Measuring food independence using compilation data from the Economy-Wide Material Flow Account

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Abstract

The ratio of import to native production of food is a measure of an economy's food independence. This, along with food waste and food quality measures, is a key indicator for how well an economy allocates resources drawn from nature. The Economy-Wide Material Flow Account (EW-MFA) measures material consumption and resource productivity, but the module has limitations when users try to extract in-depth information on issues such as food independence. The limitations come from the macroscopic approach of the module, as it only considers flow of material into the economy but not within it. For example, domestic extraction only includes wild catch and harvest. The production of food from domestic animals and crops is not considered in the final compiling. Although users may think the EW-MFA will help in understanding food independence, it does not. Here, I present a method to generate a set of supply and use tables for an extended EW-MFA framework where food production within the economy is estimated. This method leverages registry data from agriculture, fishing and trade statistics that are used to compile the EW-MFA. The data is further enriched using productivity factors from literature and from outside experts through a minimal modeling approach. The resulting tables give an interesting view of how food matter flows into the economy and food available for consumption. This provides a measure for food independence within the economy as well as food availability. By extending the EW-MFA in this way, we expand the value of the Eurostat module and use the framework's design. The use of registry data reduces the need for surveys and other costly data collection.

Keywords.

Keywords: material flow, food, environment

1. Introduction

The Economy-wide Material Flow Account (EW-MFA) is an annual statistical summary of the input and output of material into a national economy. The account is one of the environmental economic accounts that is included in EU Regulation No 691/2011 and is considered to be side account of the system of national accounts (SNA) with the goal of bridging economic measurements of productivity, labor effort, consumption, etc. with measurable indicators of environmental burden.

In its title, the EW-MFA promises to create a statistical picture of how manufactured goods, raw material and waste flow in and out of an economy. This is done by breaking material flow down by pathways according to import, export, domestic extraction and processed output. The account classifies materials into several categories: metals, non-metals, biomatter, fossil energy materials, waste, and other material. Each material category is then further sub-divided, giving a coarse but reasonable breakdown of the material demand of the economy. This material classification differs from the CPA 2.1 material classification commonly used in the SNA, since the EW-MFA focuses on the environmental burden from the economy rather than the economic activity that produces the material, which is the foundation in the CPA 2.1. The EW-MFA does not identify the economic beneficiary of the material flow nor the producer of waste.

Eurostat uses the EW-MFA figures to derive numerous indicators about the material dependency of economies, such as domestic material consumption, resource productivity, material accumulation and the circular economy rate, with added input from the waste account. The EW-MFA is also closely tied to United Nations' sustainable development goals (SDGs), particularly to SDG 12, responsible consumption and production. The macroscopic nature of these indicators hides some of the nuances and inaccuracies that are unavoidable in the compilation of the EW-MFA, and the final outcome is first and foremost an effort to generate a scale that is comparable between economies. This means that some of the initial goals behind calling for the compilation of the EW-MFA have been muddied.

A detailed view of how materials flow in and out of economies is, however, highly relevant to the participants within the economy, especially during times when import and exports may be disrupted or when agriculture struggles due to environmental changes. Questions such as "How dependent is the economy on imported goods?", "Is the economy self-sufficient in terms of food production?", "Is the economy primarily a raw material producer for other economies?", "What is the proportion of raw or minimally processed material from the economy?)" and "Which material intake is generating too much waste?" could be addressed starting from a material flow account. The EW-MFA is unfortunately not designed to supply the relevant data to address these questions due to the somewhat macroscopic approach in the account, but the framework of the account is relatively simple to extend in order to get insight into issues such as these. The compilation of the EW-MFA is also a convenient access point to data sources rich in details, where a more focused account to address such issues without entering into the classification used in the National Accounts.

The work presented here is one demonstration of how the EW-MFA framework can be extended in order to address questions on food availability and food independence within the economy. This processing includes some heuristic decisions of what is classified as human food and modelling of the yield of food from raw materials by domestic processing. The sensitivity of the outcome to these decisions is not a major issue, except in the case of provision of food from wild-caught fish.

The shortcoming of EW-MFA to describe food supply and export

The conceptual flow structure of the EW-MFA is shown in Figure 1 below, which is re-drawn from Eurostat's compilation guidelines.

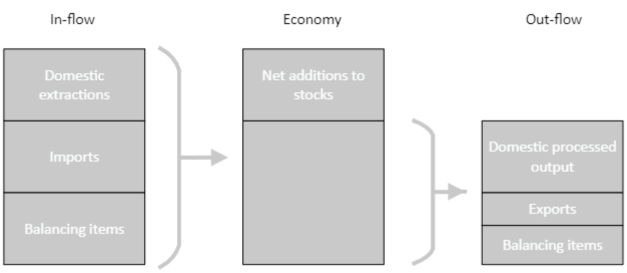

Figure 1: Schematic representation of how material flows in the EW-MFA

The in-flow of material comes from three potential sources, or nodes. The domestic extraction (DE) node includes all material taken from the natural environment into the economy. This includes all wild animals, crops from fields and fodder for domestic farming. Farm animals reside within the economy and are beneficiaries of the environment and not a part of nature. The production of food from farm animals is, therefore, not a part of the EW-MFA balance, except in terms of export. The balancing items node in the schema on the intake side include the air and water that is bound to the internal processes in the economy, including all animal and human respiration and water used to produce soft drinks. The EW-MFA does not consider free-flowing water in its schema as the quantity of this would overwhelm all other material quantities. The domestic processed output (DPO) node encompasses all emissions into air, water released from processes, or waste material that are irreversibly returned to nature. Imports and exports are defined similarly as in the SNA.

The unit of measure in the EW-MFA is mass in tons or kilotons, but this causes some confusion in the mass balance. Mass in the DE node refers to the mass of the raw material, whereas imports and exports refers to the weight post processing and without packaging. Import of raw material may also result in much greater weight of imports over exports, since processing within the economy often results in mass loss, while the material remains in the same material category. A good example of this is import of aluminum oxides (Al_2O_3 which is reported in material category MF.2.2.7 – bauxite and other aluminum) for the manufacturing of aluminum (Al, also in MF.2.2.7). The removal of oxygen in the process is reported in the DPO node (either in MF.7.5 – dissipative losses or MF.7.1.1 – carbon dioxide since oxygen is removed in the presence of coal dust). This artificially indicates that material consumption and build-up of aluminum is enormous within the economy. This prompted Eurostat to develop a method for reconnecting the import and export to raw material equivalences, but this method does not work for economies that differ from the average European economy and requires a complete set of physical supply and use tables (PSUT) in the SNA along with complete import/export tables in the CPA 2.1 classification to do a Leiontief projection for the import/export tables.

Extending the EW-MFA schema with focus on food

Figure 2 shows a schematic for the extension of the EW-MFA structure to identify flow of food for human consumption within the economy.

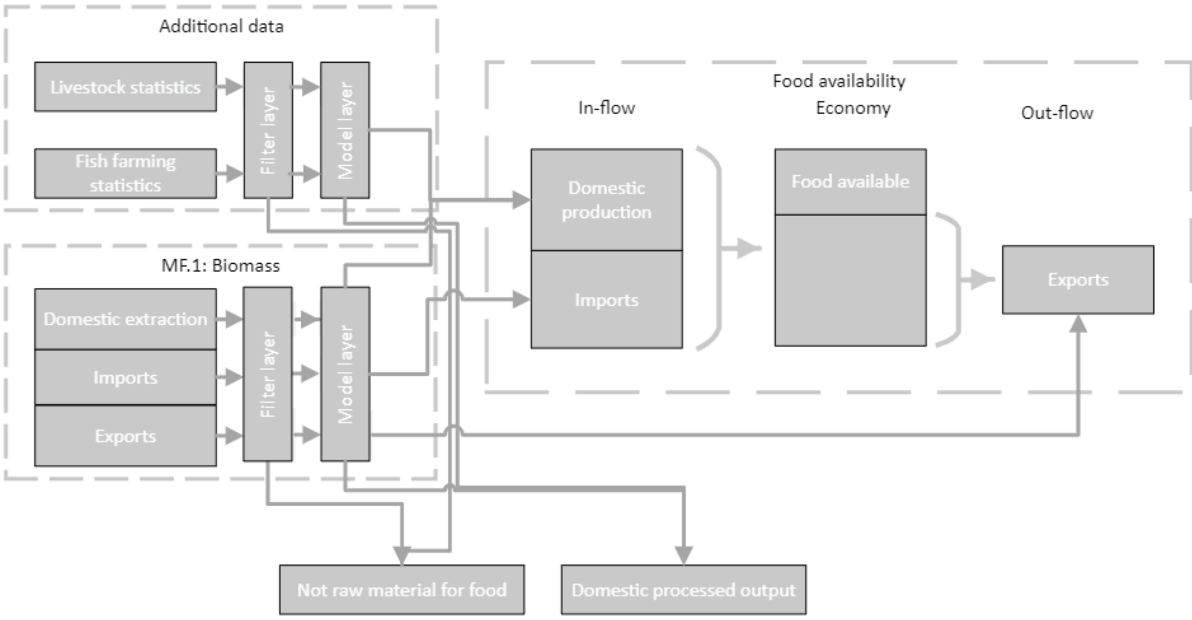

Figure 2: Schema underlying extracting information of food availability

Human food is part of the MF.1 - biomatter material category within the EW-MFA. This category also includes wood and crop residue, timber, and hides which are not traditionally a food item enjoyed by people. The EW-MFA structure identifies some of these items clearly by sub-class, but in some cases, the distinction between human food and non-food is not as clear cut. A prime example of this is fish caught in the wild, where we know that a large portion of pellagric fish like smelt and capelins are processed into fish-meals and oils that are almost exclusively used as animal feed or raw material in industrial procedures. Only a fraction of this catch is exported to food markets, often as canned, brined, dried, or pickled products. This is similar to some grains and fiber crops, which are used as animal feed if the protein content is below what is considered nutritionally acceptable for humans.

The transfer of data from the EW-MFA schema is done via a filter stage followed by a modelling layer. The filter stage proportionally divides the EW-MFA data into non-food and food categories. The yield of human food is calculated in the modelling layer.

The EW-MFA data is augmented by additional data from farming and fish farming statistics, since production of milk, eggs, and meat within the economy are not a part of the environmental load of the economy. This processing also includes a filtering and modeling step that follow the same approach.

Distinction of state of manufacture

The EW-MFA includes information about three possible states of manufacture for imported and exported material: raw material, which is considered unprocessed or minimally processed goods; semi-finished material, which is material that lacks some refining to be fit for direct consumption; and finished material, which is consumer ready material. The compilation guidelines and comments on Eurostat's website claim that this information is inexactly applied, but the information is included in this analysis since it assists in deciding processing and yield.

The Icelandic food industry (mainly fish processing) exports a considerable amount of raw and semi-finished products to markets. However, the raw material, like whole fish, would be considered to be an acceptable product for consumption in many cases. Whole fish could, at the same time, belong to raw-material (for meal and oil production) and to semi-finished material (for re-packaging).

2. Results

Schematics of the outcome

The calculation returns data that can be described using a node diagram as shown in Figure 3 below. Flow of each material category (MF) is described as a mass flow from an entry node to an exit node, represented as $m(entry \rightarrow exit)$. Material can change its category and state of manufacturing in each node. By focusing on food, we initially omit most material class changes, such as those that would happen when live animals (MF.1.5.1) are converted into processed meat, non-edible parts (leather), and non-human foods (bonemeal), resulting in some part of the live animal weight (mainly water) to exit back into nature as waste (DPO).

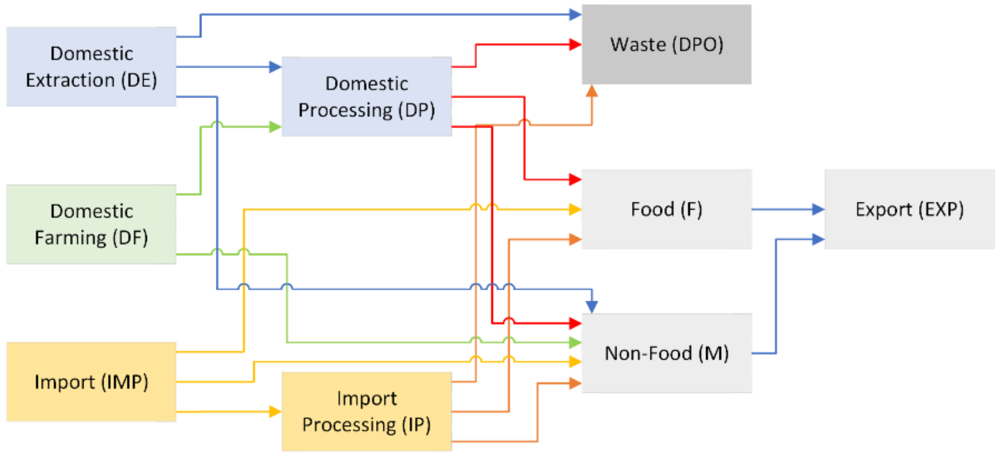

Figure 3: Schematics of the outcome data

Using definition in this diagram we can define food availability as

$$FA = [m(DP \rightarrow F) + m^{\circ}(IMP \rightarrow F)\,] - m(F \rightarrow EXP) \quad (1)$$

Where $m^{\circ}(IMP \rightarrow F)$ is the effective import of food, or:

$$m^{\circ}(IMP) = m(IMP \rightarrow F) + m(IP \rightarrow F) \quad (2)$$

Here the processing of domestically extracted material and imported material is kept separate, even when the processing may be done by the same enterprise. The definition of food is somewhat bound by mainstream European cultural preferences, omitting some of the traditional food and novelty edibles. This heuristic choice may affect the available food within the country and lessen the possibility of making cross-economic comparisons. The measurement here is in tons per material category. Food availability (FA) is useful if used in a ratio-type indicator, such as food availability per capita or any of the financial measures from the national accounts. The value of FA does not have to be positive. Negative values can occur when the broadly defined food category is enriched by processing within the economy, e.g., when fish is packaged in oil or brine or when sugar syrup or fruit extracts are exported as soft drinks and juices. This is not an unusual outcome within the EW-MFA framework. The processing of data is not set to generate food in the MF.1.6 – products mainly from biomass, but this category contains among others: all alcoholic and non-alcoholic beverages as well as soup mixes, doughs and other items that do not clearly fall into one material category.

We can define an indicator for the economic food independence directly from the data as:

$$\gamma = \frac{m(DP \to F) - m(F \to EXP)}{[m(DP \to F) + m^{\circ}(IMP \to F)]}$$

This indicator varies from a high value of (1) when the economy's reliance on imports and exports is negligible ($m(F \to EXP) = m^{\circ}(IMP \to F) = 0$) to a low value of (0) when there is little domestic production in comparison with exports and imports. γ can also be negative when local production is zero and imports in a given material category are used to manufacture and export food in the same category as would be expected for materials that are enriched in processing. Other indicators, such as raw-material yield, dependency of food groups on import raw material processing can be derived from the outcome schematics, but are not discussed further in this work.

Identifying food availability

This data lends itself well to the Sankey diagram shown in Figure 4. Sankey diagrams represent the total value within a source node by the size of the node itself. Flow from one node to another is then shown as a grayed connector bars where the flow amount controls the thickness of the connector. The flow is most commonly read from left to right in the figure. Any difference in in-flow and out-flow from a node shows up as a difference in the sizes of the gray bars on the left-hand side (use) and the right-hand side (supply).

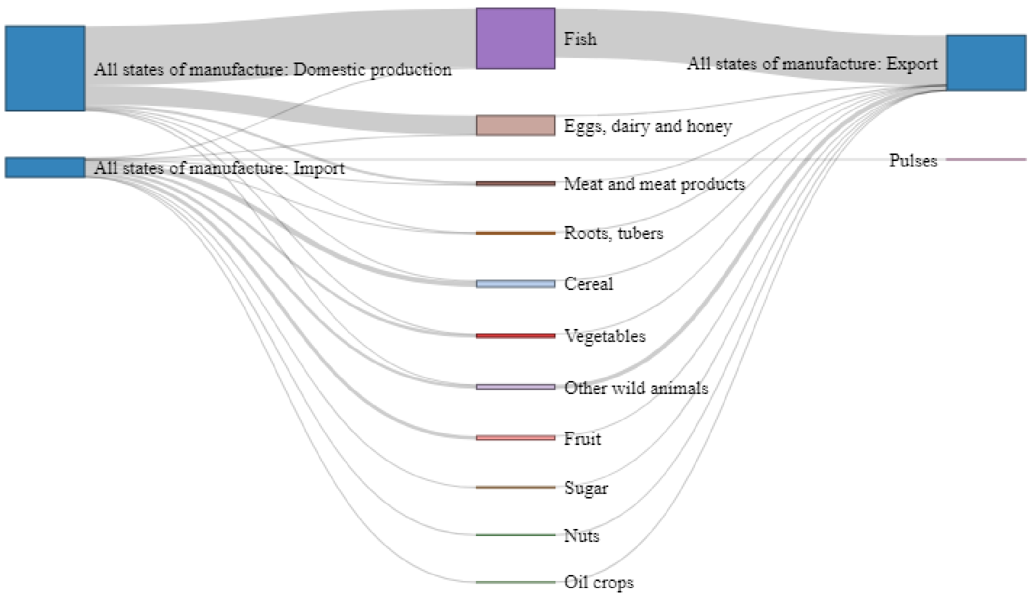

Figure 4: Sankey diagram representation of data from 2019

Figure 4 is an example of how FA can be visualized since it can be seen in the difference in the thickness of the connection bars for each material category. The figure shows clearly the quantity of fish export from Iceland as compared to other material categories. It should be noted that "other wild animals" includes whales, crab, shellfish, and other non-fish species.

Time series for food availability

Figure 5 shows the food availability of crop-type foods in Iceland since 1995. The total available amount of food in the MF.1.1 category is approximately 100 kilotons per year with the largest portion being cereals such as oats, wheat, barley, and other similar food. There is a substantial high point in cereal availability in 2008, whereas other food sources appear to be slowly increasing over time.

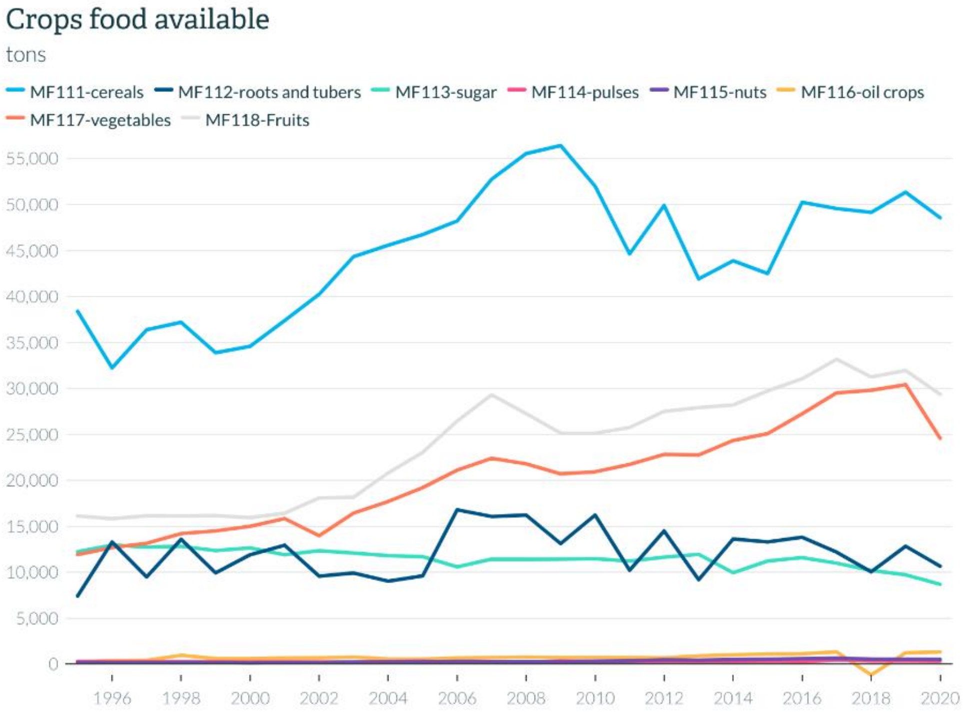

Figure 5: Availability of crops in Iceland

Figure 6 shows the availability of food from animal sources and category MF.1.6 – products mainly from biomass, which includes drinks, alcohol, soup mixes and other blended food sources. The figure clearly demonstrates some of the challenges in data from fish processing. This is a well-known data challenge in Iceland; consumption of fish in Iceland is not well understood or documented in part due to the complexity of the manufacturing itself. The fishing industry routinely varies its production in response to the market value of products and quality of the incoming raw material. Fish that is brought to shore and sold to freezing plants and slated to produce valuable fish filets and tenders, may in reality end up being processed and exported as fishmeal, which is not considered human food in this analysis. Fish oil processing can also have a large effect on the availability of food, especially since the success in manufacturing can lead to the product being classified as either food or as industrial raw material. The food availability of fish varies greatly between years as a consequence of small discrepancies in process designation for a very large quantity of catch (approximately 1,100 kilotons per year).

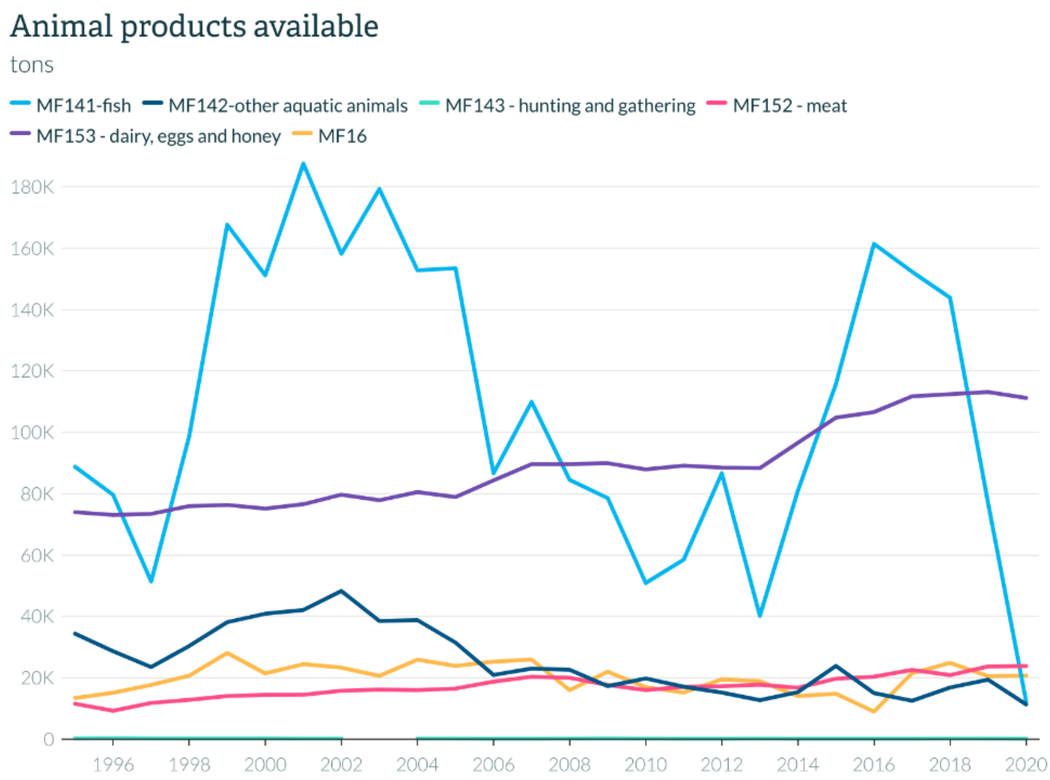

Figure 6: Food availability from animal sources in Iceland

The composition of available food is also interesting despite the high fluctuation of fish values. Figure 7 shows the food composition over several years. The fish composition appears to vary from 20 – 40% of the overall FA, which may be slightly higher than what we would expect in Iceland. Milk and meat are, in general, close to one third of the FA, which seems to be reasonable.

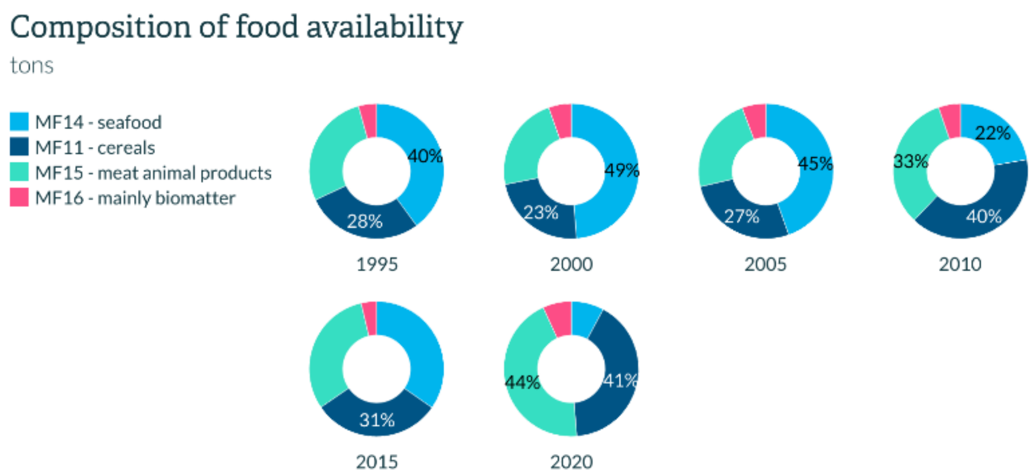

Figure 7: Composition of available food by broad categories

Food independence

Food independence here is defined according to Equation 3 above. Figure 8 shows that the food independence for Iceland is greater than zero for roots and tubers (food grows well under ground in Iceland), for vegetables (grown indoor), and for some cereal (oats and barley). The negative value for MF.1.6 is primarily due to the export of soft drinks and soup mixes from Iceland. This may be seen as a shortcoming in the analysis, since the model for domestic processing and import processing does not attempt to predict production of food into this class as there is no data available within Statistics Iceland that enables this estimate. The single negative value for MF.1.1.6 – oil crops is either an aberration in the import/export data or export of canola oil from Iceland that has not been reported in farm production. Not surprisingly, Iceland is dependent on import of sugars, pulses, nuts, and fruit.

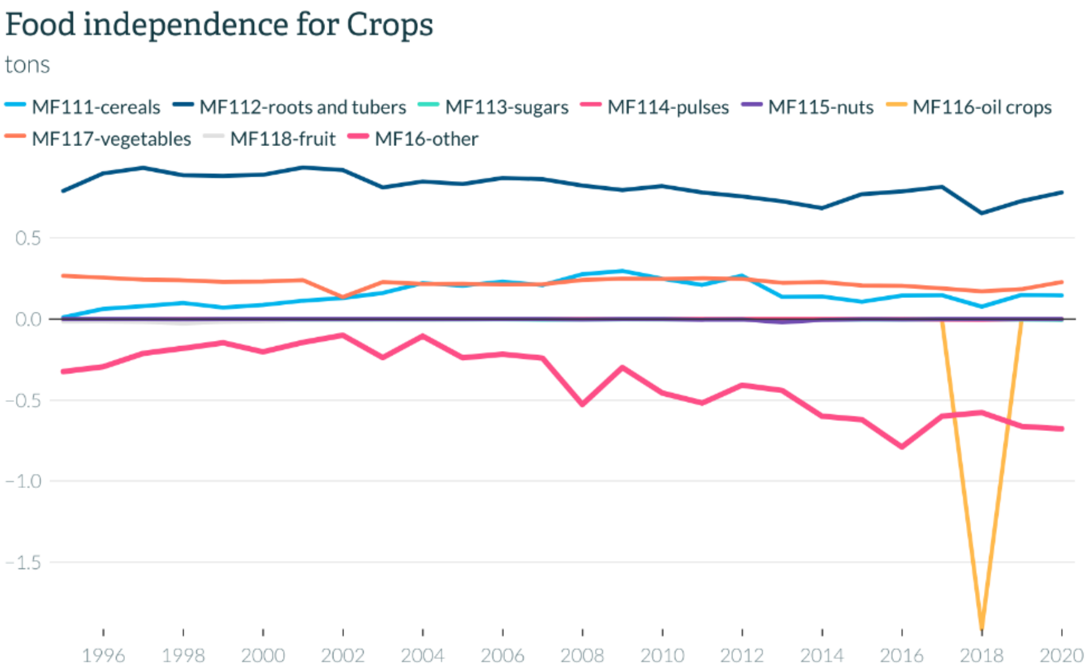

Figure 8: Food independence for crops

The food independence for meats is shown in Figure 9. The domestic production of milk and eggs is nearly one, as the domestic production far outstrips the import of food in this category. Import of meat to Iceland is also relatively restricted, which results in relatively high value of independence in this category. The food independence of fish may appear to be surprisingly low in this analysis. This is in part due to the high export of fish from Iceland, while imported fish includes tuna, sardines, and other fish that is not caught in Iceland. There is also significant import of fish to Iceland in the form of foreign operated vessels landing fish for processing. The independence value only considers food from domestic sources in the numerator. The MF.1.4.2 category, which drops below zero in the Figure 9, includes shellfish, whale, and other non-fish species. Some of these foods are processed from imported material, but others involve canning, brining or preserving the whole animal muscle in oil, which enriches the mass of the exported product.

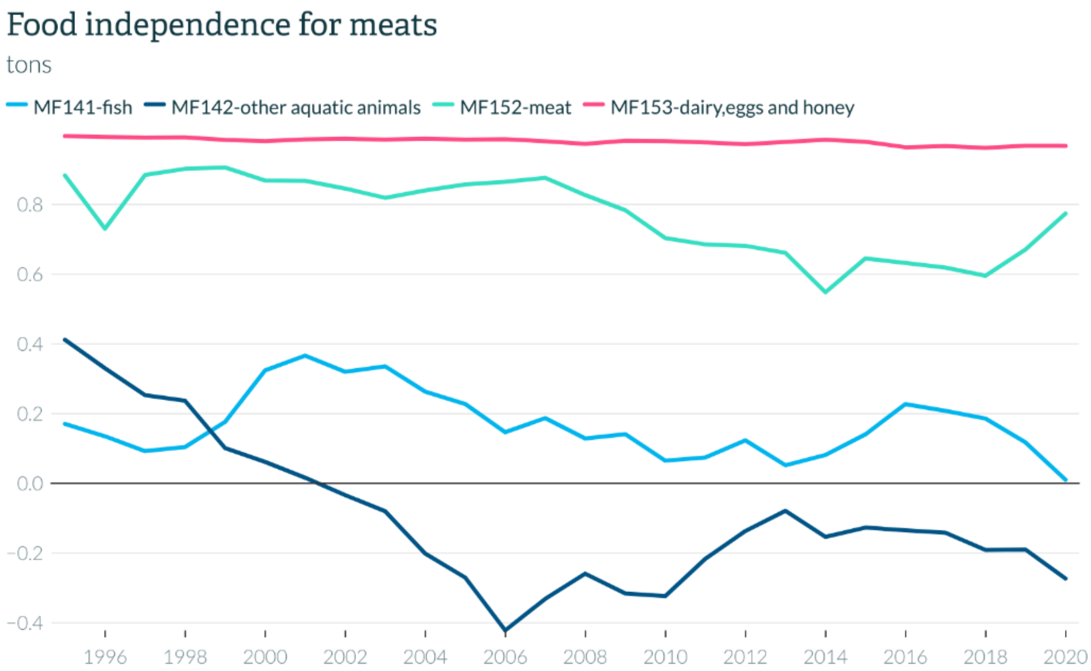

Figure 9: Food independence for fish and animal products with preliminary data from 2020

3. Discussion

Technical challenges and possible improvements of data processing

One of the key aspects in estimating food production from the EW-MFA data framework is the stable mapping of import and export data to material categories that are connected to extraction from the environment. The extension of material categories to domestic extraction for crops is also a simple matter.

Challenges arise when considering the conversion of fish catch, production of milk, and production of meat from domestically farmed animals (DF). The challenges are similar for fish and for meats and require a model that describes the conversion of raw material into other material categories.

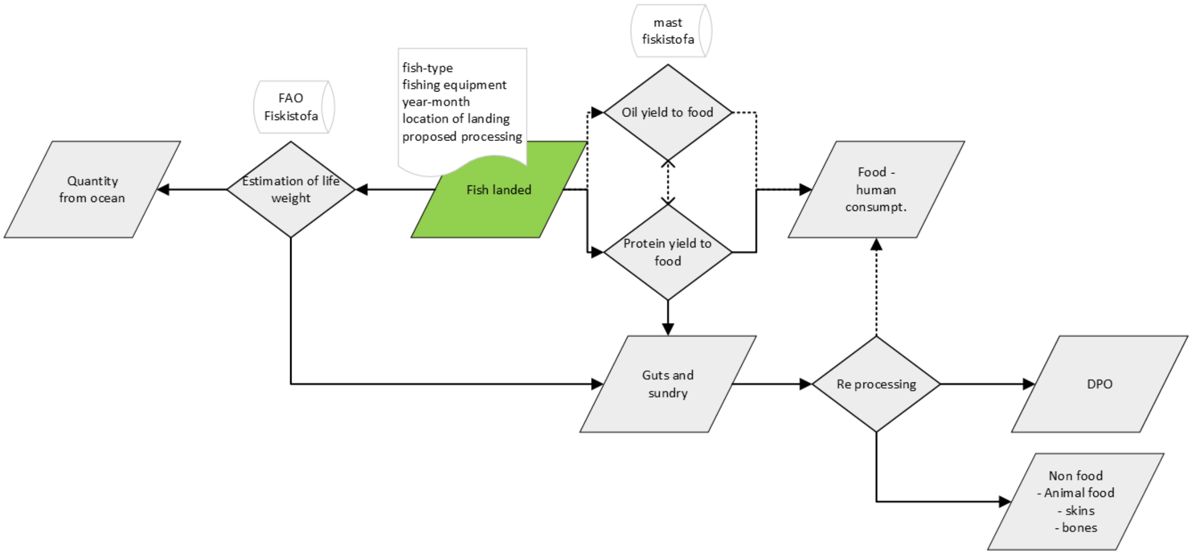

Figure 10: Schematic for modeling fish to food production

The dataflow for the model for fish processing is shown in Figure 10. The input data in the model are fishing reports that Statistics Iceland receives from the Directorate of Fisheries, *Fiskistofa*. This data is available internally and on the external data repository of Statistics Iceland. The fishing reports include detailed information such as landing weight, fish type, fishing equipment used, time of landing, port of landing, location of purchaser, and processing allocation (what is the initial proposed processing of the fish). The internal database includes the identity, size, and operator of the boat, but this information was not needed. The estimation of the from sea or live weight of the fish is well established in the protocols when fish is weighed in at landing sites. The difference between the mass of the live fish and the landed fish is the blood, feed content and other mass that is generally discarded (here it is allocated to the guts and sundry node). Fish is brought to shore in different stages of processing ranging from whole fish to fully processed. Estimates must therefore include the efficacy of processing for both on-sea and on-land processing as land processing has access to facilities that can handle the waste stream.

Estimating the food production from the raw material is a matter of building a coefficient matrix for the conversion of the reported input to miscellaneous products. Fish in the model is described by the fraction of fat, protein, water, and solids (bone/fibers) of the fish using a breakdown of head, filet, skin, dorsal and bones, guts, liver, and roe. This information is relatively well studied and documented for the main types of fish and similar compositions can be extended to other fish. Research also includes seasonal variations of roe filling and ocean temperature effects on fat content, especially for cod and haddock, which are the main wild species that are used for food production. A specific set of parameters were also created for farmed fish, although this fish is commonly exported with minimal processing. Seasonal variations were not considered in the initial development of the model, but this is a future option for the design.

The data includes information on the designated processing of the fish. Each processing type is given a set of conversion factors for protein, fat, and bone to different products assuming that no weight is lost or added in the total process. This is, however, a somewhat inaccurate approach since salting, pickling and brining and canning of fish adds to the mass of the exported product while it remains in its original material category.

Fish meal from fish smelting is a major product from fish processing and often the fallback option if markets are slow. This product is not considered to be human food, since almost all of the fish meal is sold as animal fodder. Fish meal can also be stored for a considerable time before it is exported. Fish oil from smelting is also not commonly sold for human consumption, even though its quality may be sufficient for it to be classified as such in the export data. Fish liver oil for human consumption is produced from fresh liver by cold-pressing and is a relatively small product in terms of mass

The portion of the fish that is not directly assigned to human consumption is called guts and sundry in this model. This category includes information about the remainder of protein, fat, bones, and water after processing. This node was examined with respect to possible secondary processing. Fish processors in Iceland have developed an extensive toolbox of processing for this what was formerly considered a waste product from fish. Some fish producers claim to process up to 97% of the fish in one way or another, which has increased the profitability of fishing in Iceland considerably since the total weight of the catch has remained largely unchanged since 1995. Modelling the reprocessing is a matter of deciding how much of the water is removed in the processing and how much of the reprocessed items ended back in the food category. In the end, it was decided to ignore the backflow of food, since this can also be considered in the first stage of the modeling. Allowing the reprocessing to return food product simplifies some identification of export items that could be produced in this stage.

Modeling fish processing from the viewpoint of protein and fat yield to food is a simplistic way to describe the industry, with the main benefit being that it relies on known physical properties of the fish. The weakness of this approach is that fish processing often involves blending the raw material with other materials such as salt, sugar, oils, grains, breads, or soup base before the product is exported or put on the food market. This may also move the fish from its original material category of MF.1.4.1 to MF.1.6 – mainly products from biomass. An increase in weight is most noticeable for the MF.1.4.2 – other aquatic animals or plants category which includes mussels and shellfish.

The development of the model did not consider export of fish to be a controlling parameter or a feedback parameter. Processing of fish is done for fish that enters through domestic extraction, from fish farming, and from import of raw material to Iceland. The export figures were used in a validation check of the data e.g. the yield from the processing should not be less than the export, nor is it likely that the processing yield is much greater than the export.

Export of some fish products also occurs over a timescale ranging from immediate to market by flight to month-long drying and salting processes. This also supported the decision to rely more on the chemical composition of the fish rather than any specific marketing opportunity that opens or closes for producers. Future development of the modeling needs to consider weight gain during processing from canning or brining the fish. The second iteration of the model should also include a possible flow between material categories in food processing in general.

4. Summary

The extension of the EW-MFA framework data to estimate food availability and food independence in Iceland is an exercise in going from the less specific to the more specific aspects of material flow. Food production and food consumption is a matter of considerable complexity, but this extension of the EW-MFA offers an attractive and relatively simple route to an insightful outcome.

Some obvious refining is necessary in terms of estimating the production of food from fish, but this is a well-known problem when it comes to estimating food production and consumption of fish. Modeling of food production from fish and sea animals is moderately complex and is done from a material/animal description that exists in the academic literature. These parameters are relatively static in value giving them value for cross-national comparisons for those interested in exploring this type of account. The conversion parameter matrix is built around the description of primary processing obtained in the registry data and is ultimately specific to the structure of the national food processing industry. Some default processing can be assumed as a benchmark for cross-national comparisons.

A similar model could apply to biomatter such as meat, eggs, and milk, but the initial production of the account here does not include complex modeling. The second iteration will consider a more detailed description of milk-to-food processing, since this material yields products ranging from fresh milk to whey powder and baby formula. It is, however, not useful to over-fit the data in order to predict the production of all possible food products, since the purpose of is more to estimate how much food may be available from domestic and imported sources for any given year. The modeling should therefore only approach the principle estimate of food from the raw material. For this purpose, the protein/nutrition approach to modeling food provision is more useful than tying the food production to marketing success or food fashions, which is a risk when relying too much on import/export or national account data to guide the calculations. A hybrid model of developing a slow-moving model for how input of raw material splits between material categories will, however, be useful in order to not end up with the peculiar negative food independence outcome in cases other than where the only production of food is from imported raw material.

The full data offers numerous other investigations related to food security, dependence on raw material import, and the fraction of raw material export in comparison with finished material export. The outcome data and any other methodological documentation can easily be shared with interested parties in the hope that this will assist in developing this statistical exploration of food independence from the EW-MFA framework.