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A Multifunctional Solution for Wicked Problems: Value-Chain Wide Facilitation of Legumes Cultivated at Bioregional Scales Is Necessary to Address the Climate-Biodiversity-Nutrition Nexus

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Well-managed legume-based food systems are uniquely positioned to curtail the existential challenge posed by climate change through the significant contribution that legumes can make toward limiting Green House Gas (GHG) emissions. This potential is enabled by the specific functional attributes offered only by legumes, which deliver multiple co-benefits through improved ecosystem functions, including reduced farmland biodiversity loss, and better human-health and -nutrition provisioning. These three critical societal challenges are referred to collectively here as the “climate-biodiversity-nutrition nexus.” Despite the unparalleled potential of the provisions offered by legumes, this diverse crop group remains characterized as underutilized throughout Europe, and in many regions world-wide. This commentary highlights that integrated, diverse, legume-based, regenerative agricultural practices should be allied with more-concerted action on ex-farm gate factors at appropriate bioregional scales. Also, that this can be achieved whilst optimizing production, safeguarding food-security, and minimizing additional land-use requirements. To help avoid forfeiting the benefits of legume cultivation for system function, a specific and practical methodological and decision-aid framework is offered. This is based upon the identification and management of sustainable-development indicators for legume-based value chains, to help manage the key facilitative capacities and dependencies. Solving the wicked problems of the climate-biodiversity-nutrition nexus demands complex solutions and multiple benefits and this legume-focus must be

allied with more-concerted policy action, including improved facilitation of the catalytic provisions provided by collaborative capacity builders—to ensure that the knowledge networks are established, that there is unhindered information flow, and that new transformative value-chain capacities and business models are established.

Keywords: climate change, biodiversity, nutrition, legumes (Fabaceae), value chain, food system

INTRODUCTION—LEGUMES TO MITIGATE CLIMATE CHANGE

The biggest challenge facing humanity today is how best to rapidly implement those changes which will allow adaptation to, and mitigation of, climate change whilst redressing the loss of biodiversity and ecosystem services (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019). The recommendations of the Intergovernmental Panel on Climate Change are clear (Hoegh-Guldberg et al., 2018) and embodied in the “Paris Agreement” (United Nations, 2015), which aims to keep average global temperature rise to below 2°C, and preferably below 1.5°C. Toward these goals, and at current rates of decarbonisation among the various main industry sectors, agriculture remains historically recalcitrant to lowering its greenhouse gas (GHG) footprint (Wollenberg et al., 2016). Even if fossil fuel emissions were immediately halted, current trends in global agriculture and food production would prevent achievement of the 1.5°C target (Clark et al., 2020). However, the agricultural sector (and land-use more widely), is well-placed to support the EC policy (*Green Deal*) commitment to “net-zero” emissions by 2050 (EC, 2019). Particularly since the technological solutions to remove and store CO₂ (and other greenhouse gases) are unlikely to become operational at a significant scale soon (Sanna et al., 2014).

The agriculture-based contribution to “net-zero” demands the uptake of low-carbon farming measures and among these, legumes have a central role to play (Luscher et al., 2014; Oliveira et al., 2021). The journey to net-zero should include greater focus on the delivery of *adaptive measures* to improve geochemical-cycles or -flows, and ecosystem functions via control of key climate change “drivers,” and especially sustainable nutrient solutions through more efficient use and management of reactive-nitrogen resources (Steffen et al., 2015; Ascott et al., 2017; Breitburg et al., 2018; Folke et al., 2021). In this reactive-nitrogen context, legume crops can meet their own nitrogen needs for growth via “biological nitrogen fixation” (BNF) (Peoples et al., 1995), and do not necessarily require the addition of synthetic nitrogenous fertilizer. BNF by legumes also reduces synthetic nitrogen input requirement for subsequent, or companion, non-legume crops. Deployed in well-managed cropped systems, legumes have significantly lower emissions of N₂O than would be associated with crops receiving synthetic nitrogen fertilizers (Rochette and Janzen, 2005; Rees et al., 2013). In such well-integrated cropped systems, legumes offer the greatest carbon abatement potential relative to other strategies: legume-based crop rotations and

grassland farming systems > precision agriculture of legumes > optimized soil pH > intercropping > nitrification inhibitors > improved crop varieties (Eory et al., 2020). Due to their wide diversity of types, legumes may be integrated into cropped systems and ex-farmgate value systems in many ways (**Supplementary Figure 1**). Additionally, high levels of legume inclusion need not compromise yields, since it has been shown that maximum productivity and minimum synthetic fertilizer use can be achieved at 50% legume cover (crop residence over rotation-time) (Iannetta et al., 2016). This coverage can be defined as an equal balance between non-legumes and grain-/forage-legumes over the course of the crop rotation (**Supplementary Figure 2**), particularly where various forms of intercrop-based interventions are deployed (Brooker et al., 2014).

More-sustainable bioregionally produced, legume-based food- and feed-value chains, as allowed by the biogeographical and socio-economic constraints, must be realized to help circumvent any negative impacts of global-trade. Since, in the last few decades Europe (and other major regions of the world) have increased the arable land area used for more commercially rewarding cereal production, at the expense of land area sown with legumes (Watson et al., 2017). Yet, Europe also expanded livestock and poultry production (i.e., increased feed demand) during the same period following increased demand for animal protein Food and Agriculture Organization of the United Nations (FAO) statistics (FAOSTAT, 2019). The European Commission (EC) “Feed Protein Balance sheet” (EC, 2020), highlights that the EC is self-sufficient in grass-based protein forages. and while the legume component of such forages needs to be increased, the low domestic production of high-protein legume grains has been encouraged by large-scale imports of inexpensive (tariff free) grains, especially of soya, from other countries (Kuhlman et al., 2014). By 2010, Europe was importing almost 90% of its soya demand from the USA, Brazil, and Argentina (CAPRI Dataset, 2020). This has led to wide-scale tropical deforestation and carbon emissions in some countries (Bonini et al., 2018). Thus, developing European sufficiency in grain legume supply could achieve GHG mitigation in Europe, and South America. Equally, it should also be acknowledged that grain legume production by smallholder producers in less industrialized, or more-agrarian based economies, is also critically important, and may also need to be intensified (Nassary et al., 2019; Kebede, 2020). The best routes to such intensification requires careful consideration to ensure that ecosystem functions and services in already industrialized *and* industrializing food systems allow mutual benefits (*c.f.* Wiggins, 2009). Allied to this, it may also be the case that trade protection policies need deployed to help protect the nutritional and economic well-being

of smallholders in less-industrialized regions (Brooks and Matthews, 2015).

The existential challenges posed by the impacts of climate change constitute what should be recognized as “*wicked problems*” (Churchman, 1967). That is, challenges which comprise complex interdependencies, which should be addressed using solutions that also help solve other critical negative impacts upon ecosystem functions. In this “multi-functional solution context,” and if wisely deployed and facilitated, legumes offer an intervention which can deliver multiple co-benefits including reduced loss of farmland biodiversity, improved environmental sustainability (Stagnari et al., 2017), and better human-health and -nutrition (Foyer et al., 2016).

INTEGRATED LEGUME-BASED SYSTEMS TO ENHANCE BIODIVERSITY

Intensification of food production systems, and polarization of crop choices, have accelerated the loss of biodiversity, functional, and genetic (not simply at the species-level) from farmland habitats resulting in the degradation of the system functions on which sustainable and resilient production depends (e.g., decomposition and nutrient dynamics, detoxification, pest suppression, pollination) (Hawes et al., 2005). This decline in regulating and supporting functions results in further reliance on chemical intervention to maintain crop productivity (Palomo-Campesino et al., 2018), exacerbating the impacts of climate change by inappropriate habitat conversion and agrochemical (particularly pesticide) use (Hallmann et al., 2017). Traditional organic systems seek to reverse these trends by replacing agrochemicals with biologically based substitutes (Röös et al., 2018) which, although they may benefit local biodiversity (Bengtsson et al., 2005), may not necessarily have a significant impact on system sustainability—since they still tend to rely heavily on external inputs, plowing, and livestock. Integrated crop production systems based on regenerative agricultural practices utilize diversity for enhanced resilience, thereby reducing reliance on external inputs to maintain productivity (Hawes et al., 2021). In these systems, incorporating a greater diversity of crop types, including legumes and other underutilized crops, enables an increase in production efficiency through facilitation and complementation mechanisms to deliver multiple functional and resource-use benefits over more traditional cropping systems (Lin, 2011). Enhanced biodiversity associated with diversified legume-based crop rotations may also help facilitate resilience to the impacts of stochastic-weather conditions and shifting pest pressures that are linked to climate change (Lin, 2011). Ultimately, legume-based rotations can directly contribute to climate change mitigation since such plant-protein crops have a higher input efficiency, energy conversion, lower environmental impact, and protein provisions compared to livestock production (Clark and Tilman, 2017; Leinonen et al., 2020). It has been long understood that well-integrated, diversified crop systems, incorporating a range of crop functional types offers greater potential than monoculture cropping for pest and disease control through reduced apparency of specialist

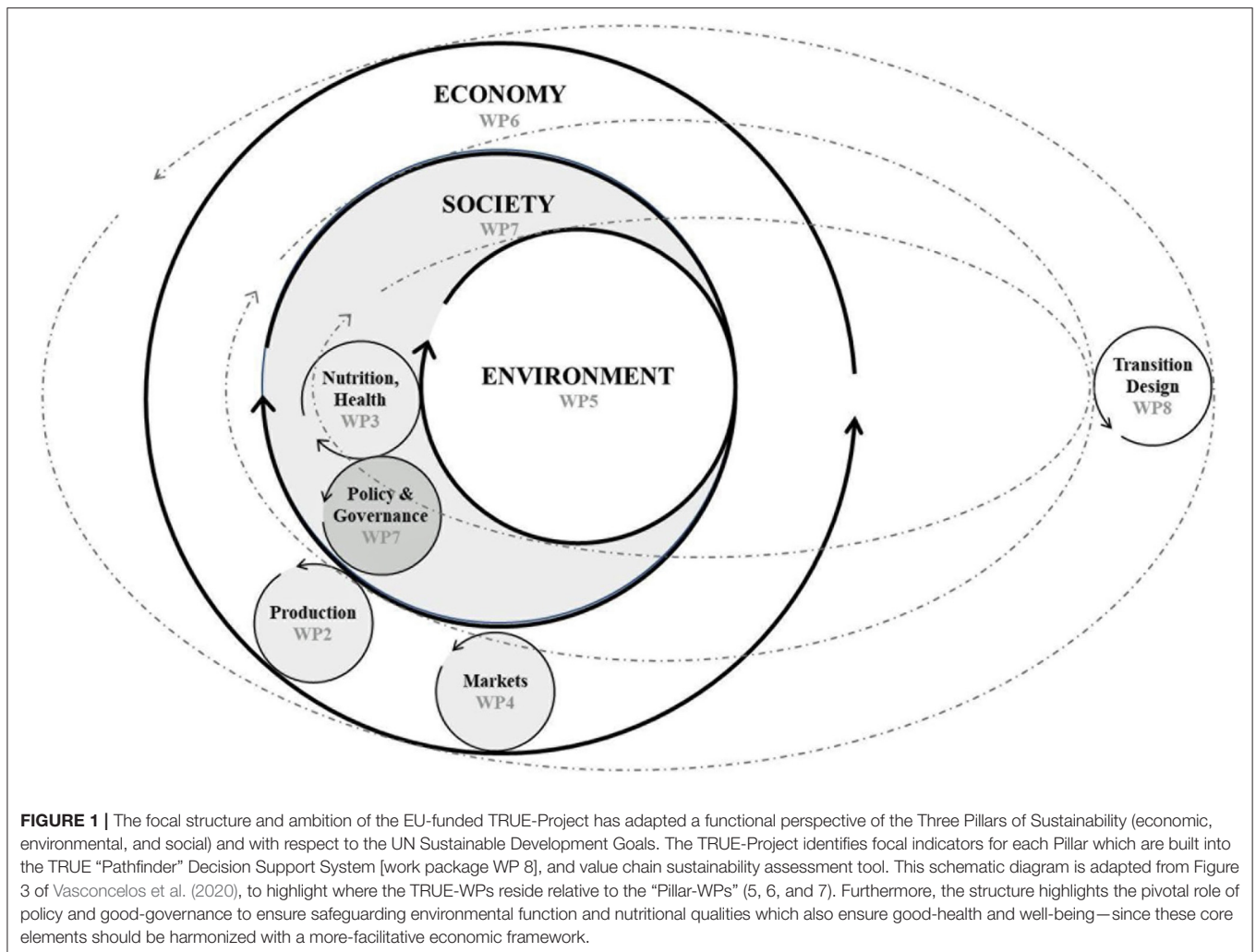
crop pests to their host and dilution of total resource available (Root, 1973). However, we acknowledge that the potential of such integrated systems is reliant only upon the development and greater uptake of integrated pest management (IPM) measures—which must be effective under the increasingly stochastic weather patterns associated with climate change (Clement et al., 2000; Sharma et al., 2010).

LEGUMES FOR NUTRITION AND HEALTH

To support the increasing demand for food and feed, it is predicted that agricultural productivity must be increased by 60% between 2012 and 2050. Climate change jeopardizes this nutritional provision 2-fold: by affecting crop productivity (and food availability) and indirectly by decreasing the nutritional quality of plant-based foods and feeds (Soares et al., 2019a). This could exacerbate the existing challenges concerning dietary deficiencies and depletion of agronomic resources. Consider: 20% of EU deaths are attributable to unhealthy diets that are otherwise preventable and current food systems are failing to guide citizens, and especially those who are most vulnerable, toward sustainable, and healthy diets that are available, affordable, appealing, and aspirational. In this context, legumes have a major role to play (Abarca-Gómez et al., 2017). One of the best-known nutrients to be affected by climate change, particularly elevated CO₂, is protein (Soares et al., 2019b). Dried legumes grains are excellent sources of protein/amino acids, fatty acids, fibers, carbohydrates, and phytochemicals, such as polyphenols (including flavonoids, and catechins) (Carbas et al., 2020). Dried grains of pulses also contain carbohydrates which promote lowered glycaemic index, so avoiding peaks in blood glucose levels that are a contributory factor to Type-2 diabetes—a major diet-related global-health issue and socioeconomically crippling health-care-cost burden (American Diabetes Association, 2013; Seuring et al., 2015). Grain legume consumption has also implicated in a reduced level of mortality (8% reduction) among the long-lived elderly, and regardless of ethnicity (Darmadi-Blackberry et al., 2004). Such nutritional health benefits are not restricted to provisions for humans (Vasconcelos et al., 2020), since as already indicated above, these can extend to improved ecosystem functions from provisions to above- and below-ground biodiversity (Altieri, 1999), and may be extended to farm animal health too via nutritional and non-nutritional capacities (Dixon and Sumner, 2003).

ADDRESSING THE CLIMATE-BIODIVERSITY-NUTRITION NEXUS

It is in these three critical contexts, the *climate-biodiversity-nutrition nexus*, that an EU-funded project structure (www.true-project.eu) was conceived and designed around a specific holistic framework (**Figure 1**) based on the *Three Pillars of Sustainability* (Passet, 1979). This aspirational structure leads one naturally to identify those accounting and functional indicators which may be effective to help define



and better-manage food- and feed-systems. For example, the FAO has identified 17 Sustainable Development Goals (SDGs) and 167 sustainable development indicators (SDIs) (FAO, 2021), which are mostly operationalized in bioregional and international decision-making. However, SDGs and SDIs developed for the national and international contexts are not operational over shorter value chains, bioregional scales, and are devoid of any specific reference to levels of legume-inclusive food- and feed-value chains. This is critical, since it is the implementation of good agronomic practices and business governance at bioregional scales which will determine the improved management of key resources (energy, carbon, nitrogen, and phosphorus) necessary to safeguard water quality, optimize soil function, and facilitate the necessary levels of crop diversification to minimize biodiversity loss, whilst also delivering optimized nutrition in an equitable manner.

The potential of whole (cropped) system-interventions and -function indicators for cropped systems at more practical field-, farm-, and regional-scales has been demonstrated (Hawes et al., 2019, 2021). Field- and farm-scale system function indicators have been allied to the evolution of approaches for whole system accounting, from farm-to-fork. These include forms

of Life Cycle Assessment (LCA) which seek to move beyond environmental footprints based solely on emissions and resource consumption per unit of a commoditized (food) product, to include system functions as important co-products delivered by farm systems (Zhang et al., 2010a,b). Such an approach can help to broaden sustainability-accounting measures provided by LCA, to functional parameters that can be applied at bioregional-scales from the field to bioregion (e.g., Patouillard et al., 2016). The utility of bioregionalized food system approaches has also been recently demonstrated via place-based short-value chains which compensate for the limitations of the global food system manifested during the COVID-19 pandemic (Laborde et al., 2020; Rivington et al., 2021).

VALUE CHAIN INTERVENTION ENTRY POINTS FOR MAXIMUM IMPACT

In these contexts, the history of policy effort from within the EC has been strongly directed toward increased production of grain legumes within Europe and such effort was initiated with the launch of the European Soya Declaration (2017),

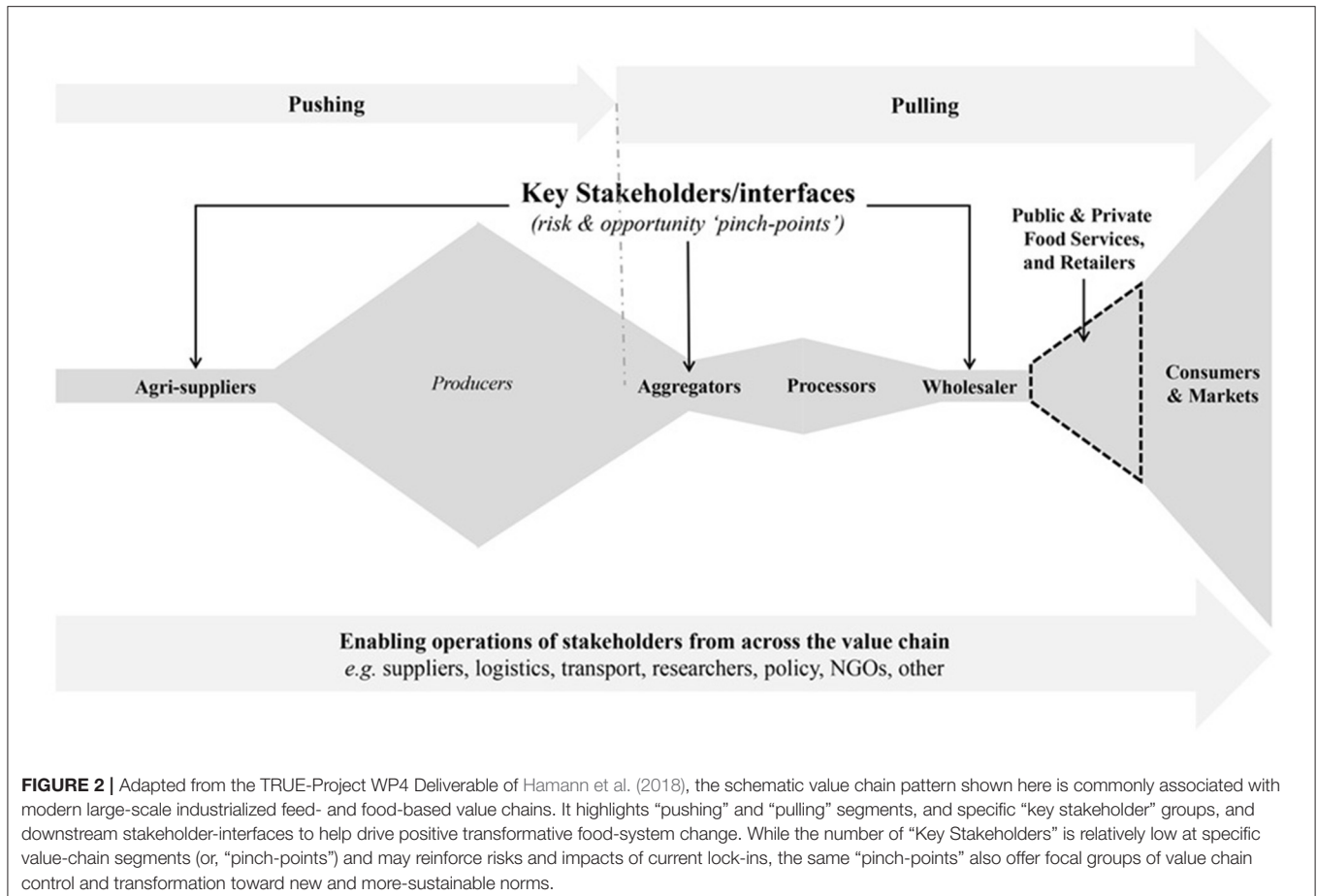


FIGURE 2 | Adapted from the TRUE-Project WP4 Deliverable of Hamann et al. (2018), the schematic value chain pattern shown here is commonly associated with modern large-scale industrialized feed- and food-based value chains. It highlights “pushing” and “pulling” segments, and specific “key stakeholder” groups, and downstream stakeholder-interfaces to help drive positive transformative food-system change. While the number of “Key Stakeholders” is relatively low at specific value-chain segments (or, “pinch-points”) and may reinforce risks and impacts of current lock-ins, the same “pinch-points” also offer focal groups of value chain control and transformation toward new and more-sustainable norms.

which has informed development of the ECs “Plant Protein Plan” (PPP) (EC, 2018). However, the “Plant Protein Plan” has been perceived by some stakeholder groups as an “animal feed self-sufficiency plan,” encouraging misuse of food-land for continued protein over-consumption (Westhoek et al., 2011)—with significant negative health, as well as environmental, impacts (Walker et al., 2005). Consequently, the climate change-biodiversity-health nexus has also informed formulation of the “Planetary Health Diet” (Willett et al., 2019) among others, and which all agree that consumption of fruits, vegetables, nuts, and legumes by humans should increase (2-fold), while red meat and sugar consumption must reduce (by half)—a dietary shift pattern which has also been advocated by the Intergovernmental Panel on Climate Change (IPCC) (Shukla et al., 2019). Here again we highlight that legume-based food systems would lower food-security risk due to the significant land-use sparing can be accommodated from even moderate (10%) offsetting of meat consumption supported by legume-derived protein (Searchinger et al., 2019; Table 6-2, p. 81).

Additional follow-up recommendations to the original Plant Protein Plan highlighted that efforts should focus on the development of infrastructure for processing plant proteins for food (Clément et al., 2018). In line with the EC recommendations, national plant protein plans are being

developed by member states, and while some approaches simply seek to design and implement strategies to establish greater levels of plant-protein self-sufficiency, these do not necessarily recommend definitive targets with respect to domestic bioregionalized value chains (production and consumption) of legume protein. Others which aim to establish protein plans as one component a foundation for “sustainable food systems” more generally, and these approaches should set legumes apart from other crops based on their functional potentials. However, some approaches recognize legumes only as another protein crop alongside other non-nitrogen crops i.e., ignoring the critical functional benefits offered by legumes such as biological nitrogen fixation, GHG mitigation, soil-carbon sequestration, biodiversity functions, food-culture, and complex provision of nutritional and non-nutritional dietary components.

CONCLUSIONS

Historically, policy-led food system transformation has been mainly realized via efforts focused on the production system as a main point of entry, such as increasing yields and crop diversification. While such an entry-approach has obvious value, there appears to be insufficient focus of policy on ex-farm

gate and market “facilitation” and “pull” factors (Vasconcelos et al., 2020; Balázs et al., 2021). Allied to this, the confused policy framework (Balázs et al., 2021), and role of specific actors in the ex-farm gate sector are also neglected or ignored. As such, “integrated practices” must not be restricted to the cropped system but extended across the full value chain. System function indicators such as gender equity and social justice also emerge as features which should be allied to greater legume-use and food-system resilience (Schipanski et al., 2016).

Consider the simple schematic shown in **Figure 2** (developed from Hamann et al., 2018), which shows that value-chain “pinch-points” may be perceived as risks or lock-ins. However, the same pinch-points may also be viewed as an opportunity for positive transformative change toward more sustainable and healthy diets. For example, perhaps encouraging the development of grain legume processing capacities (dehulling, milling, fractionation) among seed aggregators which serve as major processors for key and emerging markets. Though this may also involve justifying the use of those raw materials in their existing product range. Nevertheless, while capacities for plant-based food increase in response to rising consumer demand and commercial opportunity, where these openings are legume-based, there is no expectation that even a proportion of the legume crops must be grown bioregionally. Nor does this preclude the possibility that such plant-based products present high GHGs costs or/and poor nutrition risks (through ultra-processing). A key question for consumers and concerned value-chain stakeholders including legume-based feed processors, food manufacturers, wholesalers, retailers, and especially policy makers, might be: *to what extent does my consumption, product, or raw-material choice improve the function of production ecosystems and the sustainability of the value chains, bioregionally, and globally?* The success of any resultant initiatives to increase production and consumption of bioregionally grown legumes is likely to be governed by the ability to recruit and mentor a diverse array of “collaborative capacity builders” (c.f. Weber and Khademian, 2008). Such individuals will be essential to help establish and ensure the necessary business-to-business knowledge-networks, -flows, -capacities, and transformative governance structures, to help solve the wicked problems posed by the climate-biodiversity-nutrition nexus.

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AUTHOR CONTRIBUTIONS

This process was led and directed by PI (first and corresponding author), and the foundation determined in close collaboration and direction with CH, RV, and RR (second, penultimate, and final authors, respectively). The order of remaining authors reflects the strategic order of TRUE-Project work package (WP) leaders and co-leaders (WP 1-8). All authors contributed to conceptualization, writing, literature and methodology reviews, manuscript-editing, and funding acquisition.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2021.692137/full#supplementary-material>

Supplementary Figure 1 | This flow chart depicts in simple terms the main legume types and their basic utilities.

Supplementary Figure 2 | The grain- and forage-legume proportion as a fraction of the total legume proportion (grain and forage) across all the legume-supported rotations assessed by Iannetta et al. (2016), and available from the EU-funded project Legume Futures (Framework Programme) Data Repository held at the James Hutton Institute. The data highlights a relationship between relative uptake of grain- and forage-legume types.

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