climada module[1] advanced 27 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

It is further needed to download the TC (isimip) hazard into the entities_dir folder to run the `mrio_step_by_step` calculation:
https://polybox.ethz.ch/index.php/s/FwetsXlLeXLJPnD

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

[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

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
   iii. Normalize asset values per country as specified in the MRIO table
   iv. Encode to hazard

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

Data requirements:
First, download the TC (isimip) hazard into the entities_dir folder from **https://polybox.ethz.ch/index.php/s/FwetsXlLeXLJPnD**

Next, 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)

Agriculture

For the agricultural main sector, 5 arc minute gridded data regarding the aggregated value of (crop) production was used as the basis for the exposure. The data were generated using a triangulation of all the relevant background information, including national and sub-national crop production statistics, satellite data regarding land cover, maps of irrigated areas, biophysical suitability assessments, population density, secondary data regarding irrigation and rain-fed production systems, cropping intensity, and crop prices (Wood-Sichra, 2016). The value of production was modeled using 2004–2006 average crop-specific prices derived from the Gross Production Value published by the Food and Agriculture Organization of the United Nations (FAO) in International Dollars (I$s). It is worth emphasizing that these are not spatially-specific prices. Hence, they cannot reflect local economic realities. The technical documentation (Wood-Sichra, 2016) provides a more detailed description of the triangulation methods, which are not further discussed here.

Source (of the underlying data):
International Food Policy Research Institute (IFPRI),
International Institute for Applied Systems Analysis (IIASA),
2016, "Global Spatially-Disaggregated Crop Production Statistics Data for 2005 Version 3.2" [Data file],
http://dx.doi.org/10.7910/DVN/DHXBJX, Harvard Dataverse, V9 (Accessed 26 05 2018)

Download spam2005v3r2_global_val_prod_agg.csv.zip (ZIP archive of aggregated value of production data in CSV format for statistics or database applications)

`mrio_generate_agriculture_entity` was then used to construct a global entity file based on the underlying data.

Forestry

The forestry main sector exposure is based on 10 arc seconds gridded data of land cover from the European Space Agency (ESA). As part of the Climate Change Initiative (CCI), the ESA delivers satellite-derived land cover maps that map the dynamics of the land surface and are typically used as an input in climate modeling. The data were pre-processed to account for environmental effects such as atmospheric effects and clouds. As described in the technical documentation of the land cover map (ESA, 2015), the classification procedure was developed by the Université Catholique de Louvain (UCL) and uses unsupervised classification methods while also relying on a machine learning algorithm. Using these methods, each grid point is assigned to one of 23 land cover classes. In this study, the idea is to use the geographical distribution of forests as a proxy for the forestry main sector. Therefore, eight of the land cover classes are identified as tree cover of different types. In this application, only tree cover was considered labeled as closed, or closed to open, whereas open or mosaic forests are considered as inappropriate for forestry. Based on this, the data were altered to a coarser resolution so that they now indicate the forest density.

Source (of the underlying data):
ESA and Université Catholique de Louvain,
2015, "Land Cover Map 2015, Version 2.0" [Data file],

http://maps.elie.ucl.ac.be/CCI/viewer/ (Accessed 26 05 2018)

Download data (red button on the top-right corner) > Climate Research Data Package > Data access > LC Map 2015 (1 netcdf file, zip compression - 2.33Go)

`mrio_generate_forestry_entity` was then used to construct a global entity file based on the underlying data.

Mining & Quarrying

Spatially explicit data regarding active mines and mineral processing facilities published by the United States Geological Survey (USGS) (U.S. Geological Survey, 2005) serve as exposure data for the mining and quarrying main sector. It includes data on operations in the US that are monitored by the National Minerals Information Center of the USGS and considered active in 2003. For all activities outside the US, the USGS compiled and published a data set in 2010 that comes from industry surveys and literature published no later than 2006 and is generally judged to be plausible.

Source (of the underlying data):
[1] U.S. Geological Survey,
2005, "Active Mines and Mineral Processing" [Data file],
https://mrdata.usgs.gov/mineplant/ (Accessed 26 05 2018)

Active mines and mineral plants in the US > Download > Download mineplant-csv.zip file

[2] U.S. Geological Survey,
2010, " Mineral operations outside the United States" [Data file],
https://mrdata.usgs.gov/mineral-operations/ (Accessed 26 05 2018)

Mineral operations outside the United States > Download > Download minfac-csv.zip file

`mrio_generate_mining_entity` was then used to construct a global entity file based on the underlying data.

Utilities

The utilities main sector refers to companies involved in the production and delivery of electricity, gas, water, and other related services. As a proxy for the geographical distribution of the utilities main sector, spatially explicit data on power plants are used. The data are sourced and made available as part of ENIPEDIA, which is an attempt to collect global data and information on all the world’s power plants. The project was started by Davis et al. of the Energy and Industry Group at Delft University of Technology. In addition to the geographical location, the data describes a variety of aspects of power plants, ranging from their power output, to emissions, and owners (Davis, 2012).

Source (of the underlying data):
Davis, C. B., Chmieliauskas, A., Dijkema, G. P., and Nikolic, I.,
2014, "ENIPEDIA" [Data file],
http://enipedia.tudelft.nl (Accessed 26 05 2018),

Section Advanced > Download all power plant data

`mrio_generate_utilities_entity` was then used to construct a global entity file based on the underlying data.

Manufacturing

The manufacturing exposure is based on 30 arc minutes gridded data regarding industry- related nitrogen oxides (NOx) emissions. The data set used is generated by the Greenhouse gas – Air pollution Interactions and Synergies (GAINS) model of the International Institute for Applied Systems Analysis (IIASA), which is widely used for policy analysis and by scientists. The model estimates historical emissions based on data from international energy and industrial statistics, emission inventories and on data supplied by countries themselves (Amann, et al., 2011).

Source (of the underlying data):
Greenhouse gas - Air pollution Interactions and Synergies (GAINS) model,
International Institute for Applied Systems Analysis (IIASA),
2015, "ECLIPSE V5a global emission fields" [Data file],
http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv5a.html
(Accessed 26 05 2018)

ECLIPSE V5a global emission fields > ECLIPSE V5a Baseline scenario (CLE) > Download netCDF files of emissions (netcdf4 format)

`mrio_generate_manufacturing_entity` was then used to construct a global entity file based on the underlying data.

Services

The exposure for the services main sector is based on 30 arc seconds gridded data regarding night-time lights. The data comes from satellite observations in 2012 from satellite number F18 as part of the Defense Meteorological Satellite Program (DMSP). The data are collected by the US Air Force Weather Agency and processed by the National Geophysical Data Center of National Oceanic and Atmosphere Administration (NOAA) and records artificial lights from human habitations from the Earth's surface. The idea behind the choice of night-time lights as proxy for the services exposure is that there is a strong link between human activity and the services sector.

Source (of the underlying data):
NOAA and US Air Force Weather Agency,
2012, "Version 4 DMSP-OLS Nighttime Lights Time Series" [Data file],
http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html#AVSLCFC3 (Accessed

26 05 2018)

Version 4 DMSP-OLS Nighttime Lights Time Series > Download 'F182012' .tif file

`mrio_generate_services_entity` was then used to construct a global entity file based on the underlying data.

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 and 1.1.3.

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 in `mrio_direct_risk_calc`. It may be promising to investigate on sectorial vulnerability using a combination of expert judgment and literature review as described in the Outlook (Section 1.6).

For now, 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.

The world has been 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://worldmirio.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 in `WIOT2014_Nov16_ROW.xlsx`) 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.

<u>NOTE</u>: As described in Section 1.6, there has to be put some effort to modify the read-in process for the tables provided by EORA and EXIOBASE. For the moment only the table provided by WIOD is fully implemented and tested.

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` with the input `switch_io_approach`.

1.5. Output

In the following, the main characteristics of the output is briefly described. A reference made is to the relevant literature mentioned in the header of `mrio_leontief_calc` or the master thesis of Kaspar Tobler and Ediz Herms for more details.

```
IO_YDS =
  struct with fields:

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

IO_YDS is a struct that itself contains two main structs, namely direct and indirect. They have the same structure and contain the direct respectively the indirect damage in the field damage. Damage is a matrix where for each year as defined by the hazard and each sector x country-combination as defined by the MRIO table the damage is stored. The other fields are mainly there for labeling reasons.

```
>> IO_YDS.direct
ans =
  struct with fields:

       reference_year: 2016
            countries: [1×2464 categorical]
        countries_iso: [1×2464 categorical]
              sectors: [1×2464 categorical]
    climada_sect_name: [1×2464 categorical]
     aggregation_info: [1×1 struct]
               damage: [66×2464 double]
                Value: [1×2464 double]
            frequency: [66×1 double]
      annotation_name: 'GLB_0360as_TC_hist'
                   ED: [1×2464 double]
                 yyyy: [66×1 double]
       orig_year_flag: [66×1 double]
```

The Leontief struct is build to gain more insight into these indirect risk numbers and the sources of risk and structure.

```
leontief =
  struct with fields:

    climada_nan_mriot: [2464×2464 logical]
        climada_mriot: [1×1 struct]
         coefficients: [2464×2464 double]
              inverse: [2464×2464 double]
       risk_structure: [2464×2464 double]
                layer: [2464×2464×5 double]
```

climada_nan_mriot: a matrix with binary values showing whether the economic relationships could be assessed (=0) or not (=1). This is necessary due to the fact that relationships that could not be assessed are given the value NaN and treated as being zero in the calculations. However, it may be interesting to include the list of relationships in the report at a later point in time.

climada_mriot: see `mrio_read_table`

coefficients: either the technical coefficient matrix or the allocation coefficient matrix as described in the Leontief respectively Ghosh methodology.

inverse: either the Leontief inverse or the Ghosh inverse as described in the Leontief respectively Ghosh methodology.

risk_structure: matrix showing the contribution to the indirect risk for every sector x country – relationship. Thus, summing the columns of the risk structure ends up in the indirect risk.

layer: calculation of the different layers showing the contribution to the indirect risk on different dependency levels (1-4 layer, 5 contains the other). The sum of the layers gives the risk structure.

1.6. Outlook

MRIO tables

`mrio_read_table` read data from a provided MRIO table into a climada mriot struct. The risk currently made to work with WIOD, EXIOBASE and EORA tables. However, EXIOBASE and EORA have to be treated with caution. EXIOBASE provides a technical coefficient matrix instead of a MRIO table (needs to be accounted in the read-in-process, not yet done). In the EORA table, ‘Rest of the World’ (RoW) is not divided into the different sectors. Here it would make sense to think about how to split RoW into the different sectors. Hence, results are meaningless for the moment except for table provided by WIOD.

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.

Bibliography

Amann, M., Bertok, I., Borken-Kleefeld, J., Höglund-Isaksson, L., Klimont, Z., Nguyen, B., . . . Winiwarter, W. (2011). Cost-effective control of air quality and greenhouse gases in europe: Modeling and policy applications. *Environmental Modelling & Software*, 26(12):1489–1501.

Bianchi, A., Forzieri, G., Batista e Silva, F., Herrera, M. A., Leblois, A., Lavalle, C., . . . Feyen, L. (2018). Escalating impacts of climate extremes on critical infrastructures in Europe. *Global Environmental Change* , 97-107.

Davis, C. B. (2012). *Making Sense of Open Data: From Raw Data to Actionable Insight.* Delft University of Technology.

Emanuel, K. (2011). Global warming effects on u.s. hurricane damage. *Weather, Climate, and Society*, 3(4):261–268.

ESA. (2015). *Land Cover CCI: Product User Guide Version 2.0. [Data file].* Von https://maps.elie.ucl.ac.be/ CCI/viewer/download/ESACCI-LC-Ph2-PUGv2_2.0.pdf abgerufen

Henderson, J., Storeygard, A., & Weil, D. (2012). Measuring economic growth from outer space. *American Economic Review*, 102(2):994–1028.

Jain, V. K., & Guin, J. (2009). Modeling business interruption losses for insurance portfolios. *Americas Conference on Wind Engineering.* San Juan, Puerto Rico.

Lenzen, M. a. (2013). *BUILDING EORA: A GLOBAL MULTI-REGION INPUT-OUTPUT DATABASE AT HIGH COUNTRY AND SECTOR RESOLUTION.* Economic Systems Research.

Porter, K., & Ramer, K. (2012). Estimating earthquake-induced failure probability and downtime of critical facilities. *Journal of Business Continuity & Emergency Planning*, 352-364.

Timmer, M. P. (2015). *An Illustrated User Guide to the World Input-Output Database: the Case of Global Automotive Production.* Review of International Economics.

Tukker, A. a.-C. (2013). *EXIOPOL - DEVELOPMENT AND ILLUSTRATIVE ANALYSES OF A DETAILED GLOBAL MR EE SUT/IO.* Economic Systems Research.

U.S. Geological Survey. (30. 05 2005). *Active Mines and Mineral Processing Plants in the United States in 2003 [Data file]*. Von https://mrdata. usgs.gov/mineplant/ abgerufen

Wood-Sichra, U. a. (2016). *Spatial Production Allocation Model (SPAM) 2005: Technical Documentation.* HarvestChoice Working Paper. Washington, D.C.: International Food Policy Research Institute (IFPRI) and St. Paul: International Science and Technology Practice and Policy (InSTePP) Center, University of Minnesota.