climada module[1] advanced 23 Jun 2018

https://github.com/davidnbresch/climada_advanced
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This module implements additional features to extend the capabilities of (core) CLIMADA. This is currently work in progress, as we are currently extracting selected code from core CLIMADA.

In order to run properly, it needs at least
https://github.com/davidnbresch/climada

Since this module is in it's making, currently just selected routines described – as the module grows, there will be more structure.

[1] Before reading further, please make sure you are familiar with the basics of CLIMADA, see climada manual https://github.com/davidnbresch/climada/blob/master/docs/climada_manual.pdf

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1. MRIO economics

http://github.com/davidnbresch/climada_advanced/tree/master/code/mrio_economics
with contributions from (in alphabetical order)
Ediz Herms, ediz.herms@outlook.com
Kaspar Tobler

This module contains a risk assessment method which allows businesses from all industries to analyze their supply chain risk and it further provides valuable insights on societal impacts of natural catastrophes.

This method combines the core CLIMADA functionality with Input-Output (IO) economics. We have made an effort to be compatible with major Multi-Regional Input-Output (MRIO) tables that are freely available.

This sub-module was initially developed in the course of the master theses 'Assessing TC weather and climate risk affecting global businesses' of Ediz Herms and Kaspar Tobler. For full details on the method and model details, reference is made to these works.

1.1. Getting started

1.1.1. Requirements

Before reading further, please make sure you are familiar with the basics of CLIMADA.

In order to run MRIO economics properly, it needs at least
https://github.com/davidnbresch/climada and
https://github.com/davidnbresch/climada_module_country_risk
https://github.com/davidnbresch/climada_module_isimip

1.1.2. Process on one page

1. Import Multi-Regional Input-Output table
   - i. Obtain data from a Multi-Regional Input-Output table
   - ii. Divide sub-sectors into a number of homogenous main sectors

2. Generate a hazard event set[2]
   - i. Obtain historical events
   - ii. Produce probabilistic events
   - iii. Store intensities at centroids

3. Generate sectorial representation of assets (exposure)
   - i. For each main sector, characterize their exposure by their geographical distribution (latitude, longitude) and monetary value.
   - ii. Get NatID for each asset

[2] Provided for selected hazards by core climada and climada modules, see climada manual (p. 1)
https://github.com/davidnbresch/climada/blob/master/docs/climada_manual.pdf

iii. Normalize asset values per country as specified in the MRIO table

4. *Generate (sectorial) damage functions – not implemented yet*

5. Calculate direct damages
   i. Calculate the direct damages for the (normalized) sectorial representation of assets, hazard and vulnerability.
   ii. Multiply the relative risk with the total sectorial production from the MRIO table to obtain the absolute damages in millions of dollars.

6. Calculate indirect damages using Input-Output methodology
   i. Choose between demand- and supply driven methodology (or environmental accounting)
   ii. Propagate risk

7. Display the results – e.g. in the form of a risk report

1.1.3. Step-by-step guide

First, read in a MRIO table, i.e. define the name and location of the raw file with the mrio table and flag the table type (cf. header of function `mrio_aggregate_table.m`).

```
climada_mriot = mrio_read_table('WIOT2014_Nov16_ROW.xlsx','wiod')
```

```
>> climada_mriot = mrio_read_table('WIOT2014_Nov16_ROW.xlsx','wiod')
climada_mriot =
  struct with fields:

           countries: [1×2464 categorical]
       countries_iso: [1×2464 categorical]
             sectors: [1×2464 categorical]
   climada_sect_name: [1×2464 categorical]
     climada_sect_id: [1×2464 double]
           mrio_data: [2464×2464 double]
          table_type: 'wiod'
            filename: '/Users/edizherms/Documents/MATLAB/climada_data/mrio/WIOT2014_Nov16_ROW.mat'
     no_of_countries: 44
       no_of_sectors: 56
                unit: '1e6USD'
    total_production: [2464×1 double]
     RoW_aggregation: 'None'
```

Next, aggregate MRIO table that only consists of the main sectors. It further can aggregate several different Rest of World (RoW) regions into one. It gives a climada aggregated_mriot struct that gives information on total production and trade flows on main sector level.

```
aggregated_mriot = mrio_aggregate_table(climada_mriot,1,0)
```

```
>> aggregated_mriot = mrio_aggregate_table(climada_mriot,1,0)
aggregated_mriot =
  struct with fields:

           countries: [1×264 categorical]
       countries_iso: [1×264 categorical]
             sectors: [1×264 categorical]
     climada_sect_id: [1×264 double]
    aggregation_info: [1×1 struct]
           mrio_data: [264×264 double]
          table_type: 'wiod'
            filename: '/Users/edizherms/Documents/MATLAB/climada_data/mrio/WIOT2014_Nov16_ROW.mat'
     no_of_countries: 44
       no_of_sectors: 6
     RoW_aggregation: 'None'
    total_production: [264×1 double]
                unit: '1e6USD'
```

The input parameters `full_aggregation_flag (=1)` and `RoW_flag (=0)` specify that we require a full aggregation that includes the trade flows and total production values, but excluding an aggregation of several RoW-region as the MRIO table provided by WIOD only has one RoW-region.

Next, we can calculate the direct damages for the countries specified in the MRIO table provided. They are saved in the so-called Input-Output Year Damage Set (IO_YDS):

```
IO_YDS = mrio_direct_risk_calc(climada_mriot, aggregated_mriot)
```

```
IO_YDS =
  struct with fields:

      direct: [1×1 struct]
    peril_ID: 'TC'
      hazard: [1×1 struct]
```

Let us now derive the indirect damages from the direct damages using Input-Output methodology:

```
[IO_YDS, leontief] = mrio_leontief_calc(IO_YDS, climada_mriot, 2);
```

```
IO_YDS =
  struct with fields:

      direct: [1×1 struct]
    peril_ID: 'TC'
      hazard: [1×1 struct]
    indirect: [1×1 struct]
```

The hyperparameter switch_io_approach (=2, Ghosh model in this example) specifies the Input-Output approach that is applied. The climada leontief struct contains useful information that can help to identify sources of risk.

It is now possible to return final results as a table. Therefore it is necessary to specifiy a set of countries (='ALL') and sectors (='ALL'). Moreover it may make sense to only read out data for a specific year (e.g. =2008), every year (='ALL') or only the average annual damage (=0) as is the case here.

```
[subsector_risk_tb, country_risk_tb] = mrio_get_risk_table(IO_YDS,
'ALL', 'ALL', 0);
```

The head of the table total_country_risk shows that it gives information on direct, indirect and total country risk (analogoues for subsector_risk_tb).

```
head(country_risk_tb)
```

```
>> head(country_risk_tb)
ans =
  8×7 table
      Country       CountryISO    DirectCountryRisk    IndirectCountryRisk    TotalCountryRisk    RiskRatio     Value
    ___________    __________    _________________    ___________________    ________________    __________    __________

    Australia      AUS              558.46               761.72                 1320.2             0.00048469    2.7237e+06
    Austria        AUT                   0               57.907                 57.907             7.1523e-05    8.0963e+05
    Belgium        BEL               1.781               179.34                 181.12             0.00016306    1.1108e+06
    Bulgaria       BGR                   0                15.45                  15.45             0.00012574    1.2287e+05
    Brazil         BRA              2.1257               363.74                 365.86             8.9159e-05    4.1035e+06
    Canada         CAN                1081               1491.6                 2572.6             0.00079104    3.2522e+06
    Switzerland    CHE                   0               112.36                 112.36             8.0335e-05    1.3987e+06
    China          CHN               10584                13447                  24031               0.000757    3.1745e+07
```

1.1. Exposure

Currently, basic entities are provided for the main sectors as described in Table 1. These can be used for (direct) risk calculations. For this, it is assumed that the geographical distribution of the sub-sectors is sufficiently represented by that of the main sectors. However, the implementation in CLIMADA also enables the user to provide exposure data on a sub-sector level also.

Table 1. List of data providers that provide globally consistent and scientifically grounded data that is being used in the presented risk assessment method as a proxy for the geographical distribution of sectorial assets.

Main sector name	Source	Literature reference
Agriculture	https://doi.org/10.7910/DVN/DHXBJX	(Wood-Sichra, 2016)
Forestry	http://maps.elie.ucl.ac.be/CCI/viewer/index.php	(ESA, 2015)
Mining & Quarrying	https://mrdata.usgs.gov/mineplant/ https://mrdata.usgs.gov/mineral-operations/	(U.S. Geological Survey, 2005)
Utilities	http://enipedia.tudelft.nl/wiki/Portal:Power_Plants	(Davis, 2012)
Manufacturing	http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv5.html	(Amann, et al., 2011)
Services	https://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html	(Henderson, Storeygard, & Weil, 2012)

1.1.1. Breakdown of economic sectors

In general, the breakdown of economic sectors is defined by the specifications given by the user in the process of reading an MRIO table (Section 1.4.1) where each sub-sector as defined by the MRIO table is assigned to a main sector.

It is possible to introduce new main sectors simply by assigning sub-sectors to them. However, it is then necessary to provide exposure data for that main sector also as described in Section 1.1.2.

1.1.2. Constructing your own entity

Please see climada (core) manual for the basics on how to construct an entity from scratch.

In addition to the standard fields of a climada entity struct as described in `climada_entity_read` it is necessary to map the assets to the corresponding countries. Therefore we use the structure provided by the climada isimip module that allows to assign NatID to the assets with the help of a nearest neighbor approach using the isimip centroids.

```
for asset_i = 1:n_assets
    sel_centroid = entity.assets.centroid_index(asset_i);
    if sel_centroid > 0 && length(centroids.NatID) > sel_centroid
        entity.assets.NatID(asset_i) = centroids.NatID(sel_centroid);
    else
        entity.assets.NatID(asset_i) = 0;
    end
end % asset_i
```

See `mrio_generate_agriculture_entity` for more details.

1.1.3. Provide entities on sub-sector level

As already mentioned, it is possible to provide entities on sub-sector level also. This is easily done by

1. Constructing an entity
2. Move it to .../climada_data/entity/
3. Give it a reasonable name following the mrio naming system (ISO3_MAINSECTOR_SUBSECTOR) corresponding to the MRIO table you are going to use

`mrio_direct_risk_calc` will automatically search for additional entities on sub-sector level provided by the user. This holds for data on exposure of mainsectors also. In such a case, the name should correspond to the structure ISO3_MAINSECTOR_XXX.

1.2. Vulnerability

At present, studies examining the sensitivity of economic sectors to climate hazards are lacking. For now, only region-specific damage functions have been employed for tropical cyclones. It may be promising to investigate on sectorial vulnerability using a combination of expert judgment and literature review as described in the Outlook (Section 1.5).

The damage function proposed by Emanuel has been employed for TCs (Emanuel, 2011). It has been calibrated using disaster loss records collected from EM-DAT CRED for TCs that occurred in the period from 1981 to 2010. For each country, Emanuel's damage function was adjusted so that the total reported damage best corresponds best to the total simulated damage. For the calibration, the combination of Vhalf and s was estimated using an optimization algorithm. The optimal parameter set is the one at which the annual mean squared error between the recorded damages in EM-DAT CRED and the damages simulated in CLIMADA is minimized.

It is notable that the world can be divided into two different regions that with different orders of magnitude in the calibrated parameters: North West Pacific and the rest of the world. In the North West Pacific, the resulting damage functions are much lower (low scaling factor s) than in other countries. This could be because wind speeds in the hazard set are overestimated in this region.

1.3. Hazard

The risk assessment method is tested and implemented using the example of Tropical cyclones. However, the model can easily be adapted to other natural hazards. This is vital to provide a comprehensive multi-hazard analysis and address global policies. Therefore, the hazard_file has to be defined in the params struct and handed over to the `mrio_direct_risk_calc` function.

At this point, reference is made to the climada (core) manual and other modules that provide hazard event sets for major perils.

1.4. Risk propagation

In this method, IO models are employed to measure indirect inoperability effects. The core of IO models are IO tables that depict an economy's circular flow of goods and services.

1.4.1. MRIO tables

The presented risk propagation method makes use of MRIO tables displaying flows of goods according to industry outputs (industry-by-industry table). This decision is because the method evaluates global effects of natural catastrophes on the supply chain, which makes it necessary to map global trade flows of industries.

In general, the choice of the IO table will strongly depend on the specific application. It is desirable to use an up-to-date IO table covering a high number of economies with a fine breakdown of economic sectors. For reasons of comparability, it may also be worthwhile to use a table that is published on an annual basis. The model presented enables the use of the best-known and most renowned MRIO tables (Table 2).

Table 2. List of providers of MRIO tables that are currently supported in CLIMADA.

Name	Source	Literature Reference
EORA-MRIO	http://worldmrio.com/	(Lenzen, 2013)
EXIOBASE	http://www.exiobase.eu/	(Tukker, 2013)
WIOD	http://www.wiod.org/	(Timmer, 2015)

How to read data from a provided MRIO table into a climada mriot struct?
There are two options, one can either start with the function `mrio_read_table` to read in a MRIO table of the providers listed in **Table *1*.** List of data providers that provide globally consistent and scientifically grounded data that is being used in the presented risk assessment method as a proxy for the geographical distribution of sectorial assets.Table 1 or from scratch:

- If one starts from a table of the supported MRIO tables, download the raw data from the website. It further is necessary to set up a climada_mapping table (see climada_mapping tab) where each sub-sector needs to be assigned to a main sector. Once done, use `mrio_read_table` to read data from excel sheet.
- If one starts from scratch, populate the mandatory fields, see header section of `mrio_table_read`. Make sure all other fields have the same (corresponding) length.

1.4.2. Input-Output Methodology

Depending on the specific application it is necessary to either use a model that describes an economy that is dominated by scarce resources (supply-driven) or (demand-driven). It is therefore left to the user to choose between the standard Leontief model and the Ghosh model in `mrio_leontief_calc`.

1.5. Outlook

Multi-hazard risk
The risk assessment method is tested and implemented using the example of Tropical cyclones. However, the model can easily be adapted to other natural hazards. This is vital to provide a comprehensive multi-hazard analysis and address global policies.

Therefore the functionality has to be extended in such a way that a user can run the core calculations for each hazard separately and combine the results. For this, it is vital to make the functions universally valid e.g. with respect to the damage functions used (`mrio_direct_risk_calc`). Further, the encoding of the entity must be included in the damage calculation process to flexibly adapt to the hazard provided (now: `mrio_entity_country` and `mrio_generate_XXX_entity`).

Then the so-called Input-Output Damage Year Set (IO_YDS) can be calculated and a damage frequency curve can be derived for each hazard separately. In a last step there must be a routine that is able to combine the results.

Event impact analysis
Traditionally, Input-Output models and their extensions have been used to ex-post measure the indirect inoperability effects of events on local economies. Hence, the model can provide an additional value to the community studying sectorial impacts of natural catastrophes once the option is enabled to run the machine only using a single event instead of a hazard event set (`mrio_direct_risk_calc`).

Business perspective
Understanding and quantifying the impacts of natural catastrophes is essential for individual businesses and communities to better appraise risk management options and adaption measures.

For this, it is necessary to implement the possibility to read data provided by a company on the yearly sales and purchases as well as the total production value (in the structure of the MRIO table used). This information has then to be considered by adding it to the MRIO table.

Finally, the direct risk calculation (`mrio_direct_risk_calc)` has to be adjusted so that it assumes the correct country and sector combination as a proxy for the risk of that company and multiplies the direct risk with the businesses production value.

Vulnerability
It is desirable to account for structural differences in vulnerability using a sector-specific damage function. As done by Bianchi, et al. (2018), vulnerability of sectorial assets to natural hazards may be derived based on the combination of an extensive literature review and a survey run amongst experts.

Business Interruption: Weighting factors
For the time being, the presented risk assessment method follows a pragmatic approach and takes direct business interruption (BI) risk as given by the direct (physical) risk. Usually, BI losses are derived from the level of buildings damage using weighting factors (Jain & Guin, 2009; Porter & Ramer, 2012). Therefore it may be worthwhile to estimate the downtime of sectorial assets and facilities after a natural catastrophe using a probabilistic model.

2. Function references

This section makes reference to functions of the advanced module in order to provide the user with a starting point. Please refer to each function's detailed header (use `help functionname` in MATLAB). You might also run `compile_all_function_headers` once in order to generate a .html file with all function headers for fast reference[3].

MRIO economics

`mrio_step_by_step`: the step-by-step demo as documented above

Basic mrio table functions

`mrio_read_table`: Reads data from a provided mrio table into a climada mriot struct. Currently made to work with WIOD, EXIOBASE and EORA tables.

`mrio_aggregate_table`: Transform a full climada mrio table struct into an aggregated table that consists only of the main-sectors. Further, it can aggregate tables with several different Rest of the World (RoW)-regions.

Basic entity functions

`mrio_generate_agriculture_entity`: Construct a global entity file based on gridded data on (aggregated) crop production.

`mrio_generate_forestry_entity`: Construct a global entity file based on Land Cover 'Forestry' map from the Climate Change Initiative (CCI).

`mrio_generate_mining_entity`: Construct a global entity file based on global data on active mines and mineral plants.

`mrio_generate_utilities_entity`: Construct a global entity file based on a global data set of power plant locations.

`mrio_generate_manufacturing_entity`: Construct a global entity file based on a global data set of gridded industry-related NOx emissions.

`mrio_generate_servies_entity`: Construct a global entity file based on nighttime lights time series.

`mrio_entity_country`: Generates entity files based on a global entity struct for a predefined set of countries. Furthermore, entities are prepared for MRIO economics, including getting NatID for each asset and normalize asset values per country.

Core calculations

`mrio_direct_risk_calc`: Calculation of direct damage based on an encoded entity per economic sector (assets and damage functions) and a hazard event set. The direct damage contains information on the direct damage for each subsector x country-combination and year as defined by the general climada mriot struct and hazard provided.

`mrio_leontief_calc`: Indirect risk is derived from direct risk using Input-Output (IO) methodology. There are three IO models to choose from.

Further display functions

[3] The file ../climada/docs/code_overview.html does contain the headers of all functions of all modules (and the links to the source code); hence you might consult this file (e.g. use full text search within) and might need to install the respective module in order to use the specific function.

`mrio_get_risk_table`: Produce a quick and dirty risk table based on the results.

`mrio_subsector_risk_report`: Produce a sector-specific report based on the results.

`mrio_general_risk_report`: Produce a general risk report with key figures of overall risk and generate an excel file providing information on the direct and indirect risk as well as the composition of these ('risk structure').

Other

`climada_tc_event_damage_ens`: Calculation of topical cyclone damage based on single track file and a simple ensemble of tracks. The user gets prompted for the ocean basin and the list of storms, the code automatically fetches the UNISYS data and plots the tracks as well as the damage estimate.

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