Targets and bounds

Two types of targets are introduced: country level targets and a global restoration target.

Country targets

A country level target refers to the increase on the land exploitation that the country k needs to carry out to achieve its future production scenario. It is important to highlight that, in the case of country targets, we work with separate targets for each commodity of interest (in the case of this article it will be agricultural crops, and pasture products). Both of them are calculated analogously and the way of defining it is expressed in this item. As a proxy to quantify this exploitation, we define the total effective suitability S_{jk} for a type of commodity j as the sum over all the land units within the country Π_k of the product of the suitability index s_{ij}, the exploited area m_{ij}, and the yield ratio γ_{ij} of each land unit i:

$$S_{jk} = \sum_{i \in \Pi_k} m_{ij} s_{ij} \gamma_{ij} \tag{1}$$

The suitability index of a land unit was obtained from the GAEZ website [1] and corresponds to the highest value between all 48 available crops. The yield ratio represents how much a planning unit is exploited out of its full potential, and it is defined as the current productivity divided by the potential productivity. Magnitudes s_{ij} and γ_{ij} take values between 0 and 1, as well as m_{ij} if normalising it to the planning unit area (assuming that every planning unit has the same area).

Following this approach, country targets T_{jk} are defined as the difference between the effective suitability index of the present P and the future F. This difference can be positive or negative, implying the possibility of restoration of natural ecosystems or the need of conversion to exploited land types, respectively. We assume that suitability indexes do not change with time $s_{ij}^P = s_{ij}^F = s_{ij}$, whereas fractions m_{ij}^P and m_{ij}^F are extracted from data or predictive models [2]. Current yield ratio γ_{ij} is also obtained from GAEZ previous models [1], and it may change with time, reducing its gap on the future by a fraction $f_{\delta j}$, such as $\gamma_{ij}^F = \gamma_{ij} + (1 - \gamma_{ij}) f_{\delta j}$. We will study scenarios where we propose to close present yield gaps by a fraction f_{Cj} and then the new yield ratio will be $\gamma_{ij}^C = \gamma_{ij} + (1 - \gamma_{ij}) f_C$. Note the difference between $f_{\delta j}$ and f_{Cj}: whereas the former is given, the latter is part of the choices on our decision land use plan. Adding all these ingredients together:

$$T_{jk} = \sum_{i \in \Pi_k} m_{ij}^P s_{ij} \gamma_{ij}^C - \sum_{i \in \Pi_k} m_{ij}^F s_{ij} \gamma_{ij}^F \tag{2}$$

and operating we obtain that

$$T_{jk} = \Delta S_{jk} + \Delta S_{jk}^{1P} f_{Cj} - \Delta S_k^{1F} f_{\delta j} \tag{3}$$

with

$$\Delta S_{jk} = S_{jk}^P - S_{jk}^F \tag{4}$$

$$\Delta S_{jk}^{1P} = S_{jk}^{1P} - S_{jk}^P \tag{5}$$

$$\Delta S_{jk}^{1F} = S_{jk}^{1F} - S_{jk}^F \tag{6}$$

and

$$S_{jk}^{\tau} = \sum_{i \in \Pi_k} m_{ij}^{\tau} s_{ij} \gamma_{ij} \tag{7}$$

$$S_{jk}^{1\tau} = \sum_{i \in \Pi_k} m_{ij}^{\tau} s_{ij} \tag{8}$$

where $\tau = \{P, F\}$.

Since the yield ratio is not known for those planning units that are not being exploited in the present, we will take the weighted average of the country when an unknown yield ratio is encountered:

$$\overline{\gamma}_{jk} = \frac{\sum_{i \in \Pi_k} m_{ij}^P \gamma_{ij}}{\sum_{i \in \Pi_k} m_{ij}^P} \tag{9}$$

From Eq. 3, it is straightforward to obtain the minimum fraction of gap to be closed for a country to avoid deforestation ($T_k = 0$):

$$f_{Cjk}^{eq} = \max\left(0, -\frac{\Delta S_{jk}}{\Delta S_{jk}^{1P}} + f_\delta \frac{\Delta S_{jk}^{1F}}{\Delta S_{jk}^{1P}}\right) \tag{10}$$

Global restoration target

The global restoration target T_G is the amount of area in the world that is required to be restored at a given time. It is usually expressed as the fraction F_G of the area that is currently used for agriculture or pasture that needs to be reconverted in natural land:

$$T_G = F_G \sum_i m_i^P \tag{11}$$

where $m_i^P = \sum_j m_{ij}^P$.

Application of targets and bounds

The fraction of each planning unit to be restored or converted is represented with a decision variable vector x_i, which is defined positive for restoration ($T_{jk} > 0$) and negative for conversion situations ($T_{jk} < 0$), and has to satisfy

$$\text{For each country } k\text{:} \sum_{i \in \Pi_k} x_i \omega_{ij} \sigma_{ij}^C \leq T_{jk} \tag{12}$$

$$\text{Globally:} \sum_i x_i = T_G \tag{13}$$

Targets T_{jk} and T_G come from Eqs. 3 and 11, respectively; σ_{ij}^C represents the product of suitability and yield ratio once gaps are closed by f_{Cj}, and ω_{ij} the fraction of x_i used for restoring or converting each type of commodity:

$$\sigma_{ij}^C = s_{ij} \left[\gamma_{ij} + (1 - \gamma_{ij}) f_{Cj} \right] \tag{14}$$

In order to estimate ω_{ij}, we follow the criterion:

$$\omega_{ij} = \begin{cases} \dfrac{m_{ij}^P}{\sum_j m_{ij}^P} & \text{if } T_{jk} > 0 \\ \dfrac{m_{ij}^F}{\sum_j m_{ij}^F} & \text{if } T_{jk} < 0 \text{ and if } \exists j : m_{ij}^F \neq 0 \\ \dfrac{s_{ij}}{\sum_j s_{ij}} & \text{otherwise} \end{cases} \tag{15}$$

We define l_i^{res} as the minimum amount of area of a land unit that has to remain exploited, and l_i^{def} as the maximum area that can be natural within a planning unit, and therefore $0 \leq l_i^{res} \leq m_i \leq l_i^{def} \leq 1$. Then the decision variable x_i is bounded by the following conditions in the case of restoration and conversion, respectively:

$$\begin{cases} 0 \leq x_i \leq m_i - l_i^{res} & \text{if } T_k > 0 \text{ (restoration)} \\ 0 \leq -x_i \leq l_i^{def} - m_i & \text{if } T_k < 0 \text{ (conversion)} \end{cases} \tag{16}$$

References

[1] IIASA/FAO. *Global Agro-ecological Zones (GAEZ v3.0).* IIASA, Laxenburg, Austria and FAO, Rome, Italy. (2012)

[2] European Space Agency "Climate Change Initiative" (ESA CCI). Available online: `https://www.esa-landcover-cci.org/?q=node/158` (accessed May 2018)