new industries. Also, I include the change Δ in supply (Make) required to satisfy this change in demand. But beyond that, the ripple effect is not included. That means that the changes in demand resulting from this increase/ decrease in production of inputs for fuels or biofuels production are not included and neither the effects in supply and demand that result from this.

In case we would like to obtain the real modified Make and Use Tables, we will need to recalculate the equilibrium of the economy responding to the inclusion of this new industries and commodity. However, how to do this is still an open research question in Economics.

ii. Even when a selling price for biofuel for each of the technologies is required, as a default in the model, the selling price for all three technologies will be assumed to be equal to the selling price of fuel produced in current petroleum refineries. The reason to do this is because:
    a. Economically it only makes sense that an industry enters the economy with a "exactly the same" product if it is able to compete in prices. That mean, a new industry that produces a perfect substitute of a good in the economy, in this case biofuels being a perfect substitute of fuels, will only enter if the its selling price is at most the selling price of the current industry.
    b. We are fixing a market share with %. In real life this share will be the result of price-demand interactions, therefore, to have different prices and fix the share is inconsistent.

Data

In this section the data used to incorporate biofuels sector is described.

About the new commodity

Name	Code	Primary producer
Biofuel	324110B	3 primary producers: Gas fermentation Thermochemical Guerbet

The unit of this commodity is GGE (Gallon of Gasoline Equivalent).

About the similar commodity

Name	Code	Price of commodity ($/GGE)	Primary producer industry name	Primary producer industry code[13]
Petroleum refineries	324110	1.60	Petroleum refineries	324110

The price of the similar commodity was obtained considering the market prices for Naphtha (Trading Economics, 2020), Jet fuel (IATA, 2020) and Diesel Fuel(AAA, 2020) and an approximate percentage of these products production within Petroleum Refineries (U.S. Energy Information Administration, 2020). Only these 3 products were considered for the

[13] BEA code

price to be consistent with the aggregated product of the new bio-refineries. The information used to obtain the similar commodity price is in Table 2.

Table 2- Information to estimate Petroleum refineries commodity price

Product	Price	Product Category	% category
Naphtha	380.85 USD/Tonne	Hydrocarbon gas liquids	1.5
Jet Fuel	110.29 USD cents/Gallon	Jet Fuel	4.4
Diesel Fuel	2.432 USD/Gallon	Distillate	12.5

How much % of the current production of fuels, produced by Petroleum refineries, will be replaced with biofuel?

This is a scenario variable. However, to start I considered that biofuel commodity will replace 20% of the 18.4% of current Petroleum refineries industry production. This is considering the percentages for Naphtha, Jet Fuel and Diesel Fuel in Table 2. Therefore 3.68%.

About the new industries

Name	Code	Primary product	Secondary product	Price of new commodity ($/GGE)
Gas fermentation	324110B1	Biofuel	Bio-chemicals	5.04
Thermochemical	324110B2	Biofuel	Bio-chemicals	3.58
Guerbet	324110B3	Biofuel	Bio-chemicals	4.89

Here, as noted, it is assumed that the primary product for all the three technologies is our new commodity Biofuel. Similarly, in gray we have the consideration of which will be the secondary products. However, for simplicity, secondary products of these industries are not being currently included and are one of the future development options.

Also, the production price for each of the technologies will be used, but for model purposes, by default, the price used for each industry will be the same to the price of the similar commodity being replaced, that means, 1.60 USD/GGE. See assumption ii in Ripple effect in the economy and other economic assumptions section for more details.

Share of production by new technologies

Since we have more than one primary producer of the new commodity, we need: How much of the new commodity will be produced by each of the technologies?

Table 3- percentage of production of biofuel by each of the 3 new industries

	% of bio-ethanol production	**% of similar sector**
Gas fermentation	99.9%	3.676%
Thermochemical	0.05%	0.001%
Guerbet	0.05%	0.001%
Total	100%	

Since the data gathered until now corresponds just to one technology (Gas Fermentation) the model is initially run assuming that just one industry will be added. However, because of computation problems when normalizing the use table, when any of the industries has zero Total Industry Output, we temporarily use the percentages in Table 3. To create an special manage or exception of these cases in the buildEEIOModel() function will be a potential future development.

Technology 1 – Gas fermentation

The information for this technology comes mainly from (Eric C.D. Tan et al., 2016), (Handler, Shonnard, Griffing, Lai, & Palou-Rivera, 2015) and (Eric C. D. Tan et al., 2016).

Input purchases

How much the Gas Fermentation industry has to spend in buying each of the commodities to produce 1 GGE of biofuel.

Table 4- Input purchases for Gas fermentation technology. For commodities not present in the list, the value is zero.

Commodity code	**Commodity name**	**USD per GGE (Producer price[14])**
321100	Sawmills and wood preservation	$ 2.17700
325180	Other basic inorganic chemical manufacturing	$ 0.04649
2123A0	Other nonmetallic mineral mining and quarrying	$ 0.00652
424A00	Other nondurable goods merchant wholesalers	$ 0.57886
221300	Water, sewage and other systems	$ 0.01326
424700	Petroleum and petroleum products	$ 0.00944
325211	Plastics material and resin manufacturing	$ 0.05260
484000	Truck transportation	$ 0.01308

[14] When transforming from purchaser's prices from TEAs to producer's prices, margins from (Bureau of Economic Analysis, 2018) were used. In specific, the similar sector margins were used.

For more details on how these numbers were obtained see 5 pathways (v07 CGA 2020-07-31).xlsx. These are in 2012 dollars.

Value added

- Compensation of employees ($/GGE): 0.08
- Taxes on production and imports, less subsidies ($/GGE): 0.8

For more details on how these numbers were obtained see 5 pathways (v07 CGA 2020-07-31).xlsx. These are in 2012 dollars.

Environmental flows

Table 5- Elementary flows based on USEEIO v1.1. For elements not present, the value assumed is zero.

Name	CAS	Flow context, level 1	Flow context, level 2	Unit	Amount in unit per dollar produced of biofuels
Water, fresh	7732185	resource	surface water	m3	4.96733
Phosphorus	7723140	water	unspecified	kg	0.00007
ammonia	7664417	water	unspecified	kg	0.00027
Carbon dioxide	1243820	air	unspecified	kg	0.00000
sulfur dioxide	7446095	air	unspecified	kg	0.00258
nitrogen oxides	11104931	air	unspecified	kg	0.00238

It is worth noting that the process by which technology 1 produces biofuels generates 24.713 kg of CO2 per GGE produced. However, as mentioned by (Eric C.D. Tan et al., 2016), direct GHG emissions generated by this conversion process are entirely biogenic. Since current USEEIO model do not include biogenic emissions, the value assigned to carbon dioxide (CO2) is 0 kg/dollar of biofuel produced.

Accordingly, in Table 6, the information for the environmental flows required in useeior v2.0-GHG are presented. Note that this information is required to modify the B matrix directly and not the satellite table.

Table 6- Environmental flows for useeior v2.0-GHG

For GHG model in useeior	324110B1/us
butane, perfluorocyclo-, pfc-318/air/unspecified/kg	0
carbon dioxide/air/unspecified/kg	0
ethane, 1,1,1-trifluoro-, hfc-143a/air/unspecified/kg	0
ethane, 1,1,1,2-tetrafluoro-, hfc-134a/air/unspecified/kg	0
ethane, hexafluoro-, hfc-116/air/unspecified/kg	0

ethane, pentafluoro-, hfc-125/air/unspecified/kg	0
methane, difluoro-, hfc-32/air/unspecified/kg	0
methane, tetrafluoro-, r-14/air/unspecified/kg	0
methane, trifluoro-, hfc-23/air/unspecified/kg	0
methane/air/unspecified/kg	0
nitrogen fluoride/air/unspecified/kg	0
nitrous oxide/air/unspecified/kg	0
propane, 1,1,1,3,3,3-hexafluoro-, hcfc-236fa/air/unspecified/kg	0
propane, perfluoro-/air/unspecified/kg	0
sulfur hexafluoride/air/unspecified/kg	0

For more details on how these numbers were obtained see 5 pathways (v07 CGA 2020-07-31).xlsx.

Initial results

Using *Methodology: LCA EEIO modifications* and the *Data* described in previous section, I obtained some initial results for the inclusion of the Gas fermentation technology to produce biofuels in the US economy. These results can be obtained using the USEEIO20-GHG-Biofuels.R script.
It is important to bear in mind that the interpretation of these results has to be done with caution, considering all economic assumptions made.

The impacts obtained are according to V2.0-GHG USEEIO model and correspond to:
GHG: Greenhouse Gases (All 15 in Table 6)
MGHG: Major Greenhouse Gases (Methane, Nitrous Oxide)
OGHG: Other Greenhouse Gases (Excluding Carbon Dioxide, Methane and Nitrous Oxide)

Before/ Current economy

Table 7- Current economy GHG emissions (in millions kg of CO2e)

	GHG	MGHG	OGHG
Petroleum refineries	128,495.78	128,474.44	21.34
Whole economy	4,611,005.00	4,518,650.00	92,354.76

Adding Biofuels with Gas fermentation technology/ Future bio-economy

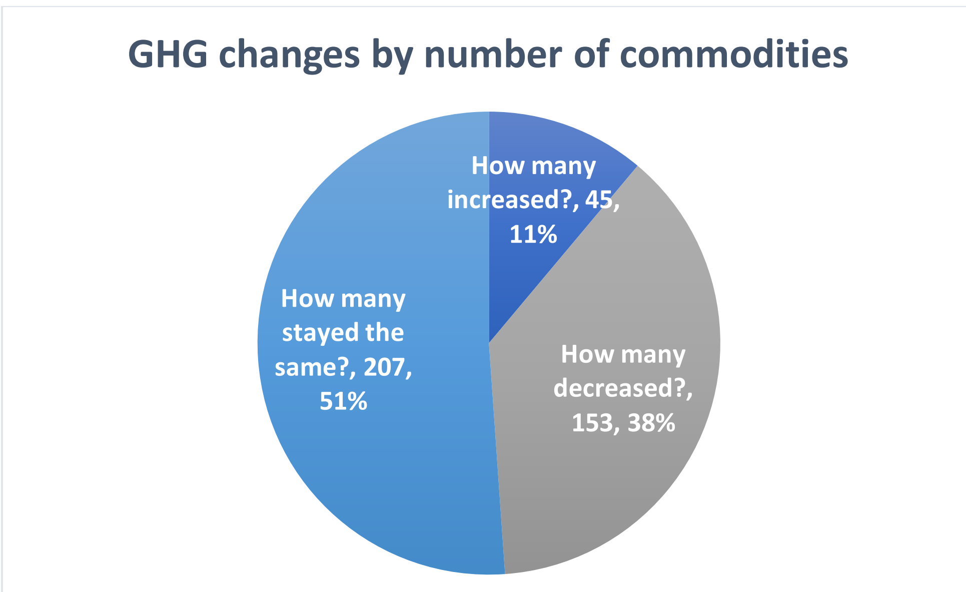
Table 8- Future bio-economy (with biofuels produced by Gas fermentation technology) GHG emissions (in million kg of CO2e)

	GHG	MGHG	OGHG
Petroleum refineries	124,361.06	124,340.17	20.88
Gas fermentation	0.00	0.00	0.00
Whole economy	4,595,352.00	4,503,005.00	92,346.52

Recall that these results correspond to a substitution of 20% of current production of Naphtha, Jet fuel and Diesel fuel by Petroleum refineries. These products correspond approximately to 18.4% of Petroleum refineries production. This means, these results correspond to a substitution of 3.68% of current Petroleum refineries production and use.

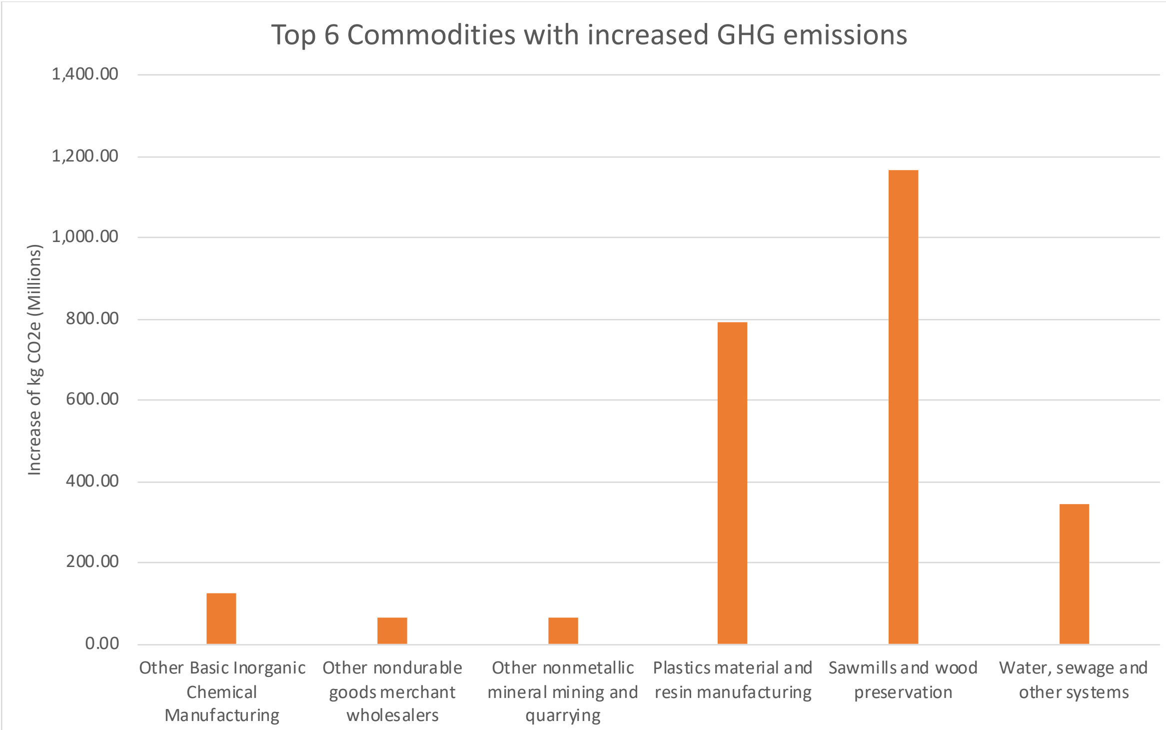
As seen in Table 7 and Table 8, when including the new commodity (biofuels) that will substitute part of current production and use of fuels produced by Petroleum refineries, both Petroleum refineries and the whole economy GHG emissions are reduced. In particular, Petroleum refinery GHG emissions are reduced in 3.22% and the whole economy in 0.34% when biofuels are included and produced under Gas Fermentation technology.

The change in GHG emissions for other commodities in the economy could have been positive, negative or zero. In Graph 1 we can see that half (51%) of the commodities in current economy maintain the same level of GHG emissions, 11% of the commodities increase its level of GHG emissions and 38% of the commodities decrease its level of GHG emissions when comparing between current economy and a future bio-economy where biofuels production with Gas Fermentation is considered.



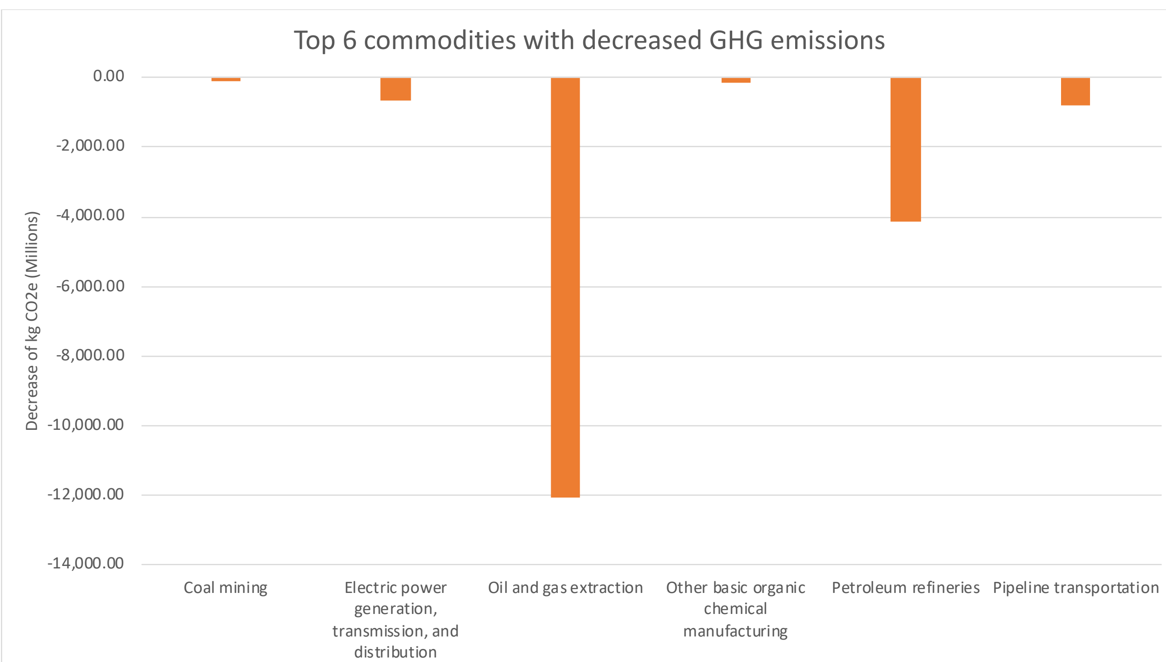
Graph 1- How many commodities increase/decrease/stay the same regarding its GHG in future bio-economy compared to current economy and the percentage associated

More detail about the commodities for which GHG emissions increased can be seen on Graph 2. Here, we can note that the top 6 commodities with increased CO_2e emissions in future bio-economy correspond to commodities used as inputs in the conversion process from biomass to biofuels. This responds to the increased demand and production of these goods in future bio-economy, given its requirement to produce gallons in the new industry.



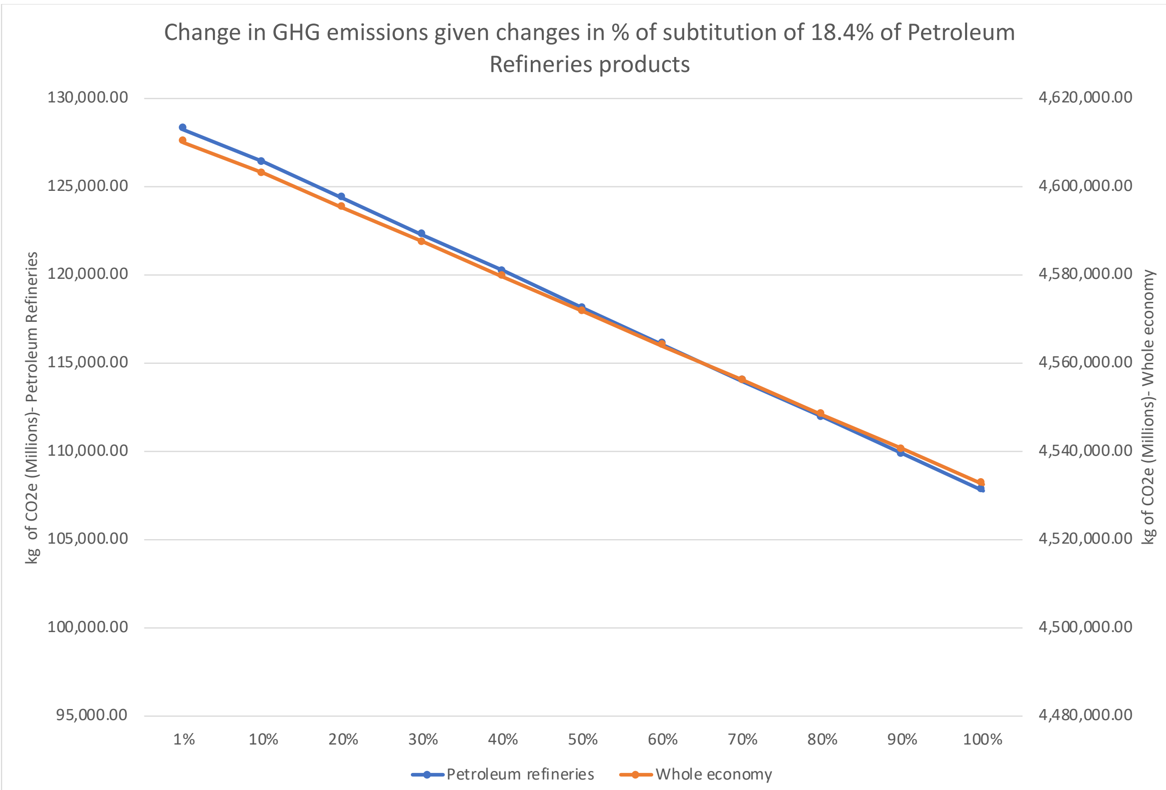
Graph 2- Increase in kg of CO2e of top 6 commodities with increased GHG compared to current economy

On the other hand, regarding commodities with decreased GHG emissions in future bio-economy, we can note that the top 6 are related to commodities produced by industries highly related to fossil fuels. This is expected given the commodity that has been partially substituted.



Graph 3- Decrease in kg of CO2e of top 6 commodities with decreased GHG compared to current economy

Finally, in Graph 4 we can see how the GHG emissions to produce fuels, in Petroleum refineries, and to produce all goods in the economy change when changing the percentage of substitution of biofuels. We can see that with substitutions of less than 50%, the slope at which GHG emissions decrease is approximately the same between Petroleum refineries and the whole economy. Then, when substitution is greater than 50%, the slope at which GHG emissions decrease is slightly steeper for Petroleum refineries compared to the whole economy. This makes sense because as the share of fuel production becomes smaller, its marginal effect in the economy becomes smaller too.



Graph 4- GHG emissions for Petroleum refineries and the Whole economy when changing the percent of substitution of the 18.4% of Petroleum refineries products from 1% to 100%.

Future developments

Here I mention some future development that can be made to improve this methodology and results:

- *Include secondary- products /biochemicals:* Co-products of these conversion processes are very important to justify the economic viability of these bio-refineries. Also, the production of bio-chemicals will be a step toward the vision of bio-economy. Therefore, the inclusion of this secondary products for the industries considered is an important future development.
- *A generalization of the methodology to add any mix between number of new commodities and number of new industries:* It will be useful to completely generalize this methodology to add any mix of commodities and industries. For example, 2 commodities and 1 industry, 2 commodities and 3 industries and so on. This will

allow an easier inclusion of a bio-industry in USEEIO. However, economic assumptions and specific considerations for any substitution must be done carefully.

- *Modify buildEEIOModel() to manage cases when an industry has Total Industry Output of zero to allow cases where only one of the 3 technologies produce in future bio-economy:* This will allow to easily evaluate scenarios where 1 technology produces everything and the other 2 produces nothing or 2 technologies produce and 1 do not, etc.
- *Improvement of data sources for releases on water and bioreactor nutrients assumptions:* There were data limitations to identify:
    - Specific chemicals releases to the water
    - The nutrients components required for the bio-reactor

  Some assumptions, that can be seen in *5 pathways (v07 CGA 2020-07-31).xlsx*, were made, but this is definitely an element for validation and improvement.
- *Organize data for other 2 technologies:* Because of time, only data for Gas fermentation technology was organized, but using the same sources information, data for the two missing technologies can be easily incorporated.

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