Supplementary Materials

METHODS

NET IRRIGATION WATER REQUIRNMENT

The net irrigation water requirement is calculated with the following Equations [86,87].

$$NIWR_i = ET_c - R_{eff} \quad (S1)$$

$$ET_c = K_c \times ET_{ref} \quad (S2)$$

$$ET_{ref} = \frac{0{\cdot}408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0{\cdot}34u_2)} \quad (S3)$$

where R_{eff} is effective rainfall (mm), ET_c is potential crop evapotranspiration (mm), K_c is crop coefficient for a given crop, ET_{ref} is reference evapotranspiration for clipped grass surface (mm/d^{-1}), R_n is the calculated net radiation at the crop surface (MJ.m^{-2}.d^{-1}), G is the heat flux density at the soil surface (MJ.m^{-2}.d^{-1}), T the mean daily air temperature at 2 m height (°C), u_2 is the mean daily wind speed at 2 m height (m.s^{-1}), e_s is the saturation vapor pressure at 2 m height (kPa), e_a is the mean actual vapor pressure at 2 m height (kPa), Δ is the slope of the saturation vapor pressure-temperature curve (kPa. ° C^{-1}) and γ is the psychometric constant (kPa.°C^{-1}).

FARM PRODUCTS CARBON FOOTPRINT

The emission parameters of the equation 6 (in the paper) are calculated as follows [49]:

$$eCO_2i = \sum_{j=1}^{N}(UF_{i.j} \times EUF_j) + PE_i \times EPE + FA_i \times EFA + EL_i \times EEL + UR_i \times EUR \times \left(\frac{44}{12}\right) \quad (S4)$$

where $UF_{i.j}$ is fertilizer j is used during crop i growth (kg.ha^{-1}), EUF_j is carbon emissions from fertilizer j production (kg.kg^{-1}), PE_i is pesticide usage during crop i production (kg.ha^{-1}), EPE is emitted carbon by per kilogram of used pesticide (kg.kg^{-1}), FA_i is the amount of fuel consumed by machinery during product a production (lit), EFA is the CO_2 emission factor of combusted fuel (kg.lit^{-1}), EL_i is energy consumption during crop i production (kWh.ha^{-1}), EEL is CO_2 emission by per kilowatt hour energy usage for crop i production (kg.kWh^{-1}), UR_i is nitrogen fertilizer application rate during crop i production (kg.ha^{-1}), EUR is CO_2 emission by per kilogram of nitrogen fertilizer used for crop i production (kg.kg^{-1}) and $\frac{44}{12}$ is molecular conversion factor of $CO_2 - C$ to CO_2.

$$eN_2Oi = FN_i \times \delta_N \times 1.57 \times 0.27 \quad (S5)$$

where FN_i is the amount of used nitrogen fertilizer during crop i production ($kg.ha^{-1}$), δ_N is N_2O emission factor by used nitrogen fertilizer (kg N_2O. kg^{-1} used nitrogen fertilizer), 1.57 is molecular conversion factor of N_2 to N_2O and 0.27 is molecular conversion factor of C to CO_2.

$$eCH_4 = Day \times E(CH_4)_{diff} \quad (S6)$$

where Day is number of farm irrigation days ($day.year^{-1}$) and $E(CH_4)_{diff}$ is methane emission from each unit of cultivated land ($kg.ha^{-1}.day^{-1}$).

ANIMAL PRODUCTS CARBON FOOTPRINT

Following equations used for calculation of animal products carbon footprint parameters [51].

farm management carbon footprint

Following Equations used for examining the farm management carbon footprint:

$$CF_{management} = F \times EF_{fuel} + E \times EF_{energy} + L \times EF_{labor} \quad (S7)$$

where F is fuel consumption (kg), E is electricity consumption (kWh), L is the number of people engaged in animal husbandry ($person.day^{-1}$). EF_{fuel}, EF_{energy} and EF_{labor} are coefficients of fuel, energy and labor factors, respectively. The large number of workers in developing countries, who are mostly farmers, has made this source of carbon emissions important for agricultural or livestock production.

Enteric fermentation carbon footprint

Carbon footprint of enteric fermentation is calculated according to [88] (Equation S8):

$$CF_{ruminate} = H \times EF_{ru} \times 25 \quad (S8)$$

where H is number of ruminant heads, EF_{ru} is emission coefficient of enteric fermentation ($kg\ methane.head^{-1}.year^{-1}$) and 25 is global warming potential value of methane on 100-year horizon.

Manure treatment carbon footprint

By using Equations S9 to S11, the carbon footprint of manure treatment is examined.

$$CF_{manure} = H \times EF_{CH_4} \times 25 + (N_2O_{D\,(mm)} + N_2O_{G\,(mm)}) \times 298 \quad (S9)$$

where H is number of ruminant heads, EF_{CH_4} is methane emission factor (kg methane.head^{-1}.year^{-1}), is N_2O direct emission of manure management (kg.N_2O.year^{-1}), is N_2O indirect emission of manure management (kg N_2O.year^{-1}). 295 is global warming potential value of nitrogen on 100-year horizon. Indirect and direct N_2O emissions calculated based or proposed approach by [88].

$$N_2O_{D\,(mm)} = \left[\sum_S\left[\sum_T(N_T \times Nex_T \times MS_{T.S})\right] \times EF_{3_S}\right] \times \frac{44}{28} \quad (S10)$$

where N_T is number of ruminant heads of species T, Nex_T is average annual excretion for animal species T (kg N.year^{-1}), is fraction of manure treated in husbandry system S for animal species T (%), is N_2O direct emission coefficient of manure management system S (kg N_2O-N.kg N^{-1}).

$$N_2O_{G\,(mm)} = \left[\sum_S\left[\sum_T(N_T \times Nex_T \times MS_{T.S})\right] \times \left(\frac{Frac_{GasMS}}{100}\right)_{T.S} \times 0 \cdot 01\right] \times \frac{44}{28} \quad (S11)$$

where $Frac_{GasMS}$ is the fraction of managed manure nitrogen for animal species T that is lost in each system S (%), 0.01 is default value of emission factor for N_2O emissions from nitrogen deposition on water and soil surfaces and $\frac{44}{28}$ is molecular conversion factor of N_2 to N_2O.

Table S1. Constant parameters in carbon footprint calculations

Parameter	Value	Reference	Parameter	Value	Reference
EF_F	3.06	[51]	EF_{CH4}	86.2	[88]
EF_E	0.92	[51]	δ_N for other crops	0.01	[91]
W_{CO_2}	1	[50]	δ_N for rice	0.003	[91]
W_{N_2O}	298	[50]	WPE	18.04	[92]
W_{CH_4}	25	[50]	WMA	2.76	[93]
EF_4	0.001	[50]	WEL	0.943	[94]
EF_L	0.9	[89]	WUR	0.2	[95]
WCF_N	4.77	[90]	$E(CH_4)_{diff}$	0.15	[95]
WCF_P	2.02	[90]			

TOPSIS method

The steps for applying the TOPSIS method are as follows [54]:

A: Decision matrix Normalization: Equation S12 is used to obtain the dimensionless matrix (D' matrix).

$$r'_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \quad \text{(S12)}$$

B. Calculation of weighed dimensionless matrix: The D 'matrix is multiplied by a diagonal matrix of the indices weights.

$$V = D' \times w_{n\times n} \quad \text{(S13)}$$

where $w_{n\times n}$ is a matrix in which the elements on the principal diameter make up the weight of the indices and the rest of the elements are equal to zero.

C. Determination of the positive (A^+) and negative (A^-) ideal solutions: To determine the ideal positive solution (A^+), from each indicator with a positive aspect, the largest value is considered and from each indicator with a negative aspect, the smallest value is considered. For the ideal negative solution (A^-), the smallest value from each positive index and the largest value from each negative index is considered.

$$A^+ = \{V_1^+ . V_2^+ . \cdots\cdots V_n^+\} \quad \text{(S14)}$$

$$A^- = \{V_1^- . V_2^- . \cdots\cdots V_n^-\} \quad \text{(S15)}$$

V_n is the best or worst value of the n^th^ column of the matrix V, depending on whether it is positive or negative.

D. Calculation of each option distance from the positive ideal solution (d_i^+) and the negative ideal solution (d_i^-)

$$d_i^+ = \sqrt{\sum_{j=1} (V_{ij} - A^+j)^2} \quad \text{(S16)}$$

$$d_i^- = \sqrt{\sum_{j=1} (V_{ij} - A^-j)^2} \quad \text{(S17)}$$

E. Calculation of the relative proximity of each option to the ideal solution (CL_i)

$$CL_i = \frac{d_i^-}{(d_i^+ + d_i^-)} \quad \text{(S18)}$$